Introduction to the urban meteorology

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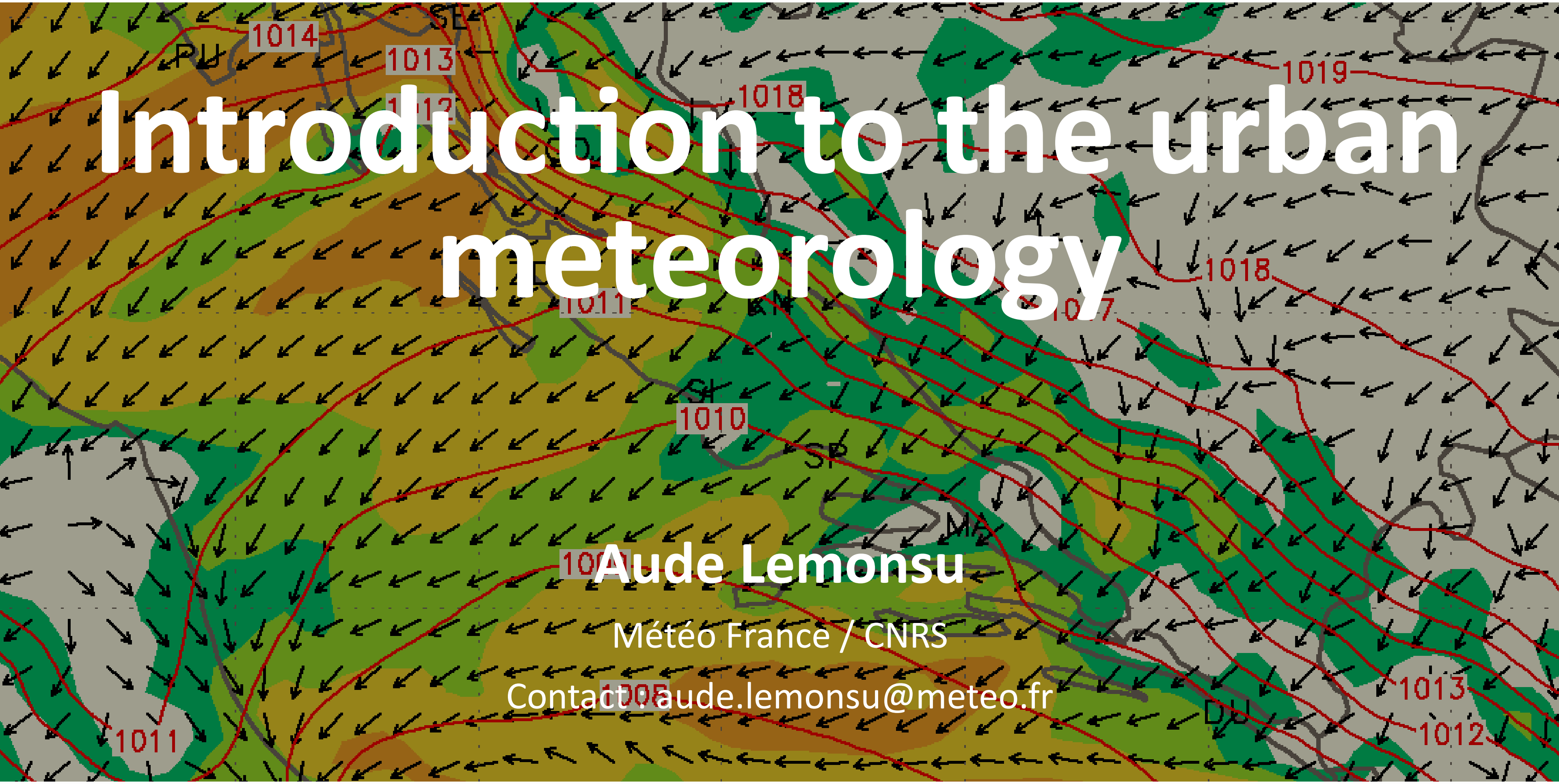
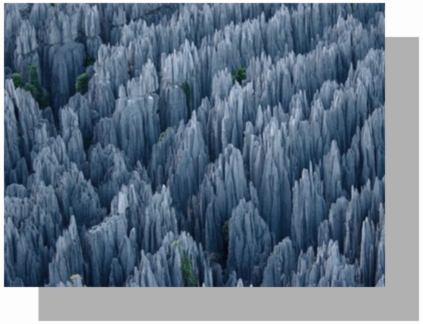


Wind and pressure modeling with ALADIN over Croazia. Credits : Croatian Meteorological and Hydrological Service

Different ways to modelize the urban areas

Initially, and still now in certain models :

- Towns don't exist and are not treated (=vegetation)
- The **towns are described as rock** with a strong roughness (ALADIN-Climat e.g.)
  - *Roughness length*
  - *Heat capacity, thermal conductivity*
  - *Albedo*
  - *Water reservoir*



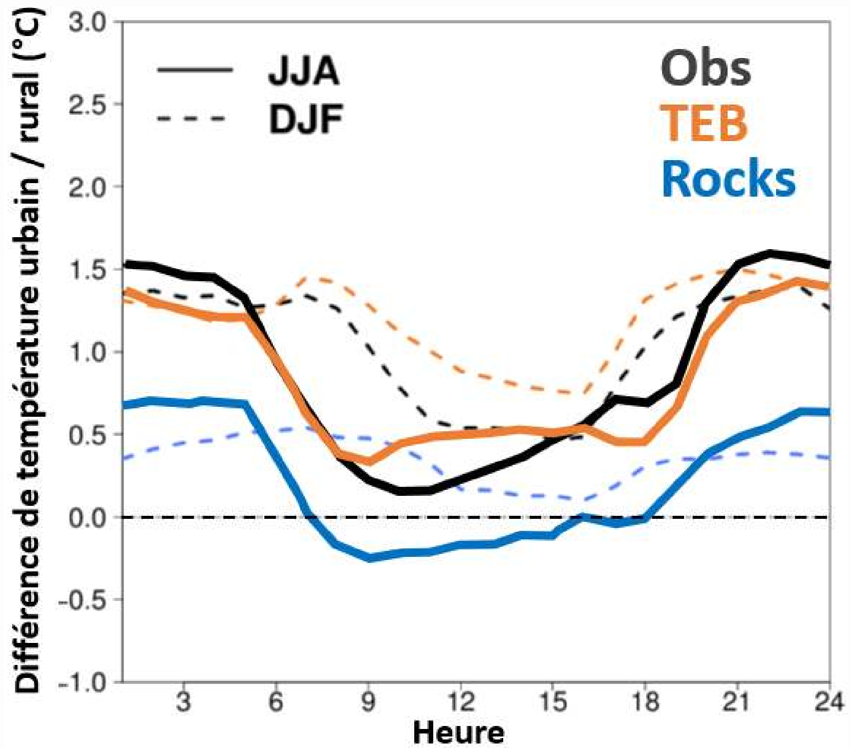
"Stone forest" Tsingy, Madagascar

This approach allows to represent :

- The waterproofness of surfaces favouring runoff
- The capacity of warming of the surfaces during the day
- The roughness effect on the flux in the inertial sub-layer

Different ways to modelize the urban areas

- **BUT**
  - **No thermal nor radiative effects linked to the geometry** of the canyon
    → underestimation of the night ICU
  - **No diagnostic of the air temperature in the street**

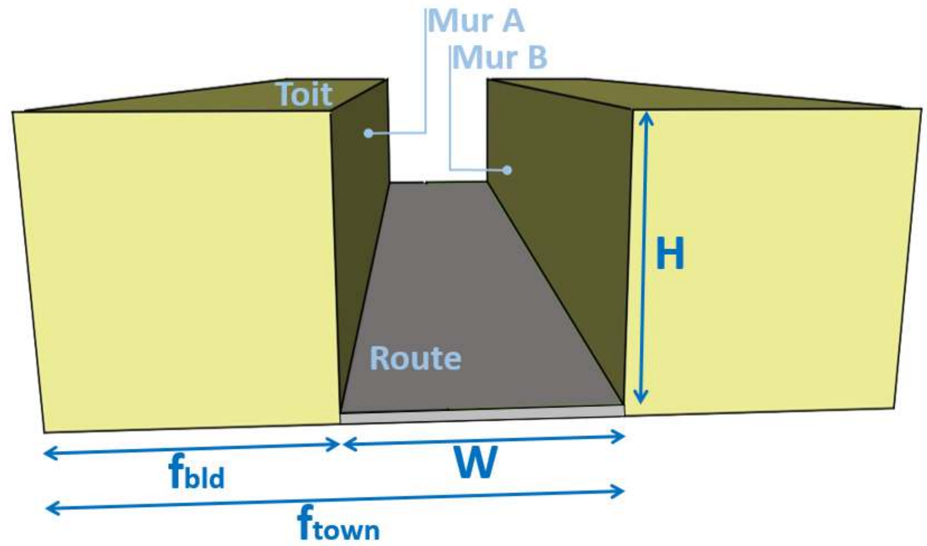


Description of the TEB model
Masson 2000, Masson et al 2002, Lemonsu et al 2003

The buidings aren't explicitely solved

The roads are represent by an **average urban canyon**

(concept of Oke 1982)



road

Description of the TEB model

Masson 2000, Masson et al 2002, Lemonsu et al 2003

- 3 distinct surfaces :
  - Road
  - Flat roof
  - Walls (A and B)

- Geometric properties :
  - Built density
  - Mean height of building
  - Aspect ratio of the canyon (H/W)

- Thermal-radative properties of the materials :
  - Albedo, emissivity of external sides
  - Thermal conductivity, heat capacity, depths of the layers of materials
  -

- Maximum capacity of interception of water on roofs and roads

Radiative balance

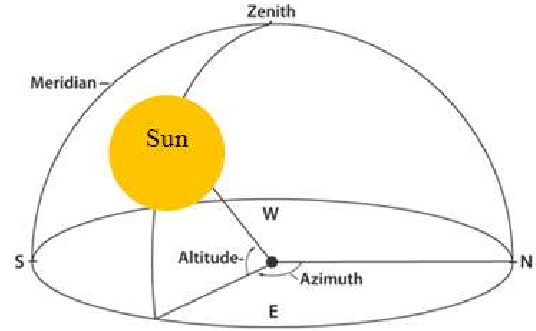
- A radiative balance is calculated for each surface (road, roof, walls), taking into account :
  - **The solar direct radiation** (directional) got by the surface
    = *geometric calculation of shadowing effects functions of the shape and the orientaion of the canyon, and of the position of the sun*

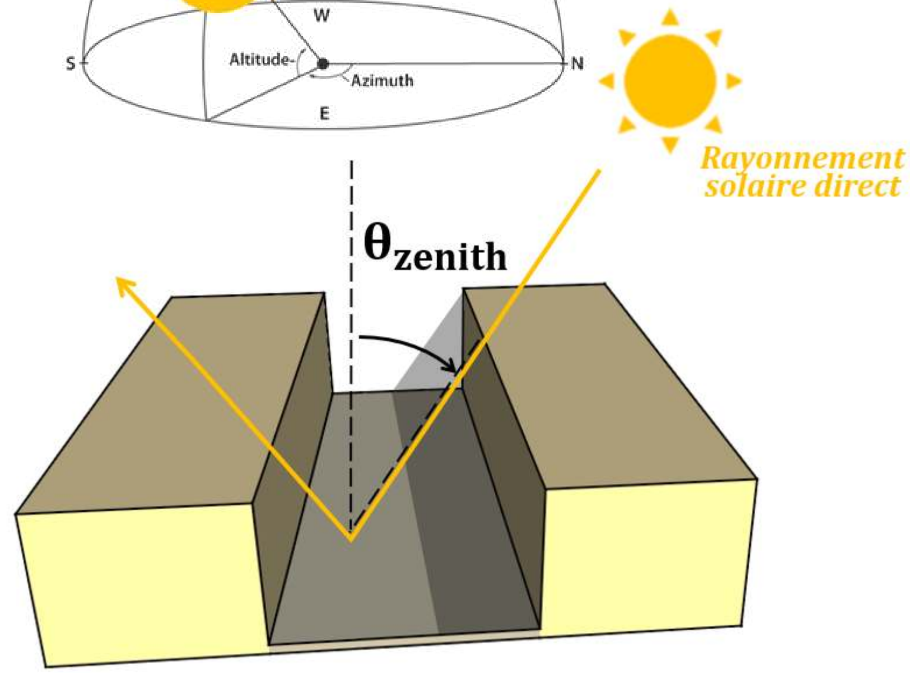
$$S^{\Downarrow}_{road} = S^{\Downarrow}\left[1 - \frac{\frac{H}{W}\tan\theta_{zenith}}{\left|\sin\theta_{azimuth} - \sin\theta_{canyon}\right|}\right]$$

$^{H}/_{W}$	Aspect ratio of the canyon
θ_{can}	Angle of orientation of the canyon
θ_{zenith}	Zenithal angle
$\theta_{azimuth}$	Azimutal angle

$$S^{\Downarrow}_{wall\ A} = S^{\Downarrow}\left[1 - S^{\Downarrow}_{road}\right]\frac{W}{H}$$ *(in the sun)*

$$S^{\Downarrow}_{wall\ B} = 0$$ *(in the shadow)*

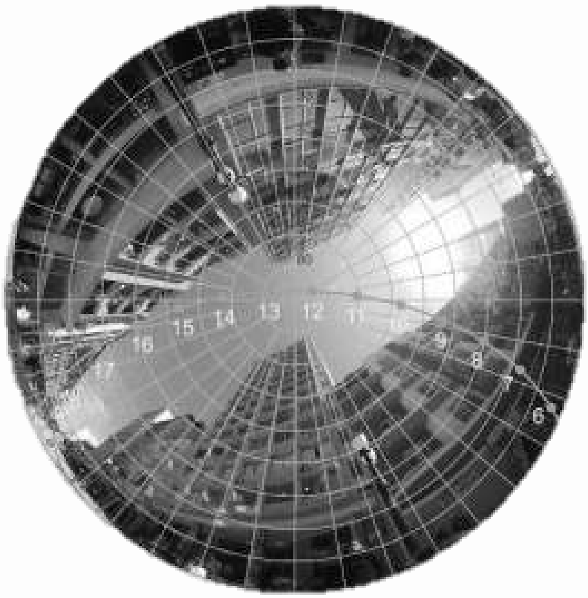


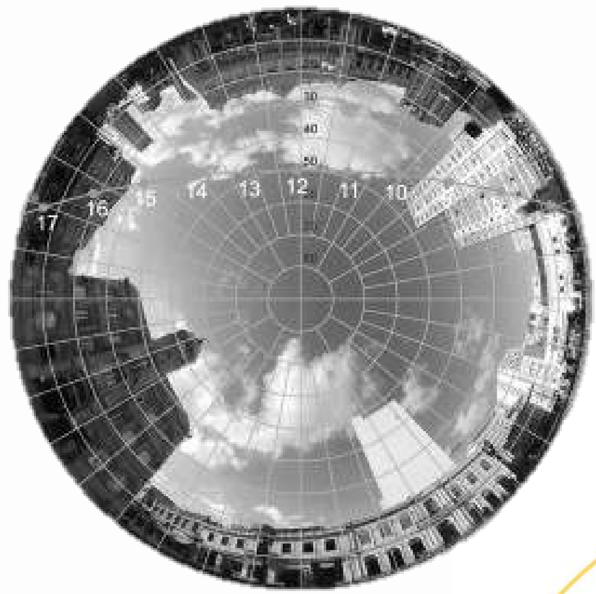


Radiative balance

- A radiative balance is calculated for each surface (road, roof, walls), taking into account :
  - **The diffusive solar radiation** (isotrope) got by the surface
    = *geometric calculation based on the sky view factor of the surface*

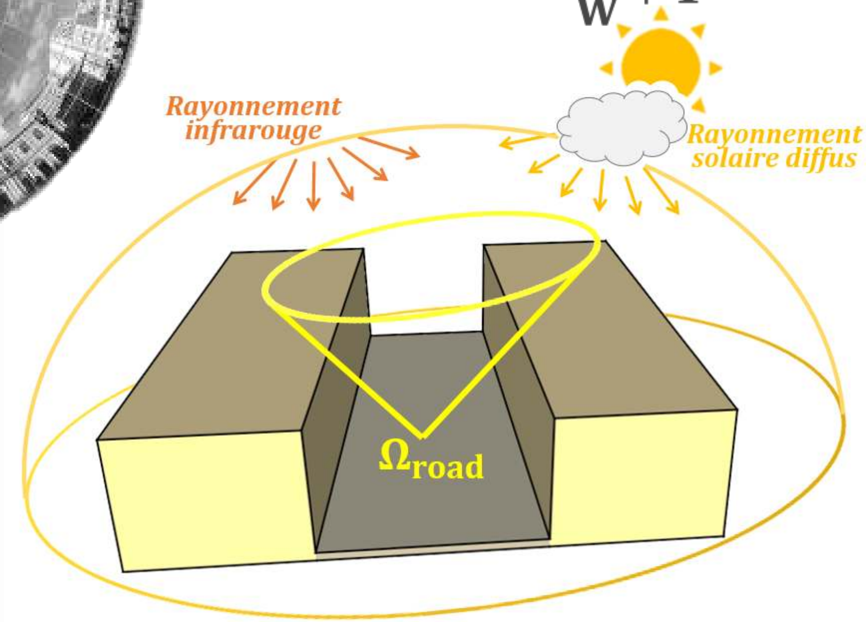
$$S^{\downarrow}_{road} = \Psi_{road}\, S^{\downarrow}$$
$$S^{\downarrow}_{wall} = \Psi_{wall}\, S^{\downarrow}$$





$$\Psi_{road} = \sqrt{\left(\frac{H}{W}\right)^2 + 1} - \frac{H}{W}$$

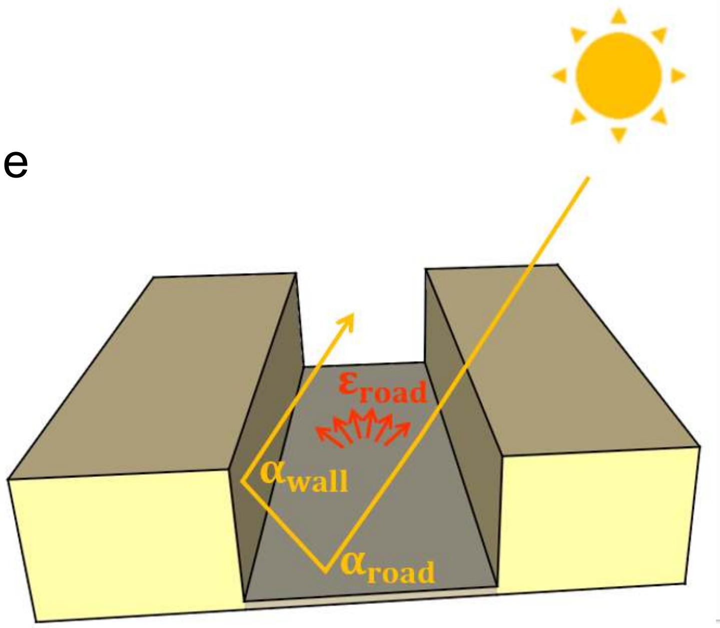
$$\Psi_{wall} = \frac{1}{2}\,\frac{\frac{H}{W} + 1 - \sqrt{\left(\frac{H}{W}\right)^2 + 1}}{\frac{H}{W} + 1}$$



The sky view factor Ψ is the fraction of the canopy of heaven seen from an observation point (here the center of the surface) according the narrowness of the canyon for a flat surface without obstacles

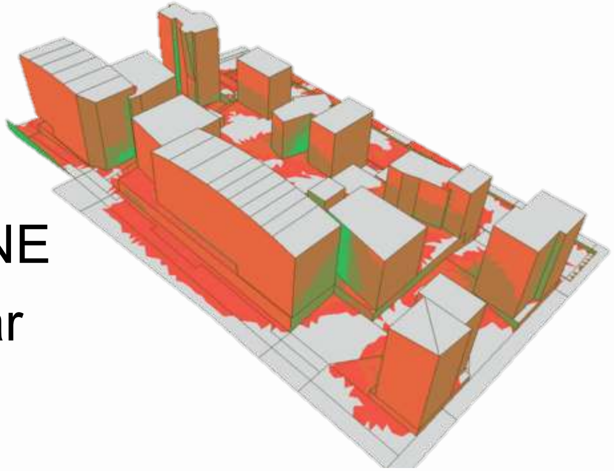
Radiative balance

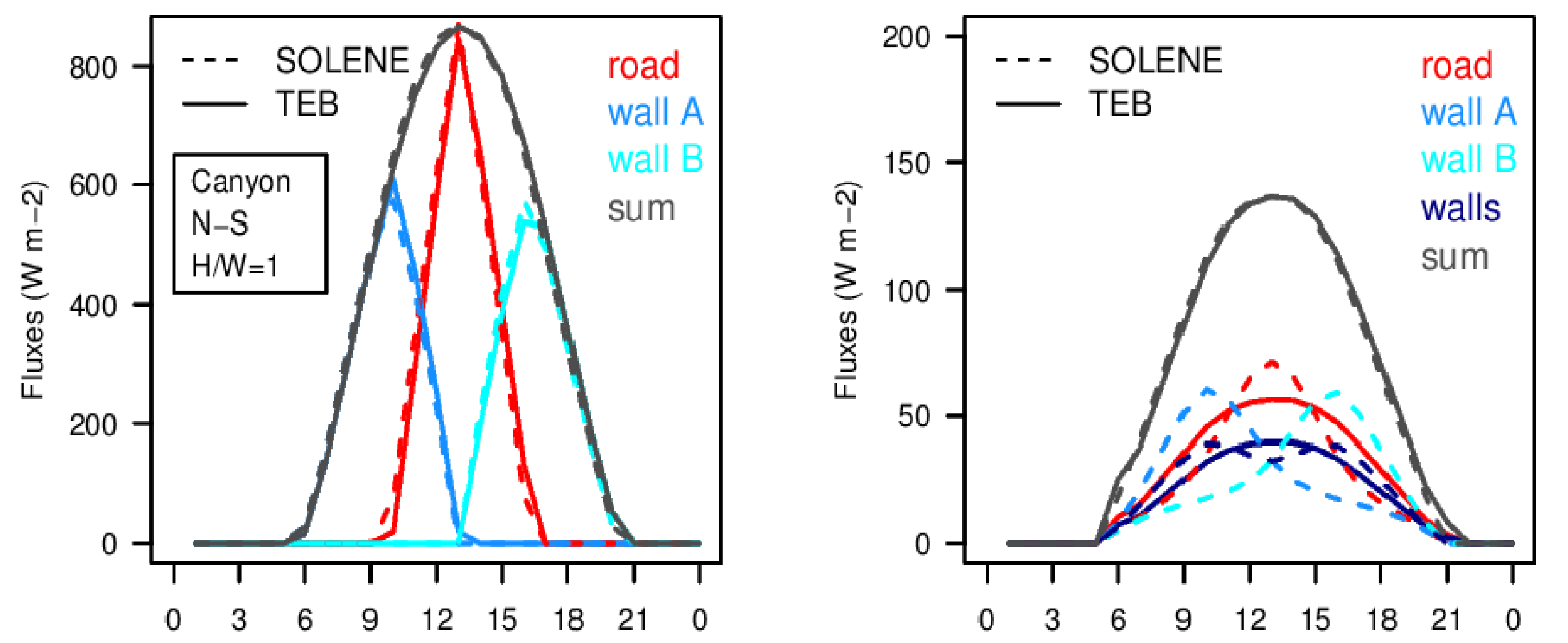
- A radiative balance is calculated for each surface (road, roof, walls), taking into account :
  - **Inter-reflections between the surfaces**
    = calculation based on the shape factors between the surfaces and the radiative properties (albedo, emissivity)
    → at each reflection, a part of the energy is absorbed by the surface
  - **REM :** the surface emissions take part in the radiative balance for the infrared radiation (functions of the surface temperatures)



Radiative balance

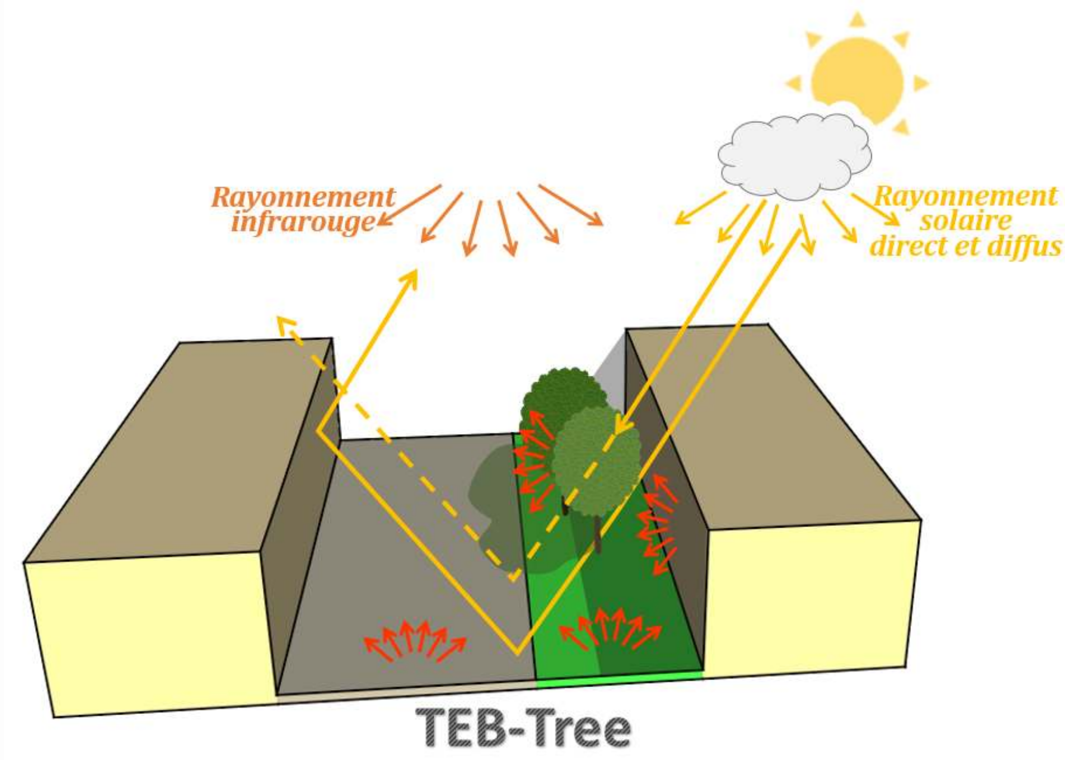
- Despite the simplified hypothesis,
  the radiative balance is correctly simulated
  → comparaison to the architectural software SOLENE
- Ex : simulation SOLENE of the maximum direct solar energy got by the surfaces



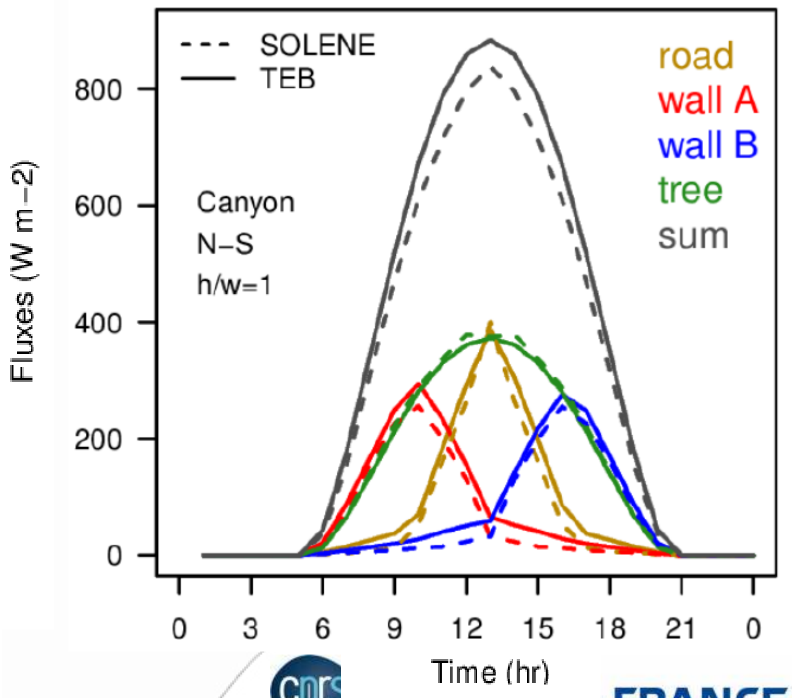


Radiative balance

- Recent developments allow to take into account the **radiative effects associated to the presence of vegetation and trees** inside the canyon
  - Shadowing and attenuation through the tree cover
  - Inter-reflections with trees
  - Infra-red emission of trees



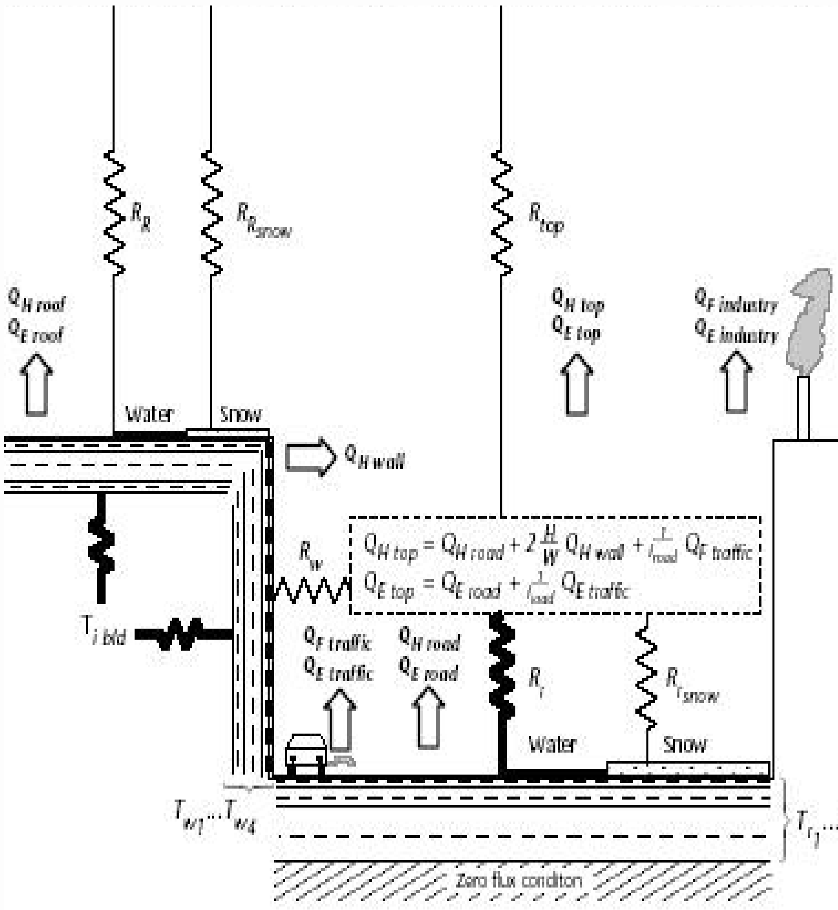
Rayonnement solaire total absorbé



Temperatures of the urban surfaces

For each urban surface, the **equation of evolution of the temperature** is solved

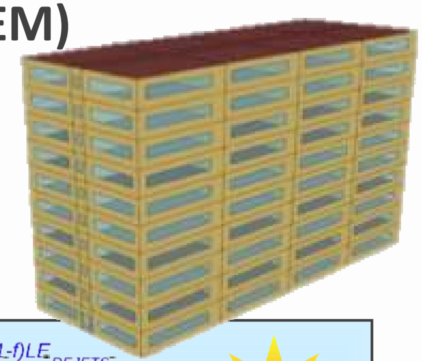
- The temperature of the first layer (fine) is assimilated to the surface temperature
- The equation of evolution depends on the energy balance for the surface layer
- It depends on the conduction of the heat for the other layers of materials
- Limit conditions for the last layer (in the deep soil for the road and in the buildings for the walls and the roofs)



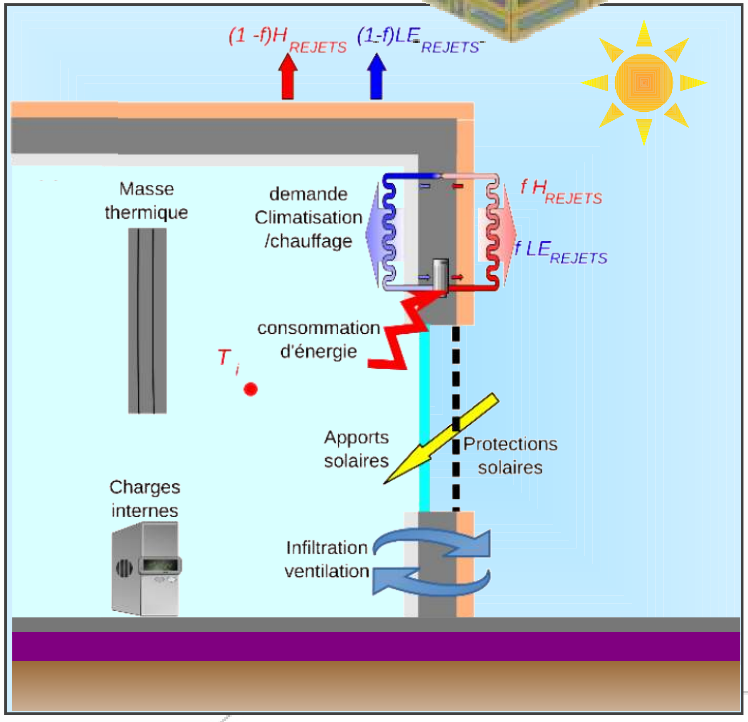
Source : Masson BLM 2000

Energetics of the building

The TEB model today includes the **Building Energy Model (BEM)** that solved the energy balance inside the building



- It’s inspired by more sophisticated building energetics models like Energy Plus
- The inside of the building is represented as a **unique thermal** area, ie without taking into account the splits between floors and apartments
- It defines a **unique thermal mass** that represent the thermal inertia of the materials inside the buildings (floors, dividing walls)
- It speficies a **fraction of window surfaces** for the Il spécifie une **fraction de surfaces vitrées** pour les facades

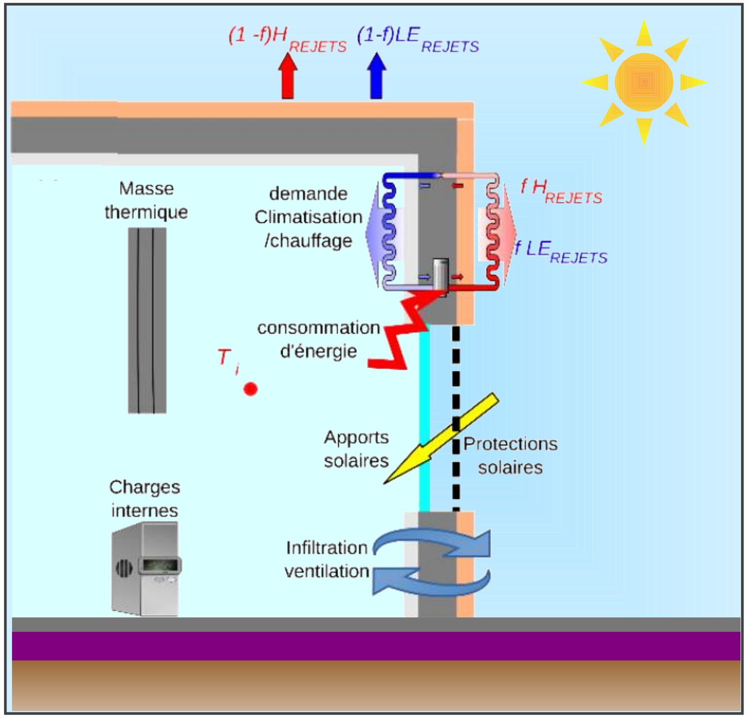


Source : Pigeon et Bueno 2012

Energetics of the building

BEM models :

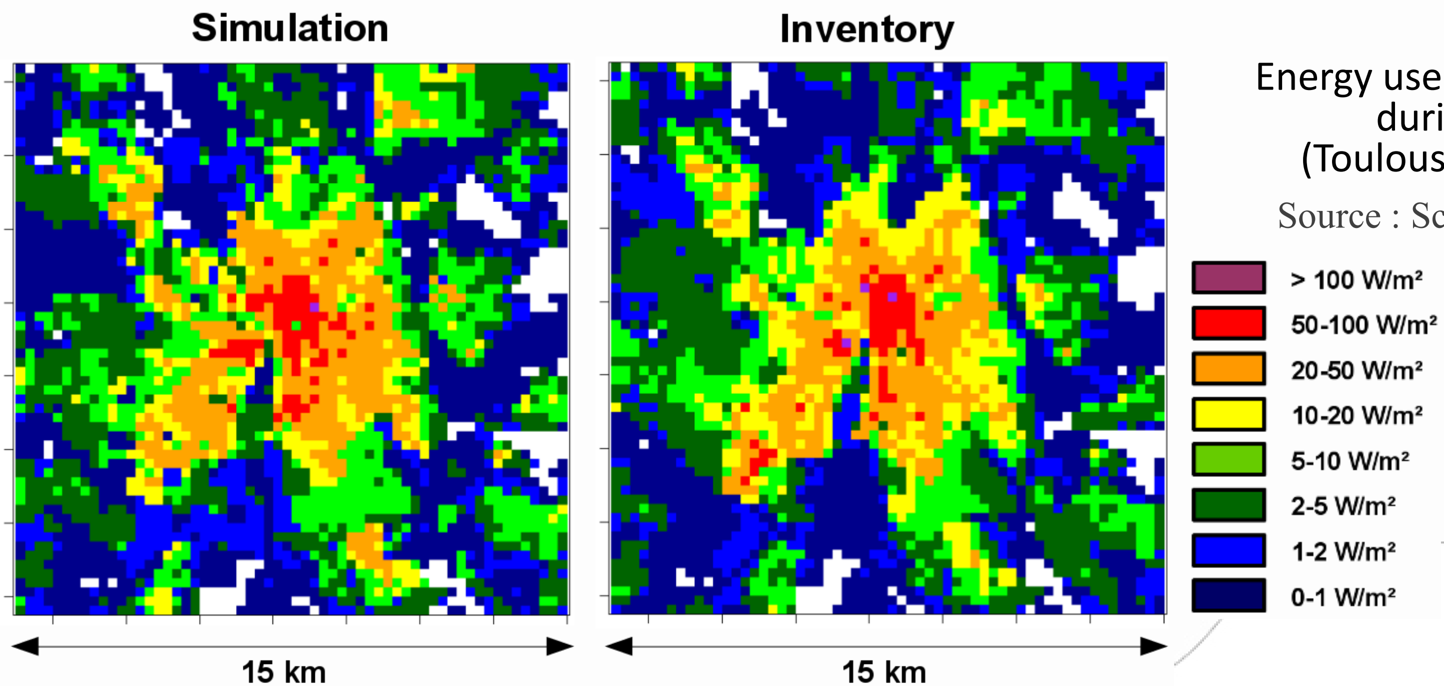
1. **The energy gains** via :
   - The penetration of the radiation in the building through the windows
   - Internal loads associated to the domestic equipments
2. **The energy exchanges** by infiltration and ventilation between the external and the internal air
3. **The functioning of the heating and cooling systems** controlled by a target temperature prescribed as an input of the model



Source : Pigeon et Bueno 2012

Energetics of the building

BEM aims at :
→ modelling the impact of the external climate on the **internal comfort**
→ Diagnosticing the **energy consumption of the buildings** lead by the use of cooling and heating systemps
→ Evaluating the **impact of the heat and wetness rejection** on the external airLe modèle TEB inclut aujourd'hui le **Building Energy Model (BEM)** qui résout un bilan d'énergie interne dans le bâtiment

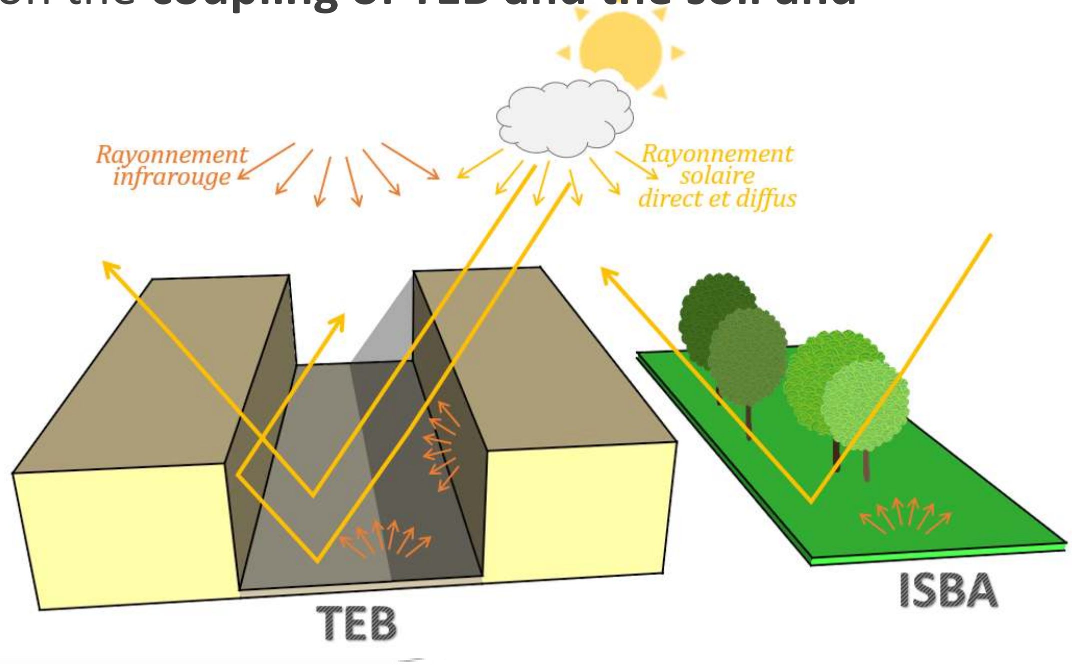


Energy use of the buildings during winter (Toulouse, 2004-2005)

Source : Schoetter et al. 2017

Urban vegetation and underground

- Initially, TEB was exclusively dedicated to the artificial surfaces
- The natural covers were modelled with ISBA in a decoupled way
  - Vegetation considered as an open surface (without obstruction)
  - Urban geometric parameters not realistic (canyon too narrow)
  - Turbulent fluxes for the vegetation calculated with the conditions at the atmospheric level
  - T2M calculated as an average of the T2M calculated by each model
- New versions were developed to integrate the vegetation in the urban canyon
- These developments are based on the **coupling of TEB and the soil and vegetation model ISBA**



Urban vegetation and underground

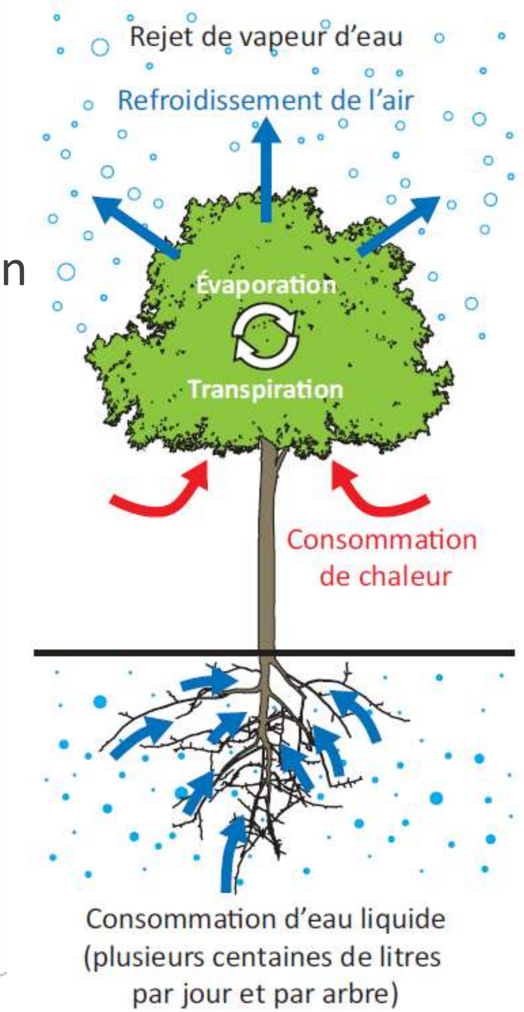
The most recent versions of the model represent

1. The full soil vegetation and the street trees
2. The green roofs
3. The urban underground and the hydrology
4. The watering systems

Urban vegetation and underground

These developements allow to model :

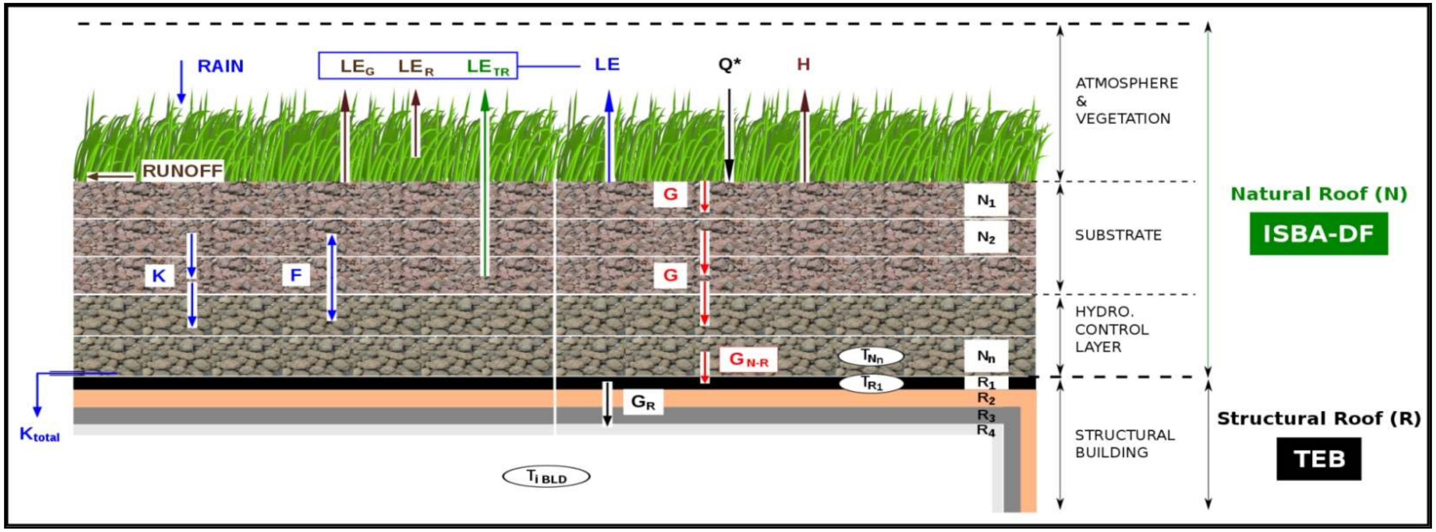
- **Interactions** built/vegetation/soil/atmosphere
- **Cooling power** of the vegetation by evapotranspiration
- **Shadowing** and attenuation of the radiation
- **Thermal isolation** of the buildings
- **Fluxes** surface/soil/network
- Evolution of the **water contents of soils**

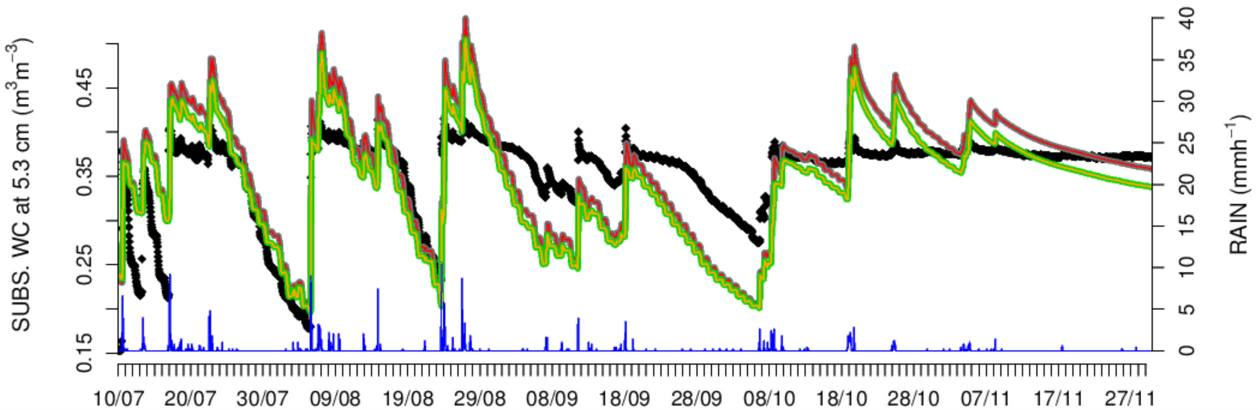


Source : APUR

Urban vegetation and underground

Example :modelling of the green roofs with the version ISBA-DF





Evaluation of the water contents in the layer of substratr

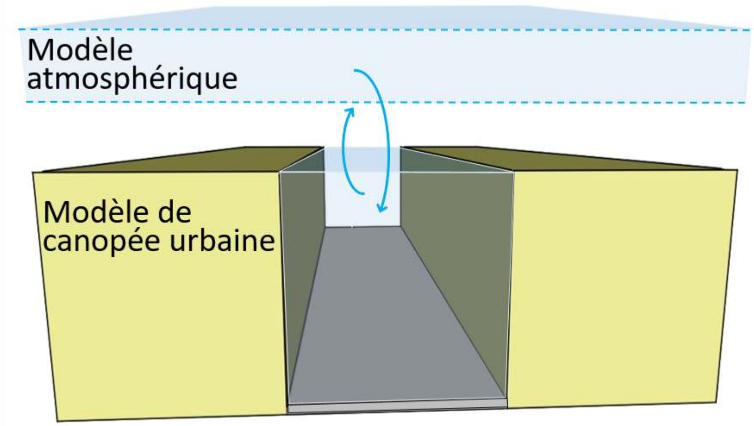
Source : de Munck et al. 2013

Atmospheric profiles in the canyon

Two main families of urban models exist :

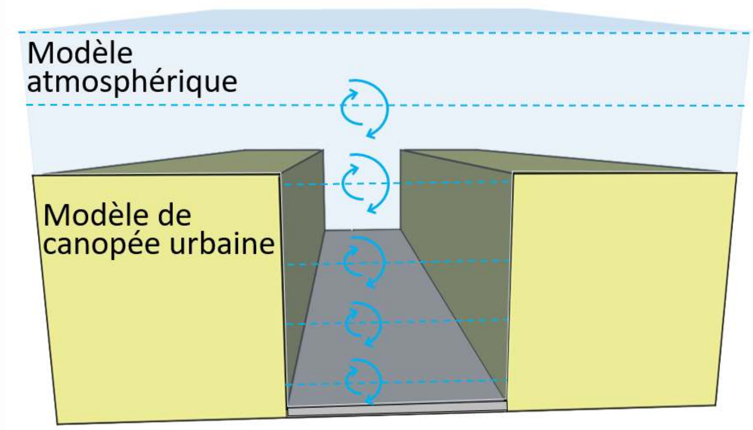
1. The 1-layer models

- The air volume in the canyon is parameterized and independant of the atmospheric model above
- The meteorological parameters are uniform in the canyon



2. The multi-layer models

- Low layers of the atmospheric model penetrate inside the canyon
- The urban surfaces modify the atmospheric properties by a drag effect



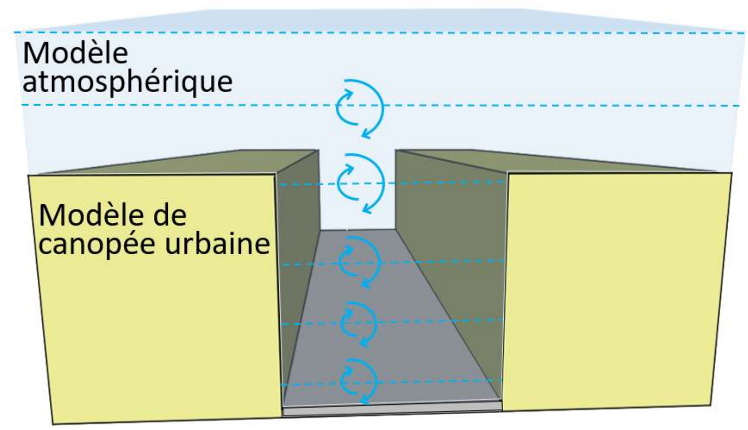
Atmospheric profiles in the canyon

Initially, TEB calculates a diagnostic of air temperature in the street halfway of the buildings

A version **TEB Surface-Boundary-Layer** was developed
(Masson and Seity 2009, Hamdi and Masson 2008)

It applied a **simplified model of the surface boudary layer** to calculate the **atmospheric profiles in the canyon** :

- Air temperature
- Specific humidity
- Wind speed
- Turbulent kinetic energy



Atmospheric profiles in the canyon

Approch of drag forces (for the forest canopies, Yamada 1982)

$$\frac{\partial U}{\partial t} = \underbrace{Adv + Cor + Pres}_{\text{Terms of large scale (atmospheric model)}} + \underbrace{Turb(U)}_{\text{Turbulent transport in the canyon}} + \underbrace{Drag_U}_{\text{Drag force from the obstacles}}$$

$$\frac{\partial U}{\partial t} = LS(U) + Turb(U) + Drag_U$$

$$\frac{\partial T}{\partial t} = LS(T) + Turb(T) + \frac{\partial T}{\partial t_{CAN}}$$

$$\frac{\partial q}{\partial t} = LS(q) + Turb(q) + \frac{\partial q}{\partial t_{CAN}}$$

- LS: Low level of the atmospheric model
- $Turb$: Turbulent scheme > > mixing length
- $Drag_U$, $\frac{\partial T}{\partial t_{CAN}}$, $\frac{\partial q}{\partial t_{CAN}}$: Parameterisation functions of the TEB fluxes and of the geometry
- $\frac{\partial T}{\partial t_{CAN}}$: Rate of warming/cooling from the urban facets
- $\frac{\partial q}{\partial t_{CAN}}$: Rate of Taux de moistening/drying up from the urban facets

$$\frac{\partial e}{\partial t} = PDyn(U) + PTh(T) + Diss(e) + \frac{\partial e}{\partial t_{CAN}}$$

- $\frac{\partial e}{\partial t_{CAN}}$: Production/Dissipation of TKE from the urban facets

Atmospheric profiles in the canyon

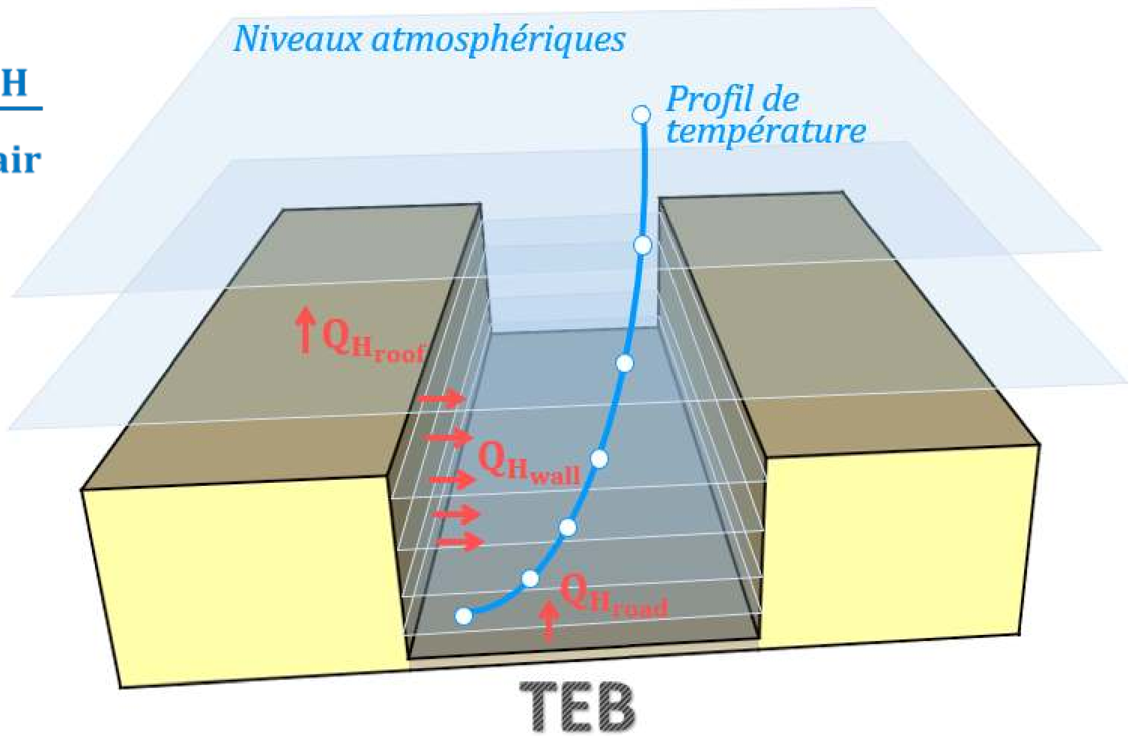
Approch of drag forces (for the forest canopies, Yamada 1982)

$$\mathbf{Drag_U} = -U_*^2 \frac{S_H}{V_{air}} - C_D U^2 \frac{S_V}{V_{air}}$$

$$\frac{\partial T}{\partial t_{CAN}} = \left(\frac{Q_{H_{roof}} + Q_{H_{road}}}{\rho C_p}\right)\frac{S_H}{V_{air}} + \frac{Q_{H_{wall}}}{\rho C_p}\frac{S_V}{V_{air}}$$

$$\frac{\partial q}{\partial t_{CAN}} = \left(\frac{Q_{E_{roof}} + Q_{E_{road}}}{\rho}\right)\frac{S_H}{V_{air}}$$

$$\frac{\partial e}{\partial t_{CAN}} = C_D U^3 \frac{S_V}{V_{air}}$$



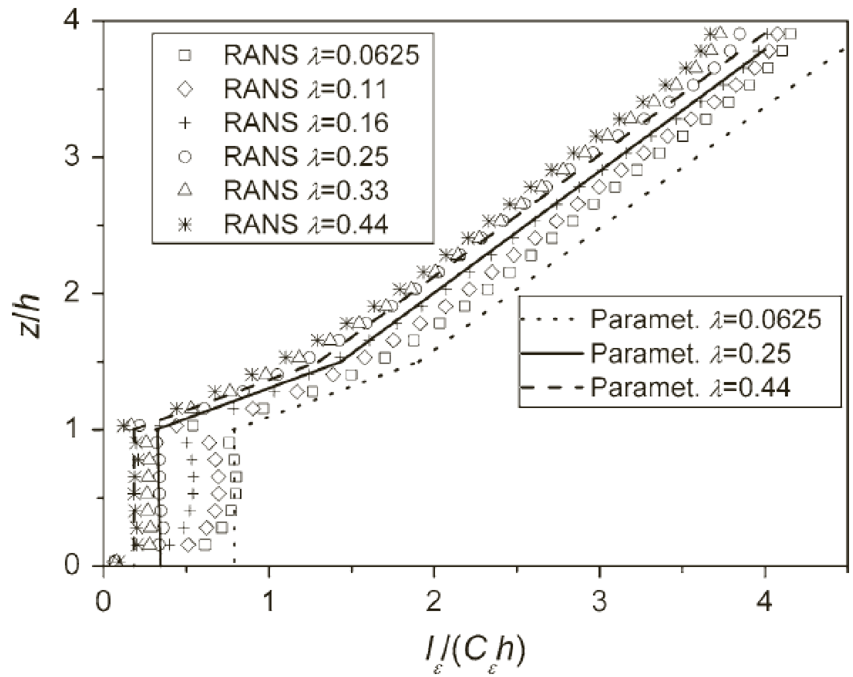
C_D	Drag coefficient
S_H	Horizontal surface
S_V	Vertical surface
V_{air}	Air volum

Atmospheric profiles in the canyon

Approch of drag forces (for the forest canopies, Yamada 1982)

Parameterization of the mixing length in the urban canopy layer
And above the buildings functions of the results of CFD simulations
(Santiago & Martilli 2010)

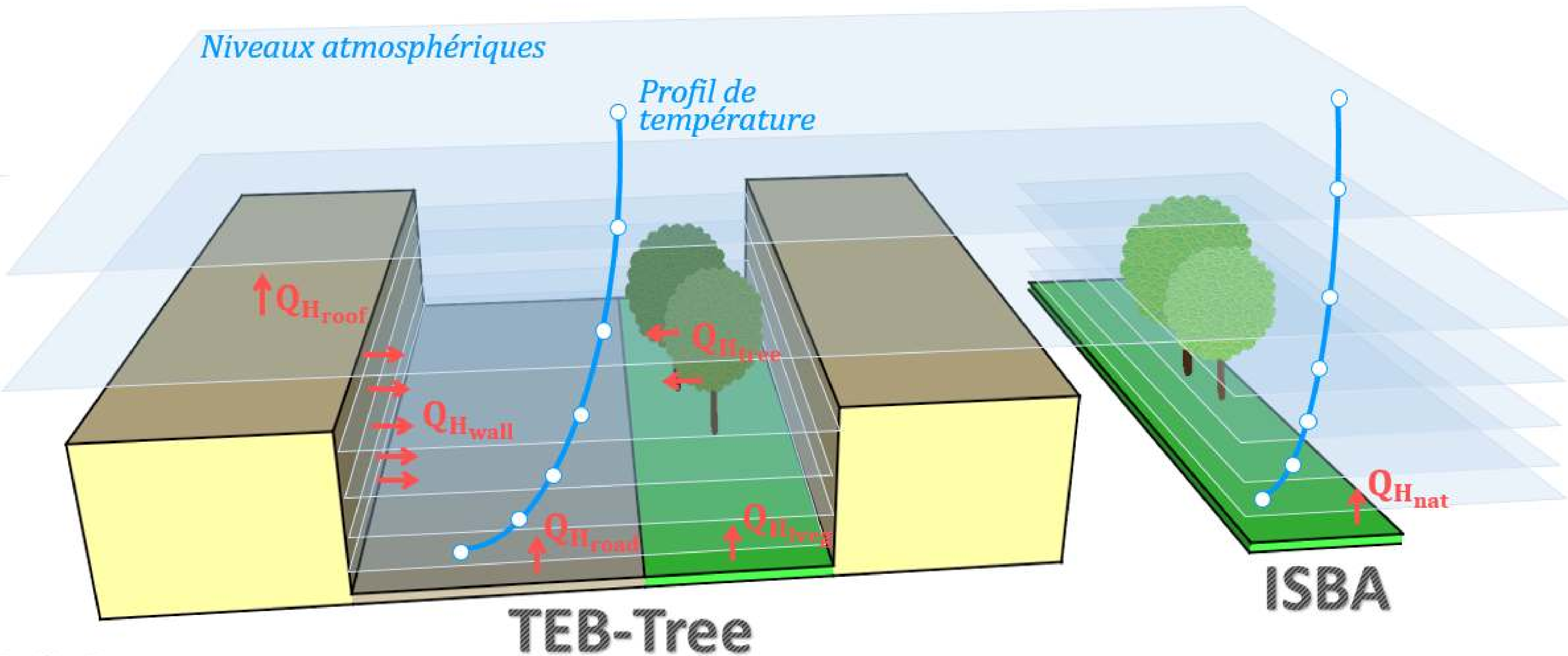
$$\begin{cases} \frac{L}{C} = 2.24(z_H - z_d) & \text{si } z \leq z_H \\ \frac{L}{C} = 2.24(z - z_d) & \text{si } z_H \leq z \leq 1.5\, z_H \\ \frac{L}{C} = 1.12(z_H - z_d) & \text{si } z \geq 1.5\, z_H \end{cases}$$



Sources : Santiago et Martilli 2010

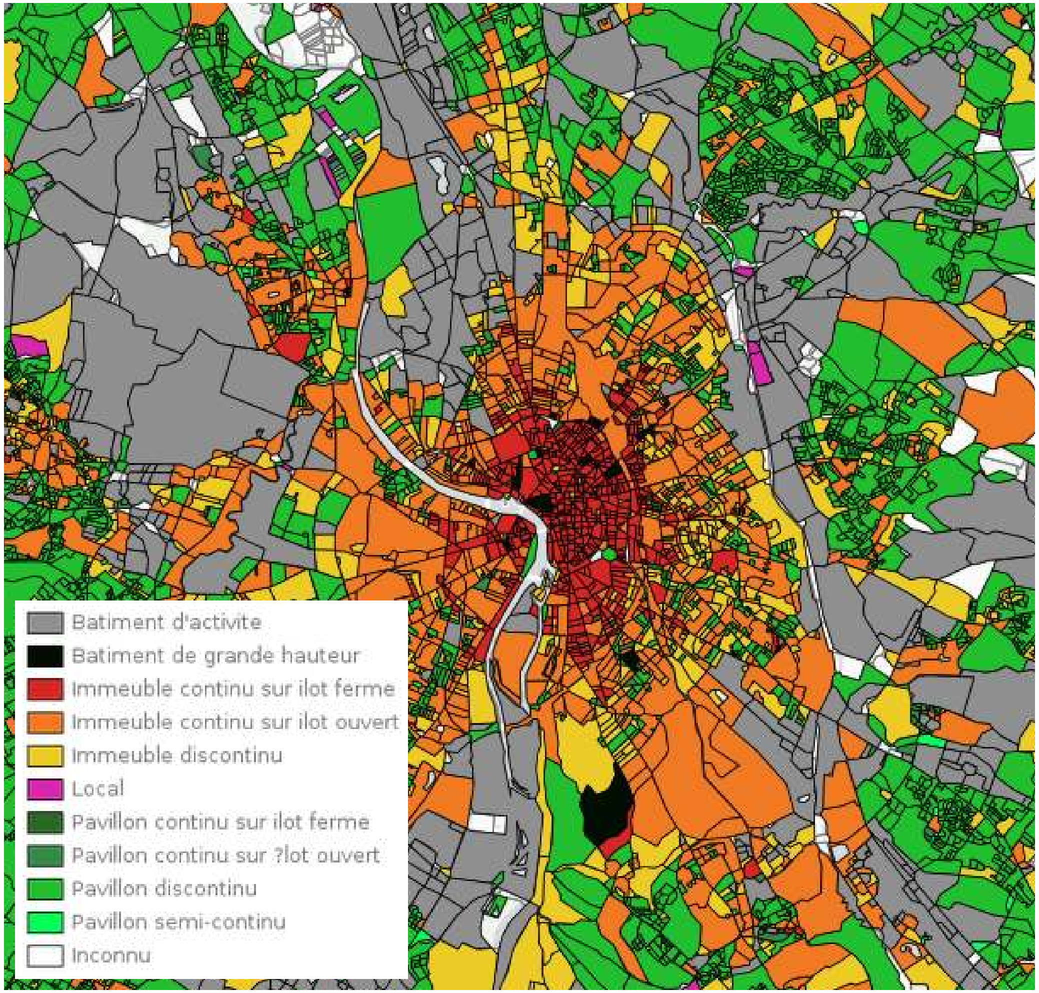
Atmospheric profiles in the canyon

Approch of drag forces (for the forest canopies, Yamada 1982)

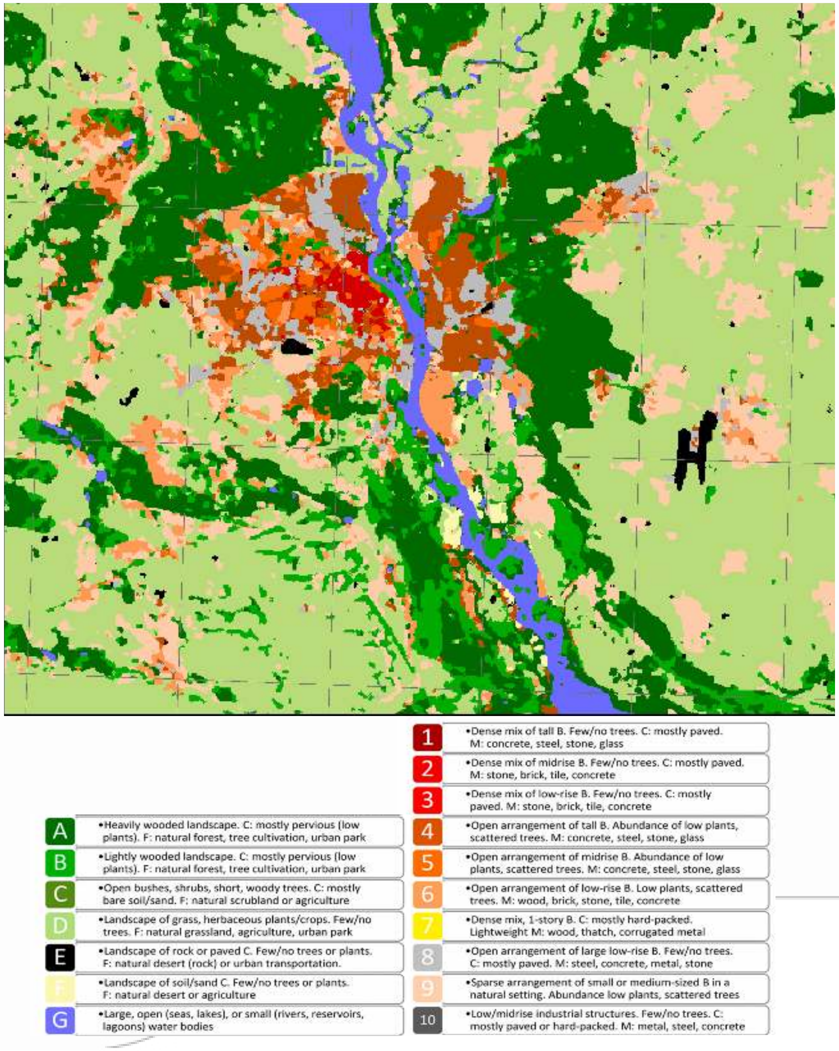


Surface databases : WUDAT et MapUCE initiatives

Classification of the urban clusters on Toulouse
French research project MApUCE

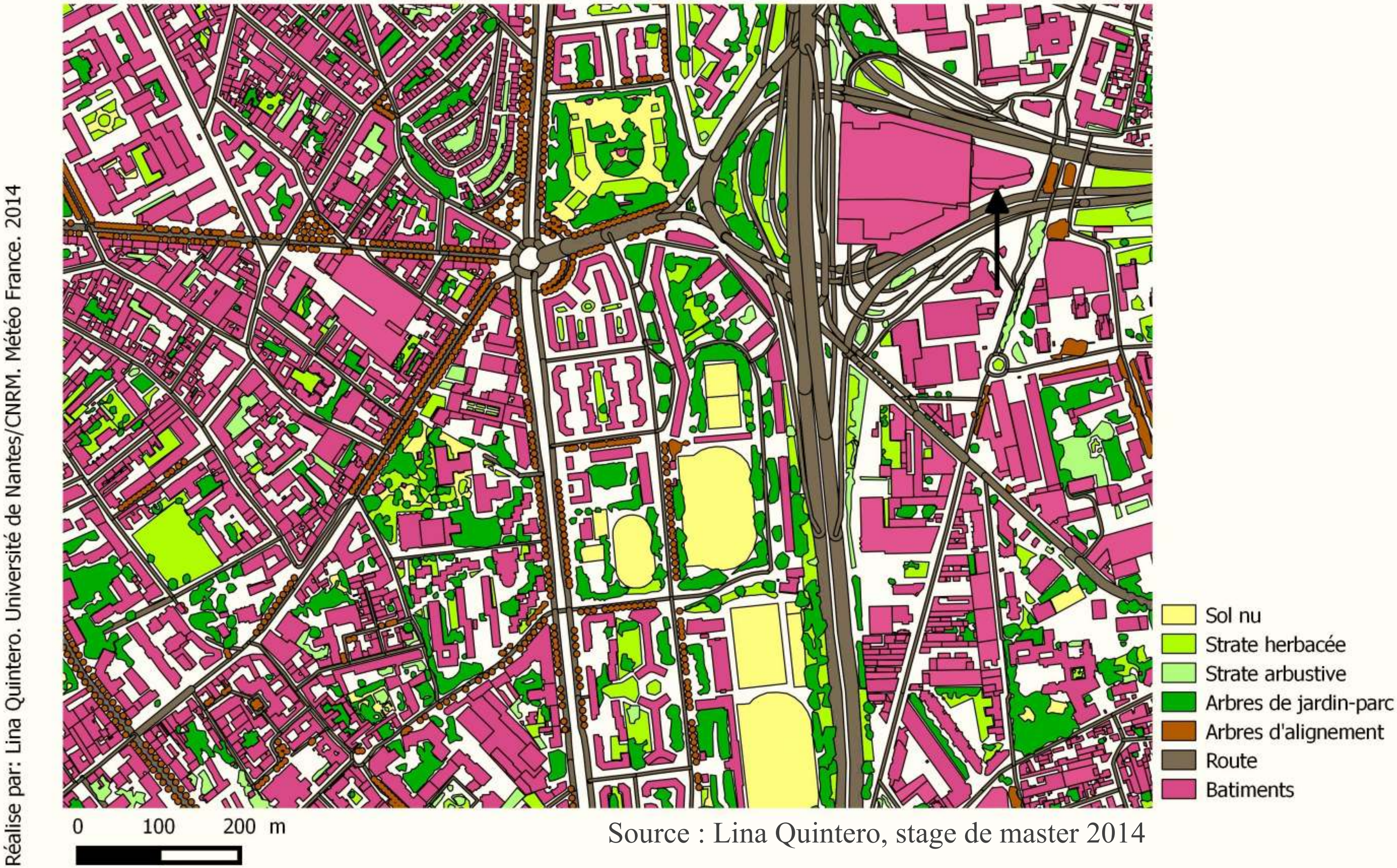


LCZ classification on Kiev, Ukraine
International initiative WUDAPT



Difficulty to caracterize the urban vegetation

Manual digitization of the layers of vegetation cover (by levels)
Toulouse, research project REQUA

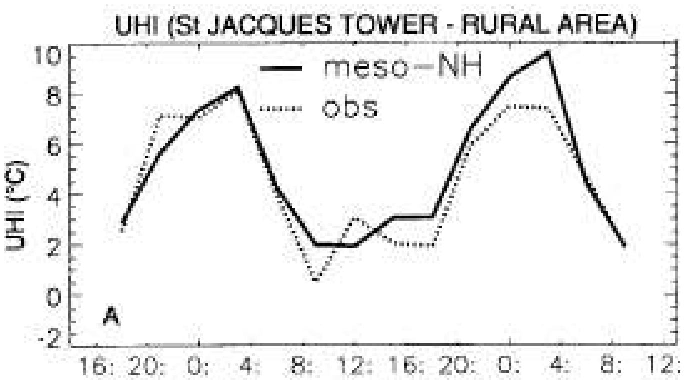


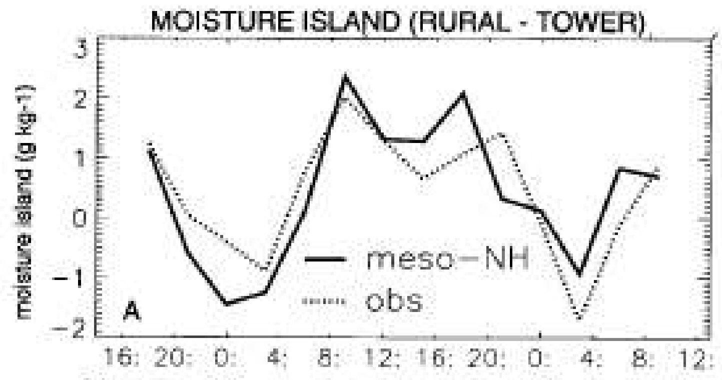
Source : Lina Quintero, stage de master 2014

Examples of applications

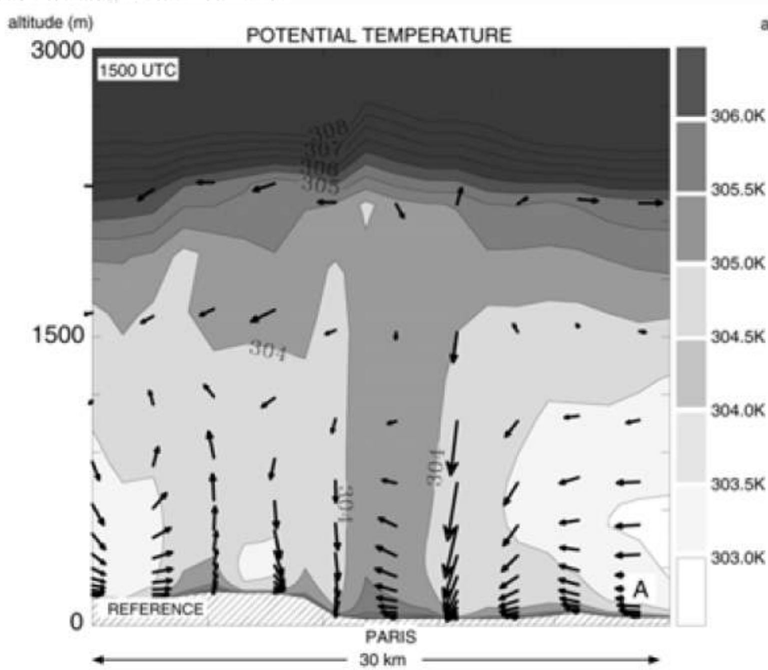
First study TEB / Meso-NH on the region of Paris at 1km resolution

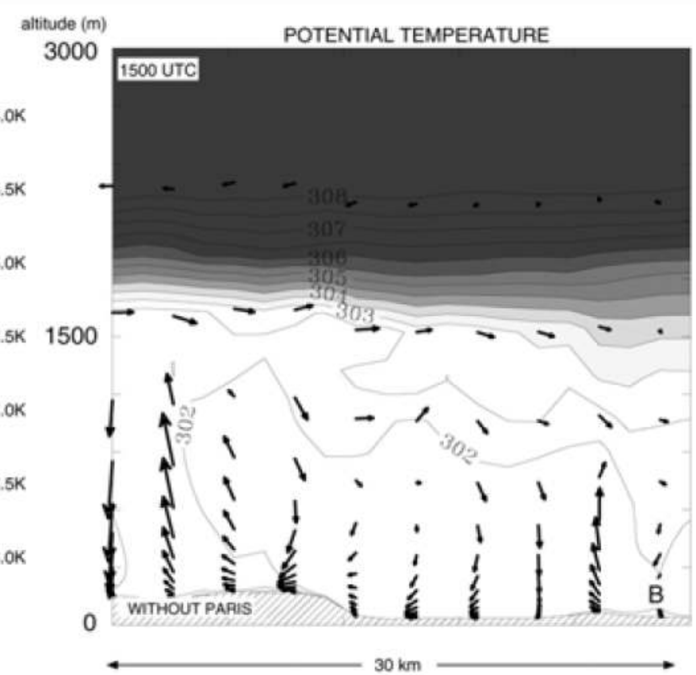
Simulation of the urban effects in an anticyclonic situation





Heat island and wetness island Paris, 12 july 1994



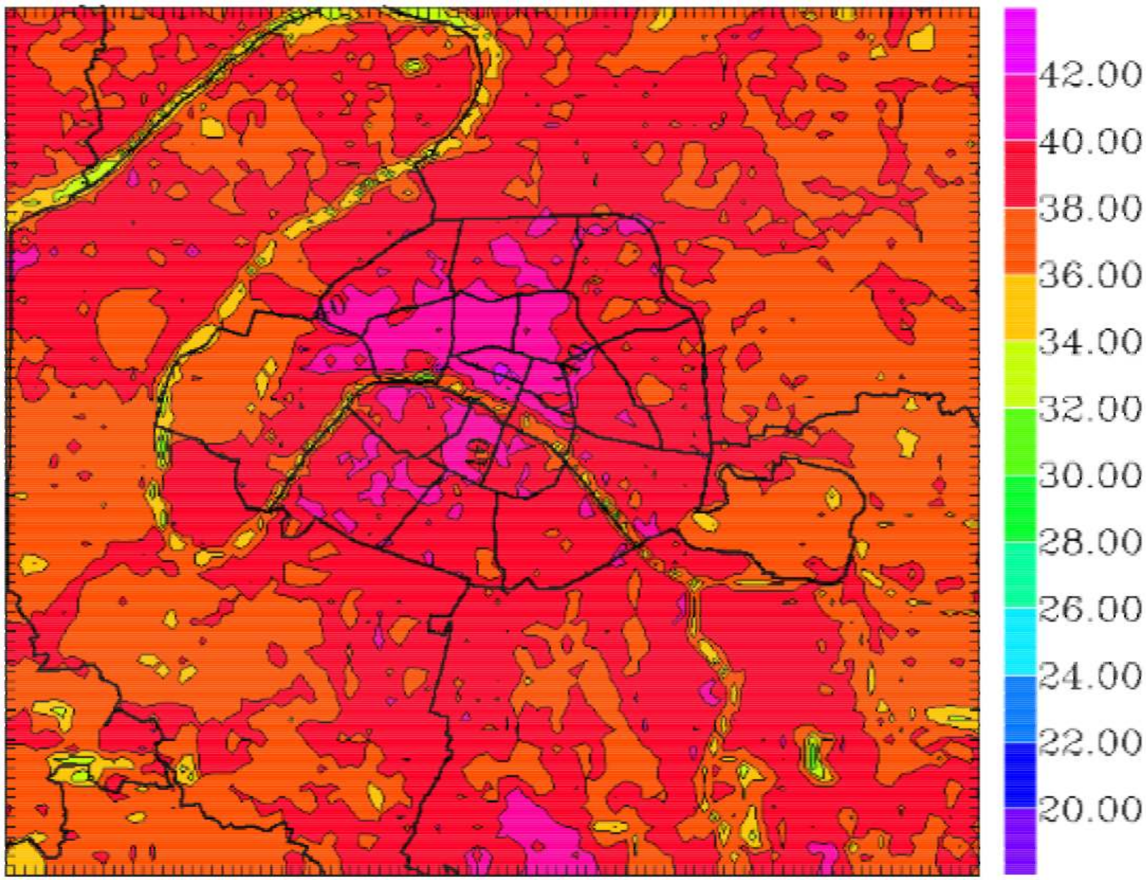


Urban effects of the struction of the atmospheric boundary layer Paris, 12 july 1994

Source : Lemonsu et Masson 2002

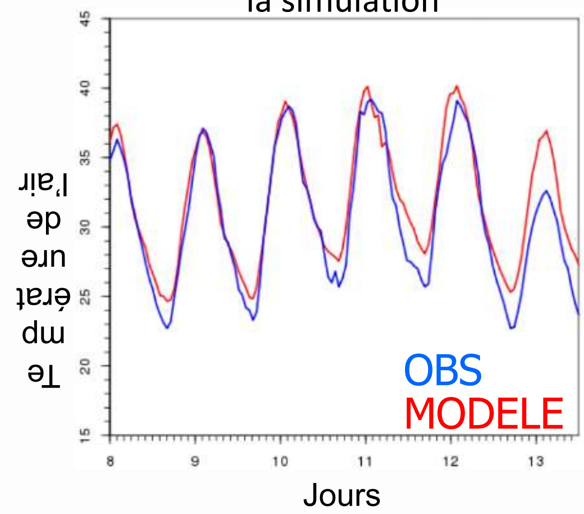
Examples of applications

Simulation of the 2003 heatwave on the Parisian region
with TEB / Meso-NH at 250 m resolution



T2m on the parisian region
during the 2003 heatwave
(spatial resolution = 250m)

Évaluation systématique de
la simulation

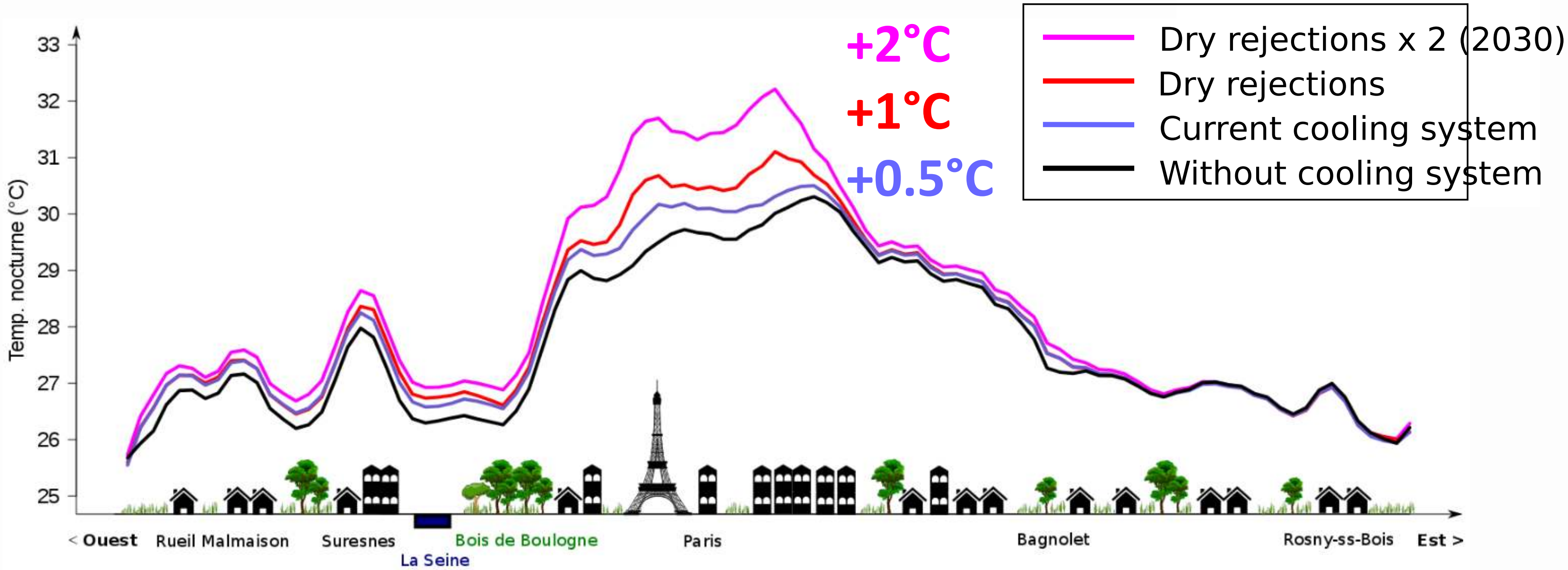


Source : Projet CLIM2 – Météo France, CLIMESPACE, CNAM

Examples of applications

Simulation of the 2003 heatwave on the Parisian region
with TEB / Meso-NH at 250 m resolution
>> Study of the **impact of the cooling systems rejections** on the micro-climate in the street

Minimal temperature simulated in the street at the level of the pedestrian



Source : de Munck et al. 2013, Int. Journal of Climatology

Examples of applications

Simulation offline avec TEB

Projet EUREQUA, Toulouse