URBAN METEOROLOGY

&

TEB

Valéry MASSON

METEO FRANCE
Toujours un temps d'avance

Urban Climate

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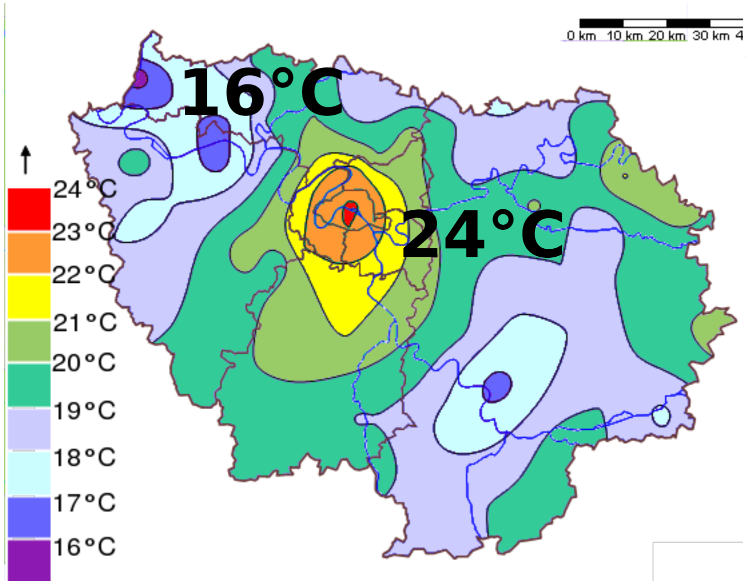
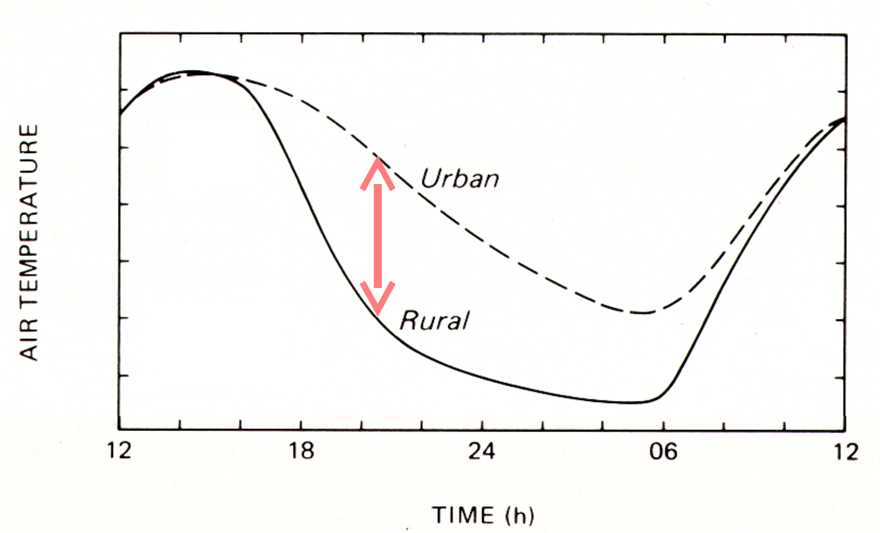
Urban Heat Island

→ city up to 10K warmer by clear nights

→ Of the order of 1K by day



Observed minimal temperatures near Paris (Ile de France: heat wave 2003)



From Oke, 1987

Characteristics of the Urban atmosphere

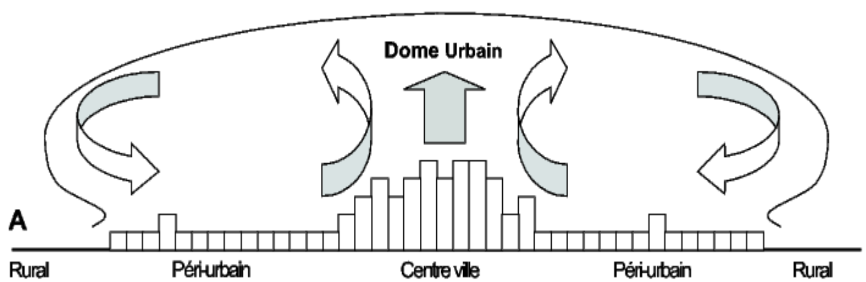
- **URBAN BOUNDARY LAYER**

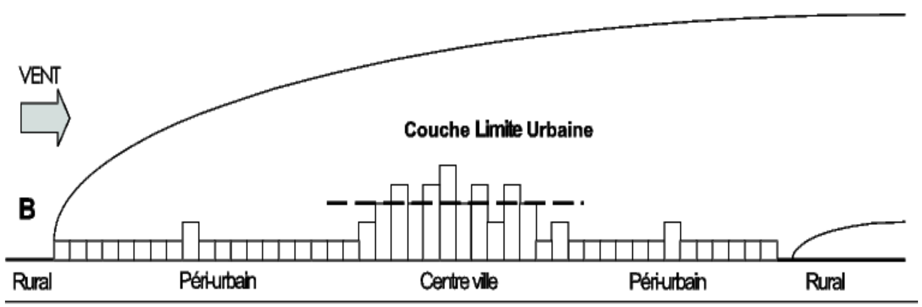
Boundary Layer above the city

- **URBAN HEAT ISLAND**

Temperature difference between city and countryside

- **URBAN BREEZE / URBAN PLUME**





CNRS dépasser les frontières

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Physical processes

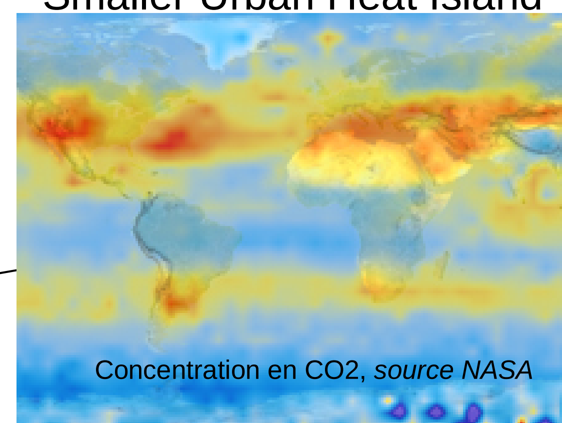
Physical processes : where do the heat comes from ?

CO_2 emissions → Global warming

Urban CO_2 emissions → Urban warming (urban heat island)

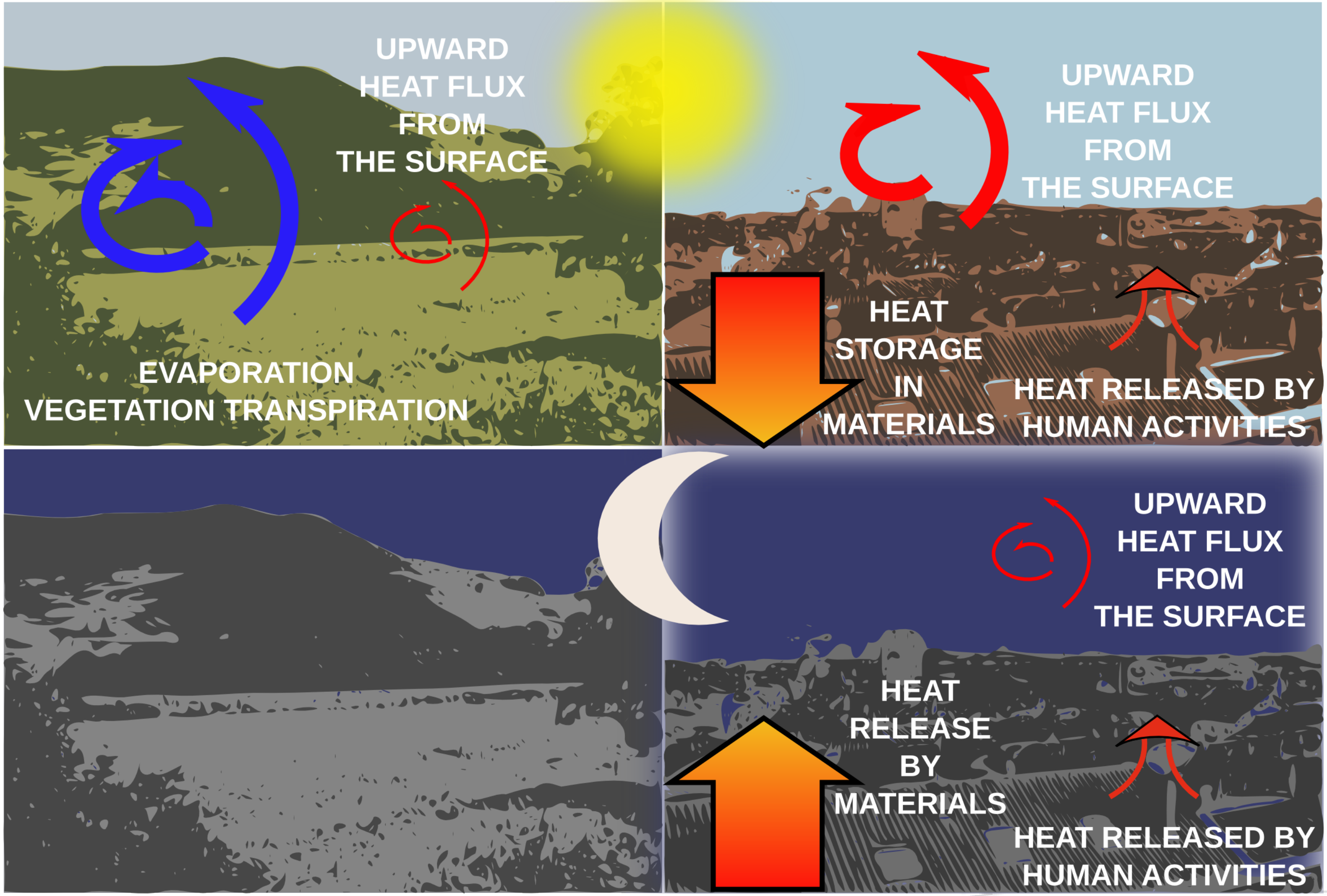
Trees in cities → CO_2 absorption → Smaller Urban Heat Island

NO !!
This is wrong



Concentration en CO2, *source NASA*

The physical processes



URBAN CANOPY ENERGY BALANCE

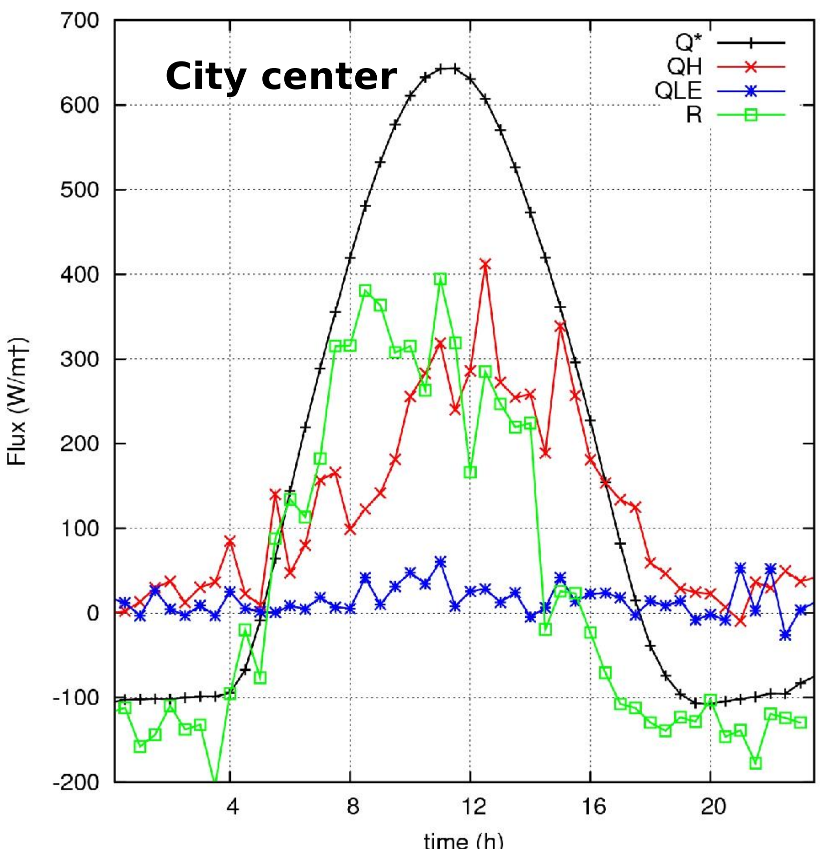
$$Q^* + Q_F = Q_H + Q_E + \Delta Q_S + \Delta Q_A$$

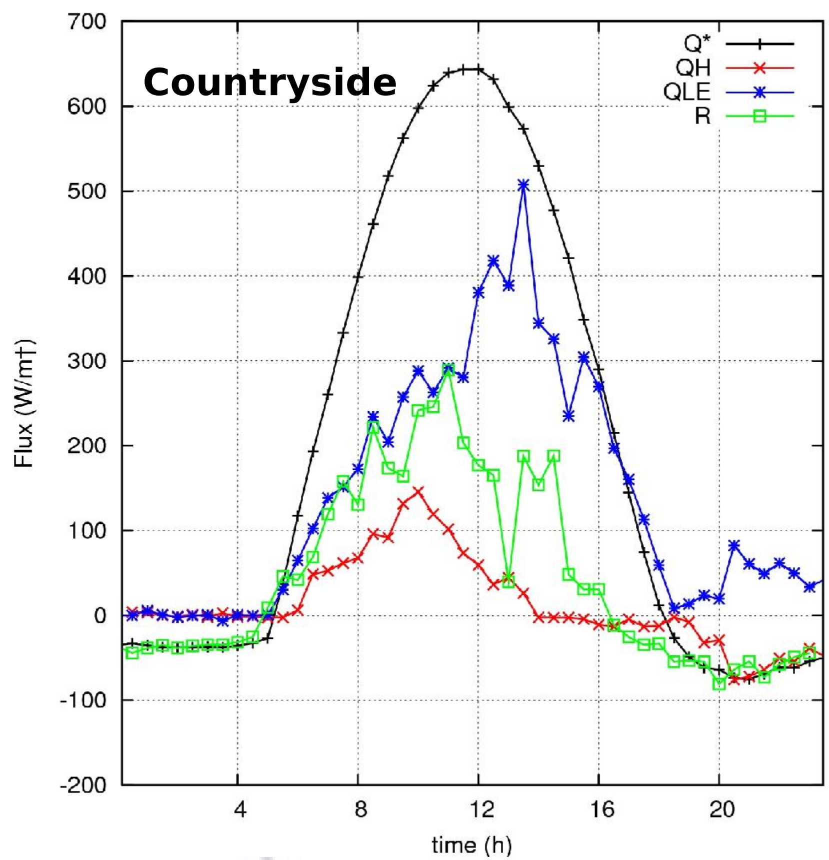
Q^*	Q_F	Q_H	Q_E	ΔQ_S	ΔQ_A
Net radiation	*Anthrop. heat flux*	*Sensible heat flux*	*Latent heat flux*	*Storage heat flux*	*Net heat advection*

Physical processes : example

the 4th of July, 2004

→ Anticyclonic situation
→ Warm temperatures (up to 34°C)
→ Very different rural/urban forcing:





Observations and experiments

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Canopy and Aerosol Particles Interaction in Toulouse Urban Layer (CAPITOUL) experiment

Toulouse

500,000 inhabitants
Old european city, brick and tiles
« Far » from the sea and mountains

Objectives

1) **Energetic exchanges between city and atmosphere**

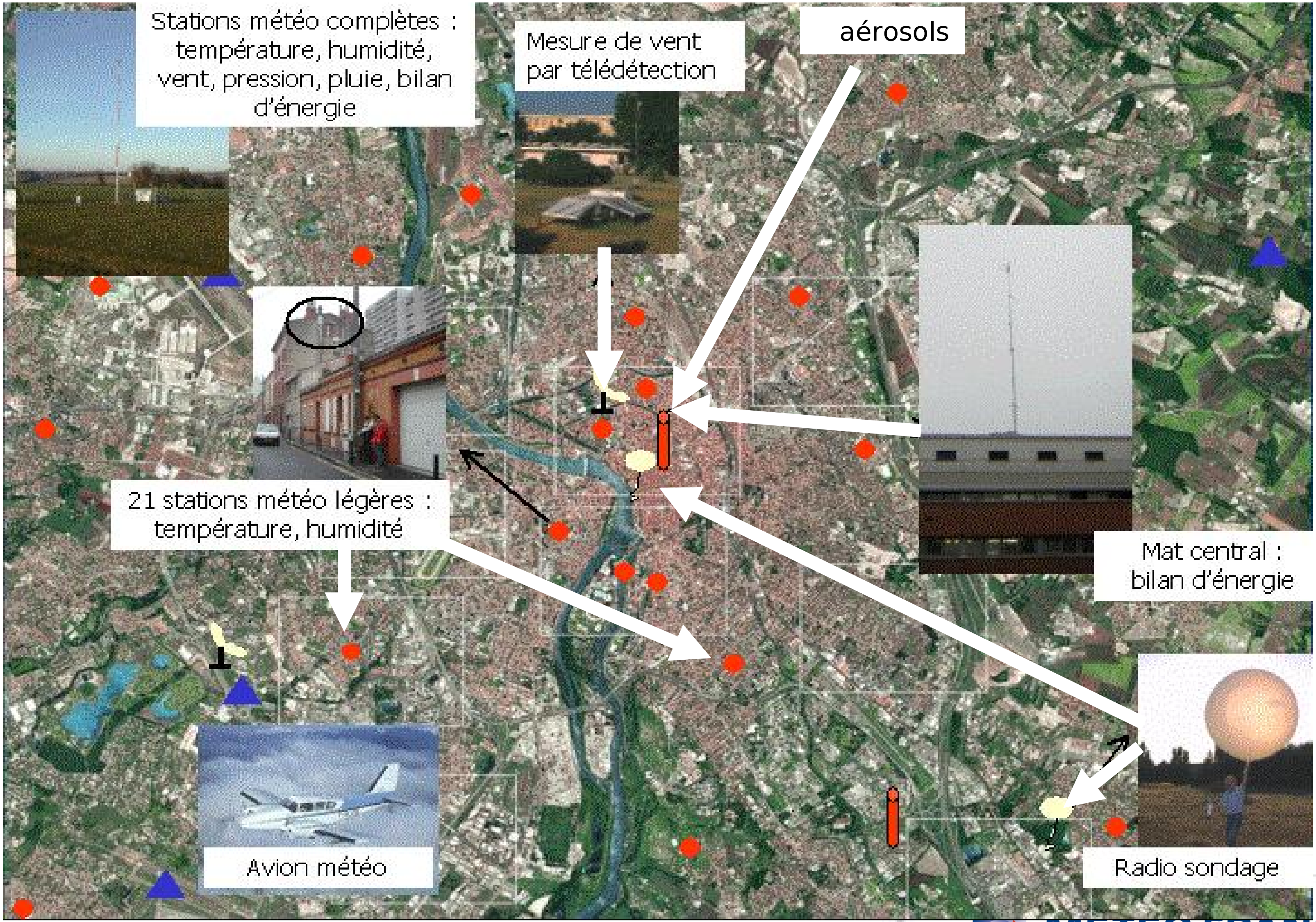
2) **The impact of the city on the atmosphere**

3) **The urban aerosol**

4) **Infra-Red Teledetection of the surface**

→ All these experimental objectives are linked with <u>modelling</u> objectives

« CAPITOUL » experimental network



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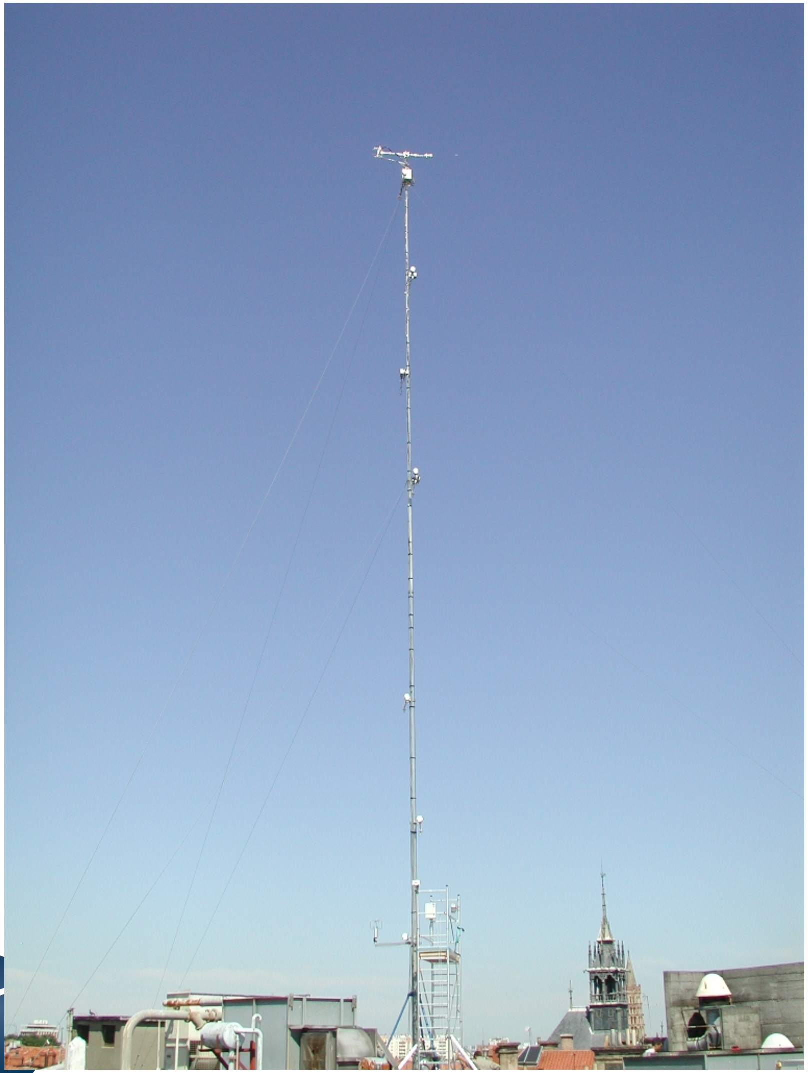
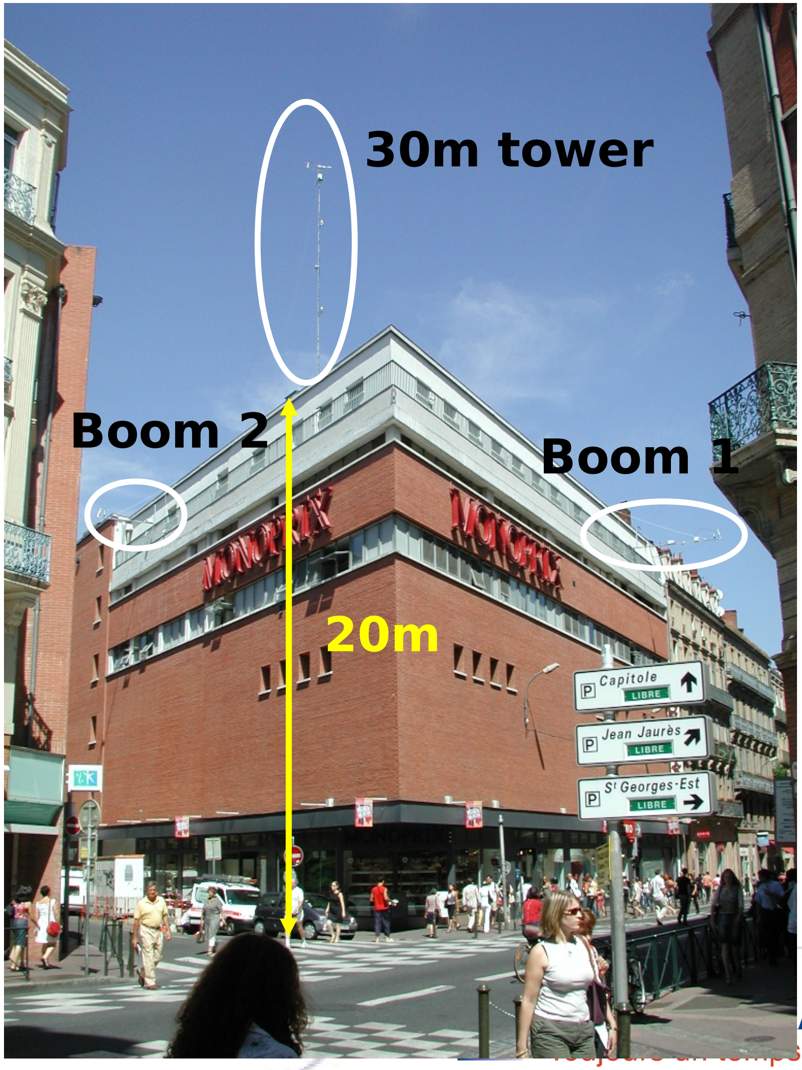
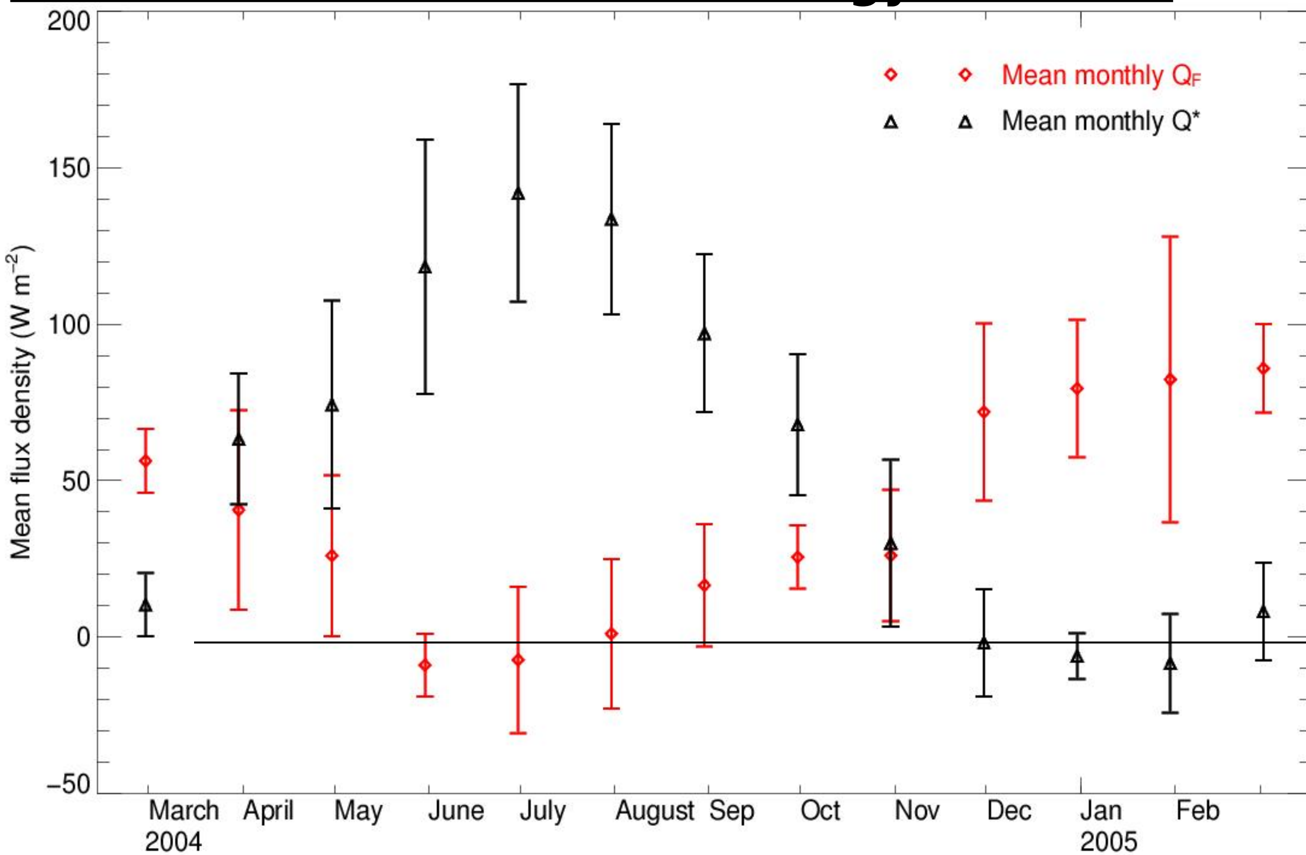
Measurements of energy exchanges





Anthropogenic Heat

<u>This is the main source of energy in winter</u>



Anthropogenic heat flux

Net radiation

summer **winter**

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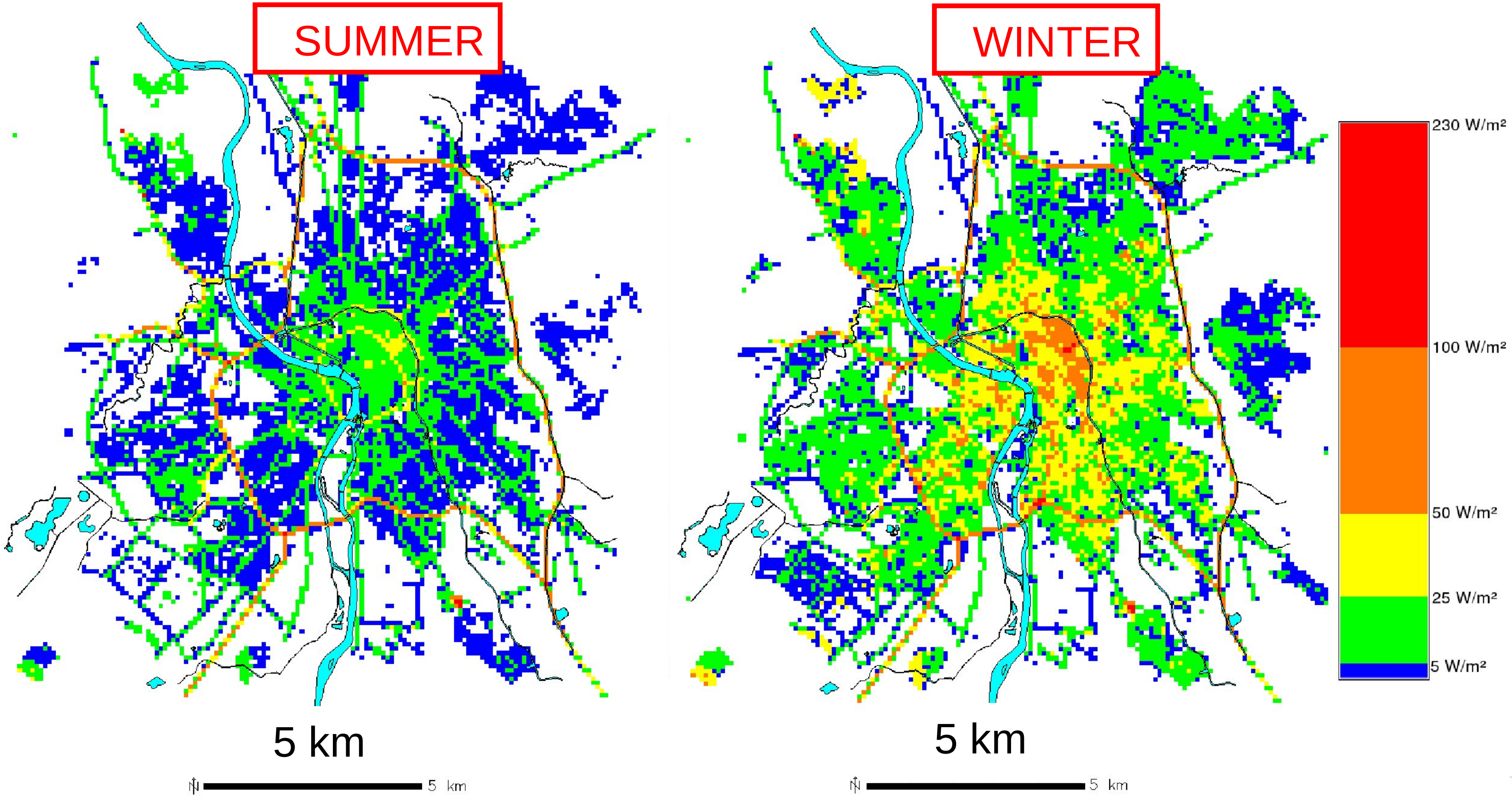
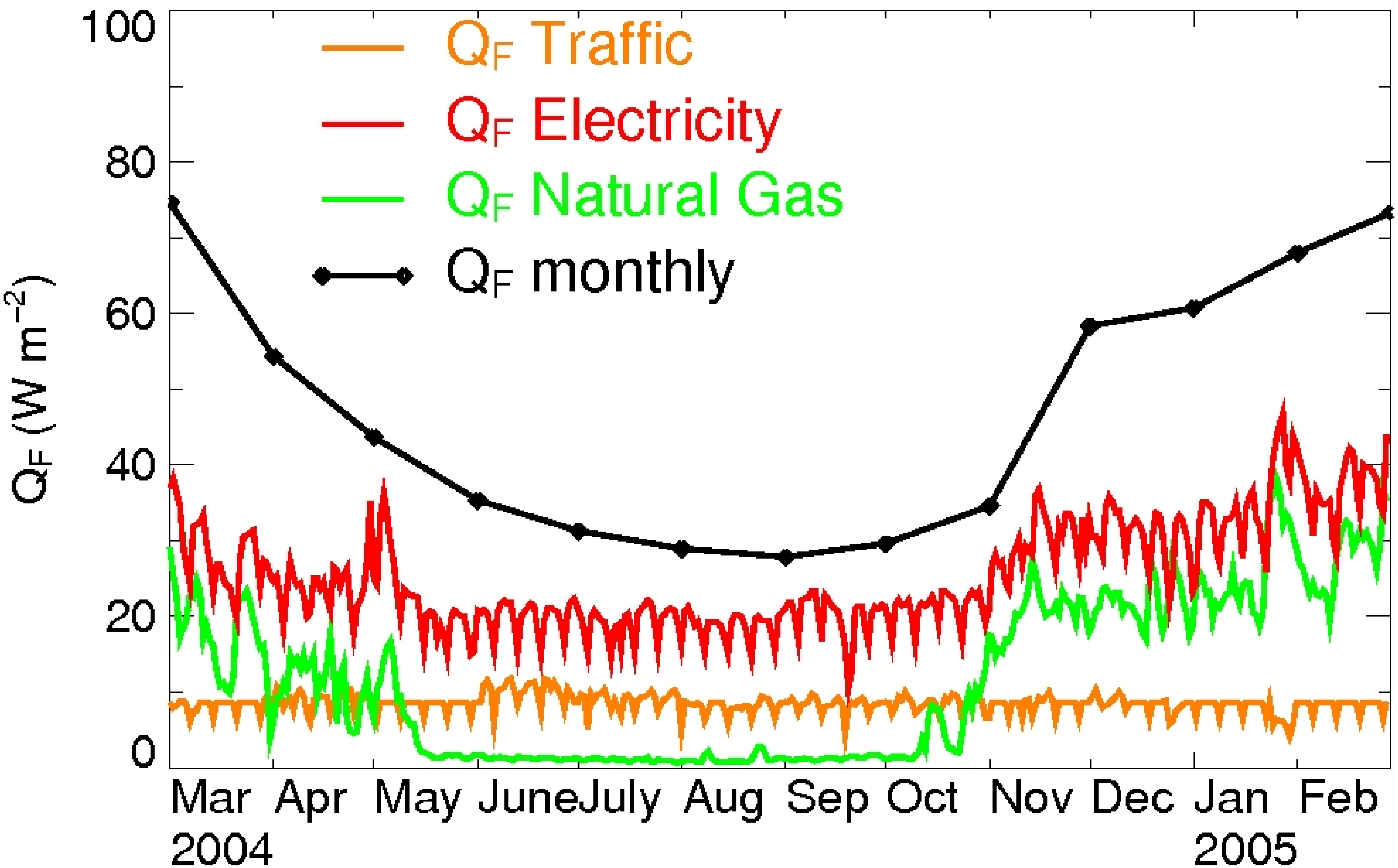
Estimation of anthropogenic heat over Toulouse, summer/winter



Inventory of Q_F for the city center



- seasonnal cycle for gaz and electricity
- cycle linked to human activities for electricity and traffic

Modelling

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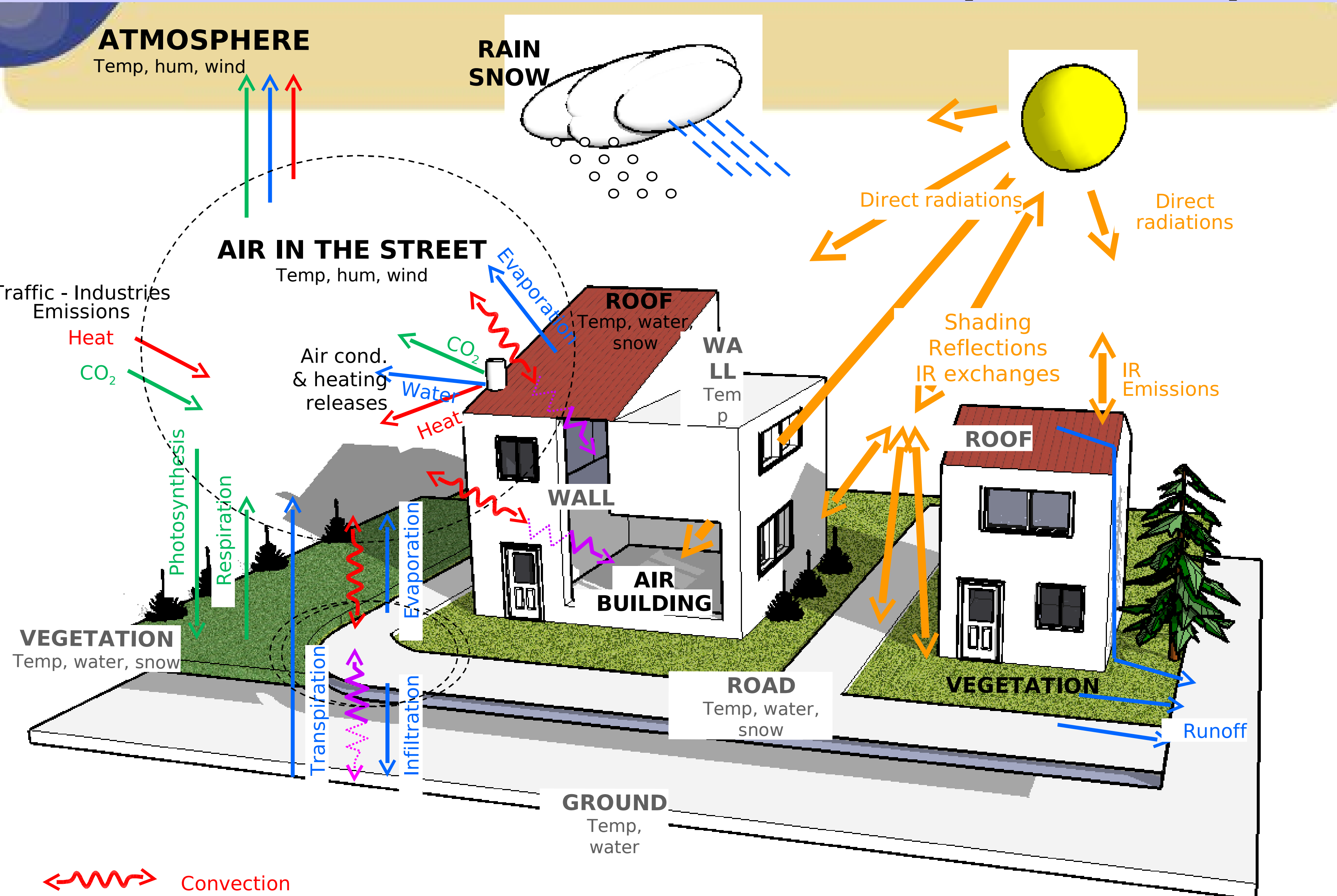
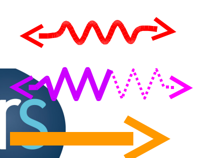
Processes taken into account in the SURFEX model for a complex urban landscape

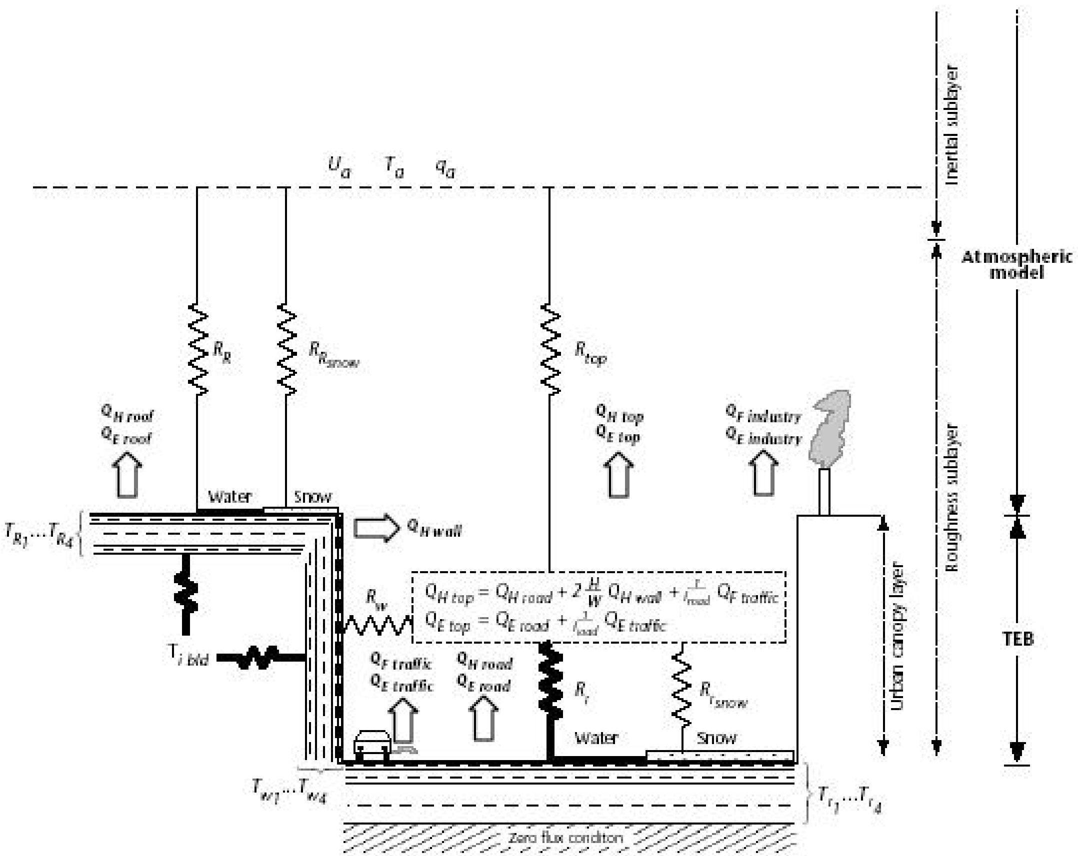




<u>On going implementation :</u>
Direct radiation through windows, air conditioning releases, vegetation in the street, road orientation, ground water infiltration, CO_2 emissions.

TEB

1) TEB (Town Energy Balance)
Masson 2000, Masson et al 2002, Lemonsu et al 2003



- Only 1 road, 1 roof, and 2 *identical* facing walls
  → ONLY ONE WALL SEB
  → Only one wall temp.
  → Only one road temp.

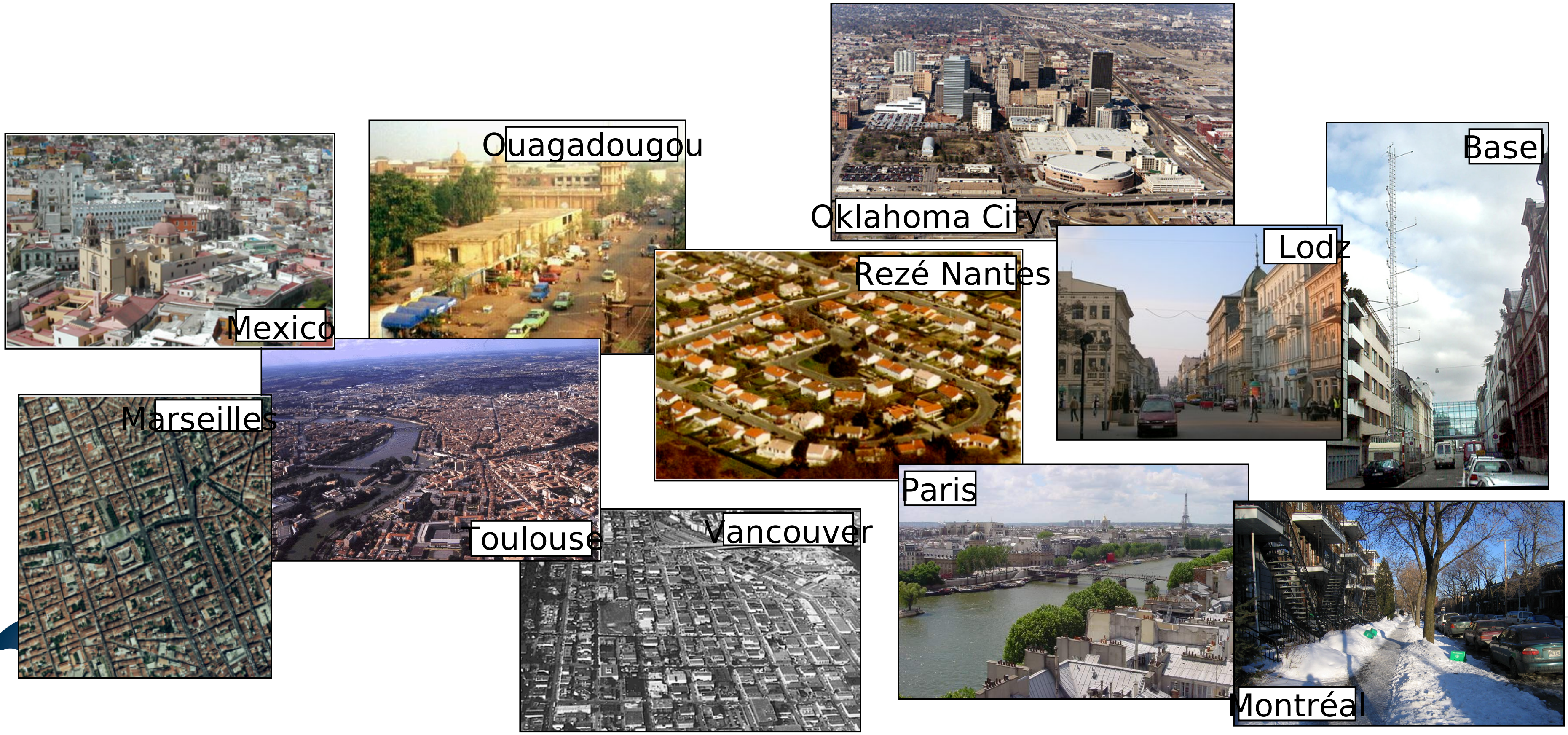
- Rain and snow interception
- Latent heat fluxes
- Heat conduction in the materials
- Anthropogenic fluxes

TEB validations

There is an important effort of measurements of urban surface energy balance & climate in the world

→ To understand urban climate

→ To validate models : here are presented the sites on which TEB has been valisated



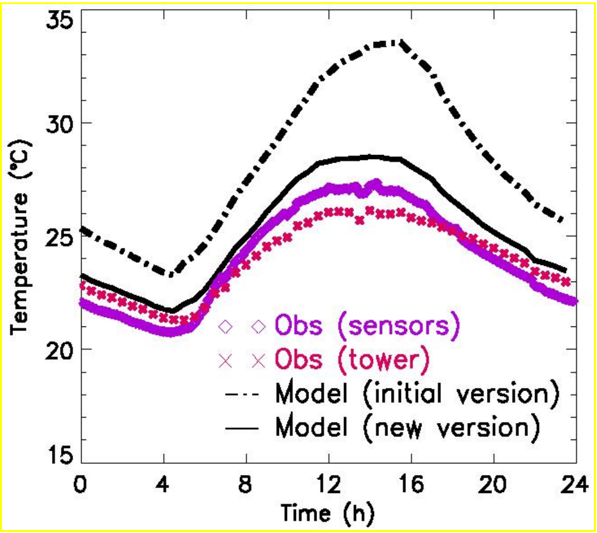
TEB : validation in summer

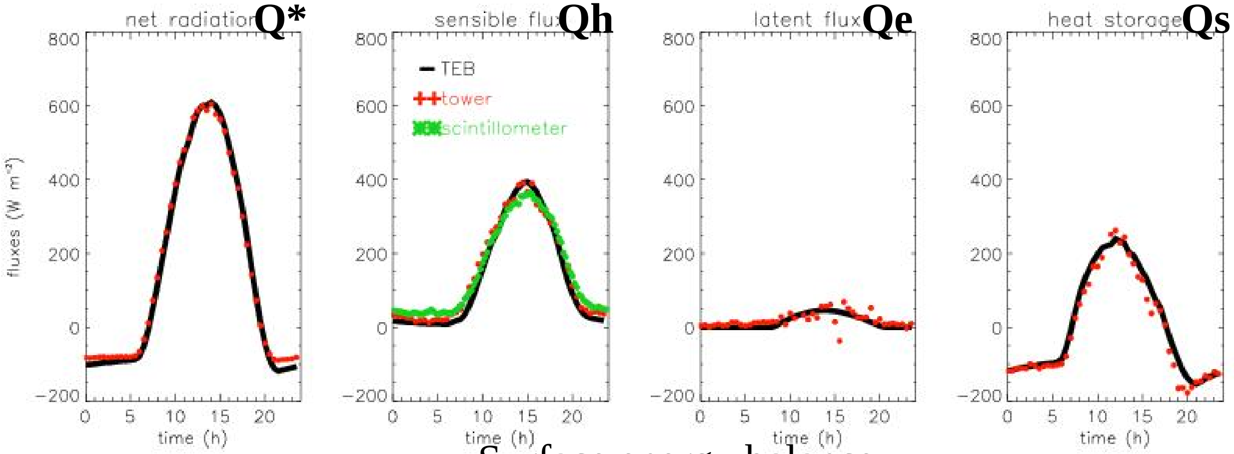
TEB has been validated against several dense urban sites:

Mexico City, Vancouver (Masson et al 2002)
Marseille (Lemonsu et al 2003)

*These validations allowed **ameliorations*** of the initial parameterizations of sensible heat exchanges in the canyon.

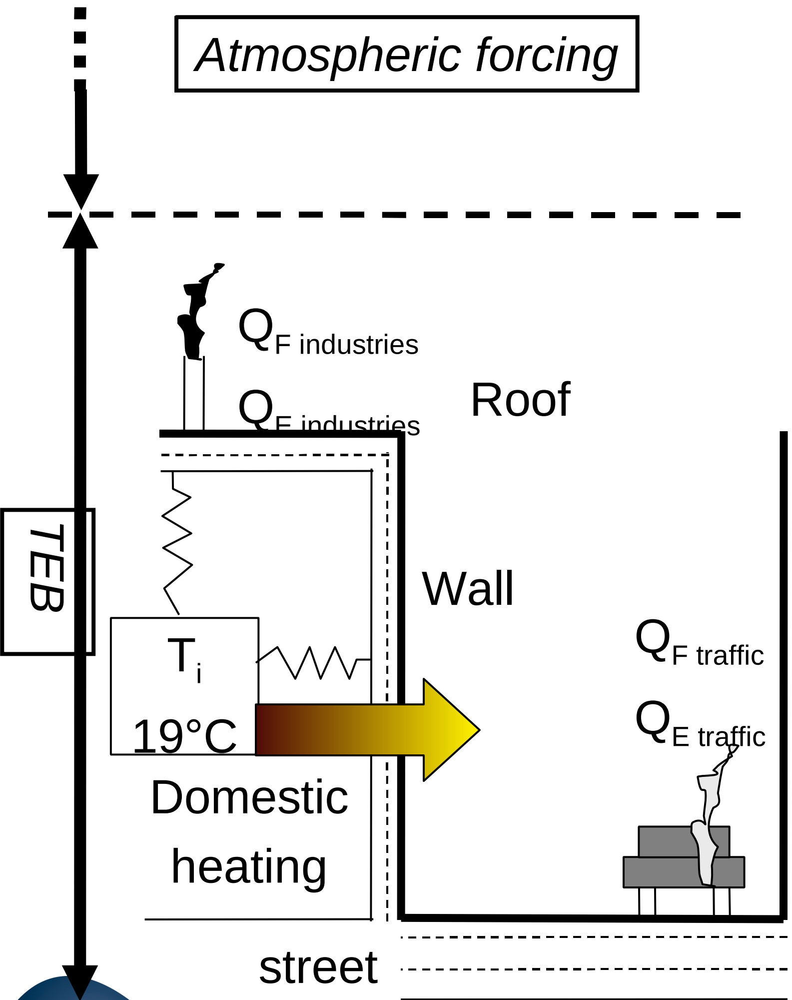
Canyon air temperature





Surface energy balance

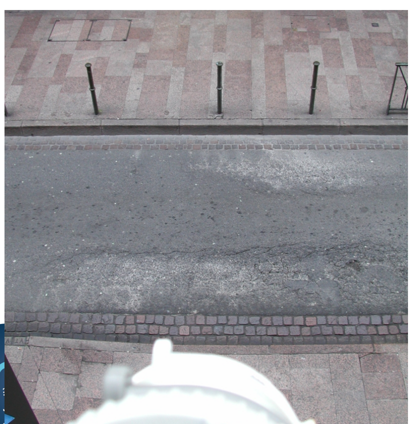
TEB : validation in winter



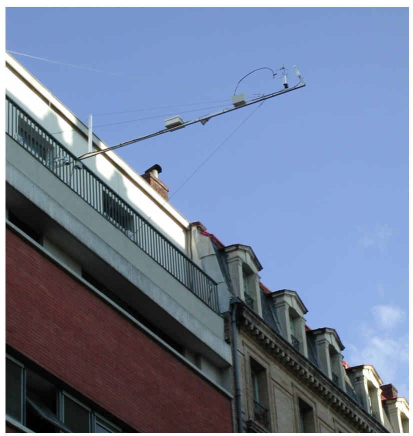
- Domestic heating computed implicitly with a minimum internal temperature of 19°C. Internal temperature has its own equation evolution, not based on energy balance.
- Focus on fall and winter periods during which heating is strong in Toulouse.
- Use of observations collected during the CAPITOUL field campaign in Toulouse at a dense urban site

The surface temperature measurements (Evaluation)

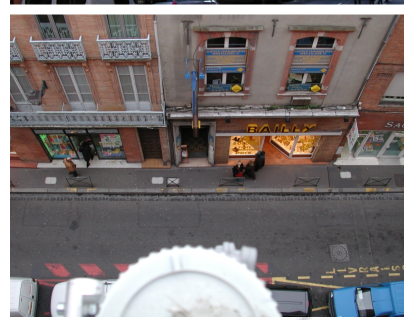
Rue Remusat
H/W 1.68, NE-SW



Rue Alsace-Lorraine
H/W 1.46, N-S

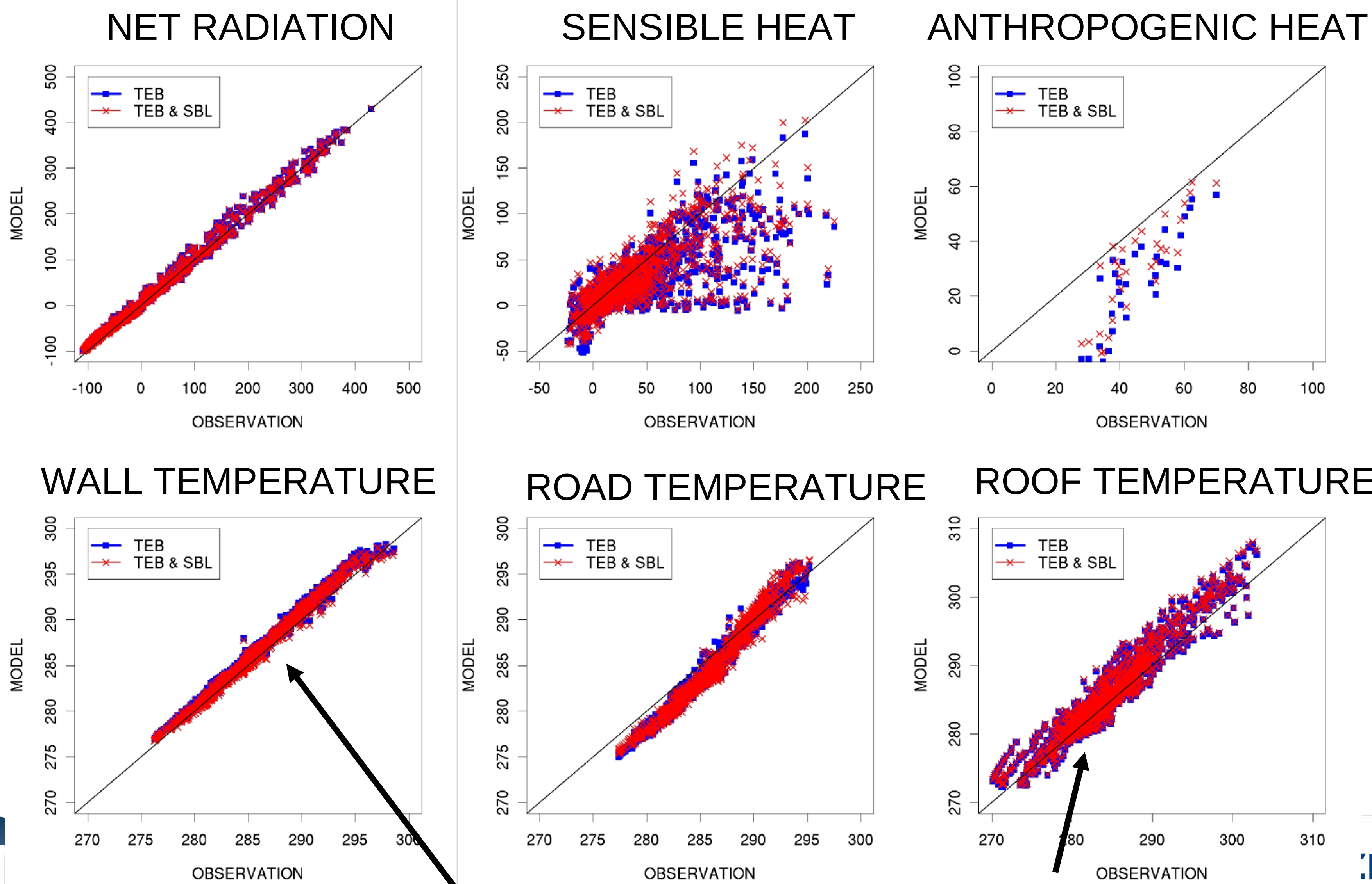


Rue Pomme
H/W 2.05, NW-SE



Roofs
(use of only 1)

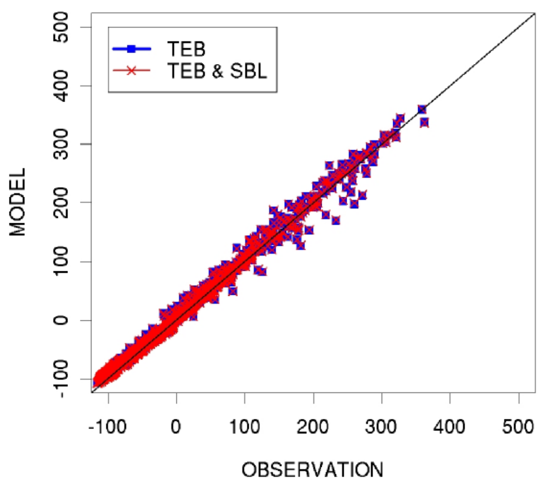
Fall results: scatterplots of model vs obs.



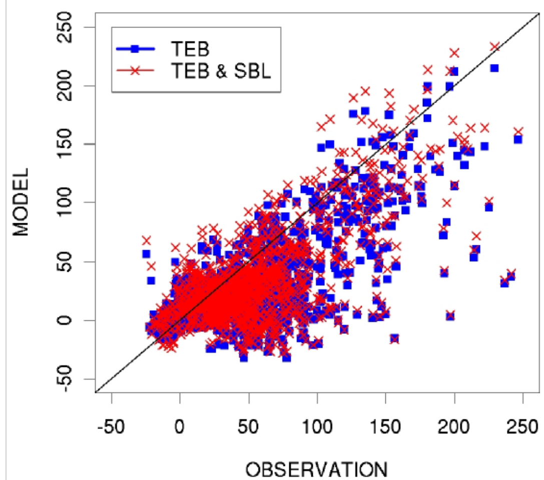
Correct building surface temperatures

Winter results: scatterplots of model vs obs.

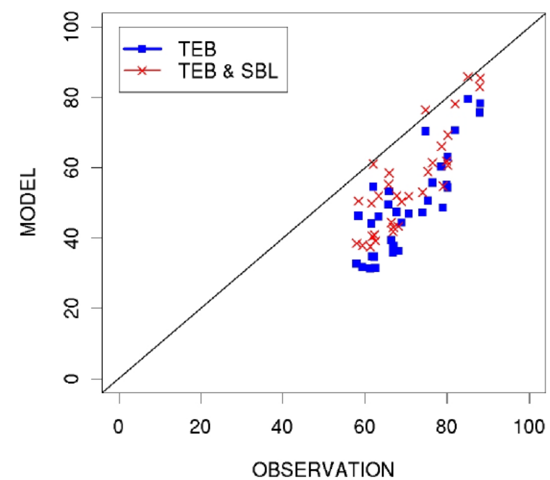
NET RADIATION



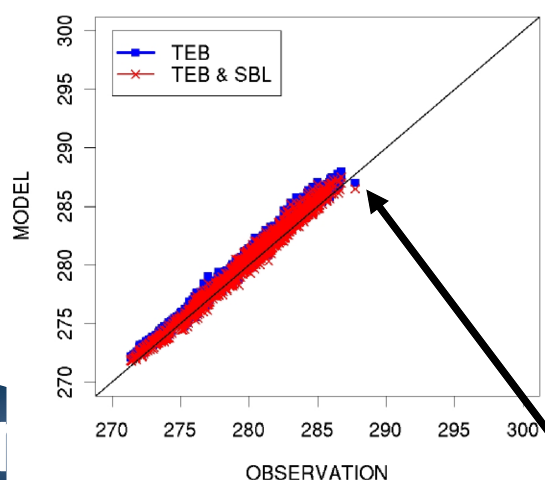
SENSIBLE HEAT



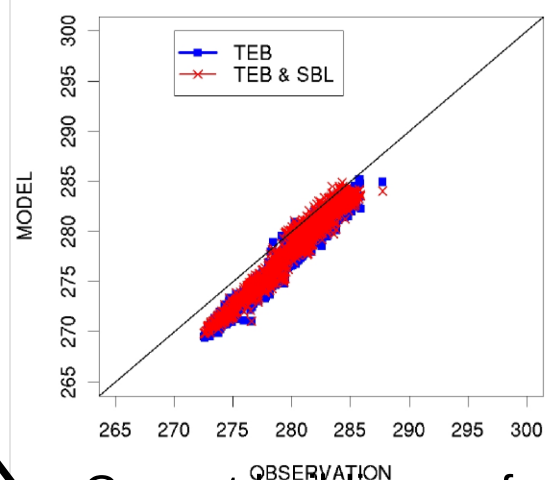
ANTHROPOGENIC HEAT



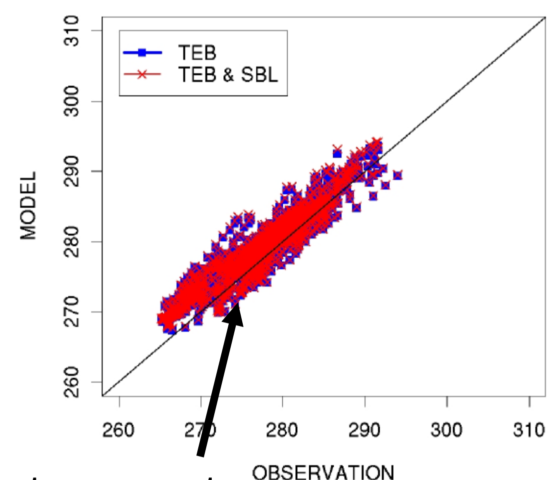
WALL TEMPERATURE



ROAD TEMPERATURE



ROOF TEMPERATURE



Correct building surface temperatures

Evaluation of TEB in cold and snowy conditions for the Montréal Urban Snow Experiment (MUSE) 2005

Aude Lemonsu[1], Stéphane Bélair[2], Jocelyn Mailhot[2], Sylvie Leroyer[3]

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1 Météo France/CNRS, GAME
2 Environment Canada, Meteorological Research Division
3 Atmospheric and Environmental Research Lab, Mc Gill Universi

Environnement Canada

cnrs

McGill

MUSE 2005 EXPERIMENT

MUSE 2005 aimed at documenting the evolution of surface characteristics and energy budgets in a dense urban area during the winter-spring transition, with evolution of snow cover from ~100% to 0%

Continuous measurements (17 March – 14 April 2005)

- Radiation components: K↓, L↓, K↑, L↑
- Turbulent fluxes: Q_H, Q_E
- Surface temperatures of urban facets
- Air temperature in street and alley
- Snow depth on roof

Manual measurements (4 IOPs)

- Surface temperatures of urban facets
- Photographs
- Snow properties: d, ρ, α, T_S

Lemonsu et al., JAMC, 2008: 'Overview and first results of the Montreal Urban Snow Experiment (MUSE) 2005'

STREET

ALLEY

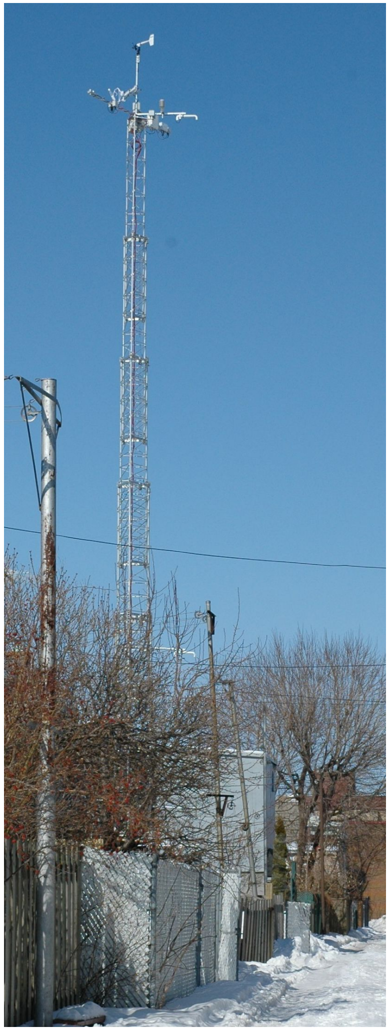
Aerial photo: courtesy J. Voogt, UWO (EPiCC Program)

Montreal:
urban snow measurements

17 March to 14 April 2005

Air temperature and humidity in canyons

Radiative temperature of walls



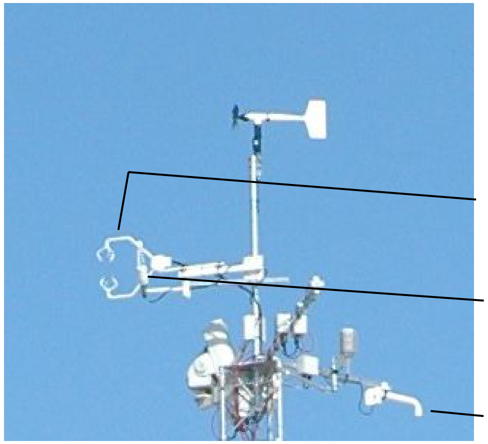
20 m tower

Radiative surface temperatures

IR camera in heated case

Incoming and outgoing radiation

CNR1 radiometer Kipp & Zonen



Turbulent fluxes by eddy covariance 10Hz

3D sonic anemometer CSAT3

H_2O/CO_2 analyzer Li-Cor 7500

Fine wire thermocouple ASPTC

Intensive observation periods

- Clear skies and southwest winds
- Four 26-hour IOPs (March 17-18, 22-23, 30-31, April 5-6)
- Measurements:
  - Hourly radiative surface temperatures using IR thermometer
  - Albedo (5 daytime measurements)
  - Snow depth and density (5 daytime measurements)
  - Pictures to document snow cover, snow melt, wet fraction

Evolution of snow cover

March 17th

100 %

March 22nd

95 %

March 30th

50 %

April 5th

10 %

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URBAN CANOPY ENERGY BALANCE

$$Q^* + Q_F = Q_H + Q_E + \Delta Q_S + Q_M + \Delta Q_A$$

Q^*	Q_F	Q_H	Q_E	ΔQ_S	Q_M	ΔQ_A
Net radiation	*Anthrop. heat flux*	*Sensible heat flux*	*Latent heat flux*	*Storage heat flux*	*Snow melt flux*	*Net heat advection*

URBAN CANOPY ENERGY BALANCE

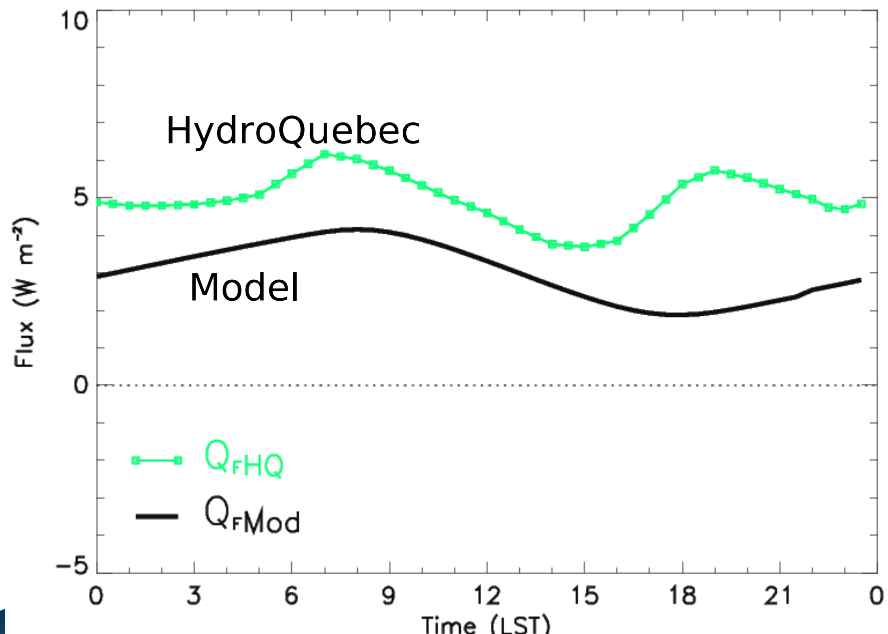
$$Q^* + Q_F = Q_H + Q_E + \Delta Q_S + \cancel{Q_M + \Delta Q_A}$$

Q^*	Q_F	Q_H	Q_E	ΔQ_S	Q_M	ΔQ_A
Net radiation	*Anthrop. heat flux*	*Sensible heat flux*	*Latent heat flux*	*Storage heat flux*	*Snow melt flux*	*Net heat advection*
↑ Measured		↑ Measured	↑ Measured			↑ Neglected *(see Lemonsu et al. 2008)*

URBAN CANOPY ENERGY BALANCE

$$Q_{res} \cong \Delta Q_S + Q_M - Q_F$$

Storage heat flux *Snow melt flux* *Anthrop. heat flux*



Q_F diagnosed as the heat flux produced by domestic heating to maintain a comfort temperature inside buildings *[Pigeon et al. 2008]*

Q_F estimated using data of electricity consumption provided by Hydro-Quebec

Q_F found to be negligible in comparison with the other fluxes

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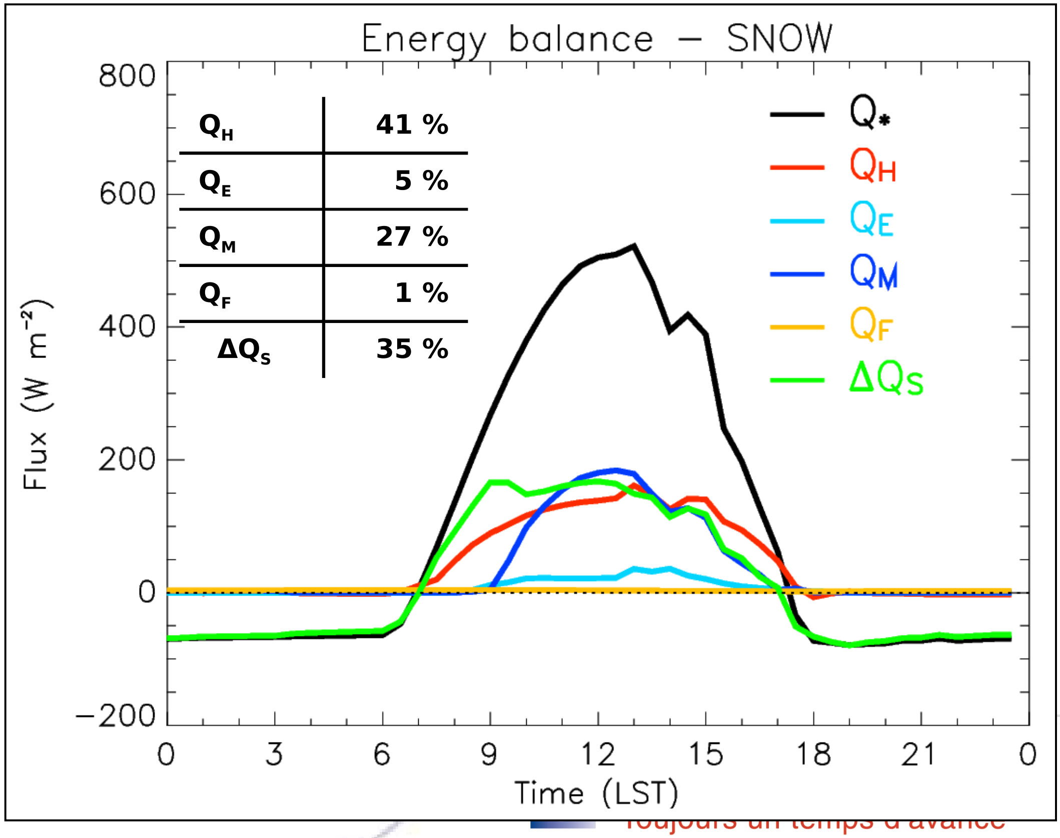
URBAN CANOPY ENERGY BALANCE

$$Q_{res} \cong \Delta Q_S + Q_M - Q_F$$

Storage heat flux	Snow melt flux	Anthrop. heat flux

Energy budget correctly simulated by TEB-ISBA with snow

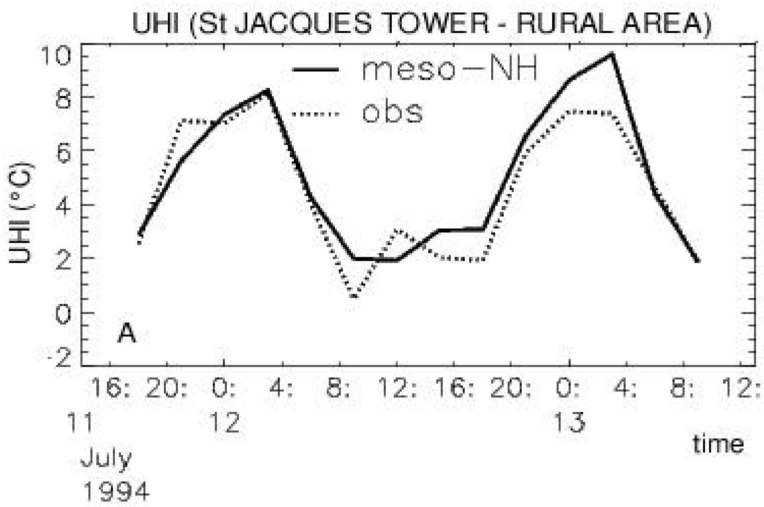
Melting is a predominant term of the budget (27 %)



Examples of Applications

Urban heat Island

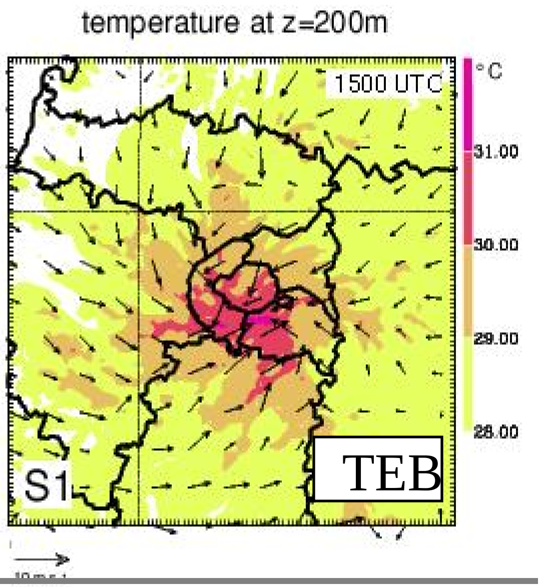
Lemonsu and Masson (2002), CNRM, Toulouse, France



3D Simulation over Paris
With the MESO-NH atmospheric model
coupled with TEB

- UHI maximum at night (positive heat flux)
- small UHI at day

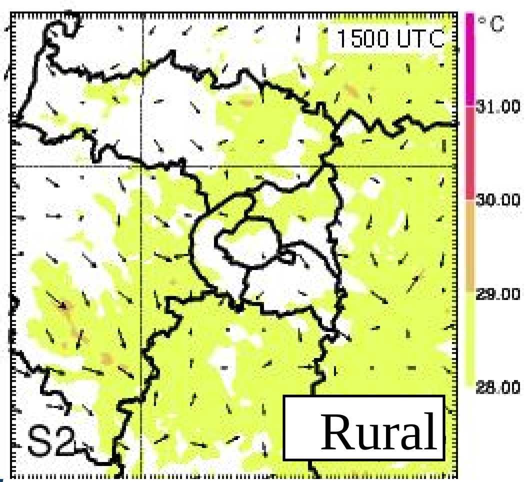
Urban breeze over Paris



With urban parameterization (TEB)

- City is warmer
- Urban breeze develops
- winds strongest over suburban area

→Effect of heat dominates over roughness



Without urban parameterization

Nothing happens

Lemonsu and Masson (2002)

Example of offline study with TEB : Nantes

Analysis of the transformations of Nantes city from 17th to 20th century :

- Ground cover, density, deviation of rivers,…
- Building type, urban design, insulation…
- Usag

- plans

End of XVIIth century

« 1835 »

« 1880 »

From 1945

- iconographies

End of XVIIth century

before 1777

after 1779

« 1866 »

Source : Benzerzour 2004

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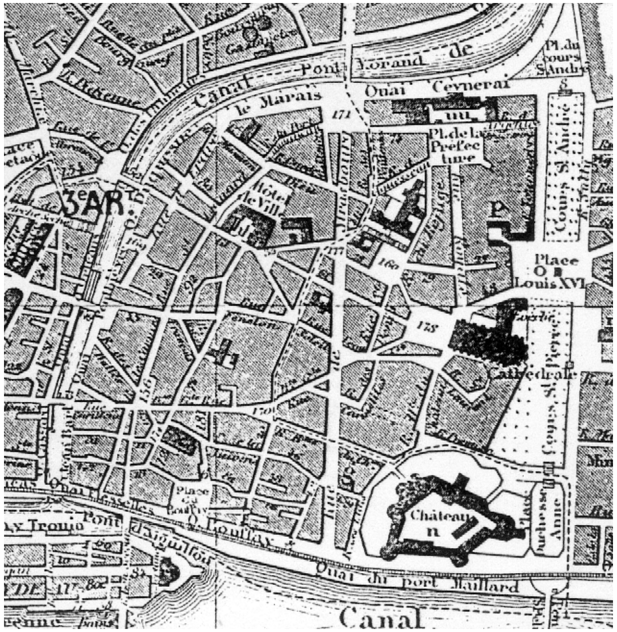
Example of offline study with TEB : Nantes



Urban micro-climate impacts are simulated with TEB :

- Wind decrease up to the middle of the 19th century (densification, increase of number of stories)
- Wind increase after (larger roads)
- Increase of 1,5°C between the 17th and the 20th century
- Slight decrease of humidity

In SURFEX

Options & Namelists

- There is very few scientific options in TEB (for the time being…)
- In ‘PGD’ step :
  - Nothing to do if ecoclimap is used
  - Possibility to specify all urban characteristics in Namelist NAM_DATA_TEB

Input data for TEB-SURFEX

INPUTS		Unit
Atmosphere	Air temperature above canopy Specific humidity above canopy Incoming solar radiation Infrared solar radiation Air pressure Rainfall rate Snowfall rate Wind speed Wind direction Carbon dioxyde concentration	K $kg\ kg^{-1}$ $W\ m^{-2}$ $W\ m^{-2}$ Pa $kg\ m^{-2}\ s^{-1}$ $kg\ m^{-2}\ s^{-1}$ $m\ s^{-1}$ deg / North $kg\ m^{-3}$
Land Use	Urban area fraction Nature area fraction Sea area fraction Lake area fraction	- - - -

Atmospheric forcings

Surface description

Input data for TEB-SURFEX

Urban morphology and building thermal and radiative characteristics	Building area fraction (inside urban fraction) Road area fraction (inside urban fraction) Wall surface / building and road surface Building height Urban roughness length Number of wall layer Number of roof layer Number of road layer Wall layers depth Roof layers depth Road layers depth Wall layers specific heat Roof layers specific heat Road layers specific heat Wall layers thermal conductivity Roof layers thermal conductivity Road layers thermal conductivity Roof albedo Road albedo Wall albedo Roof emissivity Road emissivity Wall emissivity	- - - m m - - - m m m $J\ m^{-3}\ K^{-1}$ $J\ m^{-3}\ K^{-1}$ $J\ m^{-3}\ K^{-1}$ $W\ m^{-1}\ K^{-1}$ $W\ m^{-1}\ K^{-1}$ $W\ m^{-1}\ K^{-1}$ - - - - - -
Anthropogenic heat releases	Anthropogenic sensible and latent heat flux released by traffic Anthropogenic sensible and latent heat flux released by industry	$W\ m^{-2}$ $W\ m^{-2}$
Vegetation	Area fraction of bare soil Area fraction of low vegetation Area fraction of high vegetation Leaf Area Index (for each veg. Type and month) Vegetation roughness length (for each veg. type and month) Vegetation characteristics for photosynthesis and vegetation growing (for each veg. type)	- - - - m

Surface description

Options & Namelists

- There is very few scientific options in TEB (for the time being…)
- In ‘PGD’ step :
  - Nothing to do if ecoclimap is used
  - Possibility to specify all urban characteristics in Namelist NAM_DATA_TEB
- In ‘PREP’ step : Namelist NAM_PREP_TEB :
  - Intializes the surface temperatures, water reservoirs and snow
  - Possibility to activate the SBL (or « canopy ») scheme
- During the run : Namelist NAM_TEBn
  - Only one option (thanks to Canadian developers) : choice of the thermal roughness length for roofs and roads : CZ0H
- Several diagnostics in Namelist NAM_DIAG_TEBn

Conclusions

- Most important characteristics of urban surface energy exchanges well reproduced by TEB:
  - Upward radiative fluxes (trapping, …)
  - Building surface temperature
  - Strong contribution of Q_H during the day
  - Small positive Q_H values during the night

    (thanks to energy storage during the day)
  - High values of the anthropogenic heat flux in winter
  - Snow mantel evolution & snow melt

- TEB allows both offline applications on urban impacts and online atmospheric simulations of urban climate and meteorology (e.g. UHI)

Perspectives

- Better inside building energy balance & Including direct heat releases from building through chimneys
- Including heat releases due to air conditioning
- Add vegetation into TEB, to allow human comfort studies
- Use of TEB for the forecast of the energy demand for thermal comfort in buildings at the scale of a city and with different climate change scenarios