Inclusion of a multi-layer drag approach in (TEB) urban surface scheme

Valéry Masson[1], Rafiq Hamdi[2], Grégoire Pigeon[1], Aude Lemonsu[1]

[1]CNRM-GAME, Météo France/CNRS, Toulouse, France
[2]Royal Meteorological Institute, Brussels, Belgium

Urban surface modeling in atmospheric models

- In atmospheric models, urban schemes are either
  - multi-layer (e.g. Martilli's model)
  - single layer (e.g. TEB, masson 2000, UCM Kusaka 2001)

- Single-layer schemes are numerically efficient

- Multi-layer schemes allow a better description of the air within the canyon
  - Atmospheric layers down to the road surface
  - Open research perspectives on pedestrian & canyon climate studies
  - But very complex implementation

- The objective of the SBL scheme :
  - to conciliate advantages of both
  - to discard the disadvantages of both

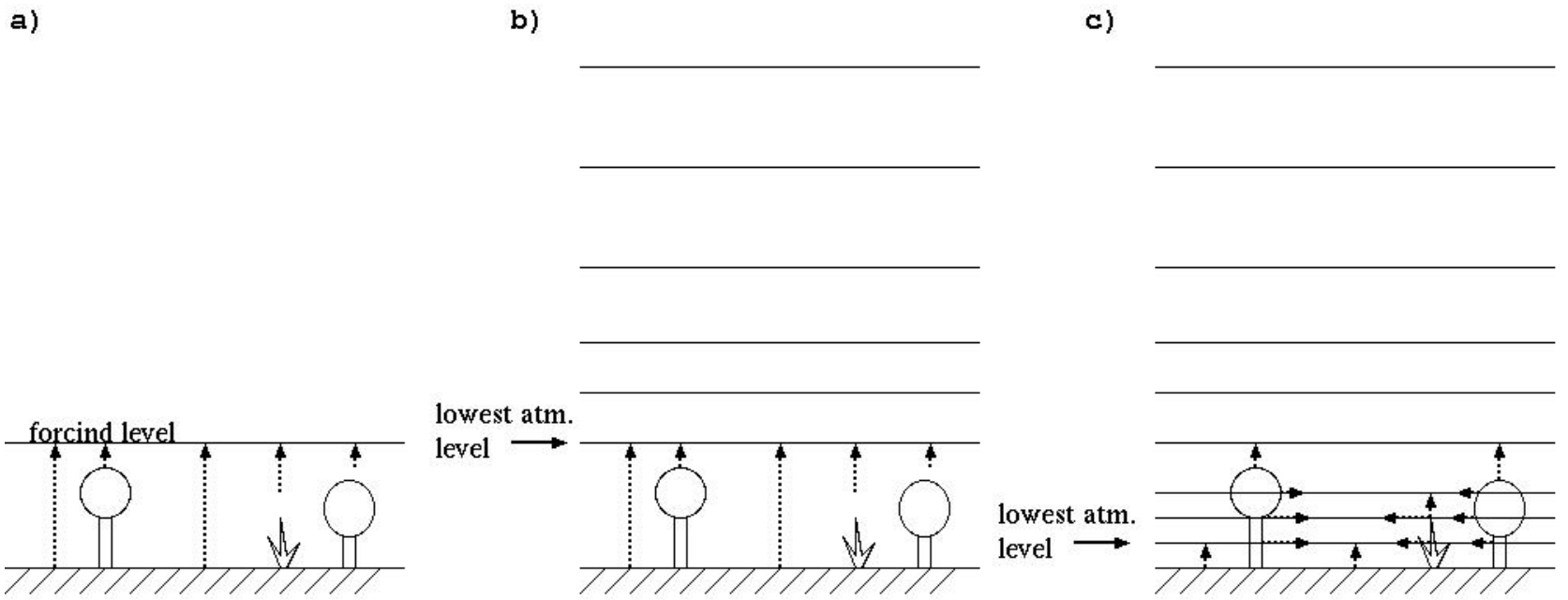
Overview of the talk

- Methodology to build single layer scheme that do as multi-layer schemes:
  - a Surface Boundary Layer (SBL) scheme in the surface scheme itself
  - Derivation from the atmospheric equations
- Validation of the SBL model
  - Neutral boundary layer
  - In Basel (cf R. Hamdi talk)
  - Over a complex region
- Application for an urbanism study : The ‘Grand Pari(s)’
- Conclusion

Overview of the talk

- Methodology to build single layer scheme that do as multi-layer schemes:
  - a Surface Boundary Layer (SBL) scheme in the surface scheme itself
  - Derivation from the atmospheric equations
- Validation of the SBL model
  - Neutral boundary layer
  - In Basel (cf R. Hamdi talk)
  - Over a complex region
- Application for an urbanism study : The ‘Grand Pari(s)’
- Conclusion

Surface Boundary Layer scheme principle : state of the art

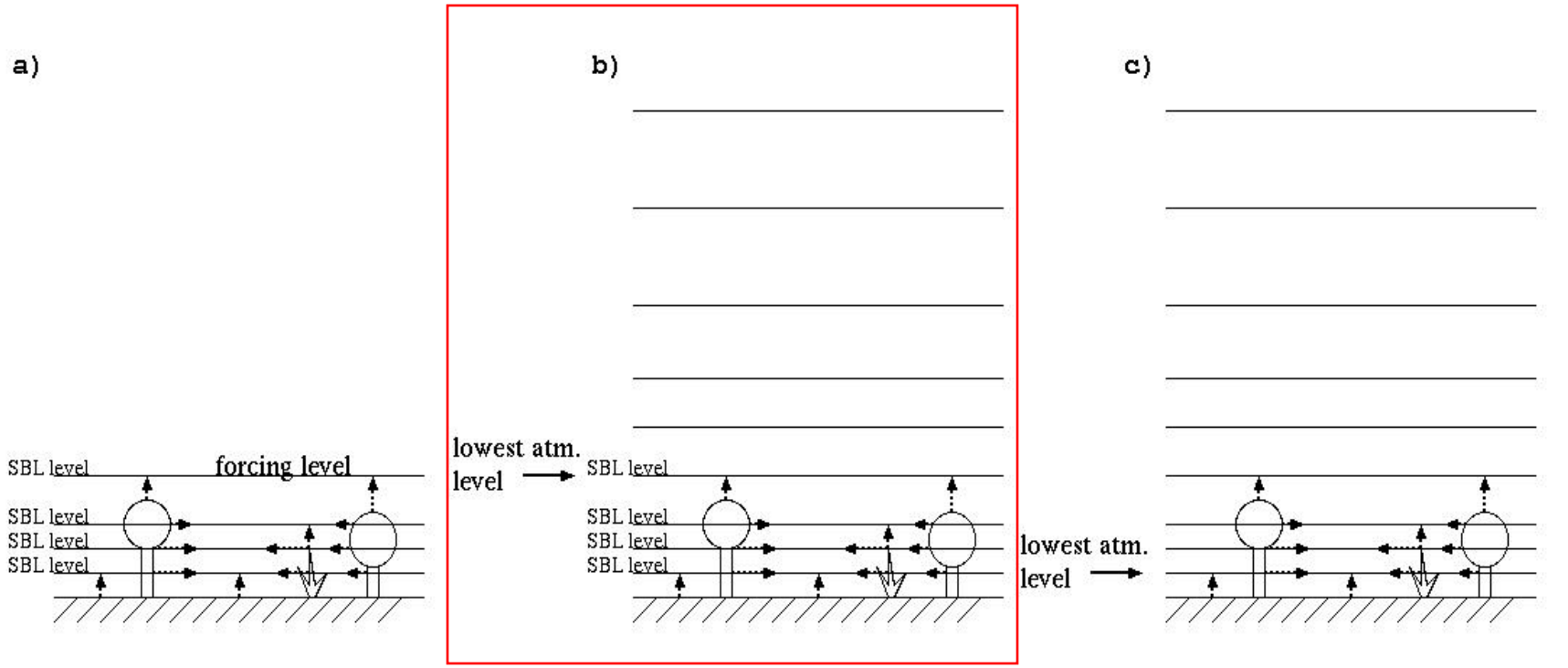


"single-layer" surface scheme forced off-line

"single-layer" surface scheme coupled to an atmospheric model

"multi-layer" surface scheme coupled to an atmospheric model

SBL scheme principle : what we want to do



"single-layer" surface scheme
+ Surface Boundary Layer scheme
forced offline

"single-layer" surface scheme
+ Surface Boundary Layer scheme
coupled to an atmospheric model

"multi-layer" surface scheme
coupled to an atmospheric model

SBL & « canopy » scheme

- Evolution equations in the SBL are :

$$\begin{cases} \frac{\partial U}{\partial t} = Adv + Cor + Pres. + Turb(U) + \mathrm{Drag_u} \\ \frac{\partial V}{\partial t} = Adv + Cor + Pres. + Turb(V) + \mathrm{Drag_v} \\ \frac{\partial \theta}{\partial t} = Adv + Diab. + Turb(\theta) + \frac{\partial \theta}{\partial t}_{canopy} \\ \frac{\partial q}{\partial t} = Adv + Turb(q) + \frac{\partial q}{\partial t}_{canopy} \end{cases}$$

$$\frac{\partial e}{\partial t} = Adv + Dyn.Prod. + Therm.Prod. + Turb + Diss. + \frac{\partial e}{\partial t}_{canopy}$$

SBL & « canopy » scheme

- Regrouping terms into 3 main types :

$$\begin{cases} \frac{\partial U}{\partial t} = LS(U) + Turb(U) + \mathrm{Drag_u} \\ \frac{\partial V}{\partial t} = LS(V) + Turb(V) + \mathrm{Drag_v} \\ \frac{\partial \theta}{\partial t} = LS(\theta) + Turb(\theta) + \frac{\partial \theta}{\partial t}_{canopy} \\ \frac{\partial q}{\partial t} = LS(q) + Turb(q) + \frac{\partial q}{\partial t}_{canopy} \end{cases}$$

The TKE equation remains the same:

$$\frac{\partial e}{\partial t} = Adv(e) + Dyn.Prod. + Therm.Prod. + Turb + Diss. + \frac{\partial e}{\partial t}_{canopy}$$

SBL & « canopy » scheme

- Supposing that:
  - The mean wind direction does not vary with height in the SBL
  - The turbulent transport and advection of TKE is small in the SBL compared to other terms
  - Above the canopy (if any), the turbulent fluxes are uniform with height (« constant flux layer »)
  - The Large-Scale Forcing terms LS(U), LS(θ), LS(q) are uniform with height in the SBL

→ These are hypotheses commonly done in Monin-Obukhov-like SBL relationships

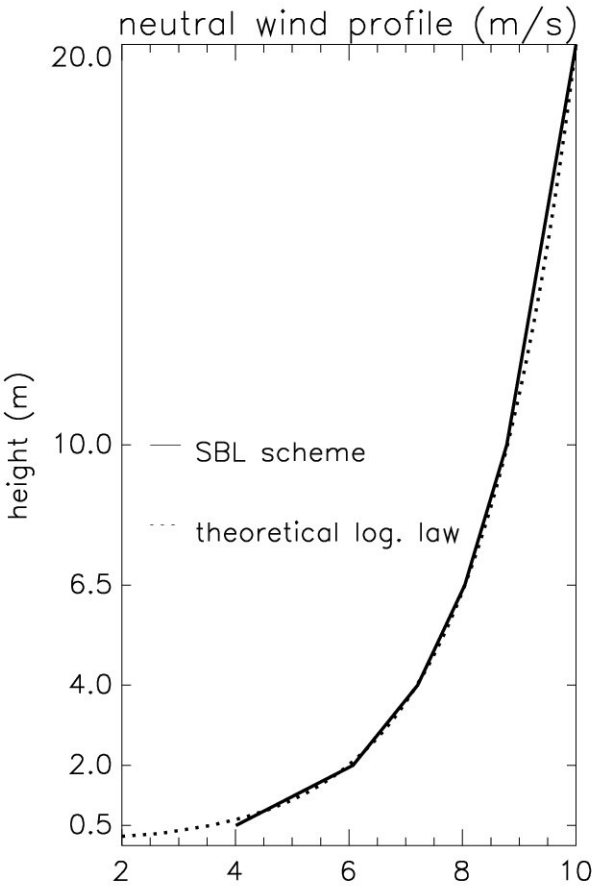
$$\begin{cases} \frac{\partial U}{\partial t} = \frac{\partial U}{\partial t}(z = z_a) + Turb(U) + \mathrm{Drag_u} \\ \frac{\partial \theta}{\partial t} = \frac{\partial \theta}{\partial t}(z = z_a) + Turb(\theta) + \frac{\partial \theta}{\partial t}_{canopy} \\ \frac{\partial q}{\partial t} = \frac{\partial q}{\partial t}(z = z_a) + Turb(q) + \frac{\partial q}{\partial t}_{canopy} \end{cases}$$

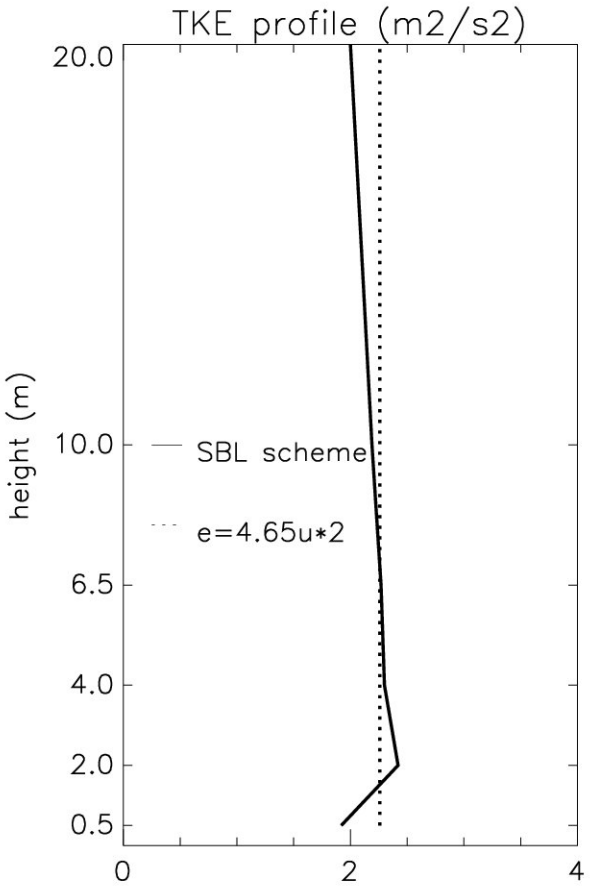
$$\frac{\partial e}{\partial t} = Dyn.Prod. + Therm.Prod. + Diss. + \frac{\partial e}{\partial t}_{canopy}$$

Overview of the talk

- Methodology to build single layer scheme that do as multi-layer schemes:
  - a Surface Boundary Layer (SBL) scheme in the surface scheme itself
  - Derivation from the atmospheric equations
- Validation of the SBL model
  - Neutral boundary layer
  - In Basel (cf R. Hamdi talk)
  - Over a complex region
- Application for an urbanism study : The ‘Grand Pari(s)’
- Conclusion

The simplest case : the neutral SBL





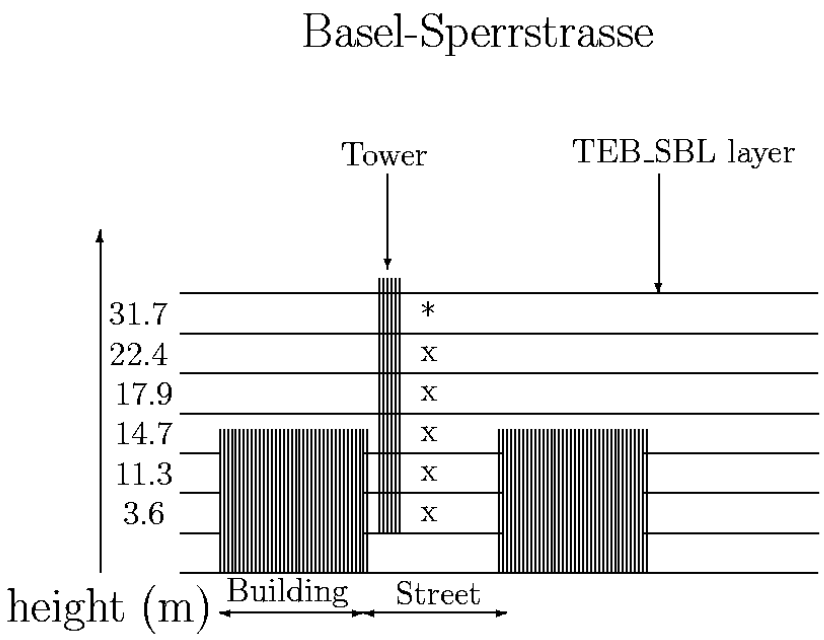
- Error on wind at 2m less than 1%

SBL canopy scheme in TEB

Hamdi and Masson 2008, *JAMC*, 47, 10, 2627-2644

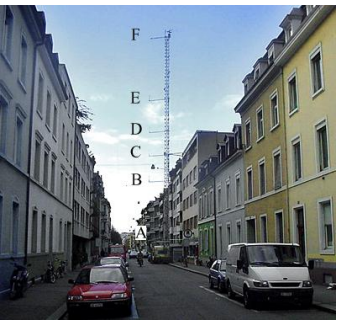
- Offline Validation with the BUBBLE data
  - City-center of Basel (Switzerland)
  - Simulation covers half of the summer IOP: from 16th to 30th June, 2002

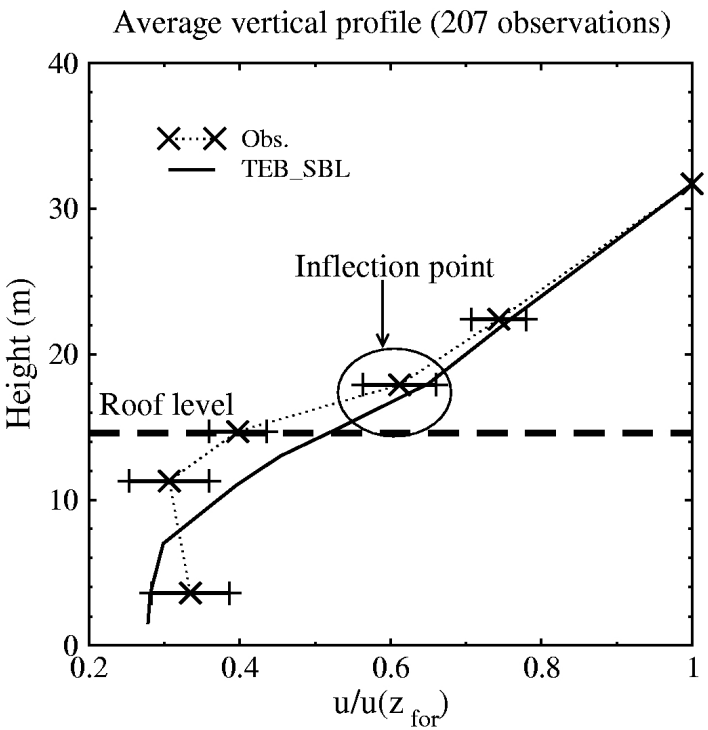
→ cf presentation of R. Hamdi

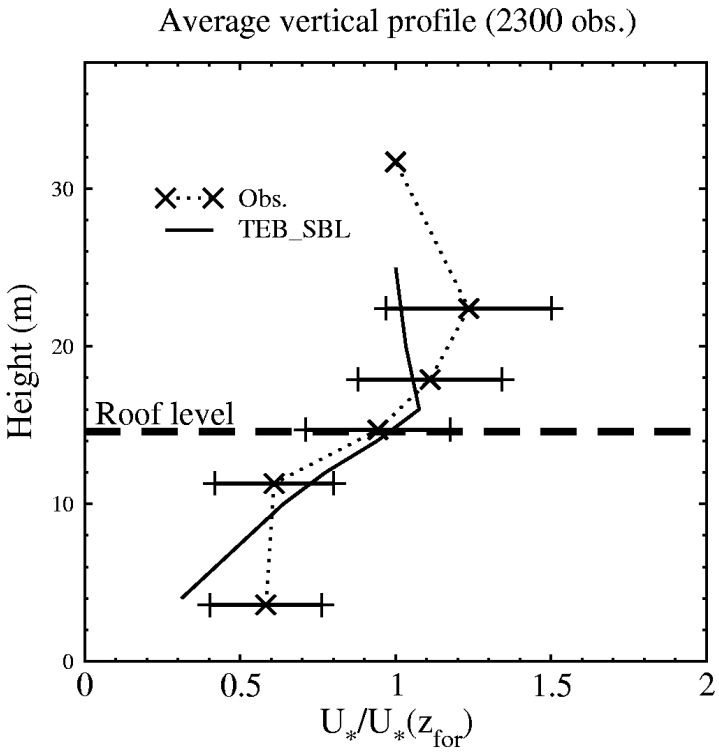


SBL canopy scheme in TEB

- Dynamical variables
  - Walls imply a drag force on the flow parameterized (CD=0.4) as : - Cd U^2
  - Walls are also a source of TKE, parameterized as : + Cd U^3
  - Both mean wind profile and momentum fluxe profile are correctly simulated

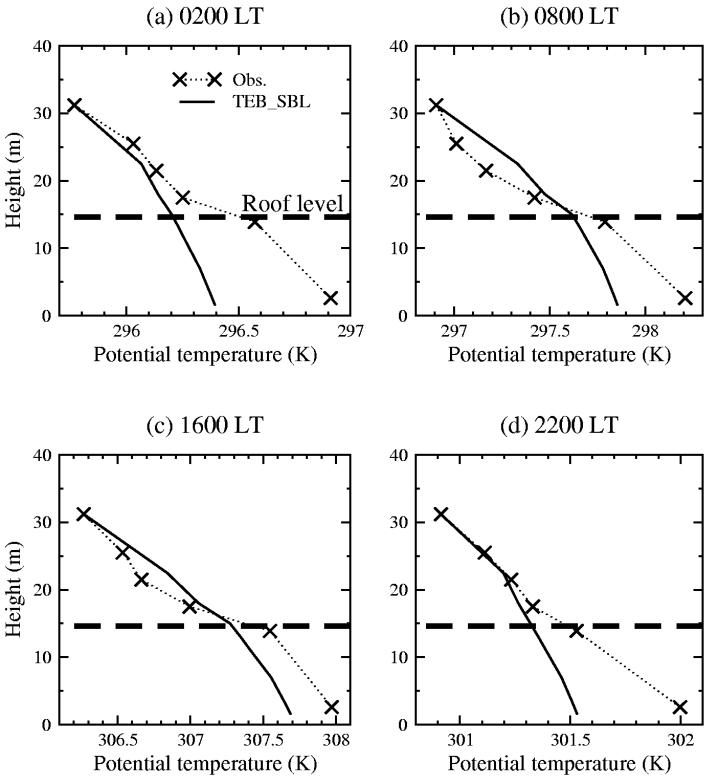


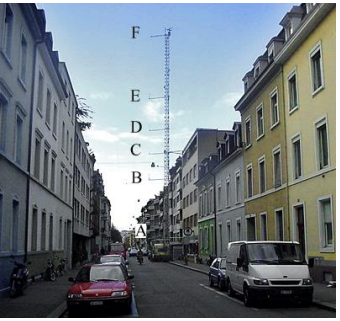


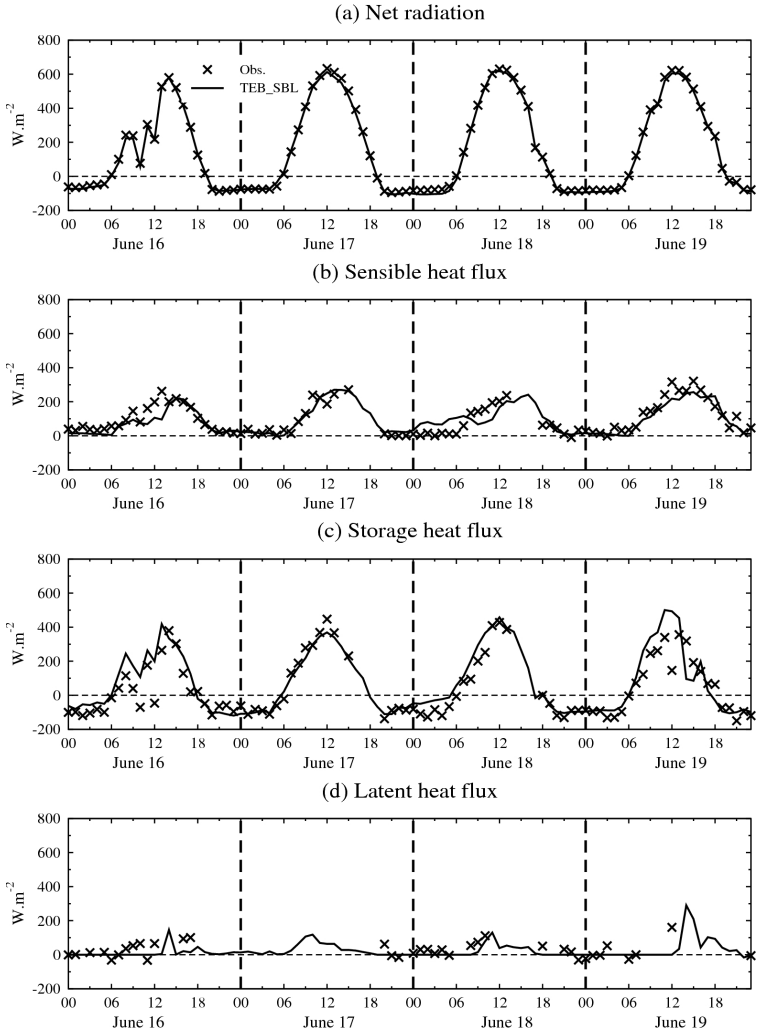


SBL canopy scheme in TEB

- Temperature and surface Energu Budget
  - Heating terms come from wall, roof, road separate energy budgets
  - Good fluxes, temperature profile good above roof level, could be improved near the road

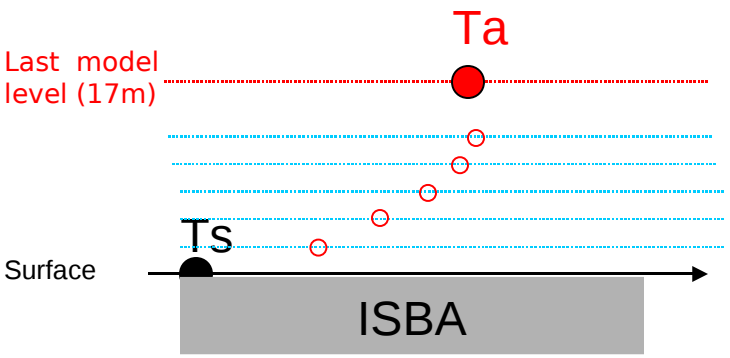






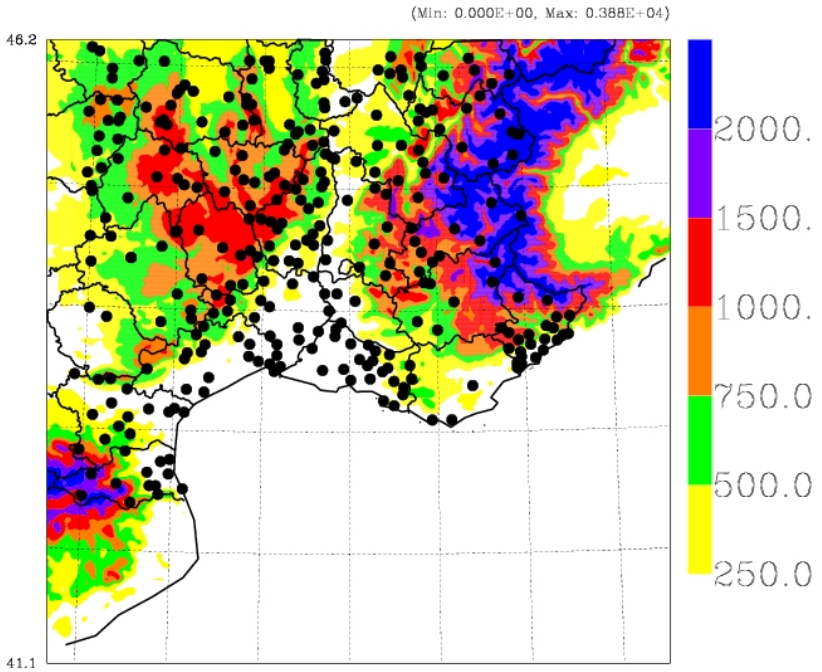
Evaluation in AROME

Surface Boundary Layer



5 levels added + turbulence scheme used

Evaluation on July 2007 and January 2007 on South East France domain



METEO FRANCE
Toujours un temps d'avance

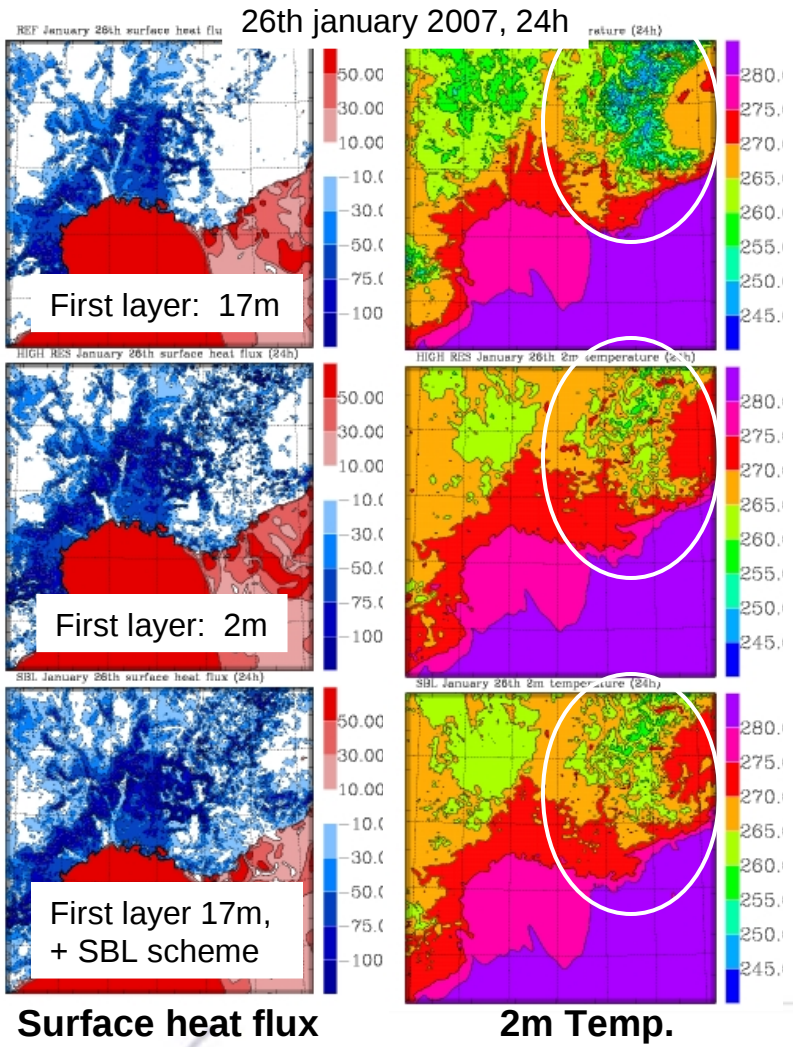
Evaluation inside an atmospheric model

Masson and Seity 2009, *JAMC*, 48, 7, 1377-1397

- 3 atmospheric runs (SW of France) :
  - Lowest atm. Layer at 17m + veg. Scheme
  - Lowest atm. Layer at 2m + veg. Scheme
  - Lowest atm. Layer at 17m + veg. Scheme + SBL

- SBL run reproduces high resolution run
  - Better surface/atmosphere nocturnal coupling
  - ↓
  - Larger negative surface fluxes
  - ↓
  - Temperature field in agreement

- Better agreement with observations (not shown)

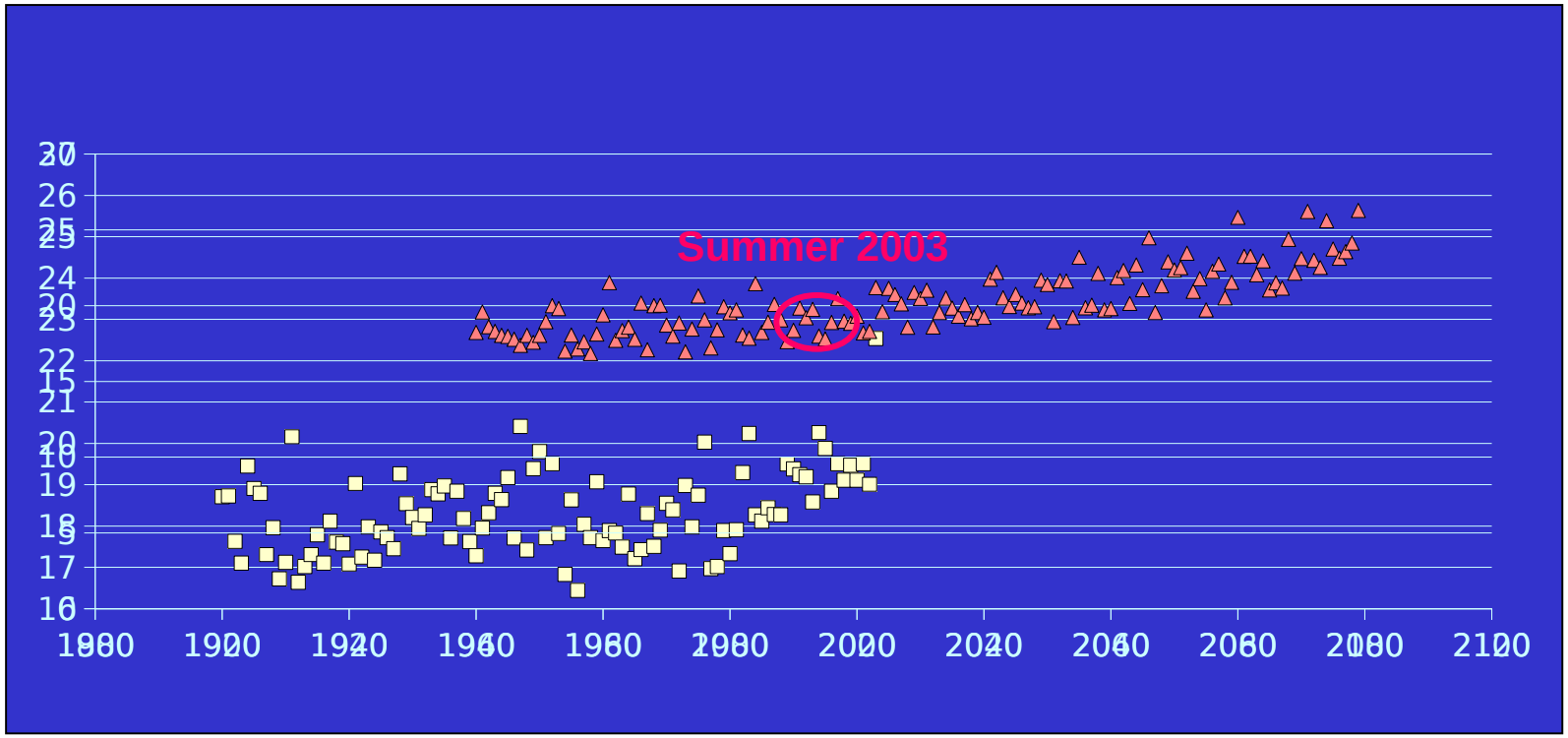


Overview of the talk

- Methodology to build single layer scheme that do as multi-layer schemes:
  - a Surface Boundary Layer (SBL) scheme in the surface scheme itself
  - Derivation from the atmospheric equations
- Validation of the SBL model
  - Neutral boundary layer
  - In Basel (cf R. Hamdi talk)
  - Over a complex region
- Application for an urbanism study : The ‘Grand Pari(s)’
- Conclusion

More intense and more frequent heat-waves to be expected

- Summer 2003 in Paris : 15000 extra deaths

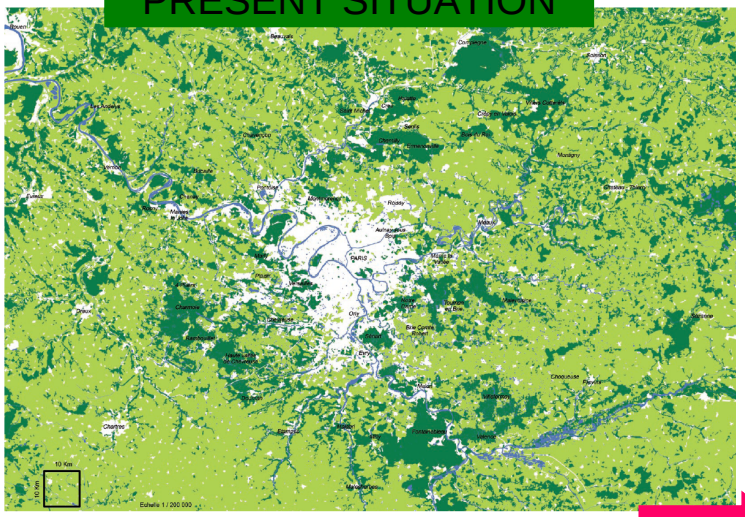


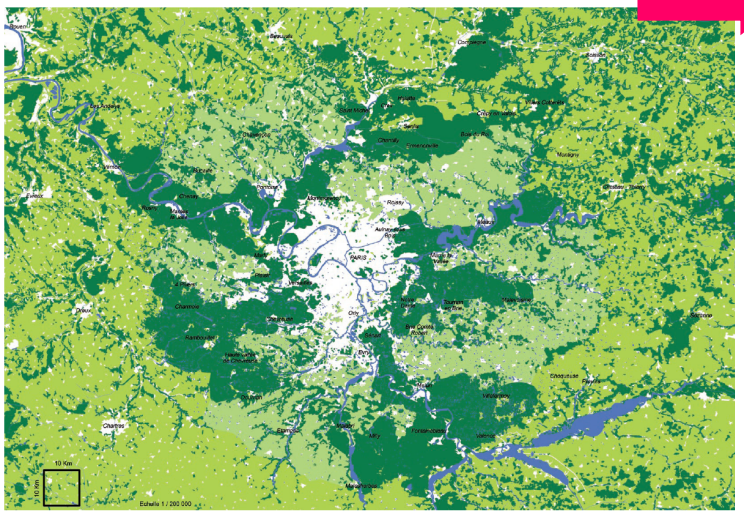
Observed Summer temperature over France

Simulated Summer temperature over France (Climate Change Sc. A2)

Impact of a project promoting forests and reflective roofs in suburban areas

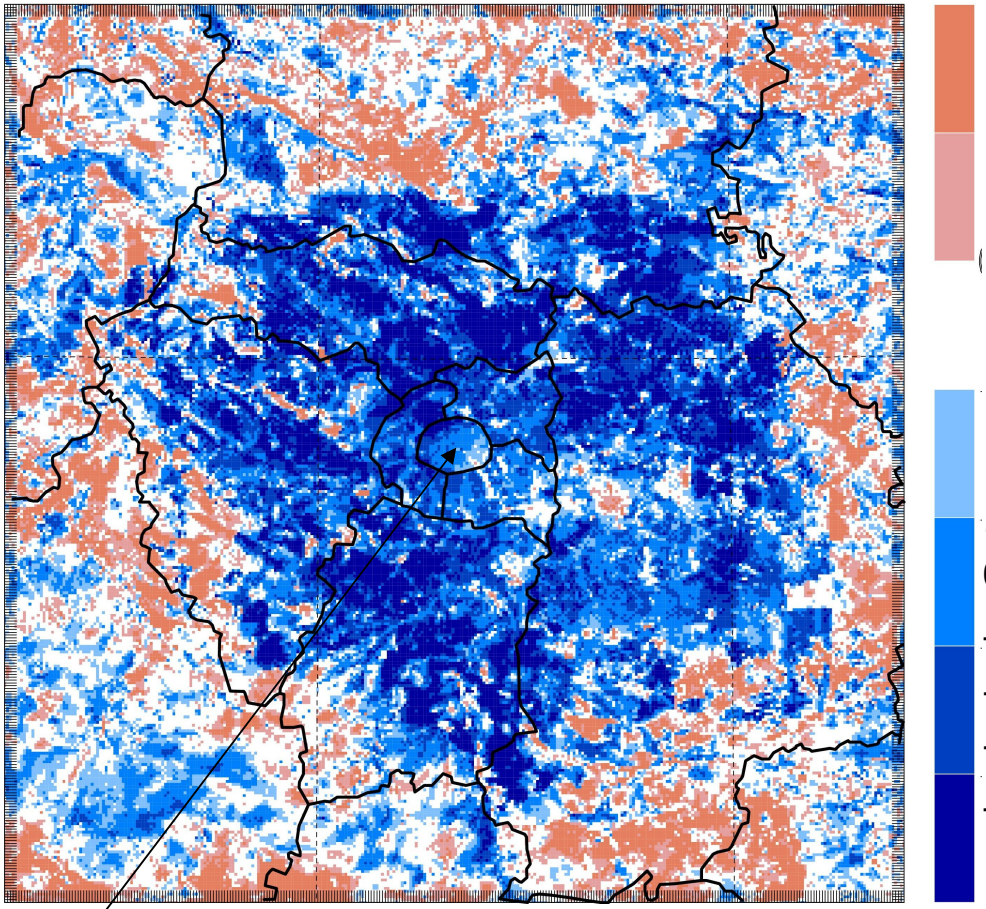
PRESENT SITUATION





PROJECTION 2030

Using TEB-SBL coupled with an atmospheric model



A cooling of 2 to 3°C. !

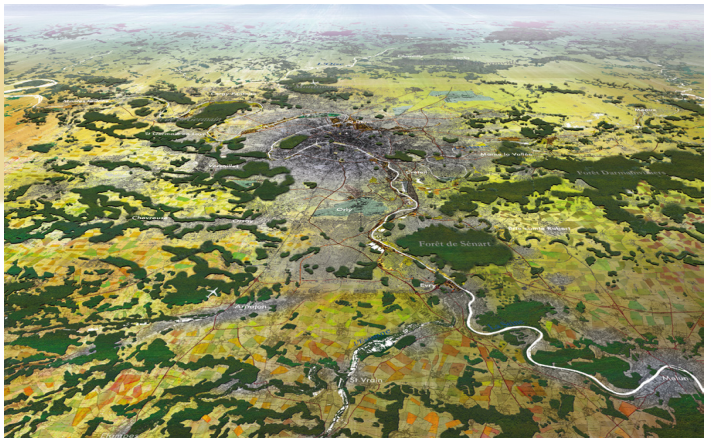
Paris down-town

Descartes urbanists group

METEO FRANCE
Toujours un temps d'avance

Night-time temperature

2008



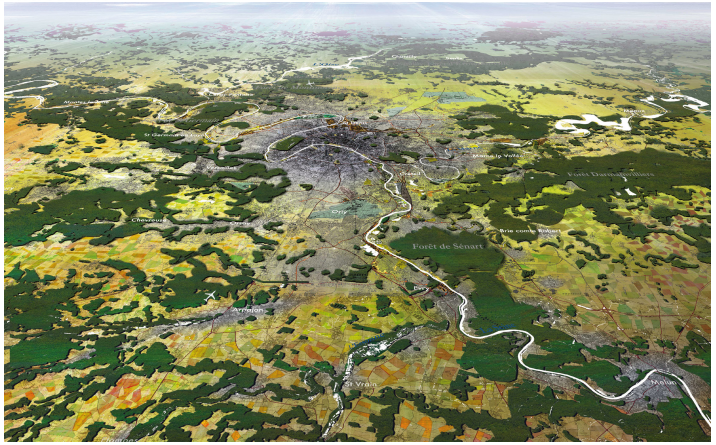
Descartes urbanists group

More forests

+

More reflective materials

2030



How to use it in SURFEX ?

- The choice to use or not canopy is done during the 'PREP' phase
  (during the initialisation of the prognostic variables → adds SBL variables)

- One can use one different SBL profile for each SURFEX tile:
  - For sea : in NAM_PREP_SEAFLUX
    - LSEA_SBL = T
  - For lakes : in NAM_PREP_WATFLUX *or* NAM_PREP_FLAKE
    - LWAT_SBL = T
  - For nature : in NAM_PREP_ISBA
    - LISBA_CANOPY = T
    - only U and Tke sources by canopy trees, depending on LAI and tree height
  - For cities : in NAM_PREP_TEB
    - LTEB_CANOPY = T
    - Sources terms by buildings for U, Tke, heat and moisture

Conclusions

- A SBL model transforms single-layer into multi-layer schemes

- SBL model provides better representation of climate inside the streets where it is important for people

- Perspectives :

  Work on the interaction between climate change and city evolution

  - Need improvements of the building energetics (e.g. air conditioning)
  - Inclusion of vegetation modeling in canyon
  - Determination of human confort index

Questions ?