How to model the Surface boundary Layer and/or canopy processes?

with a 1D turbulence scheme inside Surface schemes !

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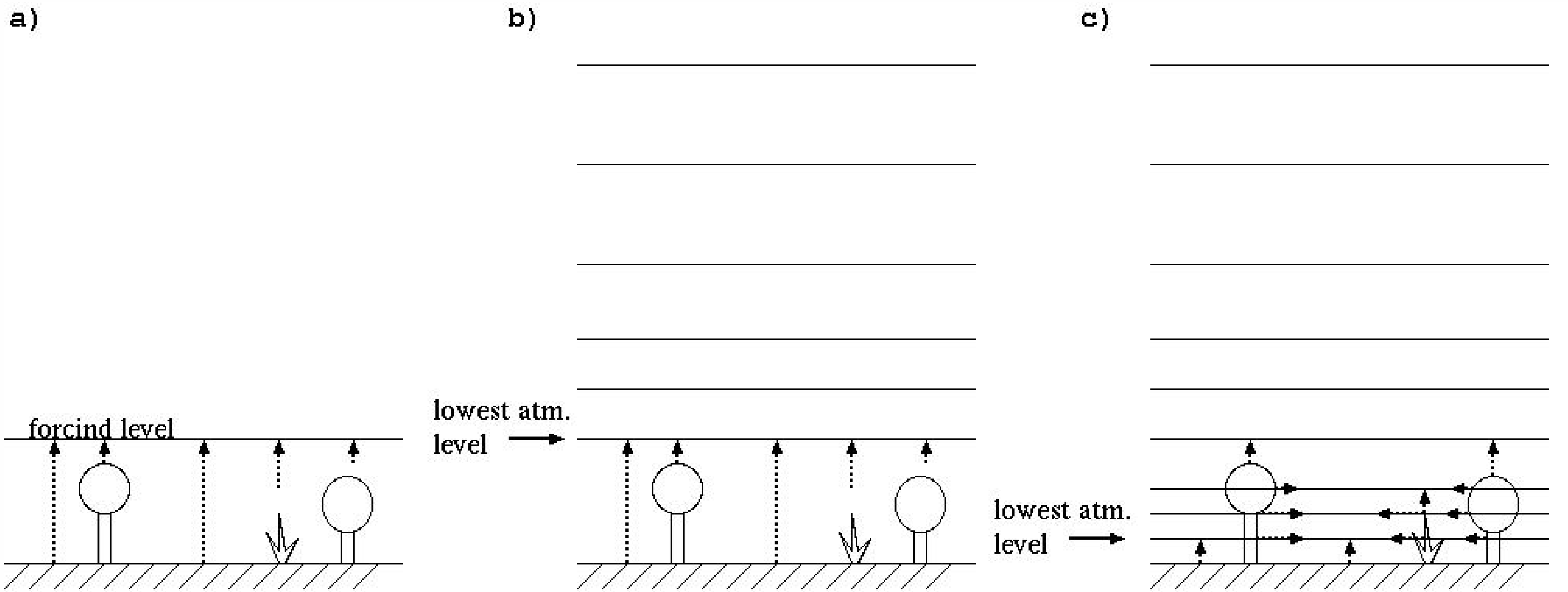
SBL scheme principle : state of the art

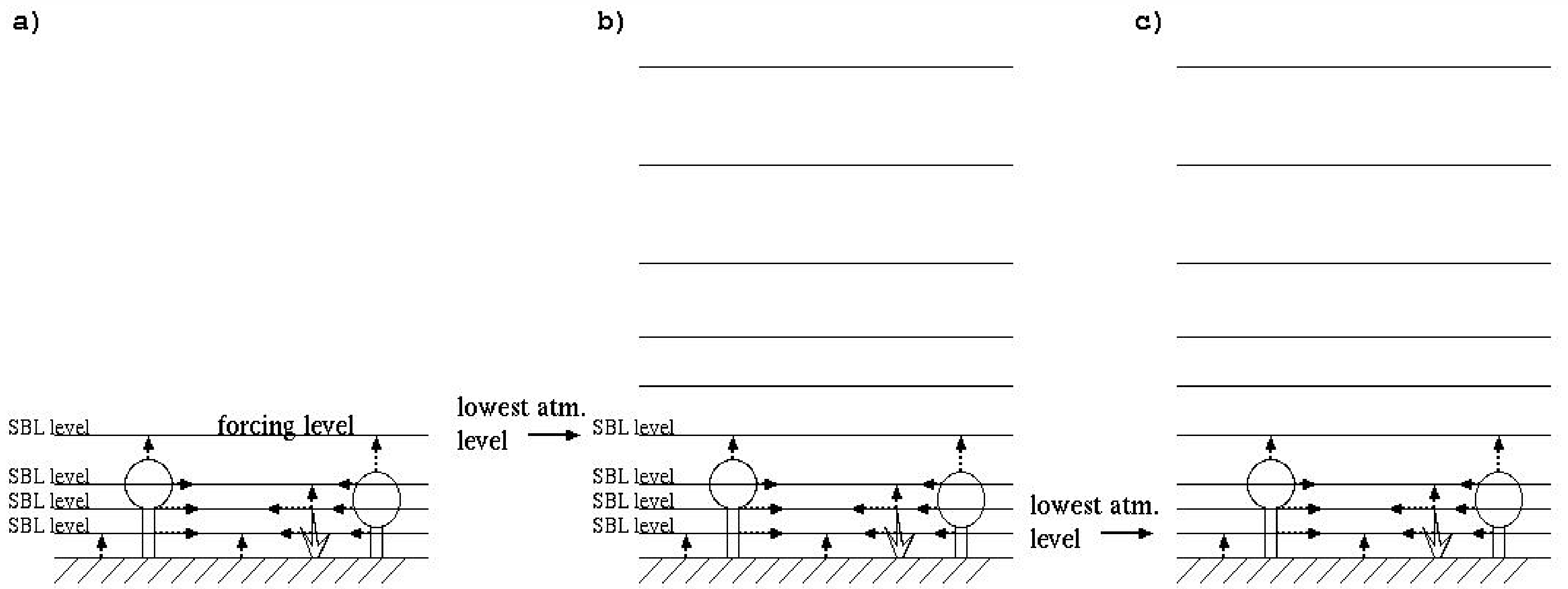


"single-layer" surface scheme forced off-line

"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

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SBL & « canopy » scheme

- Evolution equations in the SBL are :

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

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

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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

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

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

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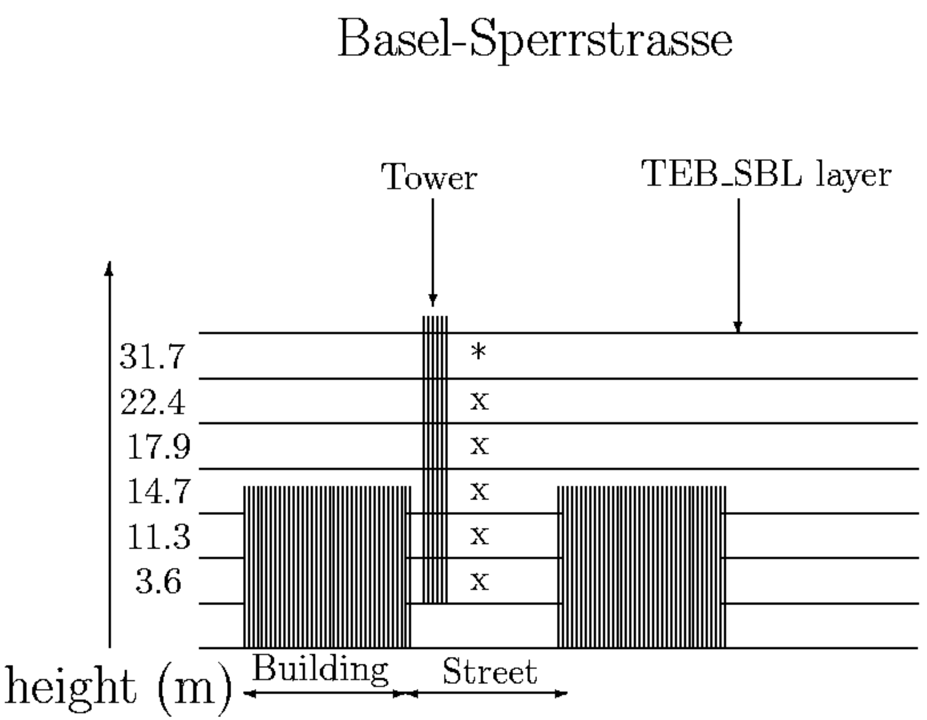
SBL canopy scheme in TEB

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



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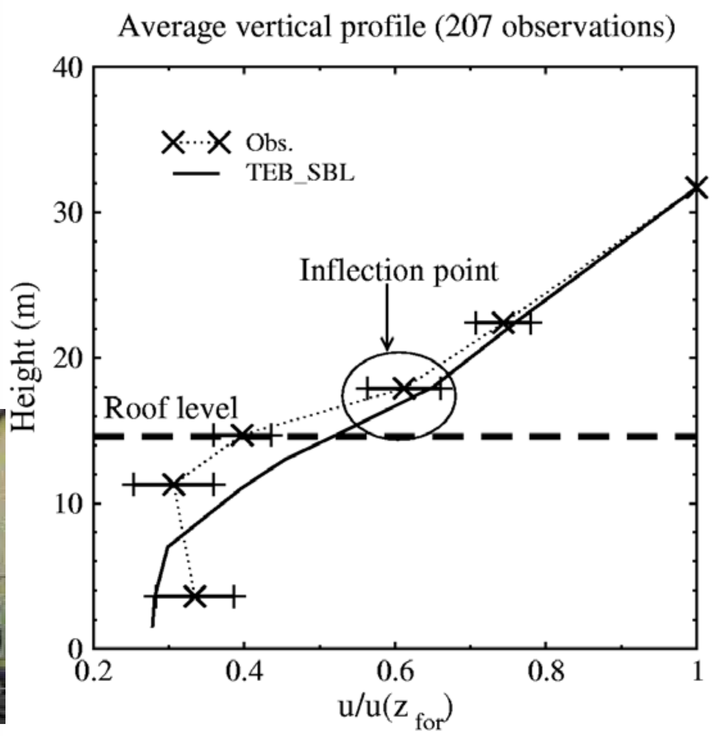
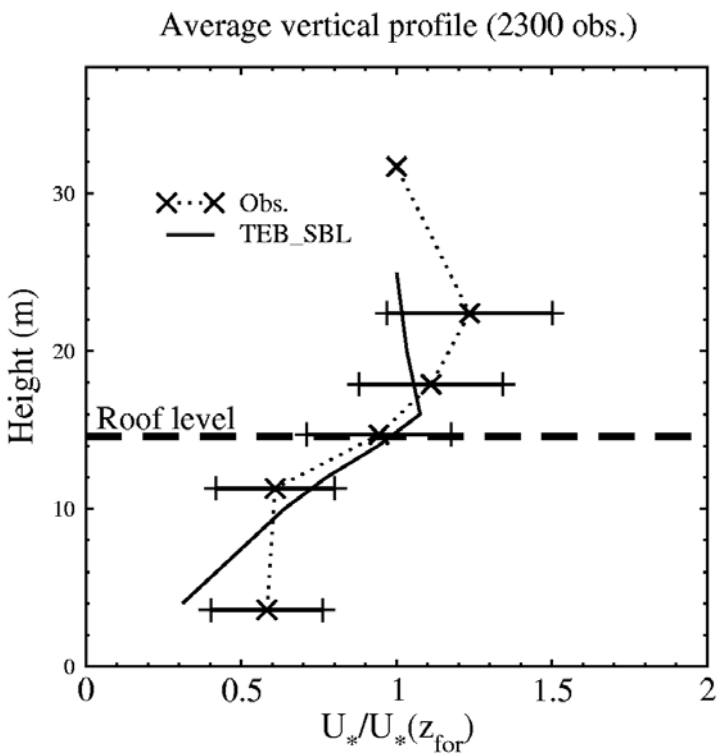
SBL canopy scheme in TEB

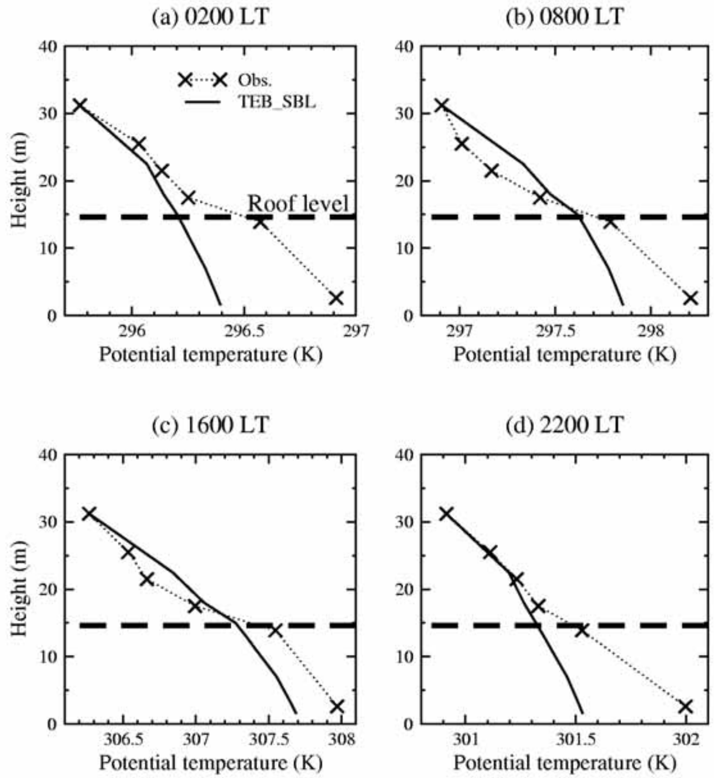
- Dynamical variables
  - Walls imply a drag force on the flow parameterized (CD=0.4) as : - Cd U^2
  - Walls are also a source of TKE, parameterized as : + Cd U^3
  - Both mean wind profile and momentum fluxe profile are correctly simulated

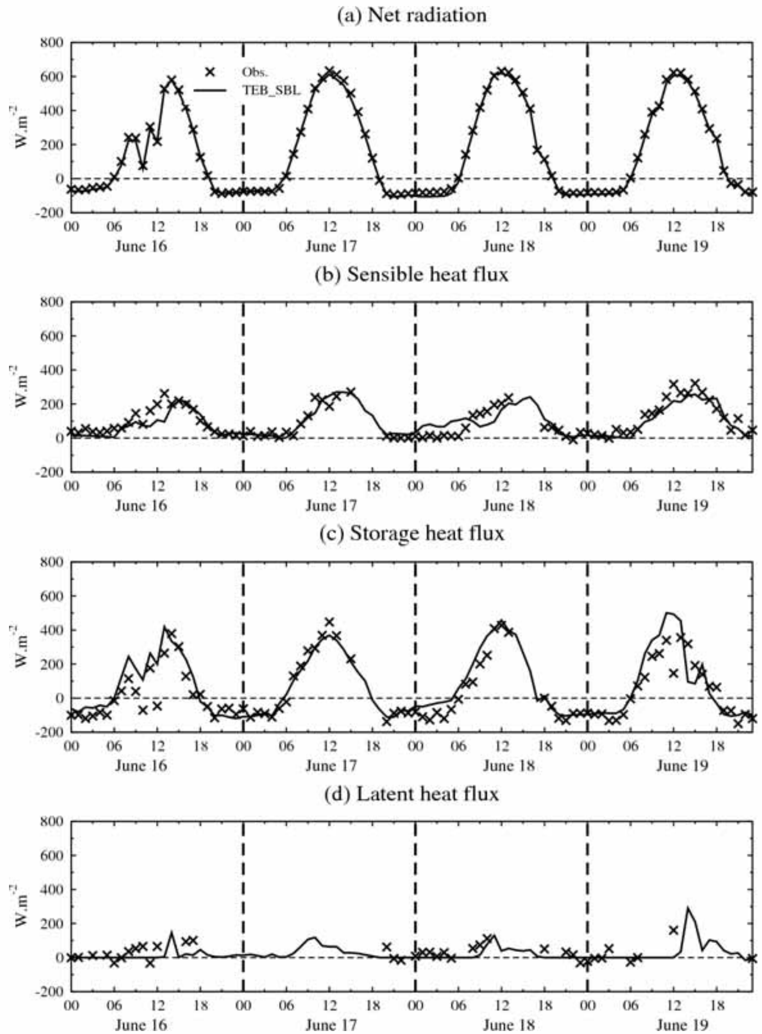




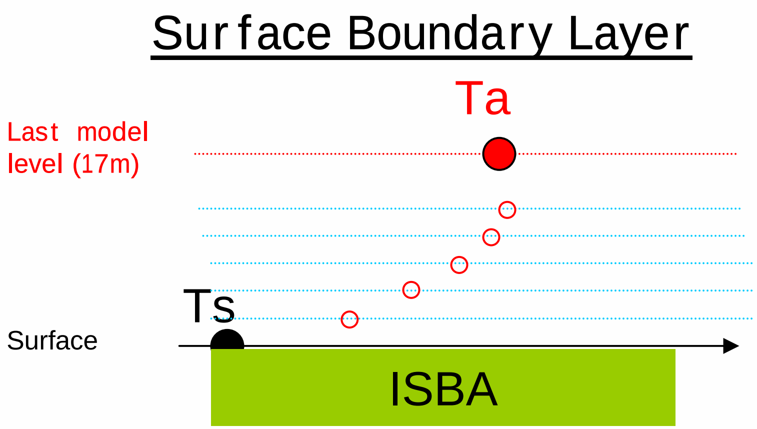
SBL canopy scheme in TEB

- 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



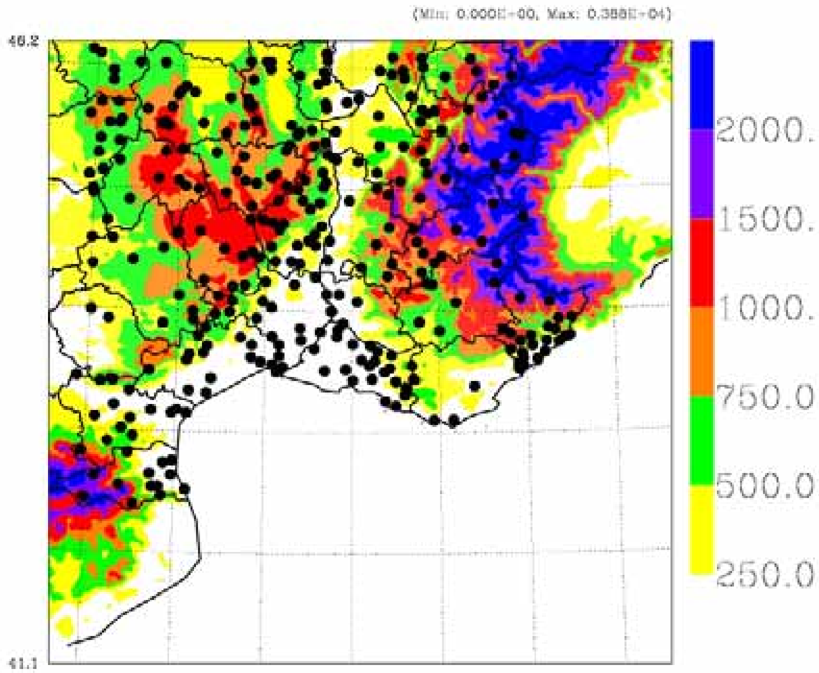


Evaluation in AROME



5 levels added +
turbulence scheme used

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



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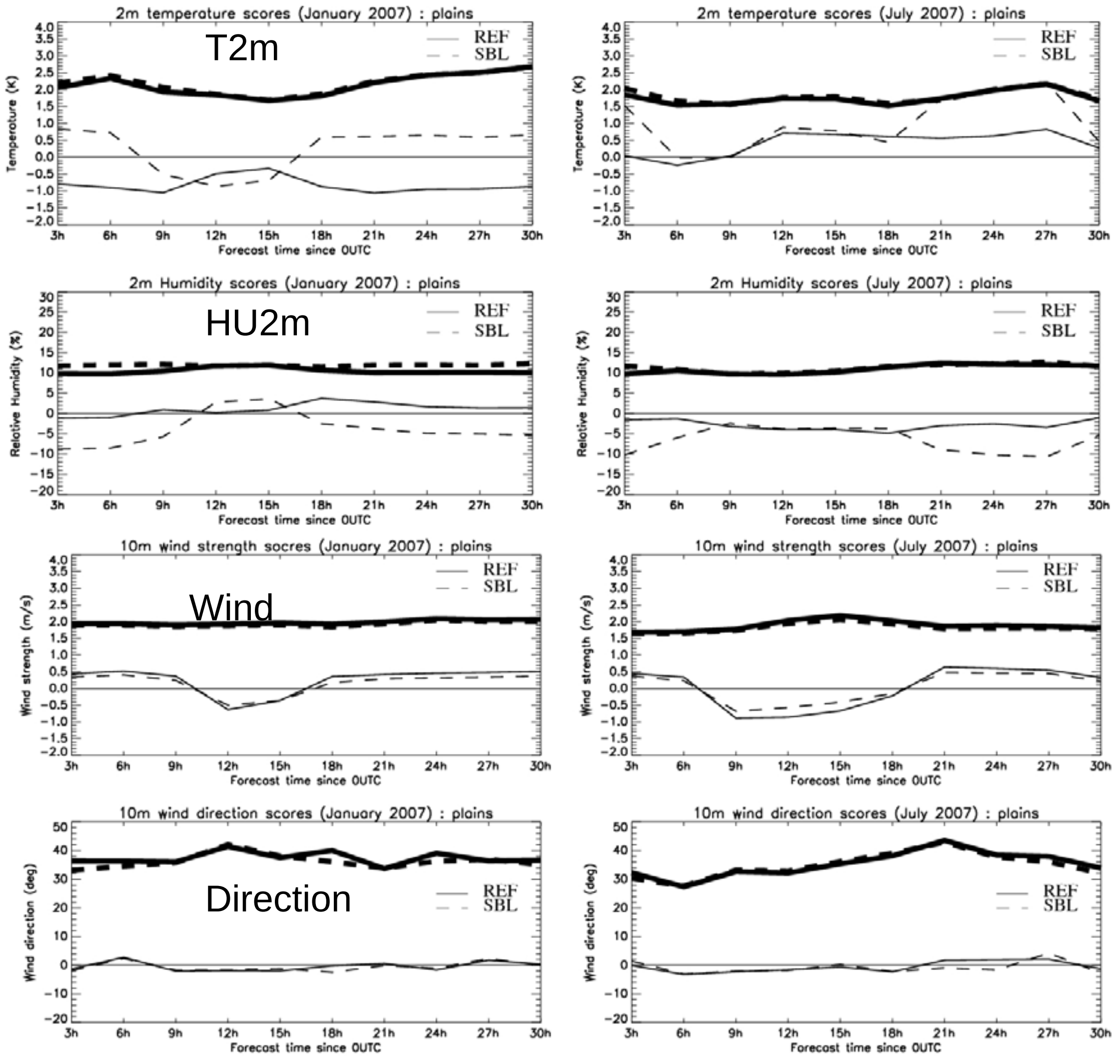
Evaluation in AROME

- Scores in plains (z<300m)



- SBL better in January, worse in July
- Reflects t2m errors
- SBL better for wind strength
- SBL better for wind direction (even if wind direction is not a SBL scheme variable !)

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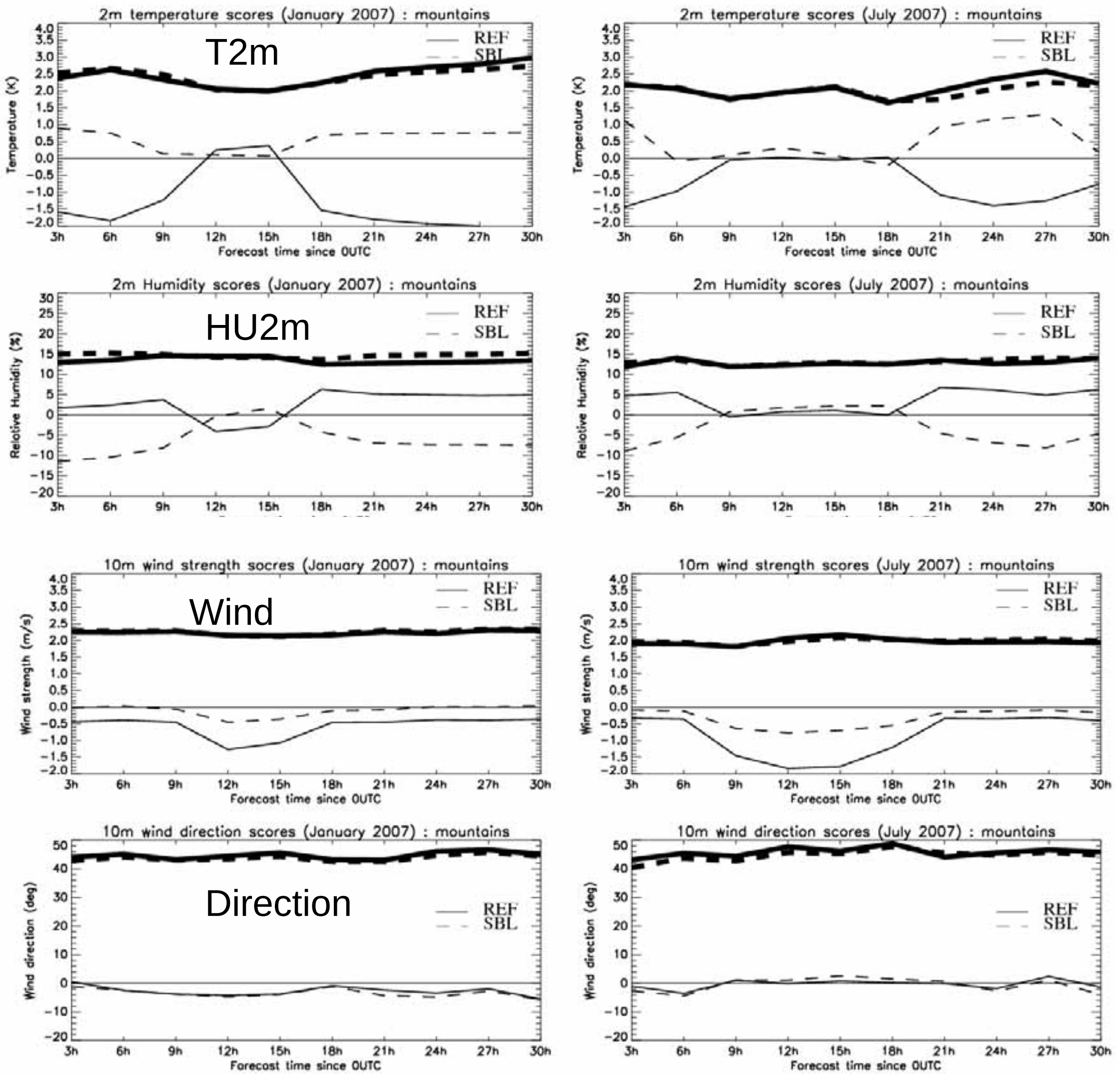
Evaluation in AROME

- Scores in mountaineous areas



- SBL better in January & July
- Reflects t2m errors
- SBL better for wind strength
- SBL better for wind direction (even if wind direction is not a SBL scheme variable !)

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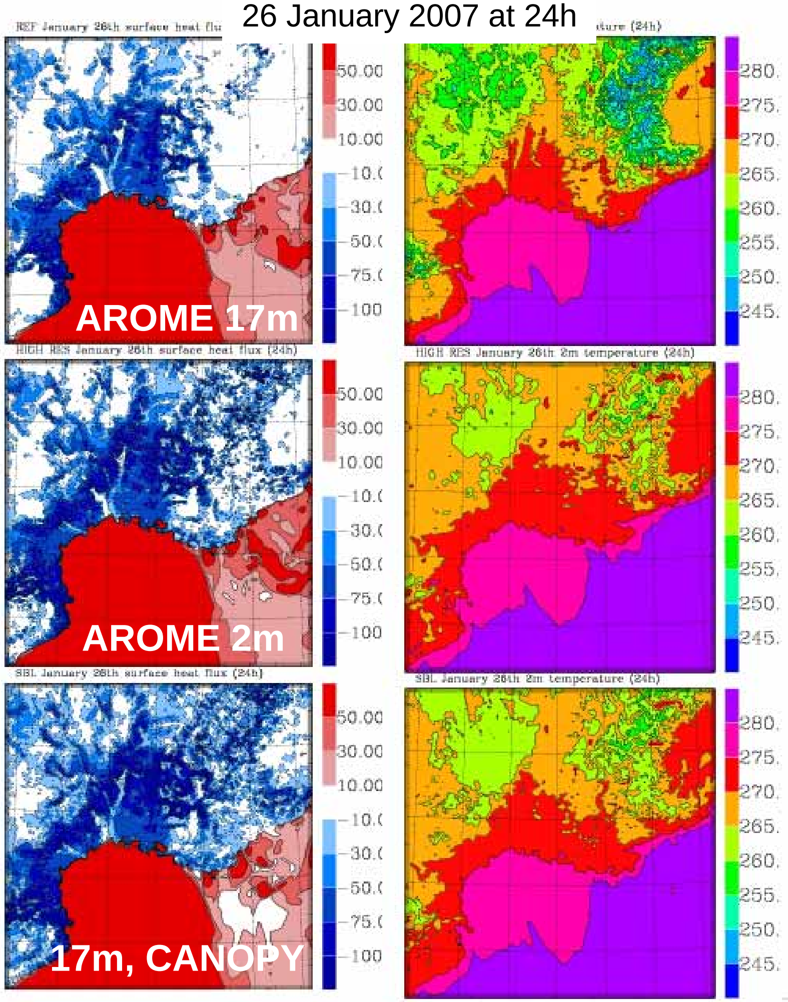
Evaluation in AROME

Better statistical scores,
Especially in mountains

No surface/atmosphere decoupling
↓
Significant (negative) heat fluxes
↓
Air cooling in the atmospheric model
↓
Better catabatic winds
↓
Better structure of temperature field

26 January 2007 at 24h



Surface heat flux 2m Temp.

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Conclusions

- One 1D SBL & « canopy » scheme has been included in SURFEX
- This allows a better physical treatment of the SBL, taking into account obstacle effects if any (e.g. buildings in TEB)
- Scores are globally improved, especially over mountains
- To couple the surface scheme (ISBA) with a very low SBL level avoids the classical surface/atmosphere decoupling
- Opens new collaboration opportunities on e.g. forest schemes including a tree canopy

Conclusions

- Thank you

SBL & « canopy » scheme

- Turbulence scheme is the Cuxart, Bougeault, Redelsperger (2000)
- Mixing and dissipative length scale, above canopy, are given by Redelsperger, Mahé and Carlotti 2001

A summary of the turbulence scheme is given below:

$$\begin{cases} \overline{u'w'} = -C_u l \sqrt{e} \frac{\partial U}{\partial z} \\ \overline{w'\theta'} = -C_\theta l \sqrt{e} \frac{\partial \theta}{\partial z} \\ \overline{w'q'} = -C_q l \sqrt{e} \frac{\partial q}{\partial z} \\ \frac{\partial e}{\partial t} = \underbrace{-\overline{u'w'}\frac{\partial U}{\partial z}}_{Dyn.Prod.} + \underbrace{\frac{g}{\theta}\overline{w'\theta'_v}}_{Therm.Prod.} \underbrace{-C_\epsilon \frac{e^{\frac{3}{2}}}{l_\epsilon}}_{Diss.} + \frac{\partial e}{\partial t}_{canopy} \end{cases} \quad (10)$$

with $C_u = 0.126$, $C_\theta = C_q = 0.143$, $C_\epsilon = 0.845$ (from Cheng et al 2002 constants values for pressure correlations terms and using Cuxart et al 2000 derivation). The mixing and dissipative lengths, l and l_ϵ respectively, are equal to (from Redelsperger et al 2001, $\alpha = 2.42$) :

$$\begin{cases} l = \kappa z / [\sqrt{\alpha} C_u \phi_m^2 (z/L_{MO}) \phi_e (z/L_{MO})]^{-1} \\ l_\epsilon = l\alpha^2 C_\epsilon / C_u / (1 - 1.9z/L_{MO}) \quad \text{if} \quad z/L_{MO} < 0 \\ l_\epsilon = l\alpha^2 C_\epsilon / C_u / (1 - 0.3\sqrt{z/L_{MO}}) \quad \text{if} \quad z/L_{MO} > 0 \end{cases} \quad (11)$$

Where L_{MO} is the Monin-Obukhov length, ϕ_u and ϕ_e the Monin-Obukhov stability functions for momentum and TKE.