Poster n°

Large eddy simulations of boundary layer turbulence during the late afternoon transition

Clara Darbieu(1), Fabienne Lohou(1), Fleur Couvreux(2), Marie Lothon(1), Pierre Durand(1), Françoise Guichard(2), Ned Patton(3)
(1) Université de Toulouse, Laboratoire d'Aérologie-CNRS UMR 5560, Toulouse, France
(2) CNRM, Météo-France, Toulouse, France
(3) National Center for Atmospheric Research, Boulder, CO

BLLAST
Boundary Layer Late Afternoon and Sunset Turbulence

The Boundary Layer Late Afternoon and Sunset Turbulence (BLLAST) campaign took place in France in June and July 2011 focusing on the evening collapse of the boundary layer. In an effort to guide the BLLAST experimental design, the present numerical study aimed at answering basic questions such as : what is the start-time of the late afternoon transition (LAT) ? Which atmospheric layers have to be experimentally investigated in priority ? To address these questions, two Large Eddy Simulations (LES) codes were used to simulate the decaying atmospheric boundary layer (ABL).

Objectives

1/ **Comparing two LES** and their ability to simulate the late afternoon transition (LAT)
2/ Studying the **turbulence characteristics** during the LAT : results found in the literature are revisited and further analyzed.
This comparison investigates:
- the validity of mixed layer scaling
- the 'S' shape of the buoyancy flux
- the decay of turbulent kinetic energy (TKE)
- the time evolution of turbulent length scales.

Large eddy simulations

- **Two LES models : NCAR and Meso-NH** (LA/CNRM/GAME)
- Same equations for both models (Navier-Stokes)
- No cloud developing
- No large scale forcing (i.e. advection, subsidence) and no geostrophic wind
- No coupling with a surface model : sensible and latent heat fluxes are imposed at surface

Study case IHOP

- Data-set collected on 14 June 2002 during the **International H_2O Project field experiment** (Southern Great Plains, US)

→ Initialization with wind, temperature and humidity profiles at 7am, as well as sensible and latent heat fluxes

- Size of the simulated domain : 10 km * 10 km * 4.8 km
- Regular grid of 100 m (horizontal) and 40 m (vertical)
- Time increments : Meso-NH : dt = 1 s, NCAR : dt ~ 2.5 s

Comparison of the two simulations NCAR and Méso-NH

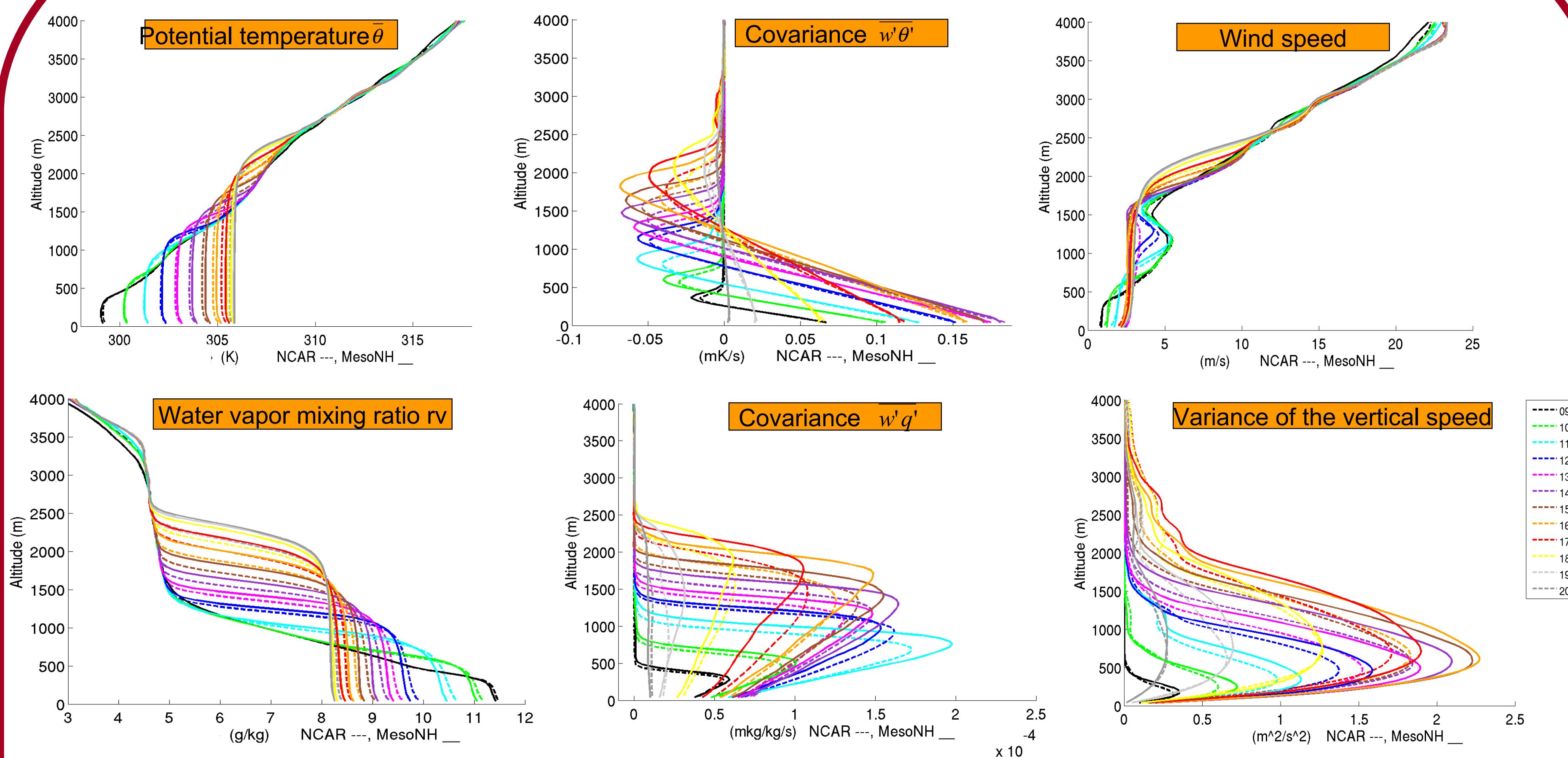


Figure 1

Intercomparison between NCAR (---) and Meso-NH (__) simulations. The evolution of the profiles of potential temperature $\overline{\theta}$, water vapor mixing ratio rv, wind speed, covariances $\overline{w'\theta'}$ and $\overline{w'q'}$ as well as variance of the vertical velocity is shown.

There is a **good agreement** between the two simulations.
The main differences come from :
- **larger** values of **entrainment** $\frac{\overline{w'\theta'}_{zi}}{\overline{w'\theta'}_{s}}$ in **Meso-NH** simulation, implying :

→ a slightly warmer and drier mixed layer (ML)
→ a slightly higher ABL height (Fig. 2a)

- **larger variance** of the **vertical velocity**

Validity of the normalization scales during the LAT

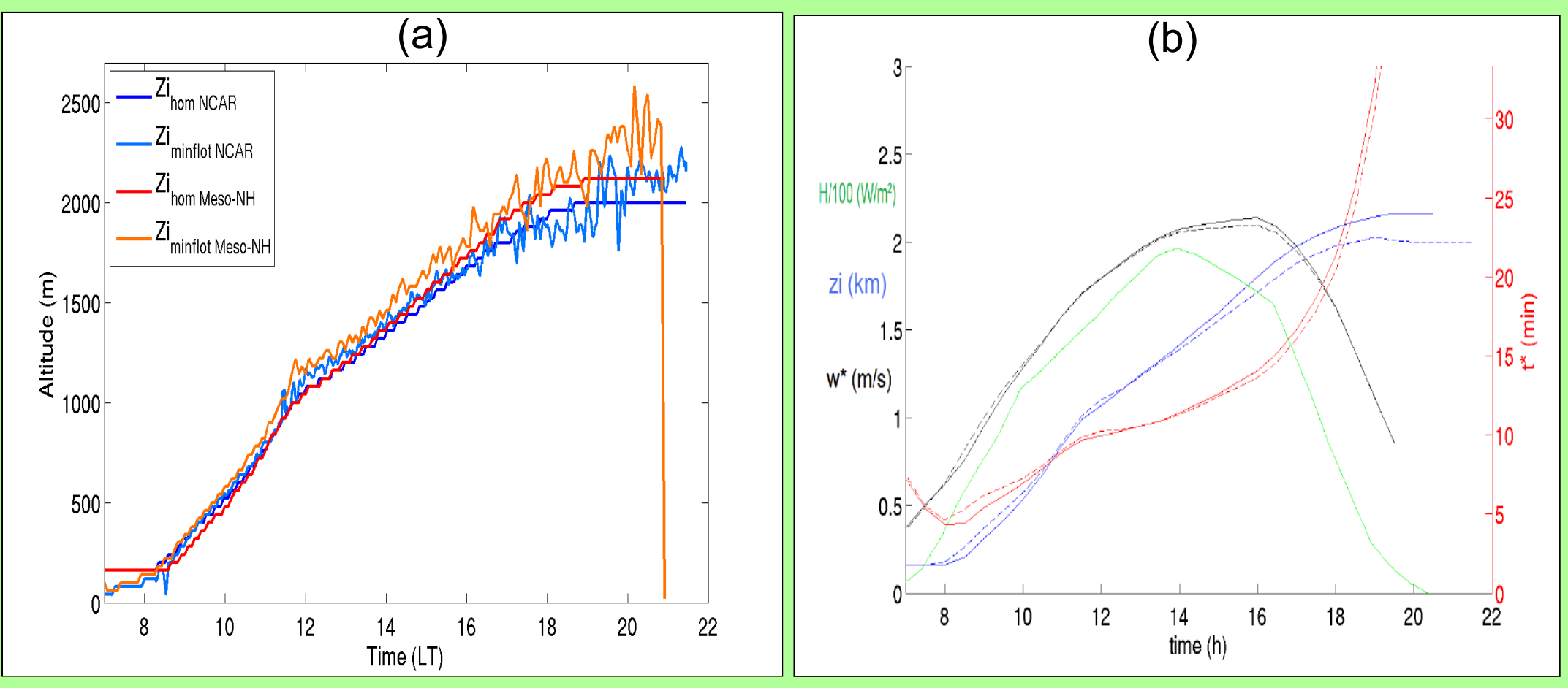
Figure 2 *Temporal evolution of :*

(a) the length scale zi, which can be defined as the altitude of the minimum buoyancy flux (zi_minflot) or as the summit of the mixed layer (zi_hom), where theta gradient exceeds a threshold.

(b) the convective velocity scale

$$w_* = (\beta \overline{w'\theta'_0} zi)^{1/3}, \beta = \frac{g}{T}$$

where T is the mean temperature in the ABL, the convective time scale $\frac{zi}{w_*}$, zi and the surface sensible heat flux H/100, for NCAR (---) and Meso-NH (__) simulations.



- The evolution of zi is very similar for both models. However, after 1700LT, zi is not well defined by the minimum buoyancy flux (fluctuations of 400 m are observed, Fig. 2a). However, zi is well defined by the height of the mixed layer.
- From 1600LT, the convection decreases and induces an exponentially increase of t_*. At 1600LT, 15 minutes are necessary for a thermal to go through the ABL whereas at 1900LT, double time is required.

→ Are these scales still relevant after

'S'shape of buoyancy flux

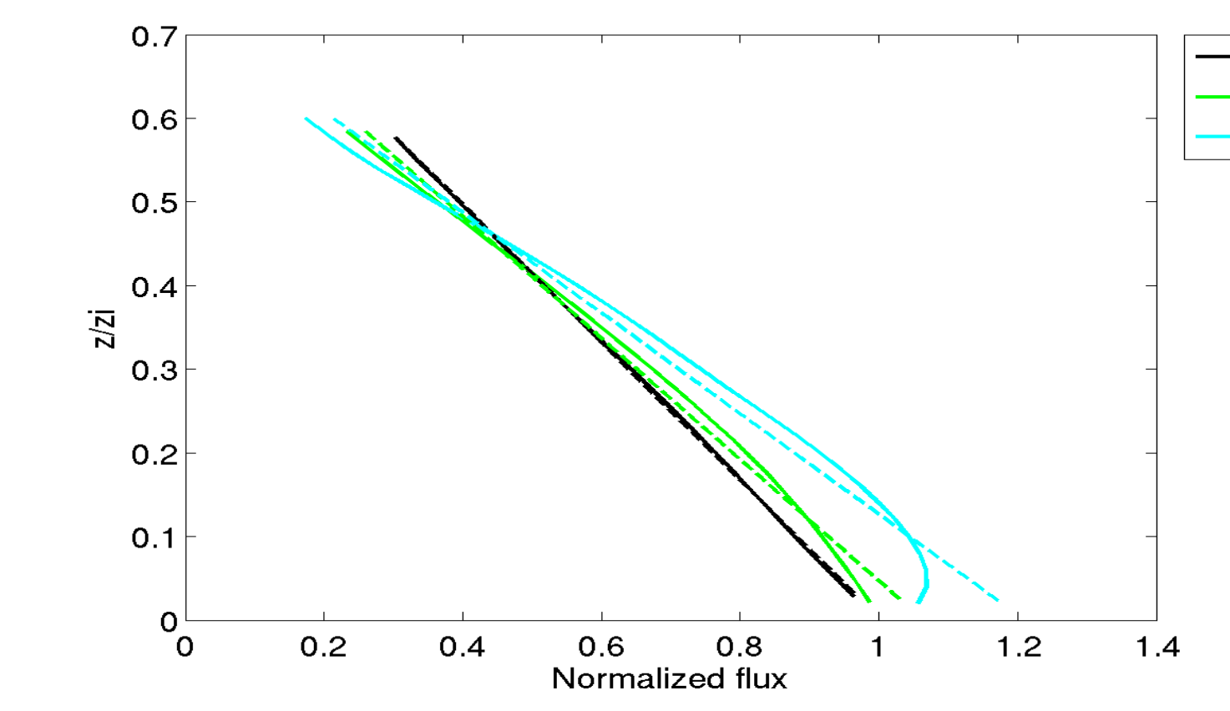


Figure 3 $\frac{\overline{w'\theta'_v}}{w_*\theta_{v*}}$ *vertical profiles and their linear regressions between 0 and 0.6zi at 1415LT, 1715LT and 1955LT*

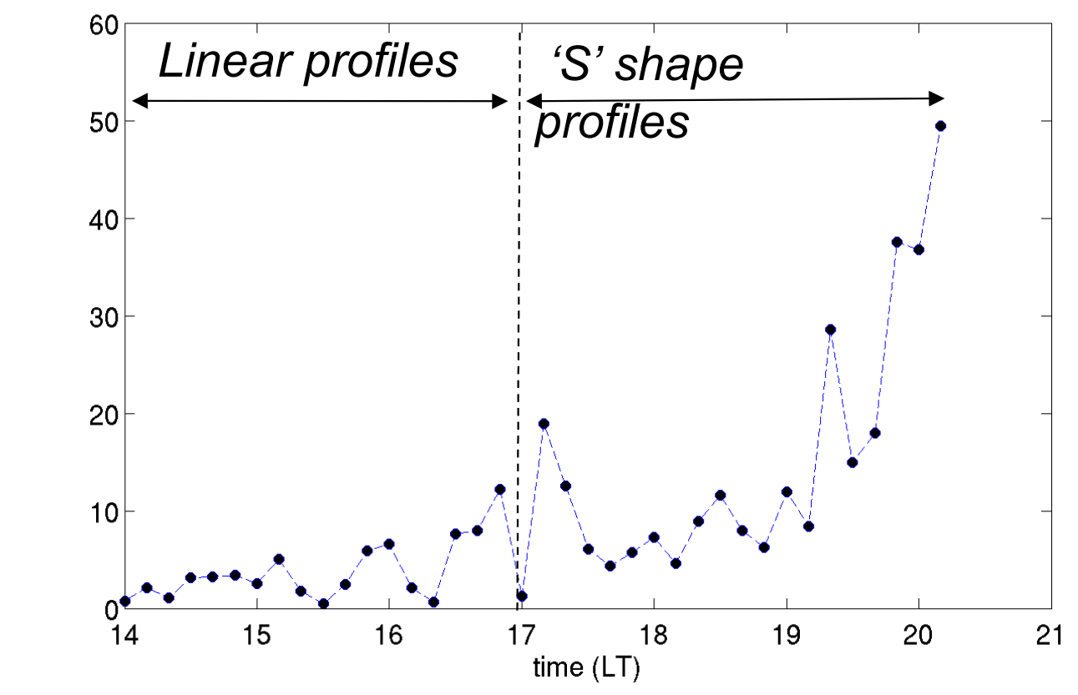


Figure 4 *Temporal evolution of the area between* $\frac{\overline{w'\theta'_v}}{w_*\theta_{v*}}$ *and the linear regression.*

The universal dimensionless **buoyancy flux profiles** are **not linear** anymore **after 1700LT** and become 'S' shaped. Indeed, after 1700LT, the turbulent transfers are significantly different than during the convective period. The convective time scale seems not short enough to allow the ABL to correctly response to the rapid changes at surface.

Decay of TKE

Decay of the mean TKE in the ABL

Niewstadt and Brost (1986) studied the TKE decay due to a sharp cut of the surface heat flux H. Sorbjan (1997) extended this study by investigating a gradual decrease of H, with a time lag between the maximum τ_f and the zero flux of 1.4 h. Here, we investigate a τ_f decrease of H, with = 6h.

The decay of the volume averaged total TKE, scaled by w_{*0}^2 (Fig. 5) is a function of two time scales (Sorbjan 1997) :
- the **external time scale** controlling the surface heat flux evolution τ_f
- the **convective time scale** t_*

In our simulation, we obtain a similar function, with a decrease of t^{-4} :
the normalized TKE remains constant for a **longer** time, then it decreases much

Characteristics	Sorbjan	IHOP
w_{*0} (ms^{-1})	0.613	2.0701
θ_{*0} (K)	0.0163	0.0966
z_{i*0} (m)	705	1300
t_{*0} (s)	1150	683
$\overline{w'\theta'}_{max}$ (Kms^{-1})	0.01	0.2
τ_f (h)	1.4	6.41
Decay rate = $\frac{\overline{w'\theta'}_{max}}{\tau_f}(Kmh^{-2})$	25.71	112.32

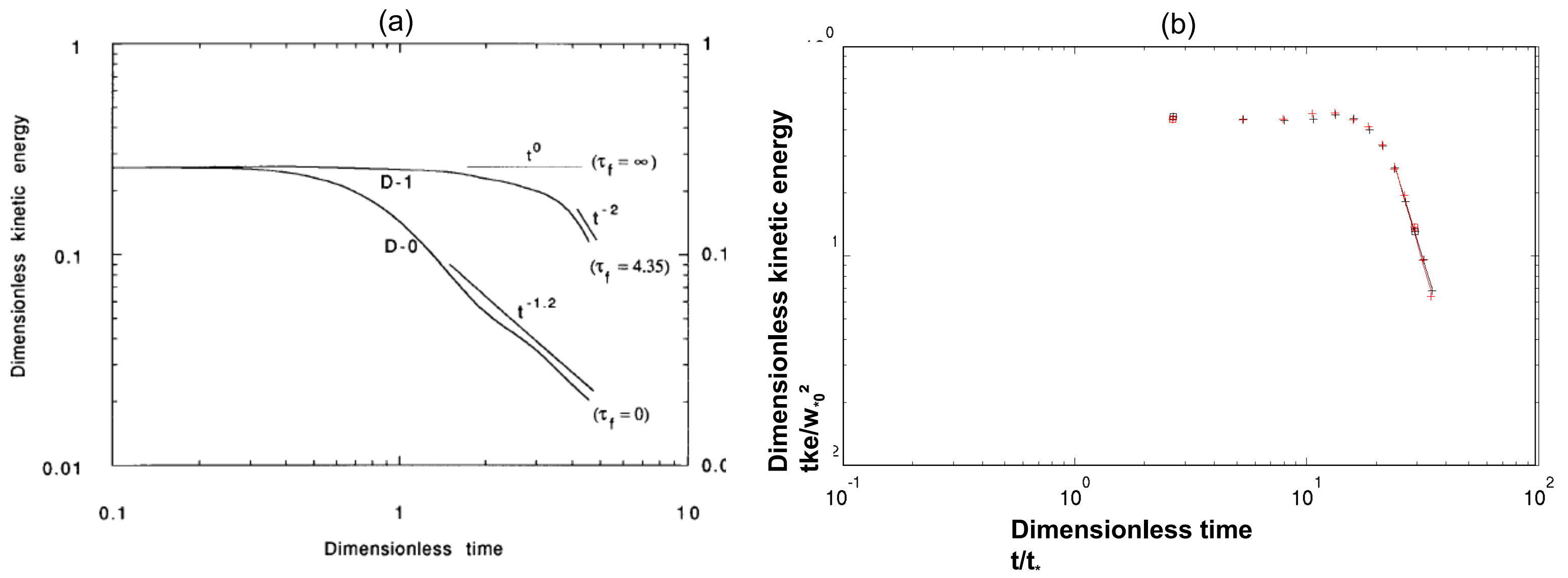


Figure 5
The volume averaged total TKE, scaled by w_{*0} as a function of t/t_{*0}. . w_{*0} and t_{*0} are the convective scales when the surface heat flux is maximum.
(a) : according to Sorbjan, (b) : with ***NCAR*** *and* ***Meso-NH*** *simulations*

Evolution of the TKE at different heights in the ABL

The analysis of the time evolution of the TKE at different heights in the ABL points out that in our case, there is an increase of the TKE at the top of the ABL, starting from 1500LT. At that time, zi reaches the sheared layer above (Fig.1) : the entrainment of momentum might explain the increase of TKE at the top of the ABL, which progressively propagates down to the surface. The evolution of horizontal and vertical variances (not shown) show that the entrainment gains the upper hand over surface convective processes.

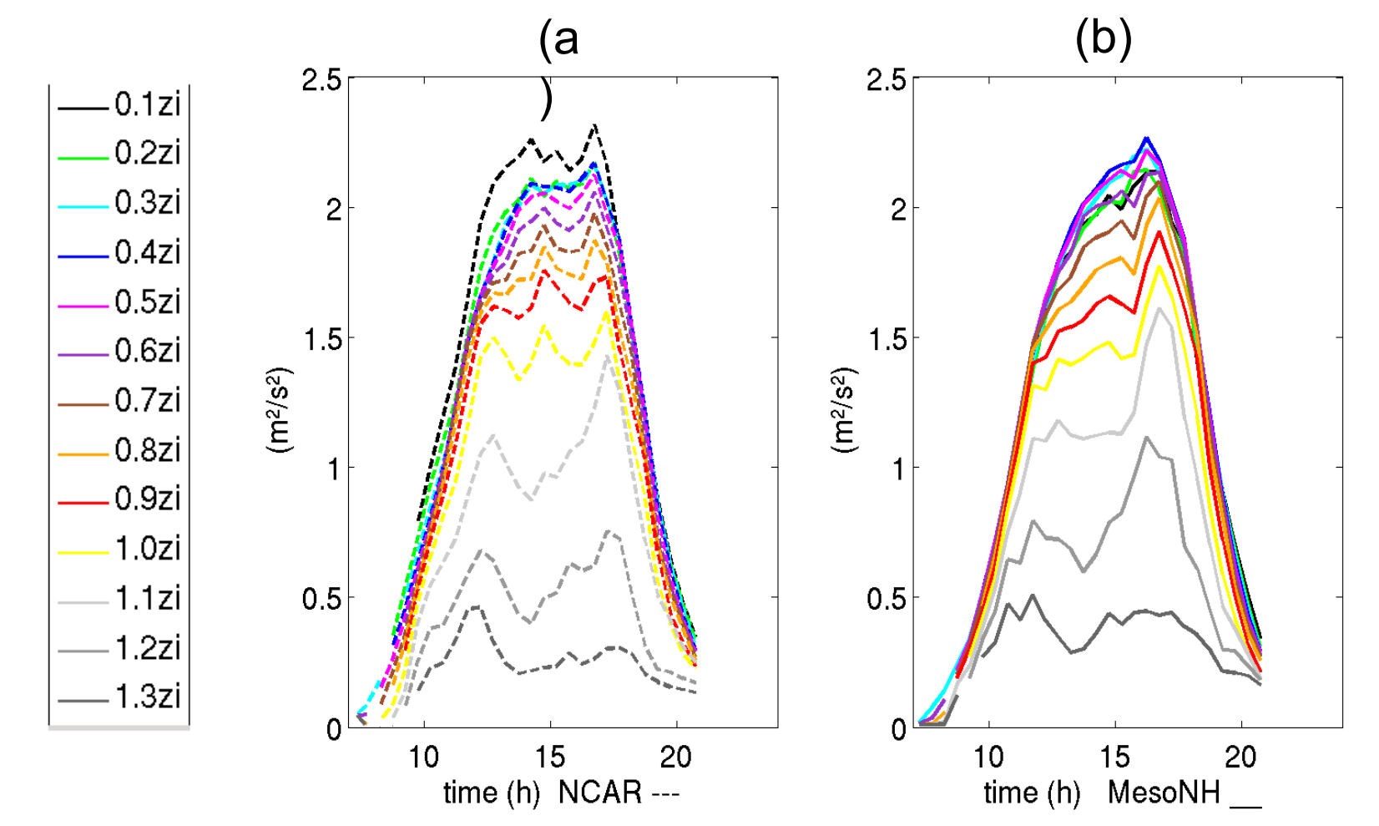


Figure 6
Temporal evolution of the TKE at different heights in the ABL for (a) NCAR and (b) Meso-NH simulations

See also the Poster n°25, BLT 2012 (Darbieu et al.) **« Turbulent kinetic energy decay in the late afternoon over heterogeneous surface : BLLAST experiment »**

Conclusion

The results of two simulations (NCAR and Meso-NH) have been investigated, for a convective boundary layer, without cloud, during the LAT. On the whole, both simulations give very similar results for mean parameters and fluxes.

- Determining the development of the ABL in the LAT is challenging. Some ways to evaluate the ABL height do not work in the LAT : in our case, the most fitting method consists in determining the summit of the ML.

- The diminishing w_*, inducing an exponential increase of t_* after 1600LT indicate that these normalization scales might not be relevant during the LAT. van Driel and Jonker (2011) suggest new normalization scales in transitional situations, based on the surface heat flux and its past.

- The universal linear profiles of buoyancy fluxes are not maintained in the LAT from 1700LT and become 'S' shaped.

- As Sorbjan (1997), we found that the decay of the TKE is a function of two time scales, t_* and .

- The evolution of the TKE at different heights points ut an increase of the TKE at the top of the ABL, from

References :

Deardorff, J. W., 1972: Parameterization of the planetary boundary layer for use in general circulation models, *Mon. Wea. Rev.*, **100**, 93–106.

Lothon et al, ., 2012: The bllast field experiment : Boundary layer late afternoon and sunset turbulence., *Submitted to Bull. Amer. Met. Soc.*

Niewstadt, F. and R. Brost, 1986: The decay of convective turbulence., *Journal of the Atmospheric Sciences*, **42**, 532–546.

Pino, D., H. J. J. Jonker, and J. Vilà-Guerau de Arellano, 2004: Role of the shear and inversion strength during sunset turbulence over land: characteristic length scales, *In: Proc: 16th AMS Symposium on boundary layers and turbulence, 9-13 August 2004, Portland, Maine, American Meteorological Society, 45 Beacon ST., Boston, MA.*

Sorbjan, Z., 1997: Decay of convective turbulence revisited, *Boundary-Layer Meteorol.*, **82**, 501–515.

—, 2007: A numerical study of daily transitions in the convective boundary layer, *Boundary-Layer Meteorol.*, **123**, 365–383.

van Driel, R. and H. J. J. Jonker, 2011: Convective boundary layers driven by non-stationary surface heat fluxes, *J. Atmos. Sci.*, **68**, 727–738.