Turbulent kinetic energy decay in the late afternoon over heterogeneous surface: BLLAST experiment

Poster 22

BLLAST
Boundary Layer Late Afternoon and Sunset Turbulence

C. Darbieu[1], F. Lohou[1], M. Lothon[1], Daniel Alexander [2], Olivier Decoster[3], Solène Derrien[1], Pierre Durand[1], Dominique Legain[4], Olivier Traullé[4], Eric Pardyjak[2], Henk Pietersen[3], Eric Pique[1]

Affiliation: [1] Laboratoire d'Aérologie, Toulouse, France (darc@aero.obs-mip.fr); [2] UTAH university, Salt Lake City, USA; [3] MAQ, Wageningen University, Netherlands; [4] CNRM/GAME, Météo-France, Toulouse, France.

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Université Paul Sabatier TOULOUSE III

Introduction

Nieuwstadt and Brost (1986) were the first to numerically study the turbulent kinetic energy (TKE) decay in a mixed-layer. This decay was the consequence of an abrupt cut of surface heat flux. The effect of progressive decrease of surface flux was analyzed by Sorbjan (1997) with large eddy simulation (LES) and Nadeau et al. (2011) with measurements close to surface (*Figure 1*) and an analytical model. They found a power law of TKE decay whose coefficient is a function of τ_f / t_* where τ_f is the time delay between the maximum and the zero value of the forcing flux and t* the convective time scale. Using the BLLAST data set two main questions are addressed:

1/ Sorbjan (1997) showed the decay of the volume average TKE over the atmospheric boundary layer (ABL) depth z_i, whereas Nadeau et al. (2011) fitted a model to surface measurements. ***BLLAST allows to study TKE decay over different surfaces and at different heights in the ABL***.

2/ As mentioned by Nadeau et al. (2011) several coefficients are observed (-2 to -6) (*Figure 1*). ***What control this coefficient and how is the decay phased with the decay of the surface flux?***

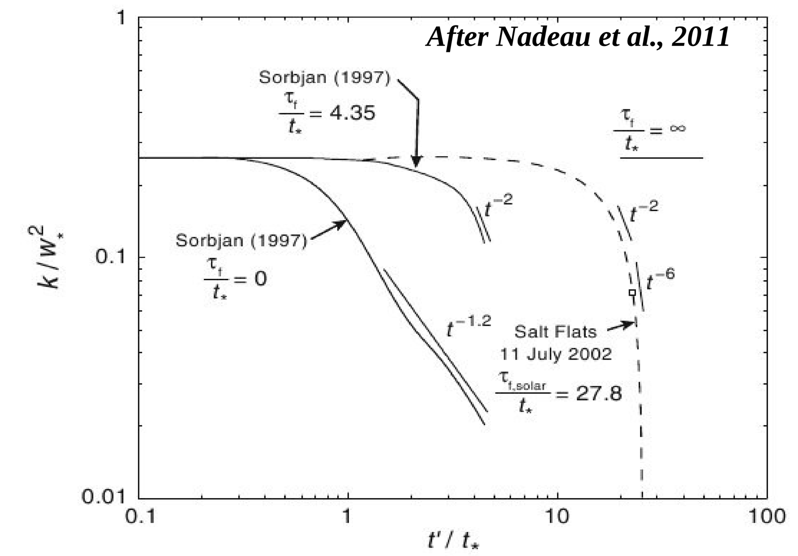
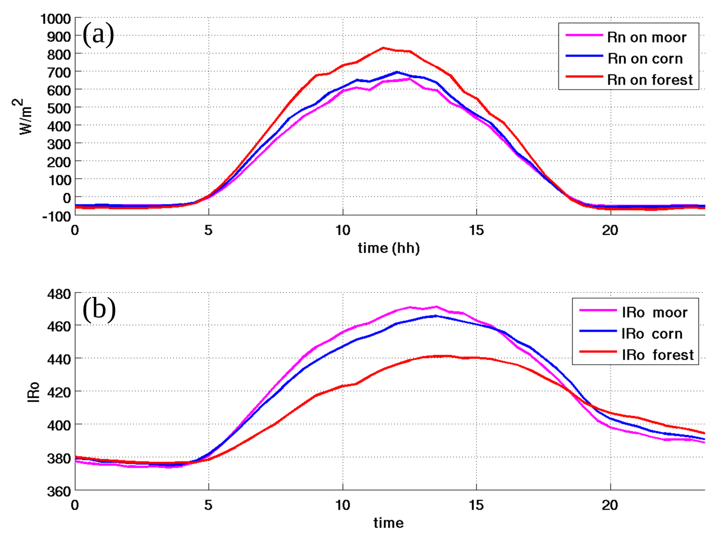


Figure 1: Normalized TKE against time normalized by the convective scale $t_* = z_i / w_*$. τ_f is the forcing timescale. The two first curves are LES results from (Sorbjan, 1997). The third curve is an analytical model that fits surface measurements over a desert in July 2001 (Nadeau et al., 2011).

BLLAST Experiment and surface heterogeneities

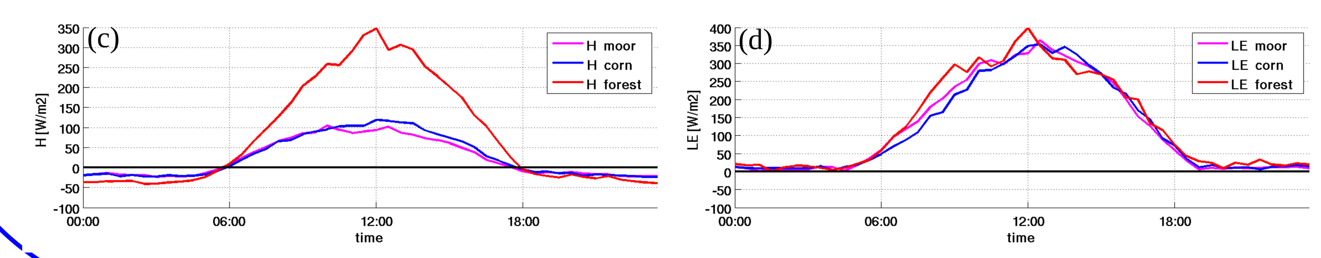
BLLAST experiment (Boundary Layer Late Afternoon and Sunset Turbulence) took place in the south of France in June and July 2011 (Lothon et al, 2012, BLT 14.B1). Eleven surface stations measuring surface energy balance were implemented over different vegetation covers. Data sets of 6 of them are used in this study (Table 1). Turbulent moment have been computed with an eddy-covariance uniform-process using EC-pack (Wageningen University). During BLLAST 12 Intensive Observation Periods (IOP) were performed during which two aircrafts (Piper Aztec (SAFIRE/ Météo-France) and Sky Arrow (CNR-IBIMET/ Italy)) flew stacked legs in and above the ABL. Piper Aztec data set are used to complete the surface measurements and deal with TKE decay at different heights in the ABL.

Figure 2: BLLAST IOPs Composite daily evolution of (a) net radiation, (b) outgoing long wave, (c) sensible and (d) latent heat flux over three different vegetation covers: moor, corn and forest.



Differences up to 100 W m^{-2} can be observed on net radiation between the three vegetation covers (moor, corn and forest) (*Figure 2a*). These differences are due to the albedo differences between the various vegetation covers, which imply different outgoing short and long wave radiation. The former is totally phased with the solar irradiance, whereas the latter displays a time shift between surface type (*Figure2b*) which is linked to heat storage in the canopy.

The sensible heat flux over forest (350 W m^{-2}) can be up to three times the flux over moor or corn (100 W m^{-2}) (*Figure 2c*). Furthermore, time shift between the maximum values can be noted. On the contrary the latent heat flux has similar values whatever the vegetation cover (*Figure 2d*).



The TKE is governed by dynamical conditions through the wind shear (Goulart et al., 2010) and by buoyant conditions through the sensible heat flux. Are the vegetation cover behaviour differences noted previously able to imply some significant TKE decay differences in the late afternoon?

Conclusion :

BLLAST experiment provides a very good data set to study the TKE decay close to the surface but also at different heights in the ABL. Those observations were rare up to BLLAST experiment. In addition to surface and airborne measurements, vertical profiles of low atmosphere performed by tethered balloons enrich the analysis, since they enable us to : 1/ investigate the impact of the surface heterogeneity on stabilisation of the surface layer, 2/ estimate the dynamical and thermal production terms of the turbulent kinetic energy budget.

The analysis of the TKE decay as a function of the buoyancy conditions at the surface shows that the power law coefficient for the TKE decay is not constant with time. This rate evolves in three stages: 1/ close to zero whereas H is already decreasing, 2/ low until H inflection point , 3/ high until sunset. The similar pattern obtained over the different vegetation cover shows that the TKE decay is strongly governed by buoyancy effects. However, disparity of each IOP curve from the average trend could be quantified and related to the wind shear to study the impact of the dynamical effect.

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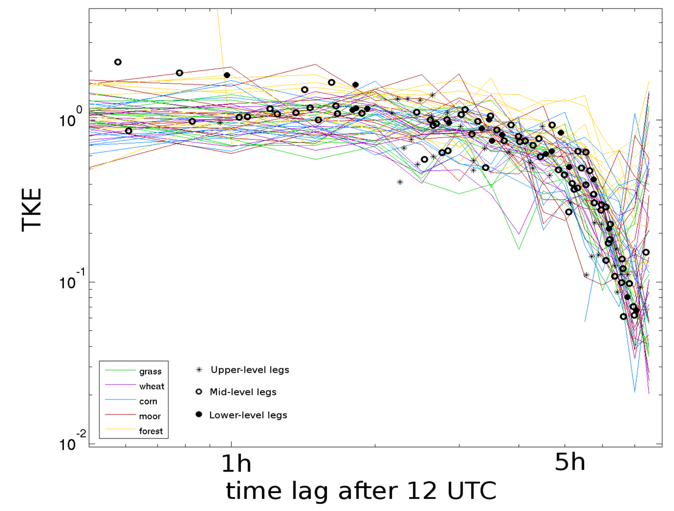
Turbulence decay

Whole BLLAST in one plot

Figure 4: Temporal evolution of TKE (from noon to sunset) measured during the 11 IOPs over the 5 vegetation covers at surface (color scale) and by the aircraft at different levels in the ABL (markers).



- Good coherence of the TKE decay whatever the IOP, the vegetation cover and the measurement level in the ABL even without normalisation.
- Note that the increase at the very end of the day is generally due to the set up of the katabatic nocturnal flow typical of the location.
- However logarithmic representation is misleading and discrepancies exist. Is it due to large scale forcing, wind shear, entrainment, surface heterogeneity?

In the following, we investigate the buoyancy effect on the TKE decay close to the surface. The eleven IOPs are used to estimate a composite IOP over each vegetation cover in order to relate the TKE decay with the sensible heat flux decay.

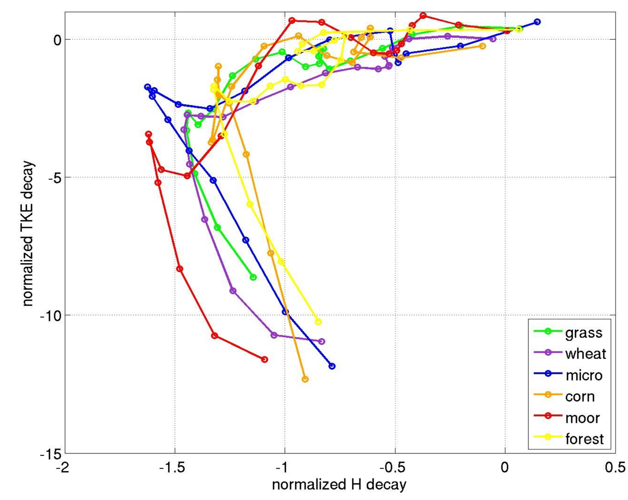


Figure 6: IOPs composite decay of TKE against IOPs composite decay of normalised sensible heat flux for the five different vegetation covers.

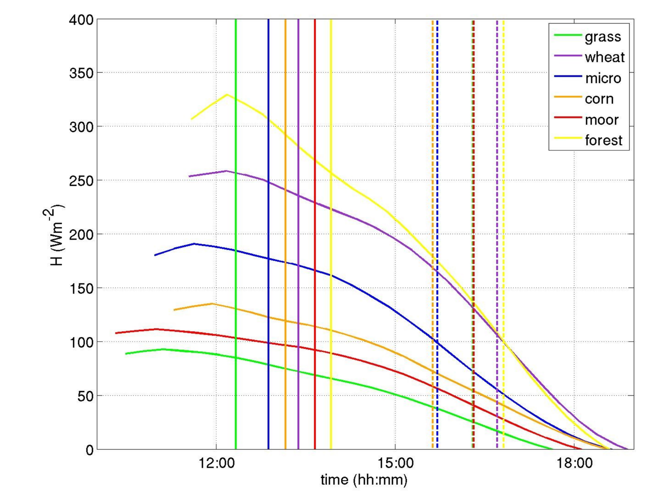


Figure 7: Composite H for the 5 vegetation covers. Continuous and dashed vertical lines are respectively for the start of stage 2 and stage 3 of TKE decay.

Buoyancy effect on TKE decay at surface

Three stages are observed in *Figure 6*:

- Stage 1: H is at its maximum and starts to decrease. TKE remains close to constant (rate ~ 0).
- Stage 2: H continues to decrease and the TKE decreases also with a low rate until H rate reaches a minimum (H inflection point).
- Stage 3: H rate increases (but is still negative) whereas TKE decay accelerates with a strongly decreasing rate.

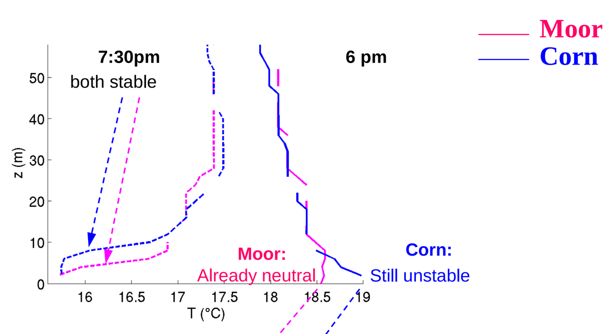
The timings of stages 2 and 3 are converted in UTC and compared to the evolution of the composite H over IOP (*Figure 7*). Stage 2 begins between 12:30 and 14:00 UTC. Stage 3 begins at the H rate inflection point whose timing ranges from 15:30 to 16:30 UTC.

Study of the surface heterogeneity impact through the tethered balloons

During the BLLAST experiment, two tethered balloons were operating over a maize field and a moor field. Vertical profiles of temperature, humidity and wind in the first 100 meters were performed to evaluate the impact of the surface heterogeneity on the surface layer. We investigate 1/ the stabilisation over the two surfaces for the 30th of June IOP and, 2/ the evolution of the dynamical and thermal production terms of the TKE budget for the 5th of July IOP.

Stabilisation over moor and corn

Figure 8: vertical instantaneous profiles of temperature given by tethered balloons over moor and corn at 6pm (-) and at 7:30pm (--)



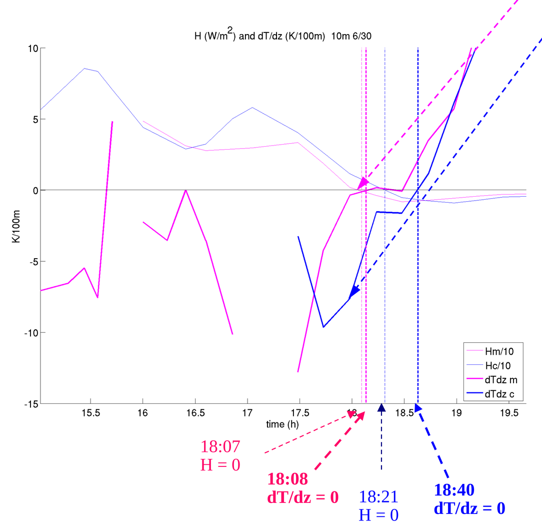


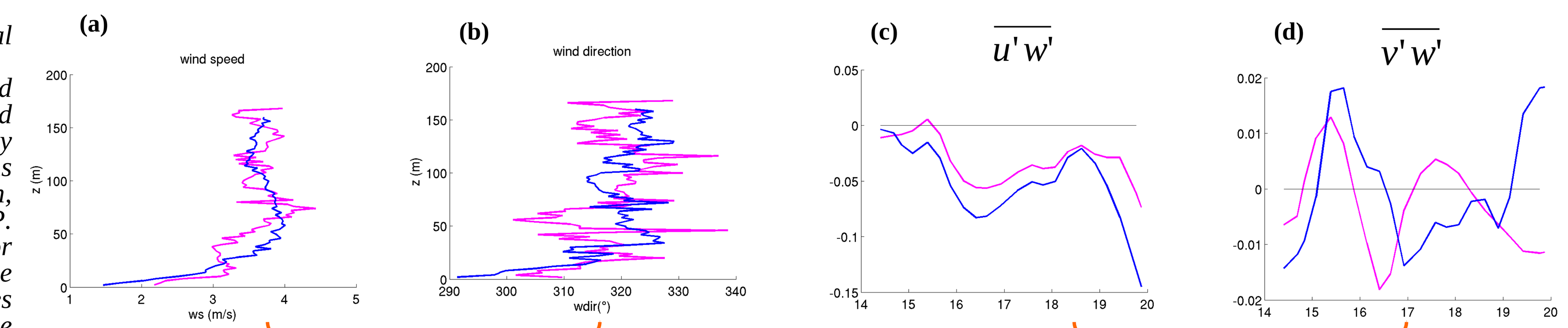
Figure 9: Temporal evolution of H and dT/dz over moor and corn, the 30th of June 2012.

Figure 9 shows that H over moor turns to zero 15 min before H over corn. The earlier stabilisation in the 10m high layer over the moor site is therefore in agreement with the delay on H. However, over the moor site, the stabilisation is perfectly phased with H = 0 whereas over the corn site, there is a delay of 20 min between H = 0 and dT/dz = 0 : there is still some instability over the corn site even if H is null. This result is observed on several IOPs and remains unexplained. Could it be due to the impact of the canopy?

An access to the shear production term in the TKE budget

Through the calculation of vertical gradients, the tethered balloons give us access to the dynamical and thermal production terms in the TKE budget at surface. Figure 11 represents the temporal evolution of these two terms. We get the shear production term from du/dz and dv/dz calculated from the instantaneous wind profiles and from the wind covariances measured at the surface stations (figure 10).

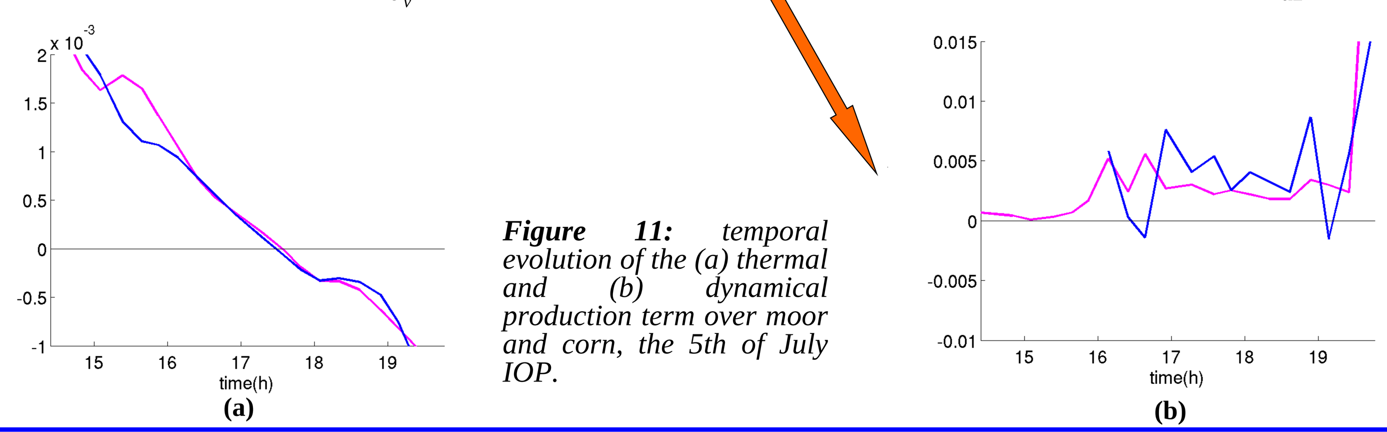
Figure 10: Vertical instantaneous profiles of (a) wind speed and (b) wind direction given by tethered balloons over moor and corn, the 5th of July IOP. (c) and (d) stand for the evolution of the wind covariances measured at the surface stations.



$$\frac{du}{dz} \qquad \frac{dv}{dz}$$

Thermal production term $\frac{g}{\theta_v}\overline{w'\theta_v'}$

Shear production term $-(\frac{du}{dz}\overline{u'w'} + \frac{dv}{dz}\overline{v'w'})$



$$\overline{u'w'} \qquad \overline{v'w'}$$

Figure 11: temporal evolution of the (a) thermal and (b) dynamical production term over moor and corn, the 5th of July IOP.

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