

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



Poster 25



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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  $\tau_1 / \tau_0$ , where  $\tau_1$  is the time delay between the maximum and the zero value of the forcing flux and  $\tau_0$  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  $z_0$ , 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 the TKE decay is it related to the decay of the surface flux?**

## Introduction

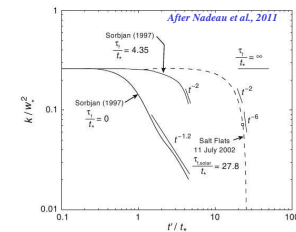


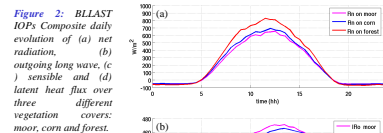
Figure 1: Normalized TKE against time normalized by the convective scale  $t = z_0 / w_e$ ,  $w_e$  is the forcing timescale. The two first curves are LES results from Sorbjan (1997). The third curve is an analytical model that fits surface measurements over a desert in July 2001 (Nadeau et al., 2011).

## BLLAST Experiment and surface heterogeneities

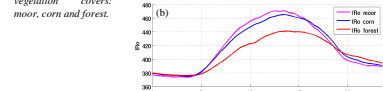
BLLAST experiment (Boundary Layer Late Afternoon and Sunset Turbulence) was held in South of France in June and July 2011 (Lothon et al., 2012, BLT 14.B1). Eleven surface stations measuring surface energy balance were implemented over different vegetation covers. Data sets of 6 of them are used in this study (Table 1). Turbulent moments 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 are used to complete the surface measurements and deal with TKE decay at different heights in the ABL.

Vegetation	Grass	Wheat	Hétérogène	corn	Moor	Pine forest
Laboratory	MAQ/ Wageningen Univ./ Netherlands	MAQ/ Wageningen Univ./ Netherlands	Bergen Univ./ Norway	Game-CNRM (Météo-France)	Game-CNRM (Météo-France)	Utah Univ. (US) & Laboratoire d'Aérodynamique (France)

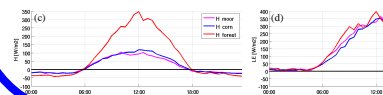
Table 1: Six of the surface stations implemented during BLLAST experiment.



Differences up to 100 W m<sup>-2</sup> 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 in phase with the solar irradiance, whereas the latter displays a time shift between surface type (Figure 2b) which is linked to heat storage in the canopy.



The sensible heat flux over forest (350 W m<sup>-2</sup>) can be up to three times the flux over moor or corn (100 W m<sup>-2</sup>) (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 (Goult 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?

### References:

- Nieuwstadt and Brost (1986) The decay of convective turbulence, J. Atmos. Sci., 43: 523-546.
- Sorbjan (1997) Decay of convective turbulence revisited, Boundary-Layer Meteorol., 82: 501-515.
- Nadeau et al. (2011) A simple model for the afternoon and early evening decay of convective turbulence over different land surfaces, Boundary-Layer Meteorol., 141:301-324
- Goult et al. (2010) On the time evolution of the turbulent for decaying turbulence in the convective boundary layer, Boundary-Layer Meteorol., 138: 61-75.

## Turbulence decay

### Whole BLLAST in one plot

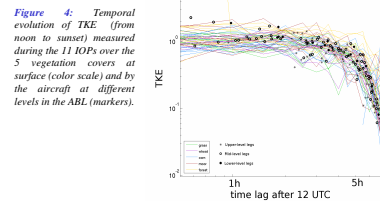


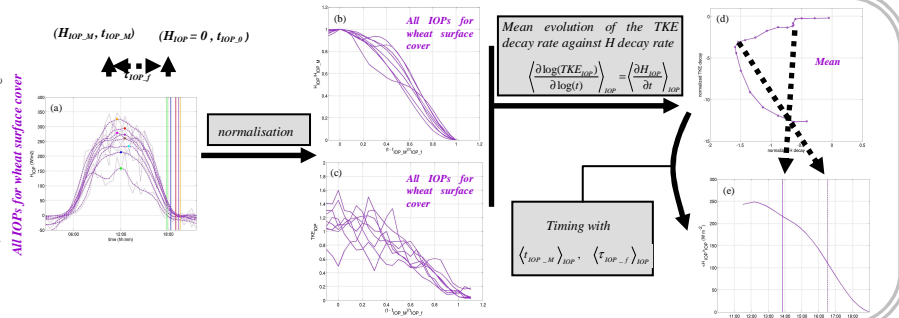
Figure 4: Temporal evolution of TKE (from noon to sunset) measured during the 11 IOPs over the 5 vegetation covers at surface (color scale) and by the aircraft at different levels in the ABL (markers).

- 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.

### Methodology

Figure 5: The sensible heat flux is used to calculate the forcing time scale  $t_f = t_{IOP,0} - t_{IOP,M}$  where  $t_{IOP,0}$  and  $t_{IOP,M}$  are the times at which  $H$  is maximum and equal zero respectively (Figure 2a).  $H$  and  $\log(TKE)$  are scaled in time (Figures 2b & 2c) and the temporal evolution of their decay rate is calculated. The averaged curve over IOPs of TKE decay against  $H$  decay shows three stages in the evolution (Figure 2d). The timing of these stages is rescaled in time using the averaged value of  $t_{IOP,0} - t_{IOP,M}$  over the IOPs (Figure 2e).



## 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 (it 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.

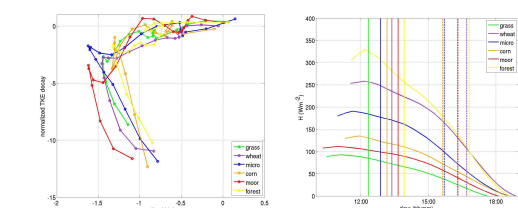


Figure 6: IOPs composite decay of TKE against IOPs composite decay of normalized sensible heat flux for the five different vegetation covers. Continuous and dashed vertical lines are respectively for the start of stage 2 and stage 3 of TKE decay.

**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, Remotely Piloted Aircrafts and turbulent measurement below tethered balloon have been performed and will enrich the analysis.

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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