14B.1 The Boundary-Layer Late Afternoon and Sunset Turbulence field experiment

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1. ISSUE

Growth of the CBL over land in the middle of the day has been extensively observed and relatively successfully modeled. However the late afternoon transition (LAT), like the morning transition, is difficult to observe and model due to turbulence intermittency and anisotropy, horizontal heterogeneity, and rapid time changes. There is a striking paucity of observations of the turbulence decay within the CBL, as well as a lack of realistic modeling studies.

This motivated the Boundary Layer Late Afternoon and Sunset Turbulence (BLLAST) 2011 field experiment, which aimed at enhancing observations of the LAT, so as to better understand the physical processes that control it, and elucidate the role of the LAT on mesoscale and turbulence scale motions, and on species transport.

1.1 Definition and scaling

The period that we are considering, which lasts several hours, starts as soon as the surface buoyancy flux begins to sharply decrease —this defines the late afternoon transition (LAT)—, and it covers the change of sign of the surface buoyancy flux in a slower evolution —which defines the evening transition (ET). Grimsdell (2002) showed that the LAT may start as early as 1300 LST, and on average around 1500 LST.

The definition of the convective boundary layer is put into question, since there is no consensus on what criteria to use. Surface layer, mixed layer, residual layer, nocturnal stable layer must be clearly defined within this context.

In daytime convective conditions, the Deardoff scaling is the base of a robust parameterization in bulk models. But during the afternoon transition, the surface buoyancy flux is small, and other small forcing processes come into play. The definitions of both the convective scaling and the stable boundary layer scaling are close to the edge during the transition period (Van Driel and Jonker, 2011).

1.2 Processes

1.2.1 Turbulence kinetic energy decay

The fundamental process of the turbulence decay is the first focus of BLLAST experiment. The TKE decay has been studied in a fairy large extent, especially with numerical studies (e. g. Monin and Yaglom (1975); Stillinger et al. (2010); Nieuwstadt and Brost (1986); Sorbjan (1997); Goulart et al. (2003)) or observations of the surface layer (Grant (1997); Fernando et al. (2004); Fitzjarrald et al. (2004); Brazel et al. (2005); Edwards et al.

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(2006)). The decay was usually studied in response to an idealized progressive or abrupt decrease of the surface heat flux. More recently, Nadeau et al. (2011) have considered realistic decrease of the surface sensible heat flux, based on observation. But most of the observational studies have focused on studying the decay of the turbulent kinetic energy in the surface layer, and the the decay of turbulence up to the top of the mixed or residual layer remains poorly documented.

1.2.2 The evolution of the lengthscales

There is also a lack of agreement and understanding on the evolution of the characteristic vertical velocity length scales during the LAT, partly due to the difficulty of observing and/or modelling this period, and to define those scales (Nieuwstadt and Brost (1986); Sorbjan (1997); Grant (1997)). Previous studies raised the assumption that the scales in the convective mixed layer and later in the residual layer increase with time because the smallest scales are decreasing faster (Pino et al. (2006)), and also a significant role played by the pressure correlation term in the TKE budget; but this has to be more thoroughly proved and explained.

1.2.3 Competitive forces

The decay of turbulence and the evolution of the characteristic lengthscales have to be related to the forcing conditions, not only to the surface heating decreasing rate, but also to competitive forces or processes generated by e.g. clouds, entrainment, radiation, shear and advection. Those processes are usually weak during the LAT, but all come into play.

(1) What is the role of the land-use and heterogeneity of the surface in the LAT dynamics? How do the heat storage and radiation come into play? Pardyjak and Fernando (2009) and Nadeau et al. (2011) have studied the turbulence decay over several types of surface and proposed a simple model for the decay in the convective surface layer. This model needs more confrontation to observations and the impact of the surface heterogeneity on the dynamics of the mixed or residual layer above needs to be considered.

(2) How does entrainment evolve? What is its role in the late afternoon transition? The numerical simulations of Pino et al. (2006) showed that the entrainment process is still active at the top of the residual layer.

(3) Radiation: Since the surface buoyancy flux is weak, radiation can have a relatively significant contribution during this phase, both at surface and at the top of the mixed layer.

(4) Other important processes will be considered: How does this transition impact on the anabatic flow / katabatic flow transition ? What is the interaction between the mixed layer and the waves that can develop in the stable layers below and above it? What is the role of shear? Do clouds modify the evolution of the turbulence and of its characteristic scales?

1.3 Global strategy

Those issues motivated a dedicated field experiment that would focus exclusively on the afternoon transition, with densification of complementary observations in time and space from the mid-afternoon to the night. Closely attached to the field experiment, numerical studies are carried out with various types of models that enable us to further interpret the observations and test our hypotheses:

(1) forecast models, for their testing on this issue and their improvement if necessary (see contribution 14B.4 by Couvreux et al. (2012));

(2) mesoscale simulations, for the understanding of the large scale circulation and forcing within which the convective boundary layer develops, and for the test of the boundary layer parameterizations;

(3) 1D mixed layer model for the understanding of fundamental processes (see contribution 14B.2 by Pietersen et al. (2012));

(4) large eddy simulation, which are able to resolve the large eddies down to a few m of resolution (see contribution P23 by Blay et al. (2012)).

2. THE FIELD EXPERIMENT

The 2011 BLLAST field campaign took place in early summer, from 14 June to 8 July 2011 in France, near the Pyrénées Mountains. The site is called “Plateau de Lannemezan”, a 600 m height plateau of about 200 km^2 area, nearby the Pyrénées foothills (Fig. 1). The surface is covered by heterogeneous vegetation: grasslands, meadows, crops, forest (Fig. 2). The campaign combined in situ measurements made with towers, balloons and airplanes with the remote sensing capability. The measurements were intensified during the late afternoon transition, during the days with favorable conditions, typically called Intensive Observing Periods (IOP). Two sites (hereafter sites 1 and 2) concentrated most of the ground-based instruments and intensive flying over operations. They were mainly associated with two different observational strategies: (1) vertical structure and (2) spatial heterogeneity, respectively. A third site (site 3) was used for the covering of the 3D circulation.

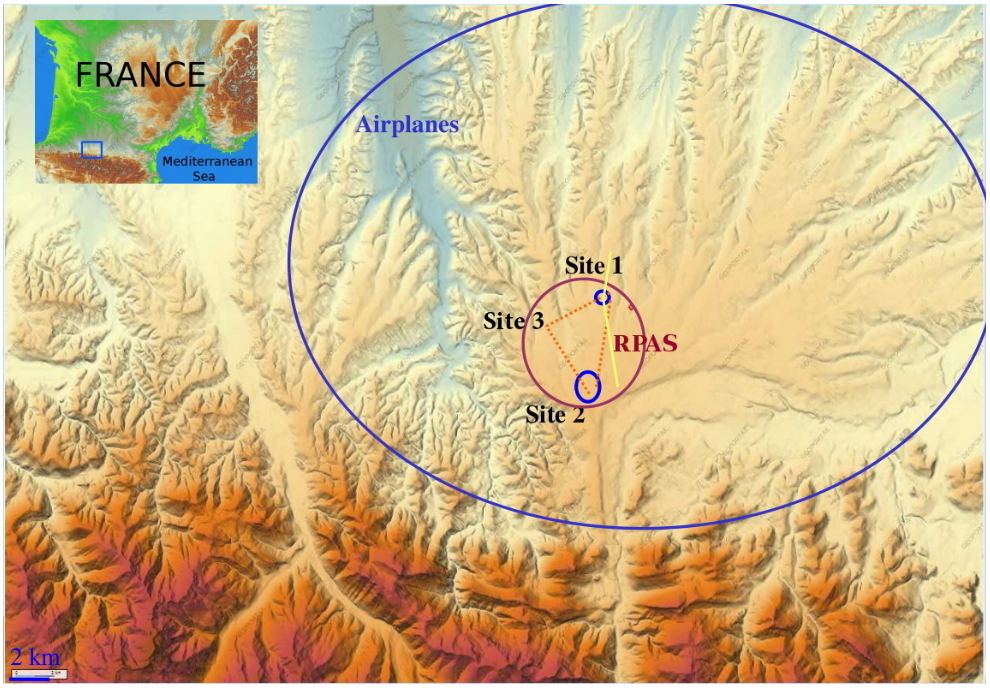

Figure 1: *Experimental area. The large blue circle delimits the exploration area of the manned aircraft, and the smaller purple circle indicates the Temporary Restricted Area (TRA) for the operation of the Remotely Piloted Aircraft Systems (RPAS). The orange dotted triangle locates the profiler network, and the yellow lines represent the paths of the two larger aperture scintillometers used. The mountain ridge south of the experimental area is about 1800 m a.s.l.*

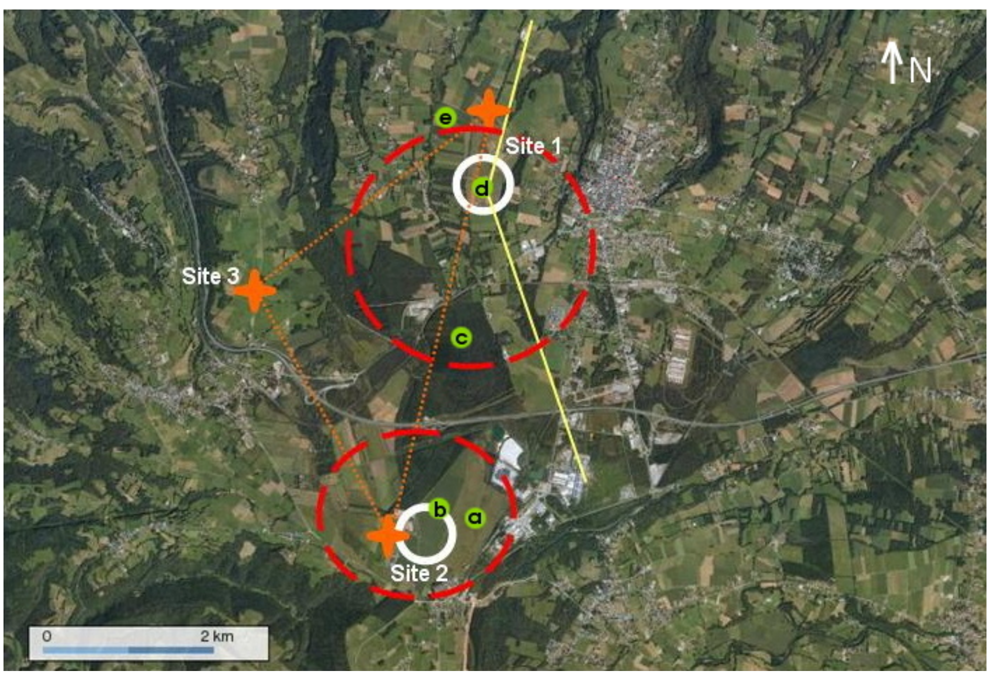

Figure 2: *Satellite view (from Google Earth) of the area, showing the instrumented site locations. Letters (a) to (e) refer to surface stations over various surfaces: (a) moor, (b) corn, (c) forest, (d) prairies, 60 m tower, (e) wheat, grass and edge. As in Fig. 1, the orange dotted triangle indicates the profiler network, and the yellow lines represent the paths of the two larger aperture scintillometers.*

2.1 Continuous observations

2.1.1 Boundary layer profiling

During the entire period of the field experiment, continuous vertical monitoring of the wind within the boundary layer was accomplished with a combination of sodar UHF (Ultra High Frequency) and VHF (Very High Frequency) profilers. Both the UHF and the sodar profiling systems can also measure some characteristics of the atmospheric turbulence. The UHF wind profiler also gives estimates of the height of the mixed boundary layer top inversion, or of other strong vertical gradients in the atmosphere. A sodar, a UHF and a VHF profilers were especially concentrated at site 1, in order to cover and monitor the whole atmospheric column. In addition, a network of 3 profilers deployed over the three sites 1, 2, and 3 was bound to estimate the 3D wind at the scale of the Plateau.

Two aerosol lidars deployed over each of site 1 and site 2 monitored the aerosol backscatter structure continuously during BLLAST, providing complementary information about the vertical structure of the atmosphere. A Doppler lidar was operated at site 1, which supplies the wind vertical velocity statistics (see contribution 14B.6 by Gibert et al. (2012)).

The sky conditions were monitored with a full sky camera at site 1 that took pictures of the entire sky every one min, for qualitative monitoring of the cloud cover. A ceilometer was collocated with the full sky camera, for a quantitative monitoring of the cloud base height.

2.1.2 Surface characteristics and heterogeneity

During the BLLAST experiment, 9 masts were equipped with a total of 26 instruments measuring turbulence. Wind components, temperature, water vapour content and CO_2 concentration were measured at high frequency on each of them. The first aim of those stations was to provide a thorough description of the fluxes in the heterogeneous landscape of BLLAST experiment, which are integrated in the airborne or scintillometer measurements. Beyond this purpose, most of the surface stations were implemented with other dedicated objectives:

- At site 2, EC-stations sampled three contiguous large areas (about 1-2 km long) with relatively homogeneous vegetation: corn, moor and forest. They were specifically dedicated to the study of the role of surface heterogeneity (see Pardyjak et al. (2011) and contribution P25 by Darbieu et al. (2012b)).
- The so-called "Small Scale Heterogeneity site" (SSH) at site 1 was focused on small-scale surface heterogeneities study. Over a 150 m square flat surface, covered with a mix of bare soil, small bushes, grass, and small puddles constitute a very heterogeneous surface whose soil characteristics (temperature, humidity) was extensively mapped.
- The so-called "Divergence site" composed of two 10 m-tower equipped with respectively 6 sonic anemometers, 6 fast response fine-wire thermocouples and 6 long-wave radiation sensors at the exact same levels. The aim of this set-up was to investigate near-surface long-wave radiation and sensible heat flux divergence, as well as the formation of extremely thin flows (Manins and Sawford (1979); Mahrt et al. (2001)).
- At the so-called "Edge site", a set-up of three masts, all equipped with sonic anemometers and fast water vapour and CO_2 sensors, was used to to investigate Monin Obukhov Similarity Theory (Monin and Obukhov, 1954) over a heterogeneous terrain by using a flux-footprint model (Van de Boer et al. (2012)). Two stations were set up into a grass and a wheat field respectively, and the third station was located at the edge between both (see contribution 8.6 by Van de Boer et al. (2012)).
- The 60 m tower at site 1 is a permanent platform of the site which provides year-round turbulence measurements at three levels. At the top of the tower, a high resolution IR camera pointed either toward the Divergence site, or toward the SSH site (see contribution 14B.3 by Garai et al. (2012)).

In addition to the in situ measurements made from the ground stations, scintillometers were used during BLLAST. They provided an integrated measurement of surface fluxes, over the heterogeneity regions interrogated by the set of surface stations mentioned previously. Three scintillometers were deployed during BLLAST, with three different pathlengths: 40 m, 3 km and 4 km.

Finally, three microbarometers were deployed at site 1 close to the SSH site, one at each vertex of a 150-m per-side triangle, 1m a.g.l. These high precision digital instruments can detect very small pressure perturbations, of the order of thousandths of hPa, at 2Hz sampling frequency. The objective was to study the small scale static pressure fluctuations produced in the atmospheric boundary layer, which can be due to turbulent motions and also to the propagation of waves of different types (see contributions 14B.5 by Sastre et al. (2012) and P28 by Román-Cascón et al. (2012)).

2.2 Intensive observation periods (IOP)

When the conditions were favorable, intensive observations were made with two manned aircraft, RPAS, tethered and radiosounding balloons, and in situ aerosol

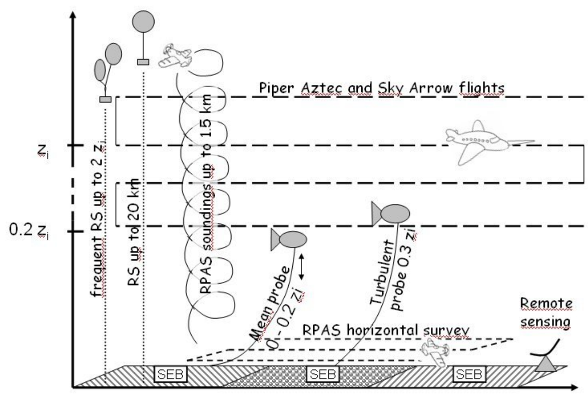

Figure 3: *Sketch of the observing strategy. RS = Radiosounding, RPAS = Remote Piloted Aircraft System.*

measurements. The potential favorable conditions were clear sky or fair weather cumulus during the afternoon and evening transitions, with light to moderate winds. Those correspond to anti-cyclonic conditions, post-frontal conditions, low pressure gradient conditions,... Over the 3.5 planned weeks of field campaign, there was a total of 12 days of favorable conditions (that is 12 IOP), including a test IOP0 on the first day. During the IOPs, the aircraft, the RPASs and the balloons were deployed intensively. Fig. 3 gives a skematic overview of the observing strategy during the IOPs, from the various systems that are described below in more details.

2.2.1 Balloons

Radiosoundings

The radiosoundings remain the reference for absolute measurements of the wind, humidity and temperature along a vertical profile of the atmosphere. A total of 67 standard MODEM and GS-H radiosondes were launched from site 1 during the IOP days at least 4 times per day at 6, 12, 18, 24 UTC, and assimilated by the Météo-France forecast models.

At site 2, a new technique was used for frequent soundings of the lower troposphere only, during the LAT. Two radiosounding balloons were simultaneously released and allowed to ascend up to about 2 km height at which time the sounding package was separated from the larger balloon and allowed to safely parachute to ground for multiple uses per package. The time interval between two soundings was 1 hour or 1.5 h. A total of 62 soundings were made with this technique, with 80% radiosonde retrieval rate.

Tethered balloons

There were 3 tethered balloons (one at site 1 and two at site 2) operating during the late afternoon of IOP days.

One balloon was equipped with one newly developed turbulence probe, operated at site 1. The probe was flown at a fixed height, generally a few hundred meters above the ground, filling the gap between the 60 m tower and the aircraft, and giving a reference for the less validated RPAS measurements.

Two other tethered-balloons were operated on site 2, over the corn field and the moor field, with up to 5 probes hanged at different levels, which measured the mean meteorological variables. Most of the time, the balloons alternatively sampled the air at a fixed low height and profiled the first 150 m. The goal was to evaluate the impact of the surface heterogeneity on the surface layer vertical structure. An example of their observations is given in Fig. 4, which nicely shows the LAT and ET from the temperature close to surface, with especially the inversion of the temperature gradient that occurs quite late in the day (slightly before sunset), and the very small temperature fluctuations observed during the LAT, compared to midday or night.

2.2.2 Aircraft

Two aircraft were chosen to contribute to BLLAST: The French Piper Aztec from SAFIRE (see Saïd et al. (2005)), and the Italian Sky Arrow from Ibimet and Isafom (Gioli et al. (2009)). The Sky Arrow participated to the campaign from June 14 to June 26 (16 flights), whereas the Piper Aztec was on field for the entire period (22 flights performed). Both aircraft measured pressure, temperature, moisture, CO_2 concentration and 3-D wind with a spatial resolution of 1 m for the Sky arrow and a few meters for the Piper Aztec.

The aircraft mainly flew in the middle-to-late afternoon. The flight plans were drawn to capture horizontal heterogeneity, vertical structure, size of the eddies and their (non-) isotropy, and time evolution. They were generally built on stacked runs in vertical planes and spiraling profiles. In addition, simpler patterns like flying a single repeated track for a large number of passes to maximize the statistics was also considered. The two aircraft were flying either one after the other in order to entirely cover the afternoon from midday to after sunset; or together during the same period, in order to have a better and simultaneous spatial covering.

2.2.3 Remotely piloted aircraft systems

RPAS have in the recent years shown their capability to probe the atmospheric boundary layer (e.g. Martin et al. (2011); Reuder et al. (2006)). For corresponding RPAS operations during the BLLAST campaign, a Temporary Restricted Airspace (TRA) was issued and activated daily

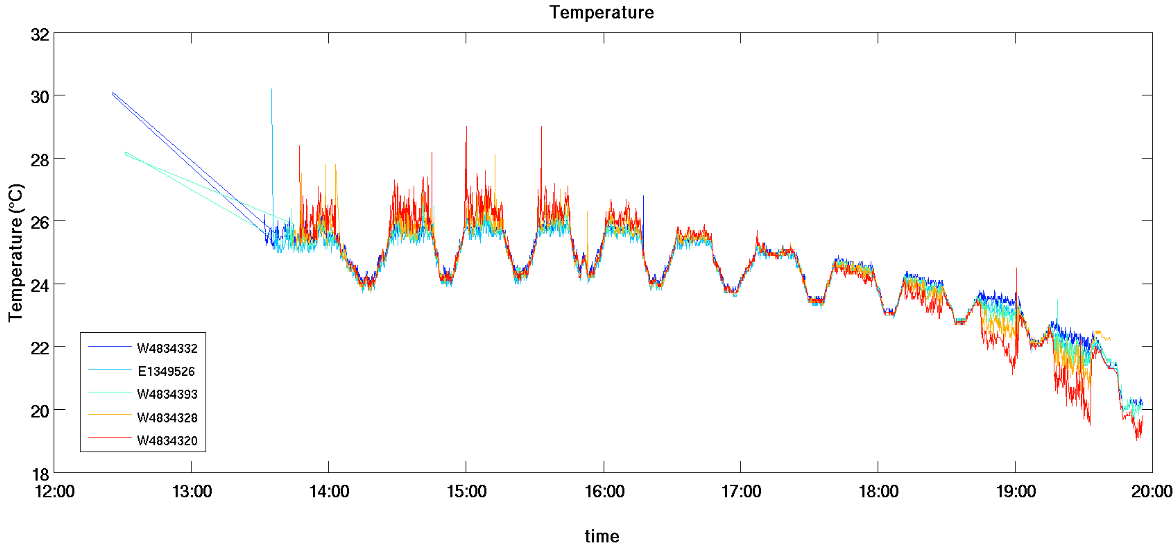

Figure 4: *Temperature observed by the 5 probes hanged on one of the tethered balloon over moor at site 2, during IOP 11 (5 July 2011). This figure shows (i) the decrease of mean temperature during the late afternoon and sunset, (ii) the inversion of the temperature gradient close above the surface, (iii) the decrease of the turbulence observed during the late afternoon transition until the nocturnal downslope wind brings new turbulence again.*

from 5:00 to 21:30 UTC. The TRA covered an area of 4 km radius including sites 1 and 2 with an upper limit of 1.6 km a.g.l. Table 1 lists the RPAS that flew, and acquired data of interest for BLLAST.

The small RPAS SUMO was mainly used for frequent profiling up to the top of the TRA and for low level (typically 60-80 m above ground) surface temperature mapping surveys. Figure 5 shows an example of one of those surveys over site 2. In addition, nearly 50 of the SUMO flights were performed with a newly integrated turbulence measurement system on board, based on a five-hole pressure probe (Reuder et al. (2012)). M2AV Martin et al. (2011) and MASC are suited for flying km-scale level legs with high-rate measurements of wind components, temperature and humidity fluctuations (Van den Kroonenberg, 2011).

The other RPAS only participated during the last 2 weeks of the field campaign. These adjunct operations were performed as a RPAS test and sensor intercomparison event organized by the European COST Action ES0802 Unmanned Aerial Systems in Atmospheric Research. In this context, the SIRUS I system provided very high-resolution (around 1 cm) visible images of the BLLAST sites. Multicopters operations were performed at the MSH site close to the 60 m tower. They provided fine-scale 3D data sets of temperature and humidity in the surface layer from only a few m above ground up to about 100 m.

Table 1: RPAS which participated to the BLLAST field experiment. PTUV = Pressure, Temperature, Humidity, Wind, LR = Low rate, HR = High-rate.

Airframe	University	Weight	Meas. var.
SUMO	Bergen	0.6 kg	LR PTUV
			HR wind
M2AV	Braünschweig	5 kg	HR wind, TU
MASC	Tübingen	5 kg	HR wind, TU
Octocopter	Lipp	1 kg	LR TU, ST
Quadrorotor	Bremen	0.45 kg	T, ST
Sirius I	Heidelberg	2.7 kg	HR surf. imagery
Funjet	Reading	0.6 kg	Radiation
			Electrical charge

2.3 Dataset

During the field experiment, a field catalog (http://boc.sedoo.fr) was supplied with quick looks of the continuous measurements and IOP observations, reports, model forecasts, analyses, and satellite images. The BLLAST web site (http://bllast.sedoo.fr) presents the project and gathers the documentation, presentations, field catalog and gives access to the data and metadata. The dataset will be firstly reserved to BLLAST

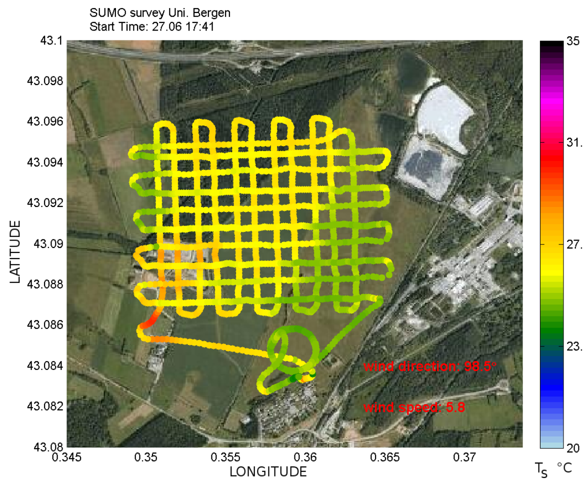

Figure 5: *Surface temperature observed by the RPAS SUMO during an exploration survey 60 m above ground at site 2, around 17h40 UTC on 27 June 2011 (IOP 7).*

participants until 30 June 2013, unless an agreement is reached with the principal investigator of a specific instrument dataset. Starting 1st July 2013, the BLLAST dataset will be opened to all.

3. Preliminary results

3.1 Surface heterogeneity

As seen before, various surfaces have been instrumented with eddy-correlation stations, in order to measure the surface fluxes and turbulence all along the day over the variety of vegetated covers found in the area. For consistency, the data of all stations have been processed with the same algorithm, called EC-PACK (Van Dijk et al. (2004)). The turbulent moments have been calculated over 5 min, 10 min and 30 min samples.

An overview of the sensible heat flux observed over 6 different surfaces and at the top of the 60 m tower is given in Fig. 6. Surface sensible flux varied a lot from one surface to the other. The largest fluxes were observed over the forest (300-400 Wm^{-2} at midday) and the wheat (150-350 Wm^{-2} at midday). The smallest flux were observed over the grass and the wet moor (30-130 Wm^{-2} at midday). The flux at 60 m high measured intermediate fluxes, which is consistent with the fact that at this height, the flux is the result of the contribution of several types of vegetation surfaces. The fluxes also varied from one IOP to the other, larger on IOPs 1-2 and 8-9-10 and 11 (post-frontal and anti-cyclonic conditions), than on IOPs (5-6-7) when warm air occupied the entire troposphere, and lead to very small sensible heat fluxes.

The wind at surface was generally weak, with 10 min average smaller than 4 m s-1 and daily average smaller than 2 m s-1 for most of the IOPs. The typical nocturnal downslope wind from the mountain was very common during the night. During the day, either the north-easterly upslope wind, or weak zonal winds were observed.

3.2 Vertical structure

During the field experiment, the vertical structure of the low troposphere was densely probed, in order to catch its rapid evolution, as well as spatial variability. As an example, we discuss here the vertical structure observed during IOP 9, on 1st of July 2011.

With the soundings from balloons, aircraft or RPAS, and with the remote sensing continuous boundary layer profiling, a very dense observation of the vertical structure was made. Figure 7 shows the combination of the observations of the ceilometer, the aerosol lidar and the UHF wind profiler of site 1 on 1st of July 2011. In addition, vertical profiles of potential temperature measured by the frequent radiosondes launched from site 2 during the afternoon are shown in Fig. 8. They were completed by soundings by the SUMO and standard radiosoundings all along the day.

Winds in the boundary layer were moderate mostly north-easterlies during the daytime, which is the typical plain-mountain circulation wind in the location. Westerly winds were observed in the free atmosphere during the whole day (Fig. 7d).

From the local maxima of the reflectivity (Fig. 7c), one can deduce mixed layer top inversion, or later, the residual inversions, or other irregularities linked with wind shear or humidity gradient. Large vertical gradients of aerosol can also be detected by an aerosol lidar (Fig. 7a). Those two information are gathered in Fig. 7. They match very well from the morning to midday, showing similar mixed layer growth. Around 1400 UTC, they start to differ, the aerosol layer top staying 100 or 200 m higher the humidity and turbulence gradient caught by the wind profiler.

The convective boundary layer grew rapidly in the morning until it reached a clearly defined residual top inversion around 1200 m at 1000 UTC (the temperature and humidity gradients were about was about 6 K and 6 g kg-1 across the inversion). From then, the boundary layer hardly increased despite the large surface fluxes observed at the two sites. This could be explained by large-scale subsidence that likely affected the area during this day. The radiosoundings of 0300 and 0730 UTC (not shown) reveal a 3 cm s^{-1} fall of the residual inversion the night before. But the UHF maximum reflectivity generated by this inversion, as well as the top of the aerosol layer detected with the aerosol lidar, shows that this fall varied a lot along the previous night (see Fig. 7). A care-

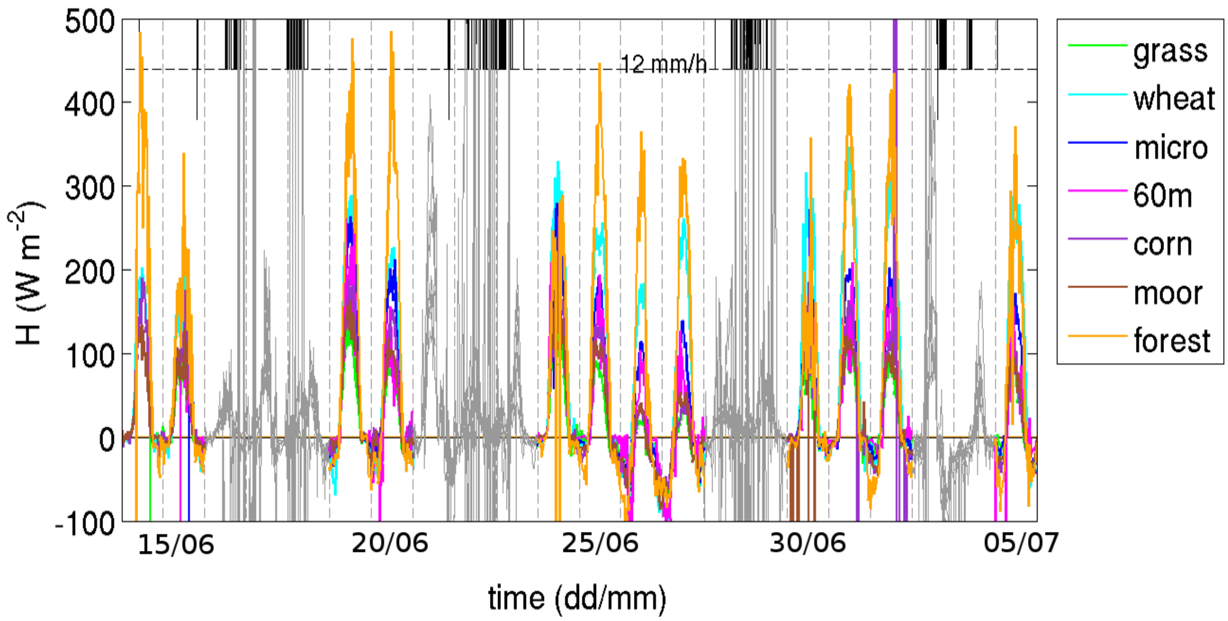

Figure 6: *Sensible heat flux at surface over the various surfaces. Precipitation is added on the top of the graph.*

ful attention will be paid to the estimates and role of the large scale subsidence during BLLAST (Pietersen et al. (2012)). According to the soundings of site 2 (Fig. 8), the surface layer started to stabilize around 1800 UTC.

The development of the boundary layer described for this day, including the large inversion, and the departure between the aerosol layer top and the UHF reflectivity gradient in the afternoon or late afternoon, was similar during several other IOPs. Numerical simulations made with a mixed layer model and a large-eddy simulation have been made for this case and revealed the importance of the large-scale subsidence (see contribution P23 by Blay et al 2012). This day was selected for a complete numerical model hierarchy approach: forecast, meso-scale, and large-eddy simulation models.

3.3 *Turbulence decay*

The turbulence decay is one of the main focus of the analyses of BLLAST data (see contributions P25 by Darbieu et al. (2012b) and 14B.6 by Gibert et al. (2012))). Here we give examples of decay observed at the surface and above.

Figure 9 shows the turbulent kinetic energy decay observed over 5 different surfaces and above, from surface stations and aircraft, for the 1st of July (IOP 9). It shows that this decay varies from one surface to the other. Consistently with what Nadeau et al. (2011) found, the forest has a late but abrupt decay, while the decay starts earlier over moor. This is closely related to the surface energy budget, with more storage in canopies over forest and

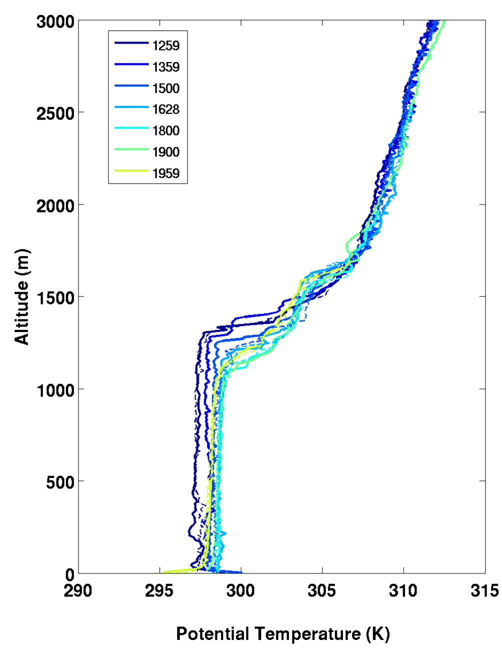

Figure 8: *Vertical profiles of the potential temperature measured by the radiosondes launched at site 2 on 1st July 2011.*

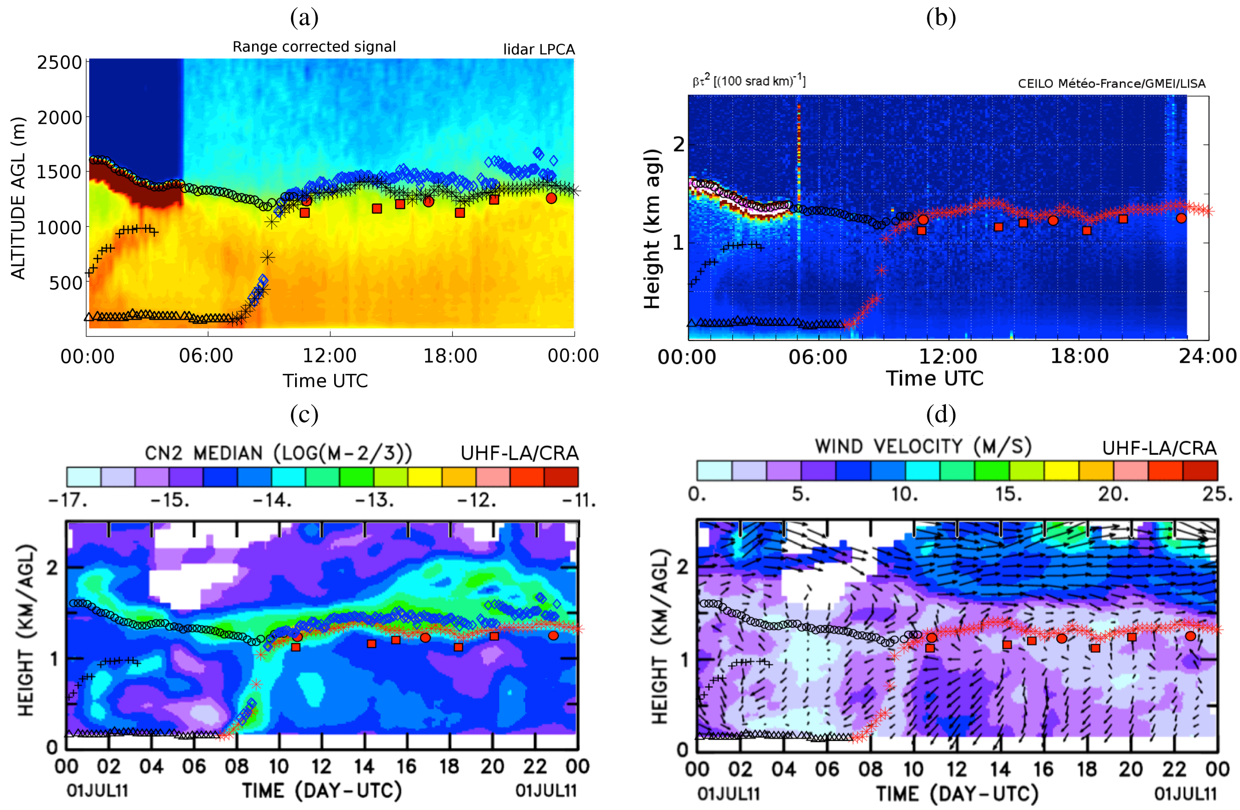

Figure 7: *Stratification as seen by remote sensing during IOP 9 (1st July 2011) at site 1: (a) Aerosol lidar measurements, (b) Ceilometer measurements, (c) C_n^2 measured by UHF wind profiler; (d) Mean horizontal wind measured by UHF wind profiler. In each panel, the estimate of the mixed layer (and later residual layer) height based on (∗and ∗) the aerosol lidar backscatter, (◊) UHF reflectivity, (●) radiosoundings and (■) RPAS SUMO are indicated. The aerosol layer defining the previous nocturnal layer is also indicated (△).*

corn.

This figure also shows in some ways the two regimes of the decay that were put into evidence by Nadeau et al. (2011): a slow decay first (during the LAT), and an abrupt decay after (during ET). But Darbieu et al. (2012b) showed how the power-law coefficients vary from one surface to the other, or from one day to the other.

That day, the Piper Aztec aircraft probed four stacked legs four times in a row during two flights. It is the first time that such in situ observations of the turbulence decay within the upper part of the boundary layer are made. Those measurements show that the TKE decay process for that day seems to be very similar in the mixed layer than close to surface. This is somehow consistent with the results of Nadeau et al. (2011) who were able to model the decay observed in the surface layer with a model based on a mixed-layer based parameterization, rather than with a surface-based parameterization. However, this is put into question by the TKE budget analysis made by citetgibe12, based on Doppler lidar measurements. Smaller scale turbulence was observed close to the top, and larger turbulence in the middle of the mixed layer (Fig. 9), consistently with thermally-driven boundary layer.

This graph is classically normalized, with the initial (midday) convective velocity and time scales. The decay slope is found to be a function of the way the surface heat flux is itself decreasing (Darbieu et al. (2012b)). BLLAST dataset should help to verify and better understand this link, and its dependence on the synoptic forcing or surface conditions. The usual scaling (Deardoff scaling taken at noon or starting time of the decay) gets close to the edge of validity (see contribution P24 by Darbieu et al. (2012a)), and this dataset will help finding new scaling laws, that would be robust through the afternoon and evening transitions.

Preliminary analysis of the decay observed as a function of the synoptic conditions reveals the role that wind shear might play in delaying the abrupt decay phase (Alexander et al. (2011)). Further work will be made to connect the decay mechanism with the evolution of the boundary layer main forcing processes. In this context,

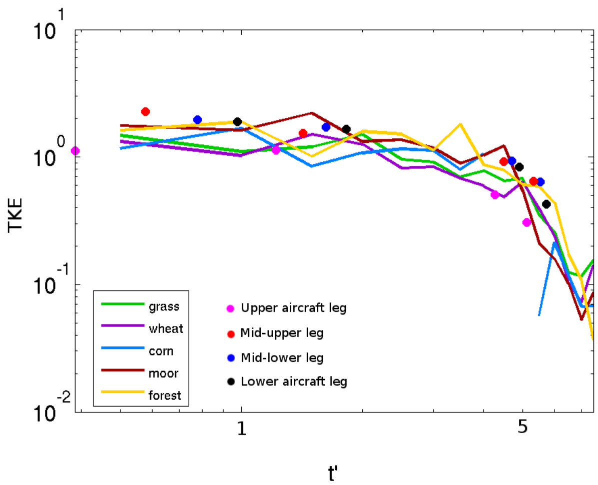

Figure 9: *TKE decay observed over 5 different surfaces during IOP 9 (1st July). Note that a logarithmic scale is used. t' is the time delay from 1200 UTC, in hours.*

other turbulence quantities should be investigated as well, including spectral estimates of length scales.

4. Conclusions

One of the main strengths of BLLAST is its focus on a well-defined issue: turbulence decay during the afternoon over land. Added to this the very large collaborating efforts that enabled to gather almost all the observational platforms that are useful for the probing of the PBL, as well as a complete hierarchy of modeling tools, it turned out to build a very rich dataset for the study of the turbulent processes which occur during the LAT, through the 12 days of Intensive Observation Periods. Especially, the frequent soundings of the atmosphere, with various techniques, allowed us to get a fine description of the rapid evolution or the vertical structure of the low troposphere. The numerous and complementary in situ and remote sensing observations of turbulence give an unprecedented exploration of the turbulent kinetic energy decay during the LAT, and should enable us to make one step further in the understanding of this process. We will also know better whether this phase of the diurnal cycle rises crucial difficulties for the forecast models.

The combination of manned and unmanned aircraft, together with numerous remote sensing systems and in situ techniques, each with different capabilities, enable the interested community to (i) test and validate new sensors and techniques, (ii) gain a critical insight into (old and new) techniques through redundancy, and (iii) participate in the process studies of the LAT.

In general the coordinated operation of manned and unmanned aircrafts was scientifically very successful. The main issues in the RPAS operation were not related to technical but to regulatory challenges. This is mainly due to the fact that corresponding rules and regulations for small RPAS below around 30 kg to be handled nationally by the Civil Aviation Authorities, are still under development or only recently established. Therefore, there is a clear lack of practical experience in the application and approval process. The BLLAST campaign contributed to opening the door to future RPAS-manned aircraft integrated experiments.

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