Measurement of the structures and processes in the atmospheric boundary layer during the late-afternoon transition using the recently developed research UAV ’MASC’, including the comparison with other UAV organised in COST Action ES 0802

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1 Introduction

1.1 The project

The overall goal of the project is the observation and understanding of the atmospheric boundary layer (ABL) structure and processes above a heterogeneous and hilly land surface during the late afternoon / early evening, when the transition occurs between the daytime convective ABL and the night-time stable ABL. While these latter two regimes have been extensively studied over decades, the late-afternoon transition (LAT) is much less understood. It is characterized by strong non-stationarity and a delicate balance of various thermodynamic processes like surface cooling and moistening, wind shear, subsidence, entrainment, and the decay of turbulence. The project was a contribution to the international BLLAST (Boundary Layer Late Afternoon and Sunset Turbulence) initiative launched by the Laboratoire d'Aerologie (Toulouse) to stimulate LAT research. This initiative brought together scientists from France, Spain, the Netherlands, Germany and the USA. Moreover, during the BLLAST field campaign, a scientific comparison of research UAVs of institutions that are member of the COST Action ES 0802, including their on-board sensors, was strived for.

Figure 1: *Participating UAVs at BLLAST field campaign: University of Tuebingen - MASC, University of Braunschweig* - M^{2}AV*, and University of Bergen - SUMO (from left)*

1.2 The UAV

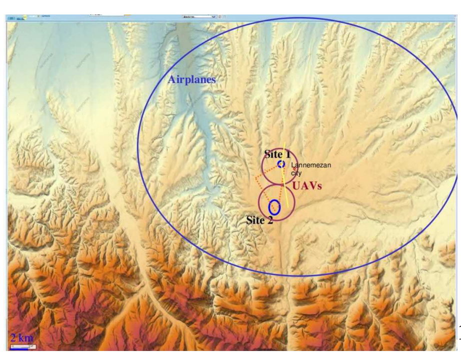
Figure 2: *MASC*

The research aircrafts of type 'multi-purpose automatic sensor carrier' MASC are electrically powered twin-engined research UAV that operate automatically (i.e. without remote control) at 20 m/s mission airspeed. The weight of a MASC is about 5 kg including a 1.5 kg scientific payload, that can easily be substituted by other sensor containers. The standard meteorological measurement container consists of fast in-situ sensors for temperature, humidity and wind vector, sampled by a board computer at 100 Hz, providing a 30 Hz resolution after anti-aliasing filtering (corresponding to a sub-metre measuring point resolution at 20 m/s airspeed). Position, ground speed and attitude of the aircraft are measured using GPS and inertial measurement unit.
The sensors are positioned far enough in front of fuselage and propellers, so that the airflow will not be disturbed, which can be a major issue for the measurement of turbulent flows in the atmosphere.

1.3 The location

The location where this short term scientific mission was carried out was the area surrounding the Center for Atmospheric Research in Lannemezan, France. The BLLAST homepage states the following about the location:

"The site is called 'Plateau de Lannemezan', a plateau of about 200 km2 area, nearby the Pyrénées foothills, at equal distance from the Mediterranean sea and from the Atlantic ocean (about 200 km), and aligned with a main S-N oriented valley which starts to the south ('Vallée d'Aure'). The surface is covered by heterogeneous vegetation: grasslands, meadows, crops, forest." [1]



[1]

Figure 3: *Topographic map of the measurement sight of the BLLAST campaign*

[1] taken from: http://bllast.sedoo.fr/campaigns/2011/introduction/area_time_frame.php, accessed on 20.07.2011

2 Measurements

There were two main goals for this campaign:

1. Gather first experience with measuring turbulent flux with the newly developed MASC UAV

2. Compare sensors with other groups of the UAV community

Table 1 shows a list of all flights that were done during the time of the scientific mission.

no.	Date	CEST	MASC	measuring unit	mission
1	20.06	10:31	1	MC 1	measuring flight 1
2	20.06	12:20	1	MC 1	measuring flight 2
3	20.06	15:54	1	MC 1	measuring flight 3
4	21.06	11:00	2	Dummy	RC flight
5	23.06	12:00	2	Dummy	test flight
6	24.06	10:36	1	MC 1	measuring flight 4
7	24.06	12:20	1	MC 1	measuring flight 5
8	24.06	20:56	1	MC 1	measuring flight 6
9	25.06	12:20	2	Dummy	test flight
10	25.06	19:37	1	MC 1	measuring flight 7
11	25.06	20:18	1	MC 1	measuring flight 8
12	26.06	18:14	1	MC 1	measuring flight 9
13	27.06	8:39	1	MC 1	measuring flight 10
14	27.06	20:00	2	Dummy	test flight
15	30.06	10:00	2	Dummy	test flight
16	01.07	10:00	1	Dummy	test flight
17	01.07	20:00	1	Dummy	test flight
18	02.07	8:30	1	Dummy	test flight
19	02.07	10:05	1	Dummy	test flight
20	02.07	13:15	1	Dummy	test flight
21	02.07	17:30	1	Dummy	test flight
22	02.07	21:00	1	Dummy	test flight
23	04.07	20:30	1	Dummy	test flight
24	05.07	11:00	1	Dummy	test flight
25	07.07	13:08	1	MC 2	measuring flight 11

Table 1: *Flight log*

In the following the measuring strategies will be discussed and a first view on the gathered data will be presented.

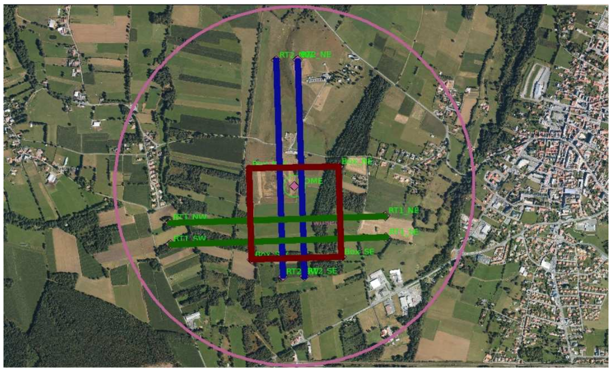


Figure 4: *Flight plan for turbulent flux measurement flights*

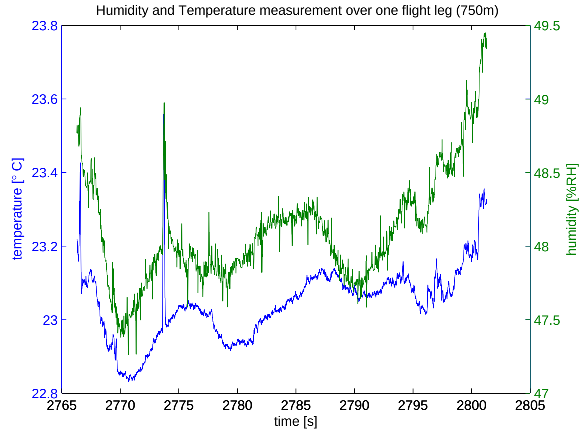


Figure 5: *Measurement of temperature and humidity across one east-west flight leg*

2.1 Turbulent flux measurement

To measure the flux of momentum, heat and humidity, ideal measuring flights are long, straight flight legs at constant speed and several altitudes. With a constant logging rate, an evenly distributed spatial grid of measuring points can be collected that will make it possible to show eddies through many length scales. A flight plan that is designed for this purpose can be seen in figure 4.

As can be seen in eleven actual measuring flights could be performed during the campaign, of which eight resulted in data that still has to be analyzed in detail. Many test flights were performed trying to improve the overall flight characteristics of the UAV. A couple of problems with the aircraft and the sensor system, as well as bad weather periods made it difficult to do more and extended flights.

If the data can scientifically benefit the BLLAST campaign is still to be evaluated. Eventually some data fusion has to be done in post-processing to get more valuable data.

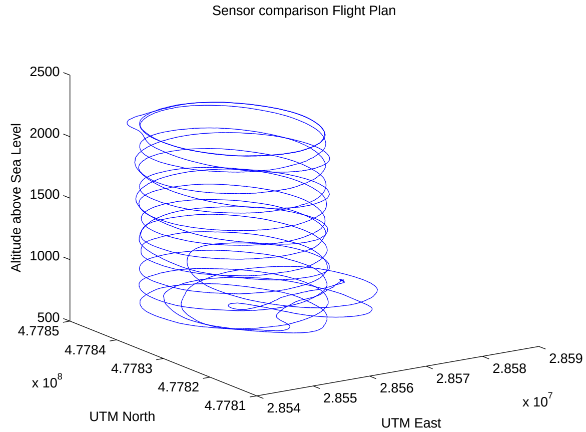


Figure 6: *Flight plan for sensor comparison flights.*

2.2 Temperature and humidity sensor comparison

One big issue in airborne meteorology, especially using UAVs, is to find lightweight sensors that are fast enough to deliver an accurate representation of the physical measurement value at the location where the UAV is currently positioned. Slow time responses of sensors will lead to delayed response to spatial changes in the atmosphere and therefore to inaccurate measurements. The highest requirements for fast sensors are surely given in the measurement of turbulent flow, where the possible length scale that can be resolved is directly dependend to how quickly the sensor reacts. But also in vertical profiling, sensor delays lead to inaccurate measurements. There are different methods to correct for these errors, but despite that, the error can still be decreased with faster sensors. The methods to correct for time delays in vertical profiles are also helpful to determine the sensor's characteristic time response. As a side project to the BLLAST campaign, a few COST members agreed to use the SUMO UAV of the University of Bergen to test several sensors, calculate the time responses and compare the results. Figure 6 shows the flight plan that was used to take vertical profiles of the atmosphere. Ascend and descend are helical paths from ground level (600 m above sea level) to 2200 m above sea level and back.

P14Rapid vs. SHT75 comparison

First sensor comparison was made with the capacitive humidity sensor P14 Rapid by Innovative Sensor Technologies, Switzerland. The datasheet states a step response t_{63} of $< 1.5\ s$ falling edge. The capacitance is measured with the capacitance-to-digital converter Picocap01 by ACAM messelectronic GmbH. The capacitance measurement board is also equipped with a PT1000 temperature sensor which can be compared to the SHT75 temperature values. In this setup, the capacitive humidity measurement is not temperature compensated. The P14 Rapid reacts faster to humidity changes than the SHT75, like predicted. At the very top height that was reached (about 2200m above sea level) the hysteresis of the P14 Rapid is almost neglectable, which is a strong indication for a very short time response. Further investigations on the actual time response are still to be done. The difference in humidity between ascend and descend is, especially in the boundary layer, rather big, which is possibly due to the meteorological

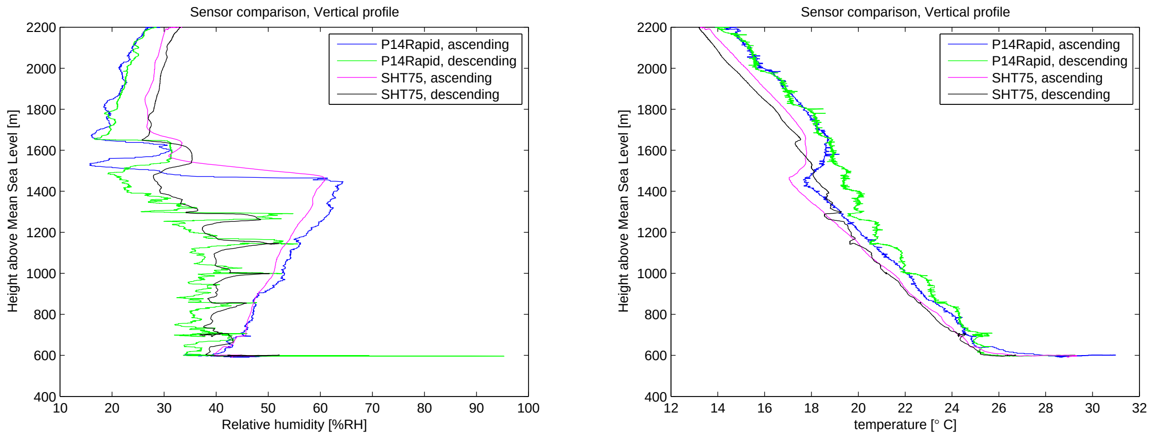


Figure 7: *Vertical profiles of humidity (left) and temperature (right) taken with two different sensors (Acam PicoCap01, equipped with IST P14Rapid and a PT1000 compared to the temperature/humidity sensor Sensirion SHT75*

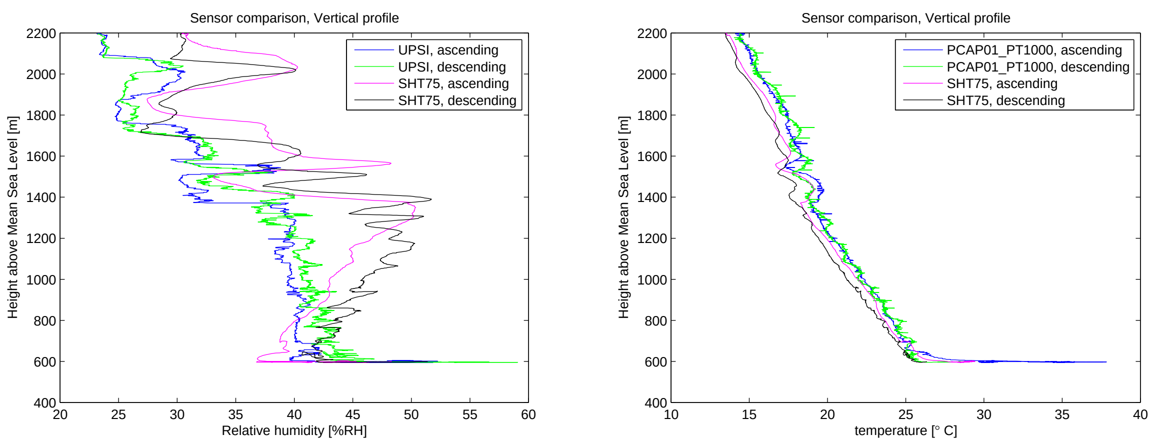


Figure 8: *Vertical profiles of humidity (left) and temperature (right) taken with two different sensors (Acam PicoCap01, equipped with IST P14Rapid and a PT1000 compared to the temperature/humidity sensor Sensirion SHT75*

situation. The peaks in descend that can be seen in both sensors are probably due to a thermal. Looking at the altitude of the UAV, it can be seen that the plane is descending much slower at the times where humidity also shows significant higher values, which is believed to correspond to the region of the thermal. The peaks are reoccuring in different heights, which can be explained by the circular flight plan.

UPSI vs. SHT75 comparison

The second sensor comparison was made with a prototype of a capacitive humidity sensor by UPSI, France. First tests in the laboratory predicted step responses of below 0.2 s. The capacitance is also measured with the capacitance-to-digital converter Picocap01 by ACAM messelectronic GmbH. The capacitance measurement board is still equipped with a PT1000 temperature sensor which can be compared to the SHT75 temperature values. In this setup, the capacitive humidity measurement is also not temperature compensated.

Just like the P14 Rapid, the UPSI humidity sensor seems to be much faster than the SHT75. There is almost no hysteresis between ascend and descend at the very top altitude level. A drawback is the rather strong nonlinear behaviour of the sensor, which cannot easily be fit to the calibrated SHT75. Temperature dependence might be a major reason for this nonlinearity and has to be calibrated in the laboratory.

PT1000 vs. SHT75 comparison

During both comparison flights there were also two temperature sensors on board. On the one hand the integrated temperature sensor of the SHT75, on the other hand a PT1000 resistance thermometer. Looking at the temperature profile (figures 7 and 8, right plot), it can be seen that the PT1000 has a much smaller hysteresis above the boundary layer, i.e. is faster than the SHT75 sensor. It also shows more structure, small changes in temperature are not smoothed. An offset between the two sensors of about 1 K can be seen and further calibration has to show which is the more trustworthy temperature measurement.

3 Conclusion

This short term scientific mission was an excellent opportunity to make first tests and evaluation of a system that has been built up moreless from scratch within the last year. The data that has been collected will give chances to evaluate the strengths and weaknesses of the UAV and the measurement system. Meeting a lot of other groups and measuring systems, not only from within the UAV community, will also make it possible to intercompare results to verify the own data.

4 Acknowledgements

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