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DACCIWA

"Dynamics-aerosol-chemistry-cloud interactions in West Africa"

Deliverable

D 1.1
Campaign

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PU	Public	**x**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
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Nature of Deliverable		
R	Report	**x**
P	Prototype	
D	Demonstrator	
O	Other	

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Changes with respect to the DoW

Issue	Comments
Deliverable delayed from Mai 2016 to September 2016.	This deliverable is a report of the main field campaign which took place in summer 2016 but the deliverable was due end of May 2016. This is caused by an oversight at the first amendment. There the field campaign was postponed by one year but the deliverable only by half a year. So the expected completion date of the deliverable was September 2016 as agreed on with the project officer (Ares(2016)1156355 - DACCIWA (603502)).

Dissemination and uptake

Target group addressed	Project internal / external
Scientific community	Internal and external

Document Control

Document version #	Date	Changes Made/Comments
V0.1	29/07/2016	First version distributed to members of WP1
V0.2	29/08/2016	Upload to DACCIWA sharepoint for approval by the GA
V1.0	19/09/2016	Final version after inputs by the GA

Table of Contents

1 Introduction

This report provides a summary document for the ground-based field campaign which took place during June and July 2016. The field campaign was conducted to address the scientific objectives of WP1: the structure of the atmospheric boundary layer (ABL) depends mainly on the energy exchange at the Earth's surface. However, due to the high natural and anthropogenic emissions in Southwest Africa, gaseous and aerosol air pollutants also affect the diurnal cycle of the ABL, as do sea breeze and monsoon flows from the Gulf of Guinea. Characteristic features, for example nocturnal low-level jet (LLJs), deep daytime ABLs, and various types of boundary-layer clouds often occur. During the course of the day a transition from nocturnal low-level stratus to stratocumulus, cumulus, and sometimes congestus and possibly cumulonimbus clouds is observed. The atmospheric processes driving this transition are sensitive to the conditions mentioned above and although the nocturnal low-level stratus and the transition to broken clouds appear quite frequently, little attention has been paid to the phenomenon so far. In WP1 the intention is to identify the meteorological controls on the whole process chain from the formation of nocturnal stratus clouds, via the daytime transition to convective clouds and the formation of deep precipitating clouds. During the measurement period, extensive remote sensing and in-situ measurements were performed at three supersites in Kumasi (Ghana), Savè (Benin) and Ile-Ife (Nigeria). The gathered observations included the energy-balance components at the Earth's surface, the mean and turbulent conditions in the nocturnal and daytime ABL as well as the de- and entrainment processes between the ABL and the free troposphere. The meteorological measurements were supplemented by aerosol and air chemical observations.

The document gives an overview of the conducted measurements including instrument availability and intensive observation period (IOP) overview, aims to inform data users and provides support for case study selection.

2 Investigation area and instrumentation

2.1 Sites

Intensive measurements were performed at three supersites in southern West Africa: Savè (Benin), Kumasi (Ghana), and Ile-Ife (Nigeria) from 13 June to 31 July (site locations and geographic information are given in Fig. 1 and Table 1). The time zones are UTC in Kumasi and UTC+1 for Savè and Ile-Ife.

The site at Savè was operated jointly by KIT (Karlsruhe Institute of Technology) and UPS (Université Toulouse III - Paul Sabatier, Laboratoire d'Aérologie). All ground-based instruments and the RPAS Ovlita were deployed at the measurement site at Savè at the site of INRAB (Institut National de Recherche Agronomique du Benin). The RPAS Aladina was operated at the Savè airfield about 4 km away from the INRAB site.

The Kumasi site was on the estates of KNUST (Kwame Nkrumah University of Science and Technology): specifically, on the grounds of the University's Department of Agriculture. The Department of Agriculture operates a Meteorological site (henceforth referred to as AGROMET) with a wide range of instrumentation housed in an extensive and maintained paddock: the supersite was deployed around this paddock ensuring that this temporary deployment did not interfere with the permanent measurements. The site was operated by NCAS (National Centre for Atmospheric

Science) with logistical assistance from KNUST. All ground-based instruments were deployed at this measurement site.

The DACCIWA supersite in Ile-Ife was the same location as permanent meteorological station, OAU-Met., established in 2014 at the Teaching and Research Farm of Obafemi Awolowo University. The dedicated measurement area covered 4,200 square meters where four meteorological masts were installed. A 15-m mast was used for wind, temperature and humidity profile measurements, 6-m mast for wind speed and direction together with soil temperature, moisture and heat flux, 2-m mast for eddy covariance system and 2-m mast for surface radiation balance. A facility building housing the project personnel, computers, meteorological devices and internet connectivity was provided which served as a control centre to coordinate the DACCIWA project activities. A 24-speaker phased array acoustic sounder (sodar) was co-located with the ground-based measurements. In addition, a tethered radiosonde system (GRAW Instruments, Germany) was deployed at specific times to obtain temperature and humidity profiles in the atmospheric boundary layer to complement the sodar-derived winds (up to 500 m approximately).

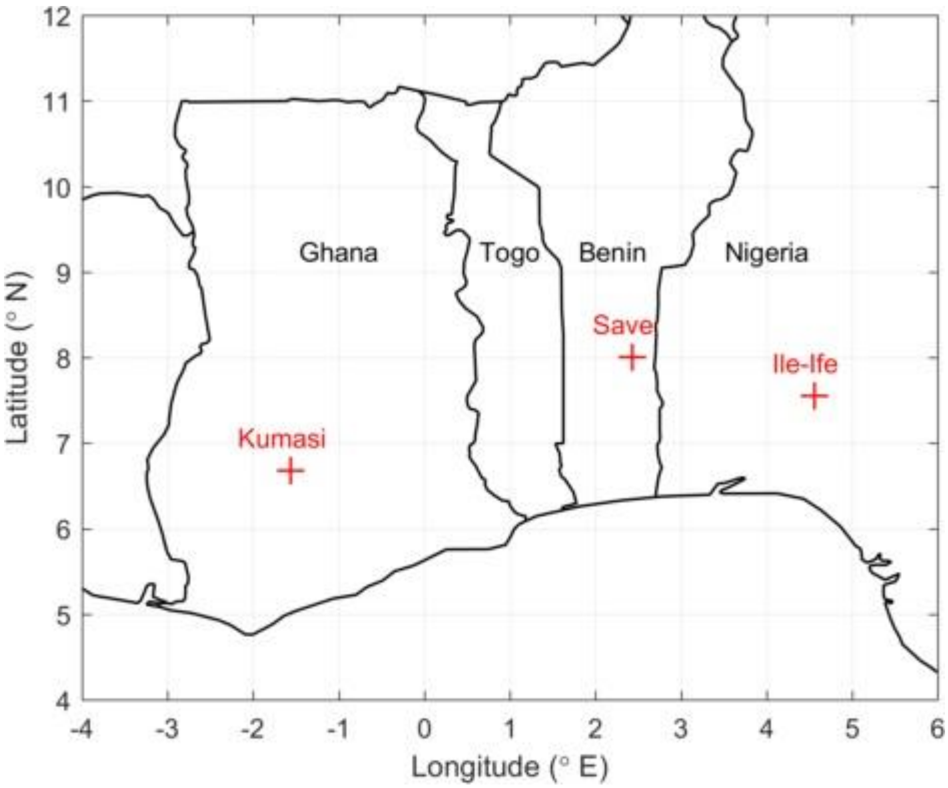


Figure 1: The locations of the supersites Kumasi, Savè and Ile-Ife in southern West Africa.

Table 1: Geographic location of supersites.

	Savè	Kumasi	Ile-Ife
Latitude	N 8°00'03.6" (Savè site) N 8°01'04.4" (airfield)	N 6° 40’ 48.56’’	N 7º 33’ 11.52”

Longitude	E 2°25'41.1 (Savè site) E 2°27'50.8" (airfield)	E 1° 33' 37.76''	E 4º 33'26.70"
Height (m MSL)	166 (Savè site) 180 (airfield)	266	274

2.2 Instrumentation

The instrumentation installed at the three supersites was selected to allow detecting the processes described in Section 1. The instruments at Savè are listed in Section 2.2.1 (Tables 2 – 6), at Kumasi in Section 2.2.2 (Tables 7 – 10), and at Ile-Ife in Section 2.2.3 (Tables 11 – 14). More information on the instrumentation are given in the **Operation Plan** for WP1 activities which was uploaded to the DACCIWA sharepoint and is attached to this document in Appendix 2.

2.2.1 Savè

Table 2: Surface measurements.

Instrument	Operator	Measured parameters
Energy balance station	KIT	Q, H, E, B, SW, LW, SM, ST, T, RH, P, wind, prec
Energy balance station and chemistry tower	UPS	Q, H, E, B, SW, LW, SM, ST, T, RH, P, wind, prec, BF, CCC

Q: Net radiation, H: Sensible heat flux, E: Latent heat flux, B: Soil heat flux, SW: Short-wave radiation components, LW: Long-wave radiation components, SM: Soil moisture, ST: Soil temperature, T: Air temperature, RH: Relative Humidity, P: Pressure, prec: Precipitation, BF: biogenic fluxes (NO, NO2, isoprene turbulent fluxes), CCC: Chemical Compound Concentration of O3, NO, NO2, CO, isoprene

Table 3: Measurements in the boundary layer and above

Instrument	Operator	Measured parameters
Sodar	KIT	Horizontal wind profile (0-600 m)

UHF wind profiler	UPS	Horizontal wind profile (200 - 4000 m)
Wind lidars	KIT	Radial velocity *WindTracer*: scanning or vertical stare (400-10000 m, depending on aerosol concentration) *Windcube*: (0-600 m)
Microwave radiometer	KIT	Temperature and humidity profiles, IWV, LWP, CBT
Radiosondes (normal RS and frequent RS)	UPS	T, RH, P, wind profiles Normal RS: 0-20 km Frequent RS: 0-2 km

IWV: Integrated water vapour, LWP: Liquid water path, CBT: Cloud base temperature

Table 4: Measurements of cloud characteristics and precipitation

Instrument	Operator	Measured parameters
Cloud radar	KIT	Radial velocity, cloud top
Ceilometer	KIT	Cloud base
X-Band radar	KIT	Precipitation
MRR, distrometers	KIT	Precipitation, drop size distribution
Cloud camera	UPS	Cloud cover

Table 5: Aerosol measurements

Instrument	Operator	Measured parameters
Grimm aerosol spectrometer	KIT	Particle concentration for particle sizes from 0.25 to 32 µm
Sun photometer	KIT & University Reading	Aerosol optical depth (normal mode and cloud mode)

Table 6: RPASs (remotely piloted aerial vehicles)

	RPAS Aladina	**RPAS Ovlita**
Operator	TU Braunschweig	UPS
Location	Savè airfield	Savè site
Meteorological parameters	T, RH, P, wind, fluxes	T, RH, P, wind
Dimensions	3.6 m x 2 m	
Weight	25 kg	2.5 kg
Maximum wind speed	15 m/s	7-8 m/s
Air speed	25 m/s	10 m/s
Clouds	No (touch bottom)	No
Night	No	No
Operation duration for 1 mission	45 min / 1 flight, 10-20 min between flights, max. 10 flights per mission, ~10 h max	90 min / flight (minimum, with thermic maybe longer)
Measurement strategy	Fluxes along constant height flight legs; 1 profile at the beginning to get profiles of wind, temperature and humidity Leg's length according to the pilot (RPAS must be visible). Flight in a 1.5 km-radius circle.	Helicoidal Profiles

2.2.2 Kumasi

Table 7: Surface measurements

Instrument	Operator	Meteorological parameters
Energy balance station	NCAS	Q, H, E, B, SW, LW, SM, ST
Flux station	NCAS	TS, P, U, V, W, H20, CO2, TL, DT
AWS	NCAS	T, RH, PP, WS, WD, PPT

Q: 1Hz Net radiation, H: 1Hz Sensible heat flux, E: 1Hz Latent heat flux, B: 1Hz Soil heat flux, SW: 1Hz Short-wave radiation components, LW: 1Hz Long-wave radiation components, SM: 1Hz Soil moisture, ST: 1Hz Soil temperature, T: 5 min Air temperature, PP: 5 min pressure, WS: 5 min horizontal wind, WD: 5 min horizontal wind direction, PPT: 5 min precipitation, RH: 5 min Relative Humidity, P: 20Hz Pressure, H20: 20Hz water vapour concentration, CO2: 20Hz carbon dioxide concentration, U,V,W: 20Hz wind speed components, TS: 20Hz sonic temperature, TL: 20Hz licor air temperature, DT: 20Hz licor dew point temperature

Table 8: Measurements in the boundary layer and above

Instrument	Operator	Meteorological parameters
Sodar	NCAS	Horizontal wind profile (0-600 m) , CT2
Microwave radiometer	NCAS	Temperature and humidity profiles, IWV, LWP, CBT
Radiosondes (normal and frequent)	NCAS	T, RH, P, wind profiles

IWV: Integrated water vapour, LWP: Liquid water path, CBT: Cloud base temperature

Table 9: Measurements of cloud characteristics and precipitation

Instrument	Operator	Meteorological parameters

Ceilometer	NCAS	Coud base, aerosol backscatter coefficient
MRR	NCAS	Precipitation, drop size distribution
Cloud camera	NCAS	Cloud cover

Table 10: Aerosol measurements

Instrument	Operator	Meteorological parameters
Sun photometer	NCAS	Optical depth

2.2.3 Ile-Ife

Table 11: Surface measurements

Instrument	Operator	Meteorological parameters
Energy balance station	OAU	Q, H, E, B, SW, LW, SM, ST, T, RH, P, wind, prec
15-m tower	OAU	T, RH, P, wind (multilevels)

Q: Net radiation, H: Sensible heat flux, E: Latent heat flux, B: Soil heat flux, SW: Short-wave radiation components, LW: Long-wave radiation components, SM: Soil moisture, ST: Soil temperature, T: Air temperature, RH: Relative Humidity, P: Pressure, prec: Precipitation

Table 12: Measurements in the boundary layer and above

Instrument	Operator	Meteorological parameters
Sodar	OAU	Horizontal wind profile (0-600 m)
Tethered radiosonde	OAU & KIT	T, RH profiles

Table 13: Measurements of cloud characteristics and precipitation

Instrument	Operator	Meteorological parameters
Handhold infrared radiometer	OAU & KIT	Cloud base temperature
Rain gauge	OAU	precipitation

Table 14: Aerosol measurements

Instrument	Operator	Meteorological parameters
Sun photometer	OAU	Aerosol optical depth

3 Strategy

Continuous measurements were performed throughout the whole measurement period. This included all instrumentation except the normal and frequent radiosoundings, the RPASs and the research aircrafts. A detailed description of the measurement strategy was summarized in the **Operation Plan** for WP1 activities which was uploaded to the DACCIWA sharepoint and is attached to this document in Appendix 2.

During the whole measurement period there was one radiosounding per day in the morning, i.e. when the low-level cloud cover is most intense, to get a statistic of atmospheric conditions. The sonde was launched at 0500 UTC in Savè and between 0530 and 0600 UTC in Kumasi and was send for assimilation. An example of such a sounding is given in Figure 2.

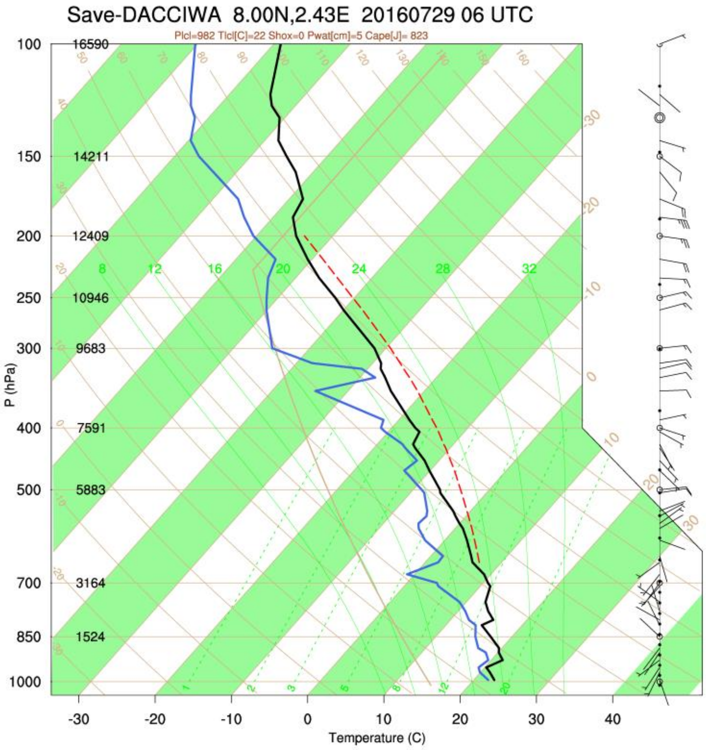


Figure 2: Profiles of temperature, dew point temperature and wind speed and direction at Savè

Briefings were performed every day via skype with participants from the three supersites. The decision about an IOP was based on weather forecast performed by a forecaster in Savè. It was aimed to capture the whole range of meteorological conditions during the IOPs. Another major information for the decision was the **status of the instrumentation** (see Figure 4 in Section 4). This information was updated every day and uploaded on the DACCIWA website: (http://dacciwa.sedoo.fr/monitoring.php?current=20160729&nav=Monitoring). During the aircraft campaign, additionally the information about aircraft flights (where and when) were considered. The decision about an IOP was distributed between the partners (including Lome aircraft operation centre during the aircraft campaign) in a briefing report. **Briefing report** and **Forecast** were put on the DACCIWA WP1 sharepoint. An example of a briefing report is given in Appendix 1.

There were 15 IOPs in total. Three IOPs were conducted before the aircraft campaign which took place between 27 June and 17 July, seven IOPs took place during the aircraft campaign and five afterwards. An IOP day (D) started in the evening of D-1 and generally lasted until the afternoon of day D. The typical procedures of an IOP at the different sites are described below and an overview of the timings of the radiosondes and RPAS is given in Figure 3.

At Savè, there were 5 normal radiosoundings (RS) with 6-hour intervals, the first one was launched at 1700 UTC on D-1 and the last one at 1700 UTC on D. Due to lack of radiosondes the 1700 UTC radiosoundings on day D were cancelled at Savè in the course of the campaign. Frequent radiosondes (FRS) up to an altitude of around 1500 m were launched in between the NRS. During IOPs 1-6 FRS were launched hourly between 2100 and 1000 UTC. Starting at IOP 7, FRS were launched in 90 minute intervals between 1830 and 0930 UTC in order to capture the evening transition as well. RPAS Ovlita performed profile flights in the afternoon during periods when no FRS were launched. RPAS Aladina performed flight pattern consisting of vertical profiles and horizontal legs during periods when stratus was present in the morning, when stratus was breaking and in the evening during transition to stable conditions.

At Kumasi, 5 normal radiosondes were launched in 6-hour intervals, starting at 1800 UTC on D-1. During IOPs 1-10, FRS were launched at 0300, 0600 and/or 0900 UTC, partly at 2 different sites at the same time. During IOPs 11-15, normal radiosondes were launched in intervals of 1.5 hours in the afternoon, evening and morning and in intervals of 3 hours during the night. During IOP 14, no radiosondes were launched during the night.

At Ile-Ife, tethered radiosondes reaching heights of up to 900 m AGL were launched during IOPs, typically between 1800 UTC on D-1 and 1700 UTC on D. Intervals were approximately 3-hourly or 6-hourly, depending on availability of helium gas and operational condition of the electric winch. IOPs 3 and 5 were partially completed due to lack of helium gas needed to fill meteorological balloons. This problem was finally resolved by release of helium gas shipped to Lagos, Nigeria from Germany in support of DACCIWA project by the customs. On July 20th, a mechanical problem developed on the drive belt for the electric motor of the winch. This situation forced partial completion of the soundings during IOP 12 (although it was rectified the next day). Another problem that occurred later on was frequent bursts of the balloons after standing outside for several hours. This posed a major challenge since number of balloons received from Germany were almost depleted. The situation was rescued by sourcing for balloons locally.

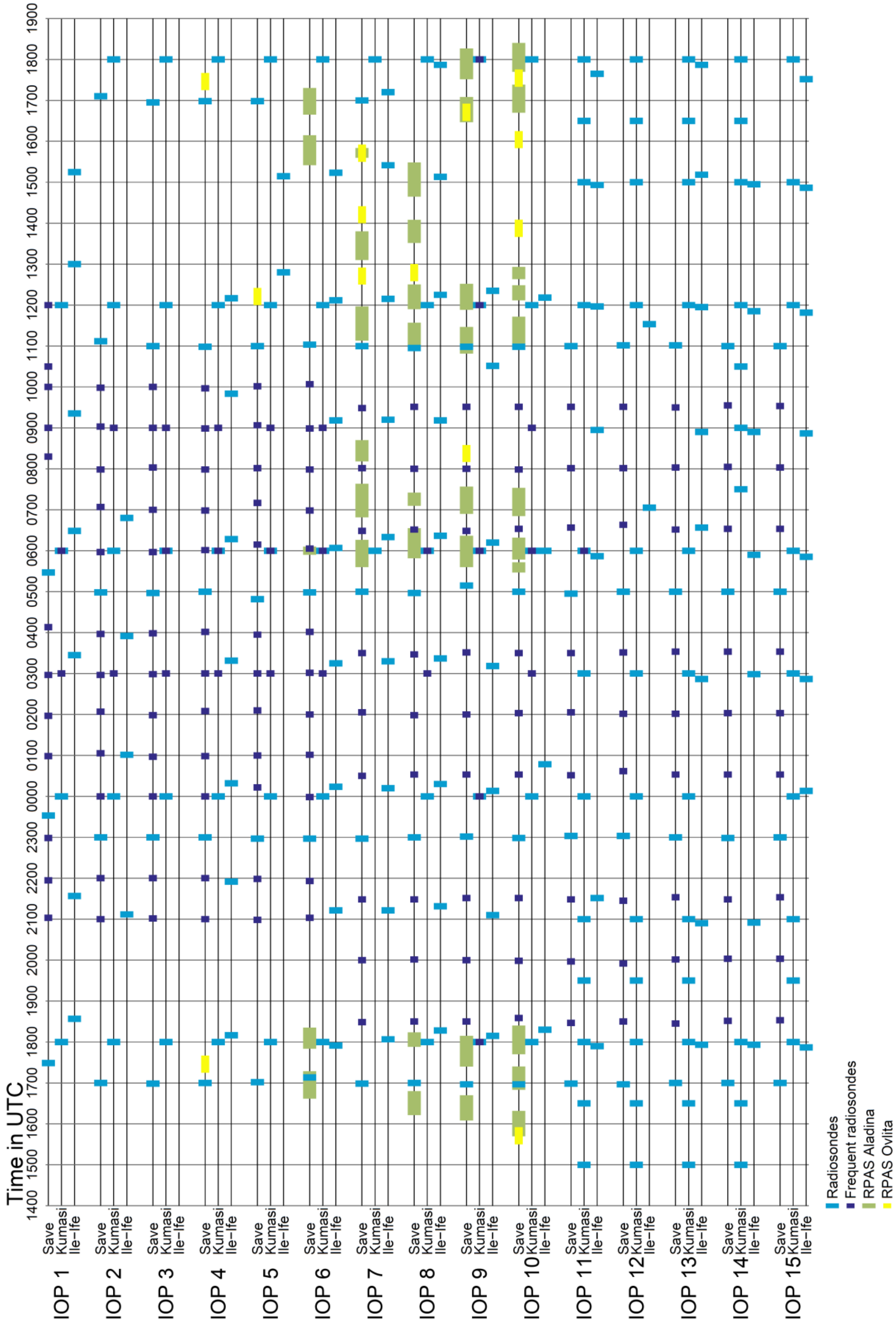


Figure 3: Time table of complementary measurements during IOPs.

4 Instrument availability and IOP days

Instrument availability was used to decide about IOPs during the campaign and will also be used for the subsequent decisions about “golden days”.

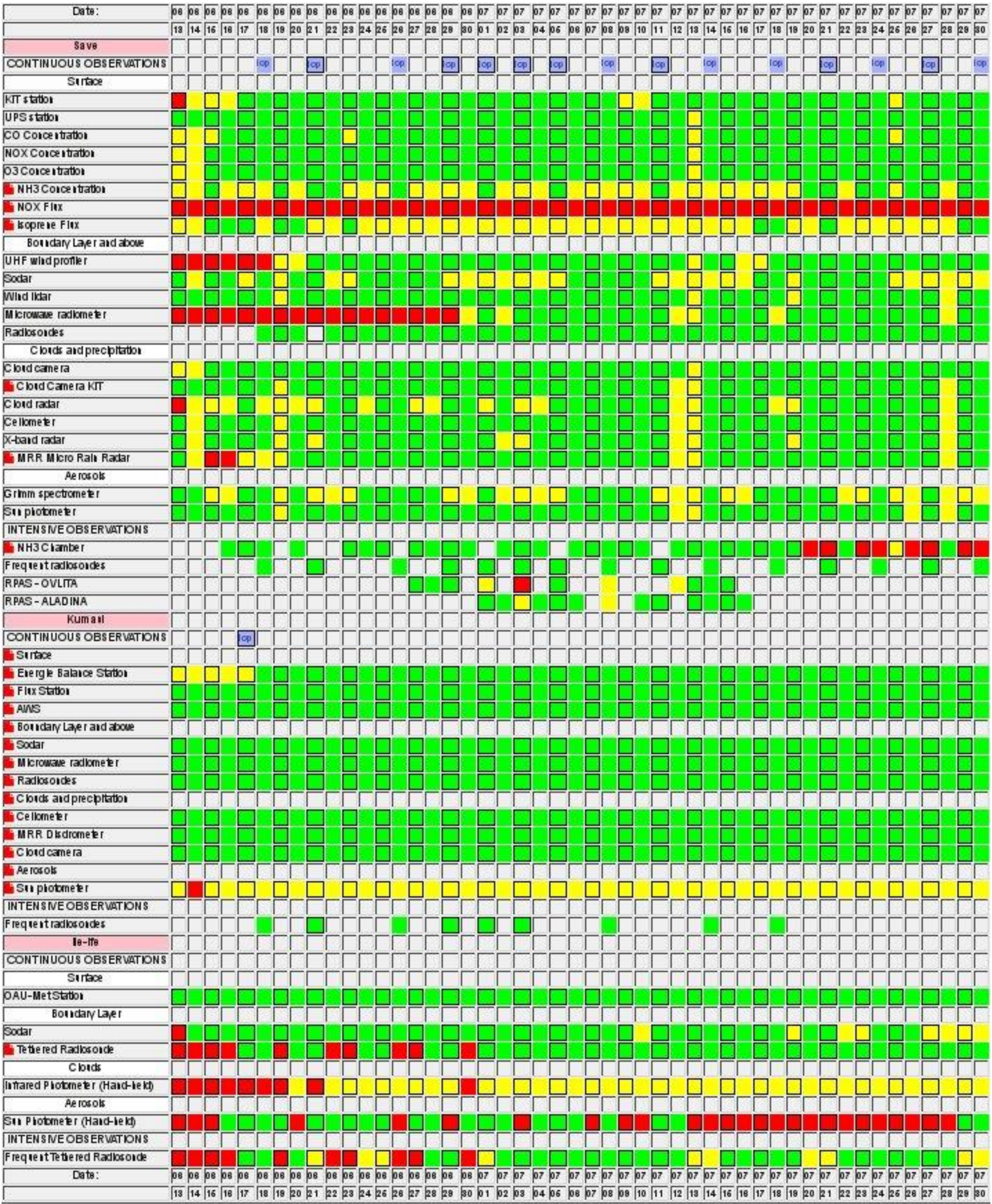


Figure 4: Instrument status during the measurement period from 13 June to 30 July 2016 at the different sites. Green indicates full data availability, green partial data availability and red no data availability. IOPs (in violet) are indicated on days D.

5 IOP overview

Due to the large number of IOPs, the whole range of different large-scale conditions (e.g. deep monsoon flow, strong monsoon flow, westerly winds, southerly winds, height and strength of the LLJ, depth and strength of the African easterly jet (AEJ)) could be captured by the measurements. This will allow investigating the occurrence (onset, depth, cloud base) of the nocturnal stratus under different conditions, which was one of the criteria for the successful achievement of the deliverable.

Comprehensive quicklooks for the better part of the instruments were produced automatically and uploaded daily to the DACCIWA website (http://dacciwa.sedoo.fr). Horizontal wind measurements from multiple instruments (e.g. UHF wind profiler, Sodar, normal and frequent radiosondes at Savè) clearly demonstrate the varying characteristics of the wind field. For example, the strength of the LLJ varied considerably from around 6 m s^{-1} (IOPs 1, 5, 12 and 13) up to 14 m s^{-1} during IOP 9 and the AEJ reached wind speeds of more than 15 m s^{-1} (IOPs 6, 7 and 8), but was also weak (IOP 2) or north of Savè (IOPs 9, 10, 11 and 12). While stratus developed during all the IOPs except for IOP 10, its onset, cloud base, depth and dissolution time differed considerably. Information on the characteristics of the stratus can be retrieved from e.g. ceilometer, cloud radar and infrared camera (quicklooks are available on the DACCIWA website). For example, during IOP 5 the stratus formed early at 2240 UTC with a very low cloud base height of less than 50 m AGL, while if formed late at 0530 UTC with a cloud base height of around 200 m AGL during IOP 3.

In the following, quicklooks from the ceilometers at Savè and Kumasi are shown for all IOPs to get an overview of the onset, cloud base and dissolution of nocturnal stratus during IOPs. The quicklooks show backscatter data detected with the ceilometers and allow to identify periods with stratus and the cloud base height.

5.1 IOP 1

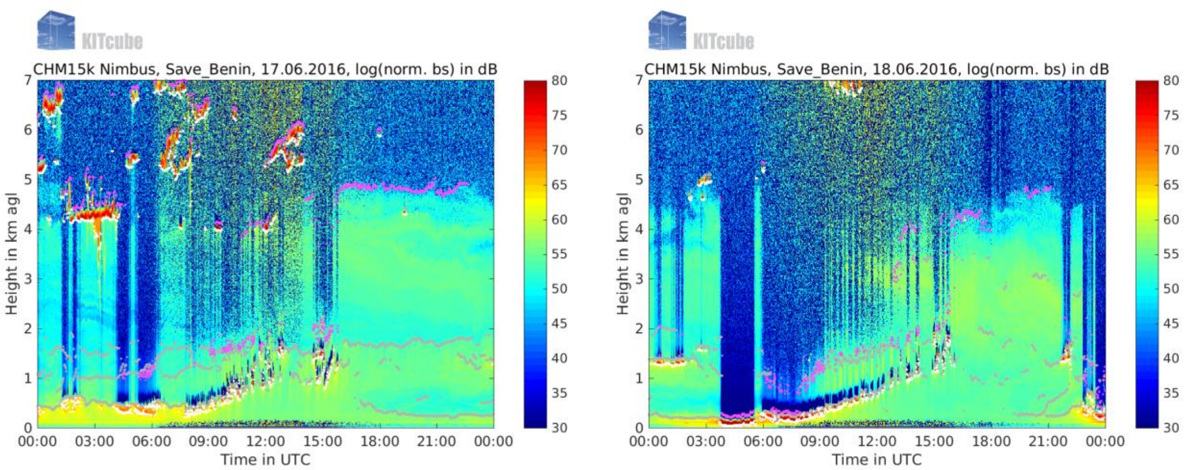


Figure 5: Ceilometer backscatter (colour-coded) at Savè during IOP 1. White dots indicate cloud base.

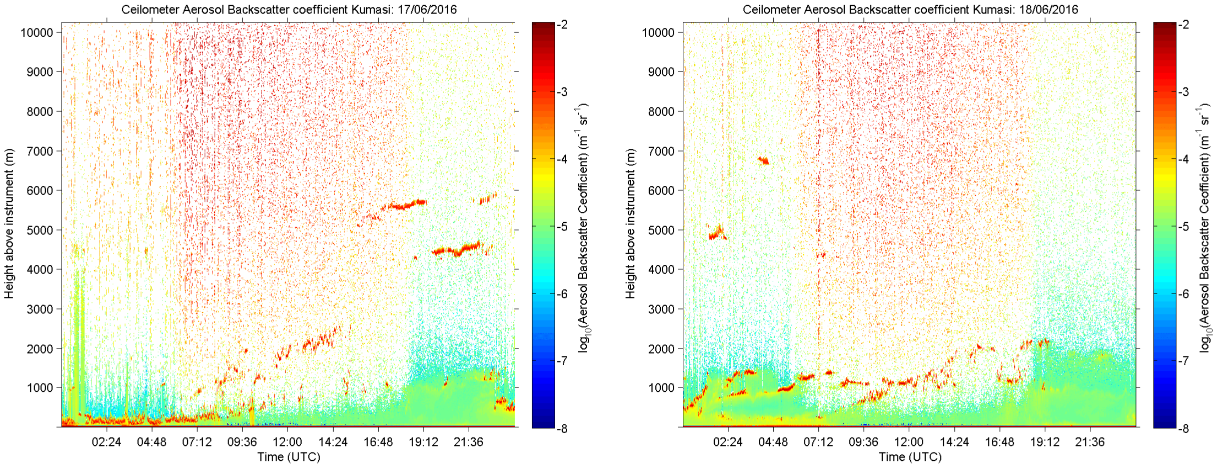


Figure 6: Ceilometer backscatter (colour-coded) at Kumasi during IOP 1.

5.2 IOP 2

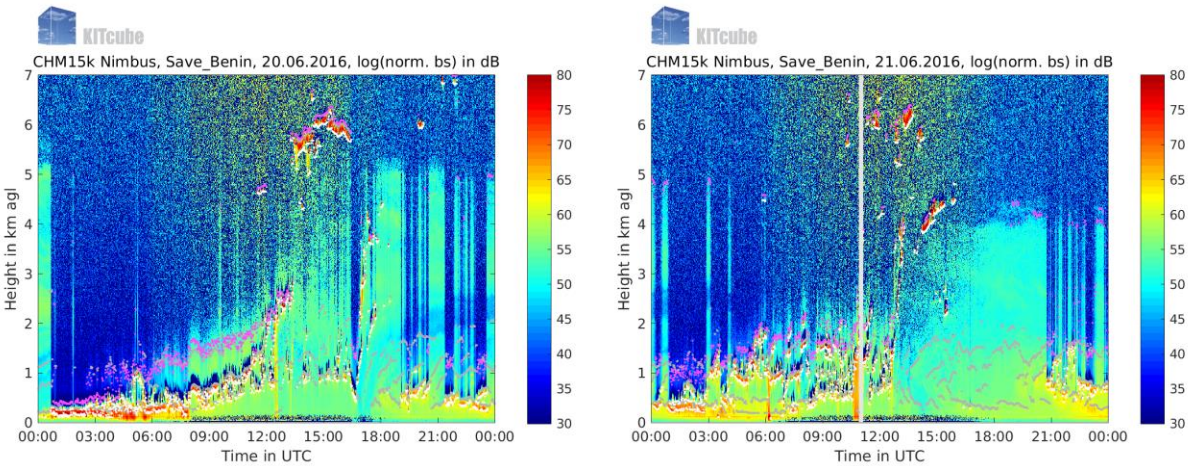


Figure 7: Ceilometer backscatter (colour-coded) at Savè during IOP 2. White dots indicate cloud base.

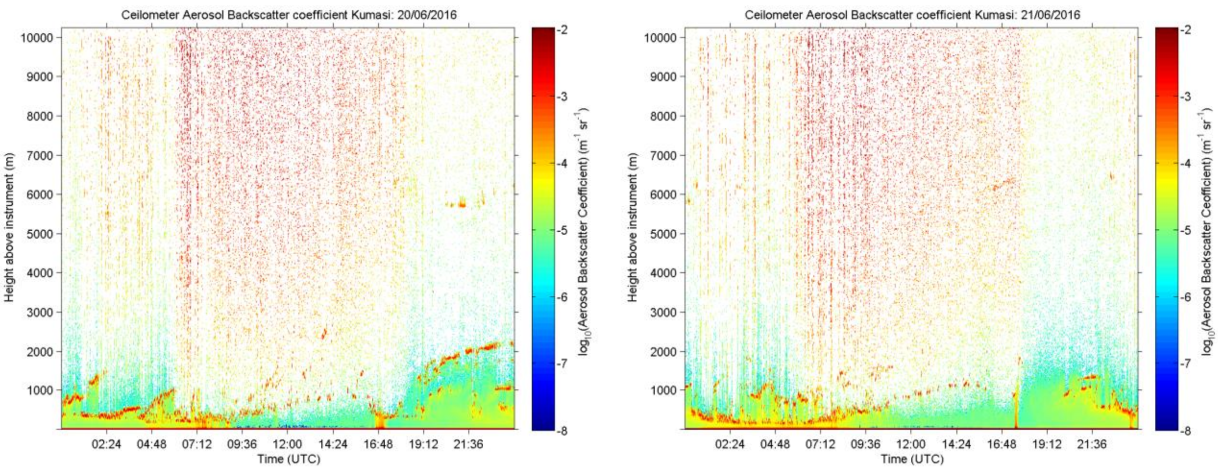


Figure 8: Ceilometer backscatter (colour-coded) at Kumasi during IOP 2.

5.3 IOP 3

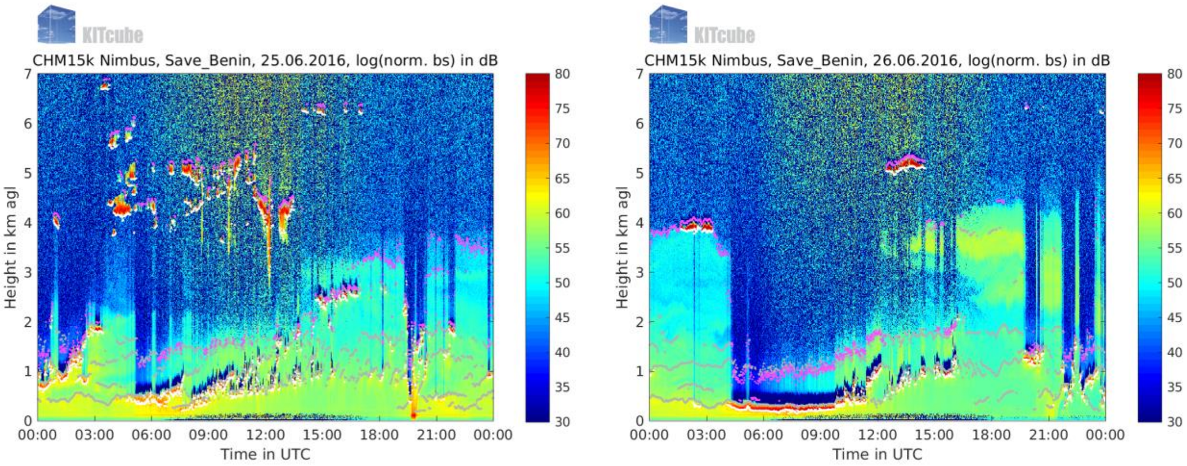


Figure 9: Ceilometer backscatter (colour-coded) at Savè during IOP 3. White dots indicate cloud base.

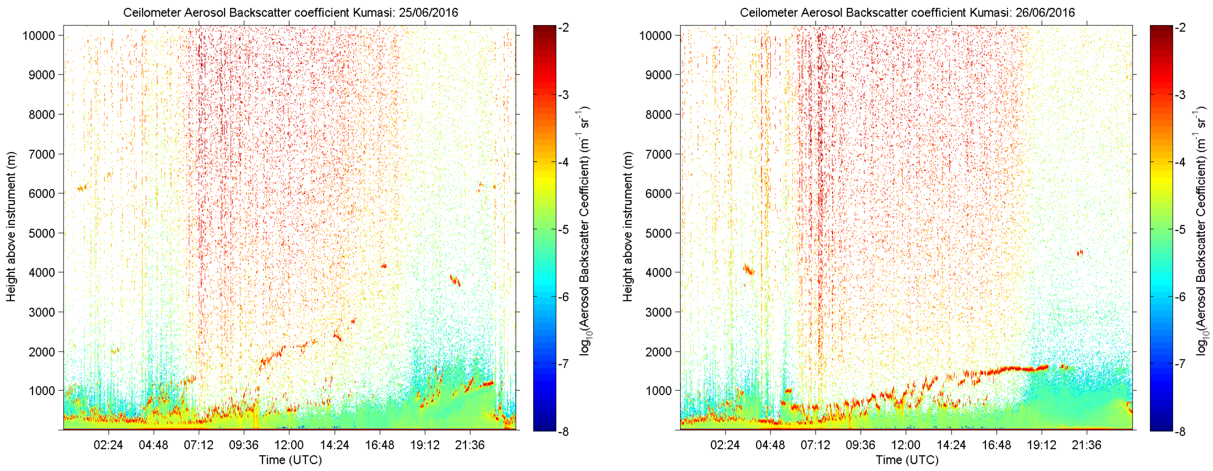


Figure 10: Ceilometer backscatter (colour-coded) at Kumasi during IOP 3.

5.4 IOP 4

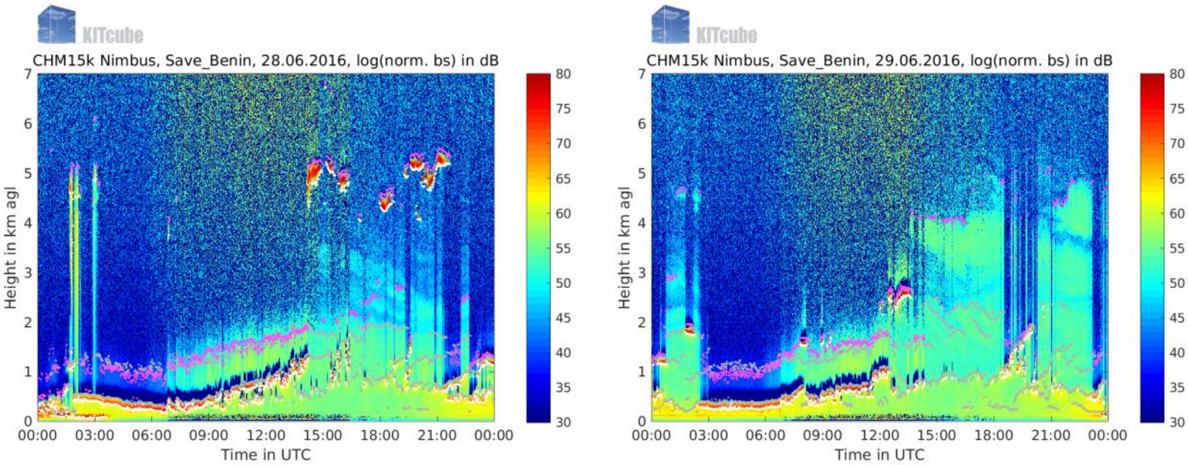


Figure 11: Ceilometer backscatter (colour-coded) at Savè during IOP 4. White dots indicate cloud base.

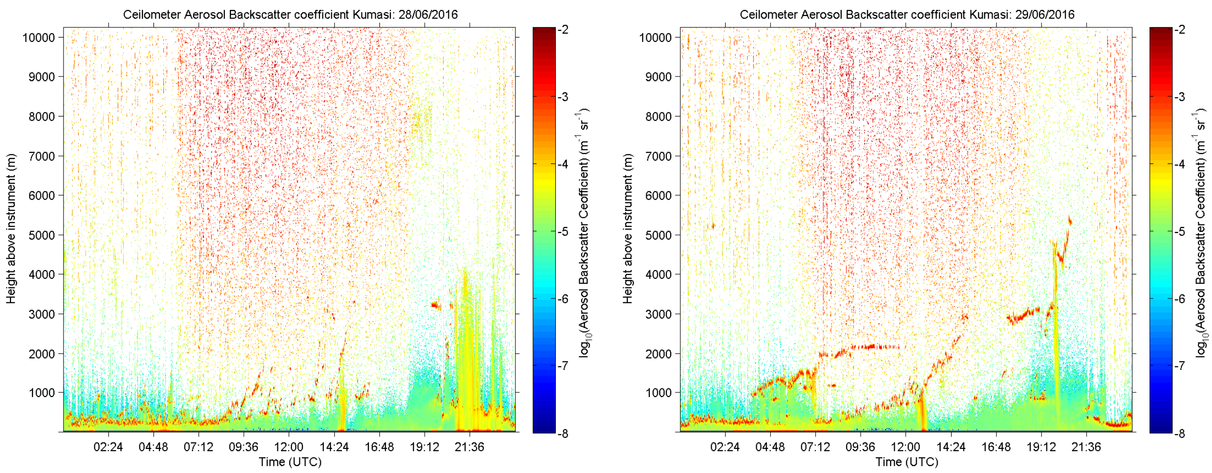


Figure 12: Ceilometer backscatter (colour-coded) at Kumasi during IOP 4.

5.5 IOP 5

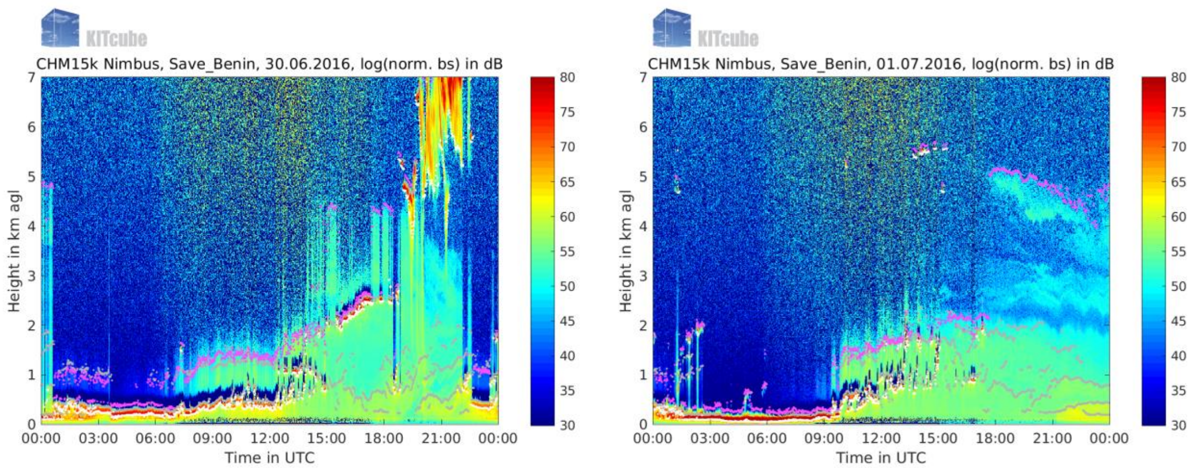


Figure 13: Ceilometer backscatter (colour-coded) at Savè during IOP 5. White dots indicate cloud base.

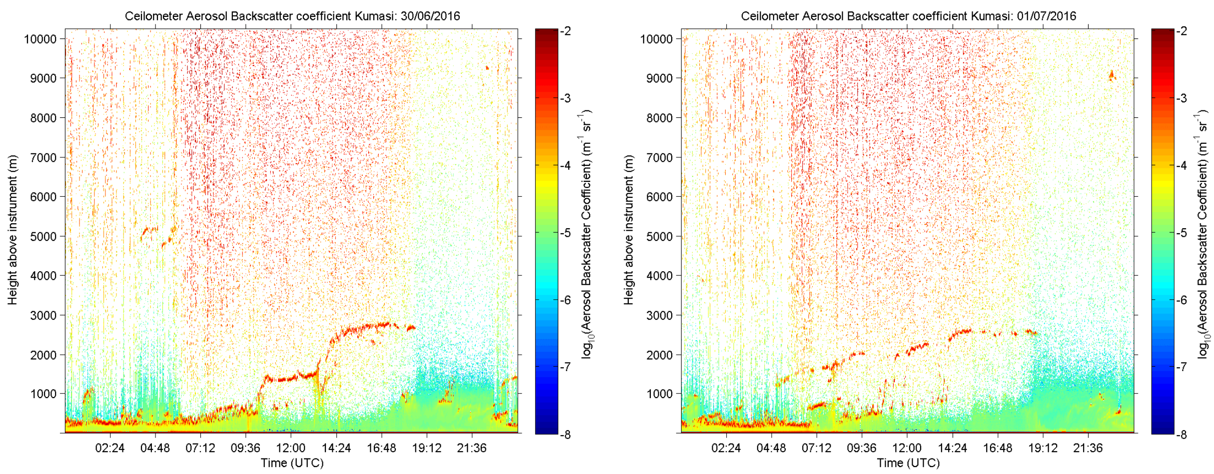


Figure 14: Ceilometer backscatter (colour-coded) at Kumasi during IOP 5.

5.6 IOP 6

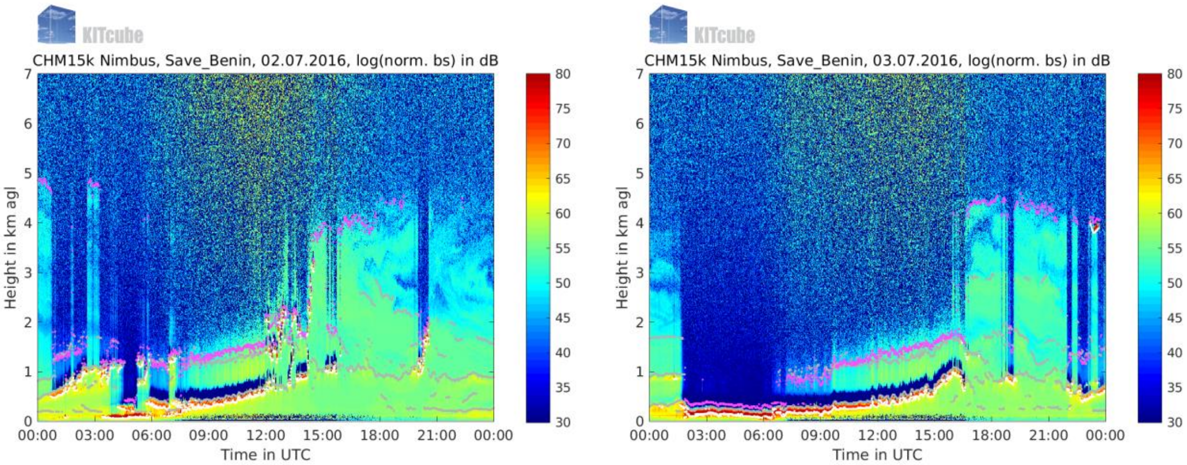


Figure 15: Ceilometer backscatter (colour-coded) at Savè during IOP 6. White dots indicate cloud base.

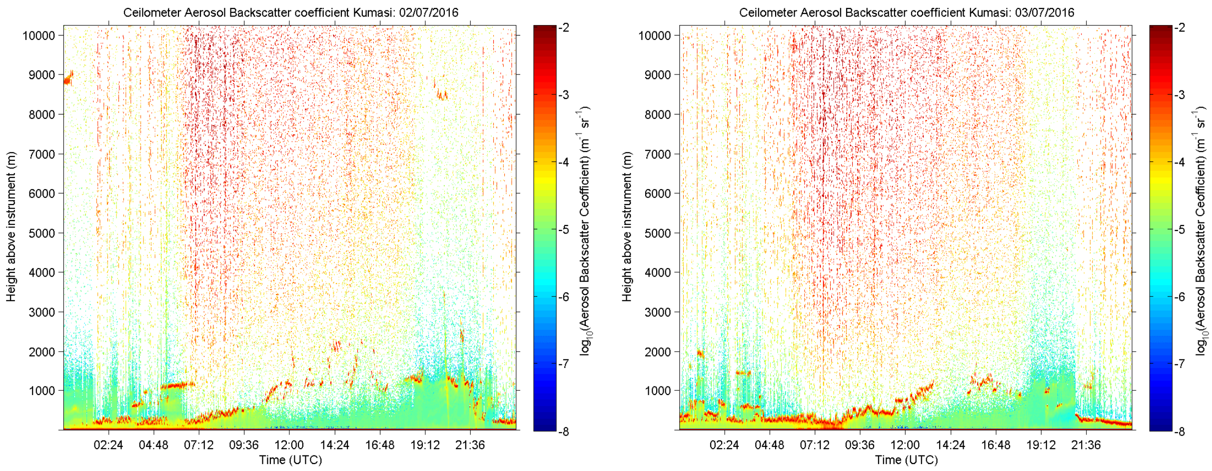


Figure 16: Ceilometer backscatter (colour-coded) at Kumasi during IOP 6.

5.7 IOP 7

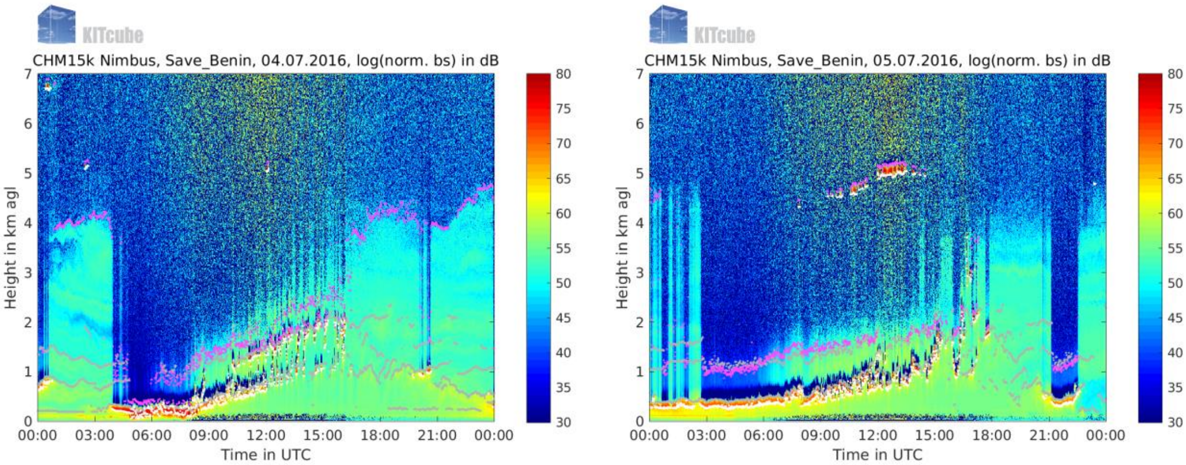


Figure 17: Ceilometer backscatter (colour-coded) at Savè during IOP 7. White dots indicate cloud base.

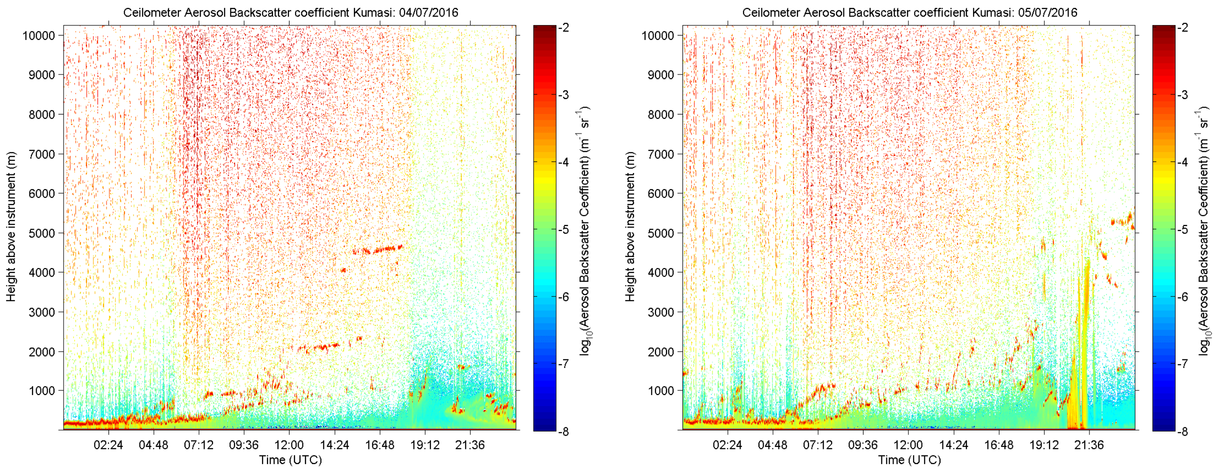


Figure 18: Ceilometer backscatter (colour-coded) at Kumasi during IOP 7.

5.8 IOP 8

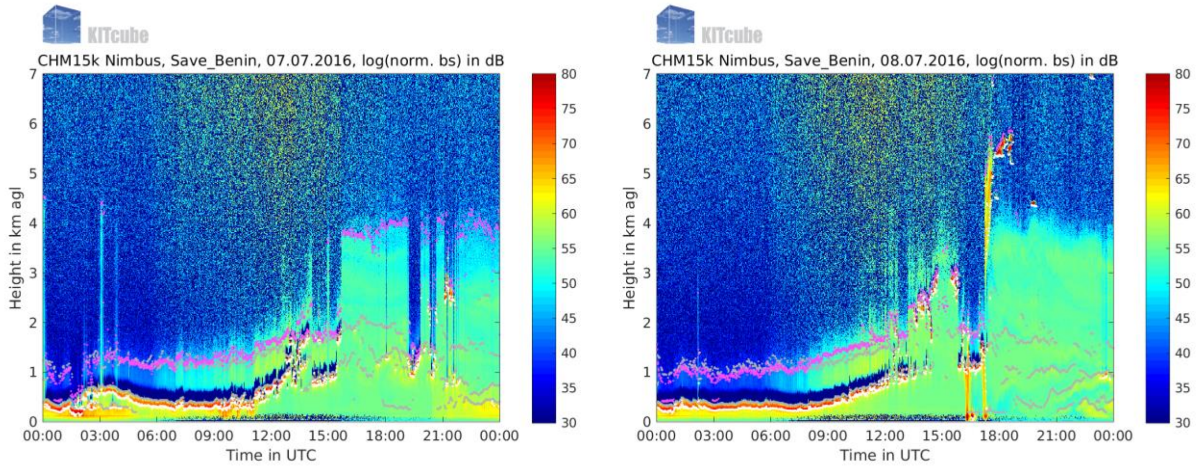


Figure 19: Ceilometer backscatter (colour-coded) at Savè during IOP 8. White dots indicate cloud base.

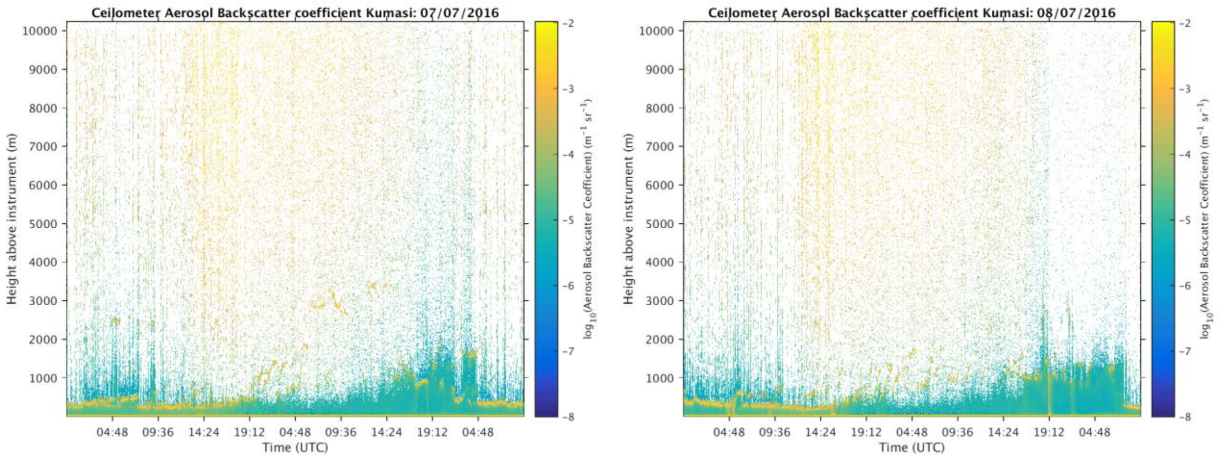


Figure 20: Ceilometer backscatter (colour-coded) at Kumasi during IOP 8.

5.9 IOP 9

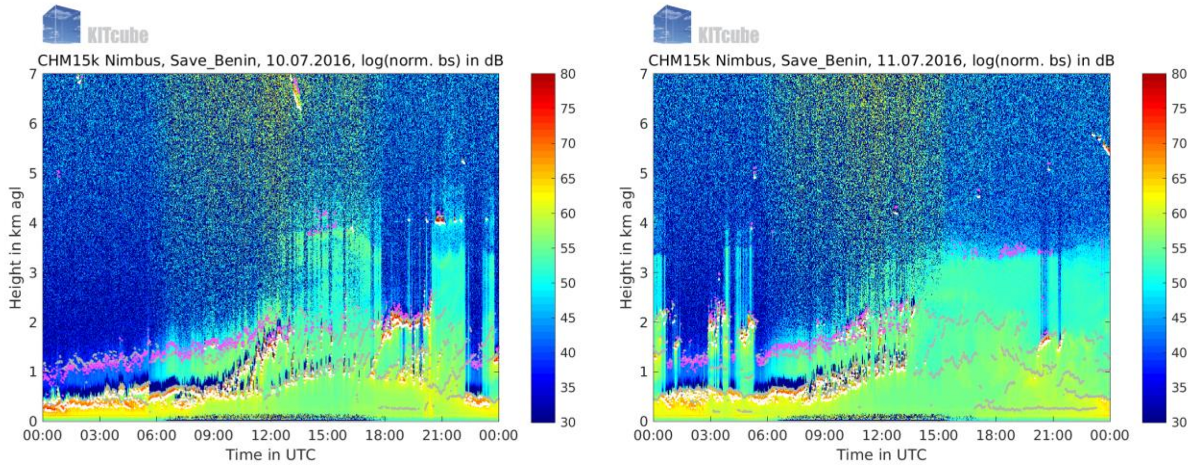


Figure 21: Ceilometer backscatter (colour-coded) at Savè during IOP 9. White dots indicate cloud base.

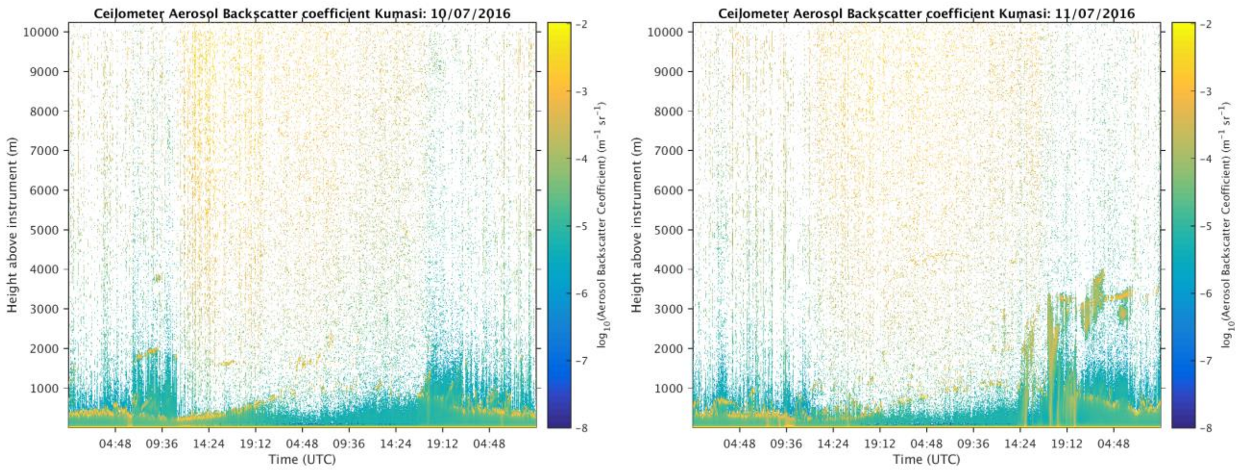


Figure 22: Ceilometer backscatter (colour-coded) at Kumasi during IOP 9.

5.10 IOP 10

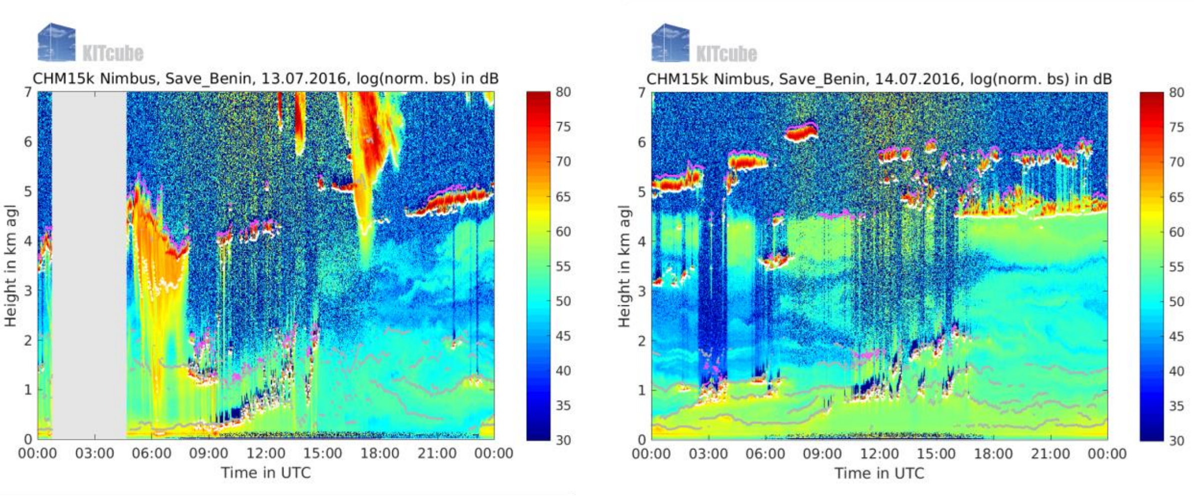


Figure 23: Ceilometer backscatter (colour-coded) at Savè during IOP 10. White dots indicate cloud base.

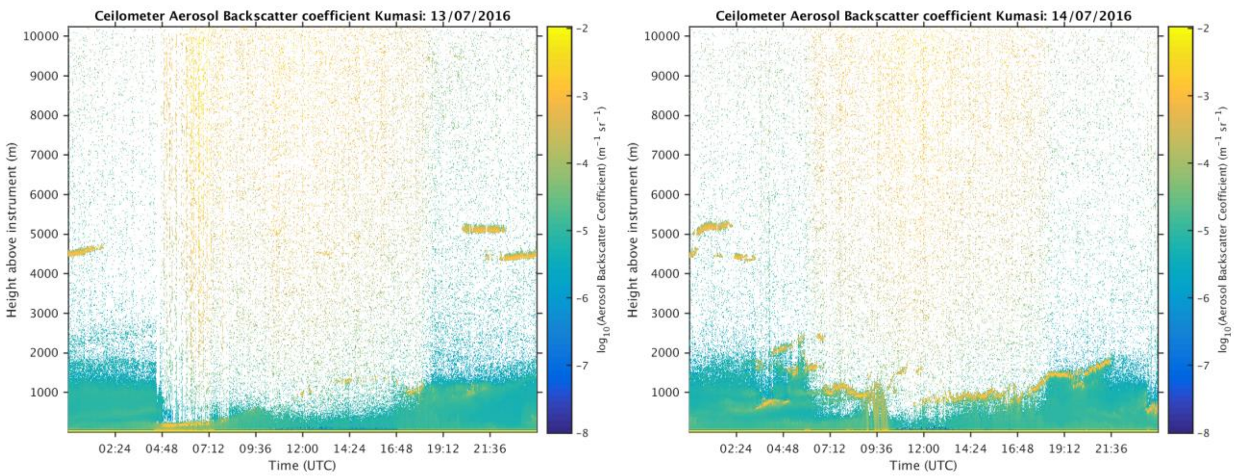


Figure 24: Ceilometer backscatter (colour-coded) at Kumasi during IOP 10.

5.11 IOP 11

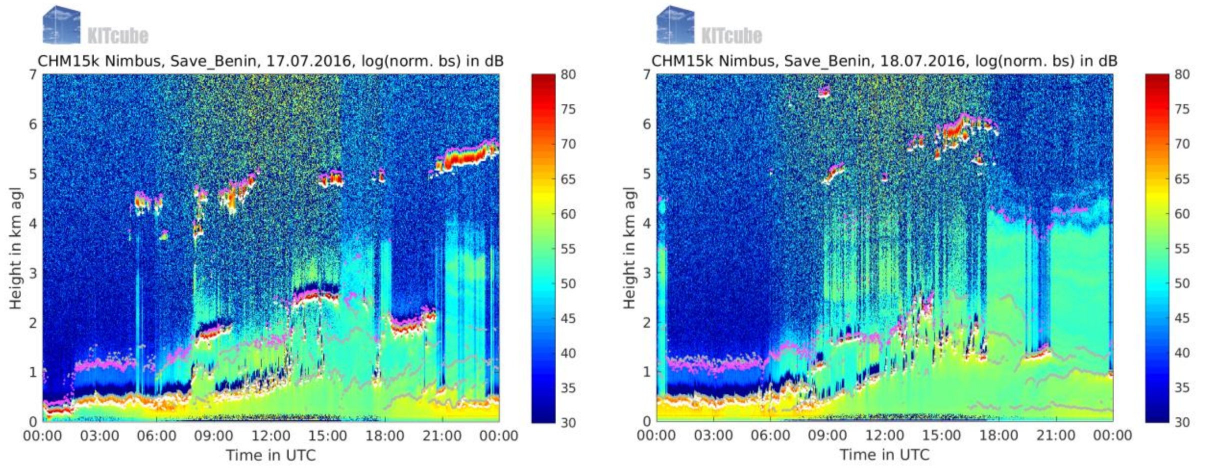


Figure 25: Ceilometer backscatter (colour-coded) at Savè during IOP 11. White dots indicate cloud base.

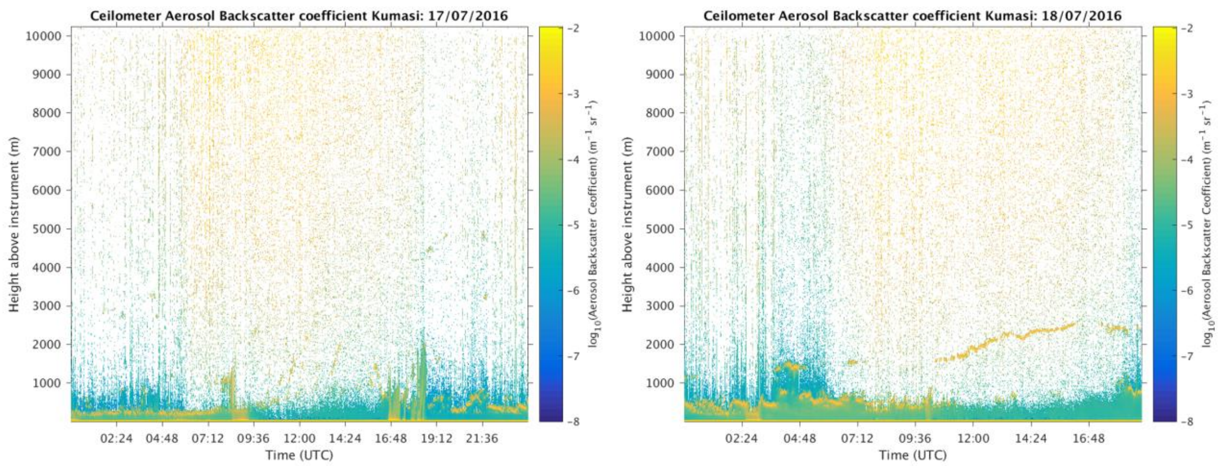


Figure 26: Ceilometer backscatter (colour-coded) at Kumasi during IOP 11.

5.12 IOP 12

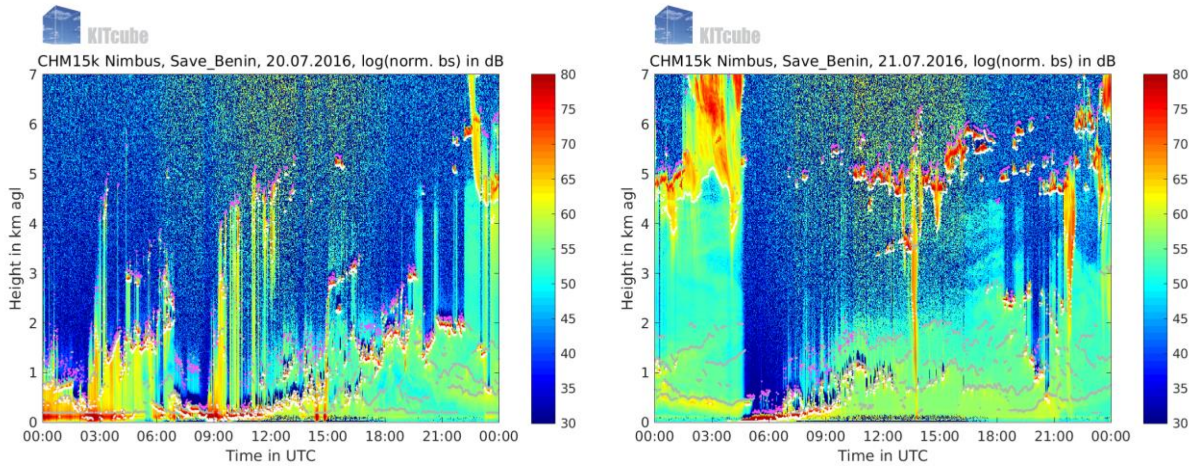


Figure 27: Ceilometer backscatter (colour-coded) at Savè during IOP 12. White dots indicate cloud base.

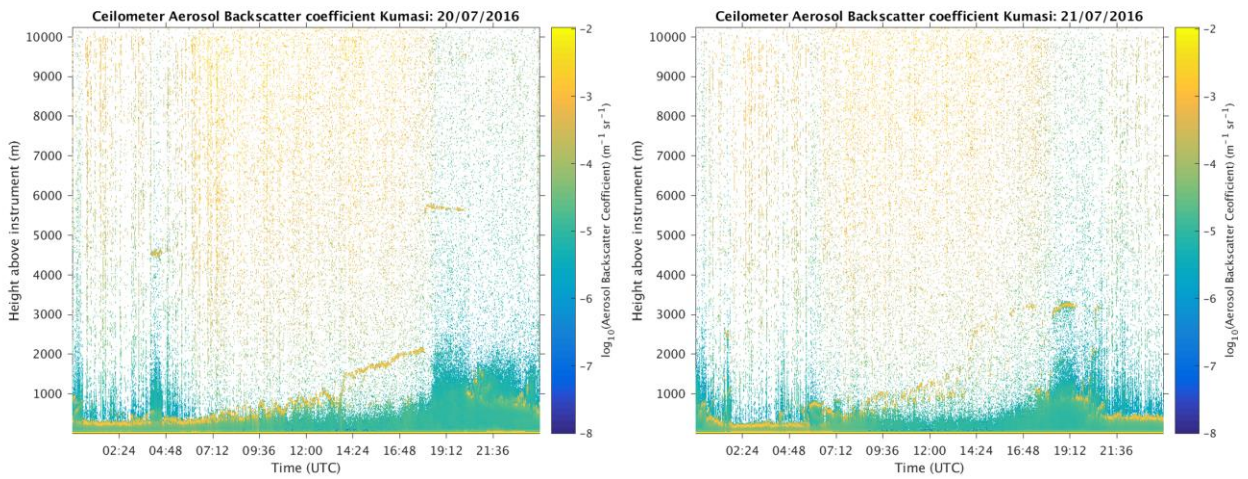


Figure 28: Ceilometer backscatter (colour-coded) at Kumasi during IOP 12.

5.13 IOP 13

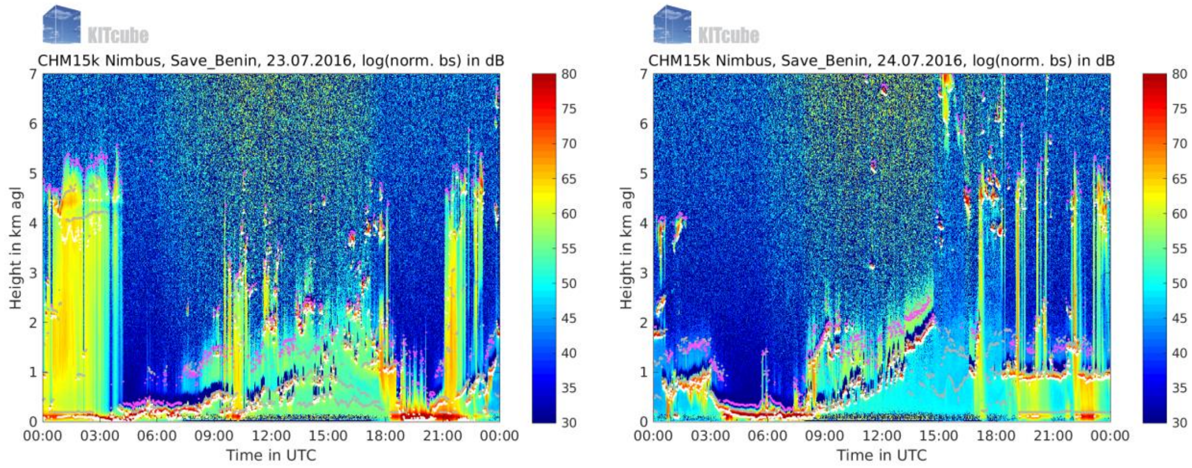


Figure 29: Ceilometer backscatter (colour-coded) at Savè during IOP 13. White dots indicate cloud base.

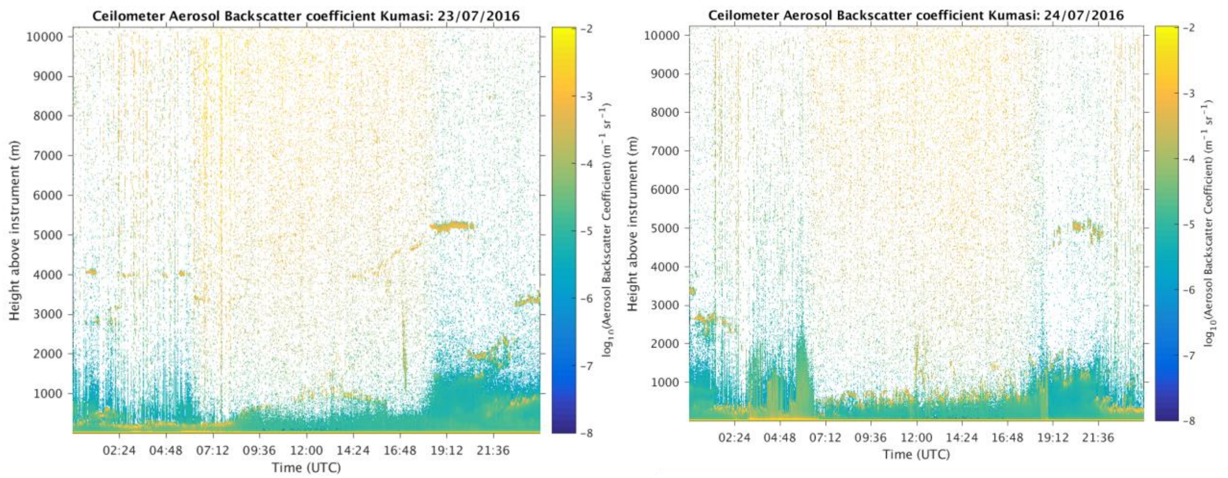


Figure 30: Ceilometer backscatter (colour-coded) at Kumasi during IOP 13.

5.14 IOP 14

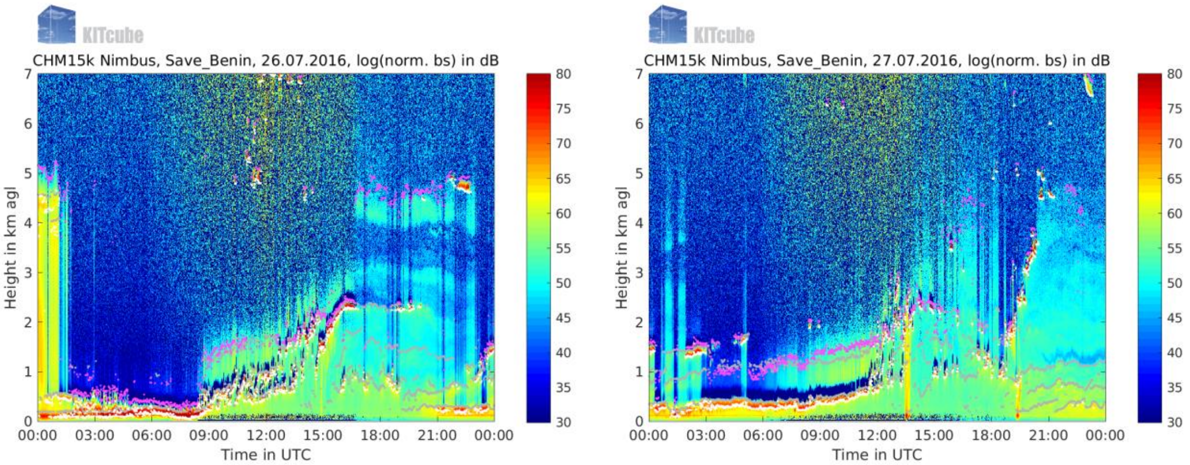


Figure 31: Ceilometer backscatter (colour-coded) at Savè during IOP 14. White dots indicate cloud base.

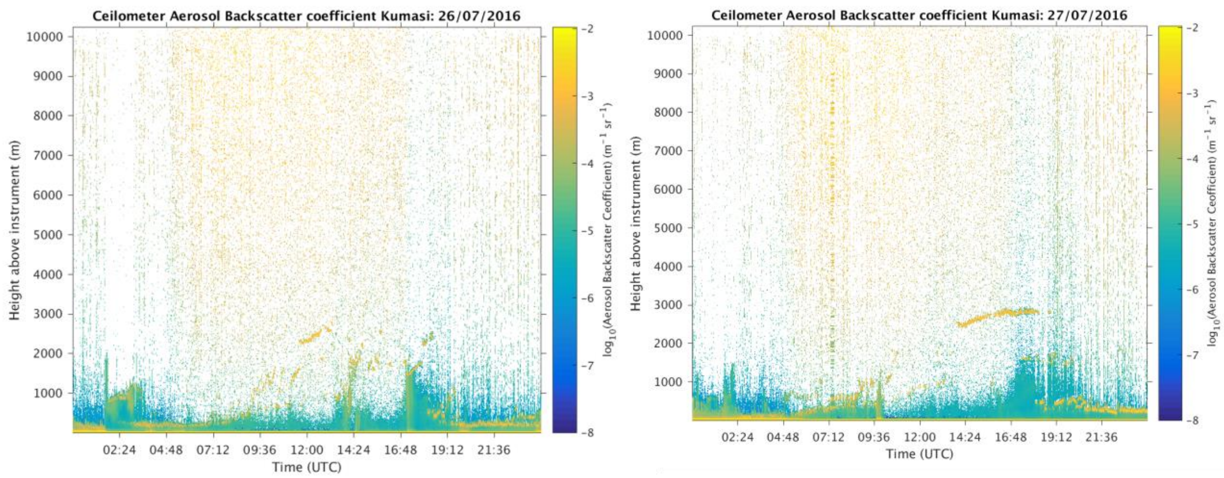


Figure 32: Ceilometer backscatter (colour-coded) at Kumasi during IOP 14.

5.15 IOP 15

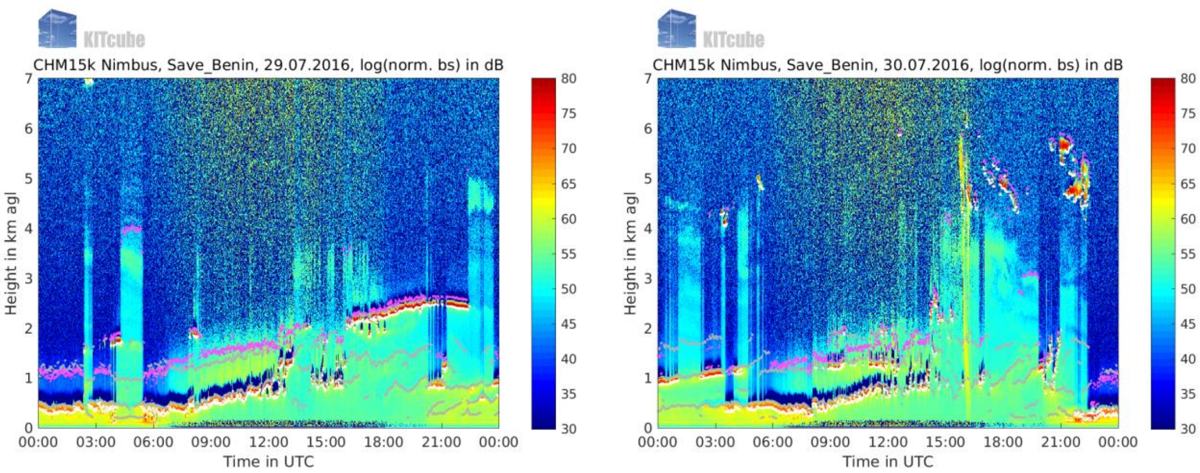


Figure 33: Ceilometer backscatter (colour-coded) at Savè during IOP 15. White dots indicate cloud base.

6 Summary

This deliverable D1.1 gives an overview of the atmospheric-boundary-layer campaign which includes measurements at the three supersites in Ghana, Benin, and Nigeria during the months June and July 2016. This period also encompasses the aircraft campaign which was led from Lomé/Togo.

Within the atmospheric-boundary-layer campaign, in total 15 intensive operation periods (IOPs) were performed. During the IOPs additional radiosoundings in up to hourly intervals as well as RPAS flights were conducted in addition to the extensive continuously operated instrumentation. The measurements cover a wide range (large-scale) meteorological conditions. Therefore, we can assume that all ingredients are available in the data set that allow to successfully determine the parameters which control the life-cycle of the low-level nocturnal stratus in southern West Africa. These overview also allows case study selection for the data users from the other work packages and illustrates that the pre-conditions for the milestones MS4 and MS5 are reached.

Appendix 1: Briefing summary report

DACCIWA WP1 briefing summary

10 July, 2016

Participants: Savè (Fabienne Lohou, Norbert Kalthoff), Kumasi (Victoria Smith), Ile-Ife (Gbenga Jegede)

1. Forecast: see on Sharepoint WP1 / Forecast

2. Status of supersite instruments available on:

hhttp://dacciwa.sedoo.fr/monitoring.php?current=20160702&nav=Monitoring

1. Operations for the current IOP#9 (10 -11 July 2016)

IOP# 9 is maintained: unusual conditions up to now with very deep and strong monsoon flow and almost no AEJ. Since we have already several good IOPs with LLC, we are searching for unusual conditions like these.

Research Aircrafts:

- Sunday 10 July
    - ATR flew today Lomé-Cotonou-Savè-Parakou: mid-level cloud flight.
    - TO flew over Savè above clouds in the morning.
- Monday 11 July: ATR and Falcon would fly over Abidjan and TO over Lomé.

Savè:

- FRS: from 10 July 1700 UTC to 11 July 1100 UTC every 1.5 hours
- RS: 0000, 0600, 1200, 1800 UTC
- ALADINA flights:
    - 2 stratus morning flights 10 July (0530 – 0830 UTC)
    - 3 breaking stratus flights 10 July (1100 – 1930 UTC)
- OVLITA: perhaps one flight if the wind does not increase to much in the late afternoon to increase the temporal monitoring of the 1745 to 1845 period during which strong humidification is observed on FRS.

Kumasi:

- 10 July, 18 UTC to 11 July, 18 UTC: radiosondes every 6 hours

Ile-Ife:

- soundings from 10 July, 1800 UTC to 11 July 04, 1800 UTC

2. Foreseen operations

Since we have LLC every day, we more or less decided to do an IOP every 3 days unless an MCS over the sites or/and rain are forecasted.

Tuesday 12 July: no IOP

A possible IOP could be done during the night from Wednesday 13 July to Thursday 14 July.

Appendix 2: Operation plan

DACCIWA – Field campaign 2016

OPERATION PLAN FOR GROUND BASED SUPERSITES

Table of contents

1 Introduction

1.1 DACCIWA project overview

Massive economic and population growth and urbanisation are expected to lead to a tripling of anthropogenic emissions in southern West Africa (SWA) between 2000 and 2030, the impacts of which on human health, ecosystems, food security and the regional climate are largely unknown.

An assessment of these impacts is complicated by:

1. a superposition with effects of global climate change,
2. the strong dependence of SWA on the sensitive West African monsoon,
3. incomplete scientific understanding of interactions between emissions, clouds, radiation, precipitation and regional circulations
4. a lack of observations to advance our understanding and improve predictions.

DACCIWA will quantify the influence of anthropogenic and natural emissions on the atmospheric composition over South West Africa and assess their impact on human and ecosystem health and agricultural productivity. It will quantify the coupling between aerosols and clouds and identify controls on the formation and persistence of low-level clouds. Further it will identify meteorological controls on precipitation, focusing the transition from stratus to convective clouds and the forcing from weather systems. DACCIWA will quantify the two way cloud and aerosol impacts on the radiation and energy budgets from the cloud scale to the scale of the West African monsoon circulation. State-of- the-art meteorological, chemistry and air-quality models, satellite retrievals of clouds, precipitation, aerosols and radiation will be assessed in close collaboration with operational centres and research findings will be communicated to policy-makers, scientists, operational centres, students, and general public using a graded communication strategy.

1.2 Scientific objectives of WP1

The structure of the atmospheric boundary layer (ABL) depends mainly on the energy exchange at the Earth’s surface. However, due to the high natural and anthropogenic emissions in Southwest Africa, gaseous and aerosol air pollutants also affect the diurnal cycle of the ABL, as do sea breeze and monsoon flows from the Gulf of Guinea.

Characteristic features, for example nocturnal low-level jet (LLJs), deep daytime ABLs, and various types of boundary-layer clouds often occur. During the course of the day a transition from nocturnal low-level stratus to stratocumulus, cumulus, and sometimes congestus and possibly cumulonimbus clouds is observed. The atmospheric processes driving this transition are sensitive to the conditions mentioned above and although the nocturnal low-level stratus and the transition to broken clouds appear quite frequently, little attention has been paid to the phenomenon so far.

In this work package, the intention is to identify the meteorological controls on the whole process chain from the formation of nocturnal stratus clouds, via the daytime transition to convective clouds and the formation of deep precipitating clouds. This will be achieved by performing detailed intensive in-situ and remote sensing observations in addition to highly resolved model simulations (large eddy simulations, LES). The intensive observational period will include measurements of the energy-balance components at the Earth's surface, the mean and turbulent conditions in the nocturnal and daytime ABL as well as measurements of the de- and entrainment processes between the ABL and the free troposphere. The meteorological measurements will be supplemented by air chemical observations.

1.3 Useful links

DACCIWA project: http://www.dacciwa.eu/

DACCIWAsharepoint: https://team.kit.edu/sites/dacciwa/

DACCIWA general operation plan:

Quicklooks and data: http://dacciwa.sedoo.fr/

Misva: http://misva.sedoo.fr/

Eumetsat: http://www.eumetsat.int/

Synop reports: http://www.ogimet.com/gsynop.phtml.en

ECMWF forecast: http://www.ecmwf.int/en/forecasts

1 Field Campaign

1.1 Investigation Area

During the monsoon season 2016 intensive measurements will be performed at three supersites in southern West Africa: Kumasi (Ghana), Savé (Benin) and Ile-Ife (Nigeria) (locations are given in Fig. 1).

The supersites are in different time zones (Table 1). For example, 0600 UTC is 0600 local standard time (LST) in Ghana and 0700 LST in Benin and Nigeria. All time lines are in UTC hereafter.

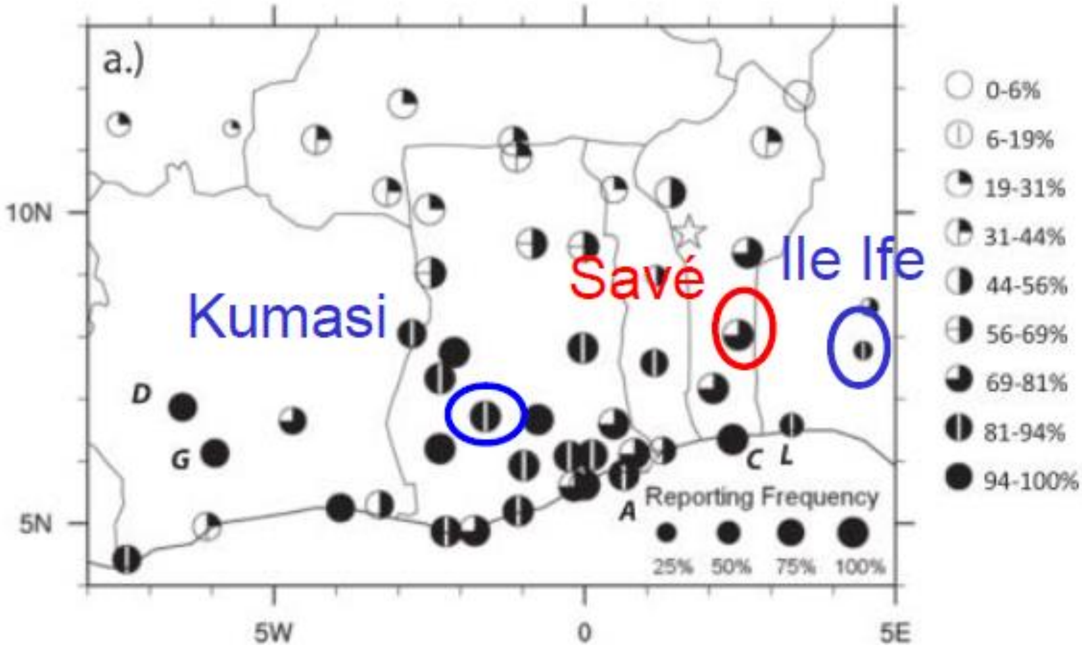


Fig. 1 Frequency of stratus in June-October 2006 (from Schrage et al. 2012). The locations of the supersites Kumasi, Savé and Ile-Ife are indicated

Table 1: Geographic location of supersites.

	Savé	Kumasi	Ile-Ife
Latitude	N 8°00'03.6" (Gobe site) N 8°01'04.4" (airfield)	N 6° 40’ 48.56’’	N 7º 33’ 11.52”

Longitude	E 2°25'41.1 (Gobe site) E 2°27'50.8" (airfield)	E 1° 33’ 37.76’’	E 4º 33’26.70”
Height (m MSL)	166 (Gobe site) 180 (airfield)	266	274

Table 2: Time zones at the supersites.

Supersite	**Time zone**
Ghana	UTC
Benin	UTC+1
Nigeria	UTC+1

1.1.1 Savé

The site at Savé will be operated jointly by KIT (Karlsruhe Institute of Technology) and UPS (Université Toulouse III - Paul Sabatier, Laboratoire d’Aérologie).

All ground-based instruments and the RPAS OVLITA will be deployed at the measurement site at Gobe at the site of INRAB (Institut National de Recherche Agronomique du Benin). The RPAS Aladina will be operated at the Savé airfield.

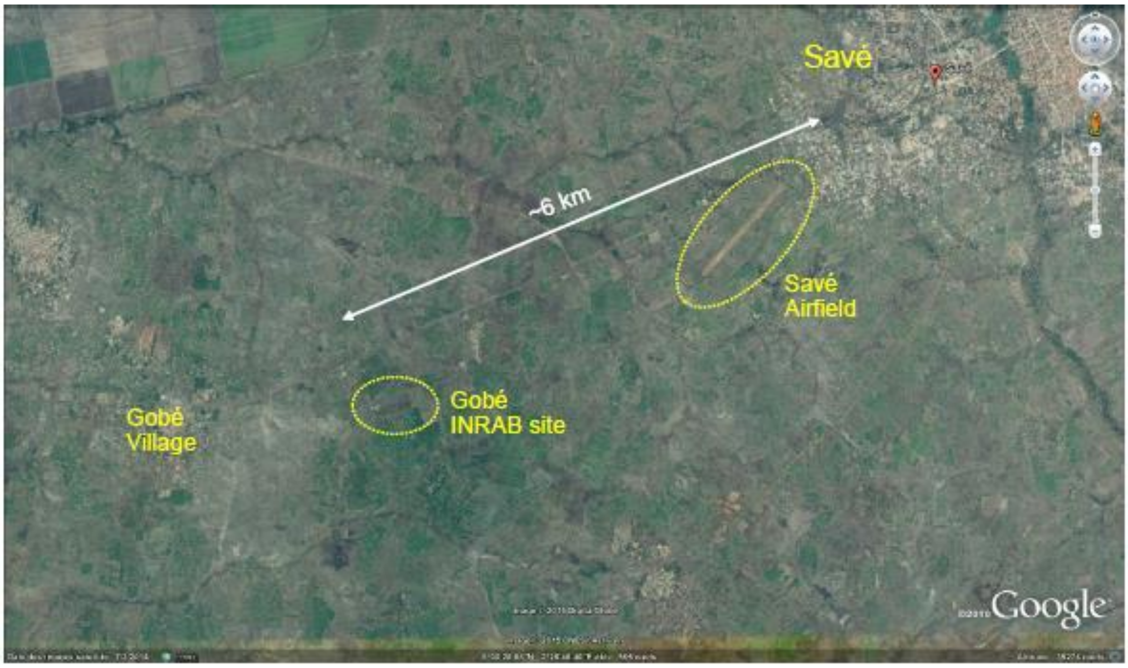


Fig. 2: Overview of measurement sites close to Savé.

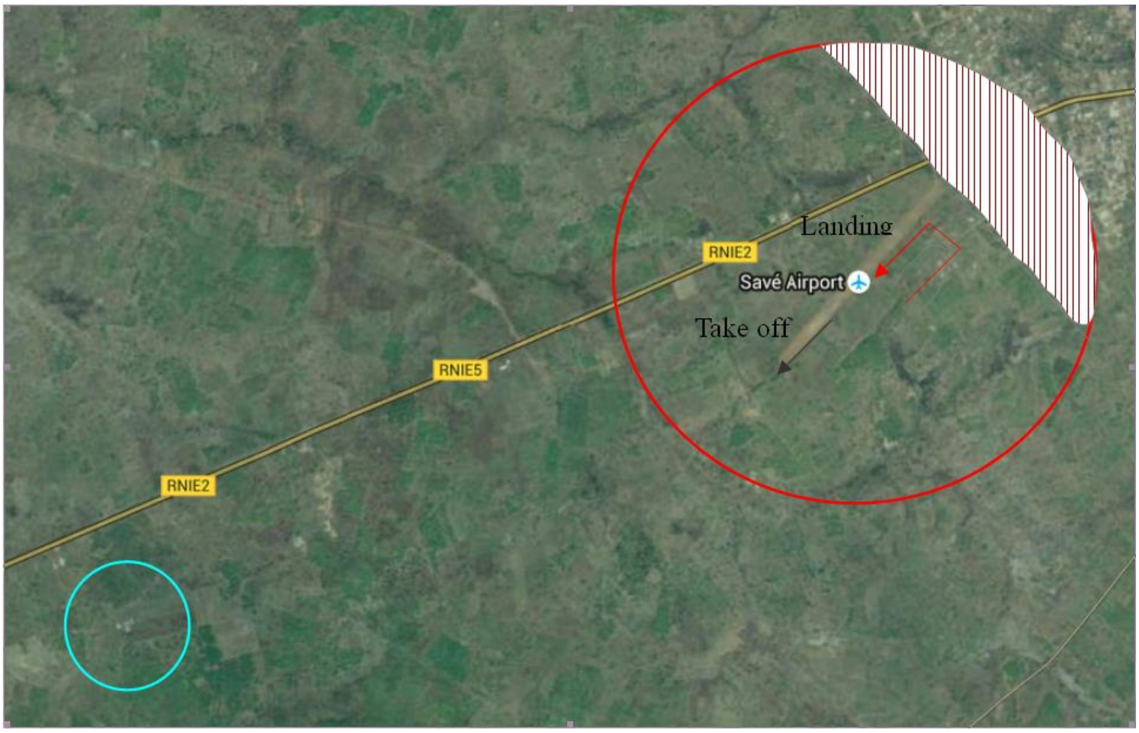


Fig. 3: Overview of airfield sites at Savé. The red circle stands for the 1 km radius zone for the RPAS Aladina operation. The white area is excluded from the ALADINA operation because of the city. The blue circle stands for the zone for the RPAS OVLITA operation.

1.3.1 Kumasi

The Kumasi site is on the estates of KNUST (Kwame Nkrumah University of Science and Technology): specifically on the grounds of the University's Department of

Agriculture. The Department of Agriculture operates a Meteorological site (henceforth referred to as AGROMET) with a wide range of instrumentation housed in an extensive and maintained paddock: the supersite will be deployed around this paddock ensuring that this temporary deployment does not interfere with the permanent measurements. The site will be operated by NCAS (National Centre for Atmospheric Science) with logistical assistance from KNUST. All ground-based instruments will be deployed at this measurement site.

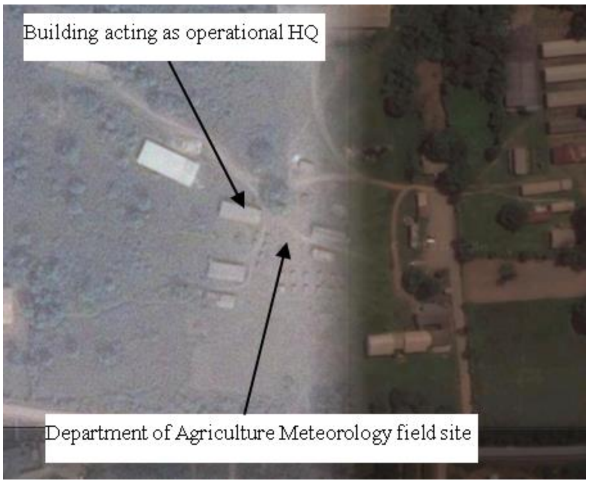


Fig. 4: Overview of the AGROMET site.

Fig. 5: 360° pictorial overview of the AGROMET site

1.3.2 Ile-Ife

Fig. 6: Instruments deployed at Ile-Ife

1.4 Time line

The measurement period at the supersites lasts from **13 June – 31 July 2016**. The aircraft field campaign will take place from **27 June – 17 July 2016**.

The setup of the instruments at Savé will start around 30th May and the teardown will end around 7th August.

For Kumasi site setup will commence around 5th June and teardown will end around 7th August.

At Ile-Ife supersite, which is the same location for the permanent meteorological station, OAU-Met, the measurements will begin in January 2016. In consonance with the scheduling for the field measurement phase of DACCIWA (WP1), data capture will run from April 1st, 2016 till end of August 2016. Beyond August 2016, record of the field data will still be continued.

2 Instrumentation

In this section, the ground-based instrumentation at the three supersites Savé, Kumasi and Ile-Ife is listed. For details on the instrument see Appendix A. Based at Lome in Togo three research aircrafts will be operated during the three weeks of the aircraft campaign. The aircrafts are BAS Twin Otter (UK), Safire ATR42 (France) and DLR Falcon 20 (Germany). Details on these research aircrafts can be found on the DACCIWA sharepoint.

2.1 Savé

Fig. 7: Instrumentation map at Gobe site.

Table 3: Surface measurements.

Instrument	Operator	Measured parameters
Energy balance station	KIT	Q, H, E, B, SW, LW, SM, ST, T, RH, P, wind, RF

Energy balance station and chemistry tower	UPS	Q, H, E, B, SW, LW, SM, ST, T, RH, P, wind, prec, BF, CCC

Q: Net radiation

H: Sensible heat flux

E: Latent heat flux

B: Soil heat flux

SW: Short-wave radiation components

LW: Long-wave radiation components

SM: Soil moisture

ST: Soil temperature

T: Air temperature

RH: Relative Humidity

P: Pressure

prec: Precipitation

BF: biogenic fluxes (NO, NO2, isoprene turbulent fluxes)

CCC: Chemical Compound Concentration of O3, NO, NO2, CO, isoprene

Table 4: Measurements in the boundary layer and above

Instrument	Operator	Measured parameters
Sodar	KIT	Horizontal wind profile (0-600 m)
UHF wind profiler	UPS	Horizontal wind profile (200 - 4000 m)
Wind lidars	KIT	Radial velocity *WindTracer*: scanning or vertical stare (400-10000 m, depending on aerosol concentration) *Windcube*: (0-600 m)

Microwave radiometer	KIT	Temperature and humidity profiles, IWV, LWP, CBT
Radiosondes (normal RS and frequent RS)	UPS	T, RH, P, wind profiles Normal RS: 0-20 km Frequent RS: 0-2 km

IWV: Integrated water vapour

LWP: Liquid water path

CBT: Cloud base temperature

Table 5: Measurements of cloud characteristics and precipitation

Instrument	Operator	Measured parameters
Cloud radar	KIT	Radial velocity, cloud top
Ceilometer	KIT	Cloud base
X-Band radar	KIT	Precipitation
MRR, distrometers	KIT	Precipitation, drop size distribution
Cloud camera	UPS	Cloud cover

Table 6: Aerosol measurements

Instrument	Operator	Measured parameters
Grimm aerosol spectrometer	KIT	Particle concentration for particle sizes from 0.25 to 32 µm
Sun photometer	KIT & University Reading	Aerosol optical depth (normal mode and cloud mode)

Table 7: RPASs (unpiloted aerial vehicles)

	RPAS Aladina	RPAS OVLI
Operator	TU Braunschweig	LA
Location	Savé airfield	Gobe site
Meteorological parameters	T, RH, P, wind, fluxes	T, RH, P, wind
Dimensions	3.6 m x 2 m	Small…
Weight	25 kg	2.5 kg
Maximum wind speed	15 m/s	7-8 m/s
Air speed	25 m/s	10 m/s
Clouds	No (maybe touch bottom)	Maybe (try)
Night	Yes	No
Operation duration for 1 mission	45 min / 1 flight, 10-20 min between flights, max. 10 flights per mission, ~10 h max	90 min / flight (minimum, with thermic maybe longer), 2 planes in turn to fly continuously
Measurement strategy	Fluxes along constant height flight legs; 1 profile at the beginning to get profiles of wind, temperature and humidity Leg's length according to the pilot (RPAS must be visible). Flight in a 1 km-radius circle.	Helicoidal Profiles

2.2 Kumasi

Table 8: Surface measurements

Instrument	Operator	Meteorological parameters
Energy balance station	NCAS	Q, H, E, B, SW, LW, SM, ST
Flux station	NCAS	TS, P, U, V, W, H20, CO2, TL, DT
AWS	NCAS	T, RH, PP, WS, WD, PPT

Q: 1Hz Net radiation

H: 1Hz Sensible heat flux

E: 1Hz Latent heat flux

B: 1Hz Soil heat flux

SW: 1Hz Short-wave radiation components

LW: 1Hz Long-wave radiation components

SM: 1Hz Soil moisture

ST: 1Hz Soil temperature

T: 5 min Air temperature

PP: 5 min pressure

WS: 5 min horizontal wind

WD: 5 min horizontal wind direction

PPT: 5 min precipitation

RH: 5 min Relative Humidity

P: 20Hz Pressure

H20: 20Hz water vapour concentration

CO2: 20Hz carbon dioxide concentration

U,V,W: 20Hz wind speed components

TS: 20Hz sonic temperature

TL: 20Hz licor air temperature

DT: 20Hz licor dew point temperature

Table 9: Measurements in the boundary layer and above

Instrument	Operator	Meteorological parameters
Sodar	NCAS	Horizontal wind profile (0-600 m) , CT2
Microwave radiometer	NCAS	Temperature and humidity profiles, IWV, LWP, CBT
Radiosondes (normal and frequent)	NCAS	T, RH, P, wind profiles

IWV: Integrated water vapour

LWP: Liquid water path

CBT: Cloud base temperature

Table 10: Measurements of cloud characteristics and precipitation

Instrument	Operator	Meteorological parameters
Ceilometer	NCAS	Coud base, aerosol backscatter coefficient
MRR	NCAS	Precipitation, drop size distribution
Cloud camera	NCAS	Cloud cover

Table 11: Aerosol measurements

Instrument	Operator	Meteorological parameters
Sun photometer	NCAS	Optical depth

2.3 Ile-Ife

Table 12: Surface measurements

Instrument	Operator	Meteorological parameters
Energy balance station	OAU	Q, H, E, B, SW, LW, SM, ST, T, RH, P, wind, prec
15-m tower	OAU	T, RH, P, wind (multilevels)

Q: Net radiation

H: Sensible heat flux

E: Latent heat flux

B: Soil heat flux

SW: Short-wave radiation components

LW: Long-wave radiation components

SM: Soil moisture

ST: Soil temperature

T: Air temperature

RH: Relative Humidity

P: Pressure

prec: Precipitation

Table 13: Measurements in the boundary layer and above

Instrument	Operator	Meteorological parameters
Sodar	OAU	Horizontal wind profile (0-600 m)
Tethered radiosonde	OAU & KIT	T, RH profiles

Table 14: Measurements of cloud characteristics and precipitation

Instrument	Operator	Meteorological parameters

Handhold infrared radiometer	OAU & KIT	Cloud base temperature
Rain gauge	OAU	precipitation

Table 15: Aerosol measurements

Instrument	**Operator**	**Meteorological parameters**
Sun photometer	OAU	Aerosol optical depth

3 Measurement Strategy

Continuous measurements will be performed throughout the whole measurement period. This includes all instrumentation except the normal and frequent radiosoundings, the RPASs and the research aircrafts.

3.1 Non-IOPs

During the whole measurement period there will be one radiosounding per day in the morning, i.e. when the low-level cloud cover is most intense, to get a statistic of atmospheric conditions. The sonde is launched 30 min prior the hour, i.e. the 0600 UTC sonde is launched at 0530 UTC.

3.2 IOPs

In total we plan on about 20 IOPs. Around 10 IOPs will be during the aircraft campaign, 5 before and 5 after the aircraft campaign. IOPs will always be at all supersites (even if the conditions are less favourable at one of the sites).

3.2.1 IOP definition

WP1-related IOPs focus on NLLJ, stratus, dissolving stratus and convective cumulus (type A) or on clear calm conditions with no MCS or other large-scale influences but no stratus and/or NLLJ (type B). WP1-related IOPs are out of rainy days and MCS perturbations.

3.2.2 IOP during and outside aircraft campaign

An IOP day (D) starts in the evening of D-1 and lasts until the evening of D. There will be 5 normal radiosoundings (NRS) with 6-hour intervals, the first one will be launched at 1730 UTC on D-1 and the last one at 1730 UTC on D. Maybe skip the first sounding at 1730 UTC on D-1 if we find out there are no important changes between 1730 and 2330 UTC.

During the aircraft campaign, frequent radiosoundings (FRS) will be performed between 2130 UTC on D-1 and 0930 UTC on D in hourly intervals. At 2330 and 0530 UTC there will be normal radiosondes instead of frequent radiosondes.

Outside the aircraft campaign, FRS will be performed between 2130 UTC on D-1 and 1030 UTC on D in hourly intervals, i.e. 1 hour later in the morning than within the aircraft campaign, to account for the missing profile flights from the RPAS OVLI.. At 2330 and 0530 UTC there will be normal radiosondes instead of frequent radiosondes.

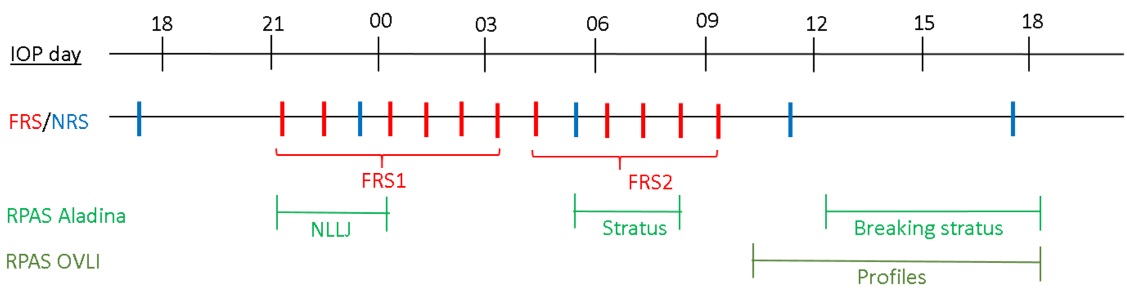


Fig. 8: IOP schedule during aircraft campaign.

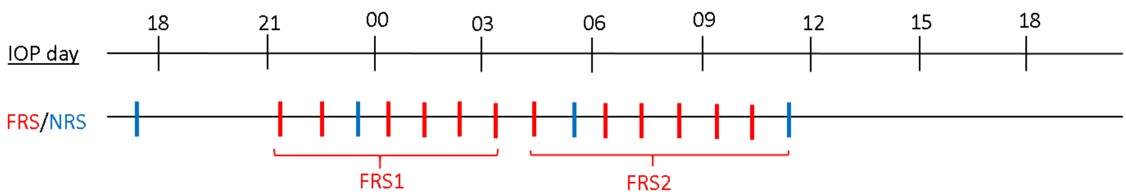


Fig. 9: IOP schedule outside the aircraft campaign.

During the aircraft campaign, the RPAS Aladina will fly during three possible periods. The first period is when the nocturnal low-level jet (NLLJ) forms. The second period is when there is stratus and the third period is when the stratus is breaking. Detailed flight patterns are given in the next section. Two of these patterns will be chosen for each IOP according to the focus of the IOP.

The RPAS OVLI will perform profiles to get atmospheric conditions in the boundary layer when the frequent radiosoundings stop in the morning.

When the research aircrafts are approaching the supersites, the aircraft crew will get in contact with supersites (science director) via satellite telephone (sea Important contact information). During fly by, the RPAS and radiosounding activities will be interrupted, i.e. the RPAS will stay on the ground (away from the runway).

3.3 Scan strategy for remote sensing instruments at Savé

3.3.1 Microwave radiometer

With the microwave radiometer we intend to get information on the integrated water vapour (IWV) in vertical stare mode with high temporal resolution, on the horizontal distribution of humidity and on the temperature profile in the lower atmosphere. Therefore, we perform a combination of PPIs, boundary layer scans and vertical stare mode.

For the beam to be above the surrounding vegetation the PPIs are performed at 15° (? try) elevation angle. Along the beam we derive IWV and liquid water path (LWP). Assuming moist air approaching Savé in the lowest 2000 m, the moist air could first be detected at about 7.5 km distance from Savé. If the moist air propagates with 5 m s^{-1} the time between the first detection and the arrival at Savé will be about 25 min (see Fig. 7). After about 50 min moist air would be within the whole measurement range. This means in order to capture the direction of the advection of moist air, PPIs should be performed at least every 30 min.

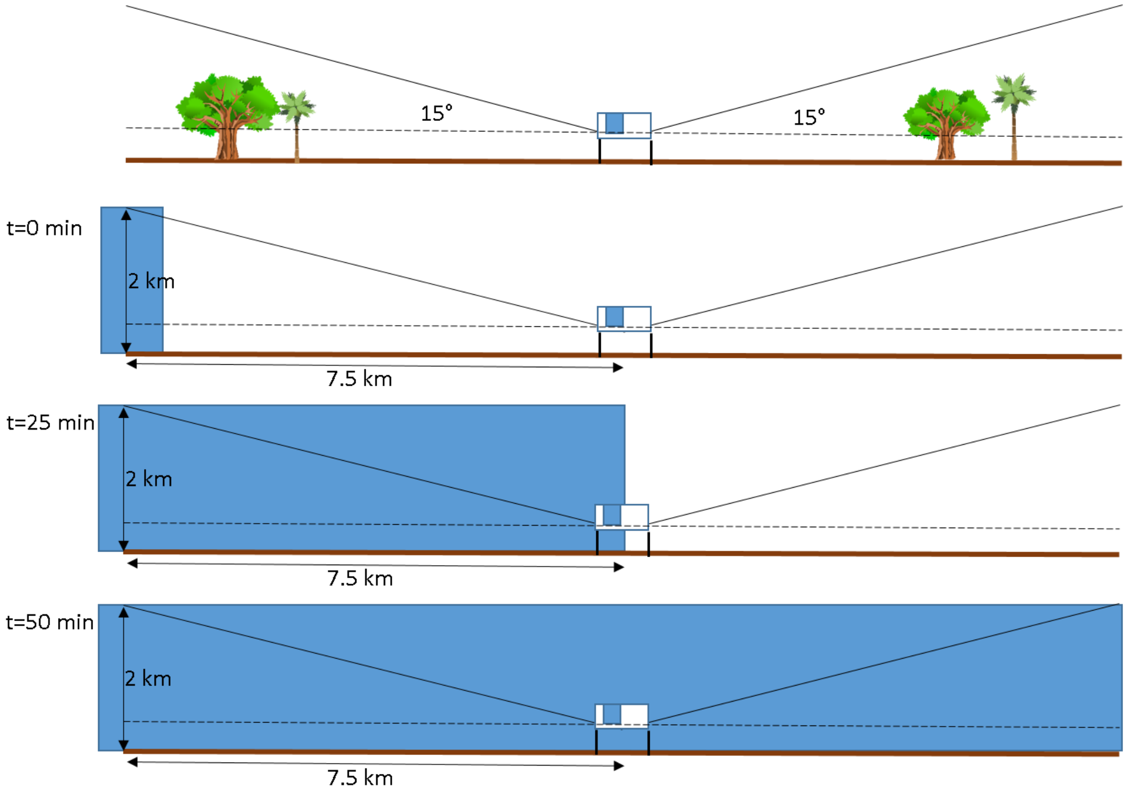


Fig. 10: Schematic diagram to illustrate the PPI of the microwave radiometer at Savé

Boundary layer scans will be performed every 30 min. Thus, the scan strategy for the microwave radiometer is:

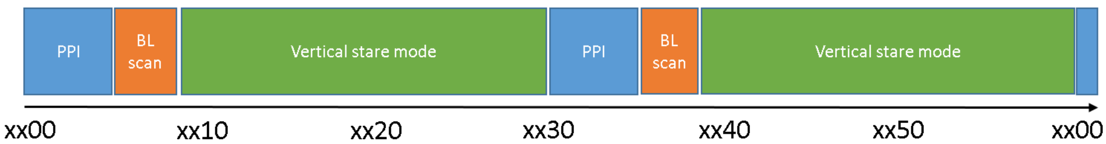


Fig. 11: Time line of the scan strategy performed with the microwave radiometer at Savé.

With this scan strategy we get the spatial humidity distribution, temperature profiles of the lower atmosphere with a temporal resolution of about 30 min and sufficient information about IWV and LWP in vertical stare mode with a temporal resolution of about 1 s.

3.3.2 Wind lidars

The wind lidar *Windcube* is operated in vertical stare mode to provide vertical wind speed with high temporal resolution in the lowest 600 m.

With the scanning wind lidar *WindTracer* we intend to measure vertical wind speed with high temporal resolution and to get information about the 3-dimensional structure of gravity waves during the night and convective cells during the day. In order to get information about gravity waves, RHI scans in mean wind direction are needed. Convective cells form in streaks during the day. Thus, it is better to perform RHI scans perpendicular to the mean wind direction during the day to cut through the streaks. We do not need the wind lidar to derive the horizontal wind speed profile, as we have the sodar and UHF.

We perform a combination of RHI scans and vertical stare mode. In vertical stare mode the measurement range is from 350 to 3000 m with a vertical range resolution of 25 m and a temporal resolution of 1 s RHI scans will be performed every 30 minutes in a sector of 60° with an increment of 30° in and perpendicular to the mean wind direction (Figs. 12 and 13).

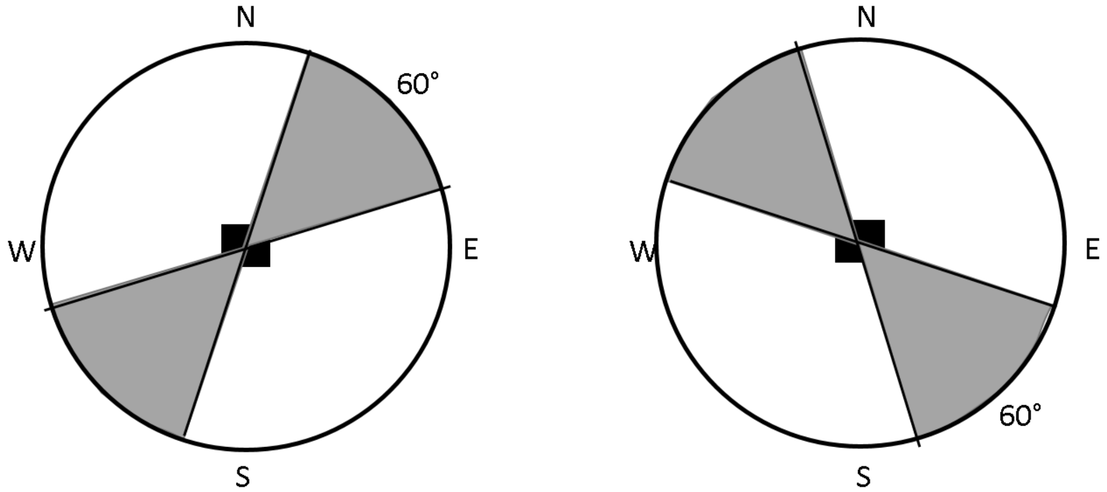


Fig. 12: Schematic diagram of RHI scans performed with the wind lidar WindTracer and the cloud radar at Savé.

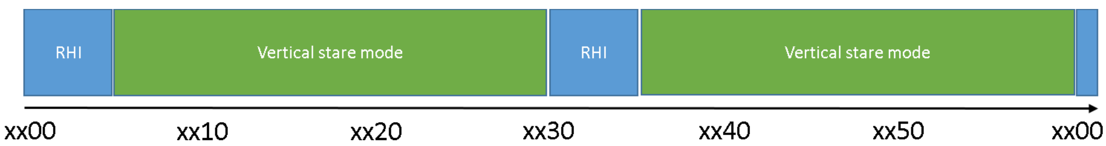


Fig. 13: Time line of scans performed with the wind lidar WindTracer and the cloud radar at Savé.

3.3.3 Sodar

The sodar provides horizontal wind speed profiles in the lowest 600 m with a vertical resolution of 10 m and a temporal resolution of 30 min.

3.3.4 UHF

The UHF wind profiler provides the three wind components, the boundary layer height, the turbulent kinetic energy dissipation with 75 m of vertical resolution and 10 minutes of temporal resolution between 200 and 4000m.

3.3.5 Cloud radar

With the cloud radar we intend to measure to vertical structure in clouds as well as spatial variability of clouds. Therefore, we perform a combination of RHI scans and vertical stare mode similar to the wind lidar. In vertical stare mode the cloud radar provides vertical wind speed profiles from 150 m to 15000 m (depending on the backscatter concentration) at a vertical resolution of 30 m and a temporal resolution of 10 s. During RHI the cloud radar scans between 45 and 115° elevation angle. RHI scans will be performed every 30 minutes in a sector of 60° with an increment of 30° in and perpendicular to mean wind direction (Figs. 12 and 13).

3.3.6 MRR

Because the 0° C level is often between 500 and 600 hPa in Africa (roughly 4000-6000 m) range intervals of 200 m are chosen. With a total of 32 ranges it then measures up to 6400 m. The temporal resolution is 1 min.

3.3.7 X-band rain radar

The X-band rain radar performs a volume scan every 5 minutes using 10 elevation angles between 0.5 and 30°. Its maximum range is 100 km.

3.4 RPAS at Savé

3.4.1 General information

The objectives of the UAV operation at Savé is (i) to get profiles of the lower atmosphere when no frequent radiosoundings are performed (OVLI) and (ii) to get flux profiles during the night (with LLJ and clouds/ no clouds) and during the day in the cloud-topped boundary layer (Aladina).

At the beginning of each flight we fly a profile up to about 700 m (depending on the actual conditions) or the cloud base. After that, we fly a L-pattern with one leg parallel to the mean wind and the other leg perpendicular to the mean wind in order to account for anisotropy. Each leg should be as long as possible (~2 km).

Based on BLLAST measurements we estimates the times for this flight pattern: a leg of 2 km takes about 120 s (2 min); changing the flight level by 200 m takes about 2 min; a profile from the surface up to 700 m takes about 5 min.

The time estimates for a possible flight pattern is: Profile up to 700 m + 3 heights with 200 m height difference with a L-pattern = 5 min + 18 min = 23 min

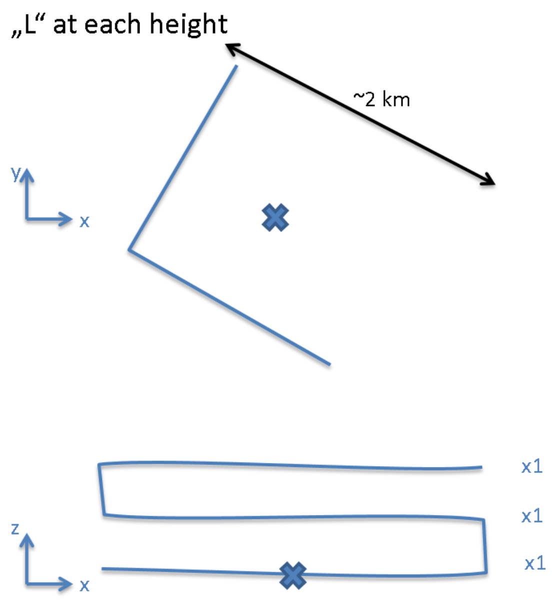


Fig. 14: General L-pattern of RPAS Aladina.

3.4.2 Specific flight patterns

Nocturnal low-level jet (NLLJ, Fig. 15)

4 levels: 1 level in the surface layer (100 m); 1 level in the sheared layer below jet nose (100 m below jet nose); 1 level in the jet nose; and 1 level in the sheared level above jet nose (100 m above the jet nose).

The levels change according to the jet nose height.

Stratus (Fig. 16)

2 or 3 levels: 1 level in the surface layer (100 m); 1 level below the cloud base (50 m). If cloud base is above 600 m, fly an additional level at half the cloud base height (i.e. if cloud base is at 600 m fly legs at 50, 300, and 550 m above ground).

The levels change according the cloud base height.

Breaking stratus (Fig. 17)

3 levels: 1 level in the surface layer (100 m); 1 level at half the cloud base height; 1 level below the cloud base (50 m if possible).

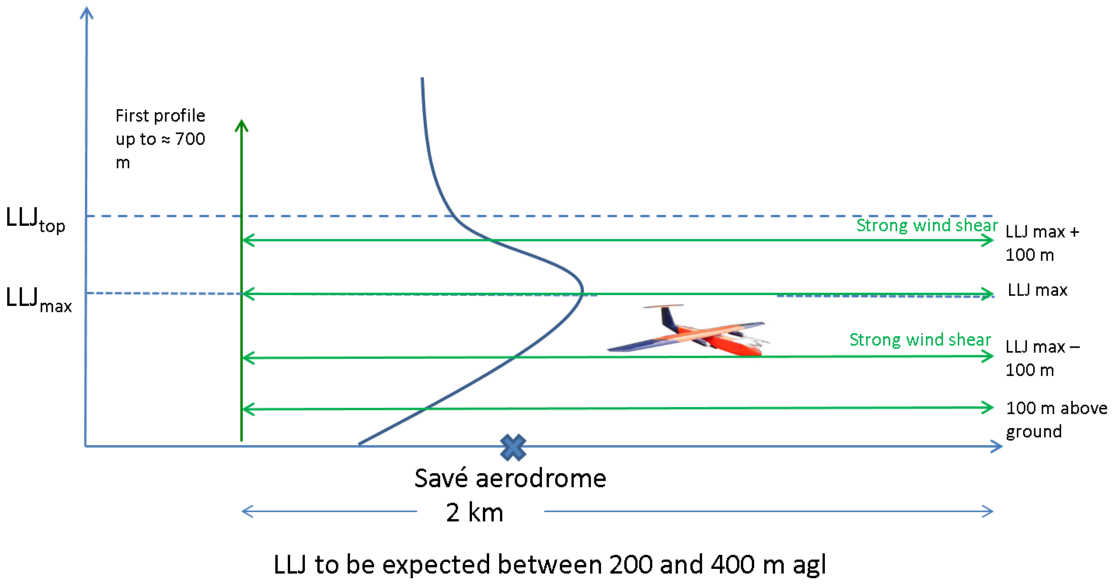


Fig. 15: Flight pattern of RPAS Aladina for NLLJ.

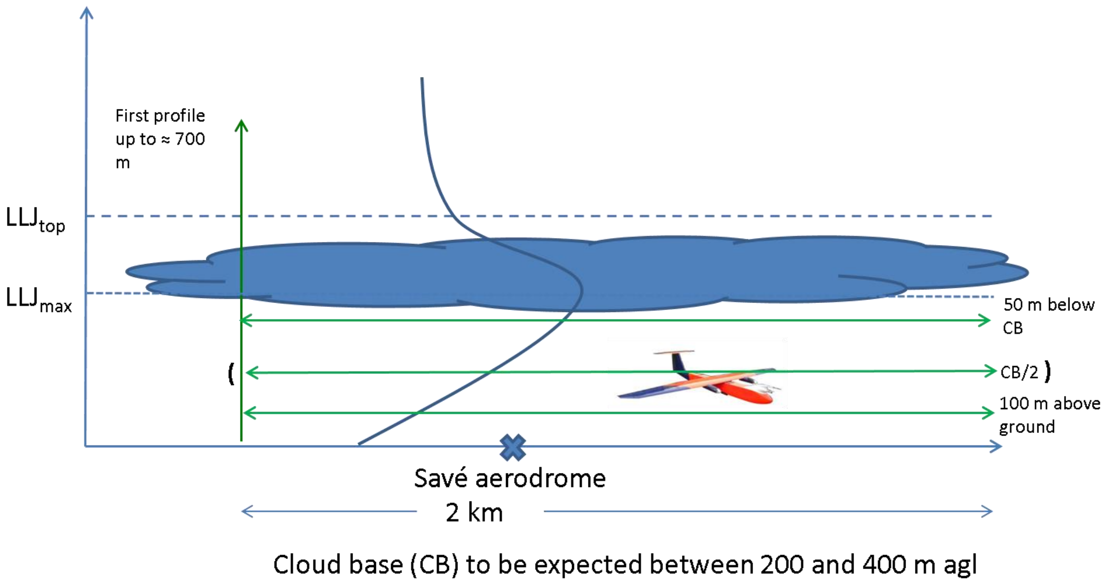


Fig. 16: *Flight pattern for RPAS Aladina for nocturnal stratus.*

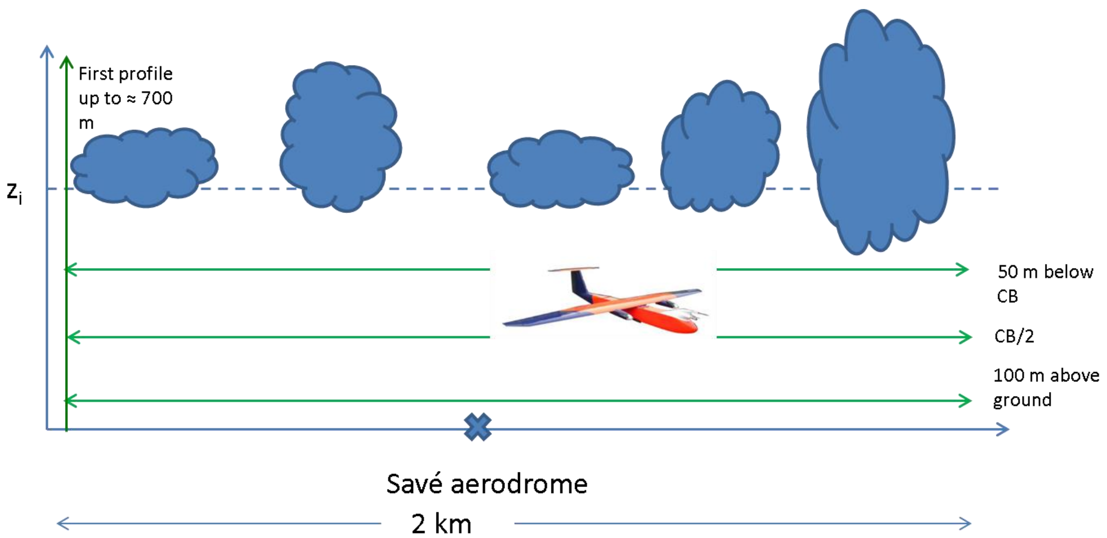


Fig. 17: Flight pattern for RPAS Aladina for breaking stratus and convective clouds.

3.5 Scan strategy for remote sensing instruments at Kumasi

3.5.1 Microwave radiometer

With the microwave radiometer we intend to get information on the integrated water vapour (IWV) and high spatial resolution of the humidity and temperature profile in the lower atmosphere: a combination of boundary layer scans and vertical stare mode will be used will therefore be used with boundary layer scans being performed every 30 min.

3.5.2 Sodar

The sodar provides horizontal wind speed profiles in the lowest 600 m with a vertical resolution of 10 m and a temporal resolution of 30 min.

3.5.3 MRR

Because the 0° C level is often between 500 and 600 hPa in Africa (roughly 4000-6000 m) range intervals of 200 m are chosen. With a total of 32 ranges it then measures up to 6400 m. The temporal resolution is 1 min.

3.6 Scan strategy for remote sensing instruments at Ile-Ife

3.6.1 Sodar

The sodar provides horizontal wind speed profiles in the lowest 600 m with a vertical resolution of 10 m and a temporal resolution of 30 min.

3.7 Research aircrafts

WP1-related flight patterns of the three research aircrafts are the stratus flights, land-sea breeze flights (LSB) and biogenic emission flights. During these flight patterns IOPs are performed at all three supersites. Details on these flight patterns can be found on the DACCIWA sharepoint in the folder Aircraft Campaigns.

4 Coordination and Organisation

At each supersite there will be a log book (electronic) which includes information on maintenance, instrument status (running or not, number of sondes available, number of helium bottles available, …).

Every day the facility status for each instrument is reported on the SEDOO website (green for running; yellow for an unknown status; red for not-running). Quicklooks are also sent to the SEDOO website (see Section 5).

4.1 IOP planning

Every morning the forecaster prepares a detailed weather forecast for the next two days and an outlook for the period afterwards. The forecaster provides a short overview with the most important information and plots and distributes this to the three supersites. There will be only one forecaster, either from the Kumasi or the Savé site, preparing the forecast for all three supersites. At 1400 UTC the weather forecast is discussed at the individual supersites. At 1500 UTC the supersites communicate per phone, compare the results of their discussions and agree on whether there should be an IOP alert on D-2 for Day D.

If there was an IOP alert on day D-2, the final IOP decision is made at 1500 UTC on day D-1. The IOP is cancelled in case of unexpected disturbances, e.g. due to a MCS at all supersites or unavailability of important instruments (facility status). If the IOP is not cancelled the IOP starts at 1730 UTC on day D-1, i.e. the first radiosonde at Kumasi and Ghana will be launched at 1730 UTC on day D-1.

During the weather forecast on day D it is decided if there is an IOP alert for day D+2.

During the aircraft campaign we send our forecast including our recommendation for an IOP on day D to the operation centre on day D-2 (per email or upload it to http://dacciwa.sedoo.fr/). In the morning briefing at the operation centre on day D-1, the operation center decides if there is an aircraft IOP on day D.

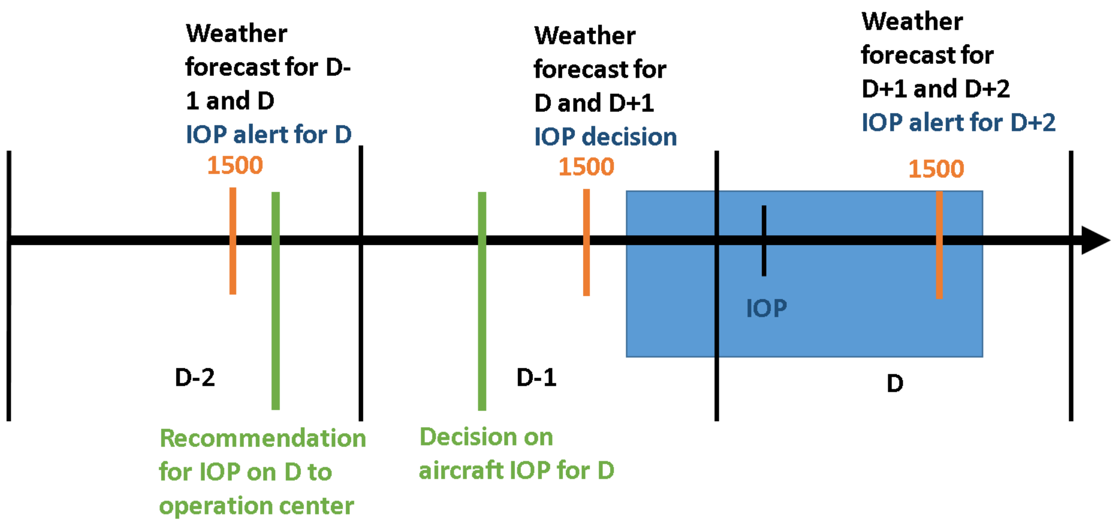


Fig. 18: Time line of IOP planning.

4.2 Forecast tools

Forecast products from ECMWF and Met Office are available on http://dacciwa.sedoo.fr/.

NCAS runs the WRF model for the area around the supersites. Quicklooks are found at https://sci.ncas.ac.uk/dacciwa/

This site is password protected and access details will be disseminated accordingly when the operations commence. The model is run daily with products becoming available around 0800 UTC.

4.3 Important contact information

Site	Position	Phone
Savé station:	Science director	+4915225625896 and +22995471459
	Operation director KIT	+4915227058481 and +22995471460
	Operation director UPS	+22995471520
Kumasi station	Science director	
	Operation director	
	Sonde Operations	

Ile-Ife station		+234-8034007146 +234-8055305482
Lome	Operation center	
SAFIRE ATR	Aircraft	+881 622 403 606
DLR Falcon	Aircraft	+881 621 464 884
BAS TO	Aircraft	+881 651 431 217

4.4 Assignment of tasks

4.4.1 Savé

At Savé, there are several positions which need to be filled by the team. Instead of assigning persons to each positions in advance it might be better to only include positions in this operation plan. Phone numbers of the science and operations directors are included in Sect. 5.3.

Table 16: Overview of tasks that need to be filled at Savé. Science director and operation directors are in contact with other supersites and operation center.

Science director	Responsible for running of site, deals with general problems / issues arising. Contact person for other WP1 super sites and operation center in Lome.
Operation directors (KIT, UPS)	Responsible for instrument status, logbook, circulation of information for decision making and reports and quicklooks; …
Forecaster	Preparation of detailed weather forecast
Radiosondes	In charge of operation of radiosondes (normal and frequent)
RPAS	Responsible for RPAS operation (one person for Aladina and one person for OVLI).

4.4.2 Kumasi

Science director	Responsible for running of site, deals with general problems / issues arising. Contact person for other WP1 super sites.
Operation directors	Responsible for instrument status, logbook, circulation of information for decision making and reports and quicklooks.
Radiosondes	In charge of operation of radiosondes (normal and frequent)
Forecaster	Preparation of detailed weather forecast

4.4.3 Ile-Ife

Table 17: Overview of tasks already filled at Ile-Ife. Science director and operation directors are in contact with other supersites and operation center.

Science director **Gbenga Jegede**	Responsible for running of site, deals with general problems / issues arising. Contact person for other WP1 super sites and operation center in Lome.
Operation directors (OAU) **Muritala Ayoola** **Lukman Sunmonu**	Responsible for instrument status, logbook, circulation of information for decision making and reports and quicklooks.
Weather forecast **NIMET/Francis**	Preparation of weather forecast.
Tethered radiosondes **Muritala Ayoola**	In charge of operation of tethered radiosondes (normal and frequent)
Ground-operations (OAU) **Adewale Ajao**	Ground operations: In charge of instruments at ground.

4.5 Staff

4.5.1 Save

Last name	First name	Affiliation	City, Country	Email
Adler	Bianca	KIT	Karlsruhe, Germany	bianca.adler@kit.edu
Bärfuss	Konrad	TUBS	Braunschweig, Germany	
Bezombes	Yannick	UPS	Karlsruhe, Germany	yannick.bezombes@aero.obs-mip.fr
Bret	Guillaume	UPS	Toulouse, France	guillaume.bret@aero.obs-mip.fr
Bretschneider	Lutz	TUBS	Braunschweig, Germany	
Brilouet	Pierre-Etienne	UPS	Toulouse, France	pierre-etienne.brilouet@aero.obs-mip.fr
Delon	Claire	UPS	Toulouse, France	claire.delon@aero.obs-mip.fr
Deny	Bernhard	KIT	Karlsruhe, Germany	bernhard.deny@kit.edu
Derrien	Solène	UPS	Toulouse, France	solene.derrien@aero.obs-mip.fr
Diallo	Binta			
Dione	Cheikh	UPS	Toulouse, France	cheikh.Dione@aero.obs-mip.fr
Durand	Pierre	UPS	Toulouse, France	pierre.durand@aero.obs-mip.fr
Gabella	Omar	UPS	Toulouse, France	omar.gabella@aero.obs-mip.fr
Gamer	Timo	KIT	Karlsruhe, Germany	timo.gamer@kit.edu
Handwerker	Jan	KIT	Karlsruhe, Germany	jan.handwerker@kit.edu
Haid	Maren	KIT	Karlsruhe, Germany	maren.haid@student.kit.edu
Jambert	Corinne	UPS	Toulouse, Germany	corinne.jambert@aero.obs-mip.fr

Tan Jerome	Nicholas	KIT	Karlsruhe, Germany	nicholas.jerome@kit.edu
Kalthoff	Norbert	KIT	Karlsruhe, Germany	norbert.kalthoff@kit.edu
Endres	Kathe	TUBS	Braunschweig, Germany	
Kohler	Martin	KIT	Karlsruhe, Germany	martin.kohler@kit.edu
Kraut	Stephan	KIT	Karlsruhe, Germany	stephan.kraut@kit.edu
Kunka	Norbert	KIT	Karlsruhe, Germany	norbert.kunka@kit.edu
Lampert	Astrid	TUBS	Braunschweig, Germany	Astrid.lampert@tu-bs.de
Leclercq	Jeremy	UPS	Toulouse, France	jeremy.leclercq@aero.obs-mip.fr
Lohou	Fabienne	UPS	Toulouse, France	fabienne.lohou@aero.obs-mip.fr
Lothon	Marie	UPS	Toulouse, France	marie.lothon@aero.obs-mip.fr
Medina	Patrice	UPS	Toulouse, France	patrice.medina@aero.obs-mip.fr
Pedruzo	Xabier	WU	Wageningen, Netherlands	xabier.pedruzobagazgoitia@wur.nl
Reinares	Irene	UPS	Toulouse, France	irene.reinares@aero.obs-mip.fr
Scheer	Simone	KIT	Karlsruhe, Germany	simone.scheer@kit.edu
Seringer	Jürgen	KIT	Karlsruhe, Germany	juergen.sehringer@kit.edu
Wieser	Andreas	KIT	Karlsruhe, Germany	andreas.wieser@kit.edu

4.5.2 Kumasi

Last name	First name	Affiliation	City, Country	Email

Brooks	Barbara	NCAS	Leeds, UK	barbara.brooks@ncas.ac.uk
Smith	Victoria	NCAS	Leeds, UK	victoria.smith@ncas.ac.uk
Bessardon	Geoffrey	UoL	Leeds, UK	eegb@leeds.ac.uk

4.5.3 Ile-Ife

Last name	First name	Affiliation	City, Country	Email
Abiye	Olawale	OAU	Ile-Ife, Nigeria	waleabiye@gmail.com
Ajao	Adewale	OAU	Ile-Ife, Nigeria	iyiolamercy2005@yahoo.com
Akpootu	Davidson	OAU	Ile-Ife, Nigeria	profdon03@yahoo.com
Ayoola	Muritala	OAU	Ile-Ife, Nigeria	rayola40@yahoo.com
Babatunde	Dimeji	OAU	Ile-Ife, Nigeria	oae.babatunde@gmail.com
Boboye	Isaac	OAU	Ile-Ife, Nigeria	iboboye@yahoo.com
Francis	Sabastine	OAU	Ile-Ife, Nigeria	sabasdekaa@yahoo.com
Imasogie	Osasu	OAU	Ile-Ife, Nigeria	imasgoddy@gmail.com
Jegede	Gbenga	OAU	Ile-Ife, Nigeria	oojegede@yahoo.com
Obisesan (F)	Dara	OAU	Ile-Ife, Nigeria	obisesanomodara@gmail.com
Ogunwale	Ayodeji	OAU	Ile-Ife, Nigeria	onileolaayo@gmail.com
Omokungbe	Opeyemi	OAU	Ile-Ife, Nigeria	omokungbeopeyemi@yahoo.com
Soneye (F)	Lanre	OAU	Ile-Ife, Nigeria	olarenwaju.soneye@gmail.com
Sunmonu	Lukman	OAU	Ile-Ife, Nigeria	sunmonula@yahoo.co.uk

5 Quicklooks and data

5.1 Realtime

Quicklooks are uploaded to http://dacciwa.sedoo.fr/. There will be no uniform output format, but all quicklooks have to be clear and self-explanatory.

The quicklooks sent daily to the SEDOO website should not be taken as validated data.

Radiosonde data will go to GTS: Kumasi via Met Office, Savé via Meteo France.

5.1.1 Savé

The quicklooks (for KIT instruments) will mostly be generated automatically during the night and send to the SEDOO website.

Table 18: Quicklooks provided during the field campaign

Instrument	Quicklook type	Upload time / interval
Radiosonde (normal)	skewTlogp diagram	After each sounding
Radiosonde (frequent)	skewTlogp diagram	Once per day after midnight
Energy balance (KIT)	Daily time series of Q, H, E, B, T, RH, u, v, w	Once per day after midnight
Energy balance and chemistry tower	Daily time series of Q, H, E, B, T, RH, u, v, w	Once per day after midnight
Microwave radio-meter	Daily time series of IWV, LWP, temperature and humidity vertical profiles	Once per day after midnight
Cloud radar	Daily time series of vertical profiles of radial velocity, LDR, reflectivity, spectral width	Once per day after midnight
Ceilometer	Daily time series of cloud base height and raw data	Once per day after midnight

Wind lidar (*WindTracer*)	Daily time series of radial velocity and SNR vertical profiles	Once per day after midnight 30 min
Wind lidar (*Windcube*)	Daily time series of radial velocity vertical profiles	Once per day after midnight
Sodar	Daily time series of horizontal wind profiles	Once per day after midnight
UHF profiler	Height-time cross section of horizontal wind, vertical velocity, CN2, dissipation over the three last days	Once per day after midnight
X-band radar	Max CAPPI precipitation sum	30 min Once per day after midnight
Sun photometer	IWV, aerosol optical depth	Once per day after midnight
Sky imager (UPS)	Full sky image	Once per day after midnight/ 1 every 15 minutes
Aerosol spectrometer (GRIMM)	Time series of total aerosol amount	Once per day after midnight
OVLITA RPAS	Vertical profiles of T, RH, wind	Once per flying day after midnight on D+1
ALADINA RPAS	Preliminary screenshots: vertical profiles of T and RH	Once per flying day

5.1.2 Kumasi

Table 19: Quicklooks provided during the field campaign.

Instrument	Quicklook type	Upload time / interval

Radiosonde (normal & frequent)	skewTlogp diagram profiles of WS, WD, T DT	After each sounding
Energy balance & Flux station	Daily time series of Q, H, E, B, T, RH, u, v, w, CO2, H2O, WS,	Once per day
Microwave radiometer	Daily time series of IWV, LWP, temperature and humidity profiles	Once per day
Sodar	time series of SNR profiles and winds	Once per day
MRR	Rain Rate, Accumulated rain, profiles of droplet spectrum, fall speed, dBz	hourly
Cloud camera	Image	Every minute
Ceilometer	Profile of backscatter, cloud base height	hourly
AWS	Time series of surface PP, T, RH, WS, WD, PPT	Updated every 5 mins

5.1.3 Ile-Ife

Table 20: Quicklooks provided during the field campaign.

Instrument	**Quicklook type**	**Upload time / interval**
Tethered radiosonde	T, RH profile	After each sounding
Sodar	Daily time series of horizontal wind profile	Once per day
Energy balance	Daily time series of Q, H, E, B, T, RH, u, v, w, short and longwave radiation components	Once per day
Sun photometer	Daily measurements of aerosol optical depth	Once per day
Infrared radiometer	Daily measurements of cloud base temperature	Once per day

15-m tower	Daily time series of wind, T, RH at 5 levels	Once per day

5.2 Post-processing

All observational data will need post-processing and validation before being sent to the DACCIWA data base after the campaign, independent of the instrument.

Uniform processing of data (energy balance, microwave radiometer, ...) after the campaign will be done as much as possible. Microwave radiometer data will be processed at KIT with retrievals from University of Cologne. Energy balance and flux calculations will be done with TK3 software at KIT.

Appendix A: Meta data of instruments at Save

A.1 Instruments of KIT

Institute of Meteorology and Climate Research - Troposphere Research

Energy balance stations

To record the incoming radiance energy at the earth surface, so called energy balance stations are used. These stations measure the components of the radiance balance (global radiation, reflected radiation, incoming and outgoing long wave radiation), the sensible and latent heat flux as well as the soil heat flux.

Fig.1: Energy balance station to register the energy conversion of the ground

Fig.2: Ultrasonic anemometer and Lyman-Alpha hygrometer of a energy balance station

Fig. 3: Radiance measuring instruments on an energy balance station

Specification of energy balance

Quantity	Device	Type	Manufacturer	Variable	Measuring Height
1	Sonic anemometer	Solent-R2	Gill	wind vector, temperature, momentum flux, sensible heat flux	4 m
1	Barometer	Model 276	Setra	air pressure (P)	1 m
1	Pyranometer	Net Pyranometer Albedometer CM14	Kipp & Zonen	global raiation, reflected irradiance	3 m
1	Pyrgeometer	CGR3	Kipp & Zonen	long-wave incoming radiation, outgoing long-wave radiation	3 m
3	Heat flux plates	Heatflux Ramco HP3	McVAN Instruments PTY LTD	soil heat flux	-0.05 m
1	Infrared thermometer	KT15	Heimann	surface temperature	
1	Temperature and humidity sensor	HMP35A	Vaisala	air temperature, relative humidity	3 m
1	Inclinometer	Inclinometer	Seika	inclinometer	4 m
1	Rain gauge	Ombrometer HP	Thies	precipitation	1 m
3	SISOMOP	SMT100		soil temperature, soil moisture	-0.1, -0.3, -0.5 m
1	Humidity and carbon dioxide sensor	Li-Cor 7500	LI-COR	CO2 / H20, latent heat flux, CO2 flux	4 m

Karlsruhe Institute of Technology

Institute of Meteorology and Climate Research - Troposphere Research

Doppler-Wind-LIDAR

Fig. 1: Scanner of the WindTracer

The LIDAR technology is one of the most advanced techniques for active remote sensing of the atmosphere. The term LIDAR is an acronym for LIght Detection And Ranging and thus leant on the better-known RADARacronym. Unlike the radio waves used there, the LIDAR technique uses electromagnetic waves, however, with much shorter wavelengths. These pulses of light were emitted into the atmosphere and reflected there by molecules and aerosol particles. Depending on the specific realization of the LIDAR system, information about the aerosol backscattering cross section, the extinction, the depolarization ratio (and thus the shape of the spreader), but also about the wind, the temperature as well as the concentration of water vapor and other trace gases can be derived from the backscatter signal.

Fig. 2: "WindTracer" systems delivered in 2004 (rear) and 2009 (front). Both systems are installed on loading bridges, allowing easy transportation.

The IMK-TRO LIDAR Network consists of three ground-based Doppler LIDAR systems that are specifically designed to measure wind. The measuring technique is based on the Doppler effect which describes the frequency shift of light which is scattered on moving objects. The centerpiece of the network are two "WindTracer" systems manufactured by Lockheed Martin Coherent Technologies: a 2µm system delivered in 2004 and a 1.6 µm system from 2009. Both systems have a 2-axis scanner, which allows for arbitrary scan patterns covering the whole upper hemisphere. Under optimum conditions the devices are able to measure the wind in 120 Rangegates in distances up to 15 km away from the measurement system. The effective pulse length of the devices, and thus a lower limit for the spatial resolution, is about 56 m and 45 m respectively. Both systems work with the same control and processing software which allows for operation as a dual-Doppler system. The construction-conditioned measurement gap of the "WindTracers" in an area of about 350 m distance from the device will be closed by the third Doppler system: a "Windcube" manufactured by Leosphere with a wavelength of 1.54 µm. The "Windcube" is able to measure the wind field in a range of 40 to 500 meters away from the device . Depending on the scanning method used, vertical profiles of horizontal and vertical wind velocity can be measured and turbulence quantities such as variances, spectra, integral length scales or dissipation rates can be determined. Additionally based on the signal-to-noise ratio a high-resolution determination of the boundary layer height is possible, which also allows the visualization of small scale processes entrainment at the upper edge of the boundary layer. By combining the two "WindTracer systems dual-Doppler techniques and thus a comprehensive representation of 3rd dimensional wind fields become possible .Additionally the precise wind measurements of the LIDAR network can be used for the evaluation of model results and the applicability of current scientific methods. A small selection of images to illustrate the potential of the LIDAR Network can be found below.

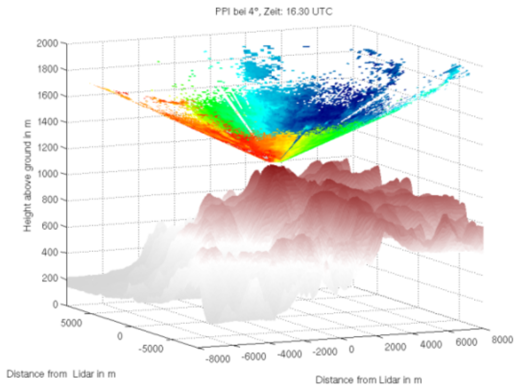


Fig. 3: So-called Plan-Position-Indicator scans (PPI) measure along conical cross sections. Here an example measured during the COPS field campaign (2007) is shown. This method gives an impression of the 3D wind field, bearing in mind that the wind can always be determined only in the beam direction

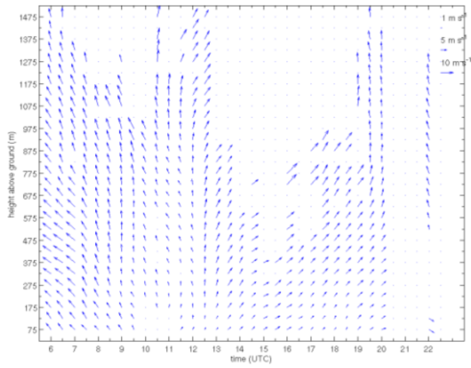


Fig. 4: Using well-known algorithms (VAD), the measured wind information during a PPI scan can be used to determine vertical profiles of horizontal windspeed and direction.

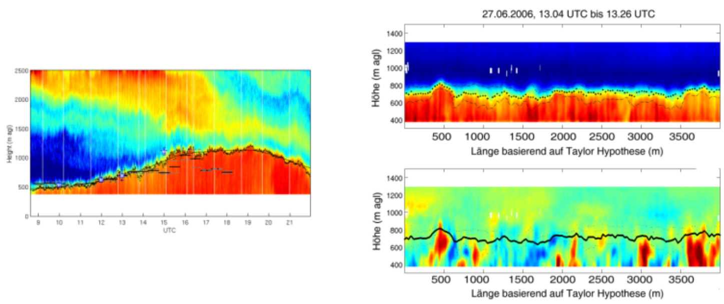


Fig. 5: High-resolution measurements of the signal-to-noise ratio and the vertical wind speed provide the ability to detect variations in the boundary layer height at different temporal scales: small-scale events in the order of less than 10 m, which can be associated with entrainment processes but also complete diurnal variations of the atmospheric boundary layer can be measured. Here are two examples of the CSIP field campaign, 2005.

Karlsruhe Institute of Technology

Institute of Meteorology and Climate Research - Troposphere Research

HATPRO microwave radiometer

HATPRO (Humidity and Temperature Profiler)

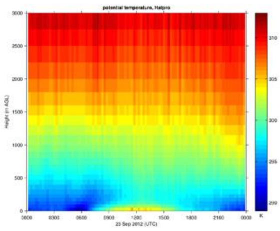
At IMK-TRO we operate two scanning passive microwave radiometers (HATPRO, Humidity and Temperature Profiler) designed by Radiometer Physics Gmbh. The instruments are part of KITcube and are deployed during various field campaigns.

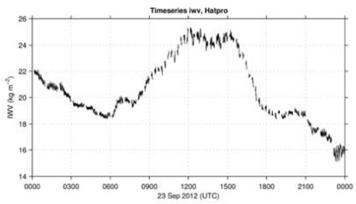
The instruments measure sky brightness temperature at 14 frequencies (7 frequencies between 22 und 31 GHz (K-band) along the wing of the 22.235 GHz rational water-vapour line und 7 frequencies between 51 und 58 GHz (V-Band) along the wing oft the 60 GHz oxygen absorption complex). From these measurements temperature and humidity profiles as well as the integrated liquid water path (LWP) and the integrated water vapour content (IWV) are obtained. In addition, an infrared radiometer detects the temperature of the cloud base.

More information: www.radiometer-physics.de

Measurement exampe

The two figures show results from the field campaign HyMeX on 23 September 2012 at Corte on the island of Corsica. In the figure on the left hand side the temporal evolution of potential temperature is shown and the figure on the right displays the temporal evolution of IWV.





Technical specifications (manufacturer`s data)

Type:	Passive microwave radiometer
Manufacturer:	Radiometer Physics Gmbh
Frequencies:	K-band: 22.24 GHz, 23.04 GHz, 23.84 GHz, 25.44 GHz, 26.24 GHz, 27.84 GHz, 31.4 GHz
	V-band: 51.26 GHz, 52.28 GHz, 53.86 GHz, 54.94 GHz, 56.66 GHz, 57.3 GHz, 58.0 GHz
Band width:	2000 MHz @ 58.0 GHz, 1000 MHz @ 57.3 GHz, 600 MHz @ 56.66 GHz, 230 MHz @ all other frequencies
Temperature profile:	Vertical resolution:
	BL-Mode: 50 m (range 0-1200 m)
	Z-Mode: 200 m (range 1200-5000 m); 400 m (range 5000-10000 m)
	Accuracy:
	0,25 K RMS (range 0-500 m)
	0,50 K RMS (range 500-1200 m)
	0,75 K RMS (range 1200-4000 m)
	1,00 K RMS (range 4000-10000 m)
Humidity profile:	Vertical resolution:
	200 m (range 0-2000 m)
	400 m (range 2000-5000 m)
	800 m (range 5000-10000 m)
	Accuracy:
	0,4 g/m³ RMS (absolute humidity)
	5% RMS (rel. humidity)
LWP:	Accuracy: +/- 20 g/m²
	Noise: 2 g/m² RMS)
IWV:	Accuracy: +/-0,2 kg/m²
	Noise: 0,05 kg/m² RMS
Weight	60 kg (without dew blower)
Dimensions:	63 x 36 x 90 cm³

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MIRA36-S cloud radar


Fig.1: MIRA36-S cloud radar (Metek Comp., Elmshorn, Germany) Fig.2:MIRA36-S cloud radar, *in field campaign.*

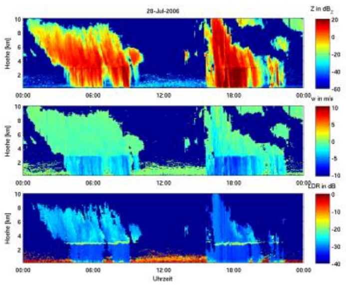

Fig.3: *Measurment of Z, w and LDR.*

<u>Technical data:</u>

Radar Type:	Mono static, pulsed, magnetron
Frequency:	35.5 GHz ± 0.2 GHz
Peak Power:	30 kW
Duty Cycle:	max 1:500; typically 1:1000
Pulse Width:	100, 200, and 400 ns according to 15, 30, and 60 m range resolution
Minimum Range:	150 m, full sensitivity -6 dB above 300 m, full sensitivity-1.5 dB above 400 m, full sensitivity above 500 m
Maximum Measuring Range:	500 range gates = 15 km / 30 m
Doppler Velocity Resolution:	0.02 m/s
Pulse repetition frequency (PRF):	2.5 kHz, 5kHz, and 10 kHz, velocity un-ambiguity of 11 - 42 m/s
FFT Length:	128, 256, 512, 1024
Minimum Averaging Time:	Moments of instantaneous spectra can be evaluated without skipping samples if NFFT > 128.
ADC for sampling the I-Q-Signals:	50 MHz / 14 Bit
Antenna Type:	Cassegrain
Diameter of Antenna:	1.2 m
Antenna Beam Width (6 dB/two-way):	0.52° x 0.52°
Antenna Gain:	50.4 dBi
Polarisation isolation:	-35 dB
Precision for Antenna Positioning:	0.1°
Scan range	azimuth direction: -183°...+183° elevation direction: -45°...+45°
Scan velocity (max), both directions:	10°/s
Acceleration (max), both directions:	10°/s²
Receiver Noise Figure (LNA + following):	3.4 dB (LNA)
Losses:	2.3 dB (T-R-switch), 0.4 dB (waveguides receiving path), 0.9 dB (w.g. + circ. transmitting path)
Sensitivity at 5 km, PRF=5 kHz, 200 ns, NFFT=256, averaging time = 0.1 s:	-44 dBZ

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Ceilometer

Ceilometer CHM15k determines up to three layers the cloud base and penetration. In addition, the temporal variability of these parameters and a vertical perspective were determined.

All this data were determinded from the uncalibrated signal of a vertically aligned lidar. The spatial resolution amounts to 15 m, the time can be selected freely, normally we use 1 minute.

The ceilometer determines the cloud base edges in a frequency range close to the visible one, so that it achieves the same result as it would have a human observer. The cross-section of backscattered cloud droplets are proportional to their surface. In contrast, the backscatter cross-section at the frequencies of (cloud-)radars is proportional to the diameter d^6. Therefore a few large droplets suffice to feign a lower cloud base to the radar.

The graph below shows a day´s measurement, which was executed in Massada, near to the dead sea in isreal. The coloured code corresponds the 10-times of 10th-logarithm of backscattered energie. White points show the cloud base edges.

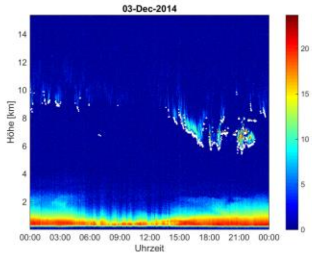

Fig. 1: *Ceilometer during transport*   Fig. 2: *Measurement of Ceilometer*

Technische Parameter:

Range:	30 m to 15000 m (realistic minimum level rather at 150 m or 300 m)
Spatial resolution:	15 m
Test time:	5 s to 60 min, mostly 60 s
Measure:	Backscatter, deduced: Cloud heights up to 3 layers, penetration/cloud thickness, vertical visibility
Measurement principle:	Lidar
Wavelenght:	1064 nm
Spread:	0,1 nm
Pulse lenght:	ca 1 ns
Pulse rate:	5-7 kHz
Beam diameter, widened:	90 mm
Laser divergency:	100 µrad
Energy per pulse:	8 µJ
Maximal power consumption:	0,8 kW

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X-band rain radar

The X-band rain radar Meteor50DX is mounted on a car trailer and thus mobile. It operates at a wavelength of 3 cm, thus it does not fulfil the criterions of Rayleigh scattering (scatterer much smaller than wavelength) for large rain drops, snow or hail. The beamwidth is 1.35°. Besides reflectivity it provides radial velocity, differential reflectivity, differential phase and the correlation coefficient between horizontal and vertical polarisation.

Technical specifications:

Frequency:	9370 MHz
Wavelength:	3 cm
Pulse modes:	4
Pulse duration:	0.3 µs … 3.3 µs
PRF:	250 Hz to 2500 Hz
Antenna beam width:	1.35°
Diameter of antenna:	1.8 m
Antenna gain:	42.5 dB
Scan range:	azimuth direction: 0°… 360°
	elevation direction: -6° … 182°
Pulse power:	55 kW min., 75 kW typ.
MDS:	-103 dBm to -113 dBm (depends on pulse duration)
Linear dynamic range	90 dB
Weight:	2800 kg

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MRR

Fig. 1: *The K-band Doppler Radar FCMW*

Specifications of K-Band FCMW Dopplerradar

frequency :	24.230 GHz
wavelength :	1.24 cm
mode :	FM-CW (sawtooth with downsweep)
Duration of a sawtooth:	0.514 ms
sawtooth frequency :	1953 Hz
Continuously radiated power :	50 mW
Diameter of the parabola :	60 cm
Beamwidth (-3-dB single-border) :	1.5 Grad
near-field distance :	~ 20 m
Sidelobes :	<-20 dB
sampling frequency of the A / D converter :	31.25 kHz
Discrete data points per FFT :	1024
Frequency sweeps per FFT (N) :	64
Period of an FFT :	33 ms
Nyquist frequency :	15.625 kHz
Discrete frequencies of the power spectrum :	512
Frequency resolution: :	30.25 Hz
Speed resolution :	0.19 m/s
Number of height steps :	32 (of which 30 are usable)
Speed channels per level:	64
Altitude resolution:	10-200 m (adjustable)
Number of spectra in a 10-s average	138
Averaging time for the output :	10-3600 s (adjustable)
For Manufacturer :	Fa. Metek, Elmshorn

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Distrometer

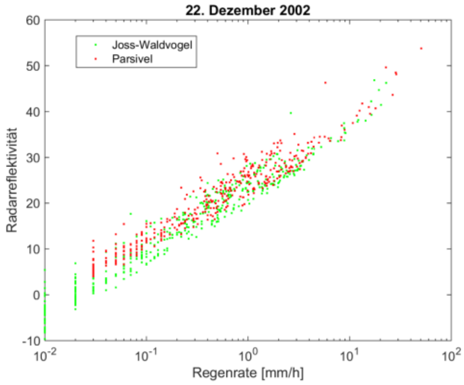

Fig.1: *The diagram shows the drop spectrum of derived value Z and R for one day . Basis are minute value respectively.*

Specifications of RD-69 disdrometer

Droplet diameter: 0.3 mm to 5 mm

Measurement surface: 50 cm²

Relationship between droplet diameter D and amplitude of the output signal:

$U_{compr.}$:	$U_{compr.} = 0.94\ D^{1.47}$
	($U_{compr.}$ in Volts, D in millimeters)
accuracy:	+/- 5% of measured drop diameter
Operating voltage:	115/230 V AC, 50-400 Hz, 5 VA
Operating temperature:	0 °C to 40 °C
Dimensions:	
-transducer:	10 cm x 10 cm x 17 cm
-processor:	10 cm x 23 cm x 27 cm
Weight:	
-transducer:	2.4 kg
-processor:	1.8 kg
Length of cable between transducer and processor:	10 m
For Manufacturer:	Fa. DISTROMET LTD, Basel

Fig. 2: *The Joss-Waldvogel disdrometer*

specifications of PARSIVEL-Distrometer

Wavelength of the laser diode:	780 nm
Power of the laser diode:	3 mW
Dimensions of the skylight (W x H x D):	160 mm x 1 mm x 30 mm
Measurement surface:	48 cm²
Diameter range of hydrometeors*:	0.2 - 25 mm
Speed range of hydrometeors*:	0.1 - 20 m/s
weight:	15 kg
Power supply:	12 V, 600 mA
interface:	RS 232
For Manufacturer:	Ott Messtechnik, Kempten

Fig. 3: *The PARSIVEL-disdrometer*

* Hydrometeors = droplets and / or ice particles

Grimm aerosol spectrometer

The aerosol spectrometer continuously measures in real time particles in 31 different size channels and present the data as:

- The aerosol spectrometer continuously measures in real time particles in 31 different size channels and present the data as Particle Size Concentration
- Particle Mass Distribution

Like all GRIMM 1100 series spectrometers, this instrument can be operated by battery and/or AC, it stores the results on a removable data logger card and collects the sampled aerosol on a removable 47mm filter. It also has an internal storage capacity of 80kb.

Specifications:

Measuring principle:	Scattering laser light and filter collection
Measuring range:	0.25 to 32 µm in 31 channel sizes
Particle counts:	1 to 2,000,000 particles/litres
Channels:	0.25 / 0.28 / 0.3 / 0.35 / 0.4 / 0.45 / 0.5 / 0.58 / 0.65 / 0.7 / 0.8 / 1 / 1.3 /1.6 / 2.0 / 2.5 / 3.0 / 3.5 / 4 / 5 / 6.5 / 7.5 / 8.5 / 10 / 12.5 / 15 / 17.5 / 20 / 25 / 30 / 32 µm
Dust mass:	0.1 > 100,000 µg/m3
Sample flow:	1.2 liter/minute, volume controlled
Reproducibility:	± 3% in max. range
Power requirement(s):	Battery power or 220/110 VAC
Size:	24 x 12 x 6 cm (9.5 x 5 x 02.5 in)
Weight:	2.5 kg (5.5 lbs)

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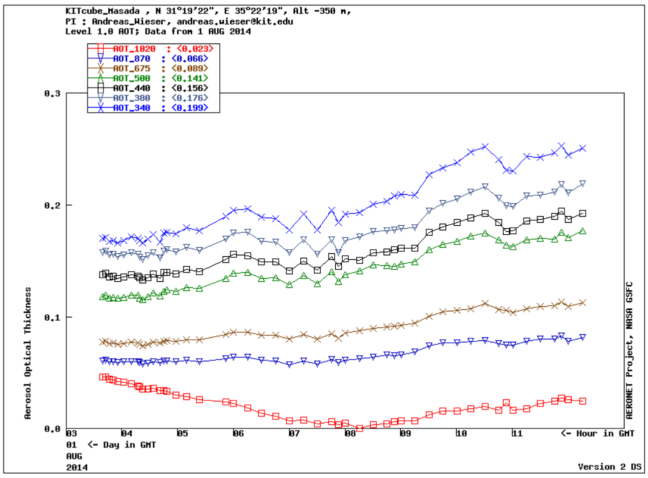
Sun photometer

The operated sun photometer is a Cimel CE 318 TP9.The photometer automatically follows sun or moon depending on the mode. Using irradiance measurements the aerosol optical thickness can be derived at certain wavelengths. Polarisation filters additionally provide information about type and shape of the aerosols.



<u>Specifications:</u>

Accuracy of irradiance measurement:	< 0.1 %
Field of sight:	1.3°
Spectral range:	340-1640 nm
Mechanical accuracy of position:	0.003°
Power consumption:	< 2 W
Total weight:	25 kg
Modes:	Sun, sky, moon
Operation range:	-30 – 70 °C (temperature)
	0 – 100% (relative humidity)

A.2 Instruments of UPS

MODEM – Normal Radiosoundings

Super Site Savé

Laboratoire d'Aérologie (LA)

PI: Solène Derrien, Fabienne Lohou

Objectives:

MODEM radio sounding system allows to acquire a profile of thermodynamic parameters such as temperature, humidity, wind speed and wind direction. The system of the Centre de Recherches Atmosphériques (LA) is a SR2K2-P from MODEM Company, used with M10 sondes.

As an in situ observation, radio sounding is still a reference measurement for atmospheric profiles in comparison to remote sensing.

MODEM SR2K2-P consists in:

- an acquisition bench (electronic and laptop)
- a ground check box (with reference sensors)
- radio and GPS antennas

The sondes are M10 model with a temperature sensor, a humidity sensor, a GPS card, a radio card and batteries for power supply.

Figure: MODEM Radio sounding System

Principe:

Usable radio frequencies are from 400 to 406 MHz (meteorological band). It allows the bench and the sondes to communicate together.

3D GPS module provides the position of the sonde (latitude, longitude, and altitude) as well speed components (North-South, East–West and Z). These data are correlated to time. Position is calculated every second by triangulation method between 4 or more satellites.
Velocity is not calculated from the difference between 2 positions but directly issued from Doppler. On short time scales, velocity is more accurate than position when it becomes less accurate on large time scales. MODEM system takes in account both measurement methods in order to provide the most accurate data.
These data are compared to GPS reference station (Differential GPS) in order to clear satellites disturbances and eventual interferences .

Ground pressure is measured by a pressure sensor in the bench, and is calibrated each year.
Pressure is calculated from ground pressure, GPS altitude, temperature and humidity according to barometric equation (Laplace law).

Temperature is measured by a thermistor chip wrapped into a glass ball. Its tiny size (0,9 x 2 mm) allows excellent response time around 1 to 1,3 sec. Temperature sensor is led on a layer processed against humidity and solar radiations.
Boom end undergoes a special vacuum metallization process reducing both solar and infrared radiation effects. Solar radiation correction is less than 1.5°C at 23 hPa

Humidity is measured by a capacitor of which value is directly proportional to relative humidity. It is composed of 3 primary components: (i) Basic layer as an electrode, (ii) A dielectric of which characteristics vary along relative humidity, (iii) A short response porous electrode as the second electrode of the capacitor.
A cap is protecting the sensor from rain and mechanical damage

Temperature and humidity are checked before launch thanks to reference sensors in the ground check box, containing a GPS repeater for indoor initialization.

Technical characteristics:

General features	
Dimensions	Width : 95 mm
	Length : 95 mm
	Height: 88.5 mm
Weight	150g (including batteries)
Pressure	
Method	Calculated from GPS altitude
Range	1100 to 3 hPa
Accuracy	±1 hPa at Surface
	±0.1 hPa at 60 hPa
Temperature	
Sensor	Thermistor
Range	+60° to –100°

Resolution	0.01°C
Accuracy	0.3°C
Response time	< 1s
Measurement rate	1 Hz
Calibration	Yes
Factory calibration	Stored on EPROM

Humidity

Sensor	Capacitor
Range	0% to 100%
Resolution	0.1%
Accuracy	3%
Response time	< 2s
Measurement rate	1 Hz
Calibration	Yes
Factory Calibration	Stored on EPROM

Wind

3D GPS	Differential calculation
Altitude range	Unlimited
Position accuracy	10 m
Speed accuracy	0.15 m/s
Direction accuracy	1 °
Position resolution	0.01 m
Horiz. speed resolution	0.01 m/s
Direction resolution	0.1 °
Measurement rate	1 Hz

Frequent and sonde-reusable radiosounding system

Super Site Savé

Laboratoire d'Aérologie (LA)

PI: Solène Derrien, Fabienne Lohou

A MODEM sounding system radiosonde (see Normal Radiosounding System) is used with one balloon for the ascent (white one in the picture) and one balloon for the descent (red one in the picture). The first balloon is separated after a preset time of ascent. The second balloon set the falling rate. Ascent and fall rates can be preset with the volume of helium used to inflate the balloons.

Figure: On the left the sonde with the ascent (white) and descent (red) balloons. On the right, the sonde MODEM M10 with its protection.

A team of two persons is needed to search the sonde with a radio-receiver antenna. The GPS coordinates of the last point recorded fix the location from where the search starts. The red balloon also helps to locate the sonde.

Surface station
Super Site Savé

Laboratoire d'Aérologie (LA)

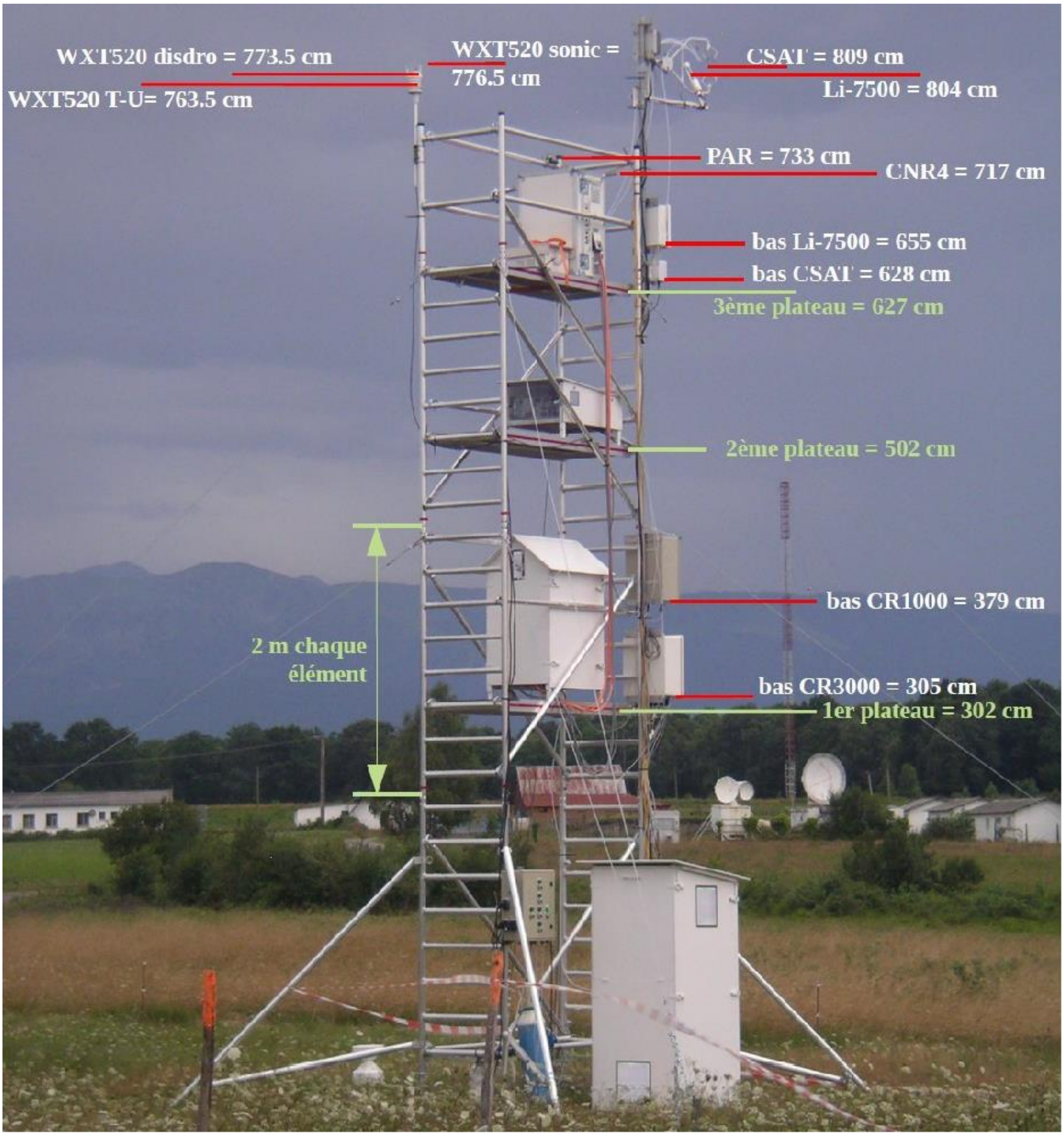


Figure: Surface station for energy balance and biogenic fluxes.

Meteorological and surface measurements

PI: Solène Derrien, Fabienne Lohou

LA will deploy a complete surface energy balance and a biogenic fluxes station based on well known eddy correlation technique. Fluxes are computed with a one day delay with the Eddy-pro software

Sensors and sampling for Meteorological parameters and surface characteristics

Parameter	Sensor	Sampling frequency (or period)	Height of measurement
Wind direction	WTX 520 Campbell	1 min.	TBD according vegetation
Wind speed			
Wind component U	CSAT 3 sonic anemometer	10 Hz	
Wind component V			
Wind component W			
Sonic temperature			
Specific humidity flux and concentration	LICOR 7500	10 Hz	
CO2 concentration flux and concentration			
Temperature	WTX 520 Campbell	1 min.	
Relative Humidity	WTX 520 Campbell		
Black body temperature of radiometer	CNR4 KIPP & ZONEN		
Outgoing global radiation			
Incoming global radiation			
Outgoing longwave radiation			
Incoming longwave radiation			
Pressure	Barometer RPT410F		TBD m
Photosynthetic Active Radiation (PAR)	PQS1 KIPP & ZONEN	1 min	
Soil water content	CS616 campbell	15 min.	-5 cm -10 cm
Soil temperature	107 campbell	1 min.	-1 cm
Rainfall	WTX 520 campbell	1 min.	
	ARG100 Environmental Measurement Ltd	1 min.	
Soil heat flux	HUSKEFLUX HFP01 (3?) 2 sensors in a large area for better sampling	1 min.	-1 cm
Full sky camera	S15D Mobotix (visible and IR camera)	2 min.	8 m

Chemistry measurements
PI: Solène Derrien, Corinne Jambert, Claire Delon

-

Sensors and sampling for chemistry

Parameter	Sensor	Sampling frequency (or period)	Height of measurement
CO concentration	48C TL TEI	10 sec.	TBD according vegetation
O3 concentration	49i TEI	10 sec.	
NO2/NO flux and concentration (1)	42C TL TEI	10 sec.	
Isopren flux and concentration (2)	FIS + ozoneur	10Hz	
NOx/ NH3 soil flux (3)	17i TEI	15 min	

(1) Concentration and flux estimated by Disjonct Eddy Covariance (DEC) method
(2) Concentration and flux estimated by Eddy Covariance method
(3) Concentration and flux estimated by a Chamber method

Remotely Piloted Aerial System

Super Site Savé

Laboratoire d'Aérologie (LA)

PI: Patrice Medina, Marie Lothon

Figure : RPAS OVLITA

	OVLITA
Dimensions	2.6 m x 1.7 m
weight	3 kg
Measured parameters	Temperature, humidity, wind
Maximum wind to fly	7-8 m/s
Nighttime flight	No
Flight duration	90 min

Sensors and sampling for Meteorological parameters and surface characteristics

Parameter	Sensor	Sampling frequency (or period)
Wind direction	5 hole probe + IMU5dof + GPS	20 hz
Wind speed		
Wind component U		20 hz

Fast Temperature	SHT75	10 hz
Fast Humidity		10 hz
Slow Temperature	SHT75	2.5 hz
Slow Humidity	SHT75	2.5 hz
GPS	MediaTek GPS MT3329	5 hz
Air speed UAS	Fisrt sensor	20 hz
Wind component UAS	Fisrt sensor	20 hz
IMU10F	ADIS16448	20 hz

LA will deploy three UAS as OVLI-TA for temperature and humidity sounding. Altitude, Temperature and Humidity are remotely control. Wind vector are calculated after landing. The plane will flight following waypoint define before the fly.

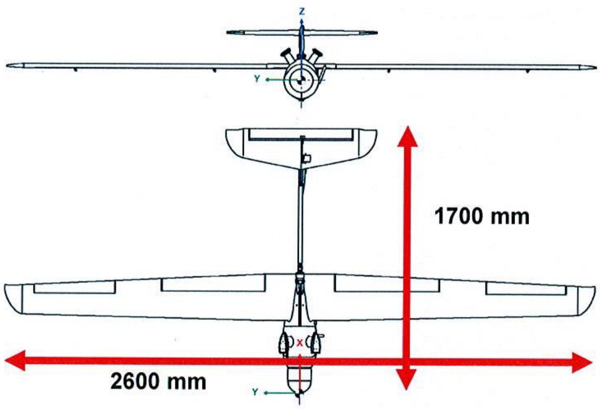


Figure 2 – Dimensions OVLITA

Figure 1 - Vue de la maquette numérique du drone OVLI-TA

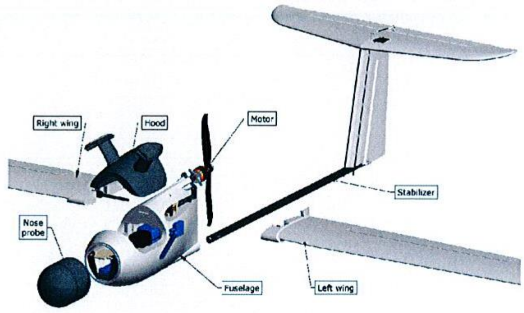


Figure 4 - Vue éclatée des sous-ensembles principaux

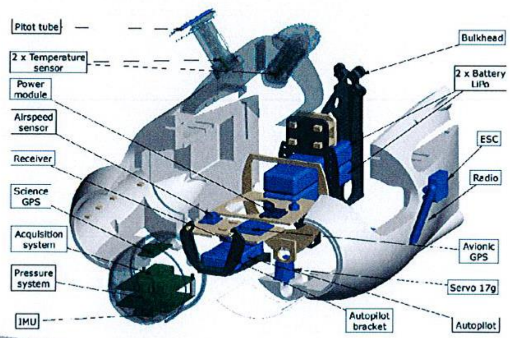
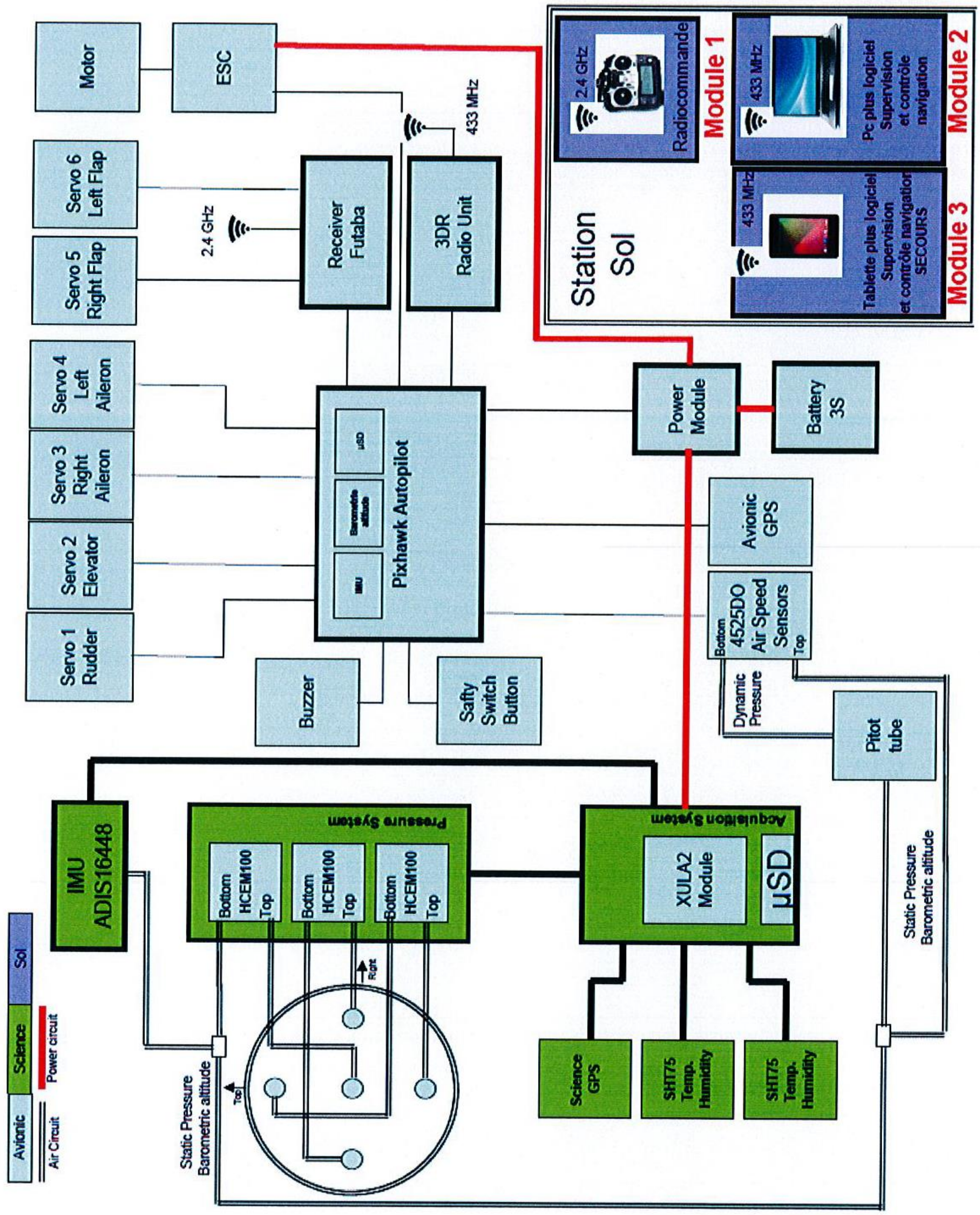


Figure 3 - Vue éclatée du fuselage (avionique en bleu et charge utile scientifique en vert)


Motor
ESC
Servo 6
Left Flap
Servo 5
Right Flap
2.4 GHz
Receiver
Futaba
3DR
Radio Unit
433 MHz
Station
Sol
2.4 GHz
Radiocommande
Module 1
433 MHz
Pc plus logiciel
Supervision
et contrôle
navigation
Module 2
433 MHz
Tablette plus logiciel
Supervision
et contrôle navigation
SECOURS
Module 3
Servo 4
Left
Aileron
Servo 3
Right
Aileron
Servo 2
Elevator
Servo 1
Rudder
Pixhawk Autopilot
IMU
Barometric altitude
µSD
Power
Module
Battery
3S
Avionic
GPS
Bottom
4525DO
Air Speed
Sensors
Top
Dynamic
Pressure
Pitot
tube
Buzzer
Safty
Switch
Button
IMU
ADIS16448
Pressure System
Bottom
HCEM100
Top
Acquisition System
XULA2
Module
µSD
Right
Top
Static Pressure
Barometric altitude
Science
GPS
SHT75
Temp.
Humidity
Avionic
Science
Sol
Air Circuit
Power circuit

UHF (Ultra High Frequency) wind profiler
Savé Supersite

Laboratoire d'Aérologie (LA)
PI: Y. Bezombes, M. Lothon
B. Campistron, L. Cabanas, S. Derrien

Objective :

The UHF (Ultra High Frequency) wind profiler provides information on the atmospheric dynamics at meso and small scale in the lower troposphere. It supplies vertical profile of the three components of the wind, in both clear air and cloudy air or rain, at 75 m vertical resolution, from 150 m to around 3000 m a.g.l, and every 5 or 15 minutes. (Vertical cover depends on the moisture in the low troposphere, and can range from 1000 m to 6000 m a.g.l.)
This radar also allows the study of the atmospheric boundary layer, with estimates of the boundary layer top inversion or strong gradients, and of the kinetic energy dissipation rate. The momentum flux can be estimated with some hypotheses.

Principle:

The principle is based on active remote sensing: a 1274 MHz electromagnetic wave is emitted with pulses in the atmosphere in five different directions alternatively, and backscattered by the fluctuations of the refractive index of the air, by biological fragments, large dust particles, insects or precipitations. The received power is related to the atmospheric turbulence or to the drop size distribution of the backscattering particles. The Doppler velocity measured along each beam allows the measurement of the three components of the mean wind. The Doppler spectral width enables to estimate the intensity of turbulence or some characteristics of the precipitation, depending on the source of the received echo.

<u>Technical characteristics :</u>

Characteristics of the location	
Location	SAVE
Coordinates Longitude : (WGS84) Latitude :	8.00102° N 2.42785° E
Altitude of the ground from sea level (m)	166m
Antenna height above the ground (m)	0.5m
Minimum elevation angle (°)	73°
Maximum elevation angle (°)	90°
Vertical cover	200 m to 3000 m a.g.l
Temporal resolution	~ 5 minutes
Characteristics of the transmitter/receiver	
Frequency (MHz) :	1274 Mhz
Peak power at antenna port (dBW)	3,5 kW
Wavelengh	23.6 cm
Radial resolution	75 m and 150m
Modulation type:	Gaussian
Characteritics of the modulation	Sweep period 500 ns, 1 µs and 2,5 µs
Characteristics of the antenna	
Antenne type	coaxial collinear antenna
Antenna Gain (dBi)	25 dBi
Number of antenna beams	5
Antenna area	2 x 2 m^2
Beamwidth	8.5°
Polarisation	Vertical
Rotation speed (rpm) (min and max)	Fixed antenna

A.3 Instruments of TUBS

Technische Universität Braunschweig

Institut für Flugführung

Unmanned Aerial System "Carolo P360" ALADINA

Fact Sheet

June 2014

P360

The fully automatically operating Carolo P360 aircraft is the largest and most powerful member of the Carolo family of Unmanned Aerial Systems (UAS) developed at the Institute of Aerospace Systems, TU Braunschweig. The aircraft has a maximum take-off weight of 25 kg and a wing span of 3.60 m.

The electrical pusher engine configuration leaves the nose free for special meteorological sensors. A combustion engine is generally compatible with the P360, but is not used for ALADINA. A large payload bay (350 x 310 x 190 mm) allows carrying various kind of instrumentation with a maximum weight of 2.5 kg. The P360 is built following a modular concept. The front compartment, wings and elevator unit can be assembled and disassembled within 15 min. Between two flights, the exchange of battery packs and saving of data takes less than 10 minutes. The battery system for the engine consists of two Li-Ion battery packs with a combined capacity of about 20 Ah.

Every electric subsystem (engine, autopilot/actuators, aerosol instrumentation/ meteorology/GPS/IMU) has its own power supply and can be operated stand-alone.

No additional equipment like a winch system or catapult is necessary for take-off. A landing gear fixed on the fuselage offers an easy handling to launch and land the aircraft on flat surfaces (e.g. grass, asphalt and snow). The terrain requires a dimension of approximately 60 x 25 m depending on wind conditions and the pilot's experience. The P360 can be operated up to a wind speed of 15 m/s.

Takeoff and landing is performed manually, while the flight mission can be controlled by autopilot.

ALADINA is able to operate at night equipped with the appropriate lighting, upon permission of the local civil aviation authorities (CAA).

Technical specifications

• Maximum take-off weight	25 kg (including payload)
• Wing span	3.60 m
• Fuselage length	1.8 m
• Typical cruising speed	25 – 28 m/s (90 – 100 km/h)
• Endurance (level flight)	> 40 min (for 20°C)
• Climb performance	6 m/s
• Ceiling	2.5 km
• Standard telemetry system	2.4 GHz
• Remote control system	Graupner MX20
• Operational ambient temperature	0 … + 40°C

Autopilot

ALADINA can be operated automatically by the autopilot system ROCS (Research Onboard Computing System), which is provided by the Institute of Flight Mechanics and Control of the University Stuttgart. ALADINA follows the flight pattern which was sent to the aircraft before take-off. Within the telemetry range of 1.5 km, the ground staff is able to follow and monitor the position, attitude and speed of the aircraft. Changes of the waypoints and altitudes are possible during the mission within that range.

ALADINA

In the case of ALADINA (**A**pplication of **L**ight-Weight **A**ircraft for **D**etecting **In**-situ **A**erosol), the P360 is equipped with meteorological sensors and aerosol instrumentation. The development of ALADINA was realized in a joint research program funded by the German Research Foundation: The aircraft itself was prepared by TU Braunschweig, the miniaturization and implementation of the aerosol sensors was done by the Leibniz Institute of Tropospheric Research, and the meteorological sensors, data acquisition and telemetry downlink for real-time data transfer were developed by the Eberhard-Karls Universität Tübingen. The integration of the sensors into the aircraft is shown below.

ALADINA payload: 1 five-hole probe, 2 temperature and humidity sensor, 3 aerosol inlet, 4 temperature sensor, 5 GPS antenna, 6 telemetry antenna b) 7, 8, 9 aerosol instruments

ALADINA is capable of measuring the atmospheric parameters temperature, wind speed and direction, as well as the aircraft parameters position, attitude and altitude with high temporal resolution (20 Hz). The relative humidity and the aerosol number concentration for different size classes are recorded with a resolution of 1 Hz.

Appendix B: Meta data of instruments at Kumasi

Flux Tower 1a	2m	
logger	Campbell Scientific CR5000	
3 x soil temperature probes	Campbell Scientific 107 Temperature Probe	Temperature measurement range: -55°C to +70° Thermistor interchangeability error:* <±0.18°C over -25 to +50°C <±0.3°C over -55 to +70°C CRBasic instruction linearisation error: <±0.03°C over -55 to +70°C Bridge resistor errors:* <±0.13°C over -25 to +50°C (worst case) <±0.35°C over -55 to +70°C
3 x soil moisture probes	Campbell Scientific 253 soil Moisture	**Range:** 0 to -2 bars (0 to 200 kPa) **Dimensions** **Length:** 3.25 inches (8.26 cm) **Diameter:** 0.75 inches (1.91 cm) **Weight:** 0.8 lbs (362.9 g)
3 x self calibrating soil heat flux plates	Campbell Sceintific HFP01SC self calibrating soil heat flux plates	Sensor Type: Thermopile with film heater Sensitivity (nominal): 50 μV W-1 m-2 Nominal Resistance: 2 Ω Temperature Range: -30° to +70°C Expected Accuracy: ±3% of reading Heater Resistance: 100 Ω (nominal) Heater Voltage Input: 9 to 15 Vdc Heater Voltage Output: 0 to 2 Vdc Duration of Calibration: ±3 minutes @ 1.5 W; typically performed every 3 to 6 hours Average Power Consumption: 0.02 to 0.04 W Plate Thickness: 5 mm (0.20 in) Plate Diameter: 80 mm (3.15 in) Weight without cable: 200 g (7.05 oz)
4 component radiation	Hukseflux NR01 – 10 4 component radiation	Measurand net radiation Measurand reflected solar radiation Measurand hemispherical solar radiation Measurand downward longwave radiation* Measurand upward longwave radiation* Optional measurand surface temperature* Optional measurand sky temperature* Optional measurand albedo or solar reflectance Required readout 4 x DC voltage, 1 x Pt100 Calibration traceability solar to WRR Calibration traceability longwave to WISG Spectral range solar 285 to 3000 x 10^{-9} m Spectral range longwave 4.5 to 40 x 10^{-6} m Rated operating temperature range -40 to 80 ºC

		Temperature sensor Pt100 Heater 12 VDC, 1.5 W Standard cable length 5 m (see options) * Required measurand instrument body temperature

Flux Tower 1b	10 feet	
IA420 logger	Moxa IA240	
GPS	Garmin GPS 18X	RMC
Sonic anemometer	Metek usonic 3	Ambient conditions-40 ... + 60 °C, 5 ... 100% Average time / number 1 ... 3600 s/ 1 ... 65365 samples Sampling rate 0.1... 30/50 Hz Measurement ranges 0 ... 60 m/s, -40 ... + 70 °C Accuracy (max. dev.) wind speed / wind direction 0.1 m/s or 2 % / 2°@ 5 m/s Resolution 0.01 m/s, 0.1°,0.01 K Output data set x, y, z, T / vel, dir, z, T Averaging method scalar, vectorial Output protocols standard, checksum, NMEA Data outputasync, polling, time synchronized Power supply 9 ... 36 VDC / 3 W (5 W with options) Serial interface RS422, RS485 (300 ... 115200), ASCI
Gas analyser	Li-Cor Li-7500RS	**CO_2 Measurements** • Calibration range: 0 to 3000 µmol mol^{-1} • Accuracy: Within 1% of reading • Zero drift (per °C): ○ ±0.1 ppm typical ○ ±0.3 ppm maximum • RMS noise (typical @ 370 ppm CO_2 and 10 mmol mol^{-1} H_2O): ○ @5 Hz: 0.08 ppm ○ @10 Hz: 0.11 ppm ○ @20 Hz: 0.16 ppm • Gain drift (% of reading per °C @ 370 ppm): ○ ±0.02% typical ○ ±0.1% maximum • Direct sensitivity to H_2O (mol CO_2/mol H_2O): ○ ±2.00E-05 typical ○ ±4.00E-05 maximum **H_2O Measurements** • Calibration range: 0 to 60 mmol mol^{-1} • Accuracy: Within 2% of reading • Zero drift (per °C): ○ ±0.03 mmol mol^{-1} typical ○ ±0.05 mmol mol^{-1} maximum

		• RMS noise (typical @ 370 ppm CO_2 and 10 mmol mol^{-1} H_2O):
		  ○ @5 Hz: 0.0034 mmol mol^{-1}
		  ○ @10 Hz: 0.0047 mmol mol^{-1}
		  ○ @20 Hz: 0.0067 mmol mol^{-1}
		• Gain drift (% of reading per °C @ 20 mmol mol^{-1}):
		  ○ ±0.15% typical
		  ○ ±0.30% maximum
		• Direct sensitivity to CO_2 (mol H_2O/mol CO_2):
		  ○ ±0.02 typical
		  ○ ±0.05 maximum

Flux Tower 2a	2m	
logger	Campbell Scientific CR3000	
3 x soil temperature probes	Campbell Scientific 107 Temperature Probe	Temperature measurement range: -55°C to +70° Thermistor interchangeability error:* <±0.18°C over -25 to +50°C <±0.3°C over -55 to +70°C CRBasic instruction linearisation error: <±0.03°C over -55 to +70°C Bridge resistor errors:* <±0.13°C over -25 to +50°C (worst case) <±0.35°C over -55 to +70°C
3 x soil moisture probes	Campbell Scientific 253 soil Moisture	**Range:** 0 to -2 bars (0 to 200 kPa) **Dimensions** **Length:** 3.25 inches (8.26 cm) **Diameter:** 0.75 inches (1.91 cm) **Weight:** 0.8 lbs (362.9 g)
3 x self calibrating soil heat flux plates	Campbell Scientific HFP01SC self-calibrating soil heat flux plates	Sensor Type: Thermopile with film heater Sensitivity (nominal): 50 μV W-1 m-2 Nominal Resistance: 2 Ω Temperature Range: -30° to +70°C Expected Accuracy: ±3% of reading Heater Resistance: 100 Ω (nominal) Heater Voltage Input: 9 to 15 Vdc Heater Voltage Output: 0 to 2 Vdc Duration of Calibration: ±3 minutes @ 1.5 W; typically performed every 3 to 6 hours Average Power Consumption: 0.02 to 0.04 W Plate Thickness: 5 mm (0.20 in) Plate Diameter: 80 mm (3.15 in) Weight without cable: 200 g (7.05 oz)
GPS	Garmin GPS 18X	RMC
2 x SW	Kipp & Zonen CMP 22	ISO 9060:1990 classification Secondary Standard **Response time** (95%) < 5 s **Zero off_sets** (a)< 3 W/m² (1) (b)< 1 W/m² **Non-stability**< 0.5% **Non-linearity**< 0.2% **Directional response**< 5 W/m² up to 80° zenith angle **Spectral selectivity**< 2% **Temperature response**< 0.5% (-20°C to +50°C) interval of 70 K **Tilt response**< 0.2%

2 x LW	Kipp & Konen CGR 4	(see specification table below)

Specification	Unit	Value	Remark
Spectral range	µm	4.5 to 42	50% point
Sensitivity	µV/Wm^{-2}	5 to 10	
Impedance	Ohm	40 to 200	
Response time	s	< 18	95% response
		< 6	63% response
Non-linearity	%	< 1	from -250 to +250 W/m² irradiance
Temperature dependence of sensitivity	%	< 5	- 40 °C to -20°C
		< 1	- 20 °C to +50 °C
		< 10	+50 °C to +80 °C
Tilt error	%	< 1	deviation when facing downwards
Window heating offset	W/m²	< 4	0 to 1000 W/m² / solar irradiance
Zero offset B	W/m²	< 2	at 5 K/h temp. change
Operating temperature:	°C	-40 to +80	
Field of view:		180°	
Directional error	W/m²	Not defined	Irrelevant to isotropic IR source
Irradiance:	W/m²	-250 to +250	
Non-stability	%	< 1	
Spectral selectivity	%	< 5	8 – 14 µm spectral range
Environmental		humidity 0 - 100% RH	
Uncertainty in hourly total	%	Not defined	95 % confidence level
Uncertainty in daily total		< 3	95 % confidence level

Flux Tower 2b	10 feet	
logger	Moxa IA 240	
GPS	Garmin GPS 18X	RMC
Sonic anemometer	Metek usonic 3	Ambient conditions-40 ... + 60 °C, 5 ... 100% Average time / number 1 ... 3600 s/ 1 ... 65365 samples Sampling rate 0.1... 30/50 Hz Measurement ranges 0 ... 60 m/s, -40 ... + 70 °C Accuracy (max. dev.) wind speed / wind direction 0.1 m/s or 2 % / 2°@ 5 m/s Resolution 0.01 m/s, 0.1°,0.01 K Output data set x, y, z, T / vel, dir, z, T Averaging method scalar, vectorial Output protocols standard, checksum, NMEA Data outputasync, polling, time synchronized Power supply 9 ... 36 VDC / 3 W (5 W with options) Serial interface RS422, RS485 (300 ... 115200), ASCI
Gas analyser	LiCor 6750	**CO_2 Measurements** • Calibration range: 0 to 3000 µmol mol^{-1} • Accuracy: Within 1% of reading • Zero drift (per °C): ○ ±0.1 ppm typical ○ ±0.3 ppm maximum • RMS noise (typical @ 370 ppm CO_2 and 10 mmol mol^{-1} H_2O): ○ @5 Hz: 0.08 ppm ○ @10 Hz: 0.11 ppm ○ @20 Hz: 0.16 ppm • Gain drift (% of reading per °C @ 370 ppm): ○ ±0.02% typical ○ ±0.1% maximum • Direct sensitivity to H_2O (mol CO_2/mol H_2O): ○ ±2.00E-05 typical ○ ±4.00E-05 maximum

		H_2O Measurements • Calibration range: 0 to 60 mmol mol^{-1} • Accuracy: Within 2% of reading • Zero drift (per °C): ○ ±0.03 mmol mol^{-1} typical ○ ±0.05 mmol mol^{-1} maximum • RMS noise (typical @ 370 ppm CO_2 and 10 mmol mol^{-1} H_2O): ○ @5 Hz: 0.0034 mmol mol^{-1} ○ @10 Hz: 0.0047 mmol mol^{-1} ○ @20 Hz: 0.0067 mmol mol^{-1} • Gain drift (% of reading per °C @ 20 mmol mol^{-1}): ○ ±0.15% typical ○ ±0.30% maximum • Direct sensitivity to CO_2 (mol H_2O/mol CO_2): ○ ±0.02 typical ○ ±0.05 maximum

AWS	2m	
System	Davis Vantage Pro	
PPT		Sensor Type: Tipping bucket with magnetic switch Accuracy:.For rain rates up to 4"/hr (100 mm/hr): ±4% of total or ± 1 tip of the bucket (0.01"/0.2 mm), whichever is greater Rain Collector : 6.5" opening diameter (16.5 cm) x 9.5" (24 cm) high without bird spikes Collection Area:33.2 in$_2$(214 cm$_2$)
WS		Resolution and Units: Measured in 1 mph. Other units are converted from mp h and rounded to nearest 1 km/h, 0.1 m/s, or 1 knot Range: 1 to 200 mph, 1 to 173 knots, 0.5 to 89 m/s, 1 to 322 km/h Accuracy ±2 mph (2 kts, 3 km/h, 1 m/s) or ±5%, whichever is greater
WD		Display Resolution: 16 points (22.5°) on compass rose, 1° in numeric display Accuracy:±3°
RH		Resolution and Units: 1% Range:1 to 100% RH Accuracy±3% (0 to 90% RH), ±4% (90 to 100% RH) Temperature Coefficient 0.03% per °F (0.05% per °C), reference 68°F (20°C) Drift ±0.5% per year Update Interval 50 seconds to 1 minute
T		Resolution and Units :1°F or 1°C (user-selectable) Range :-40° to +150°F (-40° to +65° C) Sensor Accuracy .±1°F (±0.5°C) under 110°F (43°C), ±2°F (±1°C) over 110°F (43°C) Update Interval:10 seconds Data: Instant Reading
PP		Resolution and Units: 0.01" Hg, 0.1 mm Hg, 0.1 hPa/mb (user-selectable) Range: 6.00" to 32.50" Hg, 410 to 820 mm Hg, 540 to 1100 hPa/mb

		Elevation Range -999' to +15,000' (-600 m to 4570 m) (Note that co nsole screen limits entry of lower elevation to -999' when using feet as elevation unit.) Uncorrected Reading Accuracy: ±0.03" Hg (±0.8 mm Hg, ±1.0 hPa/mb) (at room temperature) Sea-Level Reduction Equation Used: United States Method employed prior to use of current "R Factor" method Equation Source Smithsonian Meteorological Tables Equation Accuracy ±0.01" Hg (±0.3 mm Hg, ±0.3 hPa/mb) Elevation Accuracy Required ±10' (3m) to meet equation accuracy specification Overall Accuracy ±0.03" Hg (±0.8 mm Hg, ±1.0 hPa/mb)

MRR

The MRR Micro Rain Radar is a compact 24 GHz FM-CW-radar for the measurement of profiles of drop size distributions and – derived from this – rain rates, liquid water content and characteristic falling velocity resolved into 30 range gates. Due to the high sensitivity and fine temporal resolution very small amounts of precipitation – below the threshold of conventional rain gauges – are detectable. Due to the large scattering volume (compared to in situ sensors) statistically stable drop size distributions can be derived within few seconds. The droplet number concentration in each drop-diameter bin is derived from the backscatter intensity in each corresponding frequency bin. In this procedure the relation between terminal falling velocity and drop size is exploited.

Automatically controlled antenna heating allows operation under icing conditions.

Typical applications include the unattended long-term measurement of rain, real time calibration of weather radar, and monitoring of the melting zone.

Transmit Power	50 mW
Frequency	24.23 GHz
Beam Width	1.5°
Averaging Interval	10 - 3600s
Height Resolution	10 - 200 m
Number of Range Gates	30
Detection threshold height 500 m, height resolution 100 m, time resolution 10 s	1 mm / hr
Antenna Heating	230 VAC
Interface	RS232,LAN
Power	24VDC, 25W
Weight	6 kg

Manufacturer & Model: METEK MRR2 Micro Rain Radar

SCANNING MICROWAVE RADIOMETER

The **HATPRO** instrument is a stand-alone system for automated weather-station use under nearly all environmental conditions. Full atmospheric profiles are derived, retrieved data as well as raw data are stored. A variety of retrieval algorithms (custom designed or global standard algorithms) can be selected.

The system is passive with two frequency reception bands: 22-31 GHz (7 channel filter bank humidity profiler and LWP radiometer) and 51-58 GHz (7 channel filter bank temperature profiler). A range of data are retrieved including:

- Vertical profiles of atmospheric temperature
- vertical profile of atmospheric humidity (relative and absolute humidity)
- Liquid Water path (LWP)
- Integrated Water Vapour (IWV)
- stability indices
- surface pressure, temperature, relative humidity and rain flag

The system is capable of standalone operation but the AMF supply a host PC to facilitate data archiving and custom setup of the instrument. The HATPRO GPS provide the measurement timing and also position. The environmental temperature range for operation: – 60°C to + 45°C and the automatic rain-mitigation system, consisting of a hydrophobic coating and strong blower, prevent rain settling on the radome. The 1.8kW heater module prevents formation of dew and fog condensation on radome. A new radome is fitted before any deployment and replaced, while on deployment, every 6 months or if compromised. (Mechanical damage, salt build up etc all result in the hydrophobic properties of the radome being compromised).

Optical Resolution	3.5° (2.5°) HPBW at 22 (51) GHz
Radiometric resolution	0.3 – 0.4 K RMS at 1.0 s integration time
Absolute system stability	1.0 K
Receiver and antenna thermal stabilisation	< 0.02 K
Repetition rate	filter bank receiver produces one atmospheric profile per second
Humidity profile performance	Vertical resolution: 200 m (range 0-2000 m) 400 m (range 2000-5000 m) 800 m (range 5000-10000 m) Accuracy: 0.4 g/m3 RMS (absolute hum.) 5% RMS (rel. humidity)
Temperature profile performance	Vertical resolution: BL-Mode: 30 m -50 m (range 0-1200 m) Z-Mode: 200 m (range 1200-5000 m) 400 m (range 5000-10000 m) Accuracy: 0.25 K RMS (range 0-500 m) 0.50 K RMS (range 500-1200 m) 0.75 K RMS (range 1200-4000 m) 1.00 K RMS (range 4000-10000 m)
LWP	Accuracy: +/- 20 g/m2 Noise: 2 g/m2 RMS
IWV	Accuracy: +/-0.2 kg/m2 RMS Noise: 0.05 kg/m2 RMS

Manufacturer & Model: RPG Radiometer Physics Gmbh HATPRO Radiometer

SODAR

The MFAS64 is a monostatic sodar and generates different beam angles during emission and reception by phased-delayed driving and sensing, respectively, of the rows or columns of an array of 64 acoustic transducers. The phase delays in the emission and reception modes are produced digitally, resulting in long term stability of the phase-shift and related performances. General advantages of the phase array systems over three-component horn antenna systems are a smaller antenna size and a more flexible use.

Height resolution is gathered by range gating, i.e. by considering the time the pulse needs to propagate from the antenna to the measured layer and back. From the amplitude of the backscatter wave, detailed information about the turbulent structure in the atmospheric boundary layer can be obtained. By evaluating the spectrum of the backscatter wave, the wind speed can be determined. This is possible because of the Doppler frequency shift resulting from the movement of the scattering temperature inhomogeneities with the mean wind. When at least three beams are emitted at different angles, a vertical profile of the three-dimensional wind vector can be derived.

The MFAS64 can operate in single or multi-frequency modes. In the single-frequency mode, a single pulse with a defined frequency is emitted and afterwards the backscattered is recorded and evaluated. This procedure is repeated in several directions. In multi-frequency mode, sequences composed of pulses with varying frequencies are emitted and the backscattered waves for all the frequencies are received simultaneously. Up to 10 different frequencies between 1650 and 2750 Hz can be defined. Multi-frequency operation significantly increases the signal-to-noise ratio since more acoustic power can be emitted into the atmosphere without increasing the pulse-length per frequency, i.e. without reducing the vertical resolution. As with the single-frequency mode, the pulse sequence is repeated in several directions.

The antenna can emit beams in up to 9 different directions:

0° Vertically

29° East	22° West
29° North	22° South
29° West	22° East
29° South	22° North

Complementary pulse pairs with opposite directions (29°/-22°) can be emitted even within a single pulse sequence and the backscattered wave from these two directions received simultaneously. This results in a significant increase in the signal-to-noise ratio without sacrificing vertical resolution. Due to the MFAS64 phase generation technique the emission angles are independent of frequency.

The acoustic antenna can be operated in a shaded and non-shaded mode. In the non-shaded mode, the antenna directivity is highest. In the shaded mode the side lobes (emissions in other than the main direction) are smallest. Depending on the site and the application, one or the mode will provide better results.

Within a single emitted sequence, pulses of different frequency and direction can have different lengths. The shortest possible pulse length corresponds to a layer thickness of 10 m during data evaluation. Longer pulses are a multiple of this base length. It is often advantageous to have a long first pulse for better signal-to-noise at large altitudes. This in combination with height dependent vertical resolution can balance the requirements of maximum range and highest possible vertical resolution at lower altitudes. Height dependent resolution means that adjacent layers are binned together and the spectra averaged.

MFAS64 Specifications:

Number of elements	64
Frequency range	1650 - 2750 Hz
Acoustic output power	7.5 W
Number of frequencies	Up to 80, 10 within a single sequence
Beam angles	0°, ± 22°, ± 29°
Number of vertical layers	100
Thickness of layer	10 - 250 m
Lowest measurement height	20 m
Maximum range	500 - 1000 m
Averaging time	1 min to 60 min
Accuracy of Horizontal Wind speed	0.1 - 0.3 m/s
Accuracy of vertical Wind speed	0.03 - 0.1 m/s
Accuracy of wind Direction	2 - 3°
Measurement range horizontal	- 50 m/s to +50 m/s
Measurement range vertical	-10 m/s to +10 m/s
Operational temperature range	-35 to 50 °C
Power requirements	±12 VDC, 200 W peak, 50 - 100 W average
Size	72 cm x 74 cm x 25 cm
Weight	32 kg

Ceilometer

The CS135 LIDAR Ceilometer measures cloud height and vertical visibility for meteorological and aviation applications. Utilising LIDAR (LIght Detection And Ranging) technology, the instrument transmits fast, low-power laser pulses into the atmosphere and detects back-scattered returns from clouds and aerosols above the instrument.

The CS135 complies with CAA and ICAO guidance and meets or exceeds all recommendations and specifications (this includes CAP437, CAP670 and CAP746).

Tilt capability to 24° allows the sensor to be operated anywhere in the world without the sun shining directly into the lens.

The CS135 employs a novel split-lens design to increase optical signal-to-noise ratio over other instruments while maintaining Class 1M eye safety by integrating larger optics into a compact package. This optical design provides an alternative to traditional bi-axial or common-optics designs. The optical isolation of traditional bi-axial systems is maintained to increase detector sensitivity, while the new low overlap onset height of common-optics systems is incorporated to allow measurements at close ranges.

This hybrid approach, along with state-of-the-art electronics, provides a powerful and stable platform from which to measure cloud height and vertical visibility to high accuracy. With a rugged environmental enclosure that protects the instrument from the harshest conditions, the CS135 measures the atmosphere with high stability and repeatability.

Instrument Performance:

- Reporting Range: 0-10 km / 32,800 ft
- Minimum Reporting Resolution: 5 m / 15 ft
- Hard Target Range Accuracy: +/- 0.25% +/- 4.6 m
- Reporting Cycle: 2 to 120s
- Cloud Layers Reported: Up to four layers reported
- Sky condition: Up to five layers with cover in oktas according to WMO requirements for SYNOP and METAR codes
- Vertical Visibility: Reported when no clouds selected
- Laser Wavelength: 905 nm
- Eye Safety: Class 1M

Electrical Specification

- Power: 110/115/230 VAC ± 10%
- 50-60 Hz
- 470 W maximum
- Battery: Internal 12V 2Ah battery provides 1hr measurement without blower/heater, in the event of mains failure.

Interfaces:

- Data - RS232 / RS485
- Maintenance - USB 2.0 (USB 1.1 compatible)
- Baud Rate - 300 - 115200

Laser safety compliance: EN60825-1:2001

Electrical safety compliance: EN61010-1

Mechanical Specification

- Dimensions (mm): 1000 x 330 x 316 including base
- Weight:
- 32 kg (total without cables)
- 25 kg (without outer cowling and enclosure)
- Shipping weight: 58 kg
- Shipping dimensions (mm): 1200 x 450 x 450
- Maximum Windspeed: 55 m/s (shown by static load testing and survival in field use)

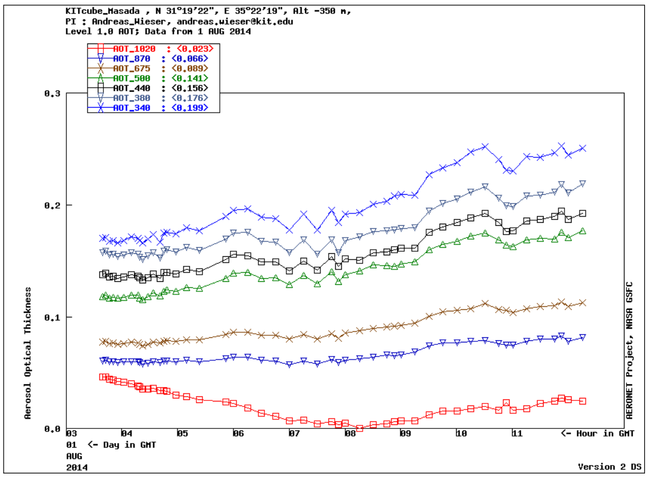
Environmental Specification

- Temperature Range (excluding battery): -40 - 60°C (-40 - 140°F)
- Battery Temperature Range: -20°C to +50°C. Alternative battery types with wide temperature ranges can be supplied.
- Humidity: 0 - 100% RH

- IP Rating: IP66 (NEMA 4x)

Sun Photometer

The operated sun photometer is a Cimel CE 318 TP9.The photometer automatically follows sun or moon depending on the mode. Using irradiance measurements the aerosol optical thickness can be derived at certain wavelengths. Polarisation filters additionally provide information about type and shape of the aerosols.



<u>Specifications:</u>

Accuracy of irradiance measurement:	< 0.1 %
Field of sight:	1.3°
Spectral range:	340-1640 nm
Mechanical accuracy of position:	0.003°
Power consumption:	< 2 W
Total weight:	25 kg
Modes:	Sun, sky, moon
Operation range:	-30 – 70 °C (temperature)
	0 – 100% (relative humidity)

Appendix C: Meta data of instruments at Ile-Ife

Parameter(s)	Device and model	Manufacturer	Accuracy	Number available
Wind speed	Cup anemometer A101ML/A100L2	Vector Instruments	distance const. 2.3 m	8
Wind direction	Wind vane W200P	Vector Instruments	Distance const. 2.3 m	2
Air temperature/RH	Temp & RH probe HMP45C/60	Vaisala	± 0.1^{o}C	6
Surface temperature	Infrared Pyranometer KT1582D	Heitronics	± 0.5^{o}C	1
Surface temperature	Infrared thermometer SI-111 radiometer	Campbell Scientific	± 0.1^{o}C	2
Soil temperature	Thermistor T108L	Campbell Scientific	± 0.1^{o}C	6
Soil temperature	PT-100Ω	Campbell Scientific	± 0.1^{o}C	6
Soil temperature	Thermocouple	Campbell Scientific	± 0.1^{o}C	1
Soil heat flux	Heat flux plate HP3/CN3	Middleton	~ 13.5 μV/Wm^{-2}	1
Soil heat flux	Heat flux plate HFP01	Hukseflux	50 μV/Wm^{-2}	4
Soil moisture	Water content Reflectometer CS 616	Campbell Scientific	± 3% of water content	1
Rainfall amount	Tipping bucket TE525	Texas Instruments	0.254 mm/TIP	1
Global radiation	Pyranometer CN1	Kipp & Zonen	23.94 μV/Wm^{-2}	1
Global radiation	Pyranometer CS300L	Campbell Scientific	13 μV/Wm^{-2}	3

Net radiation	Net radiometer (REBS) Q7	Campbell Scientific	+ 9.6 (-11.9) μV/Wm^{-2}	1
Net radiation	Net radiometer NR-LITE	Kipp & Zonen	13.9 μV/Wm^{-2}	2
Net radiation (components)	Net radiometer NR01	Hukseflux	15.74 μV/Wm^{-2}, 15.60 μV/Wm^{-2}, 9.90 μV/Wm^{-2} & 8.20 μV/Wm^{-2}	1
Photosynthetically Active Radiation (PAR)	Li COR Quantum Sensor LI190SB	Li COR	5 μA per 1000 μmoles s^{-1} m^{-2}	2
Wind	SODAR PCS - 2000	METEK	0 – 5m/s (± 0.5m/s); 5 – 35 m/s (± 10%)	1
Wind	CSAT3, USA-1	Campbell Scientific, METEK	NA	1
CO_2/H_2O	Li COR	Campbell Scientific	NA	1
Aerosol Optical Depth (AOD)	Sun photometer (Calitoo)		NA	1