UNIVERSITY OF BAYREUTH

Micrometeorology

ERC DarkMix: Large Eddy Observatory, Voitsumra Experiment 2019 (LOVE19)

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1 Overview

1.1 Introduction

The Large Eddy Observatory, Voitsumra Experiment 2019 (LOVE19) was the first full deployment of the "Large Eddy Observatory" (LEO) concept by DarkMix for observing atmospheric properties on similar scales as Large Eddy Simulations (LES). From this similarity in the resolved scales, the experiment earned the nickname of the Large Eddy Observatory.

The primary scientific objective of LOVE19 was to understand the role submeso structures play in the weak-wind and stable boundary layer (wwSBL). Turbulence in the wwSBL does not follow assumptions like stationarity and Taylor's hypothesis. Instead, the occurrence of non-turbulent, submeso structures plays a governing role in the generation of turbulence. One of the key research needs for this problem are observations in which turbulent motions can be separated from the submeso motions on a distributed basis. To this end, LOVE19 featured a large array of Fiber Optic Distributed Sensing (FODS).

This document is intended to act as a companion to the Earth System Science Data (ESSD), filling in many of the more nuanced details that are glossed over or omitted in the peer-reviewed publication. We attempt to avoid repetition between these documents when possible. Unfortunately, since this document needs to be included as part of the published data with a DOI prior to the submission of the ESSD paper, we cannot include a direct reference here. Please see the DOI repository for a reference to the ESSD paper.

This Documentation also plays the dual role of being the internal documentation for the DarkMix project as well as the external documentation for the Zenodo repository. Consequently, direct references to scripts and data may not be fully accurate for the Zenodo repository. Certain detailed data processing scripts are only available internally to DarkMix (i.e., the `DarkMix-only-scripts` directory) as they are intended for tracking the data processing from the original, raw instrument output to the refined data in the Zenodo repository, but are not necessary for understanding the Zenodo repository. Additionally, the Zenodo repository requires a "flat" structure, i.e. no subdirectories. As a result, the paths to data reported are only relevant internally to DarkMix but the file names specified are still correct for the Zenodo repository. Finally, due to the flat nature of the Zenodo repository, the DTS data were aggregated to daily intervals and archived as `.tar.gz` files.

1.2 Experiment Goals

The scientific and technique goals of the experiment are more thoroughly explained in the ESSD paper that accompanies this data set. Here we only briefly summarize the motivation and site description, which are explained with more details in the accompanying ESSD paper.

1.2.1 Technical goals

1. Environmental deployment and testing of the distributed wind direction method using microstructures applied to an actively heated fiber optic cable
2. Second ever actively heated fiber observations of distributed wind speed, with improvements in technique such as vertically-oriented fibers and paired-fibers with identical radiative properties.
3. Using the tethered balloon-carried fiber optic cable to connect between observations of the surface layer and the remote sensing of the upper boundary layer.

1.2.2 Science research questions

1. What are the factors necessary for including in the next theory of turbulence that is capable of describing turbulence in the weak-wind, stable boundary layer?
2. Are submeso scale motions observed at the surface driven by motions aloft (top-down) or are they driven by factors at the surface and propagate upwards (bottom-up)?
3. What factors drive meandering in the wind direction?

1.3 Site Description

LOVE19 was built at the bottom of a broad valley in the Fichtelgebirge mountains in Germany. The experiment site was a grass field approximately 200m by 300m at the bottom of a 40m hill which rose to the south of the site, which carries the name 'Rußwiese'. The crop cover was predominantly perennial agriculturally-used grass. To the southeast of the site was a forest patch. Grass fields bounded the field on all other sides. The creek 'Eger' formed the northern boundary of the field. Throughout the course of the experiment the grass within the site was not cut. The grass peaked at a height of 0.65 to 0.75 m near the automatic weather station. Other parts of the field had grass up to a meter, although this was not documented.

LOVE consisted of 3 Distributed Temperature Sensing (DTS) instruments (x2 Silixa Ultimas and 1 Silixa XT) observing approximately 6km of fiber optic core (section 2), a SODAR-RASS (section 4), wind LIDAR (section 4), ceilometer (section 4), a tethered balloon with a fiber optic cable (section 4.11), CSATs mounted on a 12m tower (section 3), and a full suite of standard meteorological observations (section 3). The relative location of these elements is given in Figure 1.1. The temporal availability of the various observational elements is given in Figure 1.2.

1.4 Coordinate Systems and Data Dimensions

All data are in netcdf format with dimensions of either **xyz** and **time** (for the DTS data) or a height above the surface and **time** (i.e., the remote sensing data). Each **xyz**

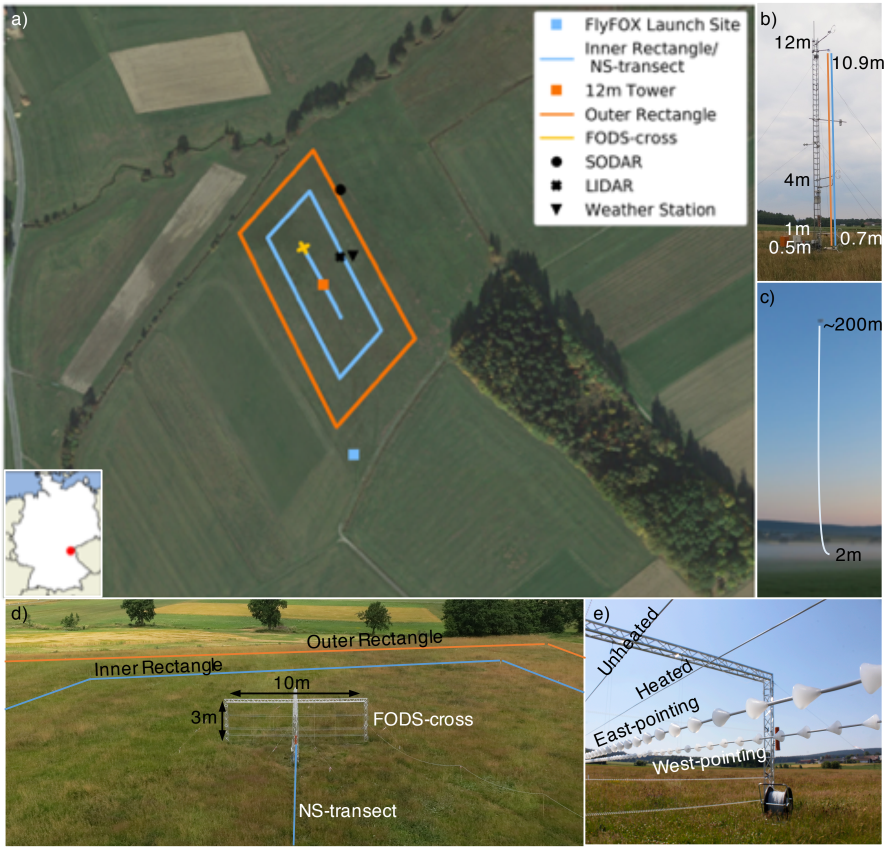

Figure 1.1 An overview of the elements available within the LOVE19 data repository. Note that this figure is from the ESSD paper and only provided here as a convenience.

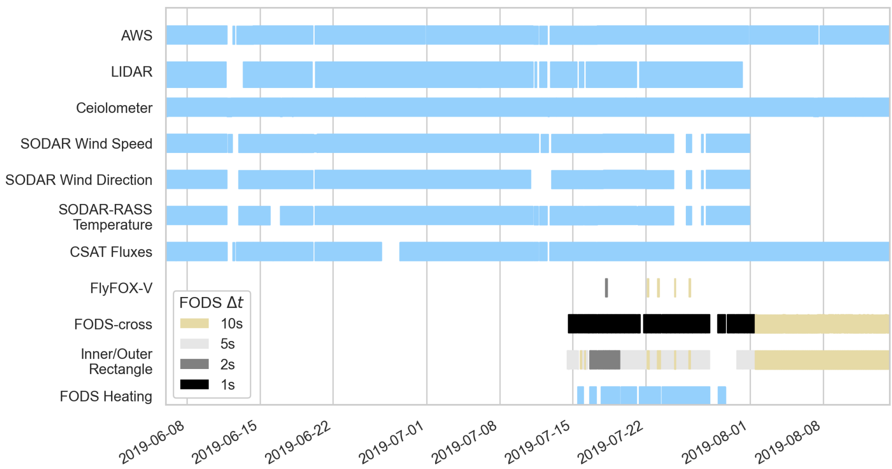

Figure 1.2 An overview of the data availability for the LOVE19 elements. Note that this figure is from the ESSD paper and only provided here as a convenience.

Table 1.1 Field-relative coordinates for the observations that do not include an **xyz**-coordinate in the netcdf.

Observation	UTM (x,y)	Field Relative (x,y)
AWS	704156.40, 5552600.53	14.37, 17.79
SODAR		2.47, 80.3
LIDAR		2.35, 16.2
FlyFOX-V Launch Area		15.37, -170.36
Tower		-13.64, -9.79

dimension further labels an **x**-, **y**-, and **z**-coordinate. The **x**, **y**, and **z**-coordinate are in a "field relative" system representing the distance on a grid in meters from a central reference point. For this reason, there are negative **z**-coordinates for points *above* the surface. For the tower, to get height above the ground you must adjust the z-coordinate by 1.55m and for the FODS-cross this distance is 1.95m (section 2.5). All other elements are either a fixed height above the surface as described in the ESSD manuscript or have a z-coordinate already adjusted to be height above the surface (i.e., FlyFOX-V, section 4.11).

The AWS can be used as a known reference point to convert between the field relative coordinate system and UTM. All additional locations are summarized in table 1.1.

2 DTS Arrays

2.1 Configurations

The DTS array went through several iterations, each requiring slight to major changes in the configuration. Each configuration file name (which also names the DTS data from the DTS devices directly and within pyfocs) is described with the date it is valid, notes from the config file, the processing steps completed, and the location of the data in the LOVE DTS Overview pdf. Internally for the DarkMix group this pdf can be found in `LOVE/DTS/config_name_documentation`. This pdf can help trace from the raw xml files to the eventually homogenized and complete data located in the Zenodo repository. Largely the lesson learned here is to be extra deliberate with configuration naming scheme and documentation for each time the configuration is adjusted. The number of slight variations that were documented in different locations dramatically increased the complexity of processing the data.

Most specifically, between July 15th and August 1st the outer array data stream was split between multiple configuration files. Notably, this occurred for the FlyFOX experiments, in which the outer array and FlyFOX were both observed by the XT (Section 4.5.4). Switching between configuration files for the FlyFOX experiments left some 5-minute intervals with data in both configurations. The conflicting archives are stored in `Outer_array/LOVE_outer_array_190715/conflictedfiles`. These files were put into the `raw_xml` folder and archived as part of running pyfocs on the the merged `raw_xml` directory. All configuration files for shepherding the data from archived xml files to finalized netcdfs can be found in `darkmix-only-scripts/pyfocsconfigurations` (note, not in the Zenodo repository).

Finally, the DTS data were switched to a low-maintenance mode between August 1-14. Both the outer rectangles and the FODS-cross were observed by the XT, again changing the temporal and spatial resolution (Figure 1.2). An unfortunate bug/instrument malfunction/user error occurred during this period, causing 5-minute gaps as frequently as every half an hour and as sparsely as every few hours.

These various configurations were homogenized to become a consistent data set. Note that as a result of DTS instrument changes (between the XT and Ultima) the temporal and spatial resolution are not consistent throughout the experiment. This inconsistency will inhibit automatically loading all the data as a large xarray Dataset dask object, since the coordinates cannot be combined. The script that homogenized the data can be found here: `darkmix-only-scripts\ESSD_fods-homogenization.ipynb`.

2.2 pyfocs

All DTS data were processed using pyfocs v0.4.4 (the only difference between this version and the DOI'ed v0.5 are features in the wind speed calculation, these differences only matter for post-processing of the ESSD repository, not for creating the repository). The current up-to-date version of pyfocs as well as tagged historical version releases are available through the github repository, `https://github.com/klapo/pyfocs`.

The `fixed_shift` distance necessary for automatically aligning different sections was found using `pyfocs.align.interp_section()` function using several days of observations without heating. This alignment was only provided for the paired heated-unheated sections, not for the coned sections. Bath locations were mapped and verified using multi-day period of data.

2.3 Zenodo Repository

The Zenodo repository contains the homogenized, physically-labeled DTS data (i.e., calibrated temperatures) for the entire experiment in netcdf format. These are located within the *FODS* directory and are further subdivided into several additional subdirectories: FlyFOX, FODS-cross, and outer-array. The "FODS-cross" netcdfs contain the DTS data for the FODS-cross, 12m tower, and the 80m NS-transect (Figure 1.1a). The "outer-rectangle" netcdfs are separated according to the fiber type (unheated or heated stainless steel and pair 1, p1, for the inner rectangle). FlyFOX data are separated according the flight date and break with the convention of including calibrated temperatures, as instead the virtual potential temperature is included.

Each netcdf file is labeled according to the type of fiber (unheated, heated, the various cone directions, and `p1` for the inner rectangle pair 1). This label also corresponds to a coordinate name that consists of a string for each **`xyz`** element, which gives labels for sections of fiber. These can be used to select for specific portions of the fiber and correspond to the naming scheme shown on the maps in section 2.4 and 2.5. This decision to divide the data by location type simplifies having fibers that represent the same physical locations (i.e., heated and unheated fibers for wind speed). These paired fibers share an **`xyz`**-coordinate. In python the **`xyz`**-coordinate can be converted to a multi-index in xarray using the pyfocs function `pyfocs.labeler.create_multiindex()`.

The DTS data described here (plus the sonic anemometer observations) can be used by the provided example jupyter notebook (`example-scripts\horizontal-array_July22nd_ESSD-example`). The example is provided in both an `.html` and `.ipynb` format. The example can be run directly within the intact Zenodo repository to recreate Figure 7 of the ESSD manuscript.

2.4 Near-surface DTS array

The near-surface DTS array consisted of two nested rectangles around the border of the field, referred to as the outer rectangle and inner rectangle. The fibers for the inner and outer rectangle were spliced together into a single long optical core: inner rectangle twisted pair first followed by outer rectangle single core stainless steel. Tension was applied to the stainless steel fiber by wrapping them around ±0.2m diameter pipes multiple times. These wrappings were held in place using electric tape.

The near-surface DTS array experienced a break near the end of the second pvc fiber immediately next to the trailer on the morning of July 28th at 3am (originally thought to be July 27, hence the confusing configuration names). The break was not noticed until July 30th, leading to a data gap. The last two days of data are stored in a quasi-configuration `LOVE_outer_array_190727_postbreak`. The data between July 28th at 3am and July 30th at 1200 are purposefully excluded from processing to avoid creating data files without data within them and potentially confusing later analysis (Figure 1.2.

2.4.1 Outer Rectangle

Fiber type: Two single core fibers offset from each other by 8cm in height. One fiber (z=1.33-1.34m above the ground) was heated and the other (z=1.18-1.19m) was unheated. These heights were consistent across the entire array. The paired fibers can be used to derive wind speed orthogonal to the fiber. See the `example-scripts/horizontal-array_July22nd_ESSD-example` in the repository for a guide on computing this quantity around the outer rectangle.

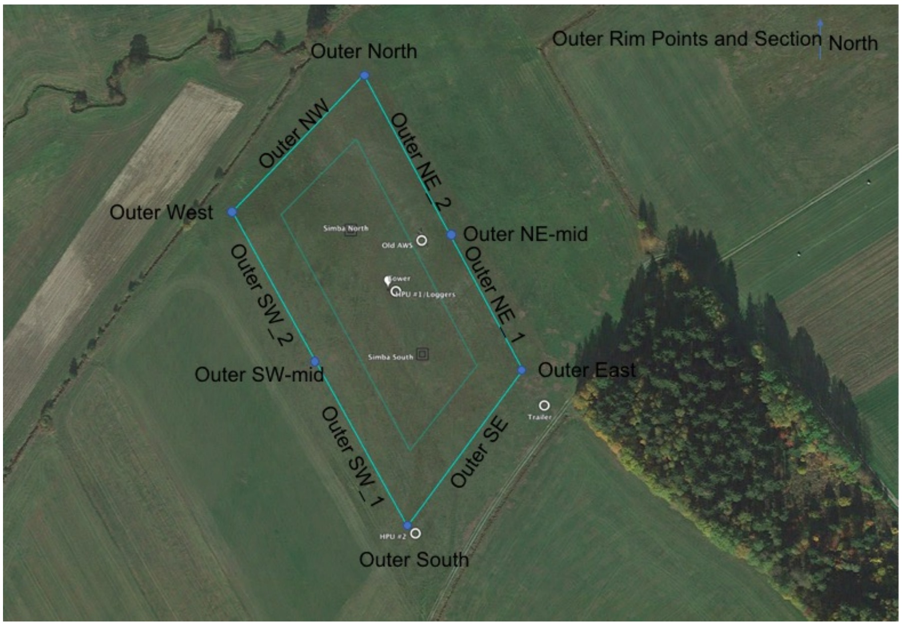

Figure 2.1 Plan view of the fiber holders (blue dots) and fiber section names for the outer rectangle. These names correspond to the section labels given in the Zenodo repository netcdfs.

The fiber was applied in a semi-complicated fashion due to needing to keep the bottom of the rectangle "open" for ease of transporting material into the center of the experiment (Fig 2.2 and 2.3). The southern most section was the last section completed so it has a different LAF that doesn't match the other sections. We started with the end of the fiber on the right of the "diamond" and moved to the northwest for the unheated fiber. At the bottom corner of the diamond we turned around and went backwards setting up the heated fiber. Finally, back at southern most corner we "closed" the box before putting both ends into the reference sections in the trailer.

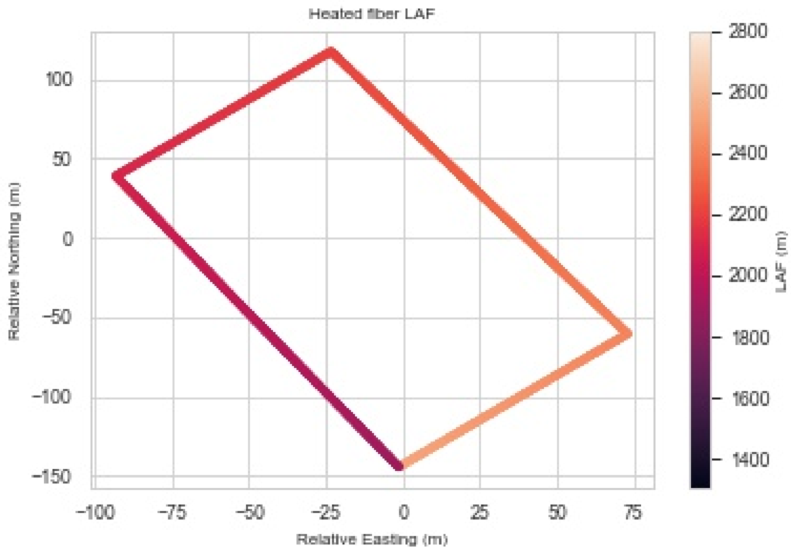

Figure 2.2 Details on how the LAF varied through the heated section of the outer rim.

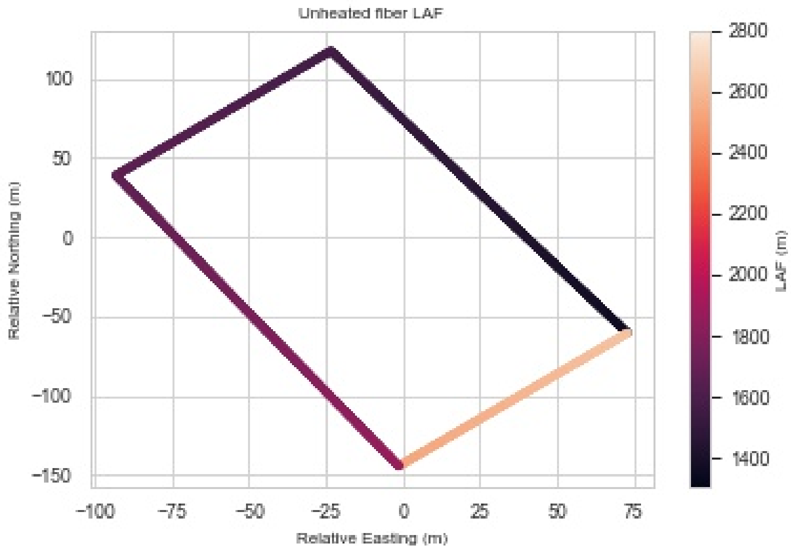

Figure 2.3 Details on how the LAF varied through the unheated section of the outer rim.

2.4.2 Inner Rectangle

Fiber type: Twisted pair pvc fiber. These fibers were spliced together within the trailer so that each twisted pair passes through the entire array and reference baths in sequence (i.e., pair 1 observes the entire array, followed by pair 2).

The two twisted pairs had an LAF-dependent temperature offset (Figure 2.5). The

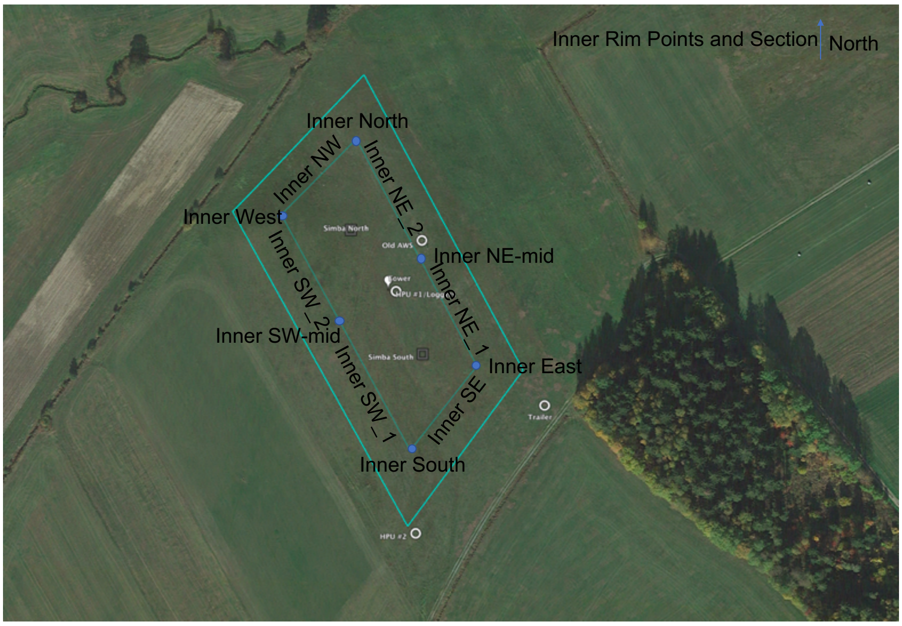

Figure 2.4 Plan view of the fiber holders (blue dots) and fiber section names for the inner rectangle. These names correspond to the section labels given in the Zenodo repository netcdfs.

cause is some power loss around the fiber holders as well as a change in differential attenuation between sections. The single-ended calibration cannot account for these changes as it uses an average differential attenuation for the entire length of calibrated fiber. Due to these differences, we only report pair 1. This simple analysis also suggests that temperature gradients smaller than 0.3K per 100m are not significant even when using very long time averages to minimize instrument noise.

2.5 FODS-cross, tower, and NS-transect

The two DTS devices type 'Ultima' were used to observe the two FODS-crosses. Additionally, the Ultima observing the north FODS-cross also observed a horizontal transect at approximately 2m height and the heated-unheated fiber pair along the 12m tower (Figure 1.1). The FODS-crosses were nicknamed "simbas" since there were small LEO elements. The naming convention for the fiber sections has a reference to that (e.g., contains "NS" for North Simba). The ESSD repository only contains the "North Simba" which is referred to as the FODS-cross in the manuscript and highlighted in its Figure 1.1. The South Simba has not been processed in any meaningful way, including mapping. It is not included in any of the pyfocs configuration files.

The FODS-cross, tower, and NS-transect consisted of two fiber types. See the ESSD manuscript for specific fiber details. Briefly there was

- A multicore fiber with stainless steel sheathing for air temperature and wind speed

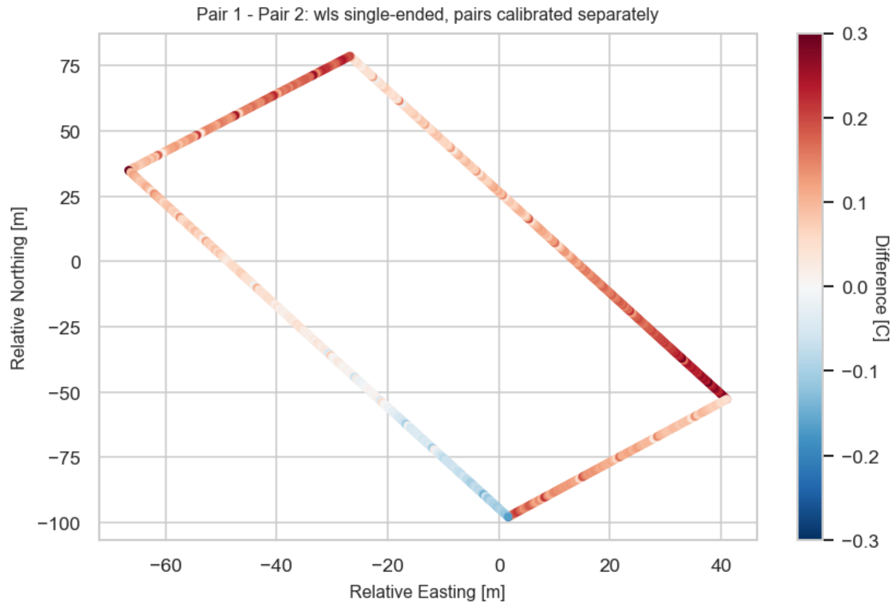

Figure 2.5 The mean temperature difference between pair 1 and pair 2 between July 22 and July 23. Some effort was made to align these two sections, but the effect of some imperfect alignment can be seen, e.g. by fiber holders.

- A multicore fiber with stainless steel sheathing and injection molded cones for wind direction

We only use the first core of the multicore fiber ("Core A") as Core B is over a kilometer of fiber length further than Core A, approximately doubling the instrument noise. Additionally, saturation effects likely drive differences in mapping that have not been reconciled between the cores.

The FODS-cross also had instrument and configuration changes, albeit fewer than the outer rectangle. The changes in temporal resolution can be seen in Figure 1.2. As with the outer rectangle the corresponding pyfocs configurations are in the configuration subdirectory available internally to the DarkMix team.

2.5.1 FODS-Cross

Please refer to either the ESSD or wind direction manuscript for specific details of the FODS-cross. Generally, it was a 8m by 8m cross that was 3m tall. The FODS-cross features quartets of fibers consisting of two pairs: a pair of heated and unheated fibers with no cones and a pair of coned fibers with cones oriented in opposite directions. The unconed fibers are intended to be used to observe wind speed orthogonal to the fiber while the coned fibers are intended to observe horizontal wind direction. There were three levels of fiber quartets along the cross axis, with the orthogonal sections offset from each other (Figure 1.1). The approximate heights were 0.5m, 1m, and 2m. See the note regarding height adjustments to convert the netcdf **z**-coordinate to a height above ground in section 1.4.

We note artifacts at the edges of the test sections from the fiber holders. These need to be excluded from analysis to avoid systematic errors. The edge-effect-free region of the horizontal Simba sections is approximately 8 m long. ↯ Note that physically mapped locations (tachymeter data) correspond to the location of the actual holders. The LAF of the refined edges of the test sections are set such that they largely exclude artifacts from edge effects though. For correctly tracking features the physical locations need to be adjusted.

In addition, during some times structures can be observed that most likely are shading effects caused by the trusses.

2.5.2 NS-transect

As part of the same long optical core for the FODS-cross and tower, the NS-transect (Figure 1.1) extends between the north and south Simba, with the tower in the middle. Substantial drooping occurs along these fiber sections (dubbed the 'Manes') as the same principle of wrapping the fiber around a 0.15 m diameter pipe was found to be unable to deliver enough tension for the 40m span between each Simba and the tower. The drooping created an approximately 20cm difference in height between the edges and middle of the NS-transect.

2.5.3 Vertical FODS at the Main Tower

At the Main Tower, a multi core fiber with stainless steel sheathing was vertically deployed as a profile from 0.2m to 11.2m and back down with one direction being actively heated. It was connected to the Simbas via the horizontal transect of Simba's Mane.

Approximately 0.5m of fiber were found to be influenced by the fiber holders at the top and bottom of the tower. These artifacts were excluded in the finalized mapping and from the location libraries in the pyfocs configuration files.

The mapping from LAF to height was confirmed by comparing the air temperature from the fibers to the sonic anemometers, specifically looking for similarity in profile shape rather than absolute values (Figure 2.6). The biases were -1.8K during the day (for the entire profile) and -2.7K at night (for the entire profile). Figure 2.6 includes this correction. The day time values reveal a potential artifact between 4m and 8m height. The night time comparison also has an offset at four meters but without the jumpiness vertically. The profile shapes between the two agree well, suggesting that the refinements of the LAF to vertical coordinate mapping were successful. See the note regarding height adjustments to convert this to a height above ground in section 1.4.

The evaluation against wind speed can be found in the ESSD manuscript. The script for carrying out the evaluation is `darkmix-only-scripts\LOVE19_windspeed-eval_vr20` and is in both `.html` and `.ipynb` format.

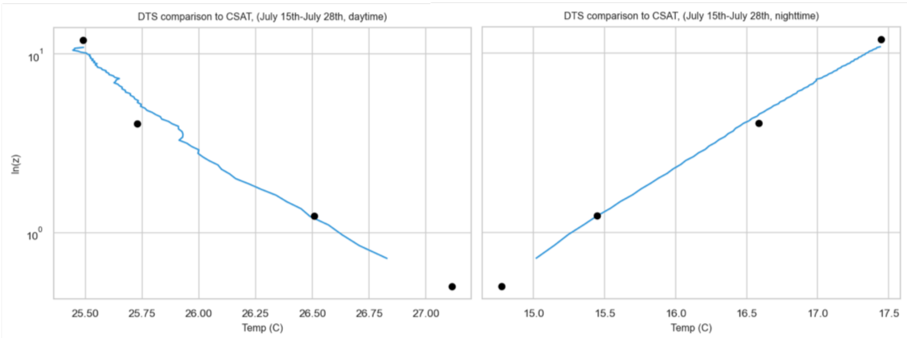

Figure 2.6 Comparison between the CSAT and FODS temperatures during daytime (0700-1700, left) and nighttime (2000-0500, right). The FODS data were bias-corrected to match the CSAT temperatures in order to facilitate comparison of the profile shape. The black dots are the mean CSAT temperature during the period.

2.6 Heating Rates

Heating was applied to the outer rectangle from the morning of July 15 to July 28. Due to differences in the length of heated fibers the heating rate can vary, as shown in Figure 2.7. A netcdf with the **xyz**-labeled heating rates, consistent with the coordinates for the XT-observed outer rectangle is available in `FODS\heating-rates\outer-rectangle_heating-rates.nc`. This netcdf was built within the `heating-rate_estimate_outer-array` notebook and is based on work from `outer-rim_wind-speeds.ipynb` which maps the heated locations.

One of the challenges for the FODS-cross was estimating the heating rate. Here we include the necessary documentation to follow the jupyter notebook in which the heating rate netcdf for the FODS-cross and tower was derived (`ESSD-repository/FODS/heating-rates/FODS-cross-tower_heating-rates.nc`. The heating rate netcdf contains two variables: a heating rate for the unconed fiber (FODS-cross + tower) and the heating rate for the coned fiber on the FODS-cross. The two variables have only a **time** dimension in contrast to the heating rate netcdf for the outer rectangle, which has both **time** and **xyz** coordinates. Since the heating rate does not vary *within* an element on the FODS-cross, no location information is needed. The relevant quantity to be derived from the included figures are estimates of the resistance, based on fiber length and a measured fiber resistance, for the circuit diagram in Figure 2.10. These resistances are slightly refined in the notebook `darkmix-only-scripts/heating-rate_estimate_FODS-cross-tower` in which the FODS-cross heating rate was built. Additionally, the heating rate was lower for the period 2019-07-21 09:10 to 2019-07-23 09:40. This change in heating is also reflected in the heating rate netcdf.

Figures 2.8 and 2.9 detail the heating for the Simbas. The HPU applied $\approx 4.3\ Wm^{-1}$ to 137 m of stainless steel fiber on the tower and the FODS-cross unconed branch for the majority of the experiment. During the period July 21, 09:20 to July 23, 09:40, the setpoint at the HPU had been set to 480 V instead of 540 V, resulting in a heating rate of $\approx 3.2 \pm 0.2\ Wm^{-1}$. For the FODS-cross coned fiber the heating rate was slightly lower

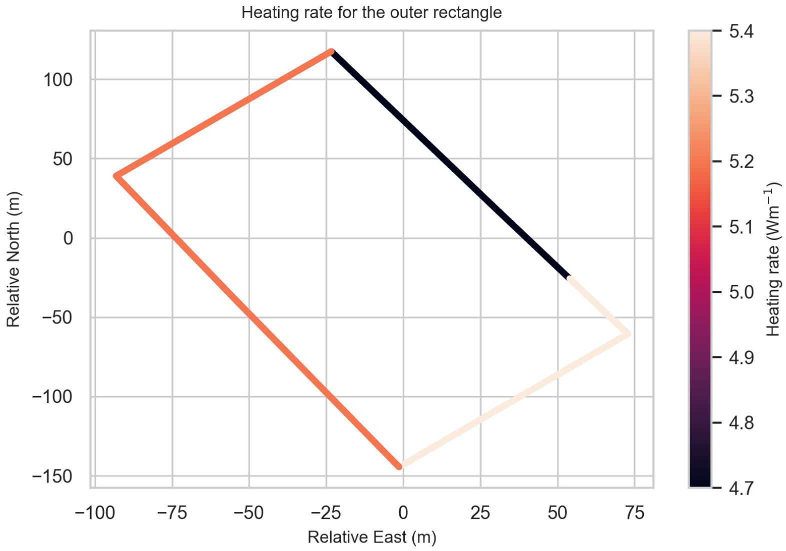

Figure 2.7 Heating rate in Wm^{-1} for the outer rectangle.

at $\sim 4.1\ Wm^{-1}$ and decreasing to $\approx 3.25\ Wm^{-1}$ during the period of reduced heating.

When evaluating the FODS wind speed on the tower, an optimal heating rate of $\sim 4.5\ Wm^{-1}$ was found, which is slightly higher than our estimates. As the goal was to derive an accurate wind speed, we opt to use this slightly adjusted heating rate for the unconed fiber. Similar adjustments to the heating rate for the coned fiber were applied for the coned fiber in the wind direction paper. The heating rates supplied in the netcdf should therefore seen as more of a "starting point" than an absolute value.

2.7 Calibration

All components were observed in a single-ended configuration. For the Ultima-observed elements, the typical spatial and temporal resolution was 0.127m and 1s. For the XT-observed elements the typical spatial and temporal resolution as 0.254m and 5s, although this varied (see Figure 1.2).

Most calibration details are provided in the ESSD manuscript and not reiterated here. We do add a figure showing the time series of the solid reference section temperatures (Figure 2.11). The calibrated temperatures of the fiber within the reference sections as well as the reference section temperatures are provided as part of the Zenodo repository. They can be found in `FODS\reference_sections` for each fiber (outer rectangle stainless steel, inner rectangle pvc fiber, and the FODS-cross), enabling users to filter periods with a poorer calibration if desired.

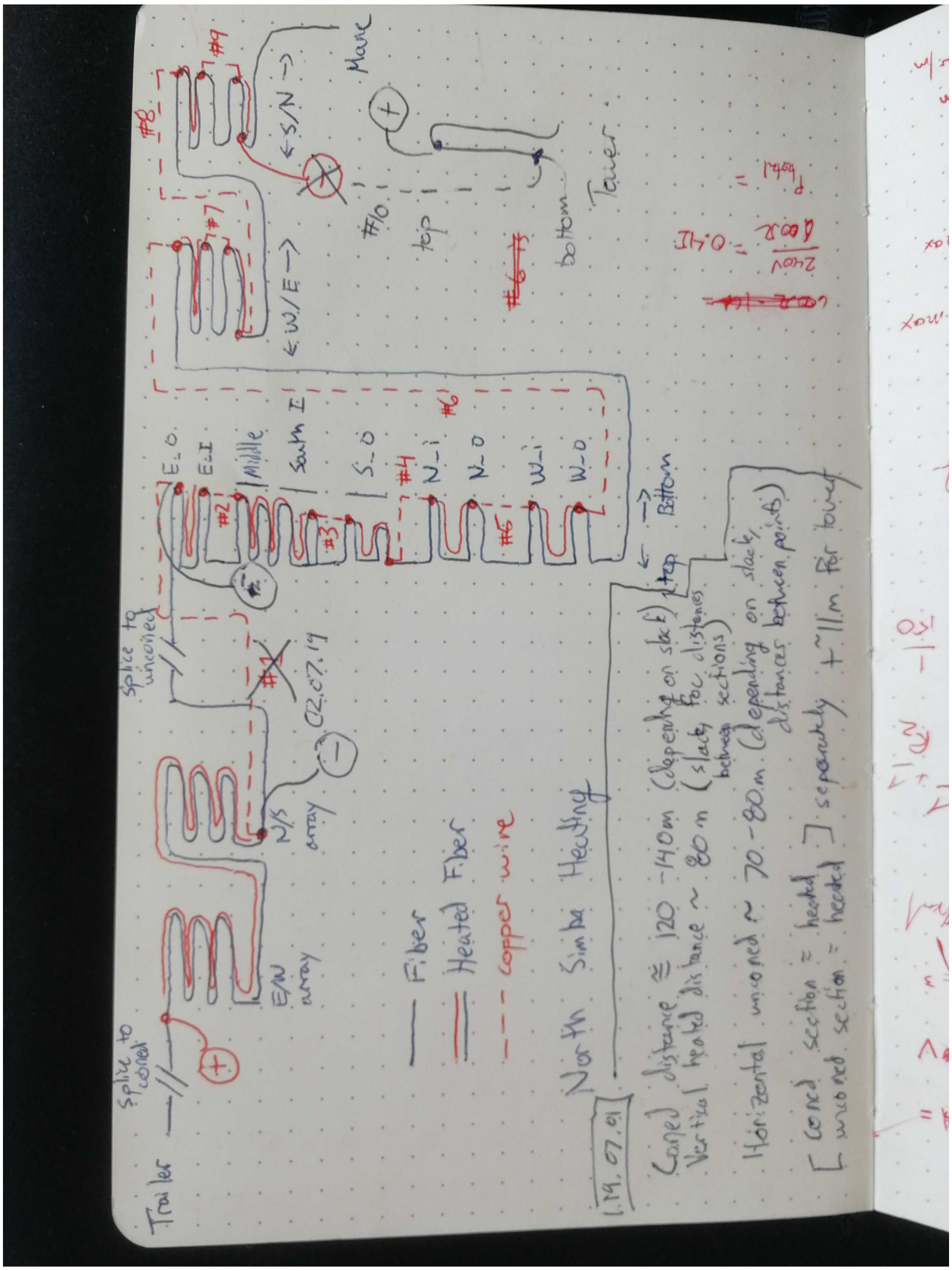

Figure 2.8 Layout of the heating for the North Simba taken from K. Lapo's labbook. The diagram was updated in early July to put the coned and unconed fibers into parallel.

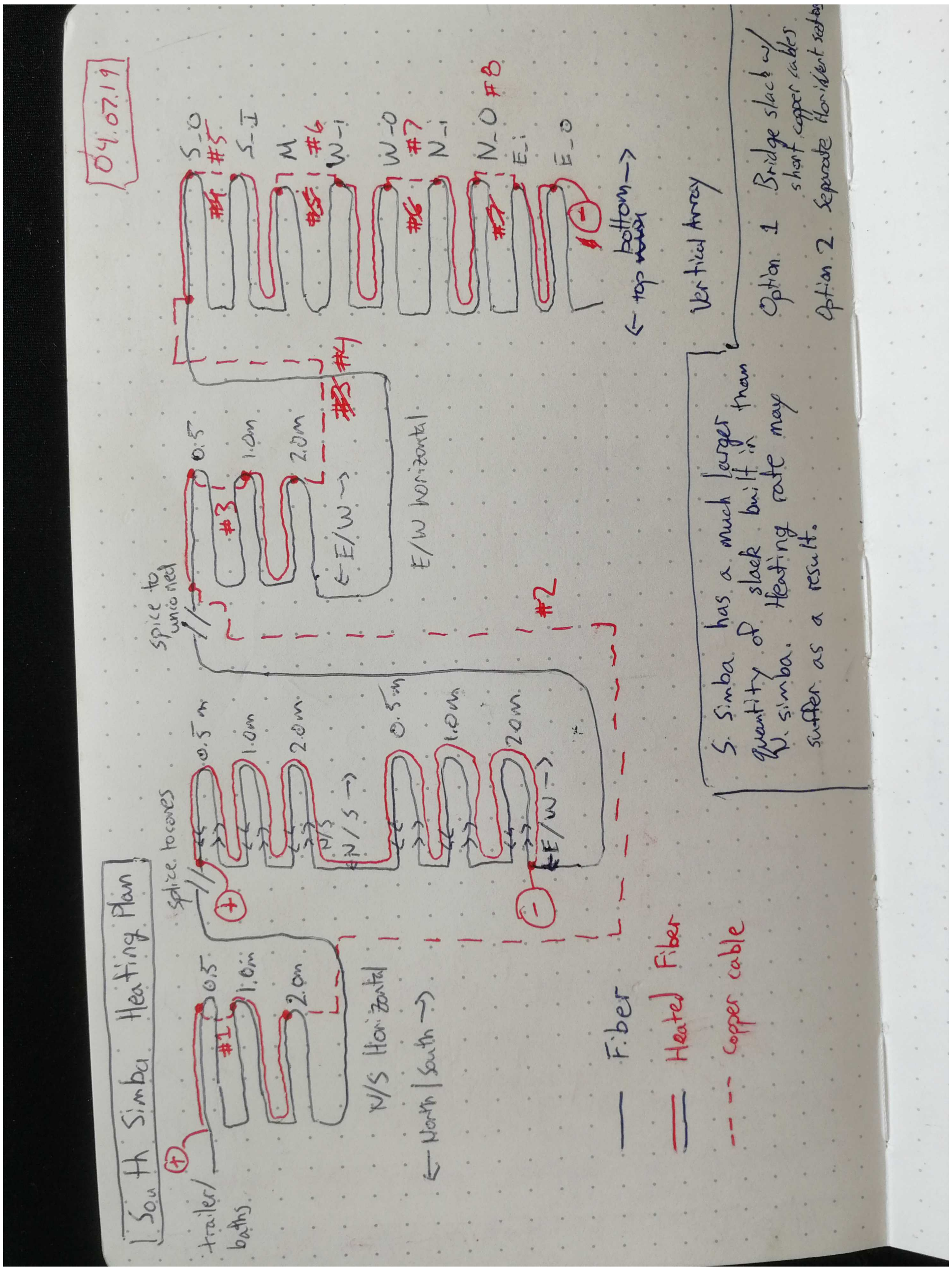

Figure 2.9 Layout of the heating for the South Simba taken from K. Lapo's labbook. The diagram was updated in early July to put the coned and unconed fibers into parallel.

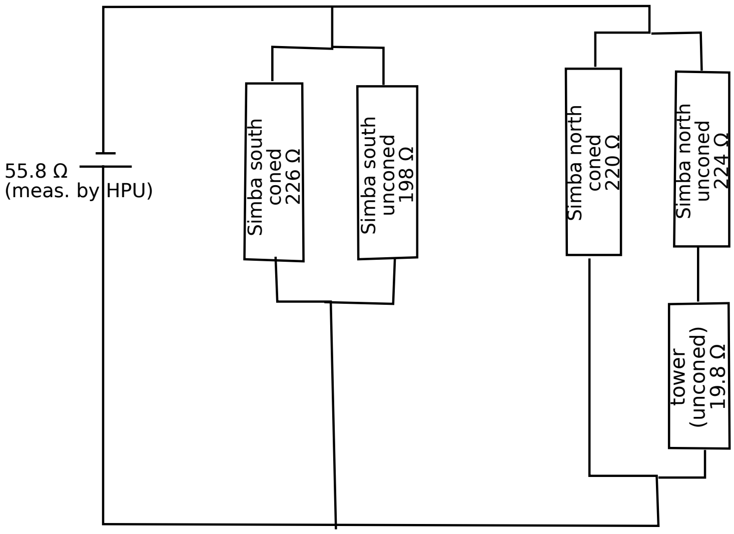

Figure 2.10 Circuit diagram for the heating of the Simbas and the tower.

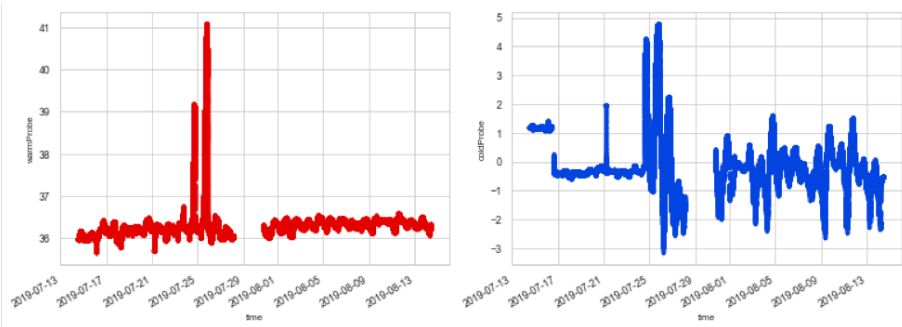

Figure 2.11 Time series of the reference temperatures inside the solid state reference sections for the warm reference (left) and the cold reference (right).

3 Ancillary Meteorological Observations

3.1 Introduction

The ancillary measurements consist of 4 sonic anemometers, 2 sonic anemometers on the FODS-crosses (one per), pressure observations, and the Automatic Weather Stations (AWS). Only the sonic anemometer and AWS observations are available through the Zenodo repository. The other observations either have problems (which are documented here) or will be included as part of later analysis.

Data in the Zenodo repository are in netcdf format. The scripts used for making these netcdfs can be found in `darkmix-only-scripts\ancillary_data_create_netcdfs` in both `.ipynb` and `.html` format. All netcdfs have at least a **time** dimension that is in UTC.

3.2 Sonic Anemometers

Four CSAT3 (CSAT3, Campbell scientific, Logan, UT, USA) were mounted on the main tower with the intent to achieve an approximately even spacing in logarithmic space (Table 3.1). The original CSAT 20Hz time series data were recorded in GMT+1. A single LICOR gas analyzer was mounted adjacent to the 4m CSAT.

Table 3.1 Sonic anemometer (CSAT3, Campbell Scientific Ltd.) at the main tower

height	s/n	SDM address	azimuth
0.50m	0322	3	280
1.24m	0235	4	280
4.08m	1756	5	280
11.99m	0205	6	280

The CSATs were processed with bmmflux for time scales of 1 minute (no rotation), 10 minutes (with 3D rotation), and 60 minutes (with 3D rotation). The bmmflux output were then reindexed to a regular time stamp to account for data gaps and stored as netcdf. The bmmflux output explanations and units (usually included as a separate .csv) have been appended to the netcdf data as attributes for each data variable. The CSAT flux data in netcdf format were converted to UTC.

The bmmflux configuration files for processing the CSAT data are in `darkmix-only-scripts/bmmflux_configurations` and includes the bmmflux configuration for the 84.375s intervals for the 12m sonic to match the LIDAR. Note that CSAT data at 84.375s are not in either repository location but will be included in future analysis. The code for converting from the bmmfux excel output to netcdf files, including labeling of the variable attributes, is also included in the `darkmix-only-scripts\ancillary_data_create_netcdfs` script.

The netcdfs have dimensions of **time** and **CSAT name**. The **time** dimension has been converted to UTC. A height coordinate, **z**, based on the Theodolit measurements is provided as a coordinate that is labeled by **CSAT name**. See the note regarding

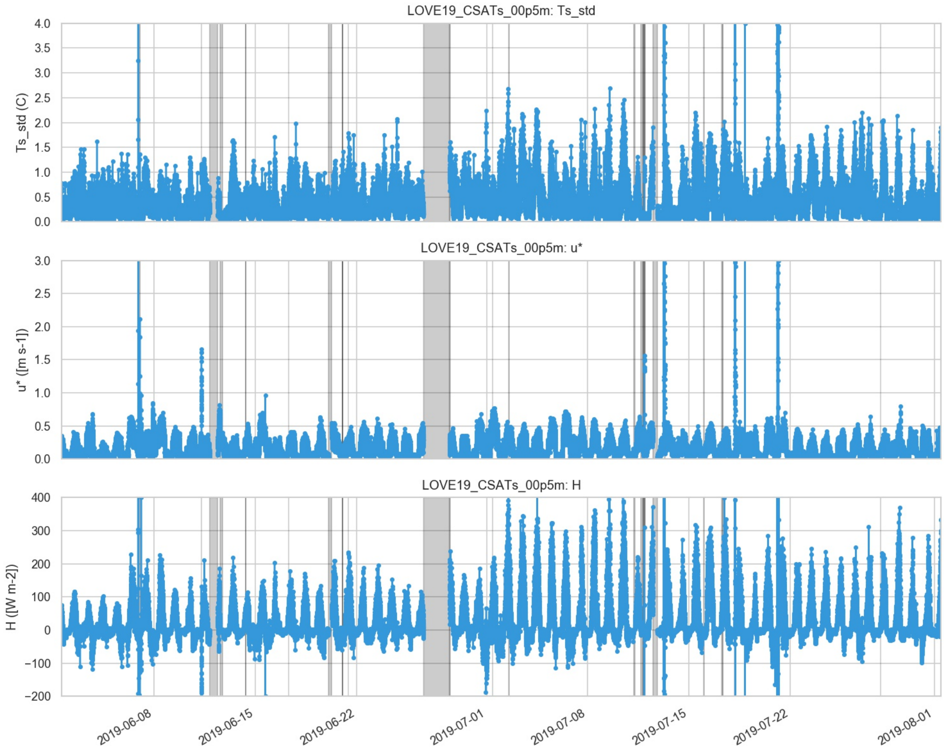

Figure 3.1 Example of the 0.5m CSAT data processed through bmmflux with a 1 minute perturbation timescale. The grey regions indicate data gaps.

height adjustments to convert this to a height above ground in section 1.4. The sonic temperatures are offset from each other and have not been bias-adjusted i.e. to the 12m CSAT.

3.3 Simba METEKS

Two METEK USA-1 sonic anemometers (Metek GmbH, Elmshorn, Germany) were installed each FODS-cross. One METEK was at 1.96 m on the northern FODS-cross. The other METEK was at approximately 1m height above the surface on the southern FODS-cross. The naming scheme was METEK1 = South, METEK2 = North. Each METEK was employed near the fiber on the north-south branch of the FODS-crosses in order to act as a reference for the development of the FODS wind direction method. Both METEKS were installed with their north arrow pointing north (Azimuth = 0°). These data are not present in the Zenodo repository, but will be made available as part of future work.

3.4 Fast-response barometric pressure observations

Due to file corruption issues, we only reliably have the 1-minute stats of the data from the Paroscientific Nanoquartz barometers. Each pressure inlet consisted of a quad-disk

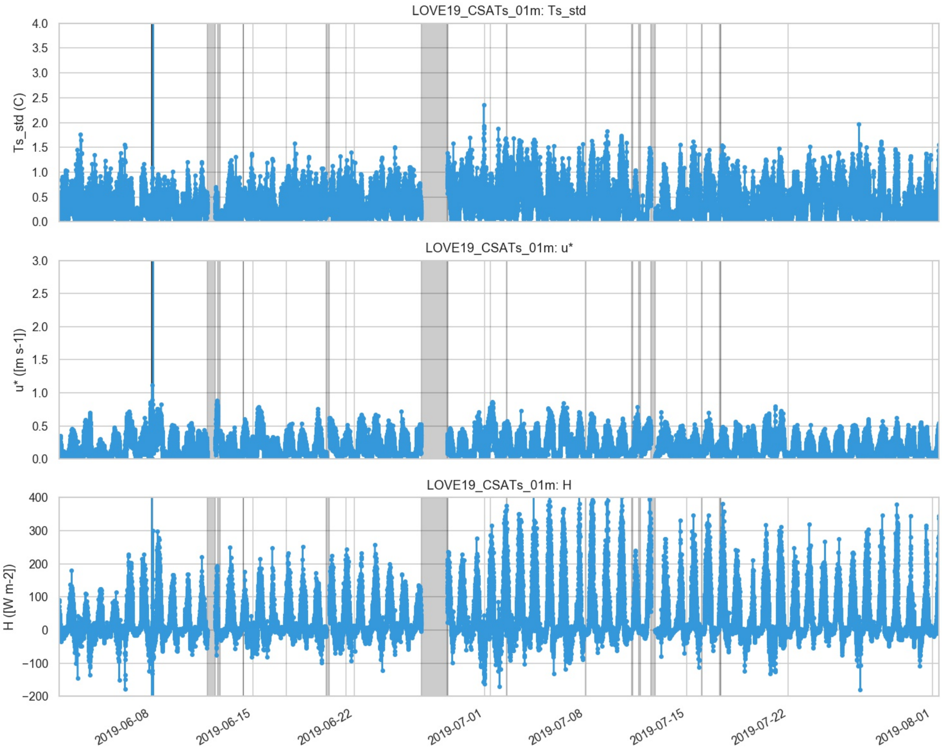

Figure 3.2 Example of the 1m CSAT data processed through bmmflux with a 1 minute perturbation timescale. The grey regions indicate data gaps.

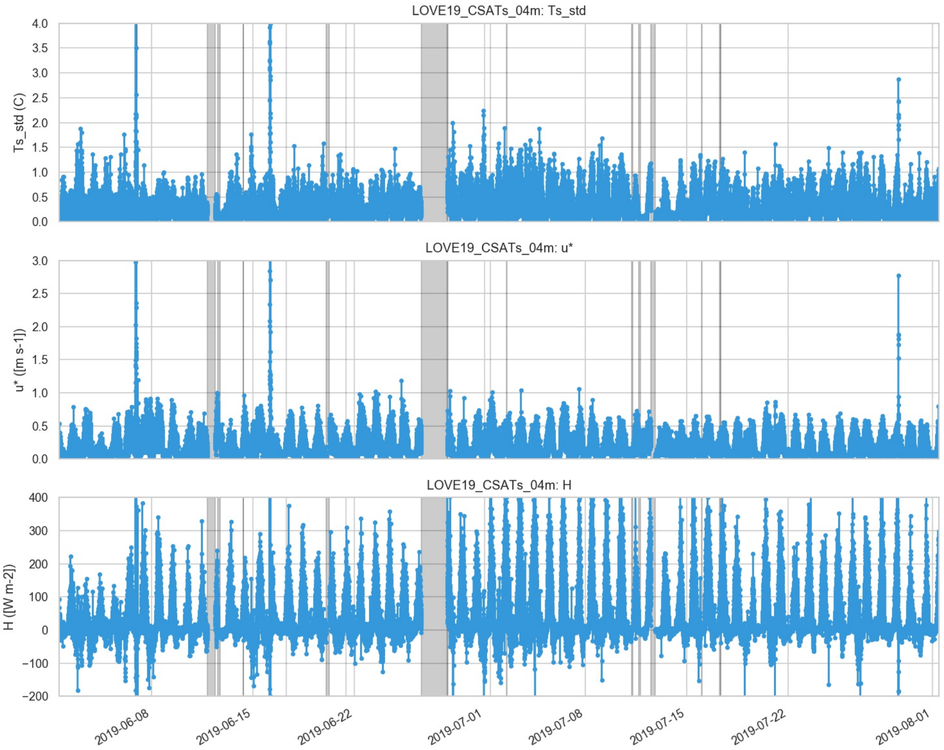

Figure 3.3 Example of the 4m CSAT data processed through bmmflux with a 1 minute perturbation timescale. The grey regions indicate data gaps.

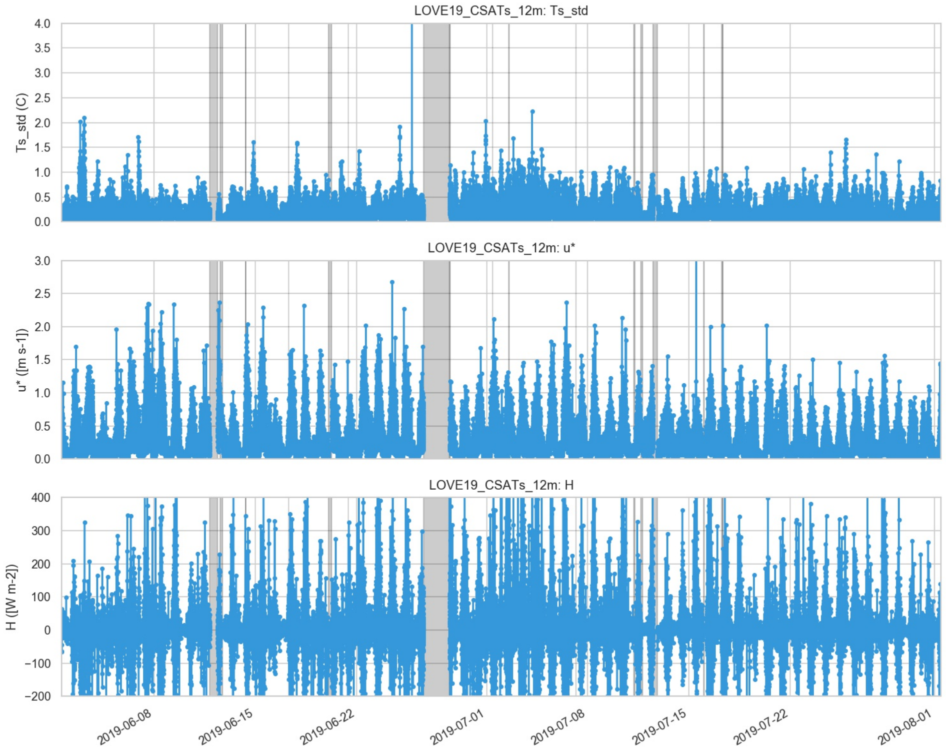

Figure 3.4 Example of the 12m CSAT data processed through bmmflux with a 1 minute perturbation timescale. The grey regions indicate data gaps.

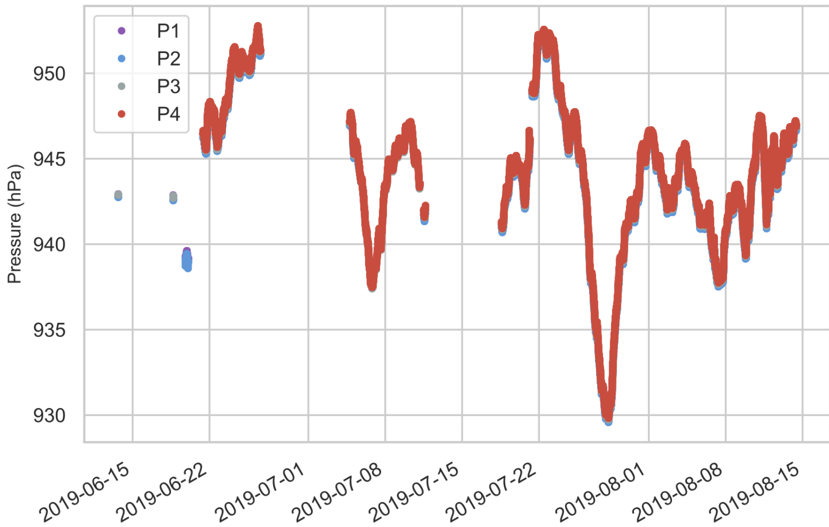

Figure 3.5 1-minute averages of the pressure port data for the duration of LOVE from the *stats* data logger file.

pressure port (Paroscientific, Seattle, WA, USA; or UBT replicates of it). Additionally, one of the pressure ports ceased operation (the one on the tower) and the data connection to the pressure port in the south east corner was intermittent. Pressure port 1 (the tower pressure port) failed entirely and stopped recording data by the end of June. The other pressure ports have considerable gaps (Figure 3.5). It is suspected that some of the problems in July stemmed from providing too low of a voltage, a higher voltage was provided after mid-July, coinciding with the more complete 1min stats time series.

All of the tsdata files were corrupted. We attempted to repair some of these files within Card Convert but without success. The 1min stats were used to reference the FlyFOX-V tethersonde pressure observation by correcting the tethersonde pressure to agree with the 1min stats both on launch and upon recovery.

3.5 Automatic Weather Station

The Automatic Weather Station refers to the long-term station located to the east of the main tower. These data were originally recorded at a 10-minute interval. An additional 1-minute output frequency was added on June 20th. Both time resolutions are available from June 20th to August 20th. The available observations are summarized in Table 3.2.

The AWS data were converted to a netcdf format with a similar naming scheme as other netcdf conversions of the data (e.g., the time dimension is labeled as **time**). The netcdf's of AWS data are in UTC.

Table 3.2 Observations available through the AWS.

Instrument	Height(s) (m)	Variables
HMP45A Thermohygrometer, Vaisala, Finland; radiation shielded and wind aspirated	2	air temperature, humidity
wind vane and cup anemometer, Theodore Friedrichs and Co, Germany	2	horizontal wind speed and direction
CNR4 Net Radiometer, Kipp and Zonen, The Netherlands	2	downwelling and upwelling shortwave and longwave irradiances
PT-100	-0.05, -0.25, -0.5	soil temperature
Radiation shielded PT-100	0.05	air temperature
precipitation	1	OTT Pluvio^2 - Weighing Rain Gauge, OTT HydroMet, Kempten, Germany

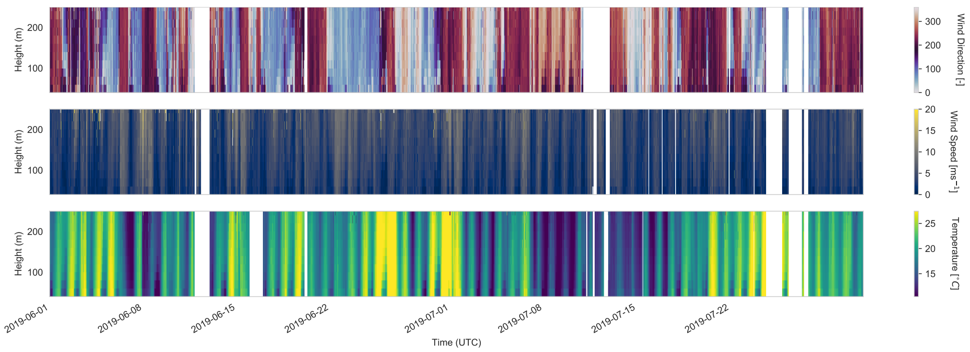

Figure 4.1 SODAR-RASS wind direction, speed, and temperature for the bulk of the LOVE campaign. White periods indicate data gaps. Note that the data gaps do not line up for each quantity.

4 Love Column

4.1 Introduction

In the Love Column the near-surface observational network (0 - 12 m height) gets connected to the observations taken with the FlyFox (0 - 200 m height), the Sodar-RASS (40m - 300m height), the LiDAR (0.08km - 5km height), and the Ceilometer (up to 8 km height). This presents the possibility of observing the ABL and its interaction with the weak-wind SBL along a vertical span of a few kilometers with very detailed profiles of wind speed and temperature.

As with the other sections, details included in the upcoming ESSD manuscript are omitted here. The jupyter notebooks used to generate the netcdfs in the Zenodo repository can be found in `darkmix-only-scripts` in both `.ipynb` and `.html` format.

The use of the data described here (plus the FODS tower observations) are demonstrated in `example-scripts\column_July18th_ESSD-example` in both an `.html` and `.ipynb` format. This jupyter notebook can be run directly within the data repository, but assumes a non-flat structure so some paths may need to be altered. The example script can be used to recreate Figure 6 of the ESSD manuscript.

4.2 SODAR-RASS

SODAR-RASS data was recorded with time in MEZ. The netcdf file on the server *LOVE_SODAR_JuneJuly.nc* has the time stamp converted to UTC (MEZ time - 1 hour). The coordinate **time** is the start of the averaging interval. Height is reported as the coordinate **z** and should correspond to the range gate's bottom value. The netcdf can be found in `remote-sensing\sodar`. The first meaningful range gate is at 40m and observations typically have reasonable values up to 300m.

There are some inconsistencies in the text files provided on the DarkMix server, with various components of the SODAR-RASS system reporting NaNs for different, non-overlapping periods (see Figures 1.2 and 4.1).

4.3 LIDAR

The Doppler wind LiDAR (Model Stream Line, Halo Photonics Ltd., Worcester, UK) was deployed in the center of the site. The LIDAR was operated in three modes: a conical Vertical Azimuth Display (VAD) scan, Range Height Indicator (RHI) scan, and a vertical stare (VST). The alternating VAD and RHI scans had a ≈ 1.5 min duration between each vertical stare period of 13.5 min. See ESSD manuscript for more details. The vertical stares were performed continuously for 14 minutes between the RHI and VAD scans, with a range gate of 24m and a temporal resolution of 1s. VST data were aggregated to 83s and converted to a netcdf format while the RHI and VAD are presented as 1min averages every 30 minutes, respectively. The RHI and VAD are stored separately. Additionally, the backscatter attenuation is provided as a third netcdf archive. All netcdfs have a dimension of height, **z**, and **time**. Each variable includes unit and explanation attributes. The netcdf can be found in `remote-sensing\lidar`.

4.4 Ceilometer

The Ceilometer used in the LOVE campaign is a CHM8k (Device name: CHM198101) from the *Lufft Mess- und Regeltechnik GmbH, Fellbach, Germany.* By using the LIDAR (light detection and ranging) and TOF (time of flight) principle, the CHM8k measures backscatter aerosol profiles and structure in multiple layers, cloud bases, cloud penetration depths and derives a sky condition index. Furthermore, the CHM8k makes it possible to determine boundary layer heights.

The bold values in square brackets are the values set in the LOVE campaign. Some additional information is also supplied here.

- Range: 5 m ... 10 km
- Time resolution: 2 ... 600 s **[60 s]**
- Range resolution: 5, 10, 15 m **[5 m]**
- Accuracy: ±1 m or ±1 % (whichever is higher)
- Cloud detection range: 5 m ... 8 km

The location of the Ceilometer area is marked in Figure 4.2. The Ceilometer is not located at the LOVE site but next to the well of the *Wasserwirtschaftsamt Hof*. This will be the future location of the Automatic Weather Station. It is approximately 400m to the northeast of the AWS.

The ceilometer data are provided as a netcdf with coordinates of **time**, **range** (height above ground), and **layer** (for derived layer quantities) in 1min averaging increments. These data are in `\ESSD-repository\remote-sensing\ceilometer`. No attributes are included in the netcdf files, please refer to table 4.1

Figure 4.2 Location of Ceilometer

Table 4.1 Explanation of the ceilometer variables in the provided netcdf

Variables	units	explanation
range	m	height above ground
beta_att	-	attenuated backscatter, labeled by range
pbl	m	aerosol layer in PBL, labeled by layer
pbs	-	quality score for aerosol layer in PBL (1: good, ..., 9: bad), labeled by layer
tcc	-	total cloud cover in eighths of the sky
sci	-	sky condition index (0: nothing, 1: rain, 2:fog, 3: snow, 4:precipitation or particles on window)
vor	-	vertical optical range, ie vertical visibility, up to 3000m
mxd	m	maximum detection height
cbh	m	cloud base height, labeled by layer
layer	m	height for the layer

4.5 FlyFox-V

The associated thesis by Antonia Fritz can be found here `http://www.bayceer.uni-bayreuth.de/meteo/de/lehre/diss/detail.php?id_obj=151341`.

4.5.1 General information

Balloon:

- Fibre type: twisted pair. Yields an "ascending" and "descending" profile.
- Observing DTS Device: XT (except Ultima for the July 18 flight)
- Fibre length: 2,200 m
- Maximum allowed flight height: 200 m
- Maximum tolerable wind speed: 10 m/s
- Balloon dimensions: length = 6 m; maximum radius = 1.5 m; Volume = 8 m^3
- Balloon filling: helium, pressurized air, and balloon gas

Tether sonde:

- Windsensor: Model Rev C, Modern Device, Providence, USA
- Temperature / Pressure / relative humidity sensor: BME280, Bosch sensortec GmbH, Reutlingen, Germany
- Data format: .csv
  - 1. column: time stamp in Unix format and UTC.
  - 2. column: temperature in °C
  - 3. column: relative humidity
  - 4. column: pressure in hPa
  - 5. column: voltage measured by the wind sensor in mV
  - 6. column: battery voltage in mV
  - 7. column: upstepper voltage in mV

4.5.2 Flight documentation

Morning flights:

- 16.07.2019 - Toni and Christoph - This flight was not measured due to problems with the DTS device.
- 18.07.2019 - Toni, Anita, and Flo

- 22.07.2019 - Toni and Karl
- 23.07.2019 - Toni and Andreas
- 26.07.2019 - Toni and Nico

Evening flights:

- 15.07.2019 - Toni and Christoph. These data were unfortunately not recorded.
- 24.07.2019 - Toni and Anita

For the precise flight documentation sheets see figures 4.3 to 4.9.

4.5.3 Documentation of data analysis

For some of the flights, the identification of the ascending and the descending profile was done in the field by holding an ice pack onto the fiber and writing down the LAF where a cooling could be seen. As this hasn't been done for all of the flights and due to some difficulties with the XT, these LAF values were verified by plotting the temperature data, searching for the first temperature artifact from the fiber on the spool. The first value at which the influence of the spool disappeared were selected as the start or end point of the two profiles. A similar approach was taken to identify the top of the profile using the fiber holder mounted on the balloon. Due to the darker color of these two objects, these locations were clearly defined. The following tabular lists the LAF that was identified in the field (field-LAF) and the LAF-ID and the LAF which were identified by plotting the data.

The choice of the start and end point was also influenced by the fact that the two profiles should have the same length.

Table 4.2 Definition of profile start and end points

		field-LAF	**LAF-ID**	**LAF**
15.07.2019				
ascending	start	NA	4677	965.74 m
	end	NA	5431	1157.41 m
descending	start	NA	5449	1161.98 m
	end	NA	6203	1353.65 m
18.07.2019				
ascending	start	950 m	8125	950.274 m
	end	NA	9758	1157.828 m
descending	start	NA	9787	1161.514 m
	end	NA	11420	1369.068 m
22.07.2019				
ascending	start	975.145 m	4719	976.416 m
	end	NA	5431	1157.41 m

Table 4.3 Bath locations in LAF space. These are the values used to calibrate each flight and do not vary.

Bath	LAFs (m)
Cold Near	[154.336, 158.343]
Cold Far	[2161, 2165]
Warm Near	[146.4, 150.47]
Warm Far	[2168.83, 2172.9]

Table 4.2 Definition of profile start and end points - continuation

		field-LAF	LAF-ID	LAF
descending	start	NA	5448	1161.73 m
	end	1343.73 m	6160	1342.72 m
23.07.2019				
ascending	start	978.045 m	4730	979.212 m
	end	NA	5432	1157.66 m
descending	start	NA	5449	1161.98 m
	end	1340.9 m	6151	1340.43 m
24.07.2019				
ascending	start	NA	4892	1020.39 m
	end	NA	5435	1158.42 m
descending	start	NA	5445	1160.96 m
	end	NA	5988	1299.0 m
26.07.2019				
ascending	start	959.131 m	3783	961.418 m
	end	NA	4554	1157.66 m
descending	start	NA	4572	1161.73 m
	end	1359.75 m	5345	1358.48 m

4.5.4 FlyFox-V setup and material

The water calibration baths, one at an ambient temperature and one heated using an aquarium heater, for FlyFOX were kept at uniform LAFs for all flights (Table 4.3). In each bath was an RBR probe that logged the bath temperature throughout the experiment, regardless of the occurrence of a flight. The bath temperatures and the time of flights is shown in Figure 4.10. The RBRs recorded in UTC+2, as noted in the lab notebook on July 5th.

These data were converted to UTC and combined with the tethersonde data. Each flight has a corresponding `*teth-rbr.nc` file. The tethersonde pressure was bias corrected to the high-quality pressure observations at the surface both prior to launch and upon recovery. The location of the FlyFox-V launching area is marked in Figure 1.1a. For a sketch of the experimental setup and some picture documentation of it see Figures 4.11 to 4.14.

LOVE, FLYFOX-V: Experimental Setup

Name(s) of operator(s)	Toni, Christoph	
Name of configuration file	LOVE_outer_array_FLYFOX_190715	
Instrument, Channel number	XT, 4	
Site description	Whale's cove	
Date	15.07.21019	
Time of measurements (UTC)	Start: 19:30	End: 22:04
Configuration	□ single-ended	□ duplexed
Additional remarks	5s averages every 10s	
Boundary layer profile		
Location on fiber (m laf*)	Start:	End:
Time of icepack attach		
Tether sonde below balloon		
Name of tether sonde file	p4_190715_ALL.csv	
Number of tethersondes used	1 (top)	
Distance of sonde to fiber top (m)	1.62m	
Height at start/end time (m agl)	Start: 0 m	End: 195 m
Pressure (hPa)	Ground: 945 hPa	Top: 925.5 hPa
Fixations for fiber-optic cable to tether (Wormies)		
Number	4	
Height of fixations (m agl)	Upmost:	Lowest:
Cold bath		
Temperature at start/end time (°C)	Start:	End:
Location (m laf)	Start: 154.336 m	End: + 4.07 m
Location (m laf)	Start: 2158 m	End: + 4.07 m
Warm bath		
Temperature at start/end time (°C)	Start:	End:
Location (m laf)	Start: 146.42 m	End: + 4.07 m
Location (m laf)	Start: 2168.83 m	End: + 4.07 m
Additional measurements		
□ RBRs switched on □ Optical connectors cleaned (m/f) □ Raspberry Pi logging	□ XT time checked & synchronized □ Calibration bath pumps & heater running	
Additional remarks (e.g. weather, calibration, optical connectors)		
Pressure regulator broken One safety device battery blinks orange Strong winds in the highest parts in the evening Meandering around 12 – 15 m height (22:35) Cloudless sky Measured angle (tether to vertical): 27° == 21.25 m height difference		

*laf = length along fiber; agl = above ground level, asl = above sea level

Figure 4.3 flight sheet of the 15.07.2019

LOVE, FLYFOX-V: Experimental Setup

Name(s) of operator(s)	Toni, Christoph	
Name of configuration file	LOVE_outer_array_FLYFOX_190715	
Instrument, Channel number	XT, 4	
Site description	Whale's cove	
Date	16.07.21019	
Time of measurements (UTC)	Start: 05:20	End:
Configuration	□ single-ended	□ duplexed
Additional remarks	5s averages every 10s	
Boundary layer profile		
Location on fiber (m laf*)	Start:	End:
Time of icepack attach	6:34	
Tether sonde below balloon		
Name of tether sonde file	p4_190715_ALL.csv	
Number of tethersondes used	1 (top)	
Distance of sonde to fiber top (m)	1.62m	
Height at start/end time (m agl)	Start: 0 m	End: 201 m
Pressure (hPa)	Ground: 946.3 hPa	Top: 926.2 hPa
Fixations for fiber-optic cable to tether (Wormies)		
Number	4	
Height of fixations (m agl)	Upmost:	Lowest:
Cold bath		
Temperature at start/end time (°C)	Start:	End:
Location (m laf)	Start: 154.336 m	End: + 4.07 m
Location (m laf)	Start: 2158 m	End: + 4.07 m
Warm bath		
Temperature at start/end time (°C)	Start:	End:
Location (m laf)	Start: 146.42 m	End: + 4.07 m
Location (m laf)	Start: 2168.83 m	End: + 4.07 m
Additional measurements		
□ RBRs switched on □ Optical connectors cleaned (m/f) □ Raspberry Pi logging	□ XT time checked & synchronized □ Calibration bath pumps & heater running	
Additional remarks (e.g. weather, calibration, optical connectors)		
High stratus clouds Raspberry Pi started logging 5 – 8 min later than the XT One safety device battery renewed		

*laf = length along fiber; agl = above ground level, asl = above sea level

Figure 4.4 flight sheet of the 16.07.2019

LOVE, FLYFOX-V: Experimental Setup

Name(s) of operator(s)	Toni, Anita, Flo	
Name of configuration file	LOVE_simba_south_rim_190716	
Instrument, Channel number	Ultima, 3	
Site description	Whale's cove	
Date	18.07.21019	
Time of measurements (UTC)	Start: 05:08	End: 8:54
Configuration	□ single-ended	□ duplexed
Additional remarks	1s averages every 3s	
Boundary layer profile		
Location on fiber (m laf*)	Start: 950 m	End:
Time of icepack attach	8:48 – 8:50	
Tether sonde below balloon		
Name of tether sonde file		
Number of tethersondes used	1 (top)	
Distance of sonde to fiber top (m)	1.62m	
Height at start/end time (m agl)	Start: 0 m	End: 199 m
Pressure (hPa)	Ground: 943.4 hPa	Top: 923.5 hPa
Fixations for fiber-optic cable to tether (Wormies)		
Number	4	
Height of fixations (m agl)	Upmost:	Lowest:
Cold bath		
Temperature at start/end time (°C)	Start:	End:
Location (m laf)	Start: 154.4 m	End: + 4 m
Location (m laf)	Start: 2158 m	End: + 4 m
Warm bath		
Temperature at start/end time (°C)	Start:	End:
Location (m laf)	Start: 146.4 m	End: + 4 m
Location (m laf)	Start: 2168.8 m	End: + 4 m
Additional measurements		
□ RBRs switched on	□ XT time checked & synchronized	
□ Optical connectors cleaned (m/f)	□ Calibration bath pumps & heater running	
□ Raspberry Pi logging		
Additional remarks (e.g. weather, calibration, optical connectors)		

New Helium put into Balu
Cloudless sky
Meandering in 200 m height (5:40 am; Video taken with field camera)
Tether sonde data saved with Toughbook instead if DarkMix put computer
Measured angle (tether to vertical; 5:45 am): 27.6° == 25.7 m height difference
=> max. flight height in the end (no wind): 225.7 m
Low level jet before sunrise assumed

*laf = length along fiber; agl = above ground level, asl = above sea level

Figure 4.5 flight sheet of the 18.07.2019

LOVE, FLYFOX-V: Experimental Setup

Name(s) of operator(s)	Toni, Karl	
Name of configuration file	LOVE_outer_array_FLYFOX_190722	
Instrument, Channel number	XT, 4	
Site description	Whale's cove	
Date	22.07.21019	
Time of measurements (UTC)	Start: 05:18	End: 8:10
Configuration	□ single-ended	□ duplexed
Additional remarks	5s averages every 10s	
Boundary layer profile		
Location on fiber (m laf*)	Start: 975.145	End: 1343.73
Time of icepack attach		
Tether sonde below balloon		
Name of tether sonde file	p4_190722_all.csv	
Number of tethersondes used	1 (top)	
Distance of sonde to fiber top (m)	1.62m	
Height at start/end time (m agl)	Start: 0 m	End: 199 m
Pressure (hPa)	Ground: 953.4 hPa	Top: 933.5 hPa
Fixations for fiber-optic cable to tether (Wormies)		
Number	4	
Height of fixations (m agl)	Upmost: ca. 195 m	Lowest: ca. 50 m
Cold bath		
Temperature at start/end time (°C)	Start:	End:
Location (m laf)	Start: 154.336 m	End: + 4.07 m
Location (m laf)	Start: 2158 m	End: + 4.07 m
Warm bath		
Temperature at start/end time (°C)	Start:	End:
Location (m laf)	Start: 146.42 m	End: + 4.07 m
Location (m laf)	Start: 2168.83 m	End: + 4.07 m
Additional measurements		
□ RBRs switched on □ Optical connectors cleaned (m/f) □ Raspberry Pi logging	□ XT time checked & synchronized □ Calibration bath pumps & heater running	
Additional remarks (e.g. weather, calibration, optical connectors)		
Cloudless sky No wind at all No fog but dew formation Super stable layer		

*laf = length along fiber; agl = above ground level, asl = above sea level

Figure 4.6 flight sheet of the 22.07.2019

LOVE, FLYFOX-V: Experimental Setup

Name(s) of operator(s)	Toni, Andreas	
Name of configuration file	LOVE_outer_array_FLYFOX_190723	
Instrument, Channel number	XT, 4	
Site description	Whale's cove	
Date	23.07.21019	
Time of measurements (UTC)	Start: 04:59	End: 8:30
Configuration	□ single-ended	□ duplexed
Additional remarks	5s averages every 10s	
Boundary layer profile		
Location on fiber (m laf*)	Start: 978.045	End: 1340.9
Time of icepack attach	5:02	
Tether sonde below balloon		
Name of tether sonde file	p4_190723_all.csv	
Number of tethersondes used	1 (top)	
Distance of sonde to fiber top (m)	1.62m	
Height at start/end time (m agl)	Start: 0 m	End: 199 m
Pressure (hPa)	Ground: 953.4 hPa	Top: 933.5 hPa
Fixations for fiber-optic cable to tether (Wormies)		
Number	4	
Height of fixations (m agl)	Upmost: ca. 195 m	Lowest: ca. 50 m
Cold bath		
Temperature at start/end time (°C)	Start:	End:
Location (m laf)	Start: 154.336 m	End: + 4.07 m
Location (m laf)	Start: 2158 m	End: + 4.07 m
Warm bath		
Temperature at start/end time (°C)	Start:	End:
Location (m laf)	Start: 146.42 m	End: + 4.07 m
Location (m laf)	Start: 2168.83 m	End: + 4.07 m
Additional measurements		
□ RBRs switched on □ Optical connectors cleaned (m/f) □ Raspberry Pi logging	□ XT time checked & synchronized □ Calibration bath pumps & heater running	
Additional remarks (e.g. weather, calibration, optical connectors)		
Cloudless sky No wind at all Little meandering at the beginning of the flight North wind (extremely slow) at the end of the flight		

*laf = length along fiber; agl = above ground level, asl = above sea level

Figure 4.7 flight sheet of the 23.07.2019

LOVE, FLYFOX-V: Experimental Setup

Name(s) of operator(s)	Toni, Anita	
Name of configuration file	LOVE_outer_array_FLYFOX_190724	
Instrument, Channel number	XT, 4	
Site description	Whale's cove	
Date	24.07.21019	
Time of measurements (UTC)	**Start:** 20:13	**End:** 21:55
Configuration	□ single-ended	□ duplexed
Additional remarks	5s averages every 10s	
Boundary layer profile		
Location on fiber (m laf*)	Start:	End:
Time of icepack attach	forgotten	
Tether sonde below balloon		
Name of tether sonde file	p4_190724_all.csv	
Number of tethersondes used	1 (top)	
Distance of sonde to fiber top (m)	1.62m	
Height at start/end time (m agl)	Start: 0 m	End: 150 *
Pressure (hPa)	Ground: 947.5 hPa	Top: 938.2 hPa *
Fixations for fiber-optic cable to tether (Wormies)		
Number	4	
Height of fixations (m agl)	**Upmost:** ca. 195 m	**Lowest:** ca. 50 m
Cold bath		
Temperature at start/end time (°C)	Start:	End:
Location (m laf)	**Start:** 154.336 m	**End:** + 4.07 m
Location (m laf)	**Start:** 2158 m	**End:** + 4.07 m
Warm bath		
Temperature at start/end time (°C)	Start:	End:
Location (m laf)	**Start:** 146.42 m	**End:** + 4.07 m
Location (m laf)	**Start:** 2168.83 m	**End:** + 4.07 m
Additional measurements		
□ RBRs switched on □ Optical connectors cleaned (m/f) □ Raspberry Pi logging	□ XT time checked & synchronized □ Calibration bath pumps & heater running	
Additional remarks (e.g. weather, calibration, optical connectors)		
* Too windy at 200 m => launched only around 150 m but the exact height is hard to tell as Balu went up and down a lot! Only few clounds in the late afternoon No clounds in the night		

*laf = length along fiber; agl = above ground level, asl = above sea level

Figure 4.8 flight sheet of the 24.07.2019

LOVE, FLYFOX-V: Experimental Setup

Name(s) of operator(s)	Toni, Nico	
Name of configuration file	LOVE_outer_array_FLYFOX_190726	
Instrument, Channel number	XT, 4	
Site description	Whale's cove	
Date	26.07.21019	
Time of measurements (UTC)	**Start:** 05:21	**End:** 08:24
Configuration	□ single-ended	□ duplexed
Additional remarks	5s averages every 10s	
Boundary layer profile		
Location on fiber (m laf*)	**Start:** 959.131 m	**End:** 1359.75 m
Time of icepack attach	5:33	
Tether sonde below balloon		
Name of tether sonde file	p4_190726_all.csv	
Number of tethersondes used	1 (top)	
Distance of sonde to fiber top (m)	1.62m	
Height at start/end time (m agl)	**Start:** 0 m	**End:** 209 m
Pressure (hPa)	**Ground:** 945.3 hPa	**Top:** 924.4 hPa
Fixations for fiber-optic cable to tether (Wormies)		
Number	4	
Height of fixations (m agl)	**Upmost:** ca. 195 m	**Lowest:** ca. 50 m
Cold bath		
Temperature at start/end time (°C)	**Start:**	**End:**
Location (m laf)	**Start:** 154.336 m	**End:** + 4.07 m
Location (m laf)	**Start:** 2158 m	**End:** + 4.07 m
Warm bath		
Temperature at start/end time (°C)	**Start:**	**End:**
Location (m laf)	**Start:** 146.42 m	**End:** + 4.07 m
Location (m laf)	**Start:** 2168.83 m	**End:** + 4.07 m
Additional measurements		
□ RBRs switched on □ Optical connectors cleaned (m/f) □ Raspberry Pi logging	□ XT time checked & synchronized □ Calibration bath pumps & heater running	
Additional remarks (e.g. weather, calibration, optical connectors)		
Cloudless sky Raspberry Pi loggs in irregular time steps (only in the beginning) Meandering in the morning at 200m Sun reached the launching area at ca. 6:50 am		

*laf = length along fiber; agl = above ground level, asl = above sea level

Figure 4.9 flight sheet of the 26.07.2019

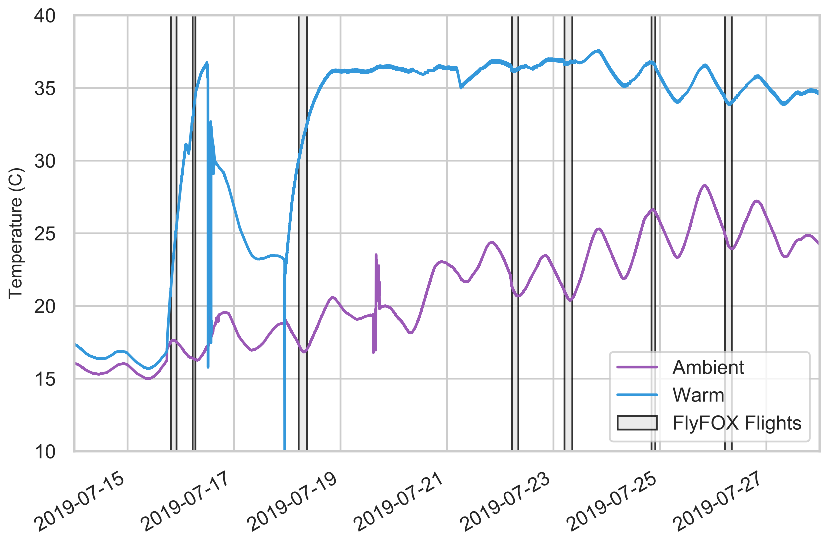

Figure 4.10 Water calibration baths' probe temperature and flight times.

Table 4.4 Material FlyFox-V

Material	Explanation
Balloon	
Winch	
Winch operator	Make sure this is waterproof
Pallet	To fix the winch on it
Stones	To put more weight onto the pallet
Gas Bottles: He, pressurized air	
2 Pressure regulators	One for Helium; one for pressurized air
Hose	To connect the balloon to the gas bottles
Strong Net	To fix the Balloon on the ground
Rope	To fix the Balloon on the ground + as a connection between the sand bucket and the climbing-carabiner
10 earth nails	To fix the net / rope on the ground
1 shackle	To fix the Balloon on one earth nail directly
Canvas	To put under the Balloon
Safety deflation device	To open the Balloon if it flies away
Tether	
(twisted pair) Fibre	spooled in a way so both ends are accessible
Empty spool	To wrap the tether around it when the Balloon is at its flying height
Little wheel	To lead the fibre around on top

Table 4.4 Material FlyFox-V - continuation

Material	Explanation
Wormies	To connect the fibre to the tether (upmost: ca. 0.5 m from fibre connection; others: every 50 m)
2 Water baths	As reference bathes
Aquarium heater	For the warm bath
2 aquarium pumps	To prevent temperature gradients within the bath
2 thermometers	To measure the temperature within the bathes (e.g. RBRs)
2 strong 12V batteries	For the winch
5 kg Sand in a bucket	As a weight while carrying the Balloon around
1 big climbing-carabiners	To connect the sand bucket to the Balloon
2 smaller carabiners	To fix the reference sensor and the fibre to the tether
'Fish scales'	To measure the uplift of the Balloon
Balloon repairing kit	
Tethersonde	To measure wind speed, temperature and pressure + needs to be fixed on a wind vane
Data logger for tethersonde	e.g. Raspberry Pi
Computer	To start the Raspberry Pi from
Receiver sonde	
Laptop	Connected to the receiver sonde to check the pressure while launching
DTS Device	
6 'Pigtails' (= Fibre connectors)	To connect the fibre to the DTS Device and to the connecting fibre
One-click device	To clean the pigtails before connecting
2 pair of cloves	

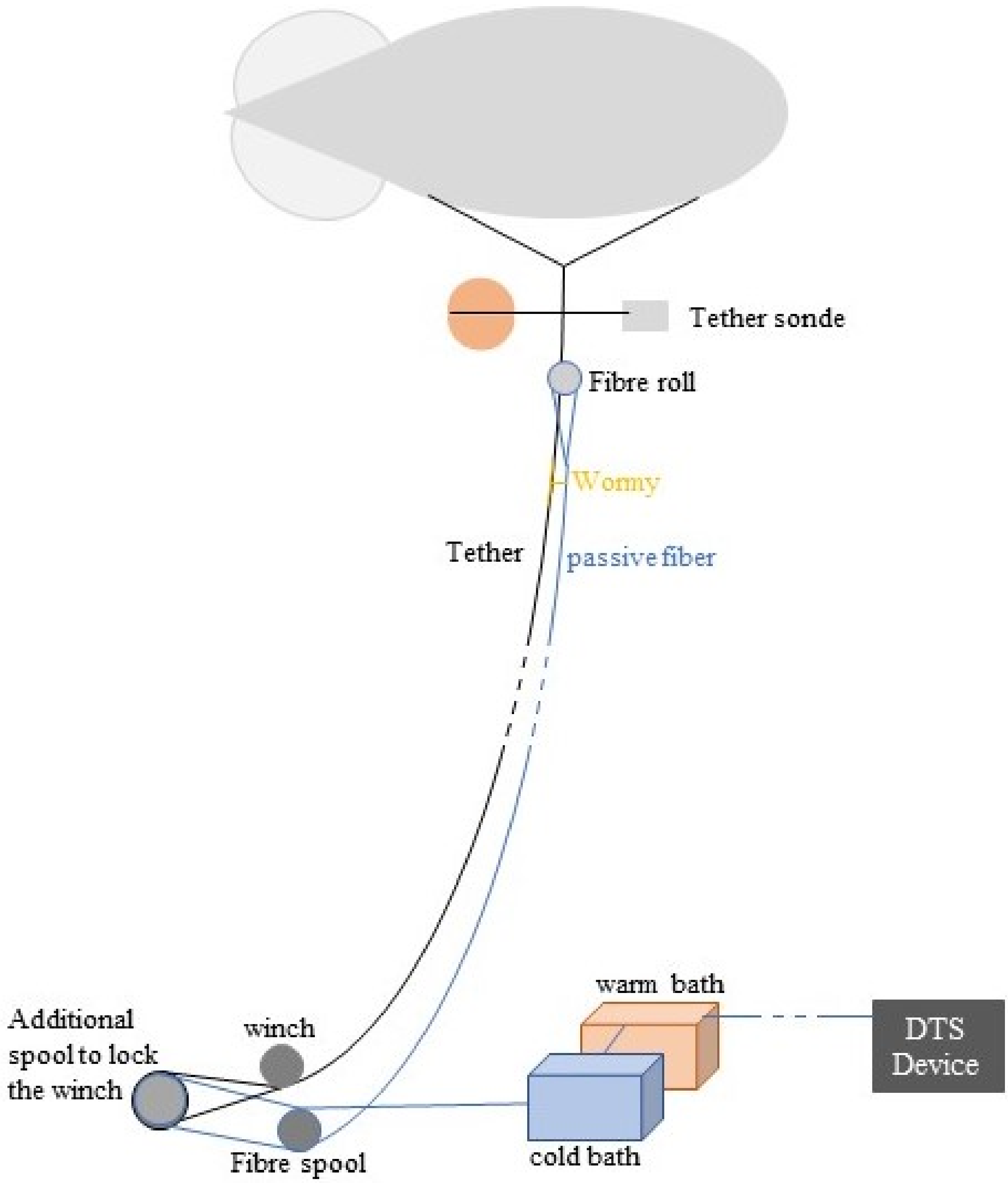

Figure 4.11 FlyFox Setup

Figure 4.12 Entire FlyFox-V launching area while flying

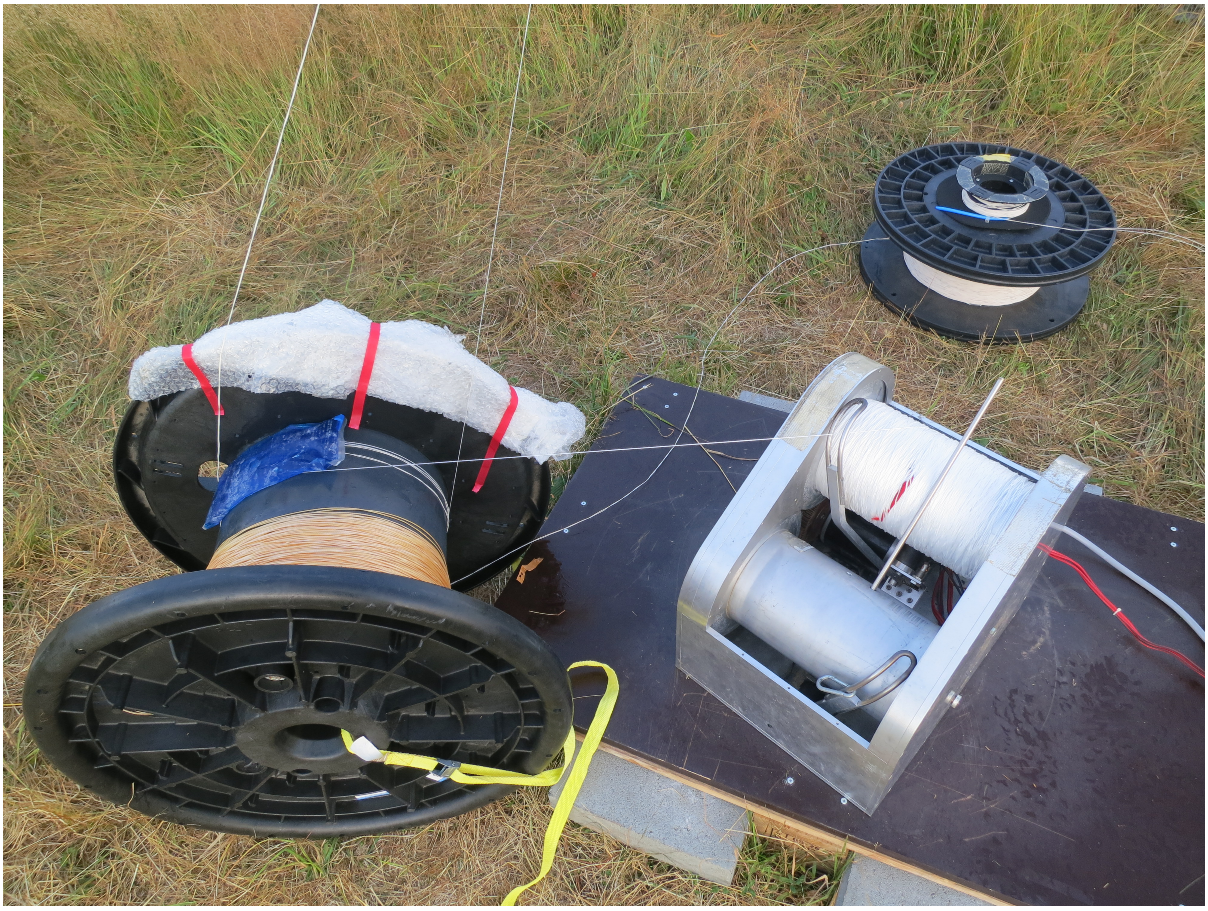

Figure 4.13 Setup of the winch when fixed at the maximum flying height

Figure 4.14 Setup of the two reference bathes (colour-coded: red = warm bath; blue = cold bath)

Appendix

Table A.1 Volumes in the series "University of Bayreuth, Micrometeorology, Arbeitsergebnisse"

Nr	Author(s)	Title	Year
1	Foken	Der Bayreuther Turbulenzknecht	01/1999
2	Foken	Methode zur Bestimmung der trockenen Deposition von Bor	02/1999
3	Liu	Error analysis of the modified Bowen ratio method	02/1999
4	Foken et al.	Nachfrostgefährdung des ÖBG	03/1999
5	Hierteis	Dokumentation des Experimentes Dlouhà Louka	03/1999
6	Mangold	Dokumentation des Experimentes am Standort Weidenbrunnen, Juli/August 1998	07/1999
7	Heinz et al.	Strukturanalyse der atmosphÃď rischen Turbulenz mittels Wavelet-Verfahren zur Bestimmung von Austauschprozessen Ãijber dem antarktischen Schelfeis	07/1999
8	Foken	Comparison of the sonic anemometer Young Model 81000 during VOITEX-99	10/1999
9	Foken et al.	Lufthygienisch-bioklimatische Kennzeichnung des oberen Egertales, Zwischenbericht 1999	11/1999
10	Sodemann	Stationsdatenbank zum BStMLU-Projekt Lufthygienisch-bioklimatische Kennzeichnung des oberen Egertales	03/2000
11	Neuner	Dokumentation zur Erstellung der meteorologischen Eingabedaten fÃijr das Modell BEKLIMA	10/2000
12	Foken et al.	Dokumentation des Experimentes VOITEX-99	10/2000
13	Bruckmeier et al.	Documentation of the experiment EBEX-2000, July 20 to August 24, 2000	01/2001
14	Foken et al.	Lufthygienisch-bioklimatische Kennzeichnung des oberen Egertales	02/2001
15	Göckede	Die Verwendung des Footprint-Modells nach Schmid (1997) zur stabilitätsabhängigen Bestimmung der Rauhigkeitslänge	03/2001
16	Neuner	Berechnung der Evaporation im ÖBG (Universität Bayreuth) mit dem SVAT-Modell BEKLIMA	05/2001
17	Sodemann	Dokumentation der Software zur Bearbeitung der FINTUREX-Daten	08/2002
18	Göckede et al.	Dokumentation des Experiments STINHO-1	08/2002
19	Göckede et al.	Dokumentation des Experiments STINHO-2	12/2002
20	Göckede et al	Characterisation of a complex measuring site for flux measurements	12/2002
21	Liebethal	Strahlungsmessgerätevergleich während des Experiments STINHO-1	01/2003
22	Mauder et al.	Dokumentation des Experiments EVA_GRIPS	03/2003
23	Mauder et al.	Dokumentation des Experimentes LITFASS-2003, Dokumentation des Experimentes GRASATEM-2003	12/2003
24	Thomas et al.	Documentation of the WALDATEM-2003 Experiment	05/2004

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Nr	Author(s)	Title	Year
25	Göckede et al.	Qualitätsbegutachtung komplexer mikrometeorologischer Messstationen im Rahmen des VERTIKO-Projekts	11/2004
26	Mauder Foken	Documentation and instruction manual of the eddy covariance software package TK2	12/2004
27	Herold et al.	The OP-2 open path infrared gas analyser for CO2and H2O	01/2005
28	Ruppert	ATEM software for atmospheric turbulent exchange measurements using eddy covariance and relaxed eddy accumulation systems and Bayreuth whole-air REA system setup	04/2005
29	Foken (Ed.)	Klimatologische und mikrometeorologische Forschungen im Rahmen des Bayreuther Institutes fÃijr Terrestrische Ökosystemforschung (BITÖK), 1989-2004	06/2005
30	Siebicke & Serafimovich	Ultraschallanemometer-ÃIJberprÃijfung im Windkanal der TU Dresden 2007	04/2007
31	Lüers & Bareiss	The Arctic Turbulence Experiment 2006 PART 1: Technical documentation of the ARCTEX 2006 campaign, May, 2nd to May, 20th 2006	07/2007
32	Lüers & Bareiss	The Arctic Turbulence Experiment 2006 PART 2: Visualization of near surface measurements during the ARCTEX 2006 campaign, May, 2nd to May, 20th 2006	07/2007
33	Bareiss & Lüers	The Arctic Turbulence Experiment 2006 PART 3: Aerological measurements during the ARCTEX 2006 campaign, May, 2nd to May, 20th 2006	07/2007
34	Metzger & Foken et al.	COPS experiment, Convective and orographically induced precipitation study, 01 June 2007 âĂŞ 31 August 2007, Documentation	09/2007
35	Staudt & Foken	Documentation of reference data for the experimental areas of the Bayreuth Centre for Ecology and Environmental Research (BayCEER) at the Waldstein site	11/2007
36	Serafimovich et al.	ExchanGE processes in mountainous Regions (EGER): Documentation of the Intensive Observation Period (IOP1) September, 6^{th} to October, 7^{th} 2007	01/2008
37	Serafimovich et al.	ExchanGE processes in mountainous Regions (EGER): Documentation of the Intensive Observation Period (IOP2) June, 1^{st} to July, 15^{th} 2008	09/2008
38	Siebicke	Footprint synthesis for the FLUXNET site Waldstein/Weidenbrunnen (DE-Bay) during the EGER experiment	12/2008
39	Lüers & Foken	Jahresbericht 2008 zum Förderprojekt 01879- Untersuchung der VerÃďnderung der Konzentration von Luftbeimengungen und Treibhausgasen im hohen Fichtelgebirge 2007 – 2013	01/2009
40	Lüers & Foken (Ed.)	Proceedings of the International Conference of "Atmospheric Transport and Chemistry in Forest Ecosystems" Castle of Thurnau, Germany, Oct 5 to Oct 8, 2009	10/2009

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Nr	Author(s)	Title	Year
41	Biermann et al.	Mesoscale circulations and Energy and gaS exchange Over the Tibetan Plateau – Documentation of the Micrometeorological Experiment, Nam Tso, Tibet 25th of June – 08th of August 2009	11/2009
42	Foken & Falke	Documentation and Instruction Manual for the Krypton Hygrometer Calibration Instrument	01/2010 Update 12/2011
43	Lüers & Foken	Jahresbericht 2009 zum Förderprojekt 01879 – Untersuchung der Veränderung der Konzentration von Luftbeimengungen und Treibhausgasen im hohen Fichtelgebirge 2007 – 2013	07/2010
44	Biermann et al.	Tibet Plateau Atmosphere-Ecology-Glaciology Cluster Joint Kobresia Ecosystem Experiment: Documentation of the first Intensive Observation Period (IOP 1) summer 2010 in Kema, Tibet	01/2011
45	Zhao et al.	Complex TERRain and ECOlogical Heterogeneity (TERRECO);WP 1-02: Spatial assessment of atmosphere-ecosystem exchanges via micrometeorological measurements, footprint modeling and mesoscale simulations; Documentation of the Observation Period May 12th to Nov. 8th, 2010, Haean, South Korea	03/2011
46	Mauder & Foken	Documentation and Instruction Manual of the Eddy-Covariance Software Package TK3	05/2011
47	Serafimovich et al.	ExchanGE processes in mountainous Regions (EGER)-Documentation of the Intensive Observation Period (IOP3) June, 13th to July, 26th 2011	11/2011
48	Hübner et al.	Documentation and Instruction Manual for the Horizontal Mobile Measuring System (HMMS)	12/2011
49	Lüers et al.	The Arctic Turbulence Experiment 2009 - additional laser Scintillometer measurement campaign 2009 at the Bayelva catchment on Svalbard: Technical documentation and visualization of the near surface measurements during the ARCTEX-2009 campaign, August, 10th to August, 20th 2009	02/2012
50	Foken	Klimawanderweg auf der Landesgartenschau in Bamberg 2012	04/2012
51	Ruppert et al.	Whole-air relaxed eddy accumulation for the measurement of isotope and trace-gas fluxes	05/2012
52	Foken	Jahresbericht 2010-11 zum FÃűrderprojekt 01879 - Untersuchung der Veränderung der Konzentration von Luftbeimengungen und Treibhausgasen im hohen Fichtelgebirge 2007 – 2013	12/2012
53	Gerken et al.	Documentation of the Atmospheric Boundary Layer Experiment, Nam Tso, Tibet, 08th of July – 08th of August 2012	03/2013

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Nr	Author(s)	Title	Year
54	Biermann (Ed.)	Tibet Plateau Atmosphere-Ecology-Glaciology Cluster Joint Kobresia Ecosystem Experiment: Documentation of the 2nd Intensive Observation Period (IOP 2) summer 2012 in KEMA, Tibet	05/2013
55	Babel et al.	Documentation of the EVENT-HMMS Experiment 2012 – Microclimatological effects of rain-out shelters within EVENT II	06/2013
56	Lüers et al.	160 Jahre Bayreuther Klimazeitreihe – Homogenisierung der Bayreuther Lufttemperatur- und Niederschlagsdaten	06/2014
57	Babel	An R routine for the simplified application of a footprint-based characterisation of a complex measuring site for flux measurements	06/2014
58	Lüers et al.	Application of a multi-step error filter for postprocessing of atmospheric flux and meteorological basic data	06/2014
59	Zhao et al.	GaFiR: a gap-filling package for ecosystem-atmosphere carbon dioxide flux and evapotranspiration data	06/2014
60	Foken et al.	Meteorologisches Instrumentenpraktikum an der Universität Bayreuth	08/2014
61	Foken & Lüers	Abschlussbericht zum Förderprojekt 01879 Untersuchung der Veränderung der Konzentration von Luftbeimengungen und Treibhausgasen im hohen Fichtelgebirge : 2007 âĂŞ 2014	12/2014
62	Mauder & Foken	Documentation and Instruction Manual of the Eddy-Covariance Software Package TK3 (update)	07/2015
63	Pfister & Sigmund	CADEX - Cold Air Drainage Experiment 2015 in the Ecological Botanical Gardens of the University of Bayreuth - Field Report	07/2015
64	Loos & Holden	WOBLS - Wind Observation of the Atmospheric Boundary Layer at the Schneeberg and Voitsumra of the University of Bayreuth - Field Report	05/2016
65	Lapo et al.	ERC DarkMix: LOVE - The Large eddy Observatory Voitsumra Experiment 2019	12/2020