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ANALYSIS OF DIURNAL SURFACE TEMPERATURE VARIATION ON MACUN CHAVAGLIET DURING SUMMER

Swiss National Park

View from the Research Area Picture by: Walter Abderhalden

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Trondheim, June 2019

Bachelor Thesis in Geography

NTNU Norwegian University of Science and Technology

Faculty of Social and Educational Science

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in Collaboration with the Swiss National Park

Abstract

With background in a project from WSL Institute for Snow and Avalanche Research (SLF) researching on upward migration of plant species due to climate change, on 120 summits in the European Alps, this BSc-thesis focuses on the diurnal temperature regimes in summer on one of eight of these peaks situated in the Swiss National Park, Macun Chavagliet (Matteodo et al., 2013). The data provided by the Swiss National Park derives from three different measurement technologies: two types of temperature loggers (iButton and USB temperature, humidity and dew point data loggers) and thermal infrared images taken by a Flir Tau 2640 camera. For data analysis and visualization, Microsoft Excel was used to create diagrams of the temperature logger data while Pix4d and ArcMap were used to create maps and process thermal infrared and RGB images. This thesis shows, that different technologies provide results with different qualities. While temperature loggers provide consecutive information about the temperature development throughout a day, but only for a specific position, the thermal infrared data provides the information about the thermal regimes over a larger spatial domain, but only for a specific moment of time. One observation where the results correlate for all methods used is that aspect has an influence on temperature development patterns, as temperature rises at an earlier moment of time and reaches a higher maximum temperature on south and east facing slopes than on north and west facing slopes. All three measuring technologies have their advantages and disadvantages and how the three methods could be used in combination with each other as well as individually, is discussed in this thesis.

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1 Introduction

1.1 Aim of this BSc-Thesis

With a background in the GLORIA project (see chapter 2) the Swiss National Park and the ecology group of the WSL Institute for Snow and Avalanche Research (SLF) pursue an additional study with an interest in obtaining more knowledge on temperature conditions and the spatial distribution of the temperature regime on 8 mountain peaks in the Swiss National Park. So, a set of temperature loggers was installed. In this BSc-study, the aim at deepening the knowledge on temperature conditions on one of those peaks. We plan to analyse the temperature history and distribution throughout a day during different weather conditions and the differences in temperature development depending on cardinal direction using three different technologies (two different types of temperature loggers and a thermal camera). The superior aim of the GLORIA project is to analyse plant species development and frequency in alpine areas according to climate change. Therefore, another important point in this BSc-thesis will be to compare the temperature development and maximum temperature throughout a day at different positions, to see in further research whether the rising frequency of plant species coincide with the temperature development of the ground cover type they grow on.

1.2 Research Questions and Study Site

Site: Macun Chavagliet

Height above sea level	2641m
GPS (CH1903+ LV95)	2’805’835 1’179’295

Macun Chavagliet is a mountain peak situated in the lake district of Macun. The Macun lake district, which measures an area of 3.6km^2 became part of the Swiss National Park in the year 2000 (Swiss National Park, 2014).

The research area was defined by a perimeter covering the area around the loggers including a dell on the western side of the area, to see if the temperature develops differently than for example on a flat grass matt.

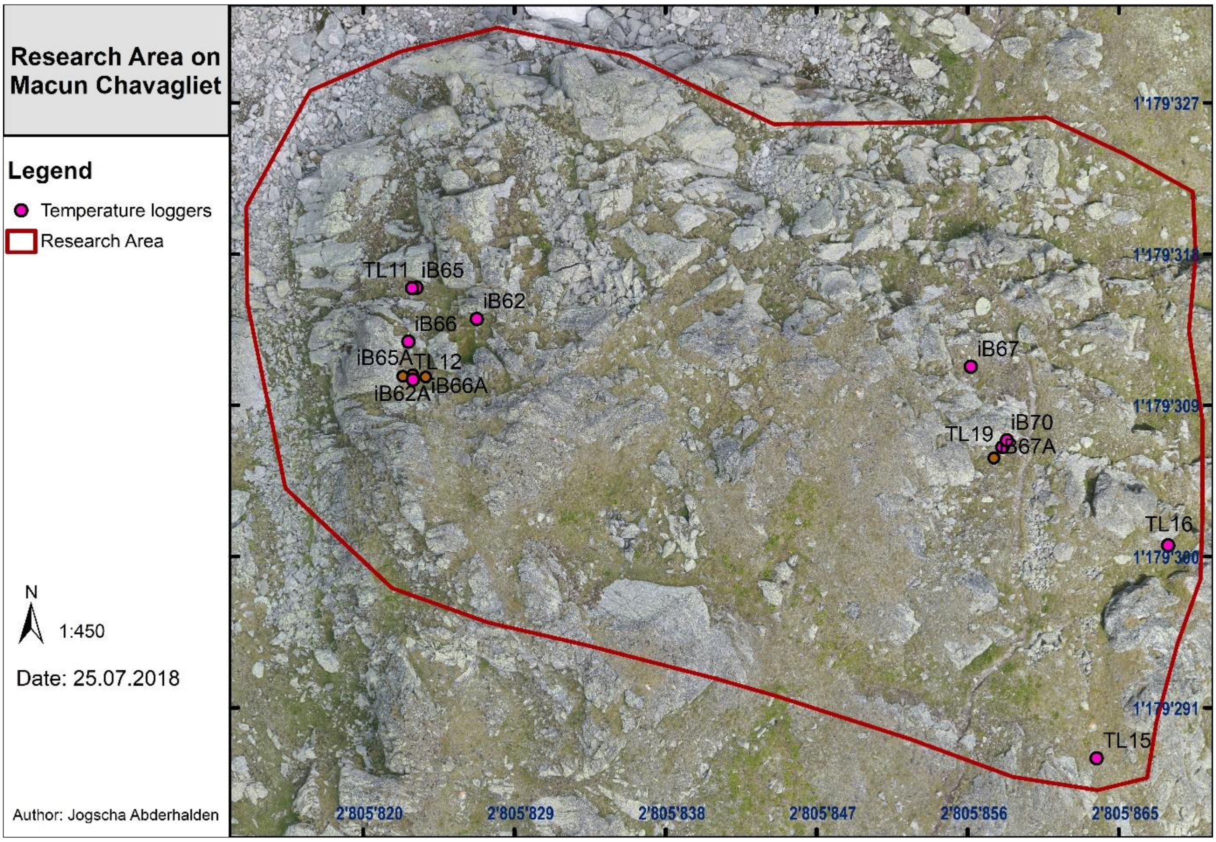


Figure 1 Map of the research area on Macun Chavagliet

The present work aims at addressing the following questions:

- Do the results of surface temperature evolution throughout a day measured with different technologies correlate? How do the results differ from each other? What are the advantages and disadvantages of using different technologies?
- What does the maximum temperature on a high-altitude summit look like, considering aspect and slope?

The stated questions will be answered, analysing data collected on a defined research area on Macun Chavagliet (Figure 1). Data collected for this project is implemented in the GLORIA project, described in the next chapter.

2 Background GLORIA Project

2.1 What is the Gloria Project?

The Global Observation Research Initiative in Alpine Environment (GLORIA) is a global network researching on ecological climate change impacts (Gloria, 2019). Climate change is likely to become a major driver of biodiversity decline, because species may no longer be adapted to the environmental conditions in a region (Bellar et al., 2012). Biodiversity will be affected both in regions strongly transformed by human activities as well as in remote natural ecosystems. Many mountain summit regions are little affected by direct anthropogenic impact and human population and provide therefore an ideal area for research on climate change impacts on natural ecosystems, which is the main topic of GLORIA (Gloria, 2019).

2.2 Additional Study Swiss National Park with WSL and SLF

In the area of the Swiss National Park, 8 peaks are selected to contribute to the worldwide programme of GLORIA (Gloria, 2019). The research network is led by Sonja Wipf and Christian Rixen from the WSL (Swiss Federal Institute for Forest, Snow and Landscape research) and SLF (Institute for Snow and Avalanche research). The general idea of the initiative is to investigate climate change impacts on vegetation at high altitudes and to find out whether species adapted to low temperature will survive in milder temperature regimes (Wipf, 2018a). The main fieldwork focuses on the temporal change of vascular plants, measured within a common design. Every 5 -7 years, experts visit the summits to collect temperature data and record the species and frequency of the plants growing there (Wipf, 2018b). Following global warming more and more species are shifting upwards to higher altitudes in an accelerating process. Seeking to identify the driver behind acceleration in species enrichment, changes in summer temperatures are determined to have a consistent and significant effect on species richness (Matteodo et al., 2013). Investigation on summer temperature changes on daily basis at one of the peaks in the Swiss National Park will is the topic of this BCs-Thesis.

3 Methods and Material

3.1 Temperature Loggers

To obtain information about the surface temperature regime on Macun Chavagliet, 12 temperature loggers of two different types were installed around the summit (seven iButton and five TL pole loggers).

3.1.1 iButton

The iButton DS1922L, is a coin sized device equalling a lithium battery. It has a storage of 8 kB, integrates a micro-controller, a temperature sensor and a battery. The device measures temperatures from -40°C to 85°C. The measurement accuracy is ±0.5°C in the temperature range from -10°C to 65°C. One iButton can store 4096 readings in that resolution (Gubler et al., 2011, p. 433). In former research projects the iButtons failed to measure, probably due to water entry (Lewkowicz, 2008). To prevent that, the devices were stuffed into balloons before they were buried in the ground. As to make it easier to find the loggers again in the field, the nub of the balloon was left on the surface to indicate where the iButton is buried (Figure 2).

Figure 2 a) iButton stuffed in a balloon and labelled,
b) nub of the balloon on the surface indicating a buried device

3.1.2 USB Temperature Data Loggers

The USB-data loggers are another technology to measure surface temperature. While the iButton measures the ground surface temperature, the TL poles measure the air surface temperature about 5cm over the ground. In this project, two models of USB-loggers were used, *EL-USB-2* and *USB-502-PLUS* (Lascar electronics, 2016; Measurement Computing, 2017). The two models have the same capacity and features, and will therefore be described as one type of logger. The loggers have a measurement range from -35°C to 80°C with an accuracy of ±0.45°C (USB-502-plus) and ±0.3°C (EL-USB-2). Data sampling can occur on a logging rate between 10 seconds and 12 hours and one logger stores 16'382 readings (Lascar electronics, 2016; Measurement Computing, 2017). The loggers are supplied with a lithium metal battery and have a battery life of up to three years at a 1 minute measuring rate. To prevent from ingress of water and dust, the cap belonging to the USB-poles has to be fitted properly (Lascar electronics, 2016). To set up and view downloaded data, the free EasyLog software can be used, and the logger connected to a PC by plugging into a USB port (Lascar electronics, 2016). To use the data for further analysis and research, the data can be exported as csv and displayed in spreadsheet programmes such as Microsoft Excel or implemented in statistical programmes such as R (Measurement Computing, 2017). The USB loggers measure relative humidity and dew point in addition to the temperature, but that information is not used in this project and therefore not further described.

As the USB-logger cannot be buried in the ground or hung up on trees (as there is no high vegetation on Macun Chavagliet), dowels that could be hammered in the ground were constructed. The dowels can be opened on top and have empty space for a logger to fit in, so that the loggers can be put in those dowels and measure the air surface temperature about 5cm over the ground (Figure 3).

Figure 3 Temperature logger dowel with USB-logger in it

3.2 Remote Sensing of Surface Temperature

3.2.1 Thermal Infrared in vegetation ecology

Thermal radiation, radiation with a wavelength on the infrared side of the optical spectrum, is emitted by the surface. Therefore, a useful method to collect data about surface temperature is remote sensing using thermal infrared cameras. Surface temperature gives important information about to climate change impacts and can be used in vegetation research, where surface temperature has an effect on development of plant species on a site (Jones & Vaughan, 2010).

3.2.2 Drone Photos with Thermal Infrared Camera

On four days, drone flights over the research area with an RGB as well as a thermal camera (Flir) were conducted. The flight plan contained 120 waypoints, which means that 120 images/flight were taken with both cameras. During some flights the battery was too low to complete the flight (mainly because of the varying air temperature and the cold air which has a negative effect on the battery capacity), which is why some flights had to be split in two parts and the drone continued where the mission was stopped in the previous flight.

To obtain a map covering the whole area, the unique images of each flight had to be set together to calculate and process a map. As to make it possible to georeferenced the thermal map layers to the RGB orthophoto, the ground control points, marked on the site with an orange plate to make them visible on the RGB images, where marked with a heap of sawdust additionally. The reason for this endeavour is that the sawdust supposingly reflects more/ absorbs less radiation than the surroundings and should therefore be visible as a colder spot on the thermal images. This however, appears to be less obvious than hoped/expected. Those spots were hard to detect on the thermal images and could hardly be used for georeferencing. Still, after georeferencing the thermal infrared layer correctly the spots could be detected when one knew where to find them.

3.3 Programmes used for Data Processing

3.3.1 ArcGIS

The orthophoto, digital surface model (DSM) and digital terrain model (DTM) processed in Pix4D (see chapter 3.3.2) were transferred to ArcMap in .tif format. In ArcMap, the maps were used for further analysis of the geomorphology and topography of Macun Chavagliet. The tools *aspect, slope* and *hillshade* were used. As input layer the DTM was used at first. However, after some analysis it became clear that the processing from DSM to DTM didn’t go as errorless as expected and that the DSM was much more accurate than the DTM. With the tool *rastercalc* the difference between the two layers was calculated and it showed a difference in meters a.s.l. up to 9 meters. In the end product, the DSM was used for calculation of aspect, slope and hillshade.

Import thermal infrared data

To import and visualize the data from the thermal infrared images, the images were first processed in FlirTools (see section 3.3.3). After processing panorama images there, the data was exported in .csv format and then added in ArcMap. As the .csv layer isn't editable it was exported as feature class. The next step was to process a raster layer from the point layer of the thermal data. To do this, the tool *point to raster* was used. As no spatial data and coordinate system are given in the processed layer, it has to be georeferenced to become visible. In order to produce a visible raster layer, the .csv file was opened in Notepad++. There, geoinformation, coordinates of the edges, pixel size, number of rows and columns, were typed in manually and the cells with error or no data were deleted. The editor file could then be saved as .tif file and be added in ArcMap as raster. The visible layer contains temperature information, but is not correctly georeferenced, and it is hard to find points of correlation with the RGB orthophoto to georeference manually with the georeferencing tool. Also, from the panorama processed in Flirtools+, it's not obvious whether the georeferencing between the unique pictures is right, as the programme does not produce a log file where it is possible to check what the programme has done.

After detecting, that the panorama images, processed in Flirtools+ are not precise, and it is nearly impossible to analyse and detect errors, due to lack of a log file, the thermal images were processed in Pix4D (see section 3.3.2). The processed thermal images were added as .tif layer in ArcMap. As the thermal images have a lower resolution than the RGB images, Pix4D cannot georeference them with the same accuracy. The thermal layers added in ArcMap are too big and positioned slightly more to the west compared to the RGB orthophoto. To georeference them correctly, the *georeferencing* tool was used. On most layers, it worked to add one control point manually (this was easiest to set on the path, as it was the most obvious structure visible in the layers to be georeferenced), and afterwards the programme could find control points automatically with the tool *add control points automatically.* For some layers, which neither seemed to have a different resolution nor were positioned differently, this did not work, for no apparent reason. For these layers 4-5 control points had to be added manually, before registering more points automatically to make the result as accurate as possible.

Cartography

When maps were produced to view the thermal layers of different flights it was a challenge to find an optimal symbology. The total temperature range across the different flights, varies quite much. The flight with the biggest temperature variation has a range from -7.8°C to 49.8°C while the flight with the least variation has a range from 12.6°C to 31.5°C. The highest temperature measured considering all flights is 49.8°C while the lowest is -10.2°C (see chapter 5, results).

For creating visually representative maps, different symbolizations were considered. The stretched colour ramp variant was excluded as the maximum and minimum temperatures during the unique flights differ so much, that maps visualized with a stretched ramp would make the maps look more alike than they are. Therefore, it was decided to classify the values. First, the colour interval was defined to be 5°C. However, with this symbolization the maps of the flights with a smaller temperature range were poorly represented as they were imaged in beige colour, more or less over the whole area. The next attempt was to define the colour interval as 2.5°C, but the result was similar, as most pixels were still in the middle of the range and therefore imaged in beige. To make the result visually more representative the best solution was to use a non-equidistant colour scale be defining the upper and lower end of the scale with colour intervals of 10°C or 15°C (-10-0°C and 35-50°C) and the middle part with 2.5°C, so that more pixels get a value in the upper and lower parts of the range and therefore a more distinct colour.

To make the layers with smaller ranges more visible the display properties were also adjusted. Contrast was set to 10% and brightness to -15% for all thermal maps.

3.3.2 Pix4D

Pix4D is a photogrammetry software, which is suited for drone mapping. In this project it was used to process an orthophoto from the RGB captures from the drone, produced contemporaneously with the thermal images and to process the thermal images. The orthophoto and the thermal reflectance maps are then used in ArcMap to analyse thermal data of Macun Chavagliet.

Processing of orthophoto

First, the RGB drone photos taken by a nex7 camera on a flight over Macun Chavagliet (25.07.2018) were pre-processed in the AscTec navigator (see section 3.3.3), a software connected with the drone to plan flights, so that the photos now contained geographical information such as coordinates. This step is not essential but makes the processing in Pix4D faster, as the software knows where to search for the position when processing a point cloud classification.

The software Pix4D requires the following steps:

1. Create project
    1. Select image coordinate system
    2. Edit camera model
    3. Create new project
    4. Import images
    5. Configure image properties
    6. Select output coordinate system
    7. Select processing options table
2. Before processing
    1. Select processing area
    2. Add GCP’s (ground control points)
3. Processing
    1. Initial processing (produces a point cloud)
    2. Analyse quality report
    3. Point cloud and mesh, DSM, Orthomosaic and Index
4. Export DTM, Orthophoto

(Pix4D, 2019b)

Going through the steps above the DTM was processed and afterwards exported into a format compatible with ArcMap.

Both, image and output coordinate system were set as LV95 1903+, which is the local coordinate system used in south-eastern Switzerland. If a global coordinate system would be used, it would be WGS84.

The drone flight plan was set to overlap by 80%. This means that the quantity of pictures capturing a single spot was high, which ensured high resolution results with no holes and little deviation.

To make the georeferencing as precise as possible, five GCP’s (ground control points) were set. When flying the drone these spots with the precise GPS coordinates were marked by an orange panel (visible on RGB images) as well as small sawdust heaps (assumed to be visible on thermal images). These spots where marked and connected in 12 images in each case, to make the location more precise during the process as the software already has the information, that the same spot is represented in all these (12) marked images.

The next step is the initial processing, where the software produces a point cloud, which (because of the high percentage of overlapping) already looks like a DTM but a closer inspection reveals that the cloud is not perfectly dense and still has some gaps. This step of the process takes about 2 hours to calculate.

After analysing the quality report and checking if geolocation, overlapping and quality of the images is as expected.

The second and third step of processing can be started, where first a point cloud and mesh are produced and finally the complete and dense DSM and orthomosaic can be processed. This process took about 14 hours for this project.

Processing of thermal images

In addition to the orthophoto, maps of the thermal images taken on the same flights as the RGB images were processed in Pix4D.

The following steps are required for such processing:

1. Create project
    1. Open new project
    2. Name project, *create in*
    3. Select images
    4. Adjust image properties (camera model, coordinate system(WGS84))
2. Before processing
    1. Select output coordinate system (From EPSG 2056 = CH1903+/LV95)(Geoid Height above Bessel1841 Ellipsoid = -47m)
    2. Select *thermal camera* in the processing options table, uncheck *start processing now*
3. Processing
    1. Step 1, initial processing
        i. Uncheck processing steps 2 and 3
        ii. Open processing options
        iii. Check settings
        iv. Start processing step 1
        v. Analyse quality report

2. Step 2, point cloud and mesh
    i. Set point density to high (low)
    ii. Set 3D textured mesh settings to high resolution
    iii. Start processing step 2
    iv. Analyse quality report
3. Step 3, DSM, orthomosaic and index
    i. Check indices *grayscale* in the tab index calculator
    ii. Start processing step 3
    iii. Analyse quality report
    iv. Analyse reflectance map in *index calculator*

The reflectance map is saved in the folder, the project is created in as .tif (including .prj and .tfw, so that the geoinformation is included).

With the images from one flight (25.07.18, flight3), a merged project was processed. This means that the thermal image project was merged with an RGB project of the same day. The aim was to detect if merging the thermal images with the RGB images makes the outcome more precise. It seems that the merged .tif result is slightly more precise than just the thermal one when added as a layer in ArcMap, especially in the outer parts of the projection. However, the layer containing only the information from the thermal images is precise enough for the purpose of this project. As the processing of the merged project took much more time (about 14h vs. 15min) than the thermal image project, it was decided not to merge the thermal image projects in the remaining cases.

3.3.3 AscTec and FLIR tools+

AscTec navigator is a software used to set up flight plans for drone flights. The computer with the flight plan can be connected to the drone navigator, so that when starting the programme, the drone flies the planned route automatically without the pilot having to navigate the drone manually. In AscTec navigator a waypoint navigation can be set up, where it is determined where, with which interval and at what resolution photos should be taken (Gradzki, 2015). With the AscTec navigator the only action the pilot has to take is to start and land the drone, as well as start the navigation with the AscTec navigator.

To create a flight plan a georeferenced as is required. When the programme is opened, the first step is to either create a new map or to select an existing map on which the waypoints defining the flight path can be planned (Gradzki, 2015). For this project a map projected in LV95 1903+

was used. When the map is selected, a new map from the area of interest can be set up. To do that, the user must navigate to the area of interest on the full screen map, then zoom in or out, and next save it, name it and confirm, before the new map will be opened (Gradzki, 2015).

When the map is opened, the next step is to create the actual flight plan by clicking on *create new flightplan* in the toolbar above the list view, opening the *flightplan editor*. For this project the *matrix tool* was used to create the flight plan. In the editor, one has to choose the utilized camera and then create a polygon on the map by adding at least three (in this case four) points on the map. The next step is to enter the required parameter (height/ground sample distance, overlap and speed), after that the flight direction must be chosen by clicking on *arrows*. When all these steps are completed, the matrix can be generated, and the parameter can be adjusted before confirming the matrix by clicking on *apply matrix* (Gradzki, 2015).

When the matrix is applied, the AcsTec Navigator will generate all waypoints and show the flight path. When the flight path is controlled and looks as desired, it can be saved, and the navigator is ready to start the flight (Gradzki, 2015).

A side programme of AscTec navigator AscTec FLIR converter was used to convert the .ara files, the format in which the thermal images were originally saved, to FLIR .jpg. The difference between the FLIR .jpg and a normal .jpg boils down to a spatial radiometric information in the image’s metadata. This type of .jpg is called RJPG (radiometric .jpg) (Pix4D, 2019a).

4 Geomorphology and Topography of Macun Chavagliet

4.1 Habitat Types and Geology

According to the mapping of Swiss National Park (Inderbitzin, 2002) on geomorphology in the Macun area, a big part of the research area, especially where most of the loggers were placed (except TL19) is *Amphibolit.* In addition to that soil type/cover, *para gneiss*, *moraine cover*, and *Alumo/Granat/Disthen/Slate* constitute most of the area of interest.

The vegetation mapping (Favre et al., 2016) shows that the vegetation cover is mostly *Loiselurio-Caricetum curvulae.* Only in the outer parts of the area *Salicetum Herbaceae* and *Caricetum curvulae typicum* were mapped.

4.2 Aspect and Slope

4.2.1 Aspect

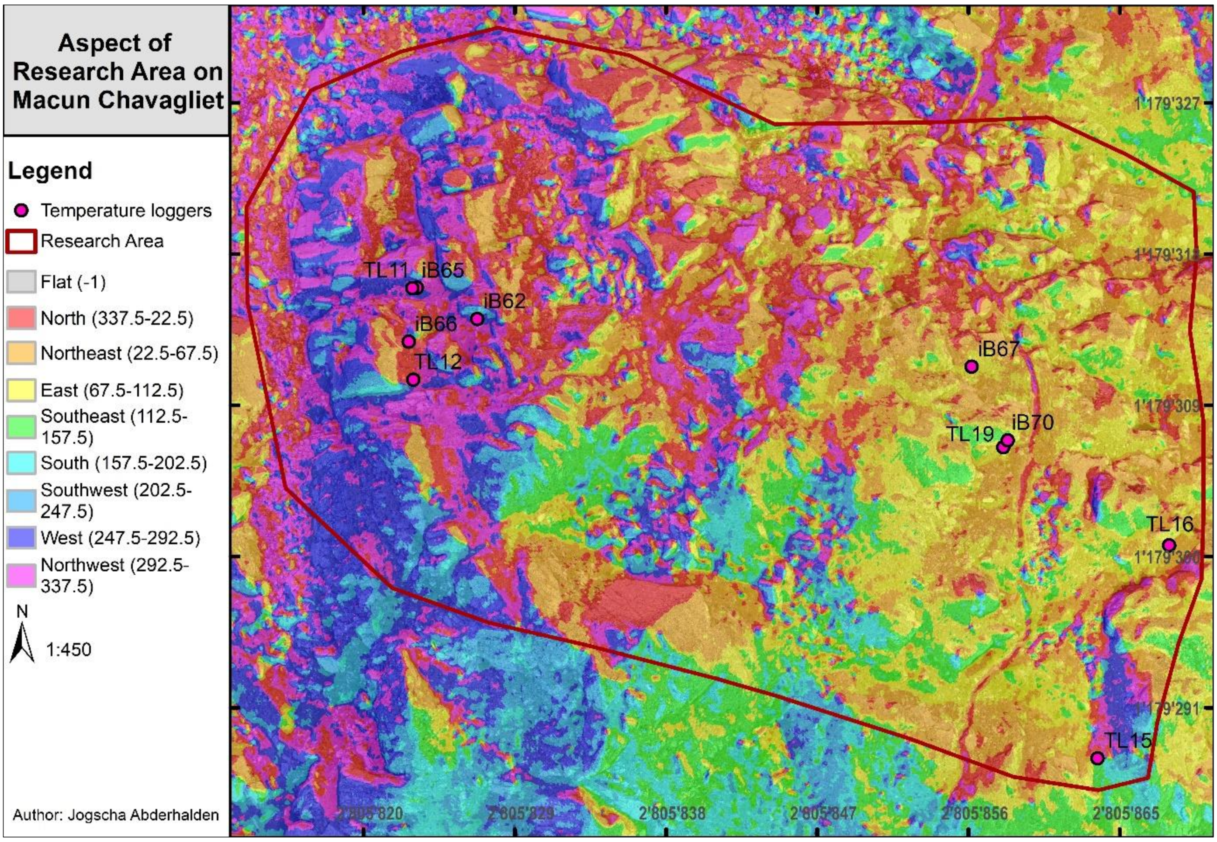


Figure 4 Overview of the aspect of the research area on Macun Chavagliet

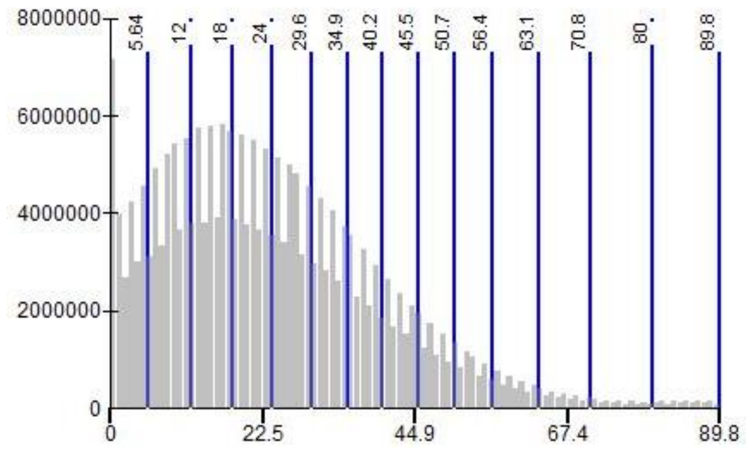
The eastern part of the area is mostly facing towards northeast, east and some parts southeast, the western part towards west and northwest with some parts facing towards north and northeast (Figure 4).

Temperature loggers

The majority of the temperature loggers were positioned in an aspect towards west (iB66, TL12, iB62A, iB64A, iB66A), and east (iB67, iB70. TL16, Tl19, iB67A). Some (iB62, iB62, TL11) were positioned towards Northwest and one logger towards east-northeast (TL15).

4.2.2 Slope

The slope on Macun Chavagliet varies between a gradient of 89.9% and flat terrain (0%), while most part of the area is in a slope range between 0-45% and the mean inclination is at 23.9% (Figure 5, 6).



Count:	218573212
Minimum:	0
Maximum:	89.8
Sum:	5'220'000'000
Mean:	23.9
Standard Deviation:	16.2

Figure 5 Classification statistics of slope on Macun Chavagliet

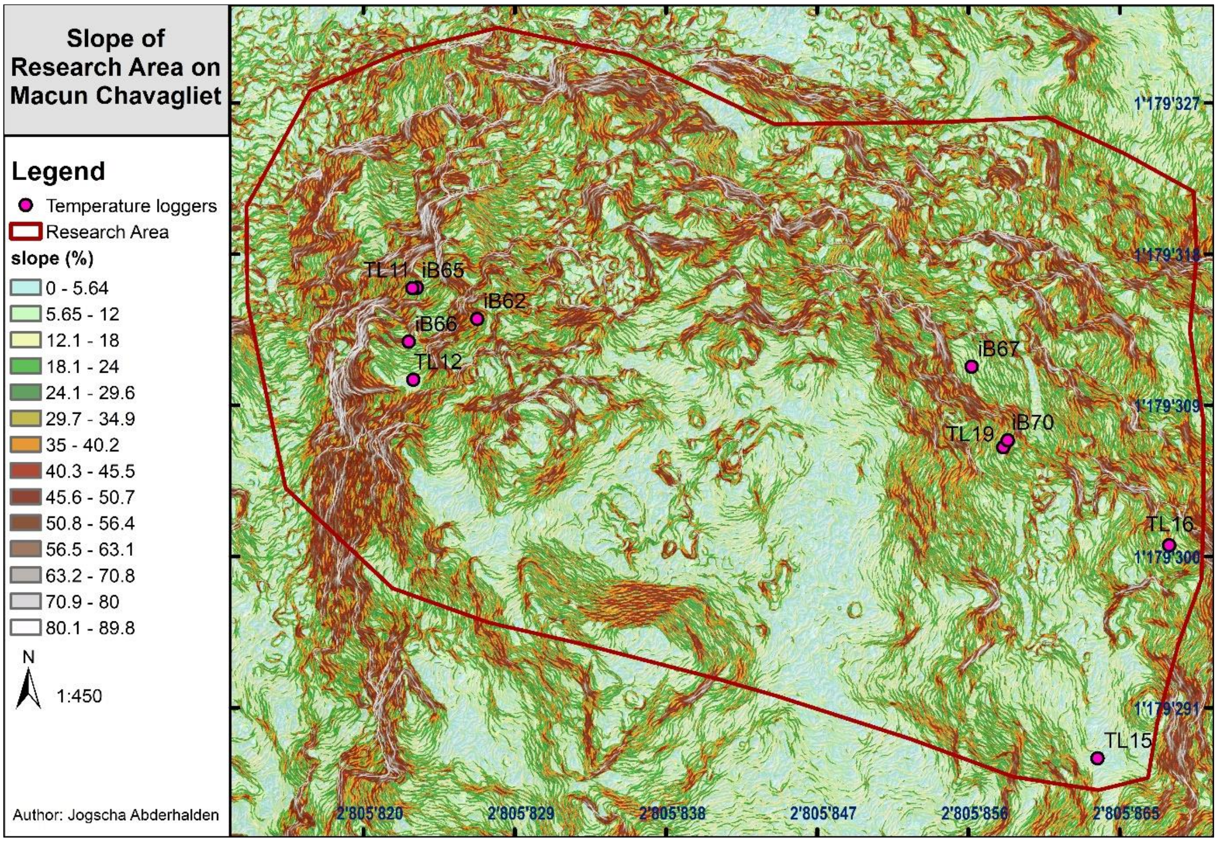


Figure 6 Overview of the slope of the research area on Macun Chavagliet

Temperature loggers

The temperature loggers were positioned at various gradients. TL12, TL15, TL19 and iB62A were positioned in nearly flat terrain with a gradient under 17%, TL11, iB62, iB65, iB66A and iB70 were positioned around the mean inclination of the area between 20-29%, and TL16, iB66 and iB67 were positioned on a gradient of over 30% (Table 1).

4.3 Surface Temperature Variations

In this thesis, the parameters taken into account for the analysis of diurnal temperature development and variation are, aspect, slope and geological and vegetational cover of the area. Solar radiation and weather data would also be relevant parameters to include. However, as information on the weather was not listed at the same time as the fieldwork (the drone flights on the dates chosen for analysis) was executed, it would have been too time-consuming for the extent of a BSc-thesis, to collect data on the weather for those dates. Additionally, the weather data, that could be collected from a nearby weather station could still only be used for an assumption about how the weather might have been at a specific moment of time, and would not provide precise information about the local cloud cover and solar radiation, which would be the two most interesting parameters in result analysis. Therefore, it was decided to leave this information out and to just concentrate on aspect and slope.

5 Results

5.1 Results Temperature Loggers

Table 1 Summary of the temperature logger data

Logger Number	Mean temperature total	Mean temperature 0+	Maximum temperature	Minimum temperature	Slope	Aspect	Period
iB62	1.517	7.44 (05.05)	16.59	-9.45	25.63	280.81	21.01.18-04.10.18
iB65	1.636	8.45 (27.05)	20.65	-6.48	28.91	285.06	21.01.18-04.10.18
iB66	0.855	6.704 (07.05)	14.63	-8.46	56.68	358.71	21.01.18-04.10.18
iB67	3.657	9.555 (18.04)	24.65	-9.95	36.64	92.48	21.01.18-04.10.18
iB70	2.205	9.371 (21.04)	24.14	-10.5	25.7	101.81	21.01.18-10.07.18
TL11	0.442	8.309 (23.05)	37.5	-13	22.79	299.96	07.10.17-04.10.18
TL12		8.41 (10.07)	33	-10	16.87	306.38	no data between 08.01 and 10.07
TL15	0.693	8.299 (22.04)	32	-29	1.57	38.66	07.10.17-04.10.18
TL16	0.516	8.12 (22.04)	31	-22.5	33.09	58.71	07.10.17-04.10.18
TL19	1.328	9.005 (20.04)	35	-24.5	16.15	82.35	07.10.17-04.10.18
iB62A	0.257	8.215 (08.05)	19.58	-7.53	7.86	352.87	21.01.18-10.07.18
iB66A	-0.221	6.848 (12.05)	11.62	-6.97	28.43	306.96	21.01.18-10.07.18

The table above (Table 1) shows an overview of the temperature logger data recorded through the whole measurement period from 21.01.2018-04.10.2018 for the iButtons and 07.10.2017-04.10.2018 for the TL poles whereas some of the temperature loggers lack data in some periods. For the analysis of the diurnal temperature development, an analysis of the whole period is not required however, to get an overview of the measured data can help to explain the differences on the analysed days and to detect whether the measured maximum temperature has something to do with the ground cover type, aspect and slope of the position. Half of the loggers were collected from their position before noon, 04.10.2018, which is why this date could not deliver relevant information, with just three TL loggers and one iButton logging temperatures for most of the day. Therefore, only the three dates 05.06.2018, 25.07.2018 and 03.08.2018 were selected for analysis.

When analysing the temperature logger data, it is apparent that there is a tendency for the loggers with an aspect in the range between 72.85 and 100.02 (east) to have a rise of temperature earlier than the others throughout day. For the loggers with an aspect towards west, the peak temperature for the day is tendentially later and the temperature declines slower (see chapter 5.1.1 and 5.1.2).

5.1.1 Results iButton

Table 2 Mean temperature (°C) of the iButtons on the analysed dates

IB number	05.06.2018	25.07.2018	03.08.2018
iB62	7.23	9.55	11.57
iB65	7.84	9.68	11.42
iB66	7.84	8.67	10.44
iB67	13.07	12.05	14.91
iB70	12.69	no data	no data
iB62A	9.35	no data	no data
iB66A	7.82	no data	no data

The table above (Table 2) shows the mean temperature measured by the iButtons on the three analysed days. All loggers registered the highest mean temperature on 03.08.2018, compared

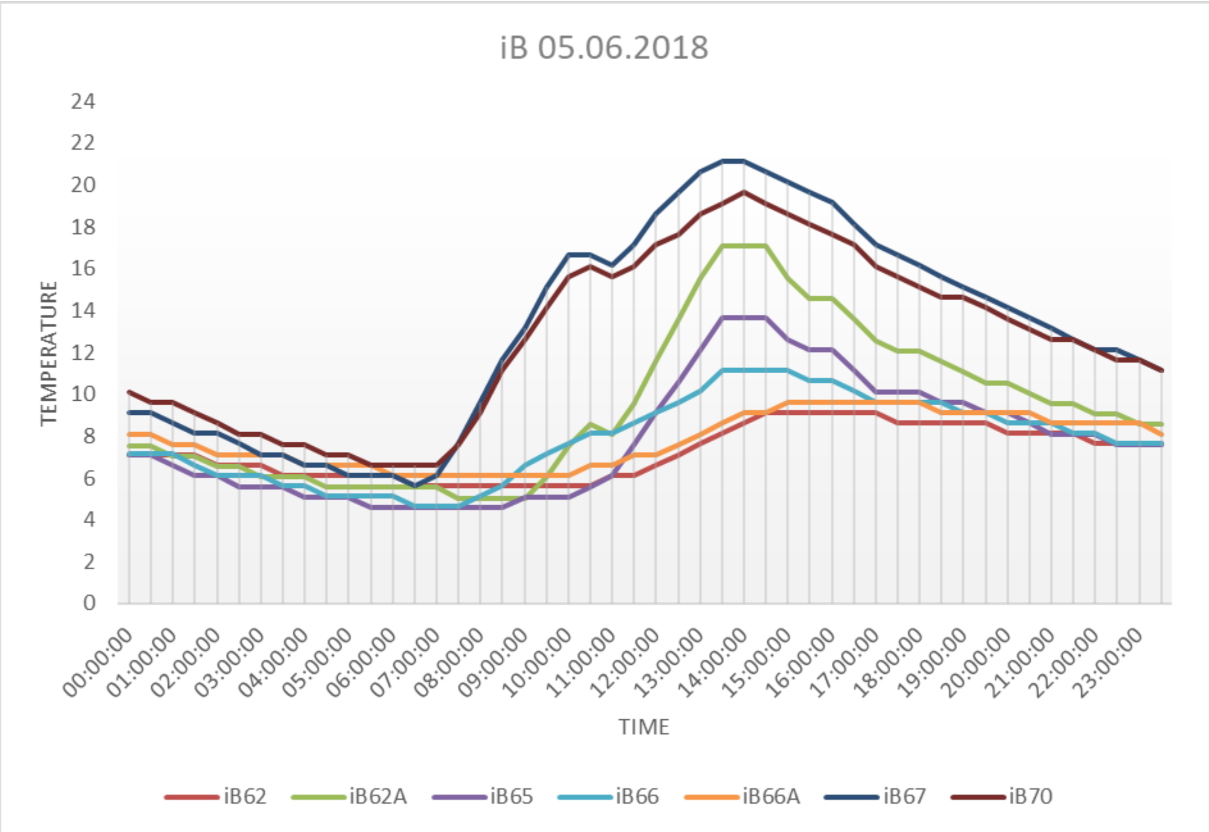


Figure 7 Temperature development (°C) iB 05.06.2018

to the mean temperature measured by the same iButton respectively. This means, that according to the iButton data, it can be assumed that the 03.08 was the warmest of the analysed dates.

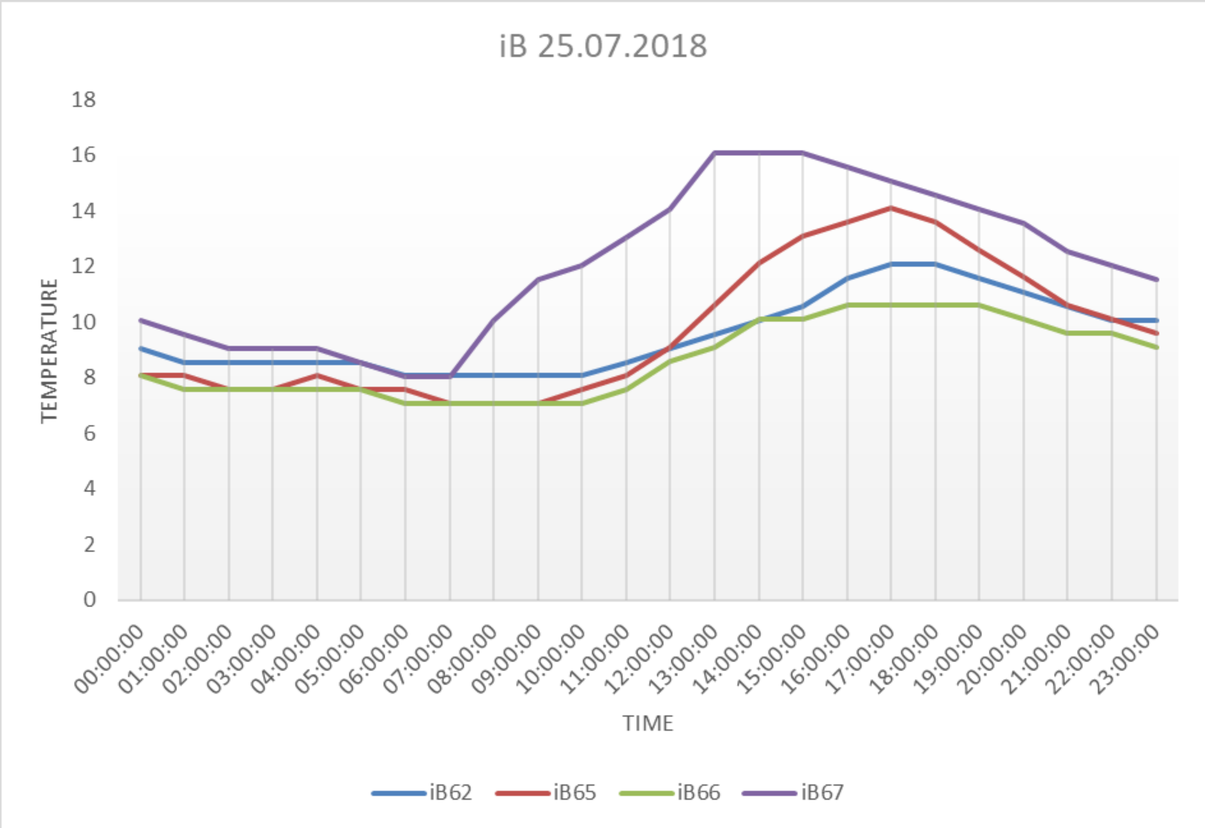


Figure 8 Temperature development (°C) iB 25.07.2018

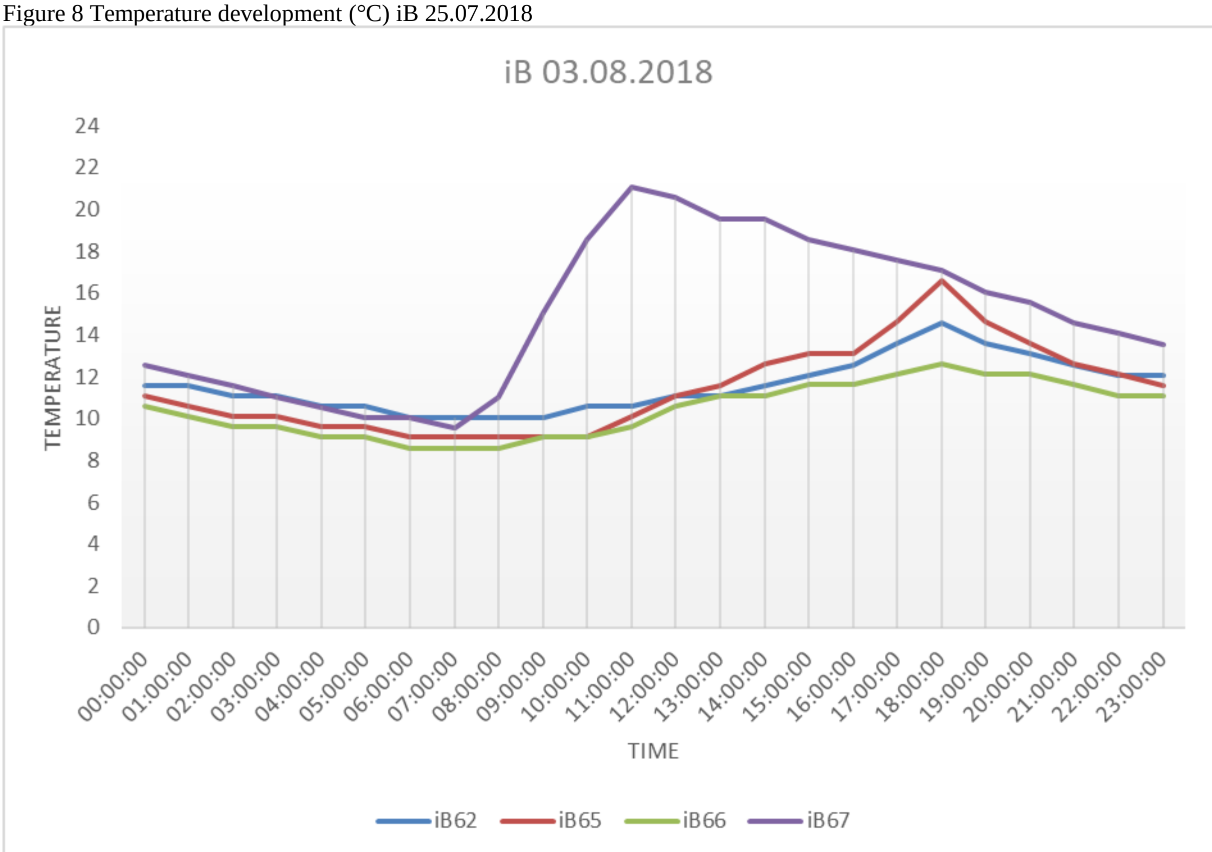


Figure 9 Temperature development (°C) iB 03.10.2018

The diagrams above (Figures 7-9) show the diurnal temperature development of the three dates chosen for analysis. IB62, iB65 and iB66 all experienced relatively similar temperature developments throughout all days analysed, while the results from iB67 differ from the other loggers. This outcome might have a coherence with the fact that iB67 was situated on the eastern side of the research area while all other iButtons were placed on the western side. IB67 measured both a higher and earlier maximum temperature on all analysed days. On 05.06.18, all loggers measured the maximum temperature for the day between 13:30 and 15:00, while iB62, iB65 and iB66 measured the maximum temperature on the other two dates (25.07, 03.10) at a remarkably later moment of time.

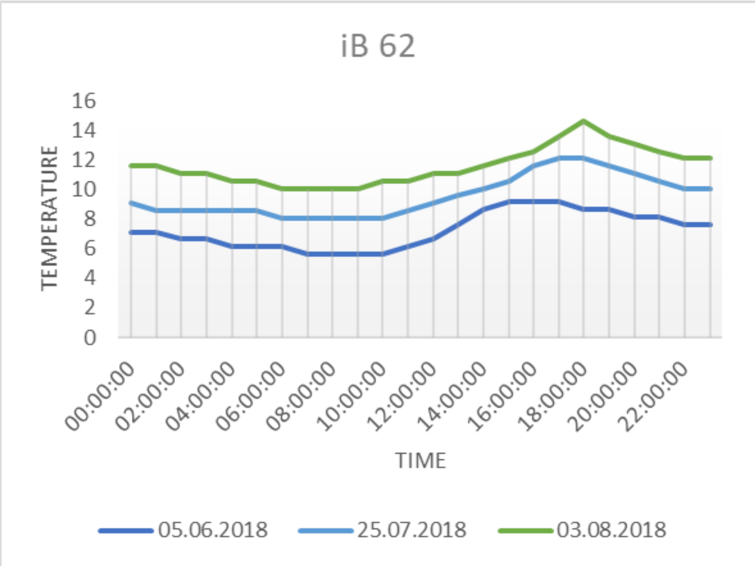


Figure 10 Temperature development iB62 on the analysed dates

IB62 showed similar temperature development on all analysed days, whereby 05.06 was the coldest, 25.07 a bit warmer and 03.08 the warmest day. On all three days, the temperature sank a bit from 00:00 until 06:00, then was quite stable until 10:00 when it started to rise. For iB62 it seems that the colder the day, the earlier the peak temperature is reached and the less steep the graph is (Figure 10).

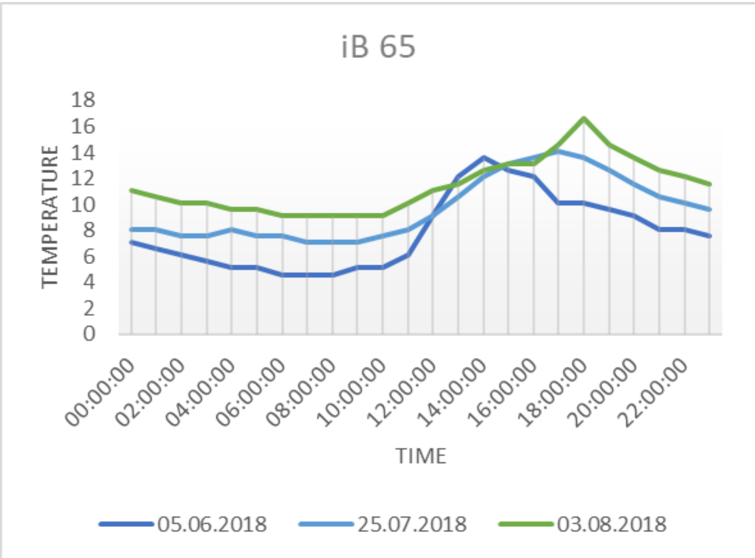


Figure 11 Temperature development iB65 on the analysed dates

IB65 showed similar patterns as iB62, with 05.06 as the coldest, 25.07 as the intermediate and 03.08 as the warmest day (Figure 11). Also, here the peak temperature was reached earlier when the day was colder. However, the graphs for iB65 appear to be much steeper and the temperature variation within one day was higher than for iB62.

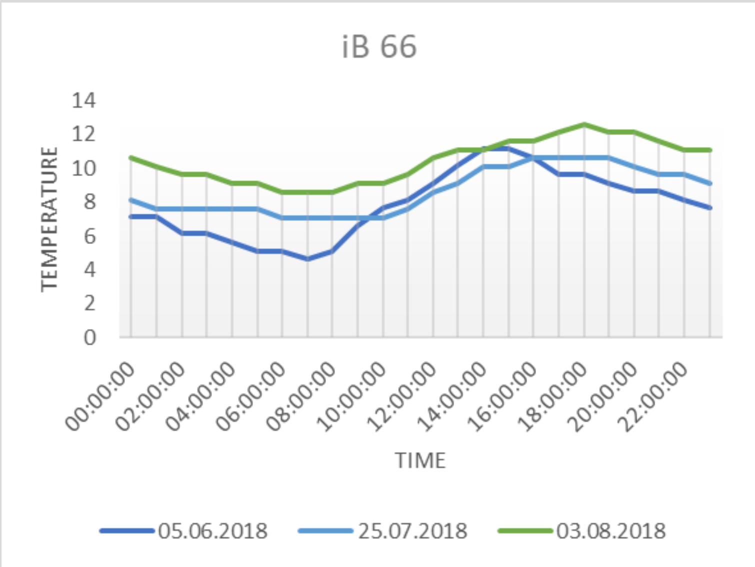


Figure 12 Temperature development iB66 on the analysed dates

IB66 showed similar patterns as iB62 and iB65 regarding which day generally was the coldest and warmest. The temperature on 25.07 and 03.08 develops similarly to the graph of iB62 (Figure 10) with a slightly decreasing temperature until 06:00, a temperature rose from around 10:00 and a reach of the peak temperature between 16:00 and 18:00. All temperature variations were gradual, resulting in a relatively flat/unremarkable trend (Figure 12). For 05.06 the graph of iB66 looks more like iB65 with a very low temperature until around 09:00 and a quite fast temperature rise from then until around 14:00 when the maximum temperature for the day was reached (Figure 11, 12).

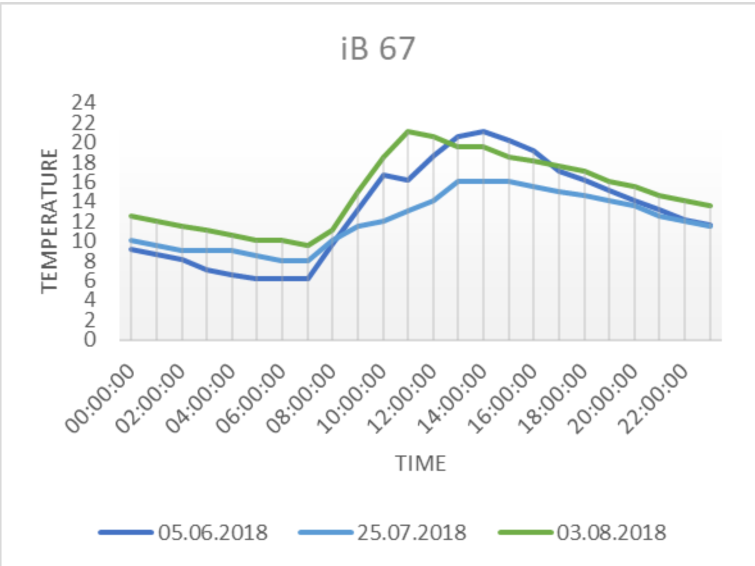


Figure 13 Temperature development iB67 on the analysed dates

iB67 showed quite a different temperature development pattern to the other iButtons. The temperature sank slightly from 00:00 until around 07:00 and then started to rise quite quickly on all analysed days, with 25.07 showing a flatter graph than the other dates (Figure 13). The maximum temperature for the day was reached at an earlier moment of time (between 11:00 and 14:00) than for the other loggers on all dates and started to sink again when the temperature for the loggers situated on the other side of the research area were still rising.

5.1.2 Results TL Poles

Table 3 Mean temperature (°C) of the TL poles on the analysed dates

TL number	05.06.2018	25.07.2018	03.08.2018
TL11	8.26	10.38	12.14
TL12	no data	10.32	12.78
TL15	9.55	10.98	13.8
TL16	10.09	10.68	13.68
TL19	11.63	11.31	14.24

The table above (Table 3) shows the mean temperature the TL poles measured on the three analysed days. All loggers measured the highest mean temperature on 03.08.2018, compared to the mean temperature measured by the same TL respectively and in total. This means that according to the TL pole data it can be assumed, that 03.08 was the warmest of the three analysed dates.

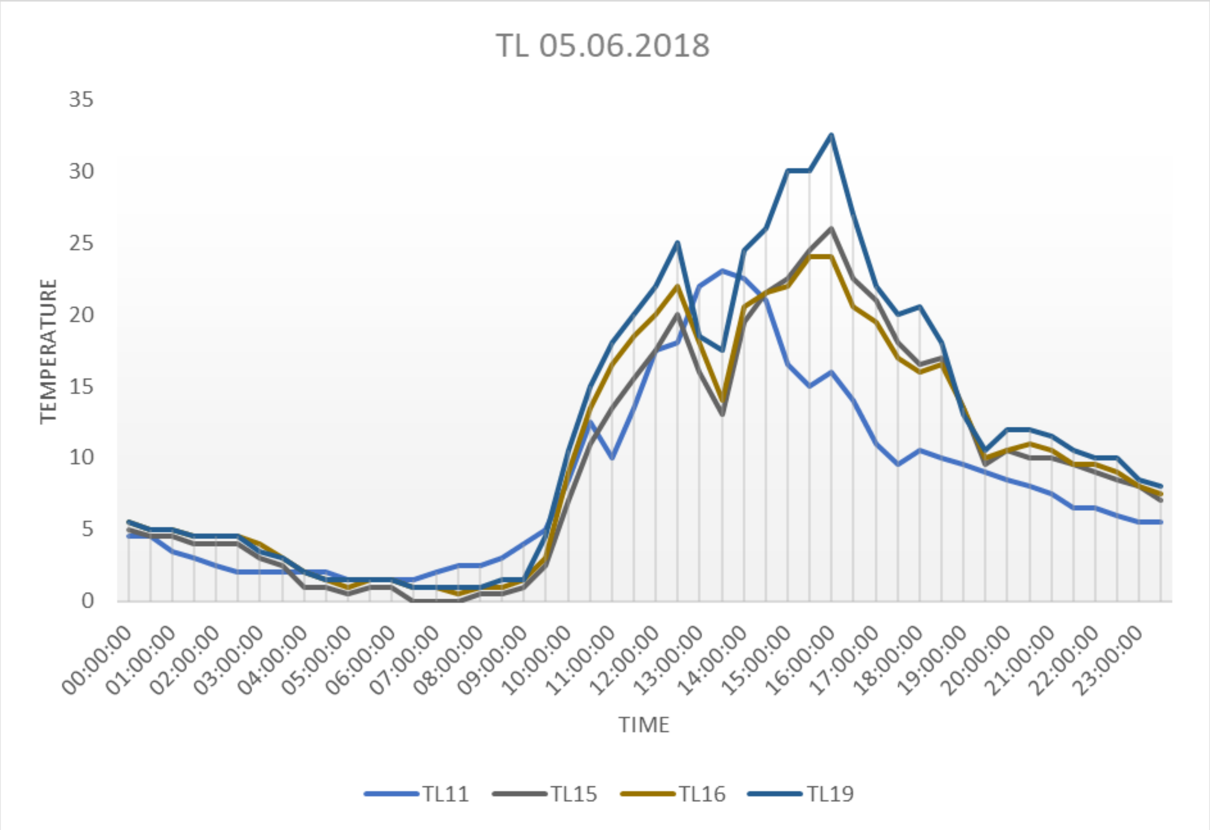


Figure 14 Temperature development (°C) TL 05.06.2018

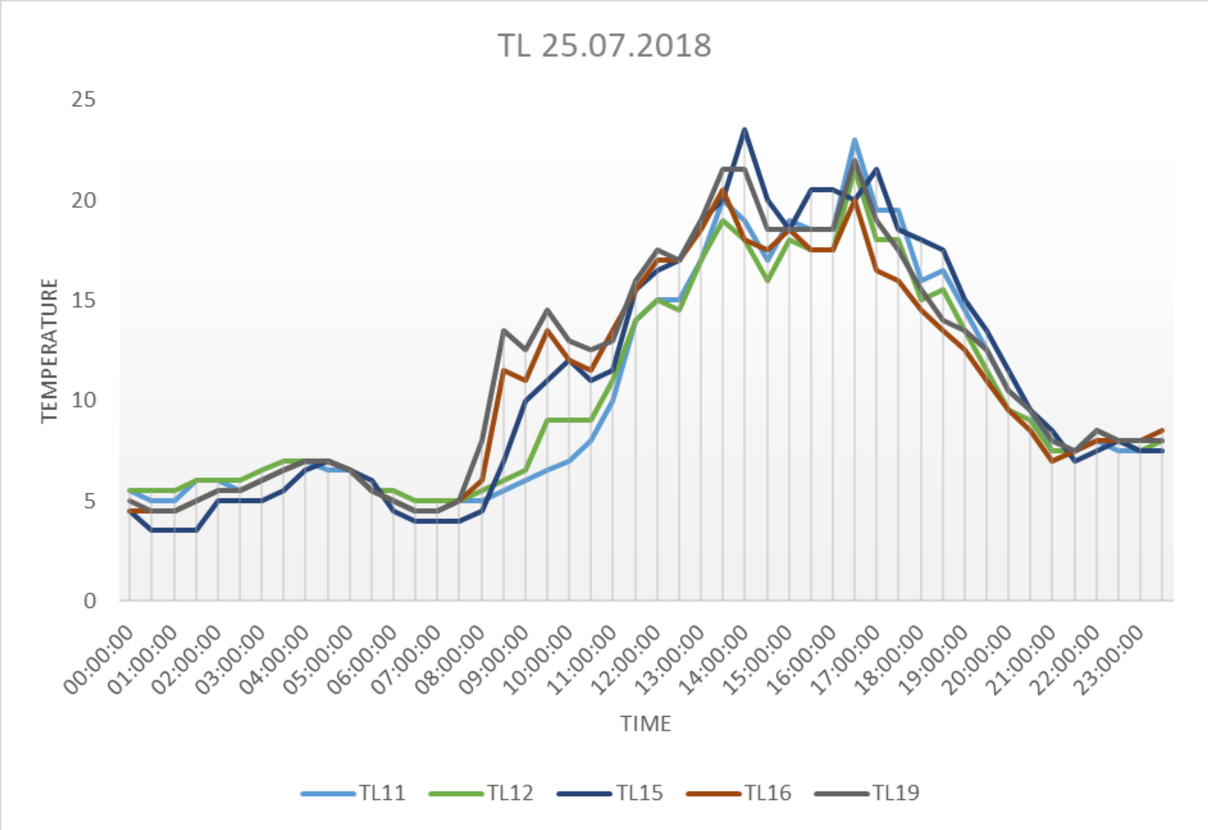


Figure 15 Temperature development (°C) TL 25.07.2018

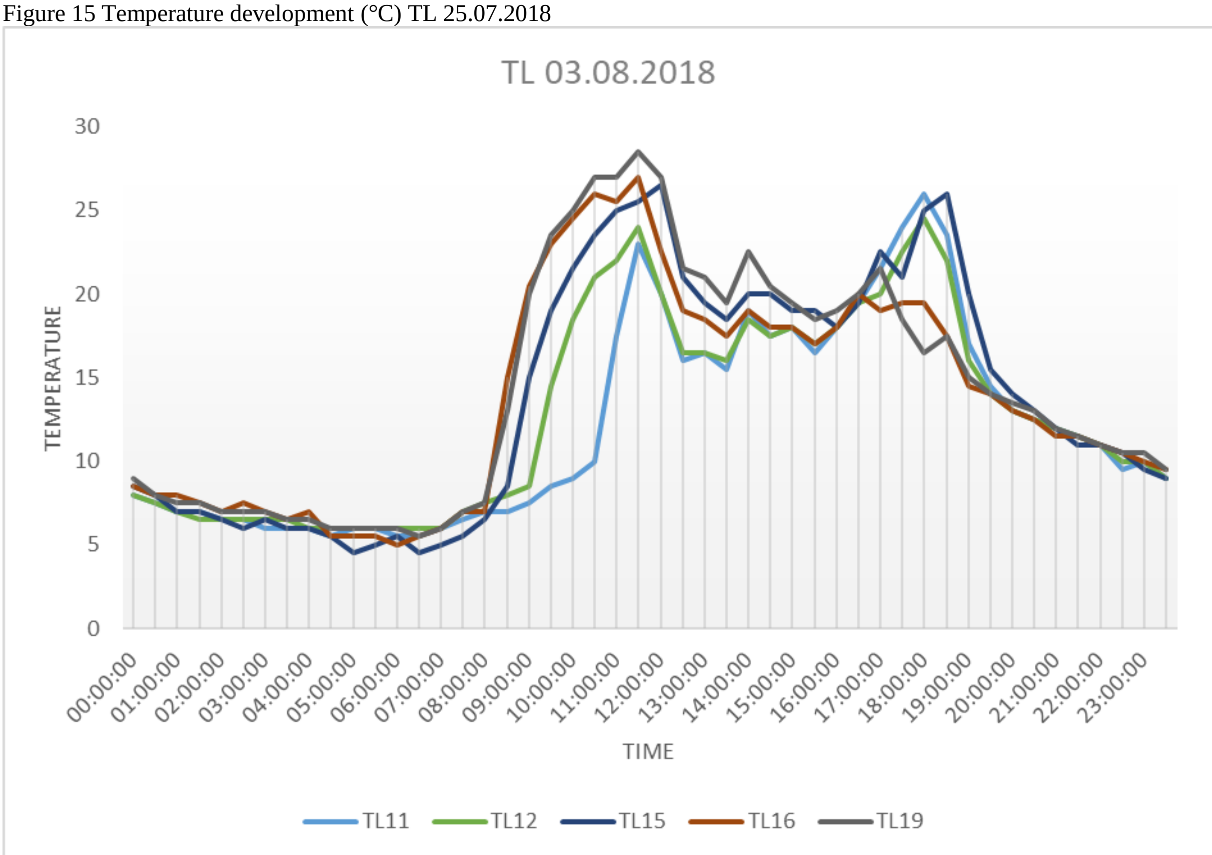


Figure 16 Temperature development (°C) TL 03.08.2018

The diagrams above (Figures 14-16) show the diurnal temperature development of the three dates chosen for analysis. What stands out is that all TL poles (except TL11 on 05.06) follow a fairly similar temperature development pattern throughout the day on the three analysed days. It cannot be claimed that one of the loggers measured tendentially warmer temperatures than the others as this differs from day to day, but the mean temperature throughout the day was the highest for TL19 and the lowest for TL11 on all three days. What seems to be typical for the measurements of the Tl poles is, that they register two temperature peaks throughout the day (except TL11 on the 05.06). However, these two temperature peaks don't appear at the same moment of time on the different dates. All TL pole loggers show very cold temperatures during the night on 05.06, when they dropped nearly to the freezing point.

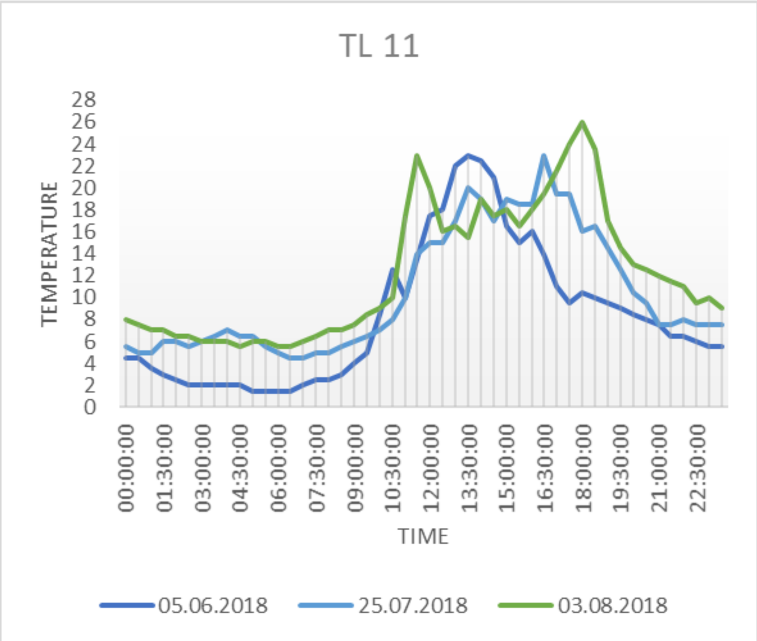


Figure 17 Temperature development TL11 on the analysed dates

TL11 showed quite a diverse temperature development throughout the day on the three chosen dates for analysis. 05.06 was definitely the coldest night and 03.08 was the warmest day overall. What is interesting is, that 03.08 showed two distinctive temperature peaks (one at ca. 10:00 and one at ca. 18:00) with a clear temperature fall in between. 25.07 also seems to have had two peaks, however, they were much closer in time (ca. 13:30 and ca. 16:30) and less distinctive. 05.06 only had one temperature peak around 13:30. The temperature started to rise quickly between 09:00 and 10:30 on all days and also fell quickly again after the last peak temperature was measured (Figure 17).

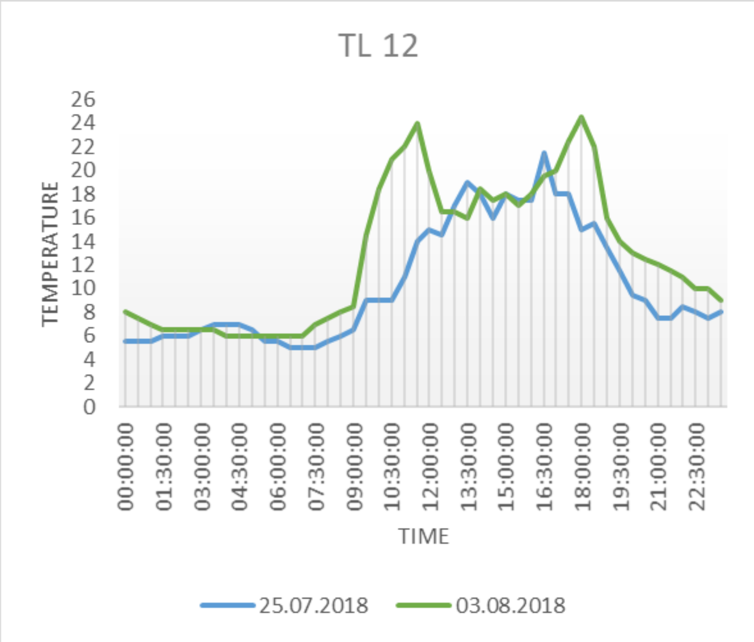


Figure 18 Temperature development TL12 on the analysed dates

TL12 has no data for 05.06, as there was an error message because of water in the logger. Overall, 03.08 was a warmer day than 25.07. On 25.07 the temperature rose gradually from around 07:30 to 13:00 when it reached the first peak temperature. Afterwards the temperature fell slightly and started to rise again to a second peak temperature, which also was the maximum temperature for the day at around 17:00. 03.08 showed a different pattern with quicker rising and falling of the temperature throughout the day, reaching the first peak at around 11:30 and the second peak (both at around 24°C) at around 18:00, with quite a drop of temperature in between (Figure 18).

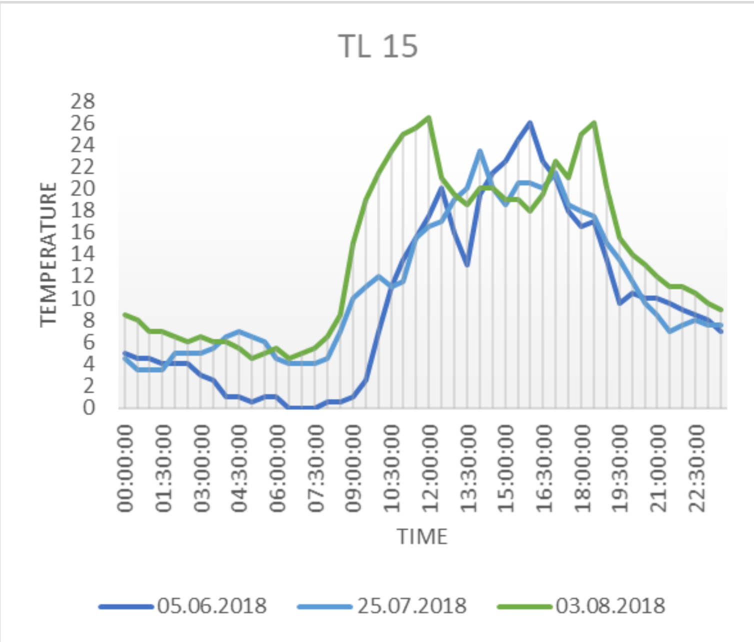


Figure 19 Temperature development TL15 of the analysed dates

In clear agreement with TL11 (Figure 17), TL15 shows that the night of 05.06 was the coldest and that the day of 03.08 was the warmest overall. Like TL11 and TL12, TL15 showed two distinctive temperature peaks, quite distinct from each other in time, while the maximum temperature on the other two days is measured at a moment of time in between those two peaks (Figures 17-19).

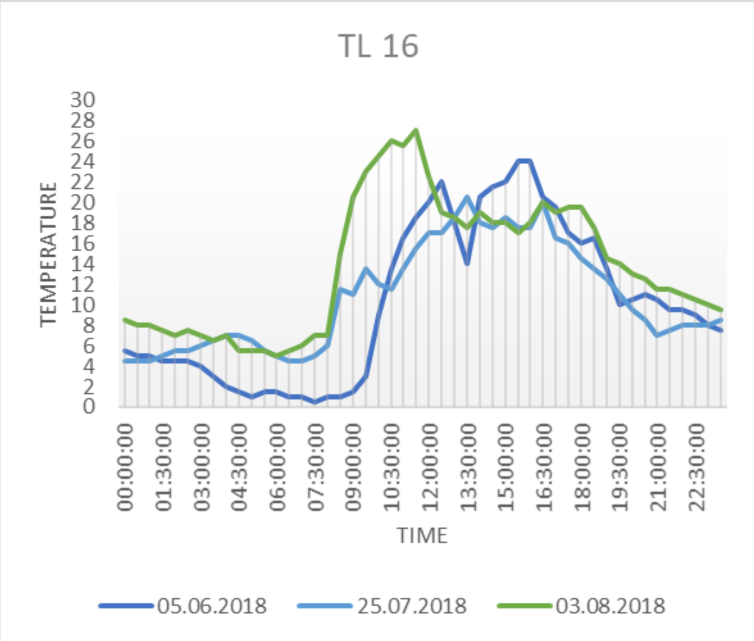


Figure 20 Temperature development TL16 on the analysed dates

TL16 showed quite a similar temperature development pattern to TL15 on 05.06 and on 25.07 (Figure 19, 20). Also, on 03.08 the temperature developed very similarly until noon. From then on, the temperature did not rise much more where TL16 was located, while TL15 showed a second temperature peak around 18:30. The temperature measured by TL16 stayed quite stable until around 18:00 after a drop form the maximum temperature at around 11:30, then starting to fall towards the night (Figure 20).

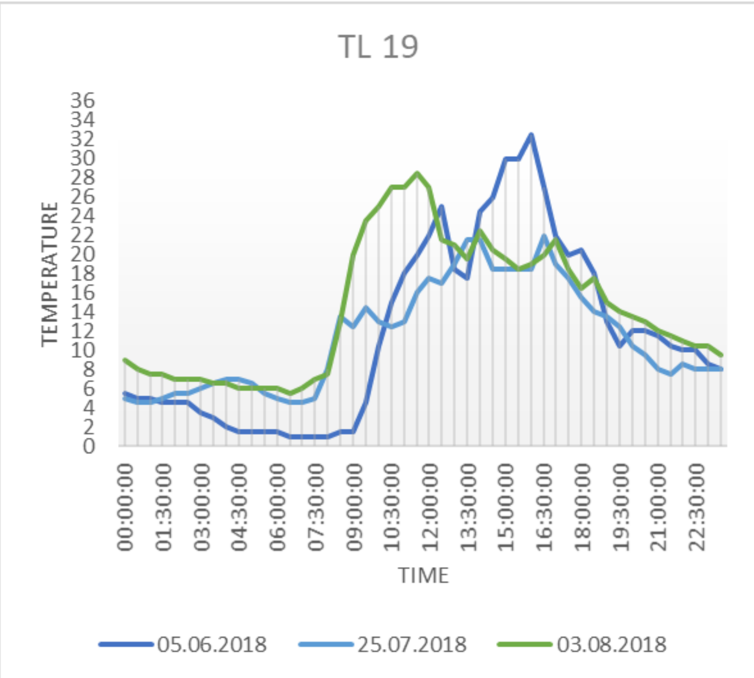


Figure 21 Temperature development TL19 on the analysed dates

Despite measuring a slightly higher temperature overall, TL19 showed a very similar temperature development pattern to TL16 (Figure 20, 21). The only significant difference is the second temperature peak measured on 05.06, which appears to be much higher, even revealing the maximum temperature measured by all loggers seen over all three analysed days (Figure 21). This means, that the highest temperature measured on the analysed days (32.5°C) was measured on the coldest of the three days as shown by the mean temperature (Table 2,3).

5.1.3 Comparison of the two Types of Loggers

Two outstanding differences are apparent when comparing the iButton results with the TL logger results. Firstly, the TL loggers mostly have two temperature peaks, or at least one peak, a drop and then a constant, slightly rising temperature for several hours before the temperature drops again towards the night, while the iButtons only have one rising period before reaching the maximum temperature for the day, followed by one temperature falling period. Secondly, the TL loggers measure a higher temperature variation throughout a day, which means lower minimum and higher maximum temperatures, than the iButtons. It seems that the TL poles are more precise in their measurements and more sensitive to temperature fluctuations then the iButtons. This could be a result of the positioning, whereby the TL poles are approximately 5cm above the surface while the iButtons in the surface layer of the soil.

On two of the three days in question, TL19 measured the maximum temperature of all loggers. On 25.07.18 TL15 measures the highest temperature (Figure 19, 21). The lowest maximum temperature is measured by iB66 on 25.07 and 03.08, whereas iB62 and iB66A measured an even lower maximum temperature on 05.06 (Figures 7-9). It has to be taken into account that iB66A was only in the field until 10.07 and therefore has no data for 25.07 and 03.08. This logger (iB66A) was the logger with the lowest mean temperature over the whole measurement period, which could be because it was not in the field during the warmest period of the year (July, August), or the position of the logger could be the reason.

The loggers TL11, TL12 and iB65 have quite similar temperature developments on all days (no data for TL12 05.06.18), considering the time of the peak temperature for a day (Figure 17, 18, 11). The graph over the whole day looks quite similar for TL11 and TL12 with two peaks and a similar rise and decrease of the temperature. This similar development could be explained by the related aspect for all three loggers (285-306°, west-northwest) (Table 1).

5.2 Results Thermal Infrared Camera

In the analysis of the thermal infrared images, the flights with the most precise data were chosen to be processed. That is, those featuring all 120 images correctly positioned so as to be set together on an index grayscale map in Pix4D. Additionally, the aim was to cover as many periods of the day as possible (flights spread evenly throughout each day in terms of time) as well as trying to obtain results from the same (or as near to as possible) moment of time for the different dates. Seen over all analysed flights, the minimum temperature registered is -10.15°C (measured on 04.10.2018 at, 10:10) and the maximum temperature is 49.76°C (measured on 05.06.2018 at, 10:40).

Analysed flights time and date

05.06.2018:

Flight3, start 10:40

25.07.2018

Flight3, start 11:00

Flight4, start 13:00

Flight5, start 15:00

03.08.2018

Flight1, start 08:30

Flight5, start 14:40

Flight6, start 15:30

04.10.2018

Flight1, start 10:10

Flight4, start 13:10

Flight6, start 15:10

To ensure more precise results and make evaluation easier, it would be preferable for a subsequent project involving thermal images, to register some weather facts for the time of each flight. This would not be a difficult undertaking and would provide further indication for the reasons the temperature changes throughout the day; for example, why it might be colder at noon than at 11:00 one day, and the other way around on another day. The following maps show the results of the thermal images when set together to an area covering the map.

05.06.2018

Flight 3, start 10:40

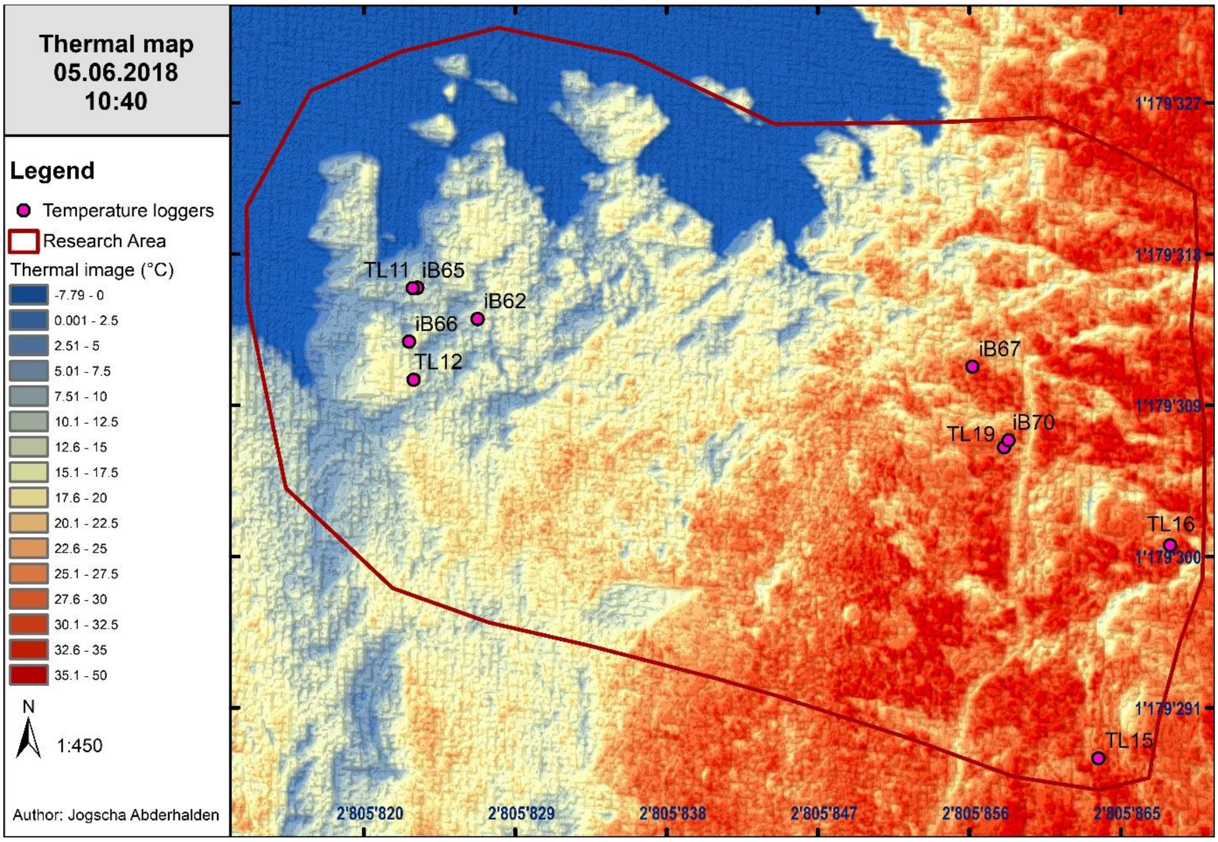


Figure 22 Thermal map of the 05.06.2018, flight start at 10:40

On 05.06.2018 only one complete flight could be realised. There are no thermal maps to compare with, from another moment of time the same day. What is evident on this map is that it shows clearly that the eastern part of the research area was much warmer than the western part in the morning. The area in the north/west, visible in blue, signifying temperatures below 0, was still snow covered in the start of June.

25.07.2018

Flight 3, start 11:00

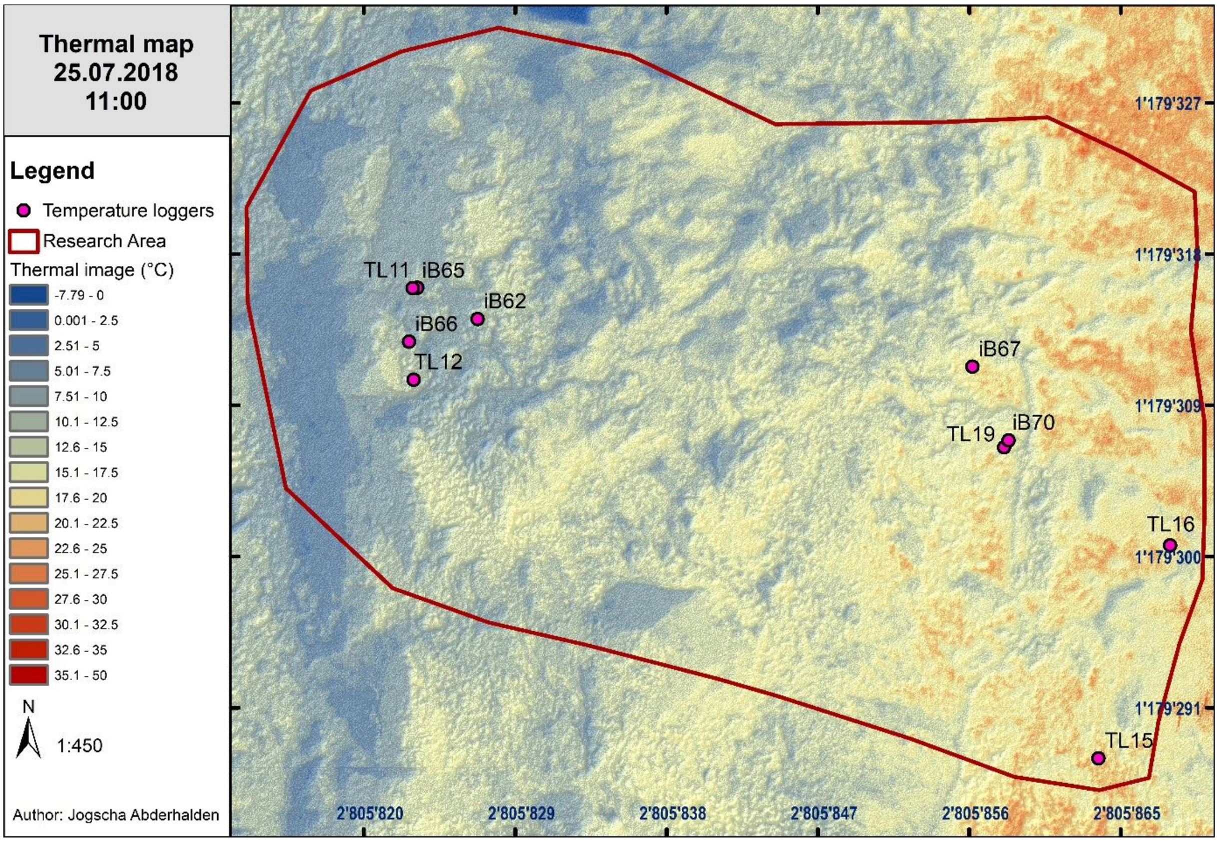


Figure 23 Thermal map of the 25.07.2018, flight start at 11:00

Flight 4, start 13:00

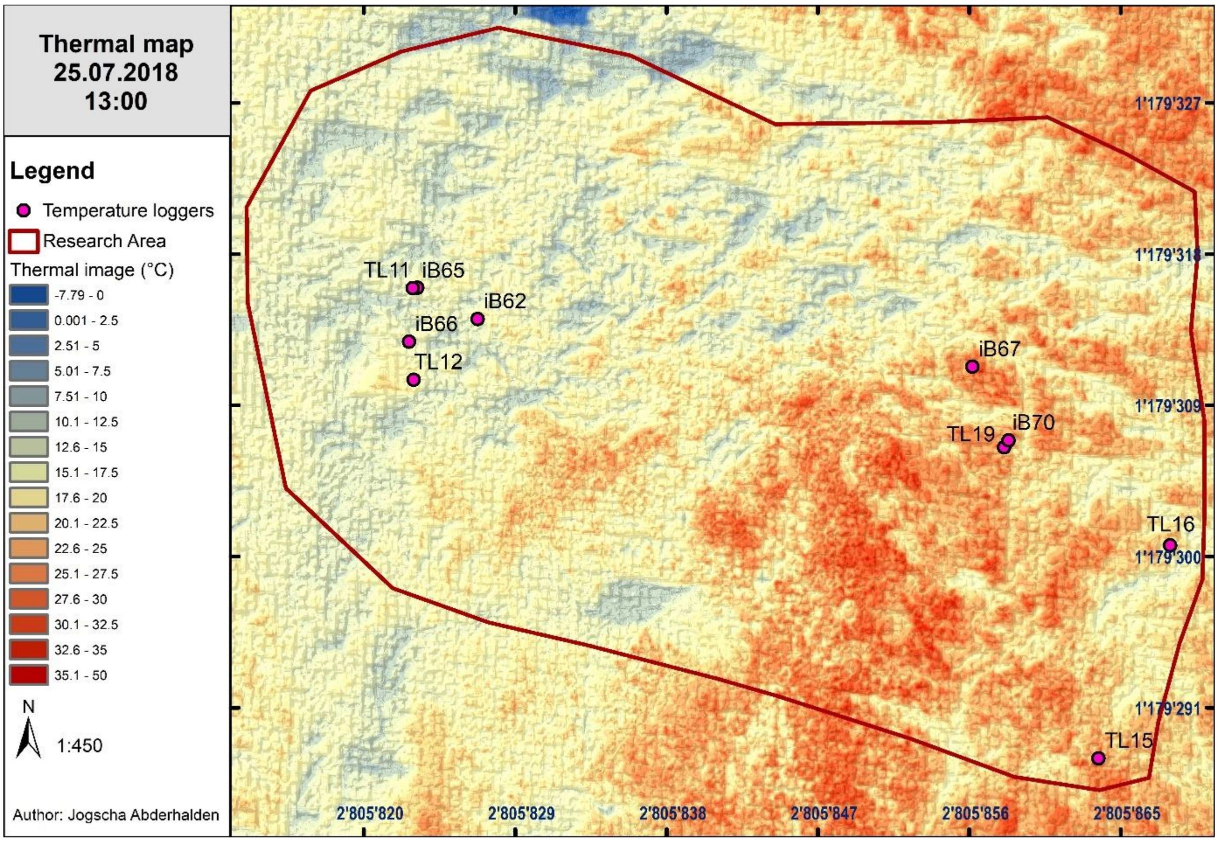


Figure 24 Thermal map of the 25.07.2018, flight start at 13:00

Flight 5, start 15:00

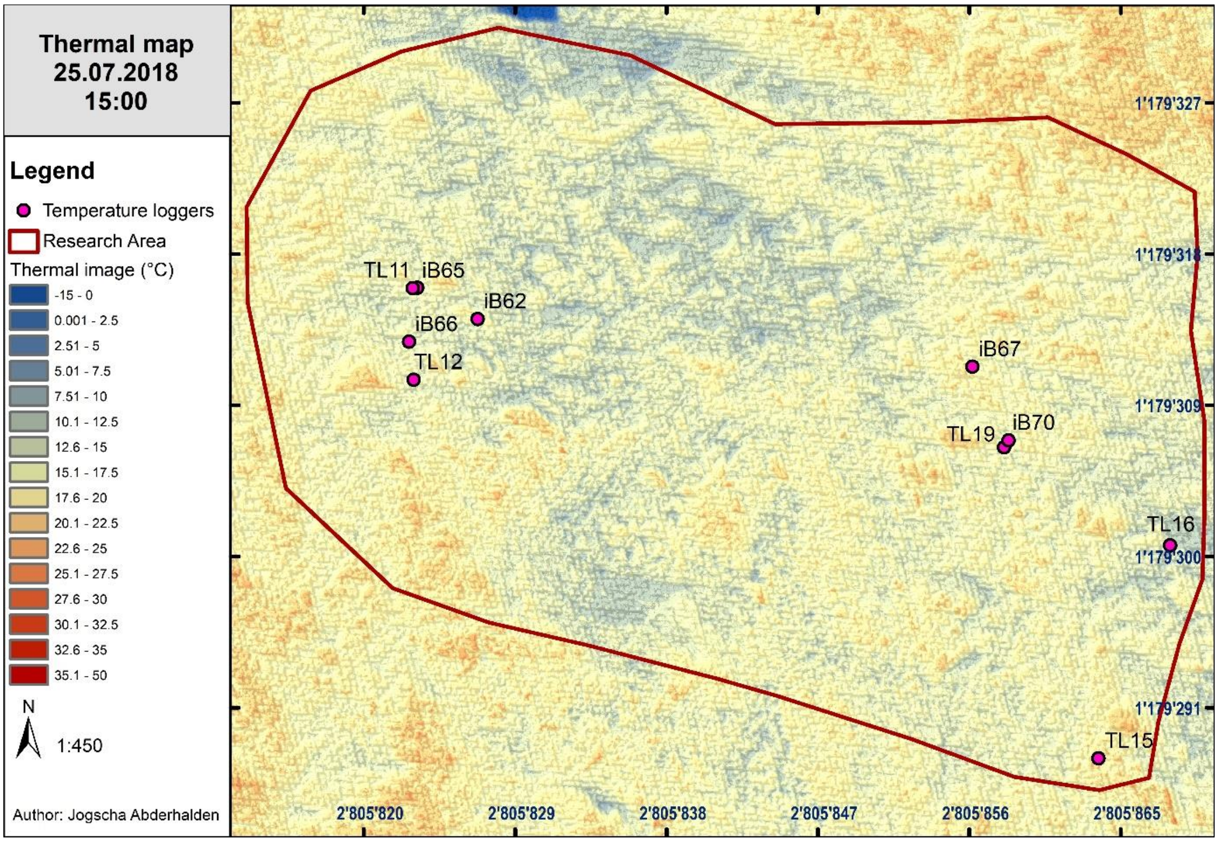


Figure 25 Thermal map of the 25.07.2018, flight start at 15:00

On the maps showing the surface temperature at 11:00, 13:00 and 15:00 on 25.07.2018 (Figures 23-25), it is apparent that the temperature rise faster in the east than in the west, whereas the eastern part of the area seems to have been cooling down again (at 15:00) while the western part reached the highest temperatures throughout the day measured with the remote sensing technology. The central part with the highest elevation seems to have remained quite cold throughout the day and shows less temperature variation than the eastern part of the research area, which registered the highest variation.

03.08:2018

Flight 1, start 8:30

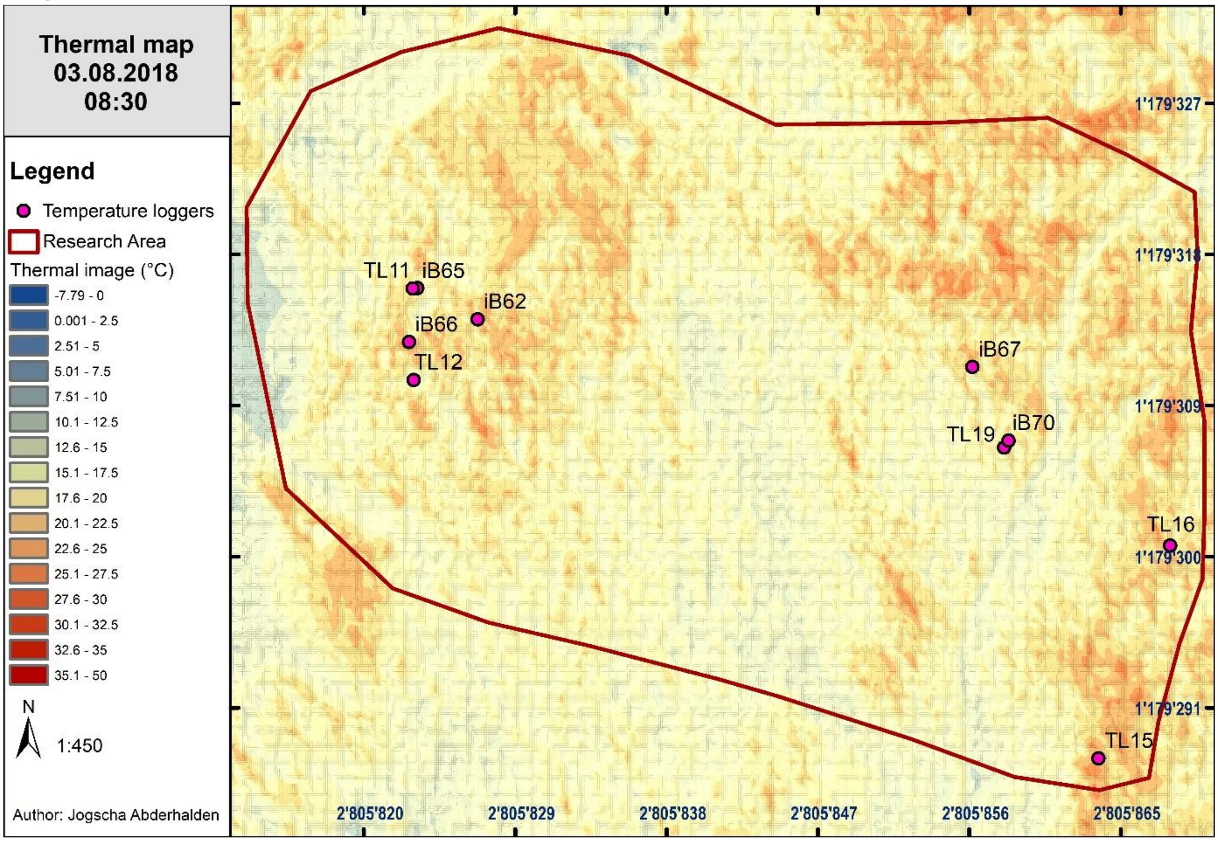


Figure 26 Thermal map of the 03.08.2018, flight start at 08:30

Flight 5, start 14:40

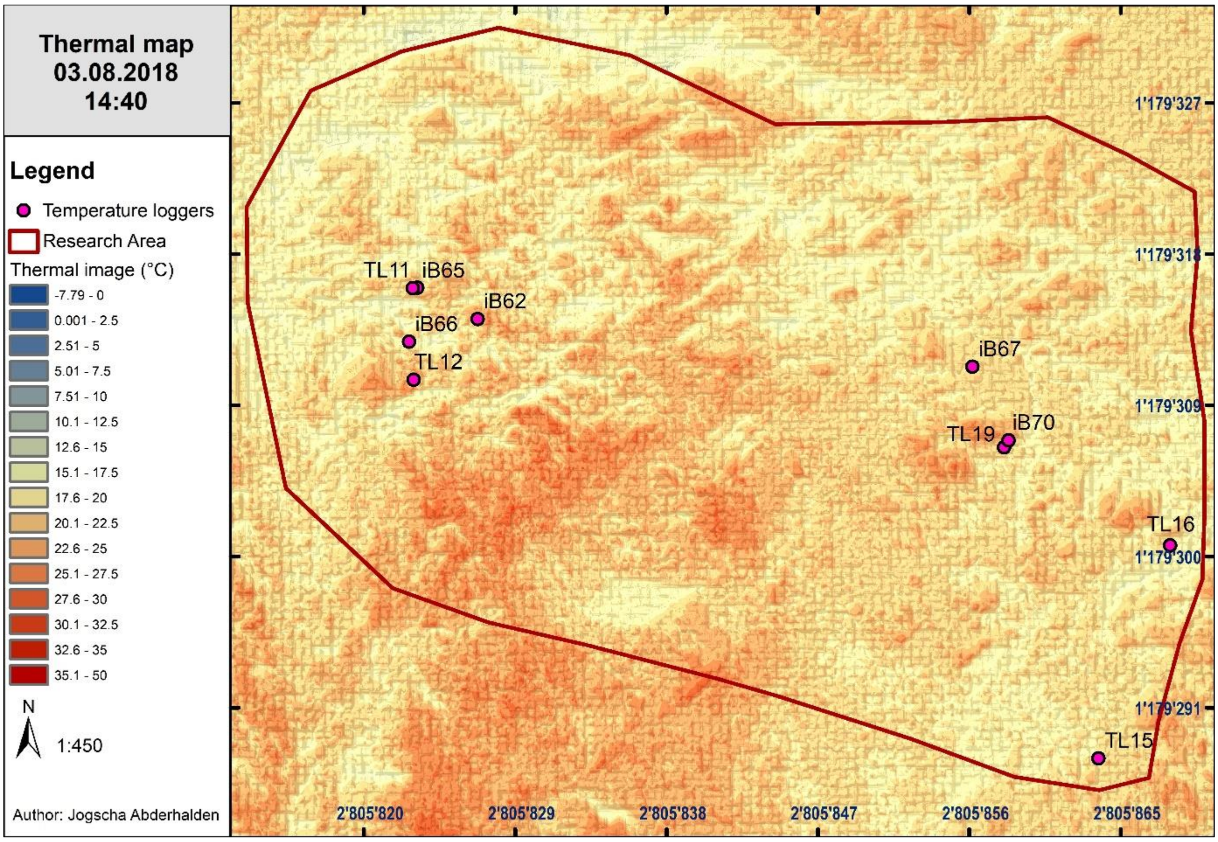


Figure 27 Thermal map of the 03.08.2018, flight start at 14:40

Flight 6, 15:30

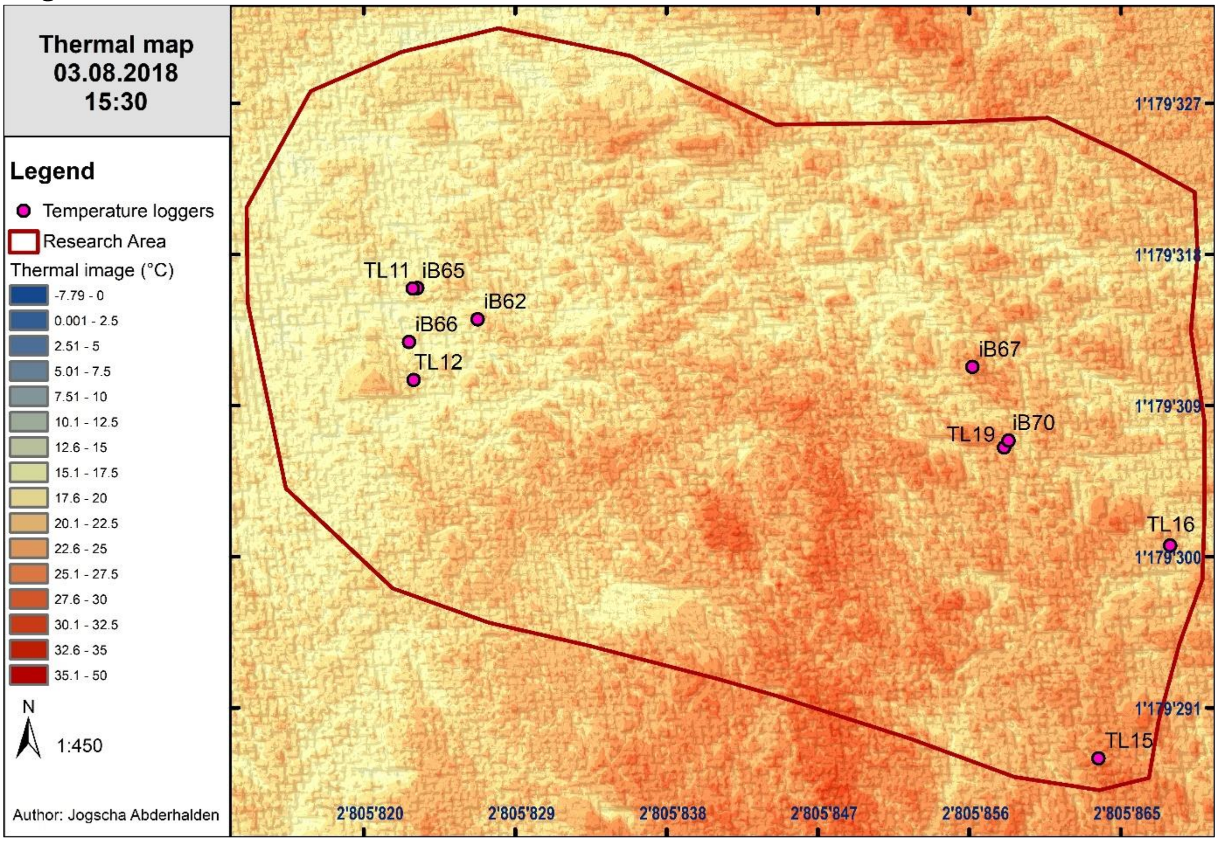


Figure 28 thermal map of the 03.08.2018, flight start at 15:30

When looking at the thermal maps of 03.08.2018 (Figures 26-28), it is noticeable that the temperatures registered on this date are much higher than on the other days, on which drone flights were run. Here it looks like the south-western part warmed up earlier than the south-eastern part of the research area. Seen over the whole area the temperature seems more homogenic than on the other days and it varied less throughout the day.

04.10.2018

Flight 1, start 10:10

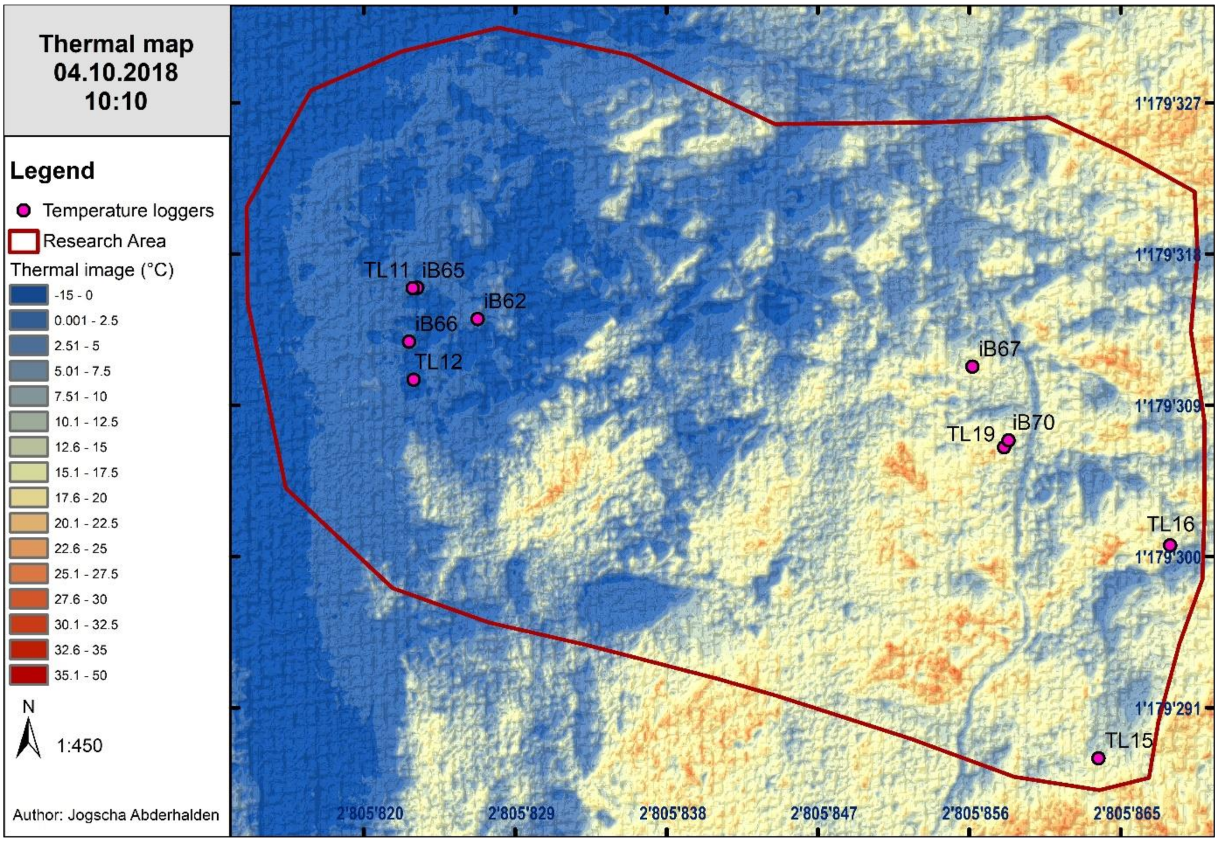


Figure 29 Thermal map of the 04.10.2018, flight start at 10:10

Flight 4, 13:10

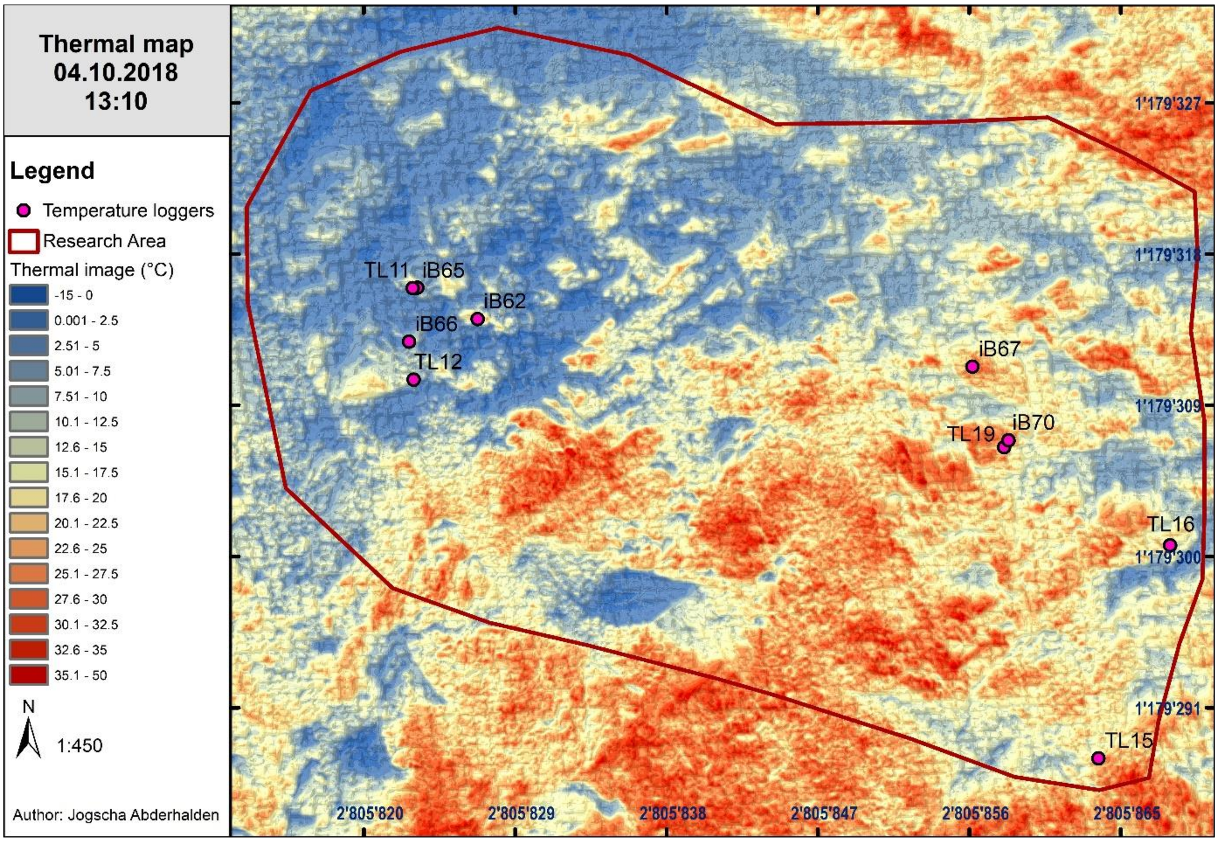


Figure 30 Thermal map of the 04.10.2018, flight start at 13:10

Flight 6, 15:10

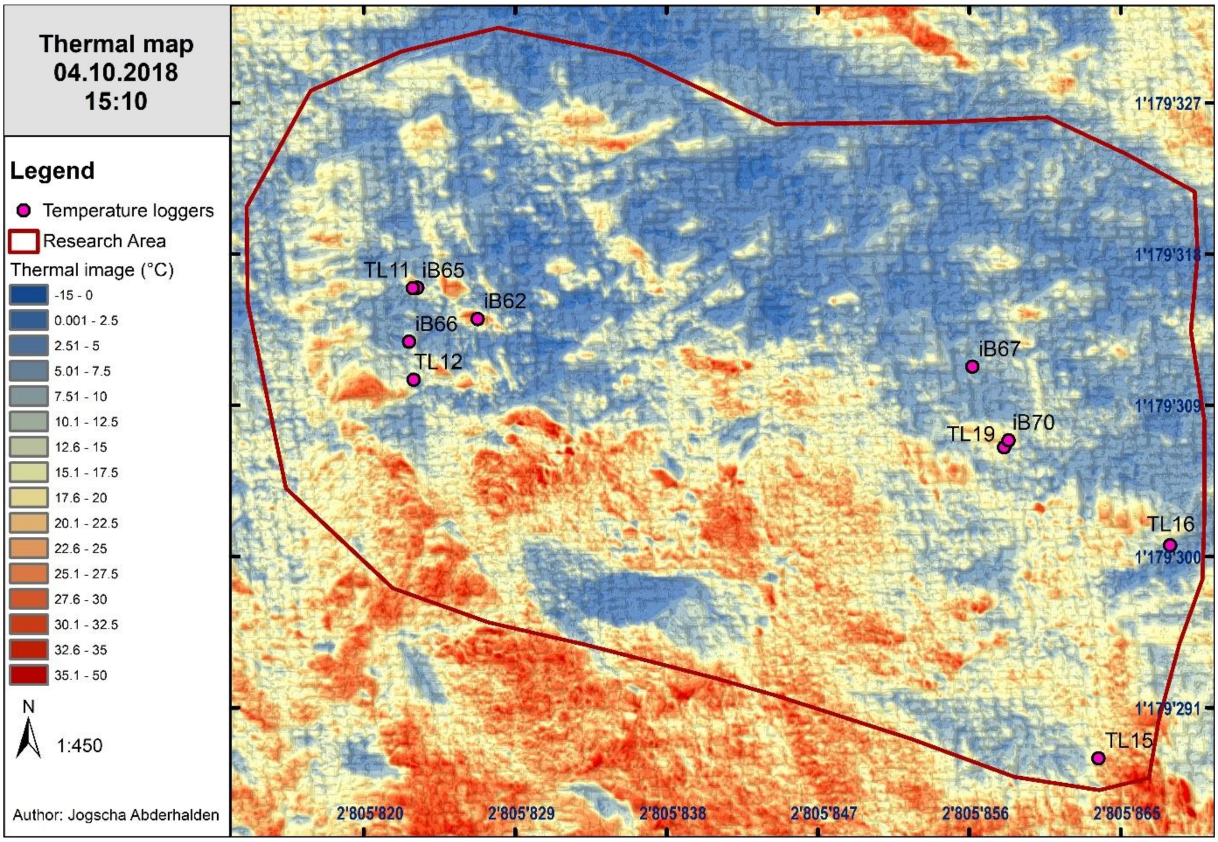


Figure 31 Thermal map of the 04.10.2018, flight start at 15:10

04.10.2018 shows quite a heterogeneous temperature development pattern over the whole research area (Figures 29-31). In the morning (10:10), in western part of the area temperatures around the freezing point were registered, while the eastern, south-eastern part seems to have been warming up at the same time. It is apparent that throughout the day, the southern part and later the south-western part of the area got warmer. The north-eastern part got quite warm when the sun was at its sun highest (13:00), while the north-western part got warmest at a later moment of time (15:10). The northern part and the top of the mountain where most of the temperature loggers were located, show the lowest temperature variations throughout the day. This occurred on all analysed days, except 03.08, where the mountains top seems to have been one of the warmest areas in the morning.

5.3 Comparison of Thermal Infrared vs. Temperature Logger Data

The main difference between the thermal infrared and temperature logger data is that the thermal infrared technology provides information on a large area but only for a specific moment of time while the temperature logger data provides continuous data in terms of time but only for a specific position.

The minimum and maximum temperature seen over all analysed dates, registered by remote sensing with the thermal infrared camera and the temperature loggers respectively are: minimum -10.15°C (04.10 at 10:10) and maximum 49.76°C (05.06 at 10:40) for the thermal infrared technology, and minimum -4°C (04.10 by TL15 at 01:00) and maximum 32.5°C (05.06. by TL19 at 16:00) for the temperature loggers. Seen overall, this means that the thermal infrared technology measured the highest temperature variation both at a single moment and in total.

On a single thermal infrared map, temperatures seem to differ dependent on ground type, aspect slope and solar radiation. Rocks, snow patches and the footpath are visible on the temperature layer using the remote infrared camera (for example Figure 29). On the thermal infrared maps, it is clearly visible that the aspect has an influence on the surface temperature development throughout a day. In the morning, the temperatures are higher in the east and south, while all pictures taken later on show that the western and northern side get warmer in the afternoon. Also, surface structures are fairly visible on most of the thermal maps, which indicates that ground cover type has an influence on surface temperature development. The temperature loggers situated in different parts of the area show similar patterns to the thermal infrared results concerning aspect. Though situated at a similar aspect, not all loggers vary evenly in their temperature regimes possibly indicating an influence of ground cover type or slope.

6 Discussion

In this chapter, the results found and presented in chapter five are going to be discussed and the research questions will be addressed. First, the different technologies, their eventual correlation and the advantages and disadvantages of using the different technologies are going to be discussed. Afterwards, the effect of aspect, slope and habitat type on the maximum temperature reached throughout a day is going to be discussed.

Do the results of surface temperature development throughout a day measured with different technologies correlate? How do the results differ from each other? What are the advantages and disadvantages of using the different technologies?

When looking at the graphs of the results of the different temperature logger technologies, the temperature development and variation differs quite a lot. The iButtons always show only one rising period, one peak and one falling period, while the TL logger poles often show two temperature peaks and generally have a higher variation in temperature. A study by Graham et al. (2012, p. 290) on fine scale patters if soil and surface temperatures in alpine California found similar results. When analysing diurnal variation in surface temperature, the authors found that air temperature near the ground showed two temperature peaks and higher diurnal variation than when measured 10cm into the ground.

The only thing the two logger technologies apparently have in common is that the loggers positioned on the eastern side of the research area tendentially registered a faster temperature rise at an earlier moment of time, as it occurs for iB67/70 and Tl15/16/19 (Figure 7-9 and 14-16). Additionally, the loggers positioned on that side of the area often register the highest maximum temperature. An explanation for that pattern could be that as the sun rises in the east, south and south-eastern facing slopes get more solar radiation earlier and are therefore warming up faster/earlier as well as probably having more hours of direct sun radiation than the loggers positioned on west/north facing slopes (Måren et al., 2015). A similar pattern is visible on the thermal maps when looking over the day. The warmest part of the area seems to move from the eastern, over the south, to the western part of the research area throughout the day. Except on 03.08.2018, where the warmest part of the area seems to move from the west to the east during the day, which could be a result of the cloud cover (Sun et al., 2000). Regrettably, there is no data available to analyse this, so it must remain a hypothesis.

Another point of correlation between both types of loggers and the thermal infrared results is that 03.08.2018, seems to have been the warmest of the analysed days, regarding mean temperature throughout the day. According to the thermal infrared results, it is also clearly the day with the least temperature variation, a trait that is not as apparent in the temperature logger results. Why the iButtons do not show this difference in temperature variation (between minimum and maximum temperature) comparing the different dates could be explained by the fact that the loggers are buried about 5cm into the ground and therefore the direct solar radiation has less effect on their measurement as they measure the temperature in the surface layer of the ground and not air temperature. Also, the TL poles are likely to be less sensitive to direct solar radiation than the remote sensing technology, as they are positioned within wooden pillars and measure the near surface area, only indirectly affected by solar radiation (Graham et al., 2012).

05.06.2018 clearly shows the highest temperature variation at one moment of time when looking at the thermal infrared results. On one hand, the reason for that might be that a part of the area was still snow covered. On the other hand, the maximum temperature registered on that day is the highest temperature registered over all thermal images with 49.76°C, which is extremely high, even 6°C higher than the maximum temperature registered on the 03.08 (43.14°). This might be a source of error, but it looks like the eastern side of the area became quite warm especially early on the day (10:40). These results partly coincide with the temperature logger results, as especially the loggers on the eastern side of the research area show a high maximum temperature (Figure 13, 19-21), TL19 even the highest of all days. However, the maximum temperatures measured by the loggers on the 05.06 were registered at a much later moment of time (between 14:00-17:00) than the thermal images showing such a high temperature on the south-east facing slope (Figure 22). There is no thermal infrared data available for later that day to analyse if the temperature might have risen even higher, but over 50°C on the surface of a high-altitude summit is unlikely (Gobiet et al., 2014, p. 1145).One possible explanation for the high maximum temperatures on the 05.06 is that it could have been a day with clear sky, while the other day might have had a higher percentage of cloud cover and eventually more wind during different moments of time throughout the day (Schneider, 1972).

A fact that makes it hard to effectively compare the results of the temperature loggers with the thermal imaging technology is that they register data with different qualities. While the temperature loggers can show constant development of the temperature over a long period of time on a specific position, the thermal imaging technology can show temperature values covering a whole area for a specific moment of time. The temperature loggers have short measurement intervals (depending on how the loggers are programmed). In this case the interval was set to 1hour/30min for some loggers, and it can be analysed how the temperature develops throughout a day receiving a value for each hour. The moments of time for the drone flights on the other hand, have to be chosen explicitly, and the weather conditions have to be adequate to conduct a flight. This means that the temperature logger technology is quite a safe way to collect data and receive information, however, only gives an idea on how the temperature develops on a specific position. To receive information about how an area of interest evolves, and to be able to see differences regarding the position, aspect and slope in a big picture, thermal imaging gives the better results. Thermal imaging could also be used to find specific positions, with interesting surface temperature development patterns, to put loggers to analyse that specific position more precisely. In other words, thermal imaging is a technology that can help to increase the research quality and value provided by the temperature logger technology.

From the results obtained in this thesis, it is difficult to claim that one technology is more precise or reliable than the other. The temperature logger technology might be more reliable in terms of weather condition dependency as research can be implemented in all weather conditions. However, water can enter the devices and cause defective measurements and the results of some specific positions cannot be applied to hypothesis on a whole area of research. To make the temperature logger results reliable and valid for a whole research area, many loggers should be distributed, covering as much as possible of the area. To obtain a purposeful distribution of the loggers, orthophoto, aspect, slope and thermal maps could be used as tools to cover the area appropriately. For example, loggers should be positioned both in the coldest and warmest areas and in the areas with the least temperature variation, to be able to detect what might have an impact on the different temperature development patterns. Additionally, the distribution of the dates, the quantity of and time intervals for the drone flights should be planned more systematically (same moments of time and same interval for all dates) to increase the comparability of the thermal infrared data.

The following list shows the advantages and disadvantages experienced using the different technologies:

Temperature loggers

+ It is possible to log regular measurements over a long period of time

+ The technology is not weather dependent

+ The data is easy to handle

+ There are fast ways to present results

+ The use of the technology is little time consuming (the loggers can be distributed and do their work there automatically)

– Does not give information on temperature development on an area if the loggers are poorly distributed

– Hard to present results covering a whole area

– Defective measurements and water entrance can occur without being noticed for a long time (because the loggers are in/over the ground on a remote place)

– The use of only one type of temperature loggers would be of advantage as to obtain results that are comparable with each other

Thermal infrared images

+ The results cover a whole area

+ The use of this technology is interesting and attractive for researchers

+ Good visuality of the results (there might be tools and programs that allow an even better visualization of the results than the ones used in this project)

+ It is easy to see differences in temperature development regarding aspect and slope

– The technology is dependant of convenient weather conditions (research on rainy days is not possible with the type of drone used for this project)

– Both fieldwork, data processing and analysis is time consuming

– It is complicated and difficult to process raw-data (good knowledge in the specific field is required)

– The battery capacity of the drone is limited (a limited number of flights can be realised in one day, as batteries cannot be charged on the summit)

– Depending on the weather conditions, the battery capacity is too little to conduct a whole flight at once (120images with 80% overlapping 40m over the ground)

What does the maximum temperature on a high-altitude summit look like, considering different aspect and slope?

Considering aspect, the maximum temperature tends to be higher in slopes facing northeast to southeast than in slopes facing west to north. Several studies support this hypothesis and generally, south-facing slopes receive more sunlight and get therefore warmer and drier, while north facing slopes are cold and humid and retain moisture (Måren et al., 2015). Also the findings of a study on the influence of aspect on vegetation by Sönmez et al. (2014), say that south-facing slopes have a higher mean temperature than north-facing slopes. From these findings, it can also be assumed that the maximum temperature might be higher. In this study, east exposed slopes are warmer than west exposed slopes. Despite the aspect, this pattern could possibly be explained by the formation of convective clouds during the afternoon (Gubler et al., 2011).

There is no hypothesis that can be set based on the results in this thesis that clearly states the effect of slope on maximum temperature. However, it seems that quite flat areas on south, south-east facing slopes and steep areas as well as terrain right under a steep slope on north, north-west facing slopes tend to be colder and reach a lower maximum temperature than the area around them. These findings are in accordance to a study on steep rock implemented on Stockhorn Plateau in Switzerland (Gruber et al., 2004).

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7 Critical Evaluation and Further Research

For a next project, it could be useful to register weather data on the days, drone images are taken as it is easy and little time-consuming to register cloud density, solar radiation and eventually to estimate the wind force before each drone flight. This would add essential information to the project analysis, and weather information would be more precise, although estimated than to have to collect weather data from places nearby in hindsight, which eventually had quite similar weather conditions as the research area. In addition, the time consumption of collecting weather data retrospectively is much higher than if it would have been registered contemporaneous with the drone uptakes. The analysis of the diurnal temperature variation of the temperature loggers conducted in Microsoft Excel is not very precise and opens for error sources. All loggers measured the temperature in either 30min or 1hour intervals. However, not all loggers started their measurement periods on whole or half hour neat, which means that some measured at for example xx:06 and xx:36, while others measured at xx:15 and xx:45. These actual moments of time had to be relativized to be at xx:00 and xx:30 in order to be able to compare the results, which entails that the results shown in the diagrams are not totally accurate. Also, the accuracy of the thermal maps probably variates as weather conditions have an influence on how precisely the drone hits the waypoints on the flight plan and the georeferencing of the map is partly done manually which causes a variable accuracy, especially on the outer parts of the area. To make the research in the field of surface temperature development and variation more relevant and useful it would be helpful to have more concise insight in what the results and data is planned to be used for in further research projects and what the researchers in those superior projects expect from the subordinated research field.

For further research on the topic, the use of statistical programmes for regression analysis on different temperature development patterns would be interesting in a first step. Further, the findings in this thesis can be used to analyse spatial surface temperature variations both on diurnal and periodical basis in research on the influence of climate change on surface temperature development and the future of biodiversity. As stated earlier, this BSc-thesis is conducted with data provided by the Swiss National Park, pursuing a study on temperature conditions and the spatial distribution of the temperature regime on 8 mountain peaks in the Park in collaboration with WSL and SLF. The study has a background in the GLORIA project analysing the development of biodiversity in alpine areas, for which surface temperature might be an interesting parameter to take into account in the research.

8 Conclusions

The comparison of different technologies measuring surface or near-surface temperature and the analysis of the diurnal temperature variations registered by different technologies, gives an insight into the advantage and shortcomings of different measurement methods. In the process we have learned, how the raw data can be processed and visualized in a convenient way and how these different methods can be used in a purposeful way in future projects to obtain optimal and desired results. Using a combination of different technologies can be appropriate but it should be set up and used in a more systematic way to obtain significant information on the spatial surface temperature variation patterns. Orthophotos, aspect, slope, thermal maps and information on ground cover and vegetation could be used as tools to distribute temperature loggers covering the whole area of interest in a reasonable way and to be able to detect differences depending on the parameters mentioned above. The results acquired from the analysis of the data from different technologies correlate in some points but differ significantly in others. In this thesis we were unable to find an explanation to all of these different development patterns. In order to obtain more precise, and reliable information with a good spatial coverage from the different methods, the efforts described in chapter 7 (critical evaluation and further research) should be considered, as they might help to understand the temperature variations and development patterns arising from the different technologies discussed in this thesis.

9 Acknowledgements

I would first like to thank the people from the Swiss National Park, my thesis advisor Rudolph Haller for introducing me to the topic and helping me to get started with my thesis, and my supervisor Samuel Wiesmann for always supporting me whenever I ran into a trouble spot or had a question about my writing and data analysis. Also, a special thanks to Rachel Lüthi, Maja Rapp and Roger Honegger for taking time to help me with some issues in my thesis.

Further on I would like to thank Irina Rogozhina of the department of Geography at NTNU for giving me feedback and valuable advice on my work and helping me with the formal issues.

Last but not least I want to express my gratitude to Philippa Palmer for revising my thesis on language and to my family for supporting me whenever I had some trouble with my writing.

10 Glossary

Surface temperature: Surface temperature is the temperature at or near the surface. It is measured at the surface or up to 5cm over or under the surface.

Ground surface temperature: Ground surface temperature (GST) is defined as the surface or near surface temperature of the ground and is measured in the uppermost centimetres of the ground (around 5 cm into the ground) (Schoeneich, 2011).

Air surface temperature: Air surface temperature is the temperature at or near the surface measured few centimetres over the ground.

Ground cover type: Ground cover is the layer of vegetation below the herbaceous layer. Here, also gneiss and rocks are referred to as ground cover type.

Aspect: Aspect defines the exposure of a slope. It is measured in ° starting at 0° north over 180° south to 360° north again.

Slope: Slope is measured in degrees or percentage of steepness. It defines the gradient of a slope. In this thesis slope is indicated as percentage of incline.

GLORIA: Is the abbreviation for the international project **Gl**obal **O**bservation **R**esearch **I**nitiative in **A**lpine Environments.

Topography: Topography derives from Greek “topo” meaning place and “graphia” meaning to write or to record. The term is used to describe the detailed study of the earth surface (Higgins, 2017).

Topology: Topology derives from Greek “topo” meaning place and “logos” meaning study. It refers to the relative position of spatial features. A topology in a GIS is a set of rules and behaviours that model how points, lines and polygons share coincident geometry (Esri, 2010)

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Figures

Figure 2-3: Pictures taken by *Swiss National Park* (Samuel Wiesmann)

All Maps and Diagrams: Maps and Diagrams are produced with data received from *Swiss National Park*