How does temperature of a night during a heatwave differ with nearby land use?

Using night of 26th to 27th of June as reference during the 2019 Swiss Summer Heat Wave

Research Paper

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Submitted by

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2021

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Abstract [B: TODO]

Our research concludes that there is a clearly visible difference in temperature development between urban and green areas. The tight measurement networks show clearly that the temperatures in the city center are higher. The combination of Low-Cost Loggers and Bicycle Measurements allowed to visualize the urban heat island during the night of June 26th-27th in Berne very well. It can be clearly visualized, that differing land use impacts temperature differently. Most notably, they can allow urban areas to cool below 20°C, that would otherwise experience a tropical night. These nights should be avoided at all costs, as they aversely impact health of the populace. We urge decision-makers to invest into the preservation and growth of vegetation and waterbodies, as they can lessen the urban heat island affect.

Keywords: Heatmap, Climate change, tropical night, vegetation, waterbody, urban climate, urban heat island.

Contents

1. Introduction

The number of weather extremes have increased year by year, with heatwaves, snowstorms, or flooding increasing in frequency [EEA 2017]. Heatwave related deaths in Switzerland are on the rise [Grize et al. 2005; BAFU 2016; BAFU 2019], especially cities are affected, e.g. due to the emergence of urban heat islands [Zhao et al. 2014]. An urban heat island is an urban area that is warmer than its surrounding rural areas due to human activities [US Environmental Protection Agency 2008]. Of note is that the time span inquired in this paper correspond to a heatwave in Bern, in one of the hottest summers to date [Meteoschweiz 2019].

As climate and temperature vary regionally, there is no unified definition of a heatwave (Meehl & Tebaldi 2014). The World Meteorological Organization mentions that, if thresholds do exist, they may either consist of a combined index of multiple variables or may be derived from only one meteorological parameter (WMO 2018). Nonetheless, Meteoschweiz writes in their Klimabulletin that "The constant heat, higher than 30°C during the 25th of June to the 1st of July 2019, led to one the hottest regional heat-periods since measurement started about 100 years ago." (Meteoschweiz 2019:2) Thus, we consider this period as a heat wave in our project.

A big impact on climate are human encroachments on natural land covers. Urban growth leads to the replacement of natural land covers, impacting the biophysical environment and land surface energy processes [Lo & Quattrochi 2003]. There have been successful attempts in showing that land use and surface temperature are related [Rinner & Hussain 2011; Weng & Lian 2006). This can result not only in changes to temperature extremes and gradients, but also in urban heat islands.

Decision-makers need to know where such heat-islands are located, what factors lead to their development, how intense they are, and what can be done to mitigate them. Thus, the need for recent and high-resolution data is ever-increasing, as well as the need to convey this data in an accurate, accessible, and easy to follow manner. One such decision-maker is Stadtgrün Bern. They are responsible for parks, recreational areas, playgrounds, biotopes, family gardens, flora in and around the city, as well as the preservation and promotion of natural diversity [Informationsdienst Stadt Bern 2021]. Stadtgrün Bern is key, as they act as a baseline decision-maker in our project. All work that we do should not only benefit them, but also be accessible to their organization and ready-for-use in their ongoing projects.

All maps and graphs created in this project went through a review- and feedback-process with Samira Neuse (Stadtgrün Bern), to ensure that needs are met, and visualizations are clear. One hand this is a boon, by providing us insight into what factors and aesthetics are important. On the other hand, it is a limitation on the breadth of our work, as time spent on addressing feedback, is time lacking for further in-depth analysis, especially on larger time periods.

Our aim is to visualize the temperatures for the 26th and 27th of June 2019, based on measurements from Netatmo Citizen Weather Stations (CWS), Bicycle Transects (BCY) through Bern, and a network of Low-Cost Devices (LOD). These data sources will be explained in the next chapter.

The research question focused on is:

1. How does temperature of a night during a heatwave differ with nearby land use? This question will be addressed through the measurements from the night of the 26th of June to the 27th of June 2019, during a heatwave.

2. Resources & Methods

2.1. Resources

To assess the heat distribution in Bern during the heatwave in summer 2019, three different data sources of temperature measurements have been used.

2.1.1 Netatmo Citizen Weather Stations (CWS)

The first data source consists of citizen weather stations (CWS) from Netatmo, a business selling consumer electronics. Citizens who buy an outdoor weather station can approve to upload their data onto a public server from Netatmo, creating a map with the temperature and other meteorologic parameters. About 500 citizen weather stations are located in Bern and its surroundings (see figure 1). As these weather stations are maintained by citizens, they may not be placed compliant with academic standards (2 meters above ground, 1 meter from buildings, in shade). The data has a time resolution of 1 h and covers the period from the 1st of June 2019 to the 30th of September 2019. The temperature was measured in an hourly interval.

2.1.2 Low-Cost Devices (LOD)

The second data source consists of a net with 79 low-cost temperature loggers in Bern and its surroundings. The net is provided by Moritz Gubler from the Institute of Geography at the University of Bern (GIUB). The locations for the loggers were chosen to represent different building types, land cover types, topographical features and points of public interest. 73 of the loggers are placed within Bern, and six are located in its surroundings (Gubler et al. 2021). The temperature was measured every ten minutes.

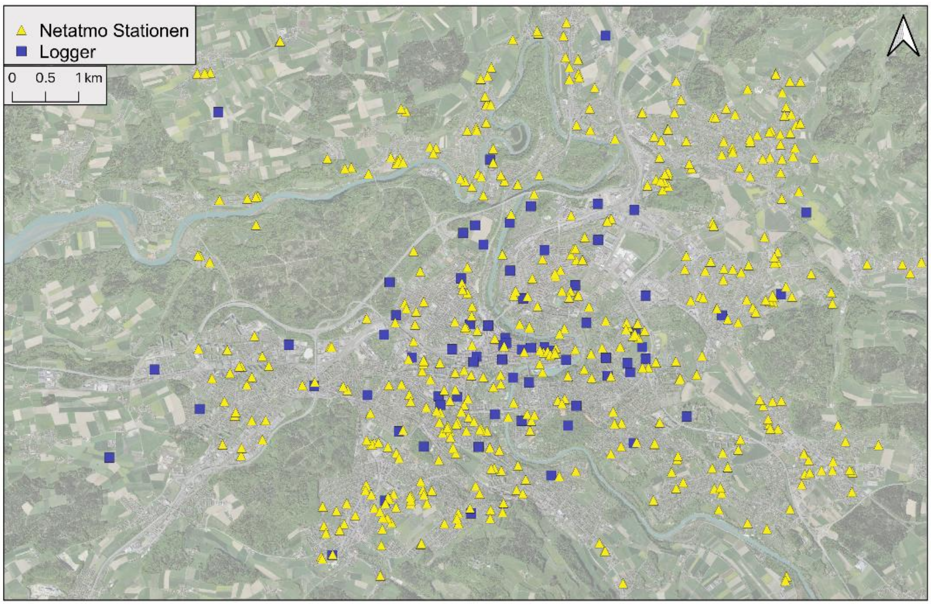


Figure 1: Overview of Netatmo Citizen Weather Stations (yellow) and Low-Cost Devices (blue) used in this paper.

2.1.3 Bicycle Temperature Measurements (BCY)

During a micrometeorological field work course in 2019, initiated through the GIUB, a mobile temperature measuring station was used to assess the night temperature in the city of Bern. The temperature measuring station was attached to a bicycle 0.8 m above ground, allowing a continuous measurement of the temperature along the bicycle's route, also because the temperature was measured every 15 seconds.

Table 1: Assessed data sources with their respective time resolution and covered periods.

Data Type	Time Resolution [min]	Covered Period
Citizen Weather Stations	60	01.06.2019 - 01.09.2019
Low Cost Loggers	10	15.05.2019 - 01.09.2019
Bicycle Measurements	0.25	26.06.2019 – 27.06.2019

2.2. Methodology

The data was provided in csv files for all sources. These files were analyzed with R, with some data clean-up in Python. For geospatial visualizations QGIS was used.

2.2.1. Preprocessing

Prior to the analysis the data relevant to the research question had to be selected. Because the bicycle measurements are only available for the night from the 26th to the 27th of June, this night was selected to study the effects of different land-use types on night temperature.
In order to answer the research questions, two maps were created with the available data.

2.2.2. Maps of the hourly temperature distribution in Bern

To visualize the development of temperatures development overnight, temperature maps for every over of the night (between 10 pm and 5 am) were created. The maps combine two different data sources: the Low-Cost Loggers and the Citizen Weather Stations. Because the two data sources have different resolutions, the data had to be processed prior to the usage for the maps. Because the loggers measure the temperature every 10 minutes, the mean of all measurements in one hour (e.g. 10:00 pm to 10:59 pm) was taken as the hourly temperature value. As the Netatmo station always measure the temperature 15 minutes before or after the full hour, the hourly temperature value only consists of one measured value. The maps were combined into a gif, to show the temperature development in an appealing and easy-to-understand way for the user.

2.2.3. Map of the Bicycle Transect between 10 pm and midnight

To visualize the temperature development in and around the city, a map was created with the bicycle data between 10pm and midnight (see figure XX). This time period was chosen because the bicycle route leads through several quarters of Bern as well as through forested areas and the more rural area of Zollikofen. The Bicycle Measurements have a higher temperature bias due to not being well-ventilated and may be impacted further by vehicle exhausts and emitted heat by asphalt. Therefore, the bicycle data was interpolated with the cooling rate of the nearest Low-Cost Devices to achieve a more accurate map of the temperature development during the bicycle ride.

2.2.4. Compare temperature development in locations with different land-use

To compare the temperature development in locations with different land-use, the temperature progression of two up to three locations in a radius of 1 km were compared with each other. Only locations of loggers were taken into account, because those are the most accurate during the night, according to Lukas Meyer, the supervisor of this project. The time period covered is between 8 PM and 8 PM of the following day, to assess if potential differences only occur at night or also during the day. The following locations were chosen:

- Plot 1: Europaplatz and Schlossmatte Familygarden.
- Plot 2: Galgenfeld with new buildings, Galgenfeld Industry and Rosengarten.
- Plot 3: Egelsee Settement, Egelsee and Helvetiaplatz.
- Plot 4: Insel Hospital, Bremgarten Forest and Bremgarten Cemetery.
- Plot 5: Thunplatz and Dählhölzli Forest.
- Plot 6: Viktoriarain and Casern area.
- Plot 7: Westside and Bümpliz Surroundings.

For each plot an overview map is provided to locate the different positions of the low cost loggers used for the plot. To provide the user information about possible explanations for the temperature difference, short descriptions were written to accompany the plots and the map.

3. Results

3.1. Maps of the hourly temperature distribution in Bern

The created overview map of the Low-Cost Devices and CWS network shows that there is a good measurement Network within and around the city of Bern. However, it is clearly visible that for some stations the temperature is much higher than expected. This is especially true for many Citizen Weather Stations. Analyzing these outliers becomes even more difficult due to lack of meta data for the CWS. There is no clearly defined way on how the stations are placed, therefore there is a certain margin of error caused by using the CWS data, as there can be a lot of outliers which are hard to spot due to the lack of meta data.

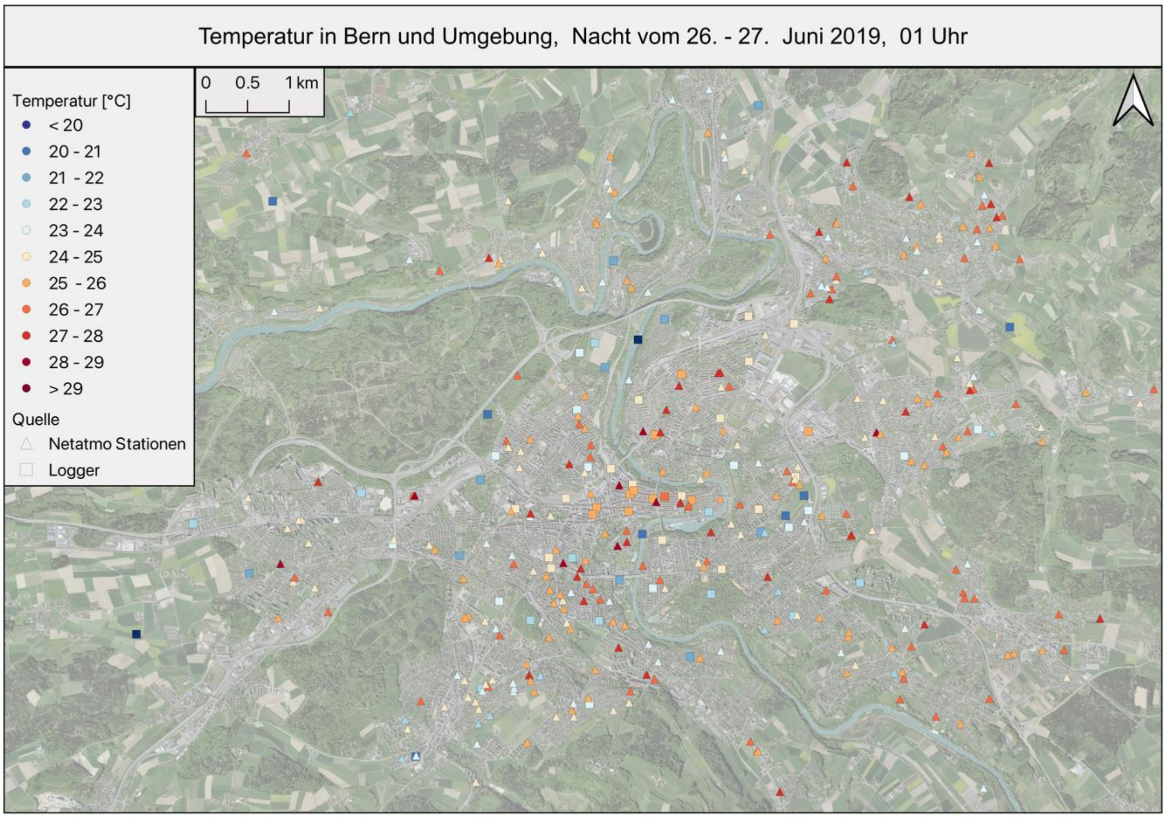


Figure 2: Temperature distribution in Berne and surroundings at 1 am on the 27th of June 2019.

3.2. Map of the Bicycle Transect between 10 pm and midnight

The mapped bicycle transect data shows clear differences in the temperature between different areas. As the transect took around 2 hours to complete, temperatures have decreased during this time. Therefore, the temperatures towards the end are lower than at the beginning. The lowest temperatures have been recorded in the Bremgarten Forest and around Zollikofen outside of the city. The highest temperatures have been recorded in the city center, especially in the Old Town. The bicycle measurements show high gradients of the temperature while entering the Bremgarten forest or the old town area. While the temperature decreases rapidly while entering the Bremgarten forest, there is a significant rise in temperature while entering the old town area.

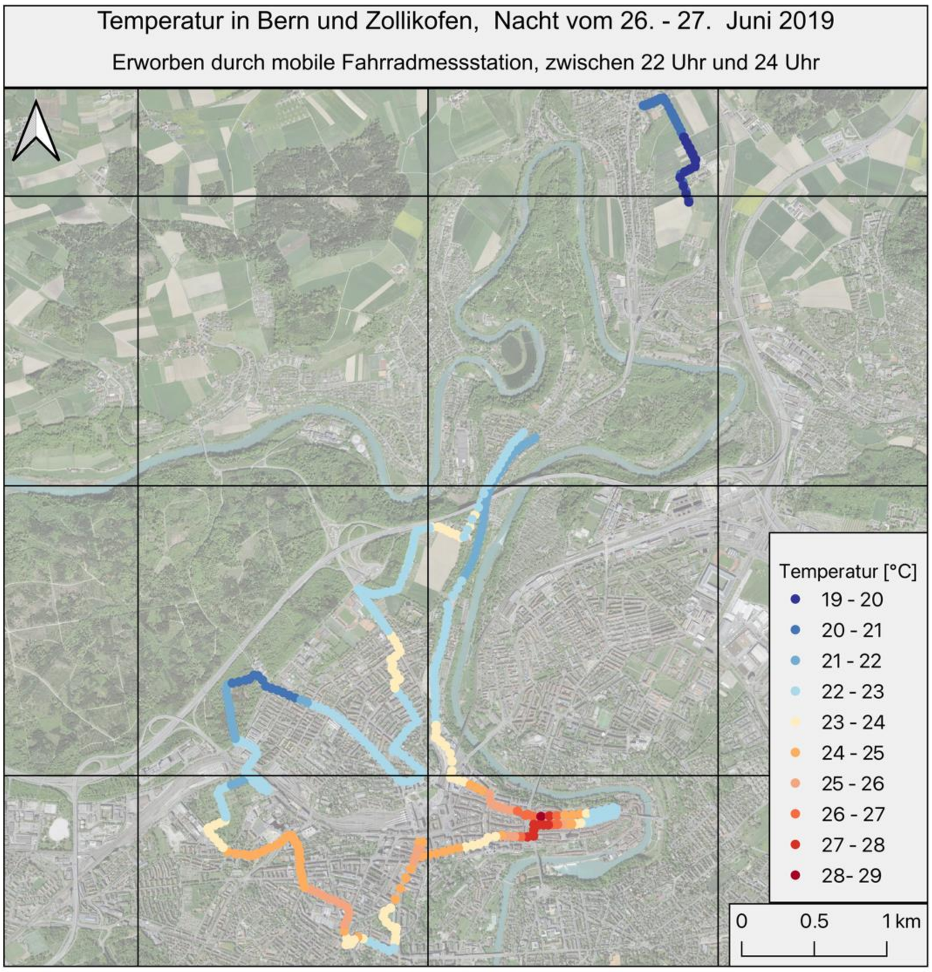
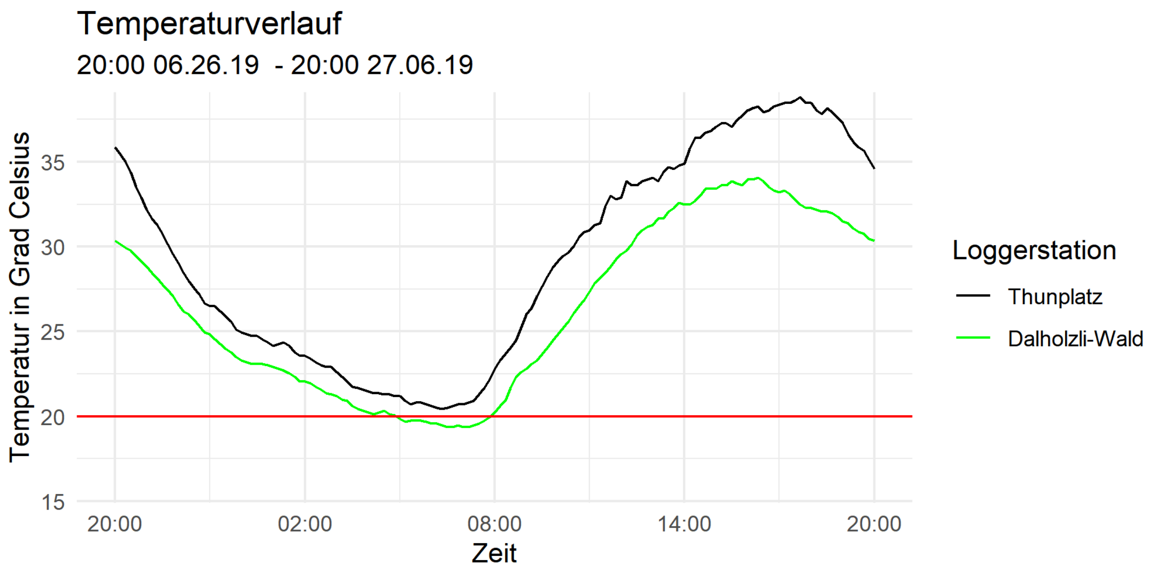


Figure 3: Temperature of Bicycle Measurements between 10 pm and midnight on the 26th of June 2019.

3.3. Compare temperature development in locations with different land-use

For this section, plot 7 was chosen as a representative for the results of the temperature comparison. The Low-Cost Devices at the Thunplatz (urban area) and the Dählhölzli Forest (green area) show that there is a clear difference in the temperature development. The Thunplatz Logger measures warmer temperatures during day and night. Also, the difference between the day-maximum and the night-minimum is bigger for the Thunplatz Logger. The Logger at the Thunplatz begins to heat up earlier and the increase in temperature lasts longer. While the recorded temperature in the Dählhölzli Forest is already decreasing at 17.00, the recorded temperature at the Thunplatz is still increasing and reaches its maximum much later than in the Dählhölzli Forest.



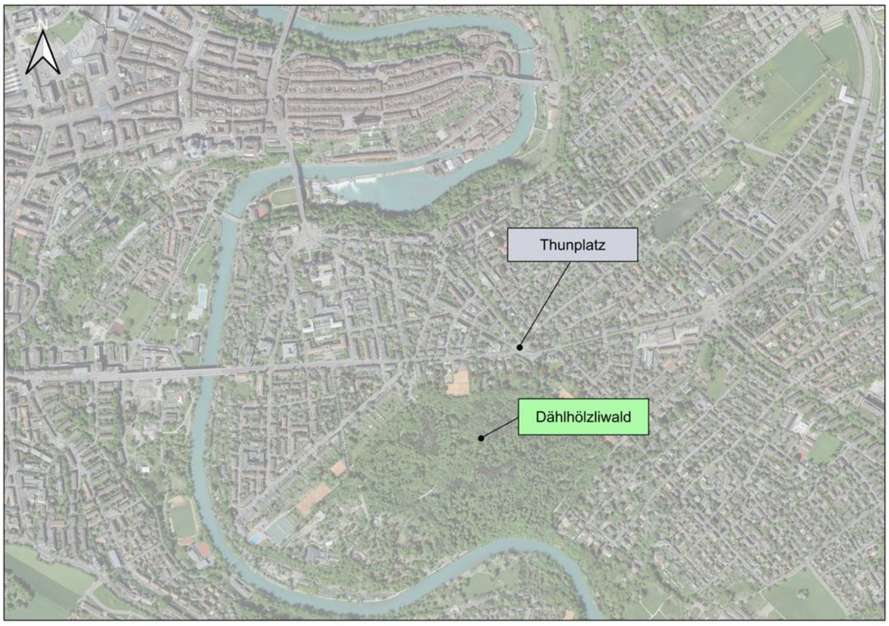


Figure 4: Above: Temperature distribution from 8 pm, 26th of June to 8 pm, 27th of June 2019 for the Logger at Thunplatz and Dählhölzliwald. Below: Location of the Thunplatz and Dählhölzliwald Loggers.

4. Reflection of (trans-disciplinary) research process

In this transdisciplinary research project, the center of attention was turning research into action. The collaboration with Stadtgrün Bern was therefore very important, particularly while framing the scope of the project. It became clear that the awareness of the city population to the impact of vegetation and waterbodies on the temperature must be raised. Therefore, a clear visualization of the problem was needed. As the project is aimed towards the public, it was also decided that the focus should rather be on if there are clearly visible impacts of green and/or blue areas on the temperature across the city of Bern and how they can be visualized best, instead of asking why there are such differences while looking at much smaller scales areas.

The inclusion and evaluation of CWS data helps bridging the gap between science and public, as the public can be included in gathering data. Interested residents get a chance to be part of a scientific project. But there are still some issues to be addressed with crowd-sourced data sets, such as reliability or meta data collection.

Throughout the project there was continuous communication between Stadtgrün Bern and the authors. Multiple options of visualizing methods were proposed and evaluated. This proofed to be a very effective strategy of communicating and finding common grounds.

5. Discussion and Conclusion[D]

Our research concludes that there is a clearly visible difference in temperature development between more urban and greener areas. The tight measurement networks show clearly that the temperatures in the city center are higher. The best data sources proofed to be the Low-Cost Devices as well as the bicycle transects. While using the CWS data one must be careful to take the inhomogeneous placement and the lack of meta data into account, as various nearby CWS stations can show different temperature timelines depending on their placement.

The comparison between nearby Loggers also shows that the warming and cooling process differs between the compared areas. The positive impact of green areas on heat regulation during a heatwave became clearly visible through our comparison.

The combination of Low-Cost Loggers and Bicycle Measurements allowed to visualize the urban heat island during the night of June 26th-27th in Berne very well. The tendency for warmer temperatures in urban areas visible from mapping the logger data could be underlined by showing the gradient of the temperature by bicycle measurements in between. The Bicycle measurements allow for a much more detailed mapping, as the spatial resolution in the areas of interest is much higher. Therefore, it becomes clearly visible where the gradient of the temperature is the highest.

While interpolating the bicycle transect data with the cooling rate of nearby loggers, we concluded that the impact of the loggers is very strong. For example, the interpolated bicycle transect data shows colder temperatures in the lower old town area. This decline in temperature does not exist in the raw data. The cooling in the interpolated data might be caused by a Logger close to the Aare river. This shows that while interpolating the bicycle transect data, it must be understood which Loggers are used for the interpolation and what is their impact. Both the raw and interpolated transect data should be analyzed and compared to spot such anomalies.

6. Acknowledgements and Team Contributions

All three members:

- Write research proposal for lecture Research in Geography (RIG).
- Group Communication proposal and presentation.
- Handling communication and setting up meetings with Lukas Meyer and Samira Neuse.
- Creating the scientific report.
- Preparation for final event.

Michèle:

- Creating the first maps via QGIS for bicycle transects and temperature measurements.
- Researching and comparing the various interpolation methods.
- Improving and iterating maps of bicycle transects.
- Improving and iterating maps of the temperature measurements.
- Situating the analyzed loggers with QGIS in a map for Samira Neuse.

Dominik:

- Overhauling and updating R scripts that were provided by Lukas Meyer.
- Implementing additional python script to further stream-line data.
- R script to analyze and compare low-cost loggers.
- Group representative for final event organization
- Debugging QGIS functions and stream-lining data.

Brian:

- Overhauling and updating R scripts that were provided by Lukas Meyer.
- Creating gifs via photoshop to animate maps.
- R script to analyze and compare low-cost loggers.
- Determine logger pairs that may be of interest to compare.
- Streamlining R code to allow for fast low-cost loggers iterations and automatic image saving.

7. Literature

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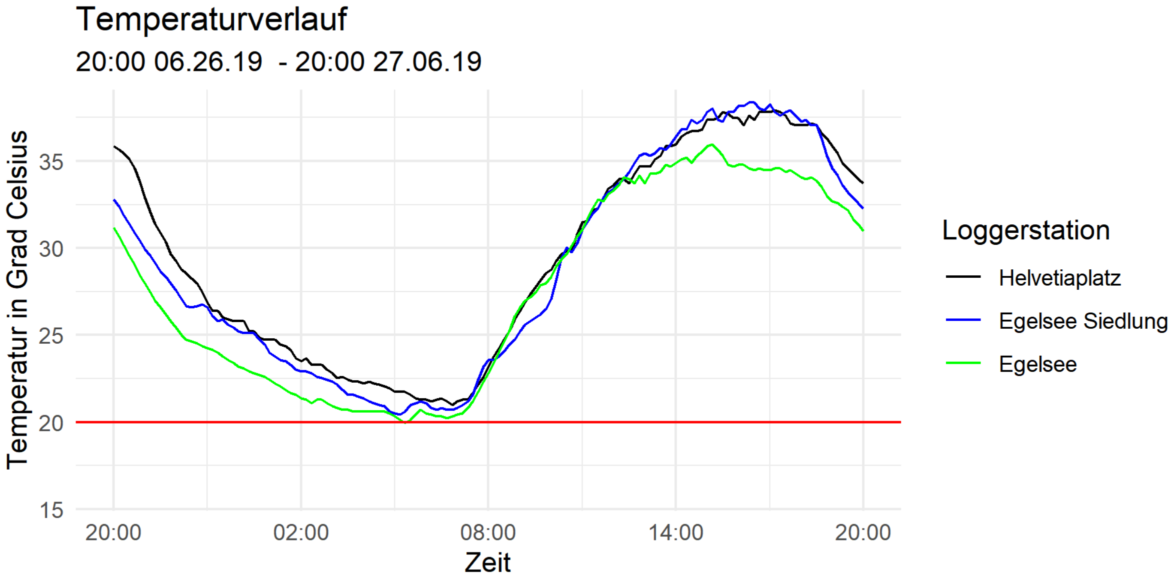
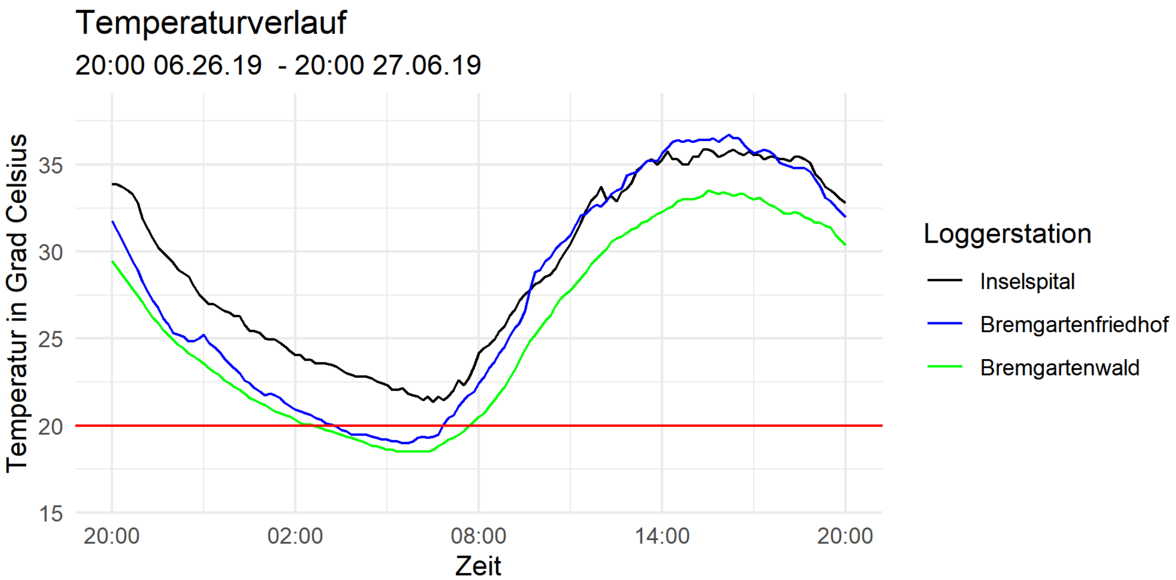
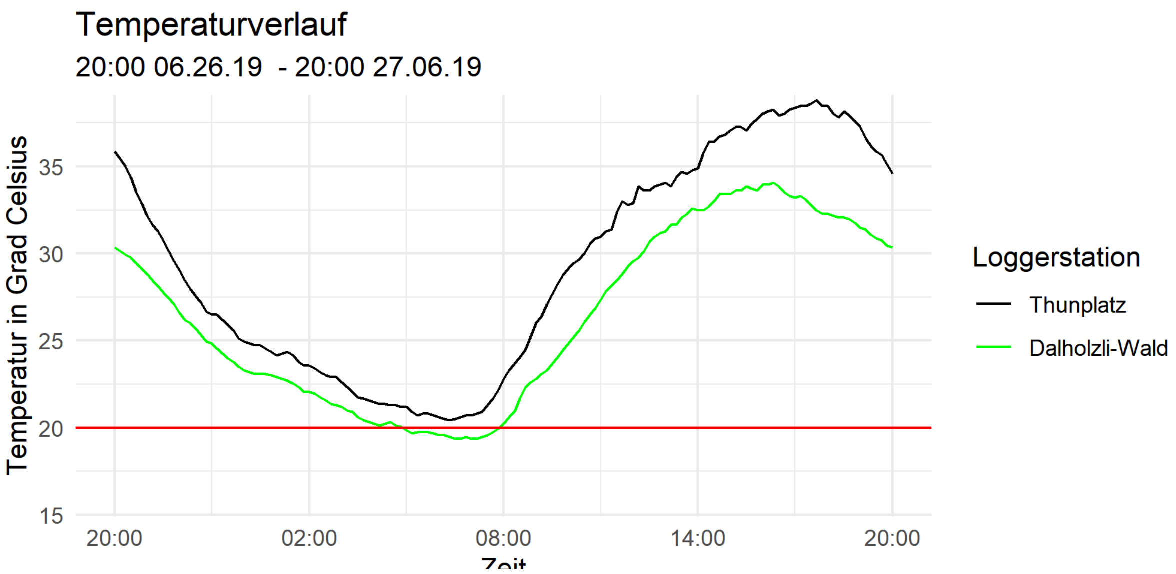
8. Supplementary Data and Plots

All of our scripts used for data-processing can be found here: https://github.com/Brian6330/RIG-HeatMap.



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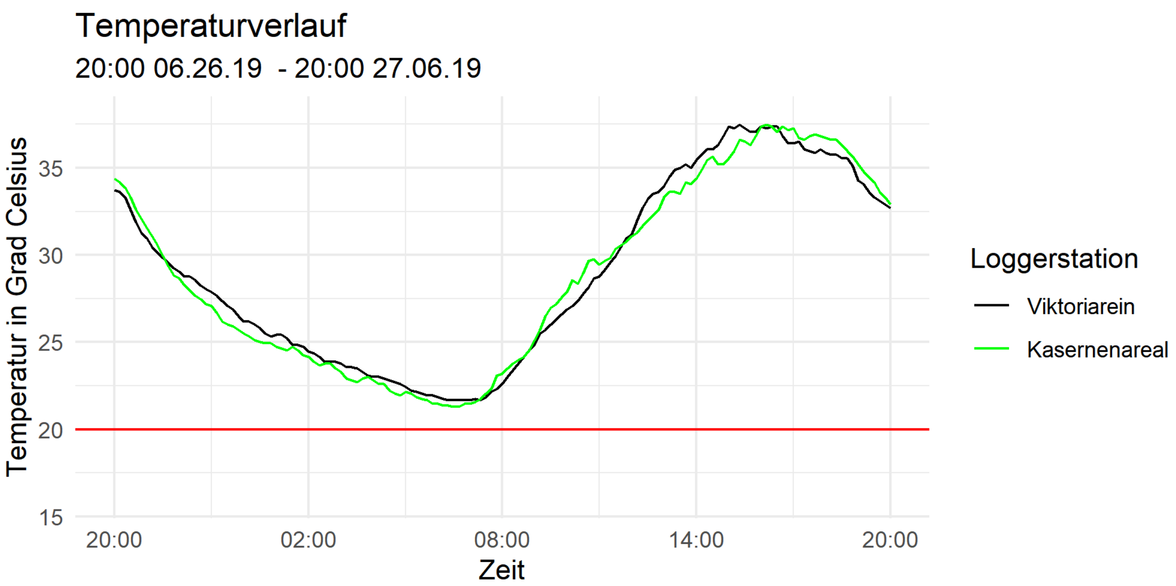
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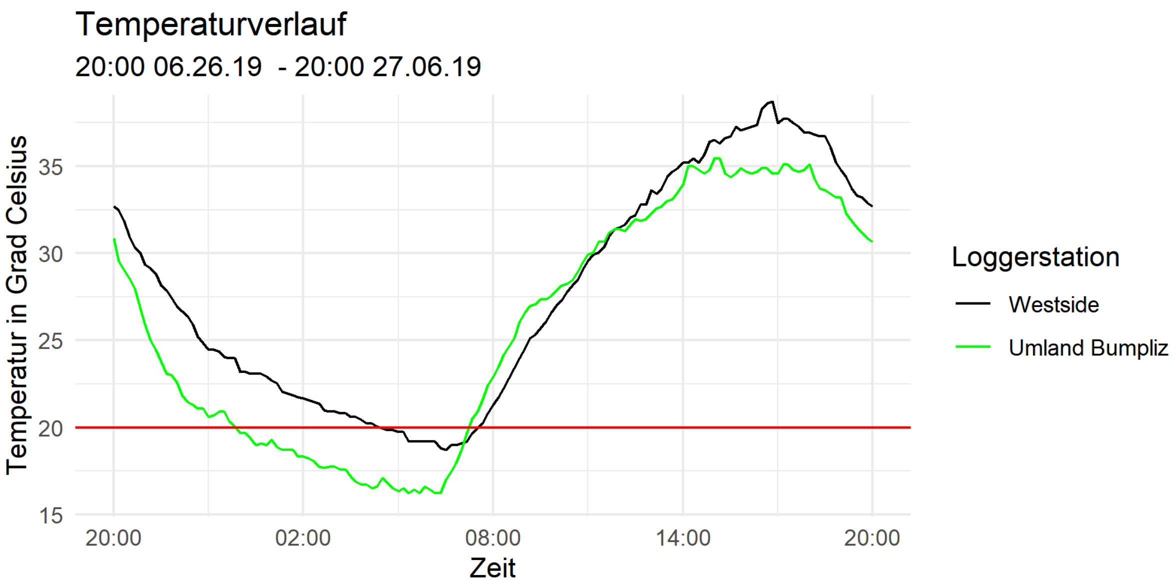
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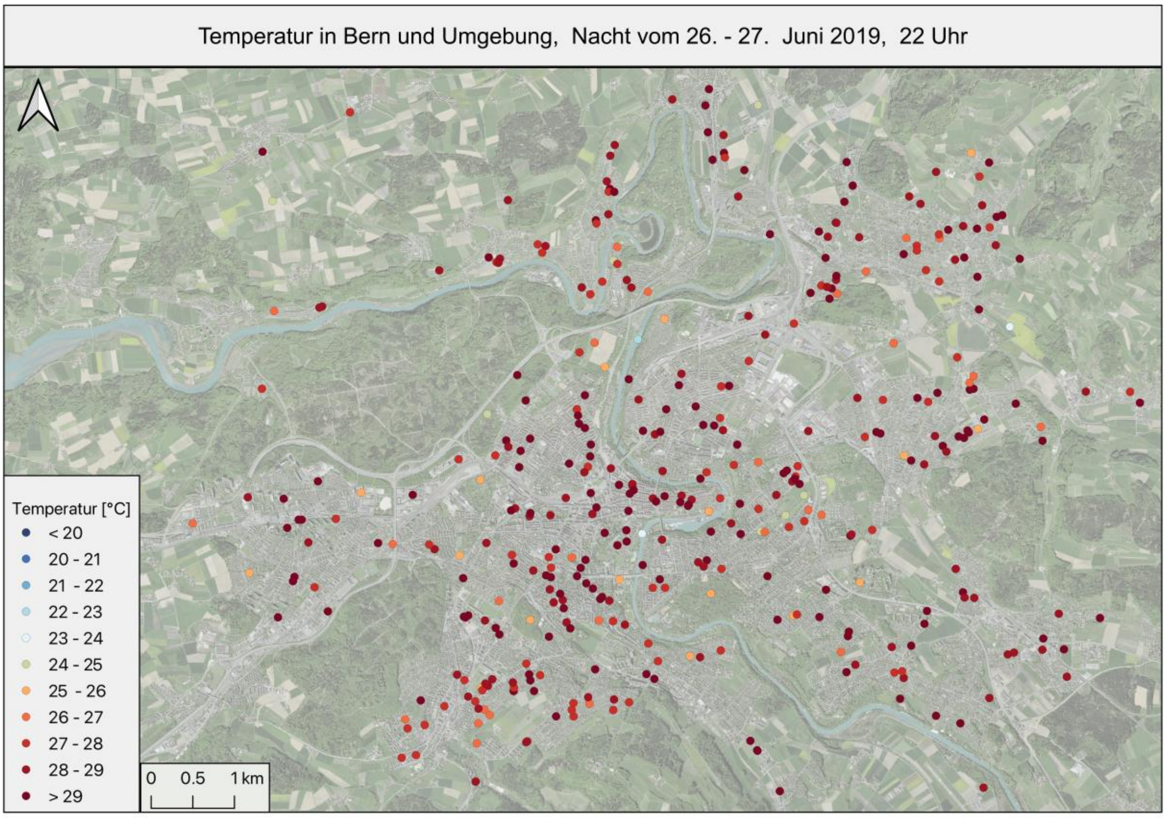

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