Recommendations for measures to reduce urban heat islands and validating the effectiveness of the measures with an IoT measurement network in cities

Table of contents

0 Summary

This project provides recommendations for measures to reduce the urban heat islands effect, which form a basis for city decision makers to implement climate change measures with the best possible cost/benefit ratio.

The meteoblue city climate monitoring system is divided into 4 modules and is limited to 3 years. However, the system is designed in such a way that the services developed for the city can be continued sustainably after the end of the three-year project period.

In the first module, a self-sufficient IoT measurement network is installed in the urban area and the surrounding area, which measures air temperature at more than 50 different locations. The locations are selected according to scientific criteria, so that all local climate zones are covered, and measurements are also conducted in road canyons where it is not possible to measure with expensive measuring instruments due to technical restrictions.

In the second module, a real-time monitoring system is set up, which uses measurements, satellite data and external models to generate so-called “heat maps” to detect and visualize the urban heat island effect at a resolution of 10 m. The real-time monitoring system is optionally integrated into existing city management platforms.

In the third module, a surface energy balance model proposes the best possible options for climate change adaptation measures (e.g., roof greening, irrigation, de-sealing) for heat islands of the city and/or already planned measures are prioritized.

The fourth module examines the climate impact of the climate change adaptation measures implemented with the IoT measurement network.

1 Project plan

Figure 1.1 describes the project plan with all work packages and milestones, which are described in detail in chapter 1.1 and chapter 1.2. The project ends after 3 years after reaching the 4th milestone. Further services that have been developed in the project can be continued sustainably after the end of the 3-year project phase.

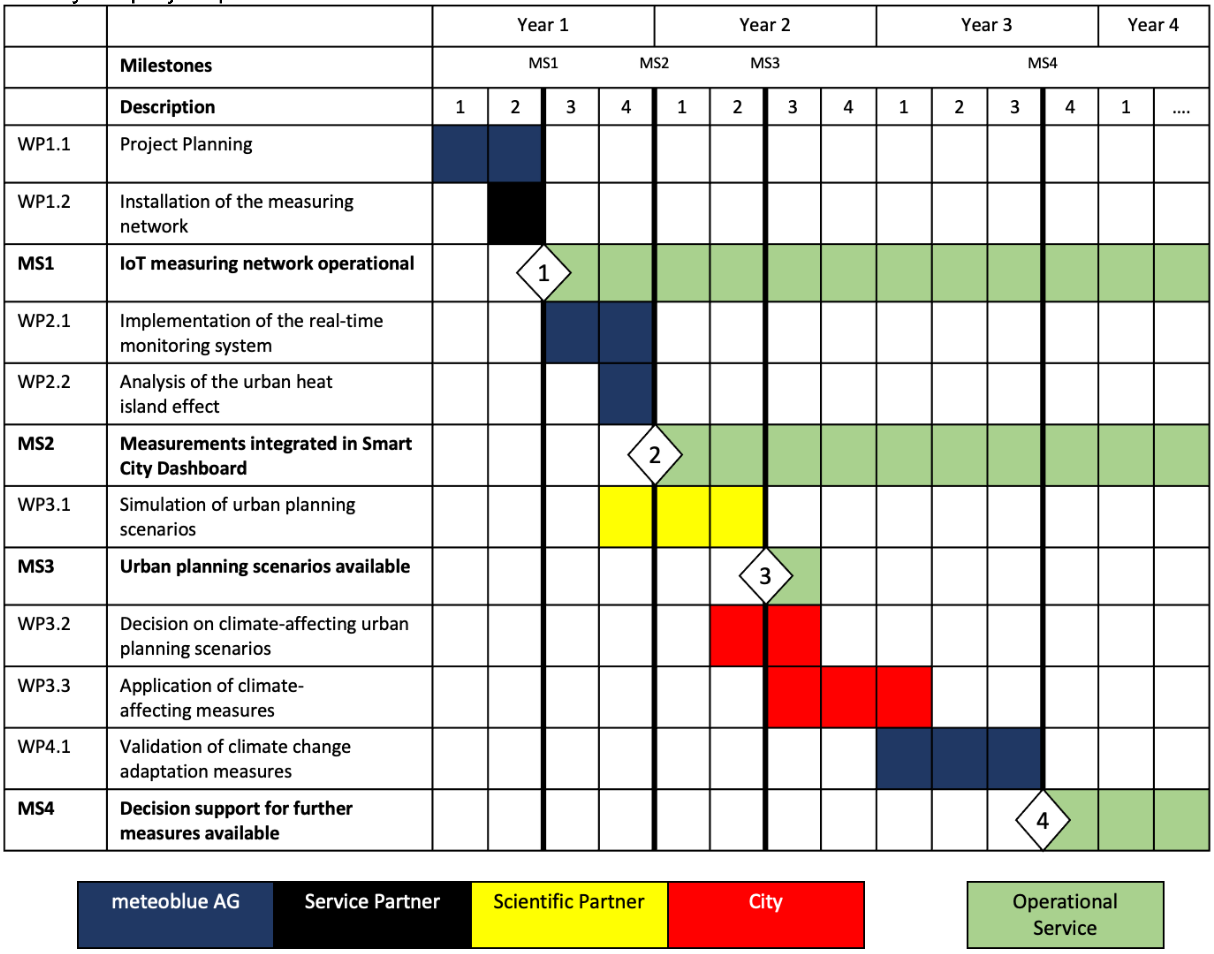


Figure 1.1: Project plan with all work packages (WP) and milestones (MS).

1.1 Description of the Milestones

The four milestones of the project are described in more detail below:

1.1.1 Milestone 1: IoT measurement network operational

The IoT measurement network is installed in consultation with all stakeholders and is now operational.

1.1.2 Milestone 2: Measurements integrated in Smart City Dashboard

Measurement data and “heat maps” as well as the analyses from package 3 are integrated into a (already existing) smart city dashboard and are available to all stakeholders in real time.

1.1.3 Milestone 3: Urban planning scenarios available

A catalogue of different urban planning scenarios is available to all stakeholders providing a solid scientific basis for climate change adaptation measures to be taken.

1.1.4 Milestone 4: Decision support for further climate change adaptation measures available

With the help of the validation of at least 4 different climate change adaptation measures in the urban area, the basis for decision support for further measures beyond the duration of the project is available.

1.2 Description of the Work Packages

In work package 1, the IoT sensor network is set up.

In WP1.1 the complete project is planned.
- Project planning over the 3 years in consultation with the stakeholders of the city administration
- Decision on the station provider
- Permission for the installation of stations on streetlights or road signs by the city
- Ensuring the transmission of the stations
- Location placement plan based on the optimization of meteorological and practical criteria

In WP1.2 the sensor network is established.
- Installation of stations according to plan
- Recording of metadata: coordinates, images, distance to buildings, etc.
- Creation of a maintenance plan for the stations

In work package 2, the real-time monitoring system is developed.

In WP2.1 the real-time monitoring system for measurement data acquisition is set up.
- Storage of data in the meteoblue database
- Delivery of data via the meteoblue measurement data API
- Display of the data on the meteoblue website

In WP2.2 the urban heat island effect is detected at a horizontal resolution of 10 x 10 m.
- Provision of satellite data and other models
- Access to the measurement data from the IoT measurement network
- Calculation of the urban heat island effect based on scientific criteria
- Creating a 20-page report for the city

In work package 3 recommendations for adaptation measures are developed.

In WP3.1 urban planning simulations are calculated with a surface energy balance model.
- Simulation of more than 30 different adaptation measures (blue measures, green measures, measures on buildings, etc.) at the particularly hot areas of the city detected in AP2.2.
- Climate simulations with the common models of the IPCC report for the future up to the year 2100 in order to be able to estimate the impacts without and with adaptation measures.
- Creating a 20-page report for the city

In WP3.2 the results are presented to the city and jointly decided on the most climate-sensitive measures, which then in WP3.3 are implemented by the city.

In work package 4 climate change adaptation measures using the dense IoT measurement network are validated.

Important tasks in work package 4 are:
- Analysis to validate at least 4 different climate change adaptation measures in the urban area
- Creating a 20-page report for the city

1.3 Description of the processes

The process of the project is described in Figure 1.2 and described separately for the different stakeholders of the project. The process begins with the data acquisition, in which the IoT measurement network is installed by the service partner and meteoblue AG provides all relevant raw data. The analysis is then carried out by meteoblue and the scientific partner, based on which adaptation measures are then prioritized by the city and further implemented. In the last step, the implementation process is evaluated by meteoblue AG and the city. Based on these results, the analysis is repeated and re-prioritized to pass through a closed feedback loop.

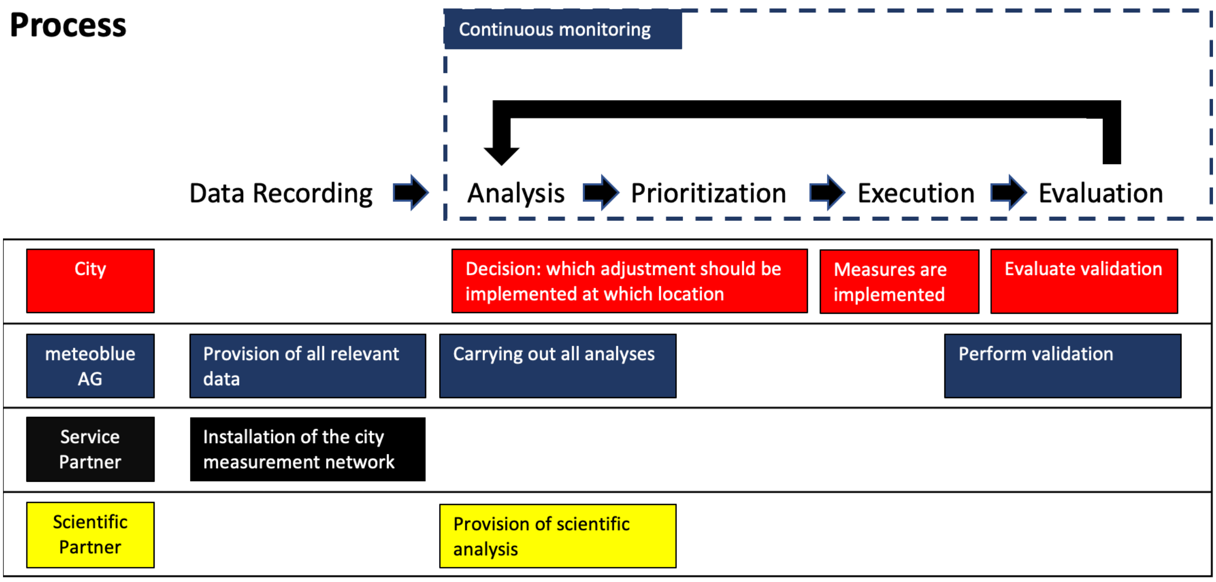


Figure 1.2: Project process: data recording, analysis, prioritization, execution, monitoring, and evaluation for the various stakeholders meteoblue AG, service partner, city und scientific partner.

1.4 Description of the tools

Figure 1.3 describes the project's tools and subdivides them into 3 categories of data.

1. **Raw data**: Raw data are measurement data or external model data from the numerical weather forecast or satellite data used to generate processed data.
2. **Processed data** is processed data from raw data, e.g., data that is processed in the data management tool and corrects the raw data. Other processed data are "heat maps", for which external model data and data from the data management tool are processed, or climate forecasts, for which external models are also used as input.
3. **Data on evidence for decisions**: This data serves as a basis for decision-making by the city to plan further measures with the best cost/benefit ratio. Urban planning scenarios and the validation of climate change adaptation measures are used for this decision-making basis.

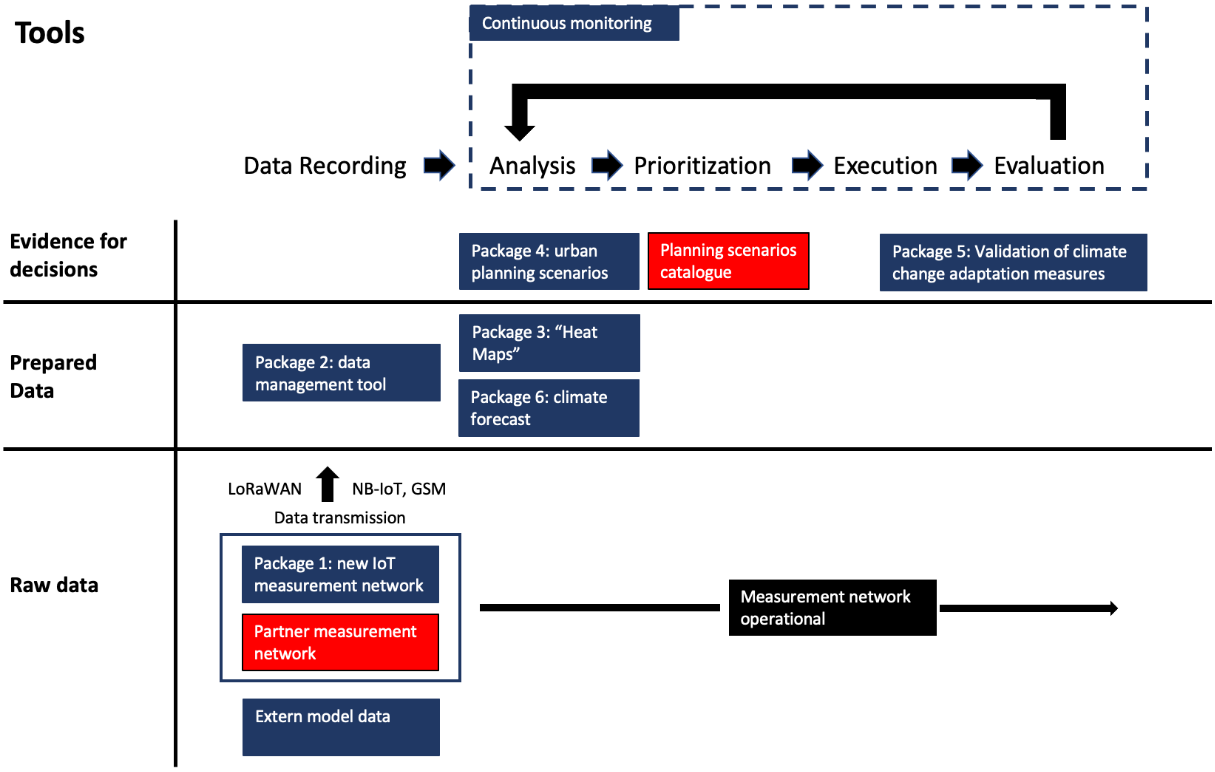


Figure 1.3: Overview of the data packages divided into raw data, processed data, and data for evidence for decisions. Prepared data is processed data, e.g., raw data changed by correction or conversion. Decision evidence data is aggregate data collected for a different purpose and based on which decisions are made.

2 Description of the data packages and modules

The following chapter describes the data packages and modules of the project. Optional modules can be ordered on request.

2.1 Package 1: Consulting in urban climate monitoring system with 50 meteorological sensors

- Order of 50 meteorological IoT sensors (air temperature and precipitation) from a weather station provider
- Installation plan based on optimization according to meteorological and practical criteria
- Recording of all important metadata
- Station Installation and maintenance of measuring instruments with a local service partner
- Ensuring data portability via state-of-the-art IoT technology (LoRaWAN or NB-IoT)

2.2 Package 2: Data management tool

- Access to the meteoblue measurement data API (raw data are available in real time)
- Number of IoT stations: up to 50
- Same timestamp for all stations
- Temporal and spatial quality control
- Filling of data gaps by model data of numerical weather models
- Data homogenization if more than two sensor networks are used
- Quality controlled and homogenized data set is delivered for the respective calendar year (one-off delivery in January of the following year)
- Number of variables in the package: air temperature, humidity, and precipitation
- Implementation of up to 2 external (already existing) data sets for air temperature or precipitation
- Real-time warning in case of station failure to specified e-mail address

2.3 Package 3: «Heat Maps»

High-resolution temperature data for the detection of hotspots (urban heat island effect) and the identification of locations where climate change adaptation measures are particularly important.

2.3.1 Package 3a: Planning Tool “Heat maps”

- For more information on the Basel example, see section 3.2
- 10 x 10 m horizontal resolution
- “Heat Maps” for day/night and summer/winter
- Local climate zones and analysis of the urban heat island effect according to different local climate zones
- Data is provided in OneDrive folders as NetCDF files and png files.
- Delivery time after order confirmation: 4 weeks.
- Report: approx. 20 pages report

2.3.2 Package 3b: Monitoring Tool “Heat maps”

- Access to meteoblue high-resolution API
- High-resolution (10 x 10 m) temperature maps in hourly resolution for integration into existing systems.
- Real-time high-resolution temperature maps and forecast high-resolution air temperature maps (7-day forecast) are available

- Virtual weather stations for 50 selectable locations in the city including the history of the virtual station since deployment and a 7-day city specific forecast for each location.
- Alerting tool for city specific heat wave forecast for the critical infrastructure of the city (e.g. hospitals, kindergarden, etc..)

2.4 Package 4: Urban planning scenarios

2.4.1 Package 4a: 1D urban planning scenarios («point»)

- Point-specific analysis for **one representative location** in an area to be defined (Chapter 3.3)
- Reduction of surface and air temperature (compared to the current state) from surface energy balance model for various climate change adaptation measures.
- 4 different strategies with different options according to Table 3.1.
- Different sizes of adaptation measures are simulated.
- Analysis separated by time of day, season, wind conditions and cloud cover.
- Coupling with climate change emission scenarios (from IPCC report) and comparing current condition with expected conditions from 2050 (optional 2085).
- Data is provided in OneDrive folder as csv files and png files.
- Delivery time after order confirmation: 4 weeks.
- Report: approx. 20 pages report

2.4.2 Package 4b: 2D urban planning scenarios («map»)

- Analysis for area development (Chapter 3.3).
- Reduction of surface and air temperature (compared to the current state) from surface energy balance model for various climate change adaptation measures.
- 4 different strategies with different options according to Table 3.1.
- Different sizes of adaptation measures are simulated.
- Analysis separately according to time of day, season, wind conditions and clouds.
- Coupling with climate change emission scenarios (from the IPCC Report) and comparing the current condition with the expected conditions from 2050 (optional 2085).
- Map presentation for the entire area development.
- Combined climate change adaptation measures for the entire area.
- Data is provided in OneDrive folder as csv files and png files.
- Delivery time after order confirmation: 6 weeks.
- Report: approx. 20 pages report

2.5 Package 5: Validation of climate change adaptation measures

- Analysis as described in Chapter 3.4 (“Triangle Experiment”)
- 4 locations in the urban area
- 2 – 4 different climate change adaptation measures (depending on city decision)
- Selection of the locations of the measuring stations
- At least 6 months (preferably 12 months) before the adaptation measure: start of the measurements. First analysis 6 months after completion of the adaptation measure.
- Report: approx. 20-page report for all locations
- Delivery time after order confirmation: 4 weeks

2.6 Package 6: Climate prediction

- https://content.meteoblue.com/en/time-dimensions/climate/climate-prediction
- https://docs.meteoblue.com/en/services/climate/climate-risk-assessment (Technische Dokumentation)
- Dissolution of the UHI effect

- Spatial extents: inner city and suburbs (different according to city), not selectable
- Horizontal resolution: 10 x 10 m
- Reference period: 1979 – 2020 (selectable, at least 20 years recommended)
- Emission scenarios: RCP2.6, RCP4.5, RCP6.0, RCP8.5
- Periods in the future: 3 periods selectable, recommended: 2020 – 2049, 2045 – 2074, 2070 – 2099
- Variables: heat days, summer days, tropical nights, ice days, frost days, heating degree days, cooling degree days, average annual temperature, number of heat waves, number of cold waves
- Data format: png (raw data as NetCDF, JSON)
- Report: approx. 20 pages report
- Delivery time after order confirmation: 2 weeks

3 Urban climate in Basel (examples)

In this chapter, the 6 different data packets are described in more detail using the Basel example.

3.1 Meteorological real-time measurements in Basel

In order to measure the urban climate in Basel and to test the effectiveness of adaptation measures, a fine-meshed IoT measurement network was installed in Basel in 2020, consisting of more than 180 Metos LoRain sensors. These 180 meteorological sensors cover Basel's city centre as well as the outskirts and suburbs and were distributed at distances ranging from 500 m (city centre) to 1 km (suburbs). This covers all important local climatic zones, highly frequented places and climatologically important places in the area of cold-air corridors. In addition to air temperature, precipitation and relative humidity are measured in 15-minute resolution.
The data is transmitted using the latest IoT technologies via the IWB's LoRa network.

The real-time measurements can now be accessed by any interested user on the meteoblue website (https://www. meteoblue. com/de/products/cityclimate/basel). The map view makes it easy to see large-scale patterns of temperature or precipitation over the urban area (Figure 3.1). Hotspots can be detected visually.

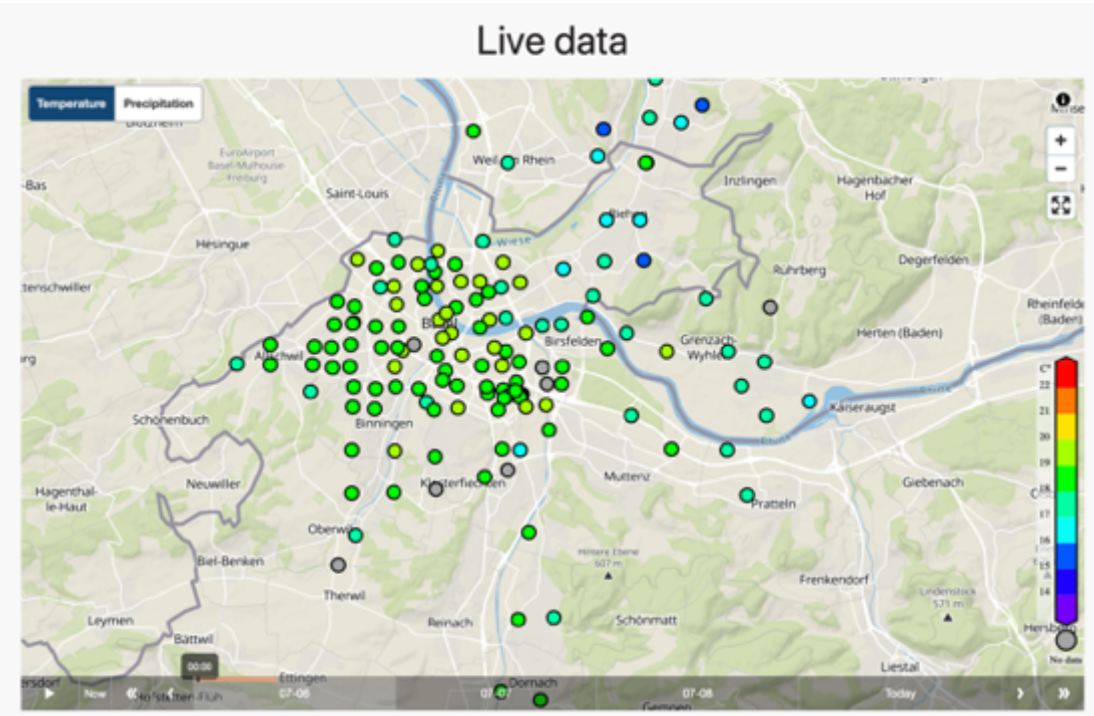


Figure 3.1: Meteorological sensors in the city of Basel.

In addition to the raw data, a range of other information is offered. These can also be accessed on the map by clicking on a station. Historical measurement data in graphical form, a 5-day forecast based on station data and statistical evaluations are available on the meteoblue website. The statistical analysis includes, for example, the average air temperature and precipitation sum in daily, weekly and monthly resolutions.
A heat ranking compares the average air temperatures of all measuring stations and assigns them a number in the ranking. This also helps to quickly identify hotspots in the city.

In addition, meteoblue AG offers a raw data API, with which interested users can secure access to the complete time series of all urban climate data since the installation in 2020.

3.2 Data management tool

Raw data is recorded, stored internally in the meteoblue database and passed on to the customer in raw format via an API interface. In addition to the raw data, meteoblue offers a quality-controlled data set at the end of each calendar year as one-off delivery.

The quality-controlled data set includes:

1. A three-stage quality control (QC0 – Screening; QC1 – static quality control for each location separately; QC2: dynamic quality control for complex comparisons between different stations)
2. A tool that fills data gaps with model values to provide a consistent dataset.
3. Data homogenization to correct radiation errors and merge different measurement networks om WMO standard (if necessary)

Different sensors (see Figure 3.2) are used to correct between the individual sensors.

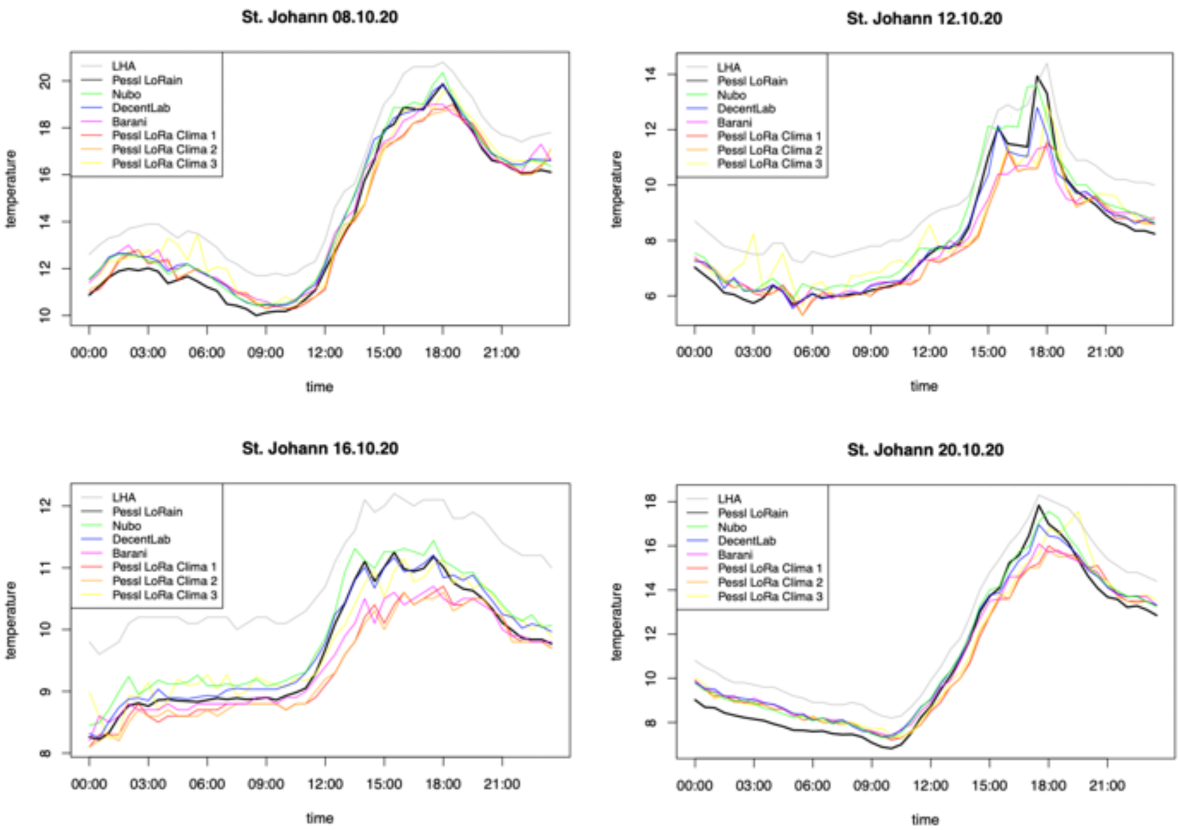


Figure 3.2: Comparison of 8 sensors at the St. Johann site, Basel, exemplary for different days.

3.3 Urban heat island effect in Basel

As climate change progresses, cities are warming up more than their surroundings. The number of tropical nights and heat days will continue to increase in cities; heat waves will occur longer and more frequently in the future.

Urban Heat Island (UHI) is a typical feature of the urban climate. It is characterized by the temperature difference between the warmer city and the cooler surrounding area. The biggest differences in temperature occur at night. Within the urban area, however, there are places that are particularly vulnerable to warming, so-called "hotspots". These are usually densely built-up and sealed areas that can store heat longer than the surrounding area.

To analyse the urban heat insulation effect for Basel, data from the meteorological network and satellite data are used to calculate so-called "heat maps" using artificial intelligence. These heat maps are created with a spatial resolution of 10 m and show in which areas of the inner city the urban heat island effect is particularly pronounced (see Figure 3.3).

Using the heat map, hotspots in the city are precisely detected and average differences in air temperature are detected. This shows that certain areas in Basel city center are on average 3 degrees Celsius warmer than the suburbs. For certain weather conditions (low wind, no radiation) warmer air temperatures of up to 8 degrees Celsius were measured in the urban area. The Basel Heat Map shows hotspots within the city, such as the SBB station, Badischer Bahnhof or the Old Town.

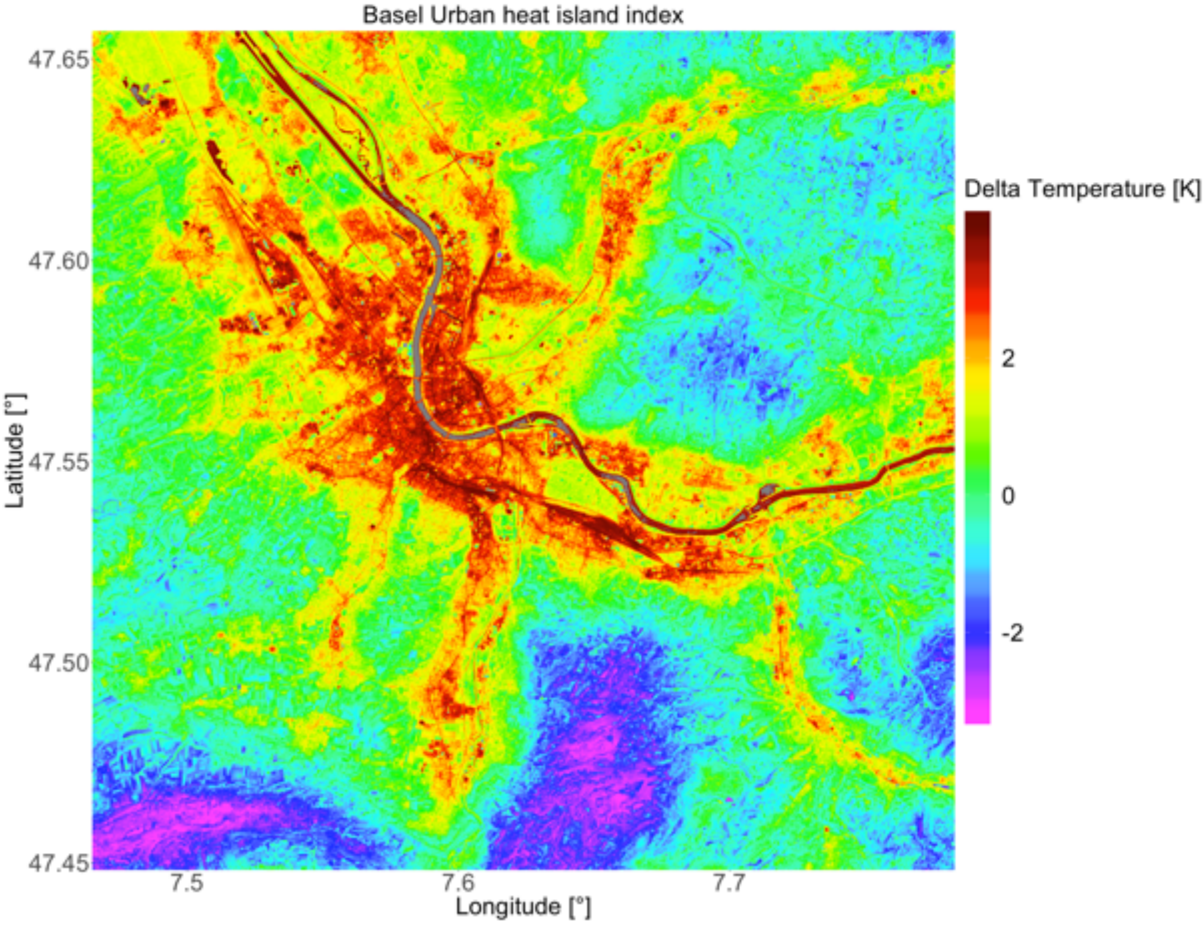


Figure 3.3: «Heat Map» of Basel city center and its surroundings

The heat map can be used in urban planning to plan measures to reduce the urban heat island effect on a site-specific basis. The reduction of the urban heat island effect by suitable measures (de-sealing, greening, irrigation, consideration of natural cold corridors) can only be implemented in a climate-efficient and cost-effective way if the local heat contribution of the urban heat island effect (via the heat map) is known. Therefore, the heat maps serve as a decision-making aid for urban planners in their decision to reduce the urban heat island effect.

With the help of the heat maps, local-specific information can be obtained on tropical nights, heat days, heating, and cooling days. These analyses can be calculated both for the current year and for the near and distant future using the most common RCP emission scenarios. The analyses thus make an important contribution to the heat management of a city and provide an important tool for supporting cities during climate change with reliable facts and figures.

3.4 Basis of urban planning scenarios

The analysis is conducted with the Surface Energy Balance Model (SUEWS) based on air temperature measurements in the surrounding of the area of interest. The analysis provides results for the surface temperature and the air temperature.

A reference simulation is carried out which simulates the current state of the area. In addition, many so-called sensitivity runs are carried out, in which the surface of the area is artificially modified. Artificial surface modification changes important surface-specific material properties such as albedo, emissivity, thermal conductivity, and others.

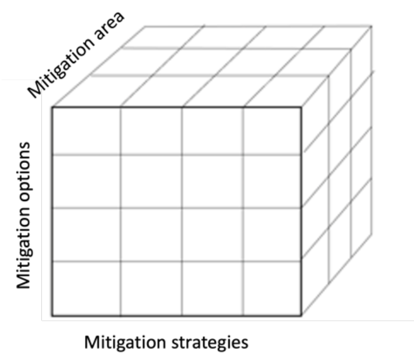
The differences (before – after) in the variables surface temperature and air temperature are determined by a difference calculation.

$$\Delta T = T_{sens} - T_{ref}$$

where T_{sens} is the temperature of the sensitivity run (after adaptation) and T_{ref} is the temperature of the reference simulation (before adaptation).

In total, 3 different groups of parameters can be changed:

1. The climate change adaptation strategy
2. The climate change adaptation option
3. The size of the adjustment measure



3.4.1 Climate change adaptation measures

The following climate change adaptation measures are being investigated:

- Blue strategies
- Green strategies
- Measures on buildings
- Technical measures to change the material properties

3.4.2 Climate change adaptation options

Different options are considered for each of the four adaptation measures (Table 3.1). Depending on the option, individual variants of the climate change adaptation measure are also offered. For example, there are several rooftop materials adapted to climate change that are tested in the analysis (see Table 3.2).

Table 3.1: Climate change adaptation options for the 4 different strategies.

Blue strategies	Green strategies	Measures on buildings	Technical measures to change the material properties
Irrigation of green areas	Roof greening	Facade greening	Heat insulating roof materials («cool roofs»)
Construction of fountains and water areas	Planting of new trees	Climate change adapted materials on buildings	Climate change adapted materials for asphalt («cool pavements»)
	Implementation of new green areas		white streets

Table 3.2: Options for adapted materials on roofs. (Source: https://issuu.com/globalcoolcities/docs/coolrooftoolkit)

Options for adapted materials on roofs	Albedo	Emissivity	Solar Reflectance Index (SRI)
Gray asphalt brick	0.22	0.91	22
Red clay roof tiles	0.33	0.90	36
White coating on metal roof	0.67	0.85	82
White concrete brick	0.73	0.90	90
White PVC	0.83	0.92	104
Double white coating	0.85	0.91	107

3.4.3 Size of the adaptation

In order to test the effectiveness of the climate change adaptation measure, the area of the adaptation can be varied in the model. This allows questions to be answered, for example, how the temperature reduction changes if the area of the adaptation measure is doubled or halved.
The temperature reduction due to the adaptation measure is simulated for the area of the adaptation measure and then extrapolated to the entire area.

3.4.4 Dependence on meteorological conditions

Surface temperature and air temperature are displayed for the following conditions:

- Time of day: day vs. night conditions
- Season: summer vs. winter conditions
- Radiation: cloudy vs. sunny conditions
- Wind: windy vs. no wind
- Current condition vs. conditions in 2050

All results will be presented in the form of charts, maps, or tables, with trends, extremes, and frequency distributions.

3.5 Validation of the climate change adaptation measures

Rising air temperatures as a result of climate change hits cities harder than their rural surroundings. The average air temperature in cities is at least 2°C higher than in the surrounding area. Therefore, the additional temperature increase due to climate change could lead to severe impact on cities. This trend will result in unknown economic damage and an increasing threat to the health of the citizens.

Due to their sealed surface, cities contribute to their own warming. For example, surface sealing prevents the leakage of water, which could later evaporate again and thus have a cooling effect on the environment. Instead, the surface (e.g., concrete or pavement) absorbs short-wave solar radiation and releases it later in the form of heat. The lack of ventilation caused by compact urban development prevents the circulation of air masses and thus the cooling of urban areas. These are just some of the factors that influence the urban climate and lead to a general warming of the city.
At the same time, it becomes clear that there are different ways of changing the climate in the city through adaptation measures.
There are different approaches to ensure active cooling in cities. The most common adaptation measures are, for example, rooftop greening and facade greening, white asphalt, de-sealing, irrigation, and greening.

The de-sealing of areas can be a very effective adaptation measure, as water-permeable areas cover a large and ever-growing part of the city. Rainwater can no longer seep and evaporate again later, which would contribute to cooling. Instead, the sealed surfaces heat up and contribute to the overall warming of the city. De-sealing can restore natural soil functions and percolation capability, making the surfaces more resilient to flooding. Unsealed surfaces can be either greened or graveled. The additional vegetation in turn contributes to the cooling of the city. The canopy of trees reduces the sunlight reaching the ground, i. e. shading keeps the ground cool and can increase thermal comfort. In addition, vegetation can have many benefits for the microclimate through evapotranspiration or regulation of air movement.

This report tests de-sealing as an adaptation measure to climate change. For this purpose, a small area, the so-called triangle area in the Swiss city of Basel in the Erlenmatt quarter near Badischer Bahnhof Basel is considered.

A large, sealed area was unsealed and covered with gravel and planted with 18 small trees. These will continue to grow in the coming years, creating a greener environment in the area (Figure 3.4). The dense IoT measurement network in Basel, which records precipitation and air temperature with more than 200 meteorological sensors, is used to detect small changes in air temperature compared to the environment (without adaptation measures). In order to detect small differences in air temperature in the Triangle area, three sensors will be installed in the area three months before the start of the renovation work. In addition, reference sensors in the vicinity (12 sensors) are used for comparison (Figure 3.5).
The difference in air temperature between the study area and the reference area outside the triangle area is calculated by the following formula:

$$\Delta T = \overline{T_{Triangle}} - \overline{T_{reference}}$$

The average values of the three sensors in the triangle area and the 12 sensors in the reference area are used for comparison.

Figure 3.4: Triangle area before the adaptation measures (left) and after (right).

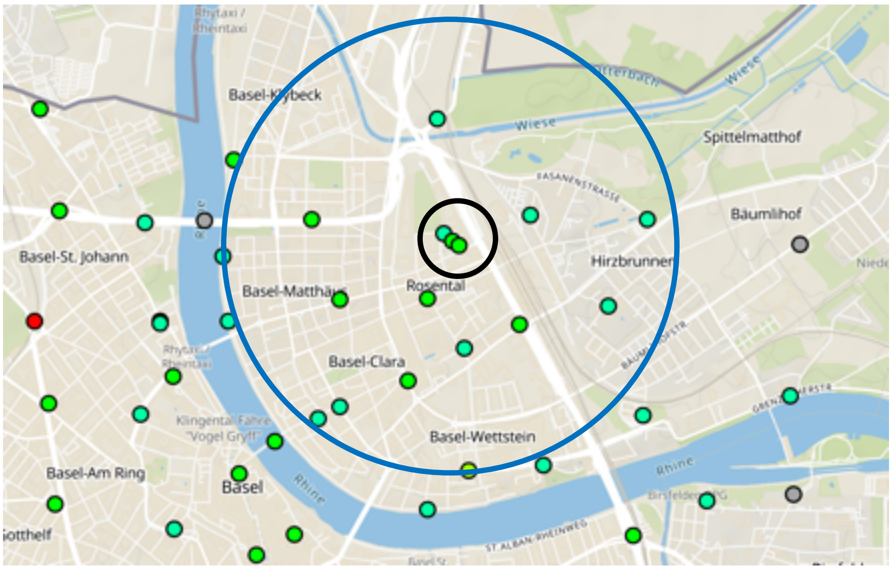


Figure 3.5: Locations of the meteorological stations in the triangle area (three stations within the black circle) and in the reference area (12 stations, blue circle) in the vicinity.

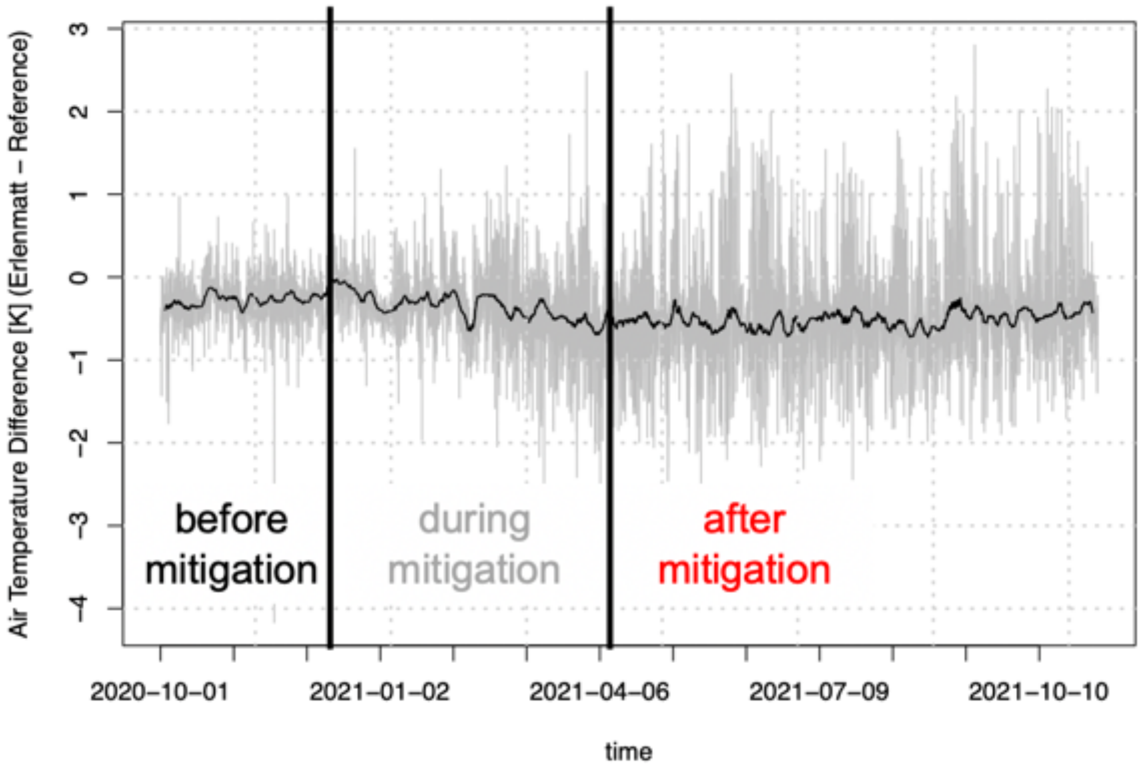


Figure 3.6: Air temperature difference between the stations in the triangle area and the reference stations in the vicinity before, during and after the adaptation measures.

Figure 3.6 shows the air temperature difference (triangle area – reference area) before, during and after the mitigation action was implemented. During the three phases, differences in Figure 3.6 can be seen. Before adaptation, the differences between the triangle area and the environment are on average 0.3 degrees Celsius below zero, which means that the environment is warmer than the triangle. After the adaptation measure, the differences between the triangle area and the surrounding area are 0.6 degrees Celsius less than 0. This means that the triangle area has a 0.3 degrees Celsius cooling effect due to the adaptation measure.

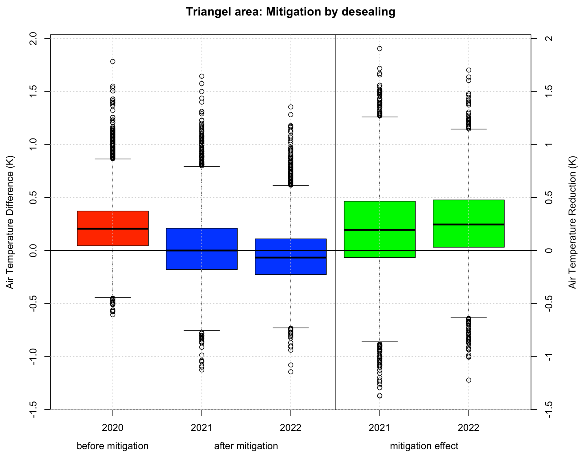


Figure 3.7: Temperature differences (in K) between the triangle area and the reference stations before the adaptation measures (red) and after the adaptation measures (blue). The resulting effect on air temperature can be seen in the green boxplot.

Figure 3.7 shows the deviations of air temperature before (red) and after adjustment (blue) compared to the reference stations. Both before and after the adaptation, a cooler temperature was measured in the triangle area compared to the reference sensors in the surrounding area. Before the reconstruction, the average temperature in the triangle area was 0.2 degrees cooler, after the reconstruction, 0.5 degrees. This makes it clear that climate change adaptation through de-sealing and planting has a cooling effect of 0.3 degrees.

3.6 Climate prediction

Nowadays, many regions around the world cope with challenges, such as the increasing frequency of extreme air temperatures, storms and floods caused by heavy rainfall. Such extreme events will occur more frequently in the future due to climate change. This trend increases the risk of economic damage and the threat to human lives from weather hazards.

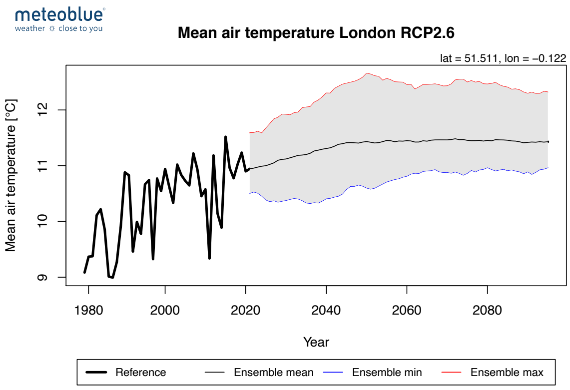
The meteoblue climate forecast provides a simple summary of complex climate change simulations for any place on Earth, based on different emission scenarios from the IPCC report.

The meteoblue climate forecast summarizes all these projections for selected locations in simple graphs and tables that can be read by any standard software and offers various configuration options as well as many variables included in the package.

The meteoblue climate forecast is available worldwide for every location in high spatial resolution. It includes the following elements:

- All common weather variables
- Four future emission scenarios by the end of the century
- Annual, seasonal and monthly aggregations
- Typical and extreme meteorological years
- Site-specific climate risk analysis
- Data are formatted as maps, box plots and time series. In addition, all data is provided in CSV and JSON formats.

Figure 3.8 shows the number of heat days as a function of the years 1979 – 2100. This illustration shows the uncertainty in climate models in the grey shade.



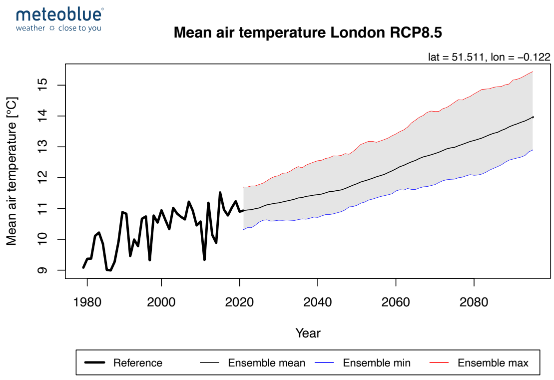


Figure 3.8: Number of hot days as a function of the years from 1979 to 2100. For historical data the ERA5 data set is used, climate forecasts from 2020 to the end of the century are calculated for four different emission scenarios. The ensemble mean of the raw models is shown in black, the ensemble maximum in red, the ensemble minimum in blue.

Figure 3.9 shows the yearly variations of different parameters. The display as box plots allows a direct climate risk assessment for the future. The example of London shows that with a 25% probability the number of summer days is over 30 for the period 2045 – 2074 (RCP8. 5). In other words, every fourth year in the medium future (2045-2074) in London will have more than 30 summer days.

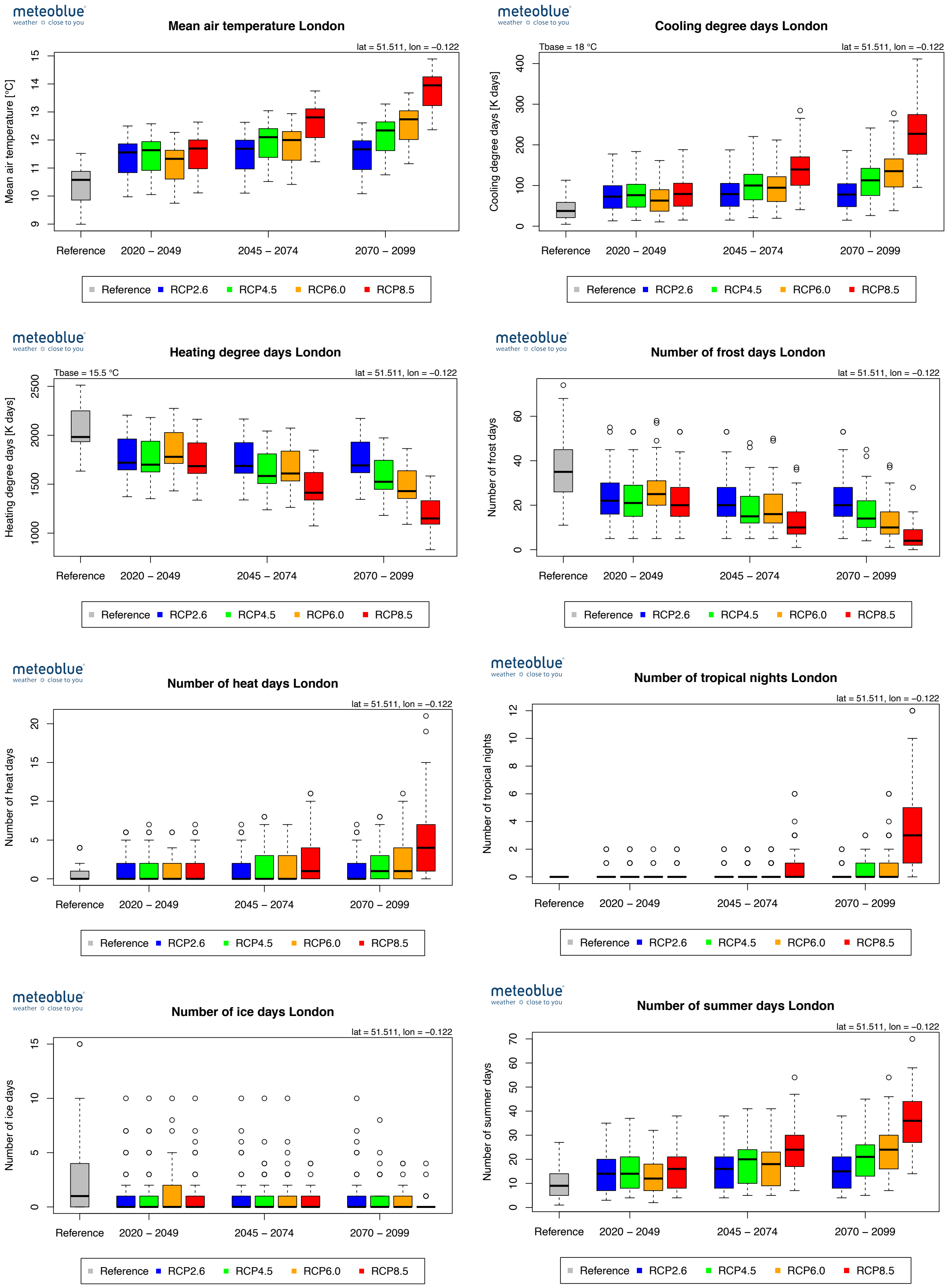


Figure 3.9: Number of ice days, frost days, summer days, heat days, length of the frost-free period, heating degree days, cooling degree days, mean air temperature and tropical nights for the reference period (1979 - 2019) and three time horizons (2020 - 2049, 2045 - 2074, 2070 - 2100) with 4 Emission scenarios (RCP2.6, RCP4.5, RCP6.0, RCP8.5) using London as an example.

Figure 3.10 shows the average value of the heating degree day index in high resolution for Frankfurt am Main for two emission scenarios and four different time periods.

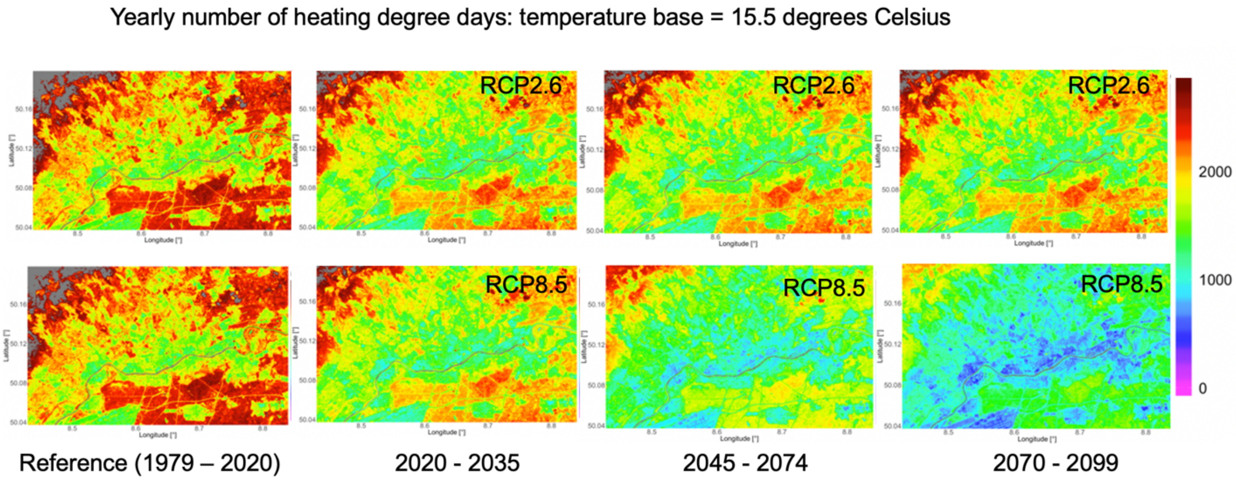


Figure 3.10: Heating degree days [K days] for Frankfurt am Main for 4 different time periods (reference period, 2020 – 2035, 2045 – 2074, 2070 – 2099) and two emission scenarios RCP2.6 and RCP8.5.

Figure 3.11 shows the average value of the cooling degree day index in high resolution for Frankfurt am Main for two emission scenarios and four different time periods.

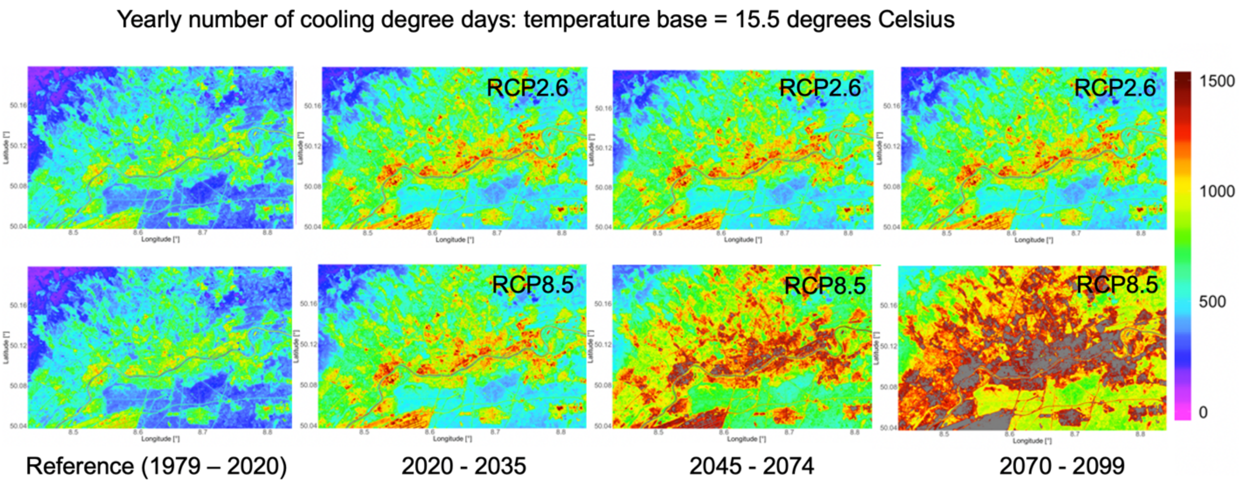
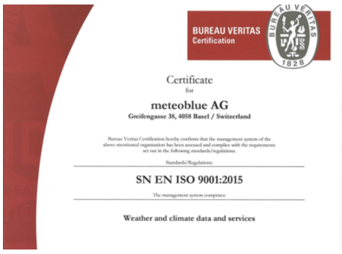


Figure 3.11: Cooling degree days [K days] for Frankfurt am Main for 4 different time periods (reference period, 2020 – 2035, 2045 – 2074, 2070 – 2099) and two emission scenarios RCP2.6 und RCP8.5.

4 About meteoblue

meteoblue provides worldwide accurate weather information of high quality for every point on land or at sea. meteoblue products and services are tailored to companies whose decisions depend on the weather and to users with a special interest in weather.
For this purpose, meteoblue creates weather information based on its own calculation models. We offer products and services based on this at competitive prices. For the general public, we offer a high-resolution weather forecast on our website, which is unique in several respects.
meteoblue uses the latest scientific and technical developments to calculate, display and deliver weather information. For forecasting, we have developed world-class, globally successful NMM weather models (such as those used in the JRC) through improved parameterisation and performance enhancement to enable us to calculate high-resolution weather forecasts at distances of 3-18 km for whole continents, and thus to provide accurate forecasts for mountainous landscapes as well. Events such as foen, thunderstorms, and sea-land winds can be made. Special algorithms allow us to adapt temperature, wind and humidity data to any location.
The meteoblue systems are geared towards global data availability, clear representations, versatile adaptation options to customer requirements and cost-effective operation.

meteoblue is ISO 9001:2015 certified since 2022.



5 Publications

List of selected publications:

Schlögl, S., Bader, N., Reiss, A., Ströbel, B., Gutbrod, K.: An overview of four use cases from a dense urban measurement network in Basel, Switzerland: Quality of the measurements, temperature and precipitation variability, and mitigation of urban heat island mitigation strategies, EMS Annual Meeting 2023, Bratislava, accepted.

Bader, N., Schlögl, S., Gutbrod, K.: High-resolution air temperature forecast for urban heat wave management, EMS Annual Meeting 2023, Bratislava, accepted.

Renold, M., Schlögl, S., Gutbrod, K., Anet, J.: Estimation, Estimation of high-resolution urban canopy temperatures based on a CNN model approach, Urban Meteorology, In preparation.

Hoy, A. and Gutbrod, K.: Showing the value of green spaces from a climate perspective: a weather sensor network for city spaces in Tallinn, EGU General Assembly 2023, Vienna, Austria, 24–28 Apr 2023, EGU23-8092, https://doi.org/10.5194/egusphere-egu23-8092, 2023.

Schlögl, S., Smalla, T., and Gutbrod, K.: Urban climate: Verfication of urban heat island mitigation strategies in the Swiss city Basel, EMS Annual Meeting 2022, Bonn, Germany, 5–9 Sep 2022, EMS2022-336, https://doi.org/10.5194/ems2022-336, 2022.

Bader, N., Schlögl, S., and Gutbrod, K.: High-resolution. temperature downscaling for global cities based on satellite imagery, weather station data and NWP model data, EMS Annual Meeting 2022, Bonn, Germany, 5–9 Sep 2022, EMS2022-384, https://doi.org/10.5194/ems2022-384, 2022

Schlögl, S., Bader, N., Anet, J. G., Frey, M., Spirig, C., Renold, M., and Gutbrod, K.: Automated detection of urban heat islands based on satellite imagery, digital surface models, and a low-cost sensor network, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-14143, https://doi.org/10.5194/egusphere-egu21-14143, 2021

Anet, J. G., Schlögl, S., Spirig, C., Frey, M. P., Renold, M., and Gutbrod, K. G.: Building a new high-density air temperature measurement network in two Swiss cities, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-9102, https://doi.org/10.5194/egusphere-egu21-9102, 2021

Schlögl S, Lehning M and Mott R (2018) How Are Turbulent Sensible Heat Fluxes and Snow Melt Rates Affected by a Changing Snow Cover Fraction? *Front. Earth Sci.* 6:154. doi: 10.3389/feart.2018.00154

Schlögl S, Lehning M, Fierz C and Mott R (2018) Representation of Horizontal Transport Processes in Snowmelt Modeling by Applying a Footprint Approach. Front. Earth Sci. 6:120. doi:10.3389/feart.2018.00120

Schlögl, S., Marty, C., Bavay, M., and Lehning, M. (2016) Sensitivity of Alpine3D modelled snow cover to modifications in DEM resolution, station coverage and meteorological input quantities. Environmental Modelling and Software, 83, 387-396.

Marty, C., Schlögl, S., Bavay, M., and Lehning, M. (2017) How much can we save? Impact of different emission scenarios on future snow cover in the Alps, The Cryosphere, 11(1), 517-529.

Marty, C., Abegg, B., Bauder, A., Marmy, A., Lüthi, M. P., Bavay, M., Hauck, C., Hoelzle, M., Huss, M., Salzmann, N., Schlögl, S., Steiger, R., and Farinotti, D. (2014) Cryospheric aspects of climate change – impacts on snow, ice and ski tourism, Chapter in CH2014 – Impacts: Toward quantitative scenarios of climate change Impacts in Switzerland, pp. 49-56.