A two-tier sensor network for real-time monitoring and modelling of urban-scale weather in Freiburg, Germany

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Background

- Weather events, such as heat waves, flash floods and wind storms, result in adverse effects to human health as well as economic losses and often display intra-urban variabilities in cities
- Weather sensor networks (WSNs) that monitor meteorological conditions in real-time play a vital role in quantifying, mapping and downscaling potential hazards (e.g. warnings or emergency response)
- Existing WSNs are typically limited to coarse networks, fail to measure all variables necessary to map, for instance, thermal comfort, or lack real-time data transmission

- In order to address some shortcomings of previous networks, we present a two-tier WSN that features
  - A highly flexible, custom-built setup of sensors with an extensive number of measured variables in selected urban and rural locations (Tier I stations)
  - A high spatial density of baseline measurements using cost-efficient ready-to-go weather stations (Tier II stations)
  - High measurement frequency and data transmission in near real-time

- With a run time of eight years, our WSN will be used to
  - Develop machine learning routines for data quality control in real-time
  - Downscale data from Tier II to Tier 1 stations
  - Provide input and validation data for numerical high-resolution modelling of urban heat, dynamics and hydrology
  - Provide researchers, city officials and the general public with instantaneous and historical data at neighborhood scale

The technical setup of the Tier I stations

- A custom-built logger board is controlled by a Raspberry Pi running a custom logging and remote control software
- A battery (3.7 V, 20,000 mAh) powers the station and is charged during the night using mains voltage from light pole
- Logger software provides full system monitoring and allows for remote access and control capabilities
- All measured data is transmitted in real-time via mobile network (LTE) and additionally stored locally
- Components are housed in a waterproof plastic box

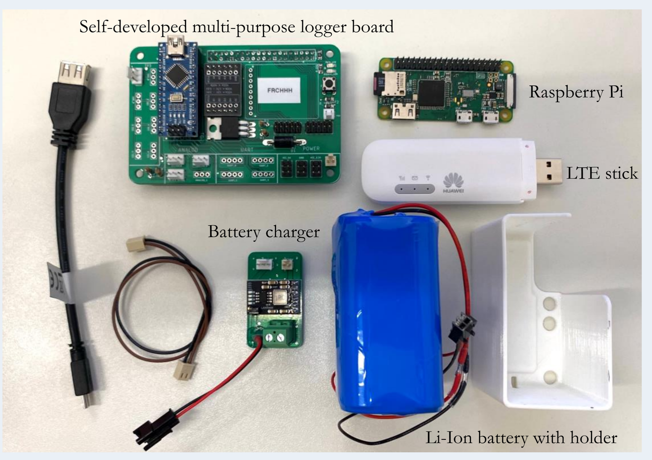

Figure 1: Logger system components.

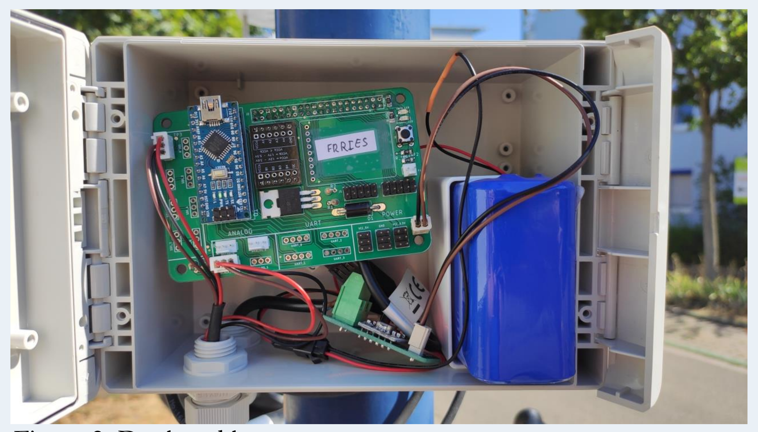

Figure 2: Deployed logger system.

An overview of the WSN

- The WSN currently encompasses 41 stations (13x Tier II, 28x Tier II)
- Measurement and transfer intervals of one and five minutes, respectively
- Installation on street light poles or custom metal poles at 3 m a.g.l.
- Site selection based on
  - Survey among experts and future users
  - Coverage of present local climate zones (LCZ)
  - Ethical aspects (e.g. equal representation of wealthier and poorer city districts)

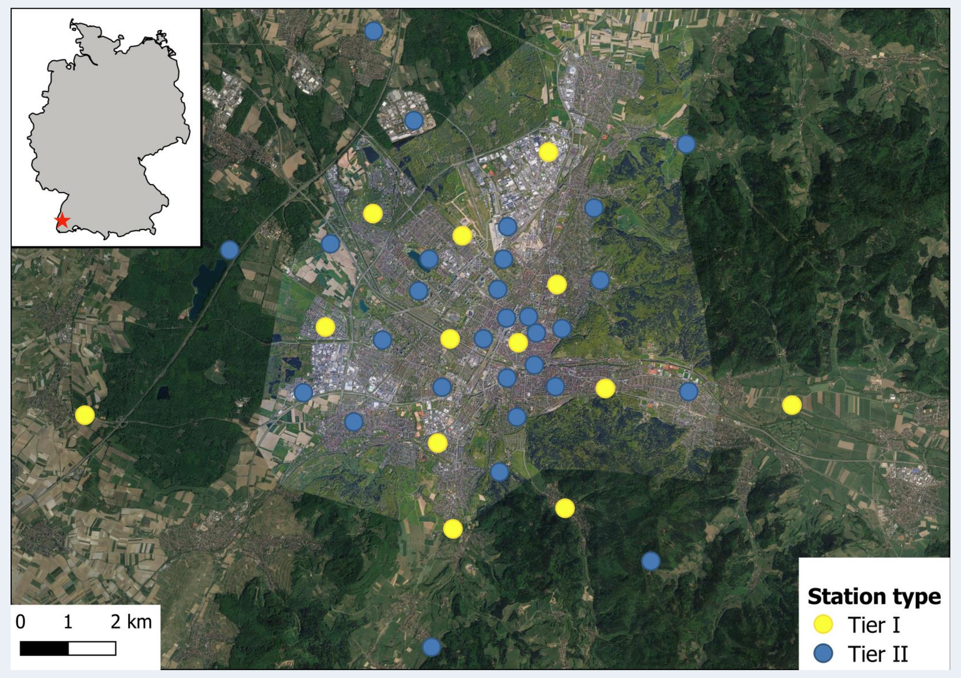

Figure 3: The spatial configuration of the WSN.

Table 1: Comparison of Tier I and Tier II station characteristics

Property	Tier I	Tier II
Deployed sensor(s)	• ClimaVue 50 (Campbell Scientific) • Black Globe (Campbell Scientific)	PESSL LoRain (PESSL Instruments
Measured variables	Air temperature, relative humidity, precipitation, air pressure, wind speed & direction, global radiation, radiant temperature, lightning	Air temperature, relative humidity, precipitation
Data transmission	Mobile network (LTE)	Mobile network (NB-IoT)
Expandability	Open for additional sensors (custom-built system)	Limited to current setup (closed all-in-one commercial weather station)

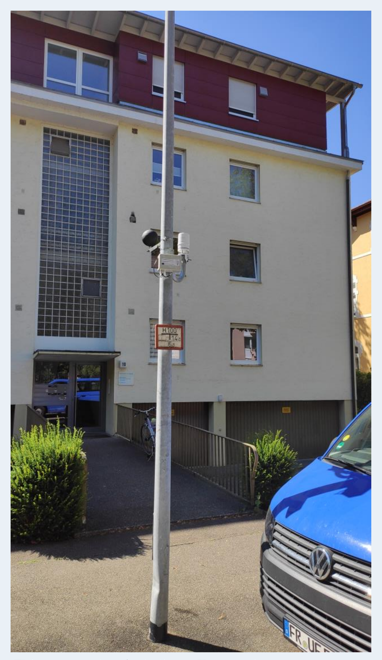

Figure 4: A Tier I station on a light pole.

Figure 5: A Tier II station on a light pole.

Figure 6: A Tier II station on a custom metal pole at a rural location.

The WSN in practice

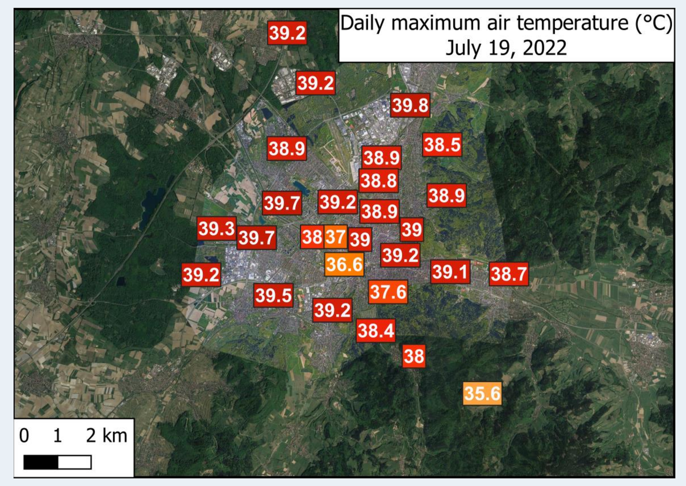

Figure 7 a-c: Visualizations of aggregated raw air temperature (top) and precipitation data (bottom) for selected time periods. Note that not all currently running stations were deployed at the displayed time periods. Moreover, all displayed data was obtained by Tier II stations as the installation of Tier I stations took place between Aug 8-10, 2022.

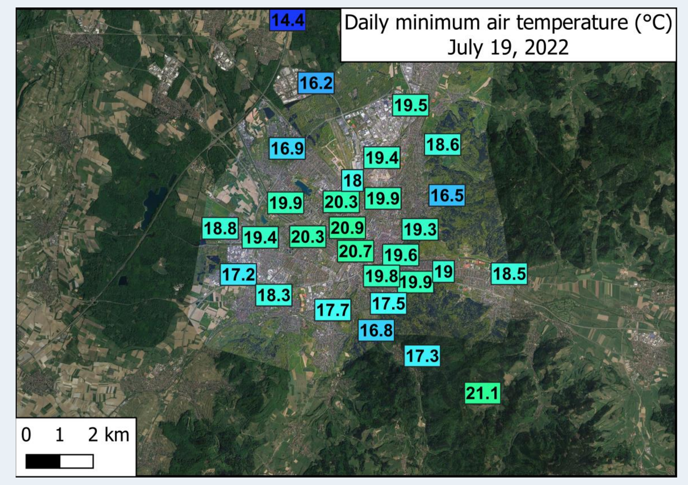

Figure 7 b.

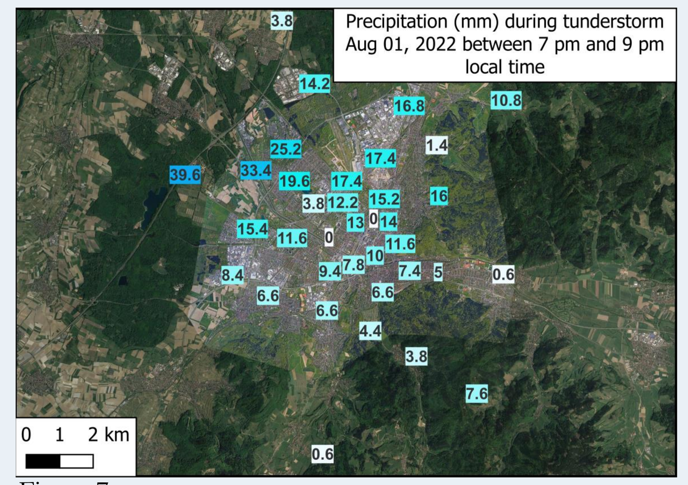

Figure 7 c.

- A Comparison of daily maxima and minima of air temperature measurements during a hot day (Figs: 7 a and b) indicates urban heat island effects, with small differences between urban and surrounding rural locations during the day (maxima) and more pronounced differences during the night (minima)
- The spatial distribution of precipitation sums during rain event shows substantial intra-urban differences (Fig. 7 c) but simultaneously highlights the need for quality control routines due to the presence of clearly erroneous measurements (e.g. values of 0 close to the city center)

The next steps

- Train and test machine learning algorithm to perform data quality routines in near real-time
- Finalize interface for real-time and historic visualizations and statistics for the general public
- Publish data sets at varying production levels for researchers and modellers

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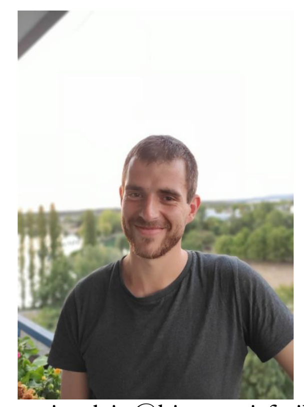

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