Quantifying the effects of microscale heterogeneity in urban surface structure on the urban heat and park cool islands in a mid-sized city in Central Europe

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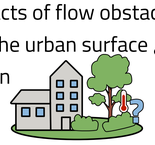
1 Introduction

In the urban boundary layer, air temperatures throughout the diel cycle are commonly higher than in rural areas. This is a consequence of modifications in the radiation and energy transfers, which depend on the microscale urban surface structure [1]. This urban heat island effect also affects medium-sized cities, but has received less attention.

Due to its topography, Bayreuth (Germany) is an ideal location to study the interaction between urban heat island effects and nocturnal cold air drainage (CAD).

We aimed to quantify the impacts of flow obstacles on CADs and of heterogeneity in the urban surface structure including city parks on the thermal variability.



2 Observation Strategy

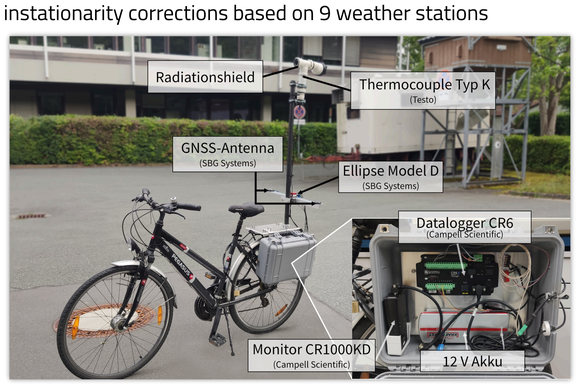
A combination of stationary and mobile measurements is used to obtain high-quality temporal and spatial meteorological data and capture the microscale heterogeneity of the urban area.

Stationary Measurements

- Up to 3 years of data from the city-wide meteorological microclimate station network using 13 high precision micro-weatherstations of the type ATMOS 41
- Classification of cold air nights based on microclimate characteristics between a rural and urban reference station (Air temperature difference of -2 K, gust speed at the rural station below 2.2 m s^{-1})

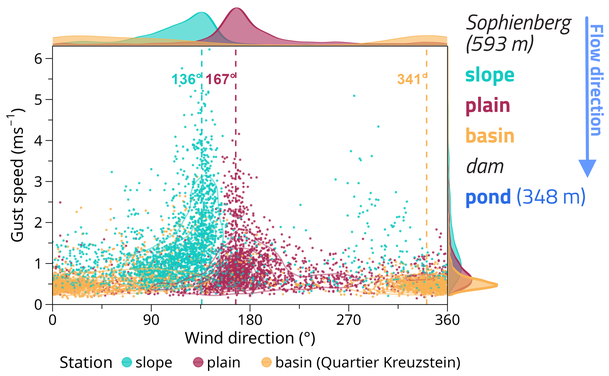
Mobile Measurements

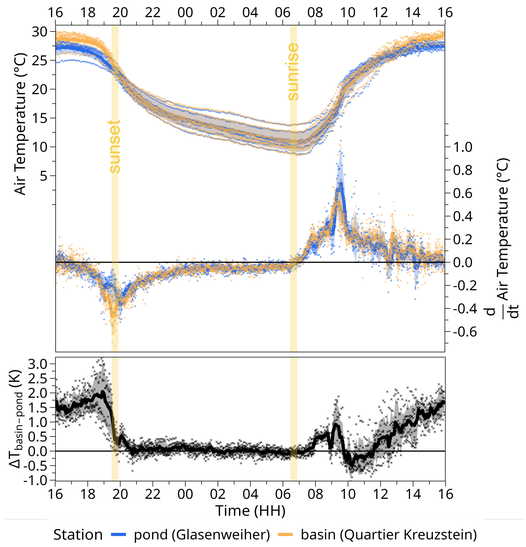
- Fast response air temperature measurements with a aspirated thermocouple (1 Hz)
- High precision position determination with GNSS ($\nabla\overline{\sigma} \approx 0.6$ m)
- Air temperature measurements on 6 cloud-free nights and days along a 11.5 km long route in southern Bayreuth
- Calculation of the difference to the mean city temperature and instationarity corrections based on 9 weather stations



3 Cold air pool and microclimate

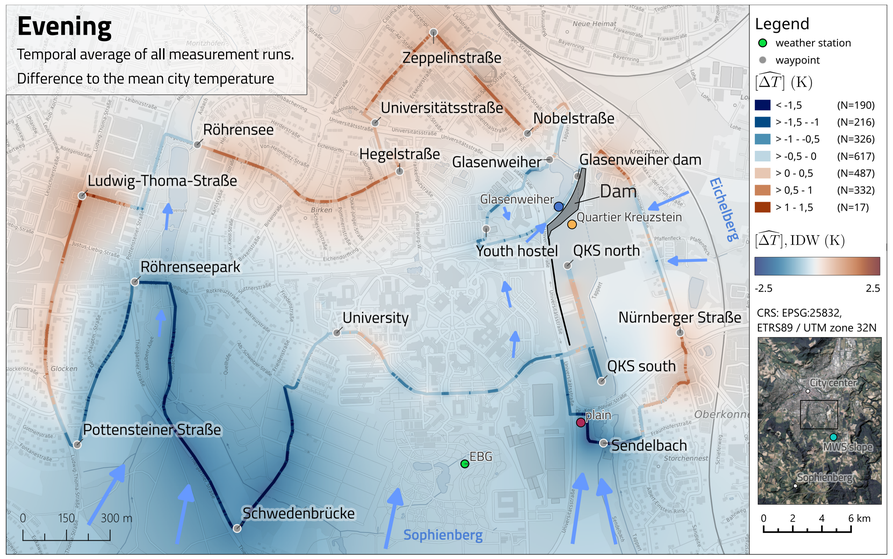
The dam (see gray structure on map in section 4) blocked the CAD originating from the surrounding topography (Sophienberg), approaching the obstacle with an average wind speed of 0.3 m s^{-1} and wind gust speed of 0.6 m s^{-1}. The blocking resulted in the formation of a cold air pool (CAP) characterized by slow and undirected winds on the upwind side. The distance between the station at the slope and basin is around 2 km.





The two sites basin and pond are separated by a 8 to 10 m high dam (distance ≈ 80 m) and are characterized by different microclimates. During the day, the cooling effect of the pond was limited by the dam.

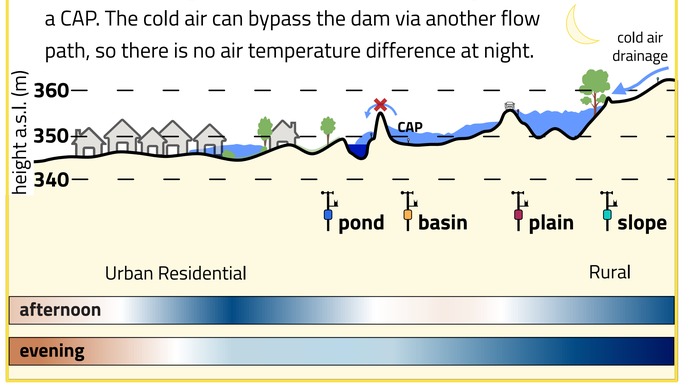
4 Air temperature distribution



- While the direct flow of cold air was blocked, some cold air takes a different path around the dam or forms locally, thus equalizing the air temperature difference between the two sides.
- The nocturnal cold air drainages reduce the ground-level air temperatures on the urban surrounding on average by 1.5 K.
- Areas shaded by single trees have a cooling effect of 1 K, areas with dense vegetation have a cooling effect of 2 K compared to the surrounding area in the afternoon.

5 Conclusion

- Our observational approach, combining mobile and stationary high quality instruments, provides a new level of insight into fine-scale microclimate patterns within urban environments that are often missed by conventional methods.
- In medium-sized cities, where building density and topography limit ventilation and cooling, the urban heat island can reach levels comparable to those of larger cities.
- The 8 to 10m high dam blocks the CAD, resulting in the formation of a CAP. The cold air can bypass the dam via another flow path, so there is no air temperature difference at night.



[1] Oke, T. R. (1973). City size and the urban heat island. 07 (Atmospheric Environment), 769–779.

Digital elevation model: Bayerische Vermessungsverwaltung – www.geodaten.bayern.de

Map background: TopPlusOpen Light Grau, Bundesamt für Kartographie und Geodäsie, 2023