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Urban Heat Effects and Targeted Adaptation under Extreme Events in the Lakeside City: A Case Study of Konstanz, Germany

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Urban climate conditions in lakeside cities are shaped by the interaction between the urban morphology and atmospheric processes modified by the lake. It is essential to understand how and where the urban effect intensifies in order to develop effective adaptation strategies under increasingly frequent and intense extreme climate events. In this study, the city of Konstanz, located on Lake Constance, is used as a case study to examine urban-induced climate responses during extreme conditions.

To assess urban climate impacts, high-resolution (1 km) simulations were conducted using the Weather Research and Forecasting (WRF) model with Building Effect Parametrization and Building Energy Model (BEP/BEM) integration. We simulated multiple extreme weather events, including heatwave and heavy rainfall events. Urban effects were quantified by contrasting current urban land use patterns with a hypothetical non-urban surface representation, allowing the evaluation of urban climate signals under lake-influenced conditions.

Results indicate that the urban thermal effect is particularly pronounced under nighttime conditions. Compared to non-urban conditions, urban areas exhibit enhanced nighttime warming, with surface skin temperatures rising by approximately 1–2.5°C during heatwaves. These patterns suggest that urban heat storage and release significantly contribute to the nighttime thermal conditions. Furthermore, this nighttime warming varies with lake proximity and land-use characteristics, indicating that these factors influence the spatial distribution of urban heat during extreme events.

Based on the findings, spatially targeted urban adaptation strategies are explored through the application of mitigation measures in areas experiencing persistent thermal stress. This study suggests that targeted approaches can effectively reduce local heat stress while limiting the extent of mitigation strategy application, emphasizing the potential for more strategic and efficient urban climate adaptation. This perspective provides useful context for climate-responsive urban planning approaches that give priority to impact-prone areas under increasing extreme events.