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Unlocking long-term insights from short-term PALM simulations: A simplified downscaling strategy using the SLUrb module

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Urban climate adaptation strategies such as including greening, surface unsealing, urban forestry, and street tree expansion are increasingly recognized as effective measures to mitigate urban heat stress. While state-of-the-art microclimate models can assess the thermal impacts of such interventions for individual heat days or short heatwave episodes, extrapolating these findings to long-term, temperature-based climate indices remains methodologically challenging. The cuboid method, originally developed to downscale regional climate model outputs using a limited set of urban climate simulations with MUKLIMO_3, offers a promising framework. Recent advances in the PALM model system now enable the application of this approach within its large-eddy simulation environment. This study within the research project "HeatProtect" presents a proof-of-concept implementation of a temperature-only cuboid method within the PALM model system to downscale regional climate data and generate high-resolution (32 m) urban climate indices. While PALM simulations with typical spatial resolutions of 1 – 10 m require higher computational efforts, the recently developed SLUrb module (single-layer urban canopy model) uses parameterized land-use and building datasets, allowing for coarser modeling tasks.

For the present use case, we reduced the original three-dimensional cuboid framework (temperature, wind speed, humidity) to a temperature-only approach with the potential to extend it to other variables in the future. Two PALM reference states, representing a typical temperate day and an extreme heat event, were conducted for Vienna, Austria. Daily mean temperatures from regional WRF model outputs are used to interpolate between these reference states, enabling spatial downscaling of daily minimum and maximum temperatures across multi-decadal periods. The SLUrb module initially derives 2 m air temperature by weighting outputs from canyon and land-surface models (LSM) according to urban fraction. With this initial representation of vegetation canopy and model setup, some local features of the urban climate, like cold air channels, could not be resolved. Sensitivity tests with thermal roughness length of forests and parallel simulations with the plant canopy model (PCM) replacing LSM, led to more realistic representation of cold air streams and forest areas during nighttime.

Static modifications of urban fraction permit assessment of greening and unsealing scenarios without additional simulations, although spatial propagation of thermal effects to adjacent areas is

not captured. To evaluate tree impacts, we performed a separate PALM simulation with complete forest coverage. Using a high-resolution (2 m) vegetation dataset, the weighting scheme was extended to incorporate for high-vegetated areas. While this approach enables the theoretical consideration of adaptation measures based on high vegetation, the rather simplified method has significant limitations, including (1) missing lateral interactions and advection within canopy, (2) non-linear mixing effects, or (3) decoupled radiation interactions.

Model verification was conducted by comparing simulated climate indices (tropical nights (Tmin ≥ 20°C), summer days (Tmax ≥ 25°C), and heat days (Tmax ≥ 30°C)) against 10-30 years of observational data from meteorological stations across Vienna. Final results, validation statistics, and detailed performance assessments will be completed by early 2026 and presented at the conference.