Evaluation of a novel city climate model

Evaluation of PALM-4U for big German cities against data from intensive observation periods

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In Short

- Extensive evaluation of a novel city-climate model
- Comparison is based on data from large measurement campaigns
- Target cities for evaluation are Berlin and Stuttgart

With the growing economical importance of cities, the people's "natural" environment for working, accommodation and recreation is an urban settlement. A growing city population is associated with a replacement of nature spots, a concentrated consumption of resources, high energy demand, and increased air pollution. The interactions between urban areas and the atmosphere have received growing attention in urban-climate research in the last decades [1]. The main challenges in the 20th century were the urban heat island problem [2] and urban air quality issues [3], both affecting human health and comfort. It is therefore necessary to include these aspects in sustainable and future-oriented city planning, especially under consideration of local and regional impacts of climate change, leading to increased threats of heat waves and declining air quality. Urban climate models (UCMs) are the tool of choice to estimate effects of the city morphology (e.g., building density, degree of soil sealing, facade greening, etc.), on air quality, and thermal/wind comfort for urban residents. Within the joint research project MOSAIK, as part of the three-year nation-wide program Urban Climate Under Change ($[UC]^2$) funded by the German Federal Ministry of Education and Research, a new modern UCM of unprecedented spatial resolution and computational performance has been developed. The highly parallelized and optimized large-eddy simulation (LES, turbulence-resolving) model PALM [4] served as the core of the new model PALM-4U (reads PALM *for you* / *for Urban applications*). PALM-4U is applicable on massively-parallel computers as well as on city planners' local workstations. To transform PALM-4U into a fully functional UCM, the following features have been added to the PALM core:

- Reynolds-averaged-Navier-Stokes (RANS) type turbulence parameterizations for fine and coarse spatial resolution;
- grid nesting to enable a zoom function allowing practitioners with limited computer resources to perform high-resolution studies for small city quarters, embedded into a coarse-resolution larger city domain;
- an energy-balance solver for all relevant urban surface types;
- an indoor-climate and energy-demand model for buildings;
- a full air-chemistry model;
- a multi-agent system (MAS) for studies of environmental effects on large groups of people.

With its LES core, PALM-4U is the first UCM with LES mode, allowing for a direct quantification of turbulence-induced fluctuations (e.g. peak concentrations or wind gusts). PALM-4U will be able to provide maps of urban climate and bio-climate standard products including physiological equivalent temperature (PET, see Fig. 1) and universal thermal climate index (UTCI), but in addition the MAS will also help to identify areas for humans with high stress potential based on the individual characteristics of the agent, such as the walking path and speed, age, clothing, etc. These hotspots cannot be determined from standard maps, because these do not take into account peoples' behaviour. The new model requires local surface information with very high resolution of building topography, vegetation, soil moisture etc., which can be derived from sources like satellite data, aerial imagery, and existing municipal data.

The main PALM-4U components as described above have been successfully developed by the end of 2019 [5] (see also former HLRN projekt nik00060). With the second phase of the $[UC]^2$ project (from September 2019 to August 2022) the BMBF is pursuing the goal of further developing PALM-4U into a product that meets the needs of municipalities and other practise users. At the same time, the model shall also be used for scientific research, and shall therefore be further developed and evaluated accordingly. One of the main goals is a further extensive evaluation of the model based on measurement campaigns conducted in the first phase within the cities of Berlin and Stuttgart. In total, five large simulations are planned for five different intensive observation periods, where different measurement strategies and systems were applied, including stationary tower measurements but also trajectory measurements with complicated pathways. Comparisons will be performed with respect to various atmospheric and chemical properties like fine dust (PM10, see Fig. 2).

First results from different evaluation simulations are shown in Fig. 1, 2, and 3. Different land-cover has a strong influence on the local micro-climate. In areas with a high percentage of sealed surfaces like in city centres, people experience intense heat stress while rural areas, forests in particular, create a more bearable climate during hot summer days. This could be reproduced in the evaluation simulations and is depicted in Fig. 1 which shows the PET distribution in Stuttgart during a hot summer day. Also the capabilities to simulate chemical properties and fine dust could be demonstrated as shown in Fig. 2. Large streets are the main source of fine dust in the centre of Stuttgart.

A direct comparison of simulation results and observational data showed a remarkable performance of PALM-4U. Figure 3 depicts the time series of air temperature observed and simulated in central Berlin. PALM-4U correctly reproduces the diurnal cycle and follows the observations. The bias between observations and simulation are due to differences in the land cover and resolved detail. Despite PALM-4U's high spacial resolution of 2 m, differences between reality and simulation model still occur. Details in the vicinity of the measurement stations might not be adequately resolved in the model. Due to the high complexity of the urban climate, this may already explain most of the bias. A more comprehensive evaluation of all measurements is yet to come as part of the ongoing project.

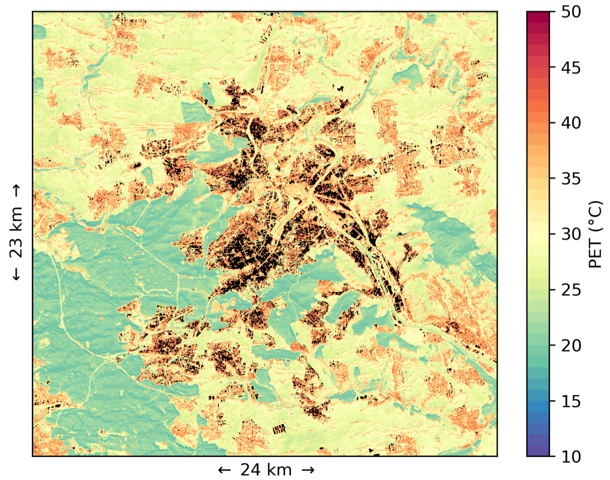

Figure 1: Mean physiological equivalent temperature in Stuttgart and its surroundings during noon. The distribution shows high values, i.e., heat stress in the city centre while low values, i.e., no heat stress are present in the nearby forests.

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http://uc2-program.org/

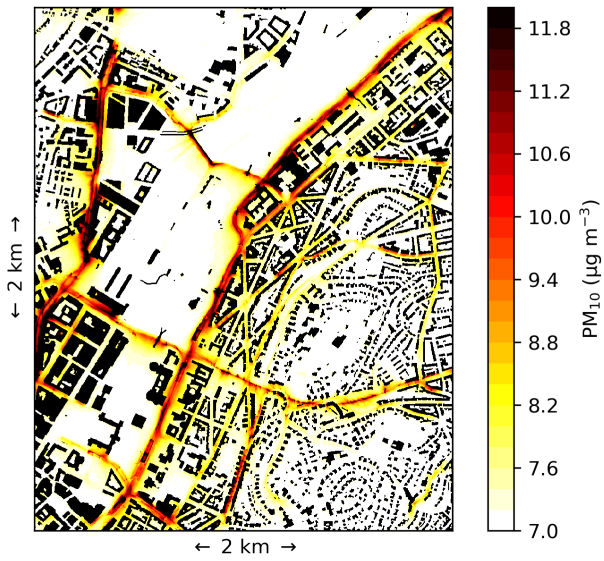

Figure 2: *Simulated PM10 concentration in the city centre of Stuttgart. High values can be observed along the Bundesstraße 14 and 27.*

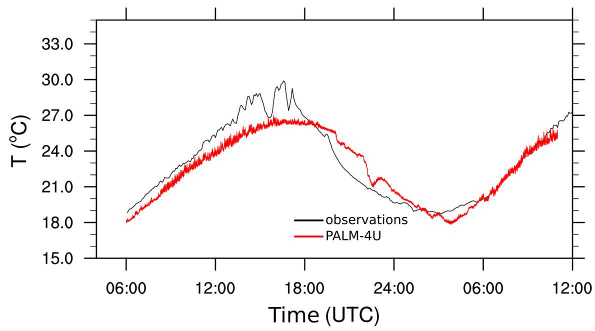

Figure 3: *Comparison of temperature observations and PALM simulation results at a measurement station in central Berlin.*

More Information

[1] Oke, T. R., *Theor. Appl. Climatol.* **84**, 179–190, (2006).

[2] Oke, T. R., *Appl. Sci.* **277**, 81–107, (1995).

[3] Kuttler, W., Oßenbrügger, J, Halbig, G. *Städte: Klimawandel in Deutschland*, Springer, 225–234 (2017).

[4] Maronga, B., Gryschka, M., Heinze, R., et al. *Geosci. Model Dev.* **8**, 2515–2551 (2015). doi: 10.5194/gmd-8-2515-2015

[5] Maronga, B., Banzhaf, S., Burmeister, C., et al. *Geosci. Model Dev.* **13**, 1335–1372 (2020). doi:10.5194/gmd-13-1335-2020

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