Decoding the Urban Microclimate: PALM Model in Focus

Sensitivity of the LES model PALM to building parameters and evaluation study with crowdsourced air temperature data

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In Short

- Urban areas experiencing detrimental effects from intensified heat load
- Accuracy and reliability challenges in LES results for complex urban areas
- Sensitivity analysis and validation of PALM model in real urban districts

Urban areas are increasingly experiencing detrimental effects from intensified heat load, leading to significant impacts on public health and mortality rates. With their intricate geometries, heterogeneous distribution of land cover types, and complex atmospheric interactions, urban surfaces play a crucial role in governing energy, mass, and momentum exchanges. These surfaces are particularly exposed to extreme climatic conditions, exhibiting the highest or lowest temperatures, the driest or most moist environments, and areas of reduced airflow. Moreover, the near surface exhibits the greatest variability in microclimates, displaying a wide range of values across different locations and throughout the day and night.

To comprehend these complex processes and their implications on microclimates, computational fluid dynamic (CFD) models emerge as an essential and fundamental tool, enable comprehensive analysis and simulation of these complex interactions, thereby facilitating a deeper understanding of urban dynamics and the development of effective strategies for urban climate adoption. Previously, CFD studies relied mainly on the Reynolds- Averaged Navier-Stokes (RANS) technique. However, advancements in computational power have ushered in the prominence of the Large-Eddy Simulation (LES) technique, offering a valuable tool for investigating flow dynamics. The continuous increase in computational resources makes LES models the most promising method to provide sufficiently detailed and accurate information on how the interaction of heat, moisture and momentum exchanges affects the local urban microclimate. This transition in methodology has resulted in enhanced insights into the intricate interactions between urban structures and flow processes, enabling a more accurate representation of real-world scenarios. However, due to the complexity of urban microclimate studies and the need for simplifications, the accuracy and reliability of LES results may be compromised, particularly in complex real urban areas with prevalent uncertainties in input data. Parameters such as building heights, physical properties, tree locations, shape, leaf area density, and land surface characteristics contribute to input data. However, many of these parameters describing the urban environment are either known only approximately or unavailable. Therefore, it is important to know the sensitivity of the model results to the uncertainties in the input data in order to assess the spread of potential deviations in model simulations or, in planning stages, which parameters are to be gathered with higher priority in data collection campaigns. Additionally, careful validation of simulation results is imperative to ensure their accuracy and reliability.

The proposed project involves a systematic sensitivity analysis and validation of the LES-based PALM model system 6.0 (Maronga et al., 2020) within real urban districts in Germany, specifically during a heatwave period and a cold episode. The model core calculates seven prognostic variables: the velocity components u, v and w, the potential temperature, the sub grid-scale turbulence kinetic energy, the water vapor mixing ratio and optionally a passive scalar for each grid point. First, the simulations will be performed to evaluate the sensitivity of the PALM model to variations in building parameters. Specifically, the focus will be on different levels of detail in building typologies, considering a wider range of building typologies than the standard building classifications used in previous studies. To enhance the accuracy of representing the diverse building stock in urban areas, we will incorporate the TABULA database from the IEE Project "Typology Approach for Building Stock Energy Assessment." This database provides detailed information on 42 building typologies specific to German cities. Simulations will be conducted with several scenarios, each varying in the level of detail. This analysis aims to determine the sensitivity of the PALM model to building parameters and understand how changes in the level of detail affect the model's results. Furthermore, the advantages and costs associated with each level of detail will be thoroughly discussed. Higher levels of detail in building parameters provide a more realistic representation of urban environments, leading to improved accuracy in simulation results. However, higher levels of detail also come with increased computational costs and data requirements. It is important to carefully consider these trade-offs when selecting the appropriate level of detail for specific applications. Additionally, the first part of the project aims to capture the dynamic interplay between indoor building climates and the surrounding microclimate by incorporating the building indoor module. The sensitivity analysis will be conducted in a Homogeneous Local Climate Zone (HLCZ) located in Bochum.

The second part will focus on the validation of PALM model by incorporating crowdsourced data. Traditional measurement campaigns and professional weather stations often face limitations in capturing intraurban temperature variations, necessitating alternative approaches. Crowdsourcing weather data has emerged as a promising method to study urban microclimates, offering enhanced spatial coverage and density. Combining crowdsourced climate data and microscale climate modelling has the potential to become a powerful tool to study the urban microclimate and develop adaptation strategies to negative climatic effects. Therefore, this study aims to assess the applicability of crowdsourced data for PALM model evaluation in various settings and elucidate the strengths and limitations of this approach. The simulations will be conducted in four representative cities, namely Dortmund, Cologne, Frankfurt, and Berlin, characterised by variations in size, population density, terrain features, and urban land use patterns. The selected simulation period will focus on a representative summer scenario characterised by a clear sky, low wind speeds, and high daytime and nighttime temperatures.

In both parts of the project, the simulations will encompass three model domains spanning from the mesoscale to the microscale, ensuring a comprehensive spatial representation. By incorporating boundary conditions derived from COSMO-D2 data, the simulations will effectively capture the influence of mesoscale weather patterns and propagate turbulent eddies to the microscale domains. The planned simulations will specifically focus on key parameters, including air velocity, air temperature, indoor air temperature, waste heat, and surface temperature. Each simulation period will span 78 hours, allowing for a comprehensive analysis of these parameters over an extended duration.

The current project requires the integration of mesoscale weather effects and high spatial resolution. PALM's nesting capabilities effectively reduce computational costs by utilizing child domains of finer resolution within a larger domain. However, in order to accurately represent the largest turbulent eddies and the height of the boundary layer during summer conditions, larger model domains with a substantial number of grid points are necessary, leading to increased computational requirements. Additionally, the wide range of turbulent scales and high wind velocities necessitate the use of small time steps, further augmenting the demand for computational resources. Given the limited resources available at local universities, accessing massively parallel computer architectures such as HLRN-IV systems become imperative to meet these computational demands.

The proposed project aims to facilitate the application of the PALM model for urban microclimatic studies and planning processes. Reproducible workflows for the preparation of the input data, analysis of the results and evaluation with crowdsourced data will be developed and made publicly available.

WWW

https://www.geographie.ruhr-uni-bochum.de/klima/index.html.de

More Information

[1] B. Maronga et al.: Overview of the PALM model system 6.0., *Geosci. Model Dev.* **14**, 8 (2020). doi:10.5194/gmd-13-1335-2020

[2] L. van der Linden et al.: Crowdsourcing air temperature data for the evaluation of the urban microscale model PALM—a case study in central Europe, doi:10.31223/X5WW8G

[3] Model Homepage https://palm.muk.uni-hannover.de/trac

Funding

The first part of the project is funded by a doctoral scholarship program from the German Federal Environmental Foundation (Deutsche Bundesstiftung Umwelt).

DFG Subject Area

313-01 and 317-01