Unveiling PALM's Sensitivity: Enhancing Urban Microclimate Understanding

Analysis of the sensitivity of the LES model PALM to building parameters and the quality of input data concerning surface descriptions and tree representation

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In Short

- High-resolution meter-scale models providing detailed insights into urban microclimates, requiring substantial computational resources
- Sensitivity analyses highlighting the trade-off between data quality, model precision and computational resources
- Analyzing discrepancies between modeled and crowdsourced data, critical for model validation
- Numerical modeling offering comprehensive simulations and capturing complexities, addressing the challenges of real-world mitigation measures complicating impact isolation

Urban areas encounter substantial climatic challenges primarily due to dense building structures, diverse surface materials, and limited green spaces. Understanding the intricate relationship between the urban microclimate and energy balance is crucial for effectively addressing these challenges. Despite decades of research, studying urban climate dynamics remains a complex and demanding endeavor. Urban climate models play a crucial role in developing strategies to mitigate adverse effects, enhancing our understanding of the complex dynamics of mass and momentum that define these processes. In this context, large-eddy simulation (LES) represents a cutting-edge technique in computational fluid dynamics, renowned for its capability to explicitly resolve and simulate large turbulent eddies. LES has exhibited exceptional performance in capturing instantaneous turbulence structures within intricate urban settings, as evidenced by several studies. However, accurate input data is crucial for producing reliable model results, often entailing substantial computational costs. High-resolution meter-scale models offer detailed insights into urban microclimates but are associated with considerable computational demands. Many parameters characterizing the urban environment are either approximated or unavailable, necessitating sensitivity analyses to evaluate the impact of data uncertainties on model outcomes. Consequently, understanding the trade-off between data quality and model accuracy is crucial for producing reliable results and effective mitigation solutions. By comprehending these sensitivities, it is possible to ascertain which mitigation measures will exert the most substantial impact on both indoor and outdoor environments. Implementing urban mitigation measures in real-world scenarios often lacks a systematic approach, making it challenging to isolate their specific impact on the urban atmosphere through in situ measurements alone. Laboratory experiments, such as those conducted in wind tunnels or test stands, often oversimplify critical thermodynamic processes or fail to fully capture interactions within the urban microclimate. Therefore, numerical modeling is indispensable for its ability to comprehensively simulate scenarios and precisely capture the intricate complexities of urban microclimates.

The proposed project builds on a foundational study that established the sensitivity of the Parallelized Large-Eddy Simulation Model (PALM) to various building parameters and evaluated the model using crowd-sourced data. Over the past project period, substantial progress was made in three primary work packages. Work Package 1 was dedicated to creating advanced Python and R scripts for preprocessing a variety of geospatial data for the PALM static driver. These scripts have been made publicly available on a GitHub repository (Preprocessing4PALM). Work Package 2 focused on sensitivity scenarios and conducting simulations for Bochum to understand how varying levels of building detail impact model outputs. By adjusting these sensitivity scenarios, the research explored the influence of different building types on urban microclimate dynamics. The simulations were conducted over 71 hours starting on February 7, 2021. Preliminary results indicated differences between model outputs across three scenarios: identical building type, four building types, and 28 building types. These differences in building roof surface temperatures were particularly noticeable during the period from afternoon to early morning hours. Work Package 3 initiated PALM simulations for Dortmund, utilizing crowdsourced air temperature data for model evaluation. The study period started on August 6, 2020, and included a 72-hour simulation using atmospheric boundary conditions from the COSMO-D2 model. The modelled and measured data show a generally good agreement and a clear representation of daily cycles. The measured data reveals a higher air temperature range than the modelled data. Discrepancies noted between modeled and measured air temperature ranges were attributed to sensor lag and remaining radiation errors in the measurement data. The results establish a robust foundation for the proposed follow-up project.

The primary objective of this follow-up project is to delve deeper into how variations in building parameters and the quality of input data impact the model's performance. Specifically, the focus will be on assessing the influence of surface descriptions and tree representations on the sensitivity of PALM. Additionally, the study will examine the influence of building retrofits on waste heat emissions and sensible heat flux during severe cold and hot weather conditions. Therefore, the follow-up project is structured into three primary sections: Analyzing the model's sensitivity to building parameters and the quality of input data; Evaluating the model using crowdsourced data; Assessing the impact of extensive area-wide retrofitting on urban microclimates.

In the initial study, despite the limitations of PALM version 23.10, we defined 48 parameters for each TABULA building type. With the recent upgrade to PALM version 24.04-rc.1, we will expand this to 136 parameters, allowing for a more comprehensive sensitivity analysis within the same domain and episode as outlined in Work Package 2 of the initial proposal. This enhancement will fortify the integration of the TABULA tool with the PALM model, enabling more rigorous analyses of building characteristics and model performance. Further sensitivity analysis will focus on input data quality, specifically targeting tree representation and surface descriptions. The scenarios to be considered include: tree data generation from different data sources such as airborne LiDAR and tree cadastres as well as tree representation only in high-resolution child domains (2 m) and absence in lower resolution domains; surface description refinement (pavement, vegetation, water type) using ALKIS land use data, Urban Atlas land use data, or CORINE Land Cover data, and incorporation of remote sensing data where applicable; and comparisons of uniform versus spatially varying soil types. The model configuration will align with that outlined in Work Package 3 of the initial proposal. We will focus on a summer scenario characterized by clear skies, low wind conditions, and high air temperatures during both daytime and nighttime.

The second section aims to pinpoint the causes of discrepancies between the modeled data and crowdsourced measurements. To accomplish this, we will conduct a comparative analysis of results from the cities of Dortmund, Cologne, and Berlin, thereby enhancing the value of the information derived from the model evaluation and pinpointing specific areas for model improvement.

The third section focuses on examining the effects of areawide building retrofitting on the urban microclimate and waste heat. At the outset, Homogeneous Local Climate Zones (HLCZs) will be identified in the Ruhr area, Germany, to serve as representative neighborhood-scale morphologies. This approach will optimize computational efficiency while ensuring representation of diverse urban forms. Subsequently, simulations will explore three scenarios tailored for severe winter and summer conditions: one using baseline building parameters derived from the TABULA project, another incorporating standard retrofit measures recommended by TABULA, and a third implementing advanced retrofit parameters.

The findings from this study will advance the understanding of how detailed building parameters and high-quality input data influence the accuracy of PALM model. By integrating enhanced sensitivity analyses, crowdsourced data validation, and comprehensive simulations of retrofitting scenarios, the project aims to provide robust, actionable insights.

WWW

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

More Information

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DFG Subject Area

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