User requirements and case studies to evaluate the practicability and usability of the urban climate model PALM-4U

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Abstract

As cities are sensitive to climate change, they must be prepared for its consequences. While high-performance urban climate models are the basis for prospective planning decisions, as of today, practice-oriented models are rare. Within the framework of the *Urban Climate Under ChangeUC*² research programme, the new urban climate model PALM-4U will be developed to simulate climate and air-pollution problems in urban areas. The joint projects KliMoPrax and UseUClim deal with both the model's practicability and usability, and, therefore, are to be conducted together with partners from German municipalities and industry, with user requirements identified and summarised for implementation into the new model. Furthermore, case studies on current and future municipal issues will be performed using the PALM-4U model. At the conclusion of the project, the new model's practicability and usability are evaluated, with the results to be summarised in an evaluation report including recommendations on further model development for both current and future everyday municipal planning.

Keywords: urban climate, urban planning, user requirements, science-practice interface, urban climate model

1 Introduction

The 21st century will be the century of cities (KRAAS et al., 2016). As more than half of the world's population live in cities, cities are the foremost areas facing the challenge of climate change. Cities are both strongly affected by climate change, and are themselves part of the cause, making the mitigation of greenhouse gases and adaptation to climate change important issues.

Within urban-development processes, many meteorological or air-quality issues play a role. A multidimensional temporal, spatial and thematic state-space exists from the city-wide to a single-building perspective, from single case studies to long-term climatologies and climate indicators, from the present status to a future development in a changing climate, from heat stress in urban canyons and indoor spaces, and from the rainwater supply of green areas to air-pollution conditions in cities.

While numerical models for the simulation of the urban atmospheric boundary layer (numerical urban climate models) are useful tools for urban development processes, current models do not fulfil the multifaceted requirements arising in the field of urban planning. For example, current models are often not free to use, are partially lacking user-friendliness, need extensive computing resources or are incompatible with the computer and software resources in municipalities. Therefore, to ameliorate these weaknesses, the research programme *Urban Climate Under Change* [UC]² aims to develop a new high-resolution and user-friendly urban climate model for cities and urban areas (SCHERER et al., 2019b).

The [UC]² research programme is divided into three collaborating modules. Modules A (MARONGA et al., 2019) and B (SCHERER et al., 2019a) develop and validate the PALM-4U model (PALM for urban applications or "PALM for you"), and undertake three-dimensional observations of the urban atmosphere. Module C is concerned with the new model's suitability and usability for practical applications (see Fig. 1). The model results, therefore, have to provide reliable information for a great number of applications. To meet the requirements of computer infrastructure and the expertise level of prospective users, application examples and user groups

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Figure 1: Overview of the structure of the [UC]² research programme (From SCHERER et al., 2019b).

will be directly integrated into model development and data collection.

Within the preparatory and executive spatial planning, municipalities and planners depend on up-to-date and climate-relevant data to enable a sustainable planning process. The availability, further processing and interpretation of these data in the applied programme design serve as a basis in the realisation of a planned project.

This article summarizes the scientific methods employed in the research programme, whose aims include

- identification of the demands and operating procedures of potential user groups of the PALM-4U model,
- testing and evaluation of the practical deployment of urban climate models in urban planning within a continuous exchange and application process, and
- evaluation of the applicability and user-friendliness of the new urban climate model.

2 Structure and working plan of module C

Module C is a collaboration of the two consortia KliMo-Prax (Climate Models for Practice) and UseUClim (Review of practical and user serviceability of an urban climate model to foster climate-proof urban development) dealing with the new model's practicability and usability.

The KliMoPrax consortium consists of the six research partners *Research Institute for Water and Waste Management* (FiW, coordinator); *BKR Aachen Noky & Simon; Deutscher Wetterdienst, Branch Office Essen (DWD, scientific coordinator); German Institute of Urban Affairs (Difu); GEO-NET Umweltconsulting GmbH* and Social Research Centre Dortmund (sfs) working together with the German municipalities of Berlin, Bonn, Essen, Hamburg, Karlsruhe, Munich and Stuttgart. In a wide user dialogue, the demands and abilities of the municipal users are evaluated and condensed into the User and Requirements Catalogue (URC) (common module C report, phase one, see Fig. 2 and Section 3). As a result of phase one, case studies (from whole city aspects to quarter developments) are defined, and climatological and air-quality questions will be answered with the help of calculations with the PALM-4U model (phase two, see Fig. 2). An evaluation report will show to what extent the user requirements relative to the new urban model are fulfilled, and where gaps exist (common module C report). Further focal points of the KliMoPrax consortium are scientific reports about future challenges of applied urban climate research (Section 6.1), as well as how a new, easy-to-use urban climate model may change stakeholder roles, and their interactions in the application processes of such a model (Section 6.2).

In the UseUClim consortium, the overarching concept is to provide input for model development in module A, as well as to review the urban climate model's practicability with regard to the living lab approach. Living labs are platforms that gather all pertinent stakeholders, and thereby support a systematic user-science interaction (WESTERLUND and LEMINEN, 2011). The UseUClim consortium's living lab is divided into three phases: 1) exploration, 2) experimentation and 3) evaluation. In parallel with these activities, two focal points are pursued (see Fig. 2), including the exploration of software interfaces to serve further in-depth analysis methods in the field of climate-proof urban development, and the continuation of activities aiming to disseminate the obtained knowledge and achievements. The UseUClim consortium is headed by the Climate Service Center Germany (GERICS) in cooperation with the Fraunhofer Institute for Building Physics (IBP). The consortium is supported by four professional partners, namely, the municipalities of Chemnitz, Dresden and Leipzig, as well as Sweco GmbH, an internationallyactive architecture and engineering consultancy.

One overall goal of the [UC]² programme is to ensure practicability and usability and, thus, the applicability of the urban climate model PALM-4U to be developed within the project. Additionally, it is the aim to achieve, together with the cooperating municipal partners and other future users, a realisation of the PALM-4U model according to their needs and requirements.

The working structure of the three-year funding period and the interaction between the cross-consortium collaboration and consortium-specific working packages are outlined in Fig. 2. As a first step, the URC will be developed by establishing a broad user-dialogue process for the development of so-called user scenarios, including an online survey and desk research. The URC will serve as the guideline for real case studies, in-house trainings, and the final evaluation report. The results of the case studies and in-house training will demonstrate



Figure 2: Working structure of module C, consisting of the KliMoPrax and UseUClim consortia. Figure courtesy of GERICS.

to what extent the new PALM-4U model fulfils the requirements of users and the funding authority.

Further work packages deal with innovations in the applied urban climate research, the exploration of interfaces to other software, and the continuation of the developed structures and activities in the field of modern urban climate modelling.

3 User and Requirements Catalogue

To ensure practicability and usability of the PALM-4U model, the *User and Requirements Catalogue* is to be elaborated in phase one of the project.

3.1 Objectives

The objectives of the URC are to bring municipal and scientific requirements, as well as the demands of wider society, into harmony with the model development. Hence, the catalogue is a communication tool to transfer and translate the demands arising from urban development and planning to the model development. Thus, the recipients of the URC are both the model developers of module A and the partners from module B, in which the observational data collection and validation of the PALM-4U model will take place. The URC is a key product of module C, and consists of two main components: the first is the preparation of requirements in a tabular format, the second is an explanatory document with further information on each set of requirements (STEURI et al., 2018; WEBER et al., 2018), with both products developed in parallel. Additionally, a report will summarise all user scenarios identified and developed in cooperation with the municipal partners.

3.2 Approach and methodology

The elaboration of the catalogue follows three essential steps. The first step includes an inventory and survey of current and anticipated requirements, user capacities and resources, and the expectations of municipal partners. The second step aims to identify, analyse and cluster boundary conditions, user scenarios and preliminary indications on requirements based on expert knowledge. The systematic analysis of user scenarios and exploration of interfaces relevant in urban-development processes, as well as the subsequent derivation of user requirements, are the main activities of the third step. Essential activities for the identification of user requirements include both a dialogue process with potential users (administration, associations, etc.) within the Kli-MoPrax consortium for developing a set of typical and transferable user scenarios, as well as an online survey of the UseUClim consortium with the partners from municipalities, the scientific community, and the wider society. The dialogue process is designed to accompany the development of the PALM-4U model, and is to be continued throughout the duration of the project, taking place in workshops and training sessions with potential users. The experiences from the practical partners are crucial to ascertain the suitability of the PALM-4U model for applications in urban-development processes.

3.2.1 User dialogue

Within the KliMoPrax consortium, a user dialogue targets to enlarge the use of the PALM-4U model from specialised scientists and engineering offices to a wider audience. The research question focuses on the demands and abilities of those who will be using the PALM-4U model in their daily planning process, with a focus on municipal administration.

The user dialogue is one of the key elements in formulating the user requirements from the perspective of the everyday practice in municipalities, contributing to achieve an urban climate model supporting the planning processes within the municipalities.

The methodical design of the user dialogue is based on 1) an in-depth working dialogue with seven municipalities, and 2) an open process inviting the key actors of urban planning.

- 1. The in-depth working dialogue involves professional partners from the German cities within the KliMo-Prax consortium. In a series of three round-table phases, the user requirements are outlined, different "Context-of-Use" (CoU) scenarios are elaborated, a prototype PALM-4U model is tested, and the minimal experience and potential are evaluated.
- 2. The open process includes a kick-off workshop and several events during the project, which completes the dialogue process, with the results integrated into the URC.

A new concept is to be developed for the task of specifying user requirements: the CoU scenario maintains a holistic view, and reduces simultaneously the complexity of the diversity of approaches and contexts. The CoU approach is defined by the distinct classes of practical situations resulting in different products, such as development or zoning plans. A CoU approach entails typical tasks and procedures of the municipal administration and further actors, while framing the activities of citizens and businesses within a city. System requirements for urban climate modelling can be derived from the CoU descriptions. The advantage of this concept is that the municipal actors find themselves in a specific work situation, so that it becomes possible to unambiguously identify the involved stakeholders, planning and participation processes, and the resulting products, such as development plans or permit notices. This allows the PALM-4U model to be developed in a practice-oriented sense, and ensures the integration of the model into the administration routine.

3.2.2 Online survey and desk research

The UseUClim consortium's first project phase, which is called "exploration", aims at identifying users, and conducting an analysis and synthesis of their specific requirements (see Fig. 2). The diverse user groups, which include more than the municipalities, are identified by a detailed stakeholder analysis, and included in the development process. In order to capture all potential user groups, the stakeholder analysis will be a continuous process throughout the project. In a next step, the requirements of the different stakeholders are to be analysed for development of an urban climate model that supports the users in their daily work. Therefore, an online survey will be conducted, with important aspects including (list not exhaustive):

- What is the expert status of the potential user?
- How should the user interface be designed?
- Which applications are mostly required?
- Which datasets are already available on the city level, e.g., temperature or wind data?
- Which type of visualisation is preferred?

This analysis will be carried out in close cooperation with the professional partners, and the survey will also be sent to an extensive set of potential stakeholders identified beforehand by the UseUClim consortium. With this approach, it is ensured that the results represent the requirements of a broad basis and, thus, will be transferable to other users and cities. Additionally, a literature and project review will be carried out, enabling the practice-oriented feedback from the online survey to be complemented with a scientific perspective. The results will be combined and subsequently discussed in a workshop with the partnering cities and consultancies.

3.3 Proceeding

To conclude the first project phase (see Fig. 2), the findings of the UseUClim (Section 3.2.2) and KliMoPrax (Section 3.2.1) consortia will be methodically structured and systematically synthesised in the URC. A draft version of the URC will be delivered to the partners from modules A and B, who will evaluate their own implementability requirements with respect to further model development. Additional requirements will emerge during the second and third phase of the project, which will then be continuously integrated into the URC. The final version of the catalogue will be delivered to the members of modules A and B at the end of the project. Requirements that are currently not implemented will be identified for a further model development.

4 Case studies and in-house training

In phase two of the project, the KliMoPrax and Use-UClim consortia will test the usability of the PALM-4U model using different approaches.

Within the KliMoPrax consortium, case studies will be performed in cooperation with the abovementioned German cities to assess the practicability of the PALM-4U model and its web-based graphical user interface (GUI; see MARONGA et al., 2019), which will enable operation of the PALM-4U model through the GUI's cascaded menu navigation. In this way, the municipal employees will be able to simulate the urbanplanning test cases without any detailed knowledge of the source code and special data file formats of the PALM-4U model.

The test cases are chosen based on the orography of the participating cities, their urban structure, and current



Figure 3: Structure of the direct user tests. The communication between the user (municipal employee) and the PALM-4U model is managed by the GUI, which controls the data transfer of input data, such as digital elevation models (DEM), building information models (BIM) and meteorological data, as well as the visualisation, download, and data storage after the simulation. Figure by courtesy of DWD.

municipal practice (e.g. urban land-use planning, urban development and urban renewal). New PALM-4U model developments, such as human biometeorology, an indoor climate and energy-demand model, an urban chemistry model or a multi-agent model considering critical hotspots based on human behaviour (MARONGA et al., 2019), shall be taken into account provided the necessary data are available.

The computer simulations are to be performed as follows:

- Direct user tests: In some of the cooperating cities, municipal employees will carry out test cases to be instructed and guided by KliMoPrax experts (see Fig. 3).
- Indirect user tests: For the remaining cities and urban-planning applications, the KliMoPrax consortium will perform both the calculations and analyses with the PALM-4U model, and provide the results to the respective municipal staff.

The case studies will enable assessment of the GUI in communicating the wishes of the municipal user to the PALM-4U model, including the effectiveness of data transfer (see Fig. 3).

The UseUClim consortium's second project phase, which is called "experimentation" (see Section 2), provides its professional partners two multi-week test phases to review the novel model's user-friendliness and practicability, as well as to identify the potential for future development. Both test phases are launched with individual in-house training to ensure sufficient time for a comprehensive introduction. These introductory on-site meetings are not restricted to urban planners, but also address employees from further related disciplines, enabling wide publicisation of the model, which, according to the lab concept, explores user acceptance from relevant working areas at an early stage (DE RUYTER et al., 2007).

In the first test phase, representatives from the municipal partners and the consultancy are trained in operating a beta version of the PALM-4U model, whereby the focus lies on the GUI and the visualisation of the output data. The user feedback of the independent model application will be evaluated and reported to the developers. In the second test phase, the implementation of user requirements, as well as the functionality of the PALM-4U model's release candidate, will be verified with further testing on well-defined, small-scale case studies. Besides testing the model itself, the interoperability with other applications will also be evaluated using case scenarios.

Thanks to the two test phases, the PALM-4U model is to be incorporated into a real-world setting and integrated as effectively as possible into the daily routine of users (BALLON et al., 2005; HIGGINS and KLEIN, 2011; WESTERLUND and LEMINEN, 2011). Overall, the second project phase is an excellent opportunity to learn from and with the professional partners, as well as to foster collaborative innovation (WESTERLUND and LEMINEN, 2011; ROBLES et al., 2015).

5 Evaluation report

All findings of the case studies and in-house training (see Section 4), as well as the analysis of the results of the URC, form the basis of the evaluation of the PALM-4U model from the point of view of the users in the third project phase. This differs from the model verification and validation against measurements conducted in modules A and B (MARONGA et al., 2019; SCHERER et al., 2019a). After the in-house training and the two test phases, to what extent the model suits urban-planning processes will be evaluated. Thus, the UseUClim consortium will provide feedback reports after both test phases. After completing the first test phase, an internal UseUClim workshop will be organised with the professional partners to review the first practical experience with the PALM-4U model. Therefore, feedback regarding actual user experiences is collected at a rather early stage in the urban climate model development process, and provides a first evaluation of model practicability (DE RUYTER et al., 2007).

After completion of the test phases, the third project phase called "evaluation" will take place (see Fig. 2). For this purpose, a joint UseUClim–KliMoPrax evaluation workshop will be organised to address the needs of the users, the model developers (module A), and model evaluators (module B). This workshop offers for users the opportunity to directly give feedback to the model developers with respect to the proper implementation of the original needs and requirements of the users. The major outcomes of this workshop will be summarised in an evaluation report, and delivered to the participants of modules A and B.

The assessment to what degree the requirements of the URC are fulfilled is an important measure of the evaluation. A gap analysis will lead to recommendations on further PALM-4U model development from the perspective of the current and future planning needs of the cities. The evaluation report offers an essential basis for further developments beyond this stage of funding, with the focus on how to ensure a sustained free usability of the PALM-4U model and its GUI, model maintenance, and the development of further user-orientated PALM-4U applications and modules, such as precipitation or mobile apps.

6 Consortium-specific focal points

As many of the challenges of the climatic, socioeconomic and technical transformations are converging in cities like the rays through a magnifying glass, it is, therefore, meaningful to say that the 21st century will be the century of the cities (KRAAS et al., 2016). Special working packages of the KliMoPrax and Use-UClim consortia will address the transformation processes, which are described in the following.

6.1 Future challenges of urban climate research

A KliMoPrax scientific report (supported by the Use-UClim consortium) deals with the future challenges of urban climate research, whose main questions are:

- 1. What are the essential requirements of the "city of tomorrow"?
- 2. Which mega-trends, innovative ideas, disruptive developments and political requirements will transform our cities?
- 3. What are recent and future concepts to simulate the urban climate?
- 4. What are the unanswered and emerging issues that need to be addressed in future urban climate research and modelling?

Two important requirements in the urban context are the Sustainable Development Goals and the Paris agreement (UNFCCC, 2015). The 2030 Agenda for Sustainable Development (UNITED NATIONS, 2015) directs the attention on sustainable cities and communities with the 11th Sustainable Development Goal: "Make cities inclusive, safe, resilient and sustainable". The New Urban Agenda postulates additional requirements (UNITED NATIONS, 2017).

The Paris agreement with its threshold of a global temperature rise well below 2 °C, focuses on a dramatic reduction of greenhouse gases. In Germany, the Paris Agreement will be implemented by the "Klimaschutzplan 2050" (BESCHLUSS BUNDESKABINETT, 2016), whereby, in the city-relevant sectors mobility, building, and energy, greenhouse-gas emissions shall be reduced by 55 % (relative to 1990) by 2030, which requires a transformation towards CO²-neutrality in cities.

Recent urban development in Germany focuses on reducing urban sprawl and forcing compact cities together with socio-economic aspects and ideas like sponge cities (MILBERT, 2015; HALBIG et al., 2016; GAINES, 2016). This gives a strong hint that future cities will be completely different to those today, with central questions including urban energy consumption (heating and cooling), innovative sustainable mobility concepts and residential designs, optimised blue and green infrastructure, participation of the urban residents, megatrends such as big data, smart cities, and autonomous driving.

The scientific report follows the demand that climate change makes basic research in the field of climate more and more important (MAROTZKE et al., 2017), since the climate may change the thresholds of livable urban conditions, for example, heat stress. Therefore, the tasks of urban climate research are

- 1. to observe, to anticipate, and to analyse the climatic impacts of the developments in cities forced by the aforementioned goals of sustainable development, the mitigation of climate change, and the adaption to climate change and socio-cultural developments.
- 2. to support the government, the cities and the science in transforming cities.
- 3. to develop ideas for designing urban climate models that take into account the effects of the transformation of the cities, as well as the interactions between the population, the urban corpus, and the living urban environment.

6.2 Changing stakeholder processes, new roles and mainstreaming

In preparing for a sustainable implementation of the PALM-4U model in urban-planning routines, two reports are to be produced incorporating the findings from the user dialogue. A first working report uses scenario techniques to analyse the effects that a practically-applicable urban climate model may have on stakeholder constellations in urban-planning processes, and the potential for new services to emerge when urban climate models become widespread and easy to use. This may evolve into new potential users and stakeholders providing commercial services to a range of customers. The second report will focus on the elaboration of a comprehensive strategy of how to mainstream urban climate models in municipal administration environments and urban-planning routines.

6.3 Exploration of software interfaces

In the UseUClim consortium, the two test phases also function to identify and specify software interfaces of the PALM-4U model to serve further in-depth analysis methods not directly implemented by module A, such as on the building level. From the user experiences and Meteorol. Z. (Contrib. Atm. Sci.) 28, 2019

technical issues uncovered during the two test phases, a compilation of the interface requirements will be derived and conveyed as guidelines to the model developers. Hence, these results are an addition to the general requirements, and support a modular software architecture, enabling module A to integrate a wide range of functional components within the software product life cycle.

6.4 Continuation of activities

The dissemination of achievements obtained in this project will contribute to improving the quality of urban climate modelling and, additionally, the ability to consider climate-change information in sustainable and climate-proof urban-planning processes. The UseUClim consortium's overall objective is to link climate-serviceresearch outputs to decision-relevant questions to support communities and the building of high-level capacities. To have a real impact on communal, urban, landuse planning, and to ensure that the model is used and further improved after completion of the project, a coherent dissemination strategy is to be elaborated by the UseUClim consortium consisting of several elements:

- Integration in existing climate-service infrastructure, such as the GERICS-Stadtbaukasten (adaptation toolkit for cities), which is a general framework that supports cities in their adaption to the expected impacts of a changing climate (CORTEKAR et al., 2016).
- Elaboration of an understandable and easy-to-read guidance document that describes the PALM-4U model and its output products, including, for example, a delineation of specific model configurations, as well as a description of variables and file names (GETTELMAN and ROOD, 2016). Additionally, a compact compilation of the utilisation requirements will be developed to support the transferability in Germany and beyond (supported by the KliMoPrax consortium).
- Improvement of the science-practice interface with the provision of training and education activities. This step aims to bridge the gap between urban climatology and its application in urban planning (ERELL et al., 2011; NG and REN, 2015).
- Disseminating the results via printed communication material and a contribution to various web portals, such as the Climate-ADAPT platform of the European Environment Agency and the European Commission.

7 Summary and outlook

The KliMoPrax and UseUClim consortia will identify the requirements of potential users for implementing these requirements into the new model PALM-4U. For this purpose, there will be permanently ongoing communication with users, consisting of workshops, learning labs, training courses, and the assessment of the performance of computer simulations in the form of realistic test cases. Several scientific reports will summarise the challenges of future cities, the innovation potential of urban development, and the continuation of PALM-4U model development in both Germany and other countries. With the novel model PALM-4U, the development towards integrated, sustainable, urban adaptation will be supported and made feasible.

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