Abstracts

Modelling the impact of an urban development project on microclimate and outdoor thermal comfort in a mid-latitude city

Julian Anders, Leibniz Universität Hannover, Germany

This study assesses the impacts of sustainable urban development adapted to climate change in the city of Stuttgart, Germany. We use the state-of-the-art meteorological modelling system PALM-4U to simulate the microclimate and outdoor thermal comfort of the development site Neckarpark during a heatwave.
We compare the atmospheric conditions of the current urban structure before the development project (2018) and the future state, representing the new district after completion (2025). Our results indicate that the restructuring barely affects surrounding neighbourhoods, but leads to mean near-surface air temperature increases in the centre of development between +0.25 K and +2 K. Differences in Physiologically Equivalent Temperature (PET) show a heterogeneous pattern at daytime, with a large amplitude and temporal variability in the diurnal cycle (-9 to +12). At night, the planned buildings increase the mean PET by +1 K to +6 K. The new buildings reduce the effect of adaptation measures designed to increase the cooling effects, i.e. urban trees and vegetation, amplifying the thermal stress during heatwaves. Our study confirms the complex composite impacts of urban restructuring due to the thermal and dynamic flow processes. The paper may serve as a guide for the use of meteorological models to assess microclimatic impacts of planned development projects, contributing to urban planning and adaptation strategies.

Does facade and roof greening reduce heat stress in urban environments? A PALM case study for Magdeburg.

Pierre Monteyne, Leibniz Universität Hannover, Germany

Cities are under increasing thermal stress from rising temperatures and the urban heat island effect. Thus, climate adaptation strategies are gaining importance, one of which is greening of building roofs and façades. Greening buildings can moderate both indoor and outdoor ambient air temperatures by enhancing latent heat flux. However, the effectiveness in application is still uncertain. To analyze the impact of façade greening on indoor and outdoor air temperatures, large-eddy simulations were carried out with PALM model system on a residential building in the city of Magdeburg, Germany. The building was recently retrofitted with a green façade, providing an excellent real-world scenario to study urban greening. Additional simulations were carried out to evaluate how the outdoor ambient air temperature changed when increasing the building green fraction across the entire neighborhood. The simulation results indicate that the influence of individual façade greening on outdoor ambient air temperatures is minor and localized. Temperatures are reduced up to approximately 10 meters away from the façade, but only directly orthogonal to the surface. Results suggest that significant (> 0.5 K) reduction of outdoor ambient air temperatures on a relatively large spatial scale requires extensive building greening of an entire neighborhood. Additionally, in the case of fully greened buildings, reductions in indoor temperatures of more than 1.5 K are achievable.

Effect of radiation interaction and aerosol processes on ventilation and aerosol concentrations in a real urban neighbourhood in Helsinki

Jani Strömberg, University of Helsinki, Finland

Large eddy simulation (LES) is an optimal tool to examine aerosol particle concentrations in detail within urban neighborhoods. The concentrations are a complex result of local emissions, meteorology, aerosol processes, and local mixing conditions due to thermal and mechanical effects. Despite this, most studies have focused on simplification of the affecting processes such as examining the impact of local mixing in idealised street canyons or treating aerosols as passive scalars. The aim of this study is to include all these processes into LES using PALM, and to examine the importance of radiative heating and aerosol processes in simulating local aerosol particle concentrations and different aerosol metrics within a realistic urban neighborhood in Helsinki under morning rush hour with calm wind conditions. The model outputs are evaluated against mobile laboratory measurements of air temperature and total particle number concentration (Ntot), and drone measurements of lung deposited surface area (LDSA). The inclusion of radiation interaction in LES has a significant impact on simulated near surface temperatures in our study domain increasing them on average from 8.6 C to 12.4 C. The resulting enhanced ventilation reduces the pedestrian level (4 m) Ntot by 53%. The reduction of Ntot due to aerosol processes is smaller, only 18%. Aerosol processes impact particularly the smallest particle range, whereas radiation interaction is more important in the larger particle range.

The LES-LES self-nesting capability in PALM

Antti Hellsten, Finnish Meteorological Institute, Finland

The LES-LES self-nesting capability has been part of PALM already for some time. Self nesting allows nesting of smaller child domains with higher resolution inside a larger parent domain with lower resolution. Child domains can have their own children in cascading and parallel arrangements. Self nesting has proven very useful in various problems enabling large domain size and localized high resolution at the same time. This often yields significant savings in computational cost. In this presentation, the self-nesting capability with its properties and usage are briefly reviewed in order to promote it for the benefit of broader user community.

Application of PALM to cloud chamber simulations

Prof. Dr. Hyunho Lee, Kongju National University, South Korea

Cloud microphysics models have been widely used to simulate cloud and precipitation. In general, however, not only cloud microphysical properties but also cloud macrophysical properties have too wide acceptable ranges in observations. In addition, to compare the model results with observations, the initial conditions should be known very accurately, and the large-scale conditions should be well controlled, which is almost not possible in the real atmosphere. For these reasons, cloud chambers that can simulate cloud microphysical processes in a laboratory have been constructed, and research to numerically simulate them using large-eddy simulation (LES) models coupled with cloud microphysics models is ongoing. Although the cloud chambers are not feasible to simulate large-scale motions, they can simulate cloud microphysical processes under well controlled conditions, so they are regarded as a good tool to evaluate the performance of cloud microphysics models. Unfortunately, however, recent studies have reported considerably diverse results even when they simulate the same cloud chamber, and even the results from a single model can be varied depending on spatial resolution. In this study, we exploit PALM v6 and simulate a cloud chamber. We perform a series of LESs on spatial grid resolutions of a few centimeters. Characteristics of convergence of solution and turbulence depending on spatial grid resolutions are presented and discussed.

New Snow Scheme in the PALM Land Surface Model and First Results

Dr. Christopher Mount, Leibniz Universität Hannover, Germany

Snow modifies surface properties that can drastically impact atmospheric turbulence. To date, no LES model has incorporated a snow scheme to explore the impact spatiotemporally variable surface properties have on the boundary layer flow. We have implemented a new snow scheme in the PALM Land Surface Model (LSM) for this purpose. The PALM snow scheme is based on the bulk model developed for the ECMWF IFS HTESSEL LSM. Combined with the linearization techniques from DALES, we developed an implicit, third-order Runge-Kutta scheme to calculate snow prognostic variables. We formulated prognostic equations for snow temperature, melt, water equivalent, and density, as well as diagnostic equations for snow effective heat capacity and liquid water content. Additionally, new namelist parameters were necessary that allow constant snow and rain precipitation rates and/or a domain-wide, uniform-depth snowpack to be assigned within the LSM. However, the snow scheme is also coupled to the Bulk Cloud Model, allowing users to physically generate precipitation. The snow scheme is also compatible with all radiation modes except tenstream. First results will demonstrate the capabilities of the new scheme. Future work includes implementation of the snow scheme to the Urban Surface and Plant Canopy Models. The new snow scheme will be available in the next PALM release and will provide a new tool for users to more realistically model the surface, especially in cold climates.

3-D radiative interactions for non-orthogonal (slanted) surfaces in PALM using cut-cell grid

Dr. Pavel Krc, Institute of Computer Science, Czech Academy of Sciences, Czech Republic

The Radiative transfer model (RTM) in PALM utilises the same discretization by a regular grid and the same data structures and parallelization approach as the model core, and that makes it tightly integrated and highly scalable. However, it can be demonstrated that the discretization of arbitrarily oriented surfaces using only orthogonal grid surface elements may lead to biases that cannot be eliminated by increasing the model resolution. E.g. an idealised street canyon oblique to the grid axes is discretized by artificial steps that increase the total area of the walls by an angle-dependent coefficient. It also introduces artificial reflections among the steps which decrease the effective albedo of the walls. The currently developed version of RTM introduces a system for representing and modelling radiation among arbitrarily oriented surface elements in such a way that it avoids these biases while preserving its high computational efficiency and scalability. It keeps the discretization by the regular grid and the level of detail corresponding to the grid resolution. It also allows a combination of slanted and orthogonal surface elements without a significant performance penalty to the latter. The presentation will describe the system and demonstrate the its results on a test-case scenario. The research was supported by project TO01000219 “TURBAN” (Norway Grants, Technology Agency of the Czech Republic). HPC support: Czech Ministry of Education, e-INFRA CZ (90140).

Integrating MATSim and PALM - Coupling Large Scale Microscopic Traffic and Emission Modelling with High Resolution Computational Fluid Dynamics Dispersion Modelling

Janek Laudan, TU Berlin, Germany

Prolonged exposure to air pollution can lead to negative impacts on various physiological systems, including the lungs, heart, metabolism, and brain functions. One of the main sources of urban air pollution in cities is car traffic, making reduction of traffic-induced emissions a priority to mitigate emission concentrations and improve the health situation of the urban population. Current research either focuses on the microscopic traffic/emission modelling and uses very small domains to investigate emission dispersion like one street corridor or single intersections, or they focus on the dispersion model handling traffic emissions and use parameterized input emissions without using an actual traffic model. This talk presents the development of an integration module between the mesoscopic traffic and emission model MATSim and the CFD simulation model PALM-4U which was developed as part of the UC2 project. As MATSim is capable of simulating millions of travellers while modelling traffic on the individual vehicle level and PALM-4U is designed to be scaled onto HPC infrastructure, the described coupling mechanism enables microscopic emission modelling with accurate dispersion modelling for large scale urban scenarios. Combining high resolution traffic emissions with fine grained emission dispersion modelling enables better identification of emission hot spots of which two possible approaches are presented.

PALM-4U GUI: A cloud based user-friendly graphical user interface for the urban climate model PALM-4U

Sebastian Stadler, Fraunhofer Institute for Building Physics IBP, Germany

Within the Urban Climate under Change [UC]² project the task was defined to develop an easy-to-use cloud-based graphical user interface (GUI) for PALM-4U to enable the model's operationalization in practical applications, especially for municipalities. Therefore, the simulation-workflow with PALM-4U was examined and input data preparation, setup, simulation and result interpretation were identified as main process steps, which were then implemented in the PALM-4U GUI as coordinated modules: A web map module allows to flexibly import, create and edit city models and to create static drivers. The required input data is based on common geodata and file types. An integrated interface allows using Open Street Map data as input. Curated templates provide users with presets to create model setups for typical applications. Currently implemented are templates for thermal comfort, wind comfort and particulate matter dispersion. The GUI then creates the p3d-steering file as well as dynamic and chemistry drivers from these templates. Alternatively, a so-called "Expert Mode" allows flexible creation of p3d-files. A simulation framework based on Azure Batch was developed to run PALM-4U in the cloud environment. The GUI also provides predefined postprocessing routines depending on the templates as well as access to all simulation outputs which can be visualized and analyzed on an interactive map on the GUI. Output can be exported as raw data or images, charts and maps can be created.

Integration of PALM simulations in urban climate policymaking

Prof. Igor Esau, Nansen Environmental and Remote Sensing Center, Norway

Integration of digital twin models into policymaking process becomes essential for sustainable communities. Destination Earth is an European initiative aimed to create a global scale Earth climate system digital twin whereas the World Meteorological Organization supports development of Integrated Urban Modeling Systems. Atmospheric turbulence resolving models, such as the PALM system, have a potential to become key elements of the integrated systems and urban digital twins. To realize this potential however, models have to overcome close certain methodological gaps and overcome application challenges. Our experience reveals that urban stakeholders are interested in simulation results only when they are: readily available and visualized; provide information at scales relevant to policymaking; able to contribute to policy scenarios and projections. Further efforts are needed to design a smart methodology to offset heavy computation cost and complexity of pre-/post-processing required by the PALM system. In the co-production process with urban stakeholders in Bergen, Norway, we found that any realistic case simulations would be too costly to justify their added value to policymaking. I suggest that a useful modeling system should combine physically-based simulations with PALM with much cheaper statistical models trained on the PALM results.

Pros and Cons Working with PALM as a Consultant

Dr. Tobias Gronemeier, iMA Richter & Röckle GmbH & Co. KG, Germany

While working with PALM as a consultant for local-climate assessments, different workflows outside the PALM model package had to be developed. We present ways to successfully use PALM for local-climate assessments but also highlight areas where it still needs improvement in terms of usability.

Application of PALM at the German Weather Service

Astrid Eichhorn-Müller, Deutscher Wetterdienst, Germany

The department of Climate and Environmental Consultancy at the German Weather Service (DWD) provides high-quality climatological products and consultancy services on different scales. Close cooperation with professional associations and authorities as well as universities and research institutions help to fulfil current customer requirements. In the field of air quality, and regional and urban climatology, meteorological measurements and numerical simulations are performed on a regular basis. While DWD used the three-dimensional thermodynamic model MUKLIMO_3 for regional and urban climate simulations in the past, we are currently experiencing a change of models and want to fully stick to PALM as state-of-the-art model in the future. Recent PALM activities at DWD include the optimization and vectorization of the PALM code for our HPC systems, evaluation studies and research projects. To continue and further develop our services from the past, we have a special interest to run PALM also in RANS mode and improve PALM nesting capabilities (e.g. ICON-PALM coupling and PALM self-nesting in RANS and LES modes).

Overview of recent PALM-4U related research activities at the Austrian weather service
Online Brigitta Hollosi, GeoSphere Austria, Austria

The Austrian weather service, GeoSphere Austria (formerly known as ZAMG) has implemented the model PALM-4U as the stat-of-the-art of science and technology in urban modelling in order to exploit the potential of the building-resolving model in a variety of urban climate and environmental applications. This presentation provides a concise overview of ongoing PALM-4U related research activities at the institution. Model simulations with different model configurations and on different spatial scales were performed in Vienna, Austria. The evaluation involves comparison of model results with temperature measurements of both conventional and non-conventional weather stations, outputs from meso- and micro-scale numerical models, remote sensing data, and monitoring data obtained from a dedicated measurement campaign conducted at the headquarters' premises of the weather service in Vienna using low-cost weather stations and thermal imaging cameras.

LES at the wind turbine manufacturer ENERCON
Dr. Marcus Letzel, Enercon, Germany

The first part of this talk explains from a strategic perspective ENERCON's industrial motivation to introduce LES: a) post-incident analysis of wind related turbine damages ("after-sales") and b) estimation of damage risk due to excessive wind turbulence for planned wind parks ("pre-sales").
For the introduction of LES, ENERCON compared the strengths and weaknesses of three relevant solvers, PALM, SOWFA and WRF-LES. The talk will briefly explain the results of the solver comparison, which PALM features have proven to be useful so far, and where ENERCON sees room for improvement of PALM.
The second part of the talk is on the collaboration between ENERCON and the academic community. ENERCON has collaborated with the PALM community in publicly funded research projects. Also, ENERCON has hosted Master and Bachelor students for their final projects with PALM.
ENERCON wants to play an active role in the PALM model community in work group 16 ("Practical LES for consulting / industry – best practices"). ENERCON hopes that work group 16 will gather expertise on the practical application of PALM e.g. in complex terrain or for specific meteorological events, implying that the scope of work group 16 should be open and not limited to wind energy.

Mesoscale-coupled PALM simulations in complex terrain: Applications and challenges
Oliver Maas, Enercon, Germany

At Enercon PALM is used to perform turbulence-related wind turbine damage risk analyses. In recent projects the quality of the analyses could be significantly improved by taking inversion layer effects into account. Further improvements are expected by using mesoscale-coupled PALM simulations, which are currently tested at Enercon.
This talk presents the possible applications and challenges of this approach. Especially the combination of complex terrain, stratified flow and industrial application poses new challenges and might require new PALM features. The focus will be on two main topics: The generation of turbulence at the inflow and the interaction of mountain wakes with the outflow boundary, causing numerical instabilities. A new outflow boundary condition is proposed that eliminates the numerical instabilities and allows for using a shorter domain.

Towards the simulation of a wind machine based on an actuator disk model to improve frost protection
Dr. Clara Le Cap, Weather Measures, France

Spring frosts are a typical event occurring at a key moment of the vine's growing cycle. It damages many buds, thus affecting the future yield, weakening the winegrowers and beyond, and impacting the whole local economy. One way to fight it back is using a wind machine - a blowing fan atop a 10-m mast with an approximate flow rate of 500 m3/s. It rotates on itself in approximately 4min30s and blows a slightly positive air using the strength of the nocturnal thermal inversion to mix cold air near the ground with warmer air above. Most existing studies about wind machines focus on field measurements, but these can be subject to unexpected weather changes and undesirable topography effects. Moreover, some studies may be challenging to set up at a field scale as it requires many sensors to catch the overall effect of the wind machine. We present here an exploratory work on hijacking the wind turbine model in PALM to simulate the effect of a wind machine under radiative frost conditions. We succeeded to reproduce the effect of the wind machine on the stratified temperature with PALM and to produce a jet close to what has been measured in the field, although the model is still incomplete. It offers numerous perspectives since it facilitates the analysis by controlling the topography and the meteorological situation but also varying the design of the wind machine to study the tower's performance under various conditions.

Surface heterogeneity induced effects on the diurnally evolving convective boundary layer from coupled large eddy simulations of the CHEESEHEAD19 field campaign
Online Sreenath Paleri, University of Oklahoma, USA

Observational studies and large eddy simulations (LES) have reported secondary circulations in the turbulent atmospheric boundary layer (ABL). These circulations form as coherent turbulent structures or mesoscale circulations induced by gradients of land surface properties. However, simulations have been limited in their ability to represent these events and their diurnal evolution over realistic and heterogeneous land surfaces. In this study, we ask, to what extent can we combine a high-resolution observational data collected as part of the CHEESEHEAD19 field campaign with LES to overcome this gap and test how heterogeneity drives circulations. We simulate diurnal cycles for four days chosen from late summer to early autumn over a large (27 x 30 km) heterogeneous domain. To investigate surface atmospheric feedbacks such as self-reinforcement of mesoscale circulations over the heterogeneous domain, the simulations were forced with an interactive land surface model with coupled soil, radiative transfer and a plant canopy model. The simulations were forced laterally and aloft from NOAA HRRR data product. Heterogeneity induced fluxes and vertical velocities are calculated using time and ensemble averaging to diagnose the presence of secondary circulations. The simulations correlate well with radiosonde and tower measurements collected during the field experiment. The simulated secondary circulations contribute to 10-15% of total surface fluxes in the summertime CBL.

LES of local scale atmospheric boundary layer dynamics using PALM at the Finnish Meteorological Institute
Dr. Jukka-Pekka Keskinen

PALM is used for a variety of studies at the Atmospheric Dispersion Modelling group at the Finnish Meteorological Institute. This talk will introduce several projects, both finished and ongoing, concerning the LES of local scale atmospheric boundary layer dynamics. The topics of these projects range from the protection of cultural heritage to urban air quality. A common theme shared by the LES's in most of the projects is the use of self-nesting and downscaling together with a need for high-resolution topographical input data. A summary of the aims, computational setup, and results of each project is given.

Large-Eddy Simulation of passive plumes in neutral stratified and slightly stable boundary layers

Marilina Barulli, Ecole Centrale de Lyon, France

From an environmental point of view, it is of primary interest the modelling of the atmospheric releases of pollutant airborne substances, in order to predict their impact health and on ecological systems. For that purpose it is crucial to reliably model the dynamics of the lower atmosphere and of the phenomena that are responsible for the pollutant dispersion. In order to do that, a possible approach is that of adopting Large Eddy Simulations, which are here performed using the PArallelized LES Model (PALM). Our focus in on the pollutant dispersion from an elevated source in a turbulent boundary layer in two different conditions: a neutral and and a slightly stable boundary layer. In a first stage, the study concerns the simulation of neutral and stable stratified atmospheric boundary layers. The numerical results are properly compared to the experimental data obtained in two different experimental campaigns carried out at École Centrale de Lyon and at University of Surrey for the neutral and slightly stable cases respectively. In a second stage, the study shows some preliminary results on the simulation of the point source release of a passive scalar, whose dynamics are therefore determined by the previously simulated flow field. The study aims to investigate the reliability of LES in reproducing the plume's dynamics, discussing the influence of the grid resolution on the mean concentration and on the higher moments, up to the fourth order.

Implementing moving emissions and simulating the dispersion of ship exhaust plumes

Katrin Gehrke, pecanode GmbH, Germany

The contribution of inland navigation to the total load of air pollutants in inhabited areas has not been fully understood to date. One reason is that ship emissions are highly non-stationary in space and time. Moreover, pollutant plumes measured at a fixed location are highly variable in length and strength due to turbulent dispersion characteristics. Thus, investigating the pollution levels on the shore poses the need to generate sufficient statistics of plume dispersion.

The aim of the project is to determine the contribution of ship emissions to air pollution in the bank area of waterways under different atmospheric conditions, and to gain a better understanding of the dispersion properties of shipping-related emissions. Here, we present results of a joint project combining concentration observations at a heavily frequented waterway and accompanied high-resolution LES with PALM. In a first step we describe the technical and modelling framework how moving volume-source emissions are considered in a PALM simulation. Based on this technical enhancement, we present results of numerical dispersion experiments where we created an ensemble of statistically independent dispersion plumes for repeating shiptracks with identical emissions. We show that pollutant plumes emerging from inland navigation undergo a transformation from mainly intermittent concentration events at the river shoreline into a mean concentration without distinct peaks when advected in complex urban spaces.

Effects of RV Polarstern on the atmospheric flow and observations during MOSAiC

Dr. Robert Klingel, Leibniz Universität Hannover, Germany

During the MOSAiC expedition, the research vessel Polarstern drifted, frozen to an ice shell, in 2019 and 2020 for one year through the Arctic ocean. Hundreds of researchers from various disciplines observed and investigated the Arctic, injecting our understanding of its current rapid warming.
We apply large-eddy simulations for selected weather conditions to ensure MOSAiCs atmospheric data quality and support future analysis. PALM's virtual measurement module enables us to create synthetic data for the utilized observation platforms like the Polarstern itself, aircraft, drones, radiosondes, balloons, and surface-based systems. Analyzing the data between simulations where the vessel is included and excluded provides an insight into the it's effects on surrounding observations, a key uncertainty source for corresponding data.
Our simulations reveal that effects are not only tied directly to the vessel's wake within the turbulent flow. They indicate that vessel-induced gravity waves also bear the potential to influence surrounding measurements notably. We present and analyze:

- how influences from both sources rely on atmospheric conditions, the measurement positioning, and the considered atmospheric quantity
- the effects notably perturb measurements frequently up to a distance of more than one kilometer
- which underlying mechanisms cause the observed perturbations
- mitigation and interpretation strategies to work with corresponding data

Introduction and validation of a simplistic method to represent vehicle-induced turbulence in PALM

Giovanna Motisi, LUH, Germany

Vehicle-induced effects (VIE) and exhaust fumes interacting with turbulent flow has become known to be a critical factor when investigating the wind flow and the transport of pollutants in urban street canyons. Up to now, mainly the Reynolds-Averaged-Navier-Stokes (RANS) technique has been applied for CFD studies of the processes within urban street canyons; research studies using turbulence-resolving Large-Eddy Simulations (LES), however, were rather rare. In this paper we outline our effort to account for VIE in PALM. For this purpose, an innovative and easy to implement method was realised to represent a common car shape within the environmental LES setup: the so-called air-block method. Its concept is based on an object (representing the vehicle) in which a fixed velocity is prescribed to the objects grid volumes that equals the driving speed of the vehicle. Control of its movement, however, is achieved via a Lagrangian particle located at its center of gravity. This approach is significantly different from conventional consideration of solid objects as obstacles, since the air-block representation assumes that frictional drag is much smaller (and can thus be neglected) than form drag. By the same token the implementation is much easier to achieve. In this talk we will outline the newly-developed simplistic method to represent driving vehicles in an LES model and show its performance based on a validation study using existing wind tunnel data.

Application of PALM to modelling of indoor ventilation problems

Mikko Auvinen, Finnish Meteorological Institute, Finland

Large-eddy simulation (LES) is particularly well suited for numerical modeling of indoor turbulence. It offers the capability to resolve all relevant energy-containing scales while employing simplified modeling only for the subgrid-scale turbulence. Although the PALM-LES model has been designed for atmospheric boundary-layer problems, we have extended the range of its applicability to various indoor dispersion problems. We have validated PALM against experimental indoor concentration measurements and subsequently applied it to numerous indoor configurations with varying ventilation and thermal conditions. We are actively carrying on this work. Up to date we have published our results in three journal articles and more articles are currently under preparation.