SESSION 1

Using the building-resolving PALM model to capture micrometeorological characteristics of an urban environment in Vienna, Austria

Brigitta Hollosi, Maja Zuvela-Aloise, Anton Neureiter, Melina Frießenbichler, Peter Auferbauer, Jürgen Feigl, Claudia Hahn, Thomas Kolejka
GeoSphere Austria

This study aimed to evaluate the impact of surface heterogeneity on the spatial and temporal fluctuations of meteorological and surface conditions using a dense measurement network established at the headquarters of the Austrian weather service in Vienna, Austria. Additionally, it assessed the applicability of the PALM model to simulate the observed variations. In summer 2022, a total of 24 LoRaWAN Dragino LHT65 sensors were installed to capture micro-scale variations in air temperature and relative humidity at the site. The model evaluation was limited to the summer days of 16–17 August 2022 and 11–12 August 2023, when additional measurements were taken using drones equipped with thermal imaging cameras. The PALM model domain for the study area was nested within a larger one, and simulations with 2 m spatial resolution were compared to empirical data from the dense measurement network, thermal imaging cameras, and the high-quality monitoring station of the weather service. The model demonstrated the capability to simulate the main thermal characteristics of the study area, although it slightly overestimated temperatures at night. Compared to the measurements, it had less pronounced spatial variability in air temperature and relative humidity, but a larger one in surface temperature.

Simulating Heatwave in Urban Environments: A Case Study of Villa Ada, Rome, during October 2023

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A persistent high-pressure system characterized the first fifteen days of October 2023 in Italy. In particular, during October 11th and 12th, the city of Rome was particularly affected by the influx of warm, dry air and the consequent heatwave marked by moderate to calm wind speeds. The increasing frequency of such episodes demands a profound understanding of the interplay between Atmospheric flow, temperature field, particulate dispersion, and urban environment texture and its consequences on human health. In the framework of a broader project (PNRR-NBFC), this study aims to assess the spatial variability and heterogeneity of the air temperature, humidity, PM2.5, and PM10 fields in the Villa Ada neighborhood in Rome during 4 days (8th-11th October 2023). Villa Ada owes its name to a densely vegetated park surrounded by intense traffic roads. This makes it the ideal spot to study the interaction between vegetated canopy and the urban environment, investigating the influence of trees on particle dispersion through deposition processes. The atmospheric model MOLOCH is coupled to the PALM-4U model with two nested domains to simulate the wind, turbulence, and scalar fields. These simulations will provide substantial insight for two field campaigns planned for late 2024.

Modelling Impacts of Subsurface Thermal Anomalies on Potential Air Temperatures in Berlin

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Anthropogenic encroachments in the underground by installation of urban infrastructure like tunnels or basements have already been extensively scrutinized. They alter subsurface temperatures from their natural state, mostly inducing rising temperatures in the soil. However, scant attention has been paid to the exchange between these subsurface heat extremes and the atmospheric response as a bottom-up scheme. To fill this research gap, we simulate the impact of varying soil temperatures on heat fluxes, focusing on potential air temperatures, in an area in Berlin with the LES model PALM-4U.
In a previous study using idealized domains we found potential air temperature modifications due to changes in the subsurface temperature under specific conditions. Hence, we anticipate analogous changes in heat fluxes and potential air temperatures within a realistic urban environment. We seek to discern heterogeneous spatial patterns within a highly complex system of different land covers and building materials, as well as temporal changes within one day. Further, we compare winter and summer scenarios.
The findings will contribute to the general understanding of the coupling of soil- and atmospheric temperatures. How the accumulation of subsurface waste heat influences atmospheric conditions becomes an increasingly important factor, given the burgeoning interest in micro-climatic influences on air temperatures, particularly in urban contexts.

Evaluation of city-scale PALM model simulations for Vienna, Austria using operational and crowdsourced data

Maja Zuvela-Aloise, Claudia Hahn and Brigitta Hollosi
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The PALM model is used to simulate the spatio-temporal thermal variability under heat wave conditions in Vienna, Austria. The city-scale model simulations are performed for four consecutive clear-sky hot days in August 2022 using the WRF-Chem model output from the GeoSphere Austria as dynamical driver. The modelled hourly air temperature is evaluated against the measurements from 17 conventional weather stations of professional monitoring networks and quality-controlled data from over 1000 private weather stations of the company NETATMO. The observations show high intra-urban variability during daytime, but no clear spatial pattern, while at night higher air temperatures are found in densely built urban areas and lower temperatures in surrounding residential areas near green surfaces. Direct model comparison with observational data both with professional and crowdsourced measurements shows a good model performance. Model results generally indicate lower variability than observations, but similar large-scale spatial patterns. Evaluation of intra-urban thermal variability based on classification by land use/land cover type shows a statistically significant air temperature difference between the built-up areas and areas with high vegetation cover during the night.

Is crowdsourced air temperature data suitable for model evaluation? An analysis based on PALM simulations for German cities

Lara van der Linden, Björn Maronga and Benjamin Bechtel
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In a previous study, crowdsourced air temperature data was utilised for model evaluation during a hot summer day in Bochum. This data proved valuable due to its high spatial resolution. However, uncertainties remain regarding the causes of discrepancies between the measured and modelled data.
To test the transferability of this approach and identify its strengths and weaknesses, PALM simulations are conducted in Dortmund, Cologne, and Berlin. These cities were selected due to their varying sizes, densities, and geographical settings. Dortmund, located in the Ruhr area, is part of an agglomeration of several cities. Cologne is influenced by the Rhine Valley to the south, with the river flowing through the city. Berlin is a more classically isolated city but at the same time is Germanys biggest city. These specific characteristics of each city could influence both the measurement data and the model outcomes.
Initial results from the model evaluations will be presented, providing insights into the approach's transferability. Further research questions include whether a spatial pattern in model accuracy can be identified and if a temporal pattern similar to the previous study can be observed.

Microscale Simulation of Local Climate Zones – A QGIS-Based Set-up Wizard for Customized Cities and Adaptation Studies with Palm

Julian Anders, Björn Maronga
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The Local Climate Zone (LCZ) scheme by Stewart and Oke (2012) has introduced a classification system for urban and rural sites by linking physical properties with characteristic near-surface temperature regimes. Recently, the concept has been increasingly used for contextualizing and comparing urban climate research, especially with regard to remote sensing-based mapping, classification, and in-situ measurements. The transfer of LCZs to numerical simulations at the urban microscale, however, offers great potential that has not yet been fully exploited. We developed a LCZ-wizard, based on QGIS, that serves as a toolbox for recreating cities and designing customized urban environments based on distinct LCZ-units (100 x 100 m²) that physically represent the 17 standard LCZs. To validate the LCZ-scheme at the microscale, we used PALM to simulate each LCZ independently during an idealized heatwave event. We found that the defined surface type fractions, roughness element heights, and thermal properties are sufficient to reproduce the empirical LCZ-temperature-regimes in building and tree-resolving simulations. We also carried out sensitivity studies with respect to tree configurations, soil humidity, and model resolution. In a follow-up study we plan to compare LCZ-wizard-based set-ups against real city quarters. The LCZ-wizard can enable the scenario-based investigation of impacts of future meteorological conditions or planned urban changes - and how these differ among the LCZs.

Supporting location determination for a meteorological monitoring network in the city of Linz (Austria)

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The City of Linz identified heat stress as a strong climate hazard for its inhabitants. For gaining a deeper knowledge about local characteristics of heat stress, potential measures, and its consequences, it was decided to set up a meteorological monitoring network, focusing on the parameter air temperature. The network will consist of min. 50 monitoring stations which shall be optimally placed to cover several requirements: (1) representative measurements for similar regions within the city area, (2) show the variety of urban microclimate conditions, (3) include strategically reasonable locations, (4) use available mountable infrastructure (masts, public buildings) and (5) show extreme conditions within each similar region.
To identify a set of well-suited locations for the monitoring stations the following steps were taken: (i) an urban climate simulation was calculated with PALM-4U for a typical summer day with a spatial resolution of 10 m providing the data about heat stress conditions in the city, (ii) the concept of Local Climate Zones (LCZ) was applied to define similar regions in the city, (iii) locations of potential mountable infrastructure were incorporated, (iv) a set of criteria for station locations in each LCZ (e.g. low nighttime air temperature, sun exposure) was defined and (v) finally the best locations were identified. The study provides an example of how PALM-4U can deliver valuable urban climate data to support practical challenges of city management.

Evaluation of Areawide Energy Retrofit Performance of the TABULA Building Stock Considering the Urban Microclimate Using an LES Model

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The interplay between the urban microclimate and building energy balance is crucial for comprehending the intricate dynamics of mass and momentum exchange that characterize these processes. These interactions, coupled with internal heat gains and the thermal capacity of buildings, govern the energy requirements for heating and cooling, shaping both indoor and outdoor thermal environments. This study examines the influence of areawide building retrofits on waste and sensible heat fluxes during severe cold weather conditions in an urban district in Bochum, Germany, utilizing the Large Eddy Simulation model PALM. The research incorporates 28 building types, integrating the TABULA archetypes from the IEE Project 'Typology Approach for Building Stock Energy Assessment'. It compares a non-retrofitted baseline scenario with an advanced retrofitted scenario to evaluate the impact of energy efficiency improvements proposed by the TABULA Project. The comparison between the two simulations aims to assess the trade-offs between heat transfer rates and fluid flow patterns, offering insights into the interaction among waste heat, sensible heat, and energy performance. Incorporating urban microclimate considerations can help optimize energy-efficient retrofit design solutions for reducing energy consumption for heating in the building sector.

Addressing the Overheating in limited-domain urban simulations with PALM

Pierre Monteyne and Björn Maronga
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PALM's ability to simulate urban city quarters in heat wave situations can be constrained by the applied initial and boundary conditions, potentially leading to inaccuracies in the temporal and spatial development of canopy-layer temperatures. We found a strong tendency for overheating with time due to limitations in representingthe interaction between urban surfaces and the atmosphere or interaction with the rural, especially for extreme heat wave situations.
In Maronga et al. (2022), we showed that a 7-day simulation with a 2 x 2 km section of Berlin under heat wave conditions and using cyclic boundary conditions together with large-scale subsidence, leads to an continuous heating of the atmosphere. This overheating resulted in 2-m air temperatures of over 320 K after one week.
In the present work, we will investigate the origins of the overheating problem, based on the assumption that urban-rural circulations might play a key role for fresh air supply that are neglected when simulating limited-domain urban PALM simulations. Based on our finding we aim at developing a correction mechanism based on energetic considerations and city-scale parameters.

Maronga, Björn, Matthias Winkler, and Dan Li. "Can areawide building retrofitting affect the urban microclimate? An LES study for Berlin, Germany." Journal of Applied Meteorology and Climatology 61.7 (2022): 800-817.

SESSION 2

Characterizing Urban Flow Disturbances for Safe Operations of Urban Air Mobility

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Future design of urban air mobility vehicles needs to satisfy both safety and noise requirements. The most significant threat, in terms of their safety and noise level produced during the operation of these vehicles within urban areas, is the atmospheric disturbance generated by roughness elements such as buildings, trees, bridges etc. While previous studies have simulated flows within idealized or realistic urban configurations, flow disturbances that are important for urban air mobility (e.g., near building rooftops which could serve as vertiport and in the wake of buildings) remain elusive. To address this knowledge gap, we perform high-resolution large-eddy simulations of fluid flow over idealized urban settings (e.g., single building, aligned and staggered building arrays) using PALM (with its nesting feature) and OpenFOAM. We further apply spectral proper orthogonal decomposition to analyzing the simulation results, which allows us to characterize coherent structures near building rooftops and downstream of buildings under various meteorological conditions (e.g., wind speeds, wind direction, and stable or unstable stratifications).

Large-eddy simulation of vehicle-induced turbulence and pollutant dispersion in urban street canyons - Effects of thermodynamics and wind conditions

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The wind flow and pollutant transport in urban street canyons have been studied for decades. The processes that influence the phenomena within urban street canyons are accordingly well-known. However, they have mostly been investigated in isolation, despite their interactions. In this study the effect of vehicle-induced effects (VIE) on the turbulent flow in urban street canyons and its interactions with thermodynamics and different wind conditions were investigated by means of high-resolution LES. Thermal effects result mainly from the variation of solar heating of the building walls and the ground during the day. A surface heat flux on either the ground, the leeward wall, the windward wall, or a combination of the ground and one side wall was set, accordingly. In the same street canyon setup, we also varied the ratio of wind speed to vehicle speed. For the vehicle speed, we modeled typical scenarios in city traffic, i.e. speeds between 5 ms^{-1} and 15 ms^{-1} . The wind speed, however, was varied between 2.5 ms^{-1} and 7.5 ms^{-1}. In order to be able to separate the influence of traffic and thermodynamics or wind conditions, the set of simulations was carried out once with and once without traffic. To account for the VIE the newly implemented and validated Induced Velocity Method (IVM) is used. In this talk we will present the results of our study and discuss the findings made.

Urban Ozone Production Simulated with PALM-4U at High Spatial Resolution

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The production of ozone occurs through a series of individual reactions of different volatile organic compounds (VOC) of biogenic and anthropogenic origin. Accurate prediction of ozone production using an explicit chemical mechanism is correspondingly complex. An alternative is offered by reaction mechanisms in which VOCs with the same properties are lumped together. Based on our air quality measurements in Berlin, we were able to compare the simplified carbon bond mechanism CBM4 with the explicit MCMv3.3.1 mechanism and found good agreement in the ozone production for the VOC mix we observed.
The high-resolution simulation of ozone production for the Berlin city centre with CBM4 provides an insight into the spatial distribution of ozone precursors. For boundary conditions, the output of the EURAD-IM simulation was chosen. The calculations done on the JURECA supercomputer in Jülich show that nitrogen oxide concentrations are highest on the roads due to traffic emissions, while the concentration of peroxy radicals above the roads is low and only increases again in the windward area of the roads. Ozone production is at its maximum above the roads but still significant beyond the roads.
The project was funded as part of the Urban Climate under Change [UC]2 under the funding code 01LP1912F. Computing time was provided on the JARA partition of the supercomputer JURECA as part of proposal No. 20911 "Highly resolved Simulations of Urban Air Quality with PALM4U" (HiSUAQ).

Retrieval of Annual Air Quality Statistics from a Limited Number of LES Model Simulations

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Legislative air quality limits are based on annual statistics, like annual mean or n-th highest hourly or daily concentration. Complex CFD models may provide air quality simulations at the street level. However, these simulations are computationally too expensive for large time periods like a year. For RANS models this is usually solved by calculation of steady-state concentration fields for different wind directions, which are then scaled by the wind speed to provide concentrations for a particular hour. However this approach is not suitable for the LES models, which count for time-evolving resolved turbulence. With these models usually several periods of time extent of days are calculated. Annual statistics have to be constructed from a limited number of "typical" days, which guarantee a reasonable coverage of different scenarios during the year. We propose a method for identification of “typical” days based on k-medoids clustering. The method was validated on monitoring stations. We also demonstrate its performance on pilot PALM simulations. Target of this pilot experiment is to prove the potential to retrieve the fields of annual statistics from LES models.

Modeling the Dispersion of Natural Gas Leaks from Damaged Transmission Pipelines Using PALM

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Natural gas (NG), which mainly contains methane (CH4), is considered an energy source that has fewer long-term adverse impacts on the Earth's climate compared to coal and petroleum. The ease of production and accessibility of NG pipelines have facilitated their widespread expansion. However, the prolonged service life of these pipelines has introduced risks, leading to NG leakage incidents due to degradation over time. Accidental releases of NG from damaged pipelines pose significant threats in urban areas and contribute to climate change. Accurately predicting, measuring, and evaluating NG diffusion characteristics following a leak is crucial for taking quick safety measures, maintaining leakage within safe limits, and reducing environmental damage. This study assesses the spatial and temporal distribution of NG concentrations released on January 29, 2024, from a damaged pipeline at the TDECU Stadium Garage on the University of Houston campus. The assessment uses computational fluid dynamics modeling run with PALM adapted for urban areas. The study identifies potential high-risk areas and evaluates the influence of the surrounding urban environment on dispersion patterns. The model's validity and performance are evaluated against experimental data based on temporally highly resolved CH4 and isotopic CH4 measurements. The results provide valuable insights for emergency response planning and risk assessment related to accidental NG releases in densely populated urban areas.

Dispersion of ship exhaust plumes and current developments in the moving emissions module

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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.
Here, we present results of a joint project using high-resolution LES with PALM together with ship emissions measured directly at the exhaust. In the experimental setup, the research boat was passing the measurement location at the shore several times, to create a statistical ensemble. We modelled the ship emissions to get a comprehensive picture of the 3D dispersion process. Comparing the measurement data with the simulations, it is estimated, how much of the total emissions are detected at the measurement location. The research question is, whether it is possible to derive individual ship emissions from immission measurements. Besides, new code features introduced to the moving volume-source emissions module are descibed.

Implementation of a particle resuspension model in PALM

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In urban areas, dry deposition leads to the accumulation of particles on the ground. These particles include emissions from traffic, heavy metals, micro-plastics and other debris. In the right wind conditions, these pollutants can be resuspended, adversely affecting air quality near the ground and directly exposing city populations. However, quantifying the contribution of resuspension to pollutant exposure remains challenging. Field studies often rely on indirect measurement methods, and wind tunnel experiments use simplified topologies. Computational fluid dynamics tools (CFD) have been employed in few studies, with even fewer utilizing the large eddy simulation (LES) framework. In this talk, we will present the first implementation of resuspension in PALM, based on the quasi-static Rock'n'Roll model. This approach considers the motion of particles around a pivot point, with resuspension occurring when the moment balance is broken. We will discuss preliminary results obtained in the case of a street canyon, and review the sensitivity of both the resuspension and deposition models to surface roughness. Our findings aim to provide deeper insights into the dynamics of particle resuspension in urban environments, potentially informing better urban air quality management strategies.

Unveiling Dust Devil Particle Transport: A Large-Eddy Simulation Study

Sebastian Giersch
EBP Deutschland GmbH

Dust devils remain elusive in their contribution to dust emissions, impacting climate and air quality. This Large-Eddy Simulation (LES) study presents investigations utilizing the PALM model system coupled with an advanced dust emission scheme, which has been recently implemented to the PALM default code. Beside a technical overview on the implemented dust physics, the talk gives insights into dust release within the convective boundary layer.

Contrary to prevailing estimates, our findings reveal that under desert-like conditions, dust devils contribute on average 5% to regional dust emissions, with peaks up to 15%. This contrasts with prior measurements (>35%) and LES-based assessments (~0.1%). Notably, local emissions from dust devils surpass surrounding areas by 1–3 orders of magnitude, underscoring their significance for air quality and visibility. Additionally, our study unveils hitherto unknown large-scale convective dust emission patterns, cloesly connected to cellular flow structures within the convective boundary layer. By investigating saltation-induced dust emission, this research enhances our understanding of dust devil particle transport, crucial for estimating the contribution of dust devils to the overall dust release into the atmosphere.

SESSION 3

Intercomparison of PALM-4U simulations performed by using MOLOCH and WRF meteorological drivers

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We present the intercomparison of PALM-4U outputs by using two different meteorological mesoscale models, MOLOCH and WRF. Preliminary applications of these two modeling systems were conducted in a 1-km squared area of Bologna (the "Bolognina" case study), which is characterized by a significant presence of public and private greenery, which is reported in the PALM static driver in rigorous manner. First test was performed by using a grid-spacing of 5m for a three-days period in clear sky conditions. The discrepancies pointed out by this intercomparison are quantified in terms of vertical potential temperature, wind speed and direction, as well as for the human thermal comfort over all the domain.
Our preliminary findings highlighted that in the Bolognina case study, the extremely detailed information on urban vegetation, down to individual trees, enabled the testing and assessment of Nature-Based Solutions (NBS) strategies in an urban context.

Improvement of the PALM-FAST coupling for heterogeneous wind fields

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We present an improved version of the coupling between PALM and the aeroelastic code FAST (Krüger et al.), which is available in PALM since version 22.10. The enhanced coupling enables handling of heterogeneous wind fields. It allows for detailed turbine output in atmospheric flows that are both temporally and spatially heterogeneous, while still maintaining computational efficiency. To achieve this efficiency, both codes use a decoupled time step, where PALM employs an Actuator Sector Model and FAST uses a blade-element momentum approach. In addition, a wind speed correction (Meyer Forsting et al.) has been added. This correction addresses the discrepancy between the intended lifting-line theory and the actual Actuator Line Model. It also allows the coupling to be used in flows that are temporally and spatially heterogeneous. To evaluate the results, we conducted comparisons between different model setups and turbine measurements. Additionally, the model setups were assessed in a wake situation involving two turbines.

Krüger, S., Steinfeld, G., Kraft, M., & Lukassen, L. J. (2022). Validation of a coupled atmospheric-aeroelastic model system for wind turbine power and load calculations. Wind Energy Science, 7(1), 323–344. DOI: 10.5194/wes-7-323-2022
Meyer Forsting, A. R., Pirrung, G. R., & Ramos-García, N. (2020). Brief communication: A fast vortex-based smearing correction for the actuator line. Wind Energy Science, 5(1), 349–353. DOI: 10.5194/wes-5-349-2020

SESSION 4

PALM-SLUrb: a single-layer urban surface model for micro to mesoscale atmospheric boundary layer studies

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The implementation of a land surface model (PALM-LSM) and a building surface model (PALM-USM) in the PALM model system has made it possible to model coupled surface fluxes of radiation, momentum and heat online during the simulations. However, modelling urban fluxes with the respective models requires usage of grid resolutions capable of resolving the individual buildings and street canyons within the urban canopy. On the other hand, atmospheric boundary layers including urban boundary layers are heavily influenced by mesoscale phenomena, with horizontal dimensions up to tens of kilometres. In order to simulate these phenomena together with the metre-scale resolved urban canopy, computationally unfeasible problem sizes would have to be utilized.

In order to bridge the gap between meso and microscales in urban studies, the self-nesting system of PALM can be applied. However, even with the self-nesting system, the computational costs to represent large urban areas at the building resolving scale remain high. Hence, as an alternative strategy, we present a newly developed single-layer urban surface model PALM-SLUrb to represent urban canopies on lower non-building-resolving grids. The presentation will cover main features of the model as well as some practical aspects related to its application in PALM simulations. Additionally, we will present key findings from SLUrb sensitivity tests and SLUrb vs. USM model intercomparison experiments.

3-D Radiative Transfer in Building-Resolving Large-Eddy Simulations: Integrating the TenStream Solver with PALM Model System

Mohamed Hefny Salim, Sebastian Schubert, Fabian Jakub
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Accurate simulation of urban environments requires the inclusion of 3D radiative effects, which significantly influence local dynamics and turbulence. Traditionally, radiative urban canopy models have been integrated with large-scale radiative transfer models like RRTMG, utilizing the view factors approach to account for radiative transfer processes, such as shading and surface radiation reflections. However, this method falls short in addressing the 3D radiative transfer effects on atmospheric heating rates and dynamic heterogeneities, such as moving clouds or fog, leading to an overestimation of longwave divergence and limiting simulations to homogeneous clear-air conditions. To overcome these limitations, we integrate the TenStream solver with the PALM model system. The TenStream radiative transfer model, a parallel approximate solver for the full 3D radiative transfer equation, computes irradiance and heating rates from optical properties. This integration is facilitated through a mapping table that aligns surface and atmospheric properties between PALM and TenStream, enabling effective data exchange during simulations. Our results demonstrate the effectiveness of the PALM/TenStream coupling in capturing the complex interactions between urban surfaces and atmospheric processes. Comparative analysis with the standard PALM/RRTMG setup highlights the improvements in simulation accuracy.

Slanted surfaces: implementation, input data processing and testing

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Simulating clouds with PALM: Current status, recent developments and perspectives

Johannes Schwenkel
Leibniz Universität Hannover

Although PALM has gained popularity for simulating the dry atmosphere in idealized setups, its capability to include cloud simulations is now essential for some real-world applications. PALM offers two robust methods for representing clouds: the Lagrangian Particle Model (LCM) and the Bulk Cloud Model (BCM). These models, which are very different in their general concepts, provide powerful tools to study cloud interactions with turbulence, radiation, and aerosols in detail.
This talk will present an overview of the general capabilities of the LCM and BCM and their recent developments within the PALM framework. The focus will be on the implementation of mixed-phase microphysics in the BCM and its coupling with the Rapid Radiative Transfer Model. Additionally, the technical feature of NETCDF time series for individual particles will be demonstrated using LCM simulations, highlighting their versatility for applications beyond cloud simulation.

SESSION 5

Simulating the Amazon Forest Atmospheric Flow during an El Niño episode

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In October 2023, during an intense El Niño phenomenon, the Amazon region in Brazil experienced unusually high temperatures associated with a severe drought that impacted the local population, particularly Indigenous and riverside communities, who faced challenges in accessing water resources. The high temperatures and dry conditions also contributed to an increase in wildfires, affecting a significant portion of the Brazilian Amazon. Despite the importance of understanding the dynamics of the atmospheric flow above and within the forest, the Amazon is one of the most challenging regions for both mesoscale and microscale models. In this study, the Parallelized Large Eddy Simulation Model (PALM) is coupled with two mesoscale models: the MOLOCH model and the Weather Research and Forecasting (WRF) model. A day in October 2023 with high solar radiation and low cloud cover was chosen as a case study to simulate at high resolution the temperature and water vapor vertical profiles above and within the canopy. The model output will be compared to tower anemometric and scalar measurements collected at 19 vertical levels (from 5 to 316 meters) at the Amazon Tall Tower Observatory.

Simulating the Cooling Potential of Tilia Trees in Berlin Using PALM-LES: The Impact of Tree Age and Density During a Heatwave

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University of Bath, TU-Berlin, University of Bath

This study investigates the relationship between tree age, density, and their cooling effect on the urban boundary layer (UBL) and human thermal comfort at the microscale during a heatwave in Berlin. An empirical tree growth model based on Lalic and Mihailovic (2004) is used to derive leaf area density (LAD) profiles for Tilia trees at various ages. The Larsen and Kristoffersen (2002) tree database of 331 Tilia trees is employed to establish the physiological tree dimensions based on the empirical relationship between tree growth and leaf area/leaf area index. The PALM canopy generator is used to configure age-specific LAD profiles at a 1m grid resolution for 48 scenarios, varying tree age (10-80 years) and stem-to-stem density (10-35m). The study simulates an extreme heatwave event using PALM in LES mode.
The results are expected to show a linear correlation between tree age, density, and cooling effect, with mature trees at higher densities providing significant air temperature reduction - up to 6°C cooler during the day and 4°C at night beneath the canopy. Trees younger than 20 years will likely provide less cooling due to reduced leaf area and shading. These findings will prove valuable for urban planners implementing tree planting as a thermal buffer against heatwaves. The study offers a wide range of numerical tree parameters demonstrating the cooling effects of urban forest canopies on local microclimate at high spatial-temporal resolution.

PALM and trees in different resolutions and their effect on thermal comfort

Ronald Queck, Anne Bienert, Katja Richter
Technische Universität Dresden

Increasing the tree population in cities is one of the most effective measures against the increasing warming in cities. With regard to the thermal effect complex, they result in better shading and cooling through evaporation, but also a reduction in ventilation and an increase in air humidity. Analyses of the various influences on the urban climate using numerical simulations are heavily dependent on the quality and completeness of the trees in the model.
The work presented here shows that urban tree registers only cover a fraction of the existing vegetation. For complete coverage, tree registers should be supplemented by aeroplane laser scans and/or satellite data. Leaf surface distributions can only be recorded with terrestrial laser scanning.
Inaccuracies in the spatial allocation during evaluation currently only allow limited statements to be made about how accurately vegetation must be modelled in numerical models. The answer to this question also depends on the task at hand. A compromise between computational effort and model quality seems to be given with a grid resolution between 1 and 2 metres.
Both the direct measurements and the simulations demonstrated a cooling effect of vegetation areas. However, there were small-scale differences that may be of greater significance for the local climate. The restriction of ventilation led to an increase in heat stress under certain conditions.

SESSION 6

Investigations into the flow in and around offshore wind farms

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1 Fraunhofer IWES, 2 ForWind - Universität Oldenburg

Offshore wind energy will become one of the backbones of the energy transition in Europe and Germany in the coming decades. One mayor factor that reduces the efficiency of electric energy production in large offshore wind farms or clusters of wind farms is the availability of kinetic energy to the turbines that is reduced due to wake and induction effects. Fraunhofer IWES and ForWind - Universität Oldenburg have collaborated in several research projects in the last years to better understand the flow in and around offshore wind farms. The work has contributed to the development of simplified flow models for wind farm development and to support dedicated measurement campaigns at wind farms. In this presentation we want to present highlights from recent and ongoing work and the questions and issues that we face when aiming to simulate the interaction between wind farm and atmosphere with PALM.

Stratified flow over complex terrain and its effects on extreme wind conditions at wind turbines

Oliver Maas, Jamal Adib, Gregor Schürmann and Marcus Letzel
ENERCON

ENERCON performs large-eddy simulations (LES) to investigate wind turbine failures caused by extreme wind conditions like extreme gusts or extreme shear. Until now these simulations use a purely neutral stratification so that many physical effects, especially in complex terrain, are neglected. As a first step towards more realistic simulations, ENERCON takes the inversion layer and the stratification of the free atmosphere into account, while keeping the surface layer neutral.
This talk presents simulation results of a site with 126 wind turbines located in complex terrain on a peninsula often facing shallow boundary layers. Inflow conditions are derived from a reanalysis-based climatology of wind direction, wind speed and inversion layer height. Resulting flow fields and their effect on extreme wind conditions at the wind turbine locations are discussed. The combination of stratified flow and complex terrain causes effects like flow blockage, downslope winds, hydraulic jumps and Kármán vortex streets. A comparison to a simulation with a purely neutral stratification is made to highlight the importance of taking stratification into account.
One conclusion of this case study is that LES is an important tool in wind energy site assessment, and that it is also important to drive the simulation with an adequate, case-specific setup to leverage the full potential of LES. PALM, as an efficient and customizable LES model, enables ENERCON to do this kind of simulations.

Numerical investigation of high impact foehn storm in February 1925 using PALM

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We study the high-impact Föhn storm observed on 15 February 1925 in Switzerland using numerical models. Numerical simulations of this storm could help to better understand the impact potential of strong Föhn storms. In previous work, the Weather Research and Forecasting Model (WRF) was used for downscaling the storm from the Twentieth Century Reanalysis (20CRv2) down to a grid width of 3 km. While many features of the storm were realistically simulated, wind speeds in the Glarus Valley, where most of the damage occurred, remained well below the expected values. Here, we go one step further by using a Large-Eddy Simulation model (LES) to analyze whether high gust peaks at the bottom of the valley can be reproduced. For this, the PArallelized Large-eddy simulation Model (PALMv6.0) was coupled to WRFv4.1.2. In the first stage, WRFv4.1.2 was downscaled to a resolution of 1x1 km2 by using the "Twentieth Century Reanalysis" (20CRv3) as a boundary condition. The second stage involved downscaling PALMv6.0 to a resolution of 20 m by using the output of WRFv4.1.2 as a boundary condition. The simulation shows peak gusts of 40 m/s and more hitting the valley floor south of Näfels. The simulation shows good agreement with the damage described. Being able to realistically simulate the local characteristics of a Föhn storm that occurred a century back opens a new window to quantitative analyses of past extremes and their impacts.

Study of the Monin-Obukhov Similarity Theory (MOST) with PALM

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The Monin-Obukhov Similarity Theory (MOST) is of fundamental importance for fluid dynamics and its applications to atmospheric observations and modeling. MOST relates the mean fluid velocity (wind) and heat or scalar vertical gradients with turbulent fluxes; the theory helps to close the surface energy budget and to determine exchanges between the surface and the atmosphere. In this way, MOST is the core in the model and data analysis algorithms that deal with the air-sea/land interactions. Despite of its long legacy of diverse applications, the theory remains semi-empirical. Its original propositions are justified only for a narrow range of conditions valid for weakly stratified, homogeneous flows. There is a need to advance systematic validations of the MOST applications to stratified and heterogenies flows - those relevant to more realistic weather and surface types. We argue that such systemic validations could be performed with PALM numerical experiments. This study presents the methodology of this validation analysis, difficulties on the way, and results obtained for realistic urban environments. In particular, we will discuss the relations between meteorological and morphometric MOST parameterizations proposed for the urban atmospheric surface layer.

Parametrizing turbulent fluxes by extending Monin Obukhov Similarity Theory with an Artificial Neural Network

Benjamin Körner, Marcus Breil
University of Hohenheim

Monin Obukhov Similarity Theory (MOST) is commonly used for parametrizing turbulent fluxes. However, MOST is not always able to reproduce measured turbulent fluxes, as it is based on the simplifying assumptions of stationarity, windy conditions and flat, uniform surfaces with low vegetation. These assumptions are often violated in the real world. Extending the classical MOST approach beyond these shortcomings might improve the parametrization of turbulent fluxes.
Artificial Neural Networks (ANN) are well suited to derive interrelations between variables. In this study, an ANN is using the variables that go into MOST as well as additional variables as input to derive turbulent fluxes.
Training data is provided by simulations using the PALM model, explicitly resolving most of the atmospheric turbulence. The simulations replicate conditions, for which the classical MOST approach is not performing well. Training data is extracted from 10 simulations of a diurnal cycle. They include homogeneous and heterogeneous surface roughness patterns, different radiation scenarios and different background wind speeds. The resolution at ground level is 4 meters and cyclic boundary conditions are applied.
The results of the trained ANN are compared to those of the classical MOST approach to assess the potential of using ANNs for parametrizing turbulent fluxes.

The contribution of dispersive fluxes to the energy-balance closure problem

Matthias Mauder, Luise Wanner
TU Dresden

The surface energy balance is often not closed in real-world state-of-the-art flux data when using standard single-tower eddy-covariance measurements. This energy-balance closure problem has been studies for almost 40 years. After considering and partially excluding several potential reasons for this imbalance, it has become clear that dispersive fluxes are an important but usually neglected contribution to the energy balance. These fluxes emerge from the spatial covariance of temporally averaged vertical velocities and a scalar to be transported in convective boundary layers. This means, spatially-distributed data are necessary for their quantification, which require a large effort in real-word field experiments. In this study, large-eddy simulations are employed to quantify dispersive fluxes systematically as a function of a non-local stability parameter and the scale of thermal heterogeneity of surface fluxes. These results are compared with the residuals from the CHEESEHEAD19 campaign with dispersive fluxes determined from the multi-tower set-up of the same field experiment. We find that about half of the total residuals can be explained by the modelled dispersive fluxes of sensible and latent heat. Moreover, the relative contribution of these two non-local energy fluxes is correlated with the Bowen-ratio of the small-scale turbulent fluxes. The remaining imbalance can be largely attributed to energy storage in the canopy layer and probe-induced flow-distortion errors.

SESSION 7

PROMET: a new pre-processor to genereate dynamic drivers

Astrid Eichhorn-Müller (1), Helge Knoop (2)
(1) Deutscher Wetterdienst, (2) pecanode GmbH

PROMET is a new tool to pre-process meteorological initial and boundary conditions for PALM. The tool is written in Python and can be used to generate dynamic drivers for PALM based on mesoscale model simulations. Currently, plugins for offline nesting in WRF, WRF-Chem, ICON, and ICON-ART are available. The software code is freely available for beta-testing via Gitlab and will be integrated into PALM release 24.10.
This presentation will give a short overview on the new tool and how to use it. The acquisition of mesoscale input data from DWD sources and how to best use them will also be covered.

A complete toolchain for preparing inputs for real-case PALM simulations

Pavel Krč
Institute of Computer Science, Czech Academy of Sciences

The presentation will be about PALM-METEO, PALM-GeM and FUME, an open-source modular emissions processor which is able to process and prepare emission data for many different models, including PALM.

Tools to generate the static driver – A comparison

Sebastian Schubert; Stefan Fluck; Johanna Henning; Dongqi Lin;
Mohamed Salim; Sebastian Stadler
TU Berlin, Germany; City of Zurich, Switzerland; Fraunhofer-Institut für Bauphysik IBP, Germany; Monash University, Australia; TU Berlin, Germany; Fraunhofer-Institut für Bauphysik IBP, Germany

There are several tools available to generate a static driver for PALM with different approaches and levels of complexity. After a short introduction of GEO4PALM, palmpy, the PALM-4U GUI and palm_csd, we will present the application of each tool to generate domains for three cities (Leipzig, Germany; Wuppertal, Germany; Zurich, Switzerland) based on identical input data. We will highlight the differences in each workflow, and discuss the identified strengths and weaknesses of each tool.

Advancements in PALM-4U GUI: New Features and Practical Application

Matthias Winkler, Sebastian Stadler and Johanna Henning
Fraunhofer-Institute for Building Physics IBP

PALM GUI is an easy-to-use graphical user interface (GUI) for PALM-4U to enable the model's operationalization in practical applications. The tool therefore implements the entire modelling workflow with PALM-4U in a single user interface. PALM-4U GUI was originally developed witin the UC² - programme and its concept and initial functionalities were presented on last year's PMC-conference. This year's presentation will focus on two main topics: Firstly, the new features of the PALM-4U GUI that have been developed over the last 12 months will be presented: These mainly improve the creation of static drivers, result visualisation and the open data interface. The main part of this presentation will focus on the practical application of PALM-4U GUI and will interactivly show how to work with this tool using a concrete example.

SanDy-PALM: a new open-source repository to create static and dynamic drivers for the PALM model system

Julian Vogel, Sebastian Stadler, Ganesh Chockalingam, Johanna Henning, Afshin Afshari and Matthias Winkler
Fraunhofer IBP, Fraunhofer Institute for Building Physics

The PALM model system has demonstrated its ability to perform realistic urban microclimate simulations. However, there is still a major challenge to set up simulations: a large amount of input data needs to be collected and converted to the specific format required by the static and dynamic drivers of the PALM model. The complexity of preparing input data and the significant effort required for each simulation case have hindered researchers from efficiently utilizing the PALM model system for realistic microclimate simulations. While this issue is currently being addressed by several research groups, our contribution is a new open-source Python package that creates static and dynamic drivers out of one box named SanDy-PALM. The static driver generation supports all common raster and vector data types for case-specific inputs. We also included a novel preprocessor to create virtual cities from an LCZ map and an interface to download and process Open Street Map data. The dynamic driver currently supports WRF input data and features a sophisticated gap-filling below the first model level using a roughness-corrected surface layer scheme. For this work, we prepared several static drivers using the same test case but different data sources and ran a PALM-4U simulation for each of them. We then compared the static drivers as well as the simulation results, emphasizing the variations emerging from the use of diverse input data sources.

Enercon’s pre-processor for complex terrain

Alexander Radi, Marcus Letzel
Enercon

Enercon routinely installs wind parks in complex terrain. PALM is used to estimate available wind energy and structural loads on turbines, but it lacks a build-in pre-processor. This presentation discusses a new Python tool designed to transform GIS maps (terrain elevation & roughness) into PALM’s inputs, maximally exploiting PALM’s self-nesting capability to minimize HPC costs.
tool’s highlights include support for commonly used GIS formats, such as geotiff, geo-package and geo-tagged NetCDF as PALM static driver for easy visualisation in QGIS.
The nest creation process is fully automated and allows an arbitrary deep nesting of child nests, controlled by the assignment of “grid refinement levels” to spatial “Points of Interest” on the map.
“Terraforming” is applied: Depending on the user selected inflow type (West-to-East or dynamic driver), the terrain geometry is artificially ramped down and/or morphed into laterally cyclic shape within PALM’s domain.
All nest geometries are optimized for the selected pressure solver: Optimal grid point counts in x,y,z directions are computed for poisfft and multigrid solvers.
Python 3.8 and publicly available libraries were used. Object oriented programming with in-code doc-strings were applied. The packaged tool is installable via `pip install`. The tool design is intentionally generic, not limiting it to wind energy applications, hence feedback is requested from the entire PALM community.

Validating PALM's Canopy Generator Using LiDAR-Derived Leaf Area Density Profiles

Joshua Brook-Lawson, Fred Meier, Sebastian Schubert, Tristan Kershaw
University of Bath, TU-Berlin, TU-Berlin, University of Bath

This study presents a novel approach to derive single-tree-level leaf area density (LAD) profiles from LiDAR and UAV photogrammetry data, creating realistic, site-specific input for PALM's canopy generator, which is utilised by several PALM preprocessor tools. The method was applied to urban (Rathaus Steglitz) and rural (Britz, Brandenburg) sites in Germany. Terrestrial/aerial LiDAR scanning and UAV photogrammetry were used to collect point cloud data, which was pre-processed, segmented into individual tree crowns, and classified into woody mass and foliage. LAD profiles for each tree were calculated using a voxel-based algorithm and validated against LAI field measurements.
LiDAR-derived LAD values are expected to provide more accurate, species-specific profiles compared to previous measurement campaigns and empirical estimates. These profiles will optimise and align PALM's canopy generator with real-world measurements, enabling future studies to apply the model with increased confidence in its alignment to observed data.
This study offers valuable validation of PALM's canopy generator, establishing a foundation for further research on the model's application in assessing the cooling potential of urban forests at the microscale. Future work will evaluate the sensitivity of PALM's Plant Canopy Model to explicit (LiDAR-derived) and implicit (improved canopy generator) LAD input data sources by comparing PALM's vegetation output with site measurements.