EVALUATING A 3D ATMOSPHERIC MODEL FOR THE DEVELOPMENT OF NOCTURNAL KATABATIC COLD AIR DRAINAGE FLOWS

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Contents

Harmonisation of the simulation process

Lohmeyer

- **Which model and when?**
- **Timeframe? Scale? Spatial Resolution? 3d buildings? Vegetation? etc**
- **As project complexity increases so too does often the number of models required.**
- **As the number of required models increases so does the level of required knowledge and resources, e.g. time, license, computing power, validation.**
- **-> Need for harmonisation in the simulation process**

Introduction – PALM – 4U model system

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- **The PALM model system (Leibniz University, Hannover) includes several components which expand upon the PALM model core to create the PALM-4U system.**

- **3-dimensional prognostic flow model, based on solving the incompressible, Boussinesq approximated Navier- Stokes equations for the three components of the wind field (u, y, z) as well as scalar quantities.**

- **The PALM-4U model system offers the possibility to harmonise the simulation process by combining a 3-d flow model with components for simulating:**
  - **land-surface interactions**
  - **3-d vegetation**
  - **urban structures**
  - **radiative processes**
  - **pollutant dispersion**

Introduction – Evaluation Standards

- **Model needs to be evaluated and tested for a variety of set-ups and cases before they can be used and accepted by relevant authorities.**
- **Within Germany, the German Society of Engineers (VDI) develop and provide best practice guidelines for running models as well as a standarised framework for evaluating the results of atmospheric models.**
- **For prognostic mesoscale models, VDI 3783 Part 7 (2017) provides a number of test cases for thermally induced windfields.**
- **Test case E8 “for the evaluation of dynamic and thermally generated prognostic windfield models” from the German Society of Engineers.**

Introduction – Cold air flows

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- **In areas of heterogenous topography katabatic cold air drainage flows may develop under calm, clear-sky conditions.**
- **Cold air is generated over soil and green surfaces by radiative cooling on cloudless nights, and under the influence of gravity the cold air drains downslope. With a large catchment area the cold air drainage can form significant flows.**
- **As these weather conditions are also typically associated with an increase in thermal and pollutant loads due to reduced wind speeds and turbulence, cold air drainage flows can play an important role in the dispersion of pollutants.**
- **While 2-dimensional models are capable of describing the generation, direction and size of the cold air flows they are unable to provide values of the 3-dimensional wind and temperature fields.**

Methodology – Test case

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- **The study area is located in the region of Stuttgart in southwest Germany. The city of Stuttgart lies in a so-called ’cauldron’ where the valley floor at approx. 200 m a.s.l. is surrounded by heights up to approx. 400 m high.**
- **As part of the Stuttgart 21 development project measurement campaigns were conducted between 01 April 1997 and 03 April 1997 a measurement campaign was carried out to observe the cold air flow in the area of Stuttgart city.**
- **The results of this measurement campaign form the basis of the set-up and evaluation of the test case.**

Methodology – Test case

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- **A tethered weather balloon was deployed to measure the cold air flow near the Stuttgart planetarium.**
- **Meteorological observations from the Stuttgart radiosonde station as well as surface level observations from the nearby SYNOP station provide the initial and boundary conditions for the simulation.**
- **To evaluate the model the simulated vertical profiles of wind and temperature are compared to the observations from the tethered weather ballon at the Planetarium location direction between 22:00 and 23:00, i.e. two to three hours after sunset.**
- **The radiosonde and weather balloon measurements show an upper-level flow from a northeasterly direction at 2 ms^{-1} to 3 ms^{-1}.**

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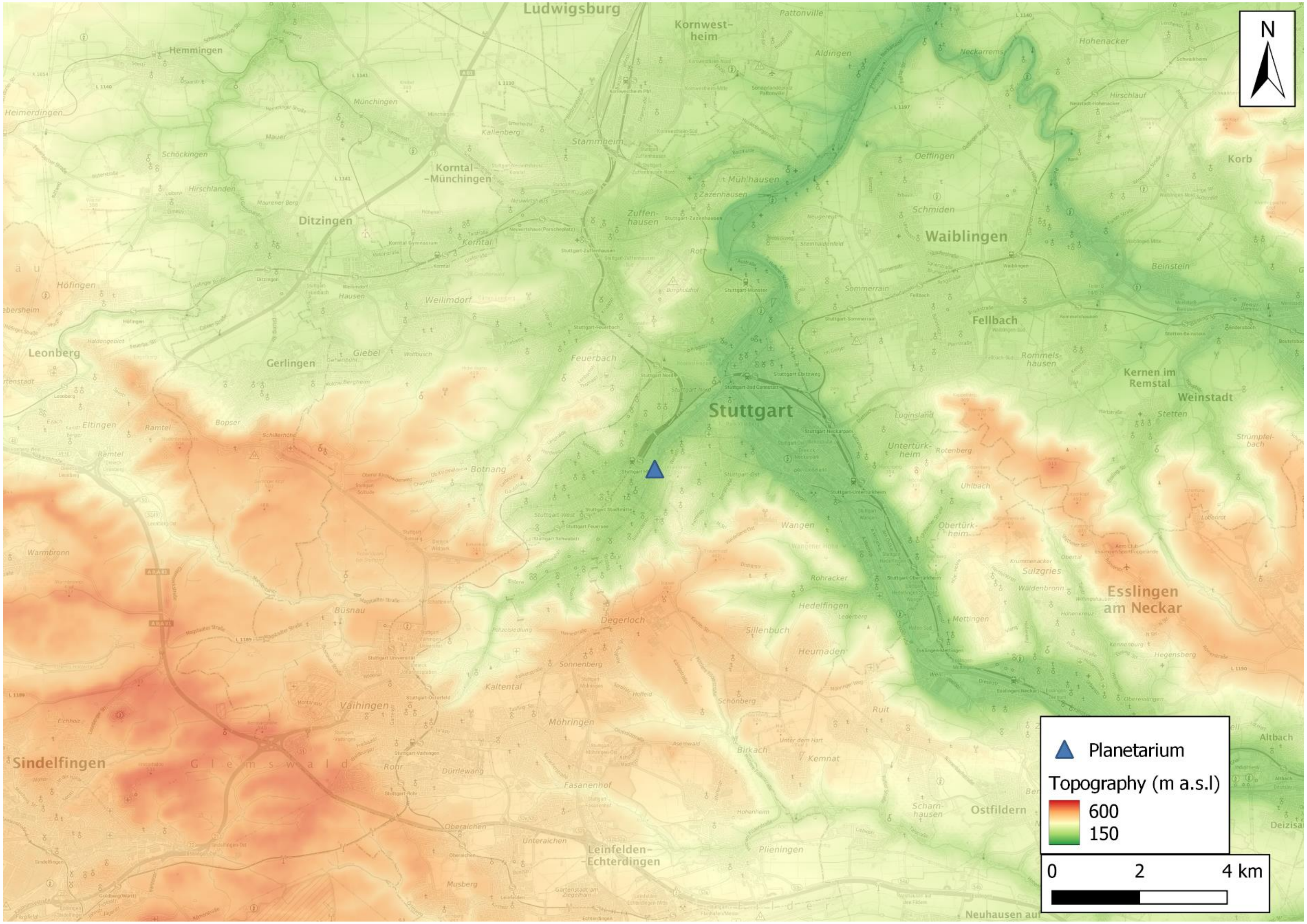

Ludwigsburg
Stuttgart
Waiblingen
Fellbach
Esslingen am Neckar
Leonberg
Gerlingen
Ditzingen
Sindelfingen
Vaihingen
Degerloch
Ostfildern
Leinfelden-Echterdingen
N
Planetarium
Topography (m a.s.l)
600
150
0
2
4 km

Methodology – PALM-4U

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- A two step offline nesting method was used where the outer domain was chosen to encompass the entire possible catchment area.
- The coarser outer simulation domain covers approx. 40 km x 40 km with a horizontal grid width of 200 m.
- The nested inner domain has a horizontal extent of approx. 20 km x 20 km with a horizontal resolution of 100 m.
- The vertical resolution is 8 m in the lower layers for both simulations.
- In this study the land-surface component and the radiation model were used, with tall vegetation and urban structures parameterised within the land surface model.
- The simulations start at 17:30, i.e. roughly two and a half hours before sunset.

Results – Cold air development

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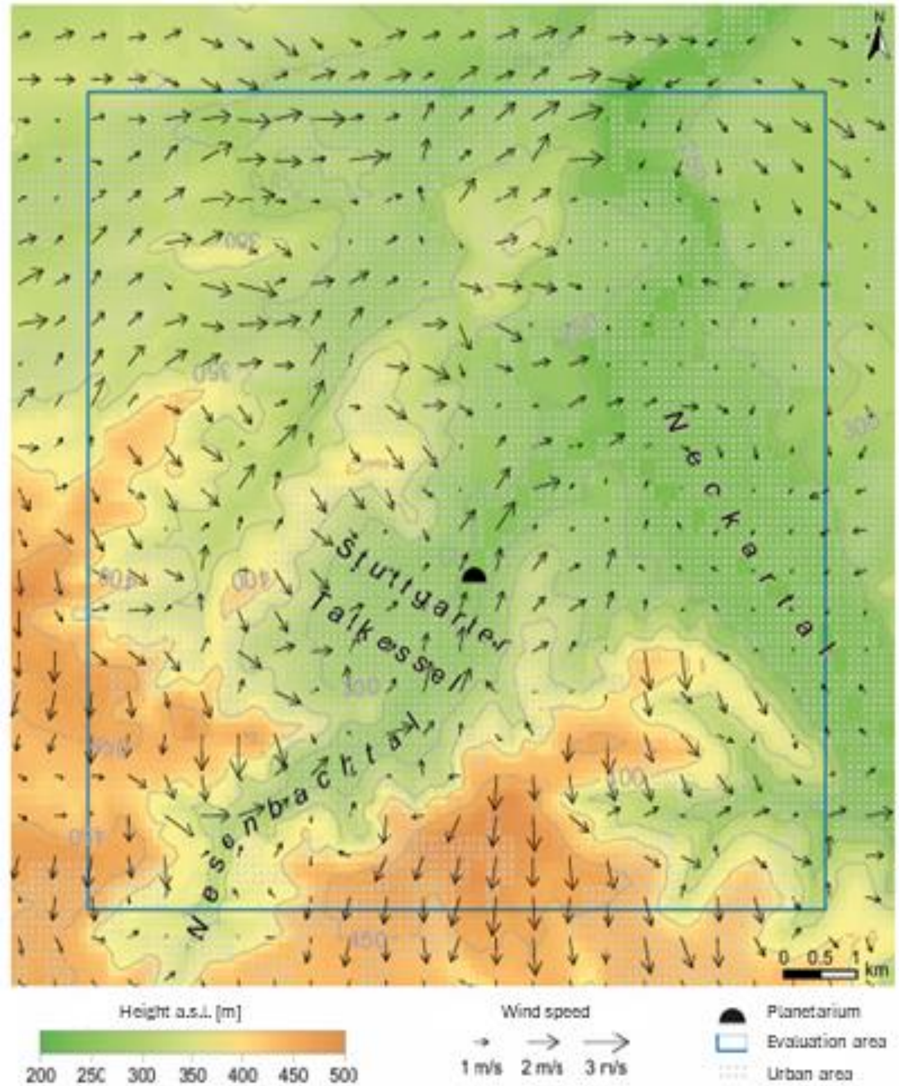
- **In the undeveloped areas of the study area, cold air forms near the ground due to the weather conditions, and then drains as a downslope wind.**

- **In the Nesenbach valley, the cold air from the valley slopes combines resulting a strong drainage flow of cold air, which carries cool and fresh air masses down the valley into the Stuttgart basin during the course of the night.**

- **The air masses reach the Planetarium from a south-south-westerly direction around 1 ms^{-1} near the surface.**



Near-surface wind direction and speed at 22:00

Results – Vertical Profiles

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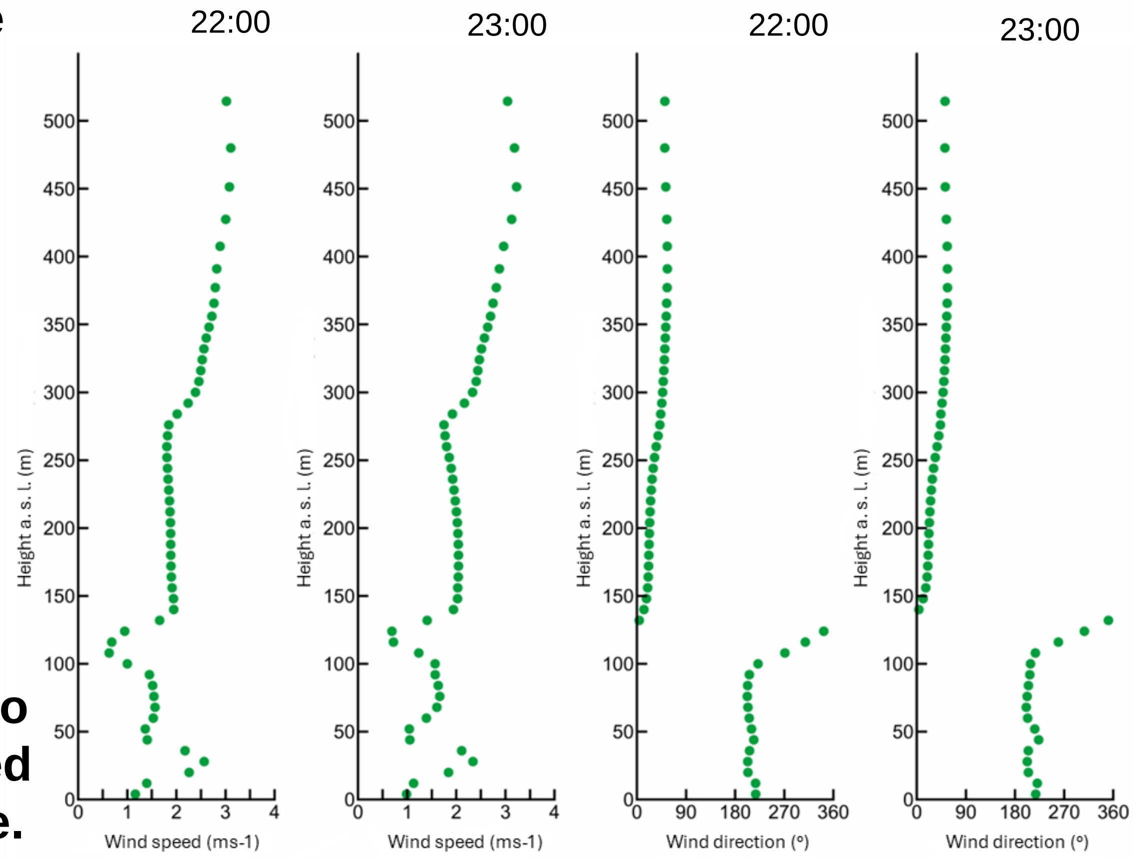
- **At both observation times, the maximum cold air flow velocities are around 2.5 ms^{-1} at 20 m to 40 m above the ground**
- **Cold air flow directions from the south-southwest up to a height of around 108 m and 116 m respectively.**
- **Above this height, the wind turns to a north-easterly direction which corresponds to the higher-level wind measured by the balloon and radiosonde.**



Simulated vertical profiles of the wind speed and direction at the location of the observation weather balloon installed at the planetarium at 22:00 and 23:00.

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Cold air layer thickness, cold air volume flow density and cold air flow direction at the Planetarium site.

	Measured value	Guideline range	Simulated value
Vertical thickness of the cold air layer (m)	95 – 110	85 – 160	112
Cold air flow density ($m^3 m^{-1} s^{-1}$)	134 – 176	90 – 195	171
Direction of the cold air flow between 25 m und 65 m (°)	-	174 – 221	207

Outlook

- **PALM-4U is successfully validated for cold air drainage flows in regions with pronounced topography.**

- **For calculating pollutant dispersion or thermal loads, further high-resolution calculation grids can be included by means of nesting, with both urban structures and high vegetation explicitly modelled.**

- **As PALM-4U is also able to simulate aerosol dispersion with atmospheric chemistry and dispersion model components, PALM-4U is able to harmonise the complex simulation process for modelling air pollution in the urban environment under varying atmospheric conditions by providing a single model environment.**

Thank you for your attention

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