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Leibniz Universität Hannover

Urban Climate Modeling With PALM

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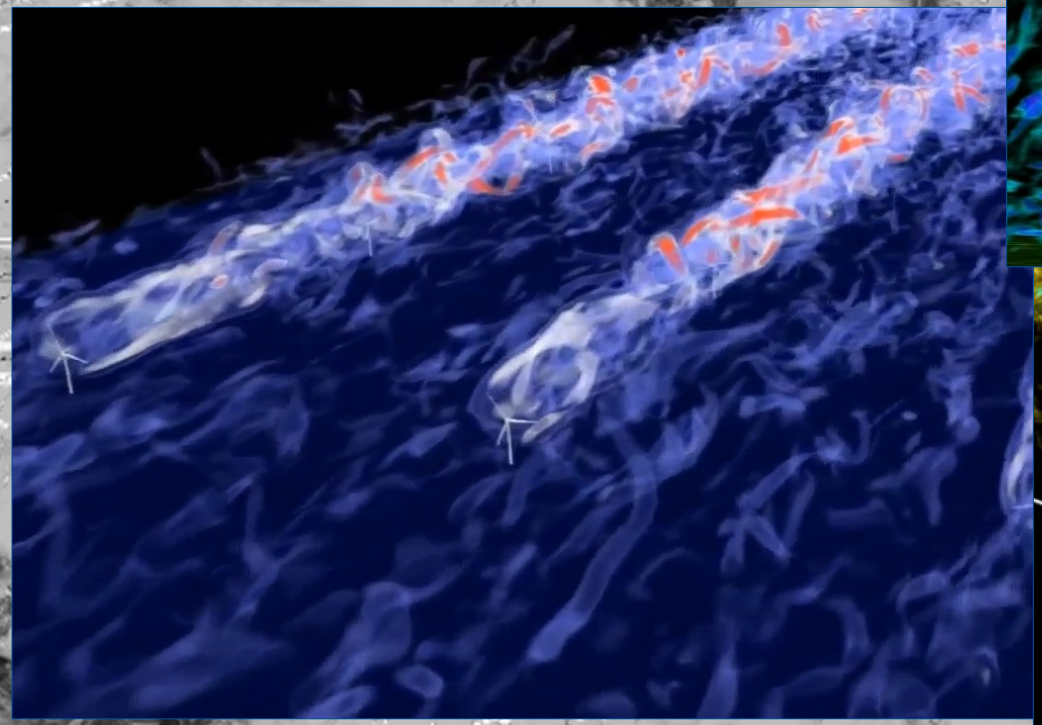
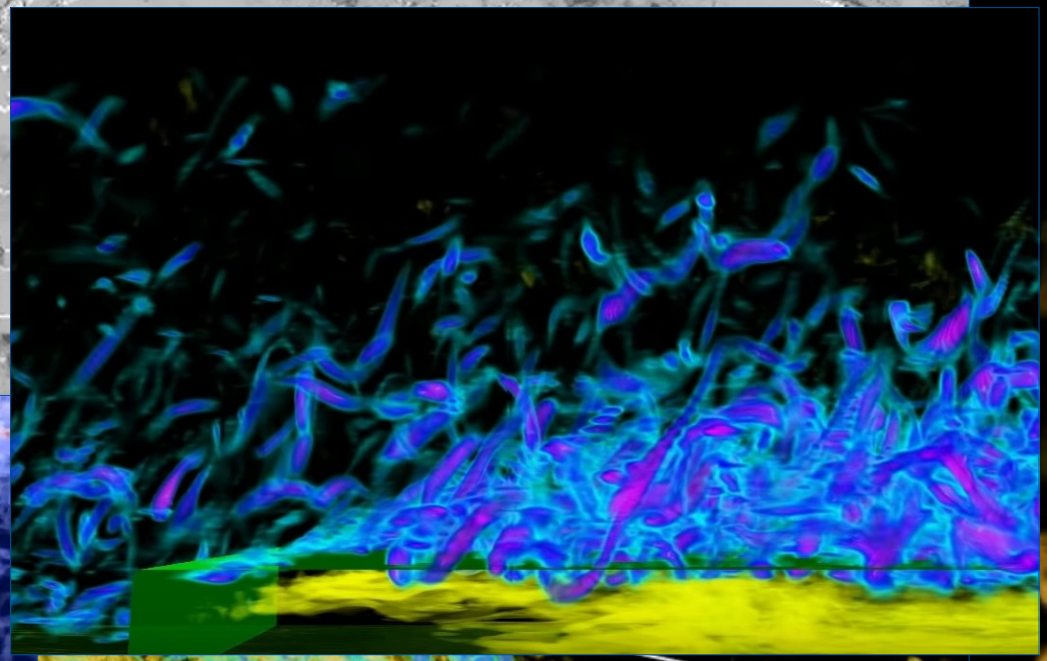
The PALM Research Group

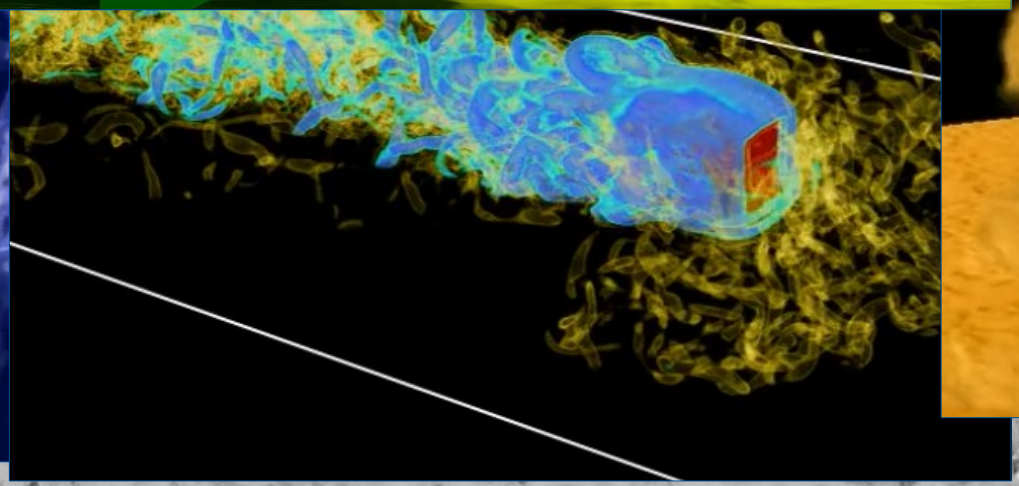
Leibniz Universität Hannover

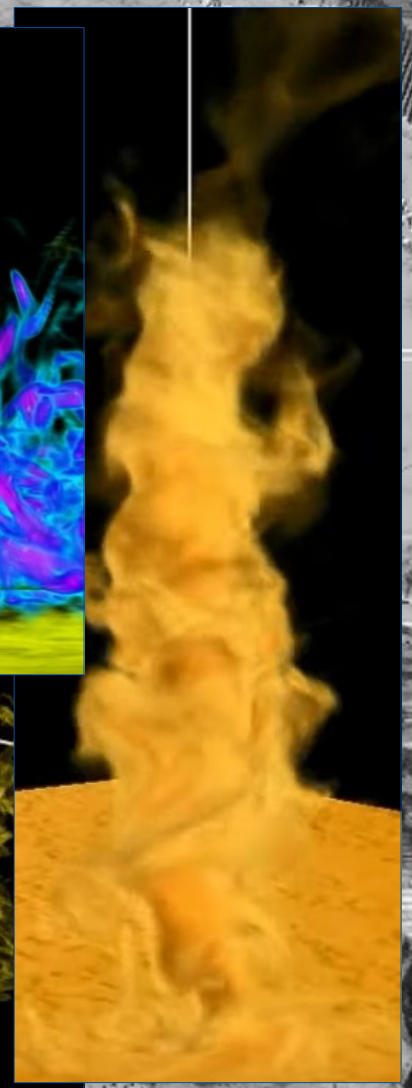
Where can you find PALM?

- https://palm.muk.uni-hannover.de
- https://gitlab.palm-model.org
- https://youtube.com/user/palmhannover





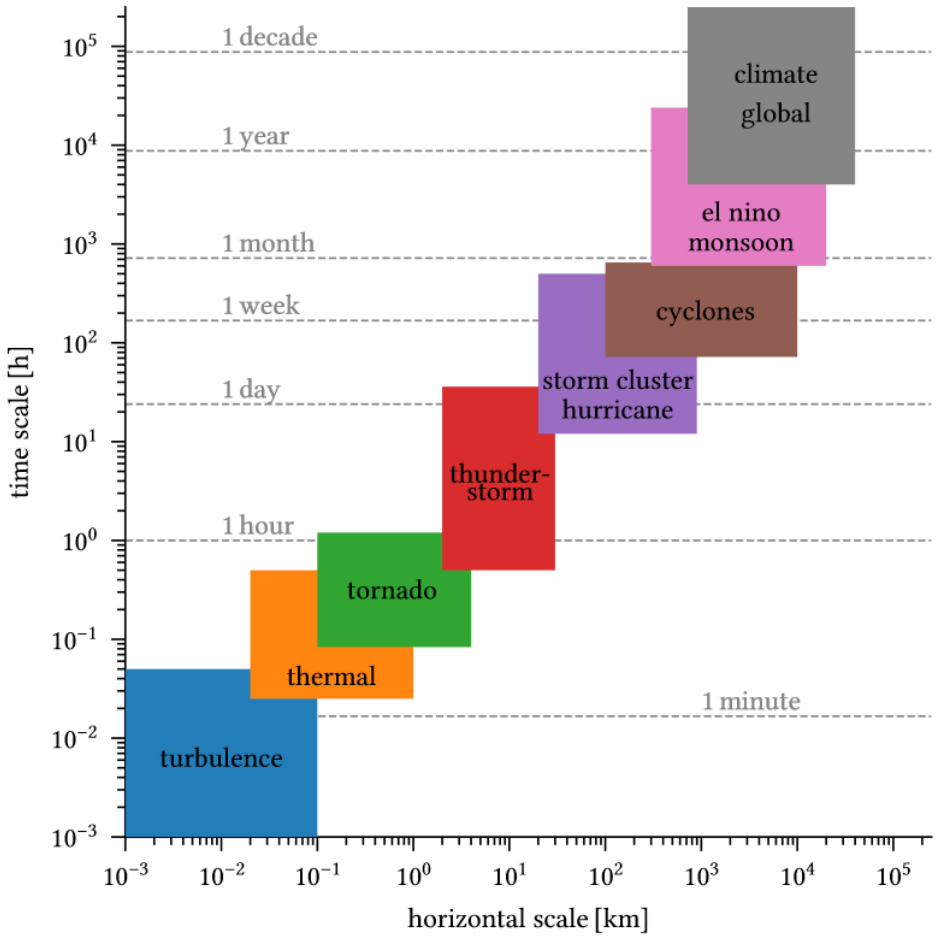




Overview

- Scales in atmospheric modeling
- Urban climate modeling in PALM
- Applications of PALM

A Matter of Scales



Rauterkus, 2021

https://unsplash.com

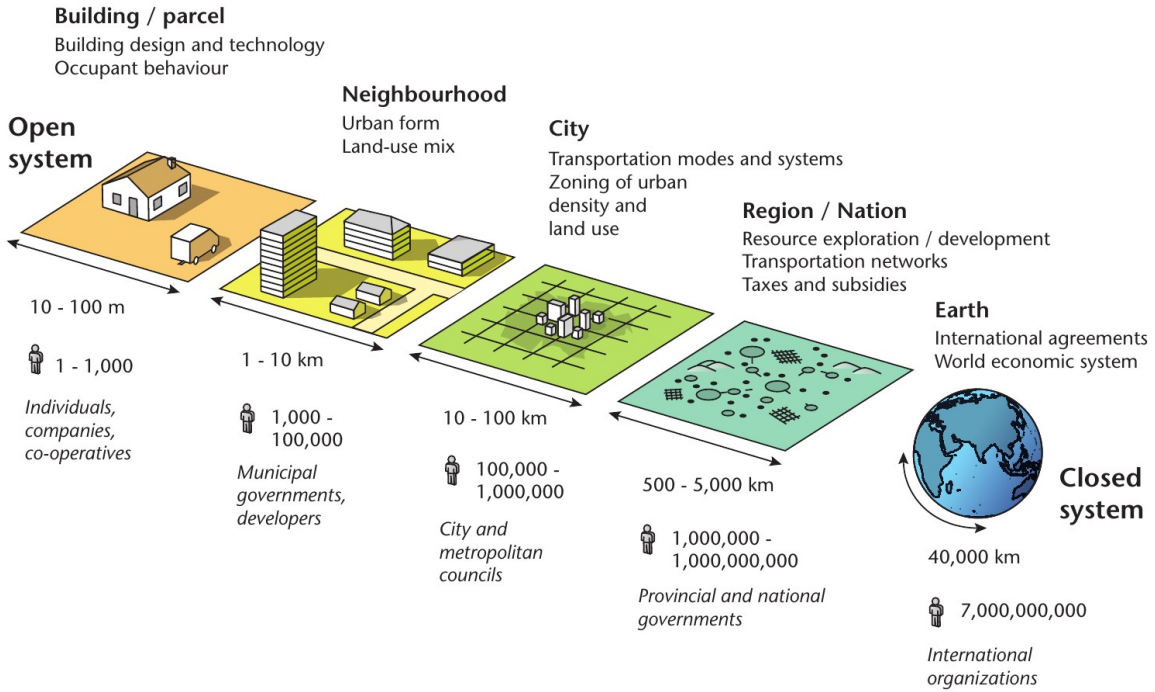
- Atmospheric motions cover several scales
- Simulating all scales is expensive
- Identify important scales

Scale Separation and Parameterization

- Split quantities in resolved and non-resolved parts

$$h = \bar{h} + h'$$

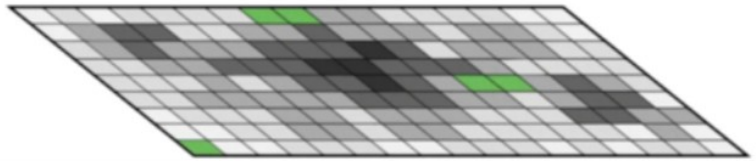
quantity — resolved — non-resolved



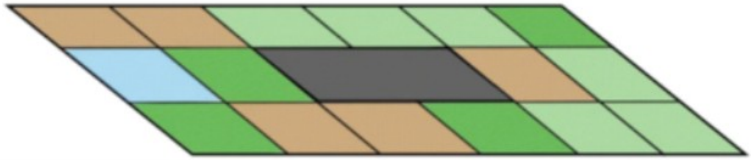
Oke et al., 2017

PALM

Mesoscale Model

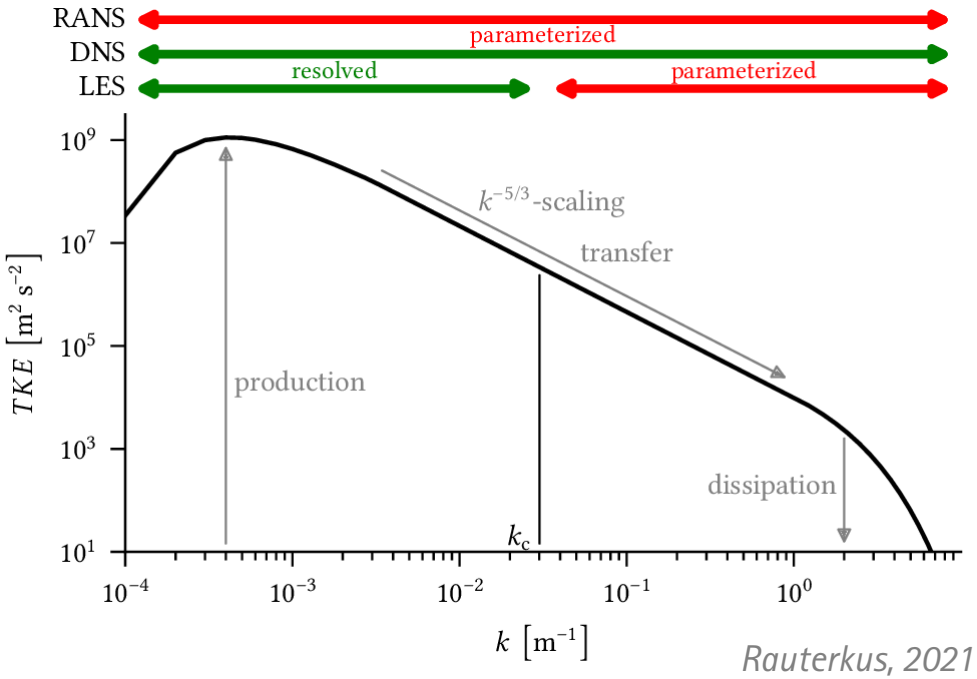


Climate model

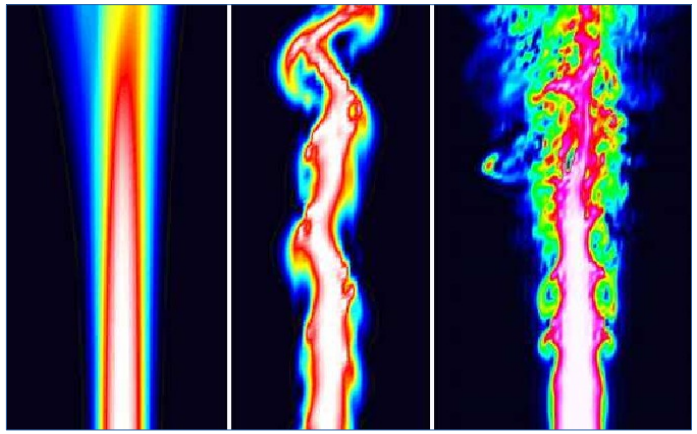


Hertwig et al., 2020

Classes of Turbulence Models



Rauterkus, 2021



Laidlaw and Villanova, 2012

- RANS: inexpensive, but no turbulence
- DNS: accurate, but expensive
- LES: combines advantages of RANS and DNS, while trying to avoid their disadvantages

The Parallelized Large-Eddy Simulation Model

- Developed since 1991 at Leibniz University Hannover
- Open Source (GNU GPL v3)
- Incompressible/anelastic 3D solver; finite differences
- Different LES closures; RANS and DNS modes available
- Highly optimized and parallelized (tested up to 32.000 cores)
- Special features:
  - Lagrangian particle mode (tracers, droplets)
  - Ocean version and atmosphere-ocean coupling
  - Plant canopy model
  - Self- and offline-nesting to large-scale models
  - Interactive land surface and radiation model
  - User-interface to plug in own code
  - Virtual measurements

PALM for urban applications

Overview

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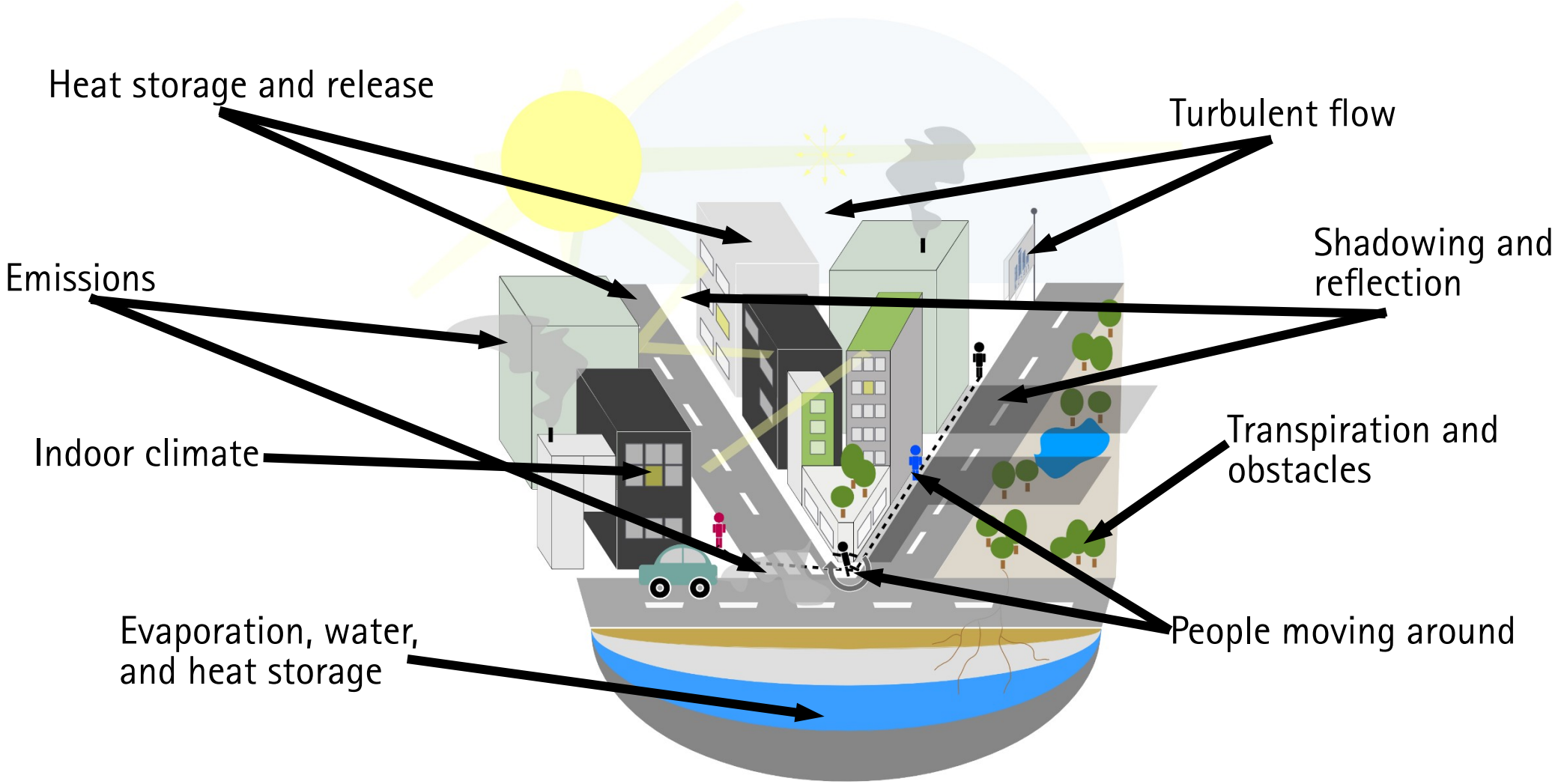
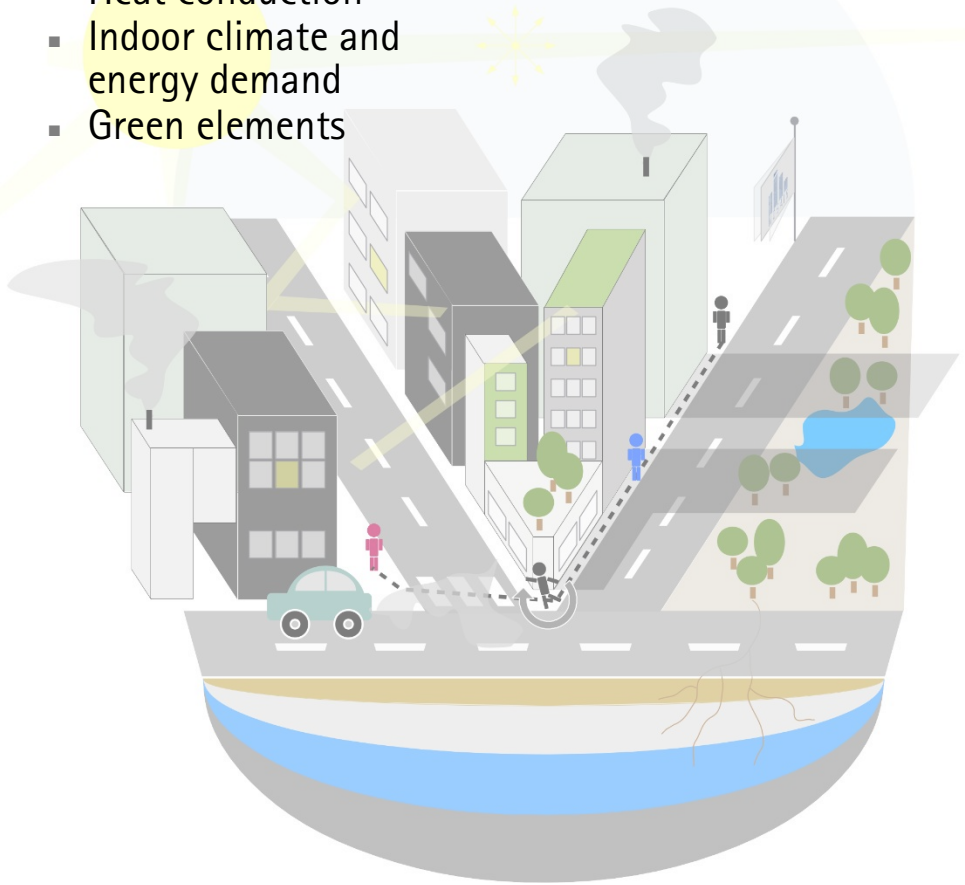
Physical Processes in Urban Climate



Overview of PALM-4U

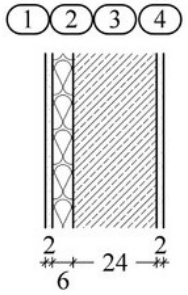
Urban surfaces

- Vegetation
- Heat conduction
- Indoor climate and energy demand
- Green elements



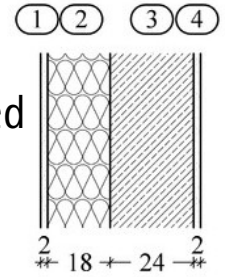
Residential 1950 - 2000 / Office 1950 - 2000

status quo



1 Mortar-Plaster
2 Thermal Insulation, $\lambda = 0.046\ Wm^{-1}K^{-1}$
3 Concrete
4 Gypsum Plaster

retrofitted



1 Mortar-Plaster
2 Thermal Insulation, $\lambda = 0.035\ Wm^{-1}K^{-1}$
3 Concrete
4 Gypsum Plaster

Maronga et al., 2022

18	asphalt/concrete mix
19	asphalt (asphalt concrete)
20	concrete (Portland concrete)
21	sett
22	paving stones
23	cobblestone
24	metal
25	wood
26	gravel
27	fine gravel
28	pebblestone
29	woodchips
30	tartan (sports)
31	artificial turf (sports)
32	clay (sports)
33	building (dummy)
34	building wall reflective
35	building wall (very) bright)
36	building wall standard
37	building window double layer glazing
38	building window tripple layer glazing
39	building window reflective
40	building roof reflective
41	building roof (very) bright
42	building roof standard

Overview of PALM-4U

Urban surfaces

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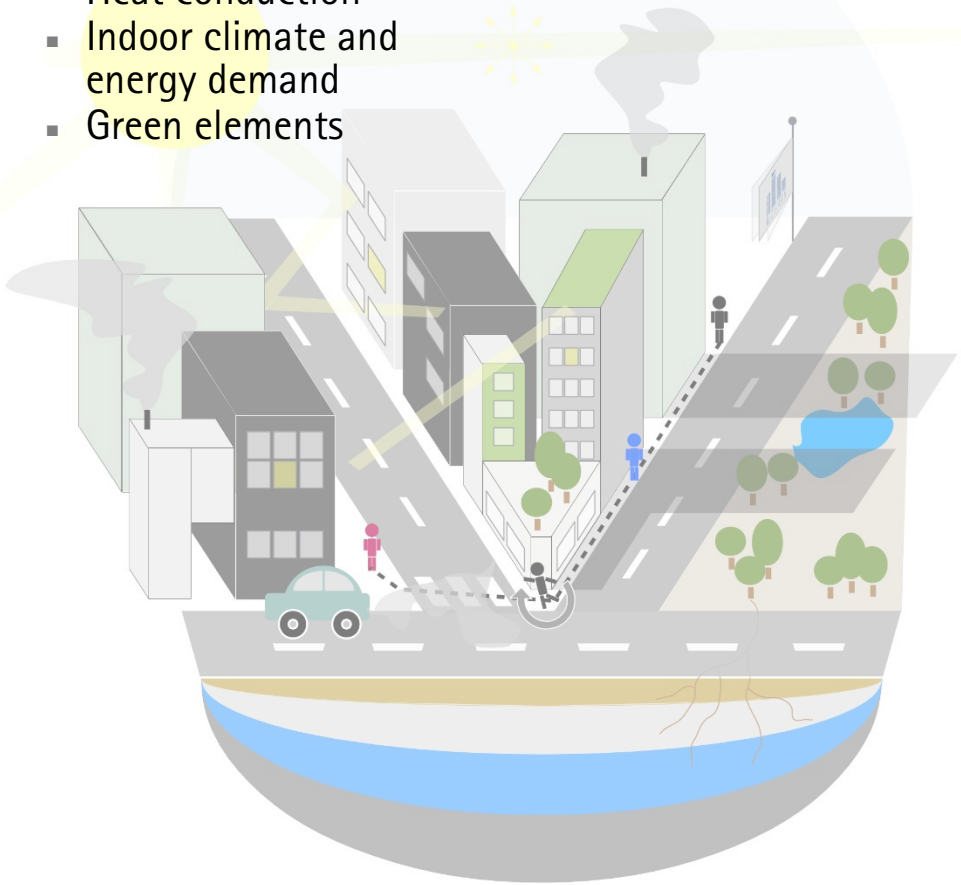

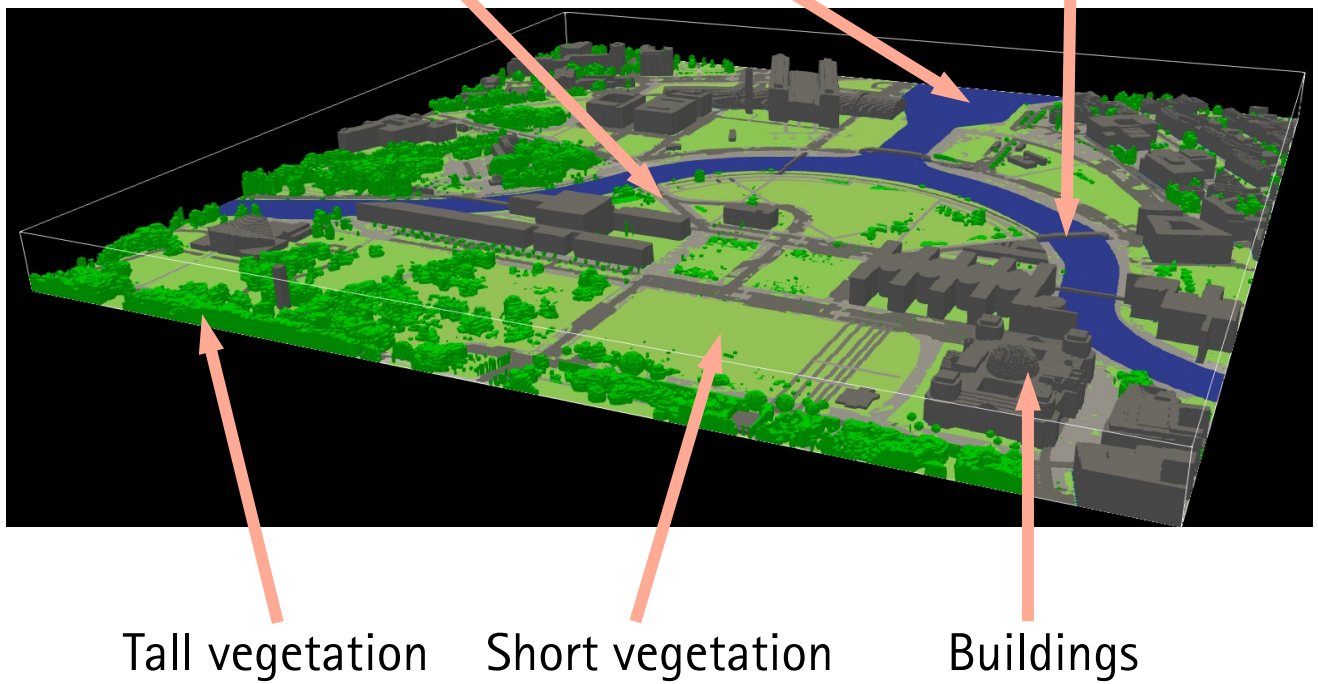

Overview of PALM-4U

Urban surfaces

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Chemistry

- Transport
- Reactions
- Photolysis
- Emissions
- Aerosols

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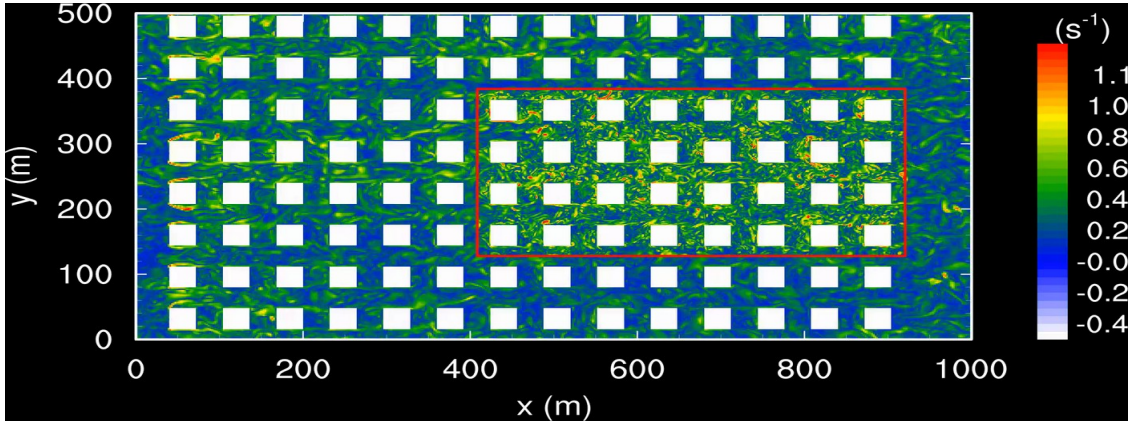
Technical solutions

- Mesoscale nesting
- LES-LES nesting
- RANS mode
- User-friendly GUI



Overview of PALM-4U

Urban surfaces
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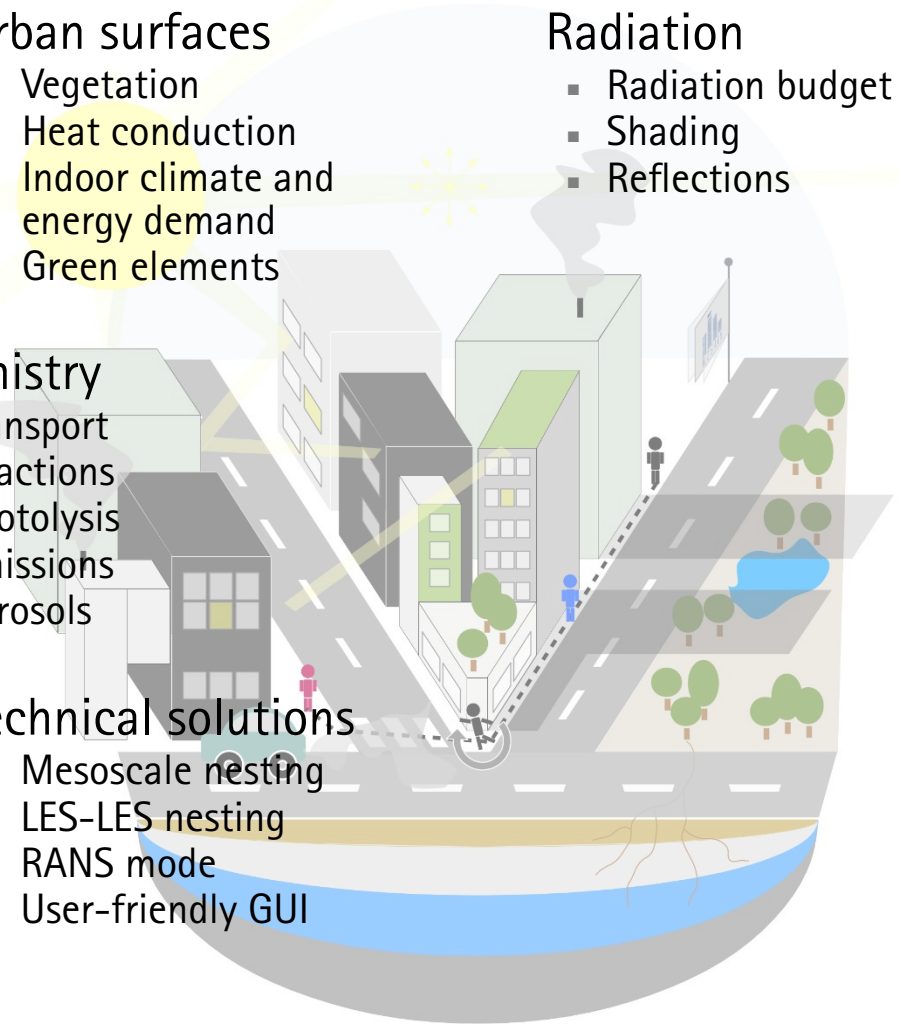
Radiation
- Radiation budget
- Shading
- Reflections

Chemistry
- Transport
- Reactions
- Photolysis
- Emissions
- Aerosols



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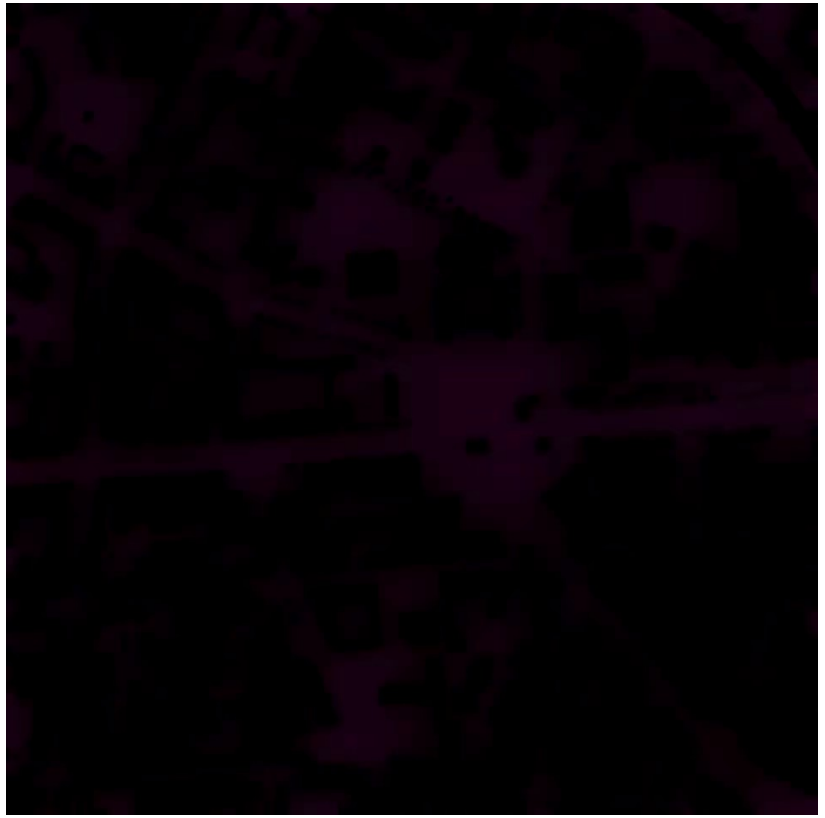

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Impact
- Multi-agent system
- Biometeorology

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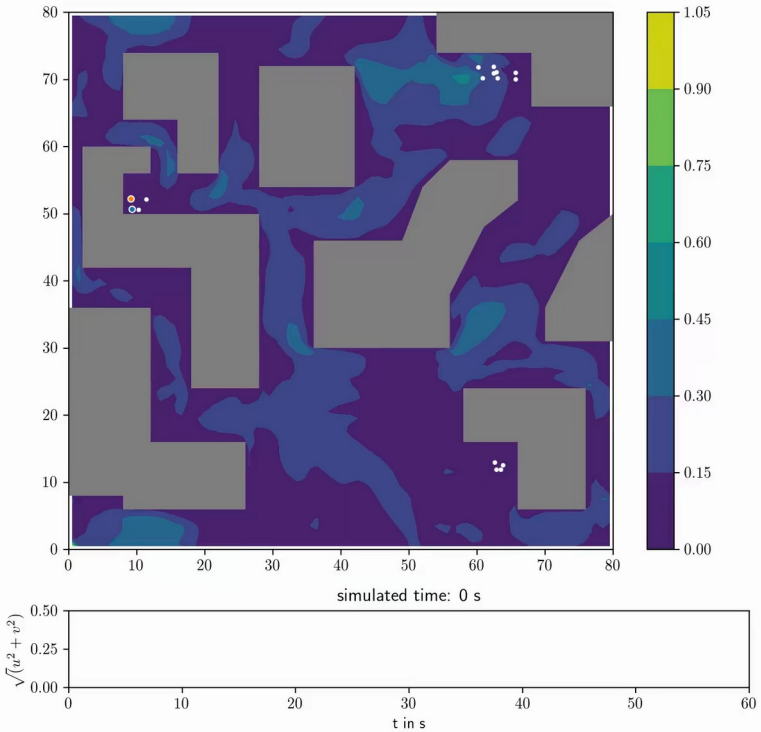

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Vegetation
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- Momentum sink
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Technical solutions
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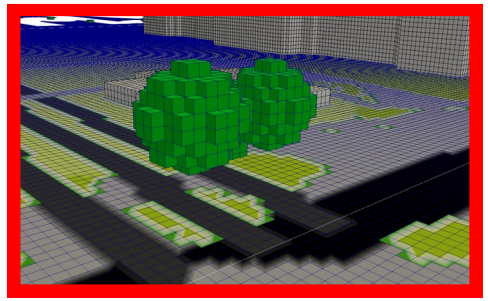

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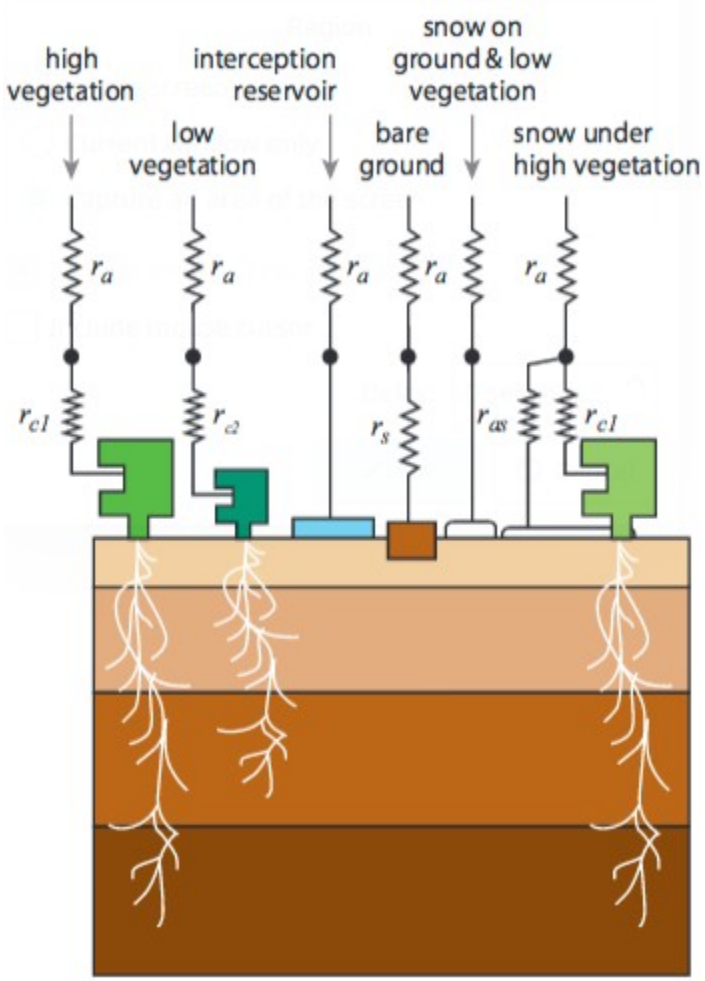
- User-friendly GUI

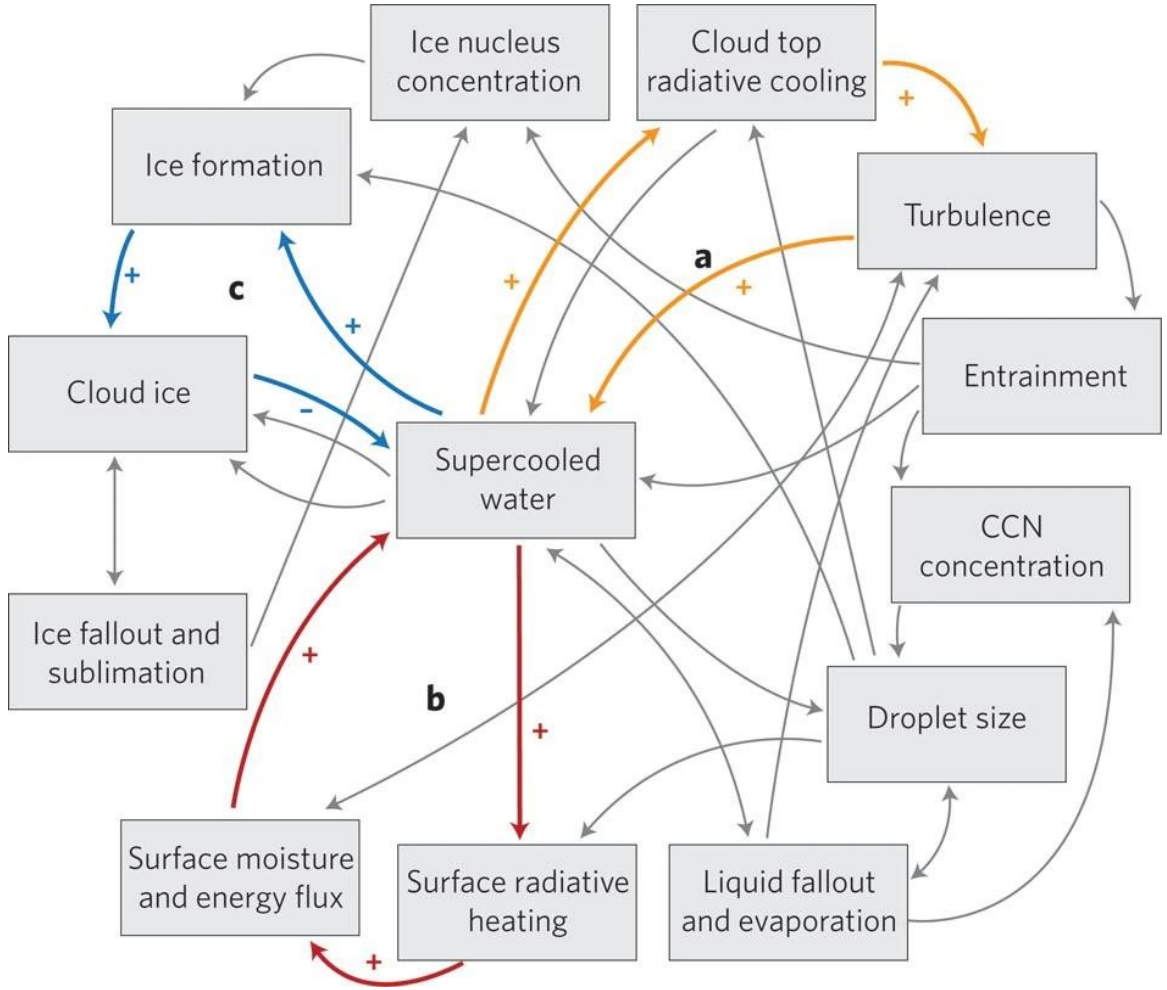
Soil
- Roots
- Soil temperature
- Soil moisture



Balsamo et al., 2009

Current Development for PALM-4U+ (2019-2022)

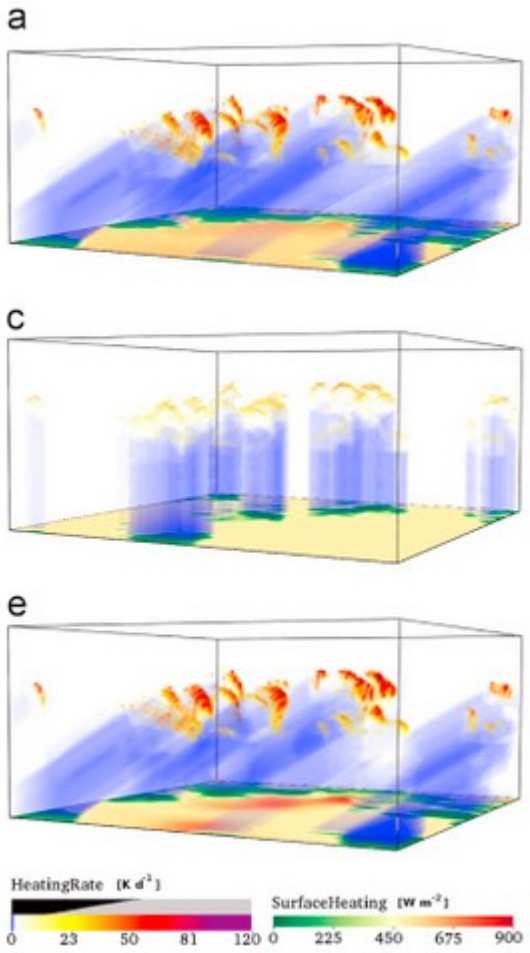
- Precipitation:
  - Mixed- and ice-phase clouds
  - Snow-packs and frozen soils



Morrison et al., 2011

Current Development for PALM-4U+ (2019-2022)

- Precipitation
  - Mixed- and ice-phase clouds
  - Snow-packs and frozen soils
- Radiation and clouds
  - Non-cartesian surfaces
  - 3D radiation (ten-stream)
  - Interactions of radiation and clouds



Jakub and Mayer, 2015

Current Development for PALM-4U+ (2019-2022)

- Precipitation
  - Mixed- and ice-phase clouds
  - Snow-packs and frozen soils
- Radiation and clouds
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- Nesting and coupling
  - Offline-nesting with WRF and ICON

Current Development for PALM-4U+ (2019-2022)

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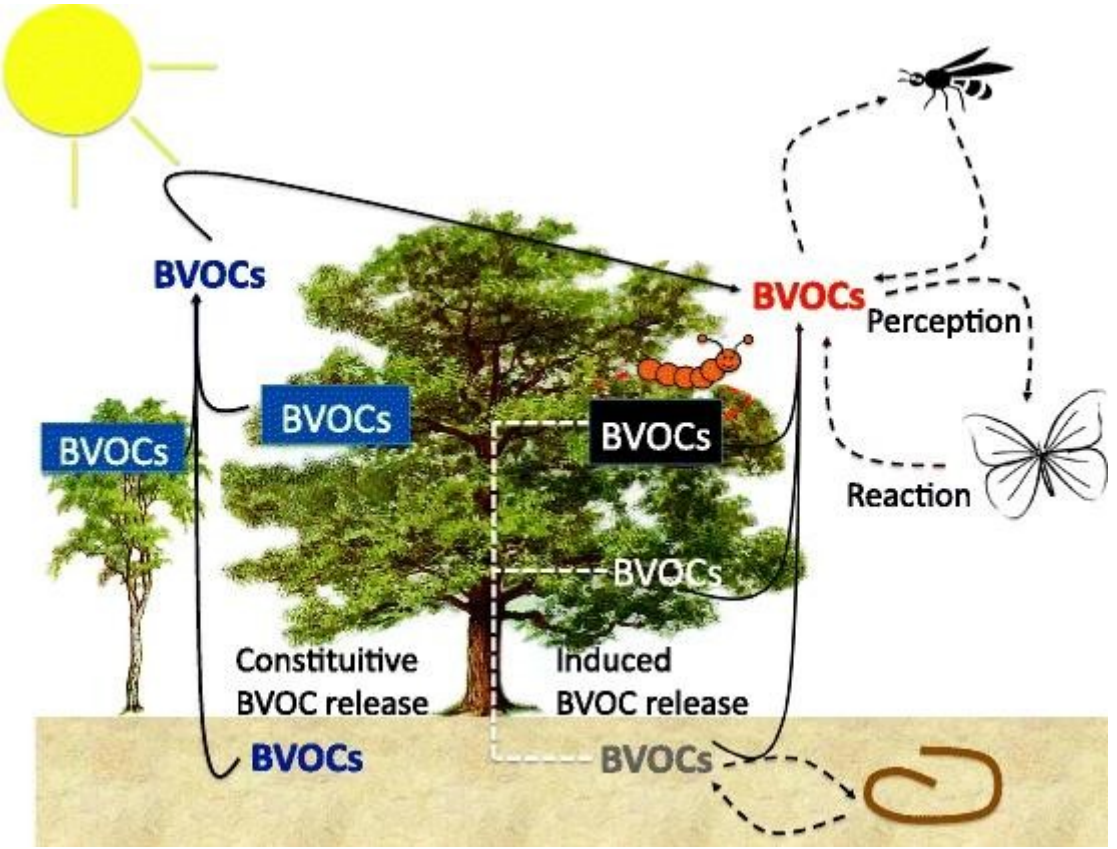
  - Non-cartesian surfaces
  - 3D radiation (ten-stream)
  - Interactions of radiation and clouds
- Nesting and coupling
  - Offline-nesting with WRF and ICON
- Air quality
  - BVOC/Aerosols/Pollen emissions and chemistry
  - Traffic emissions and multi-agent system



Trowbridge and Stoy, 2013

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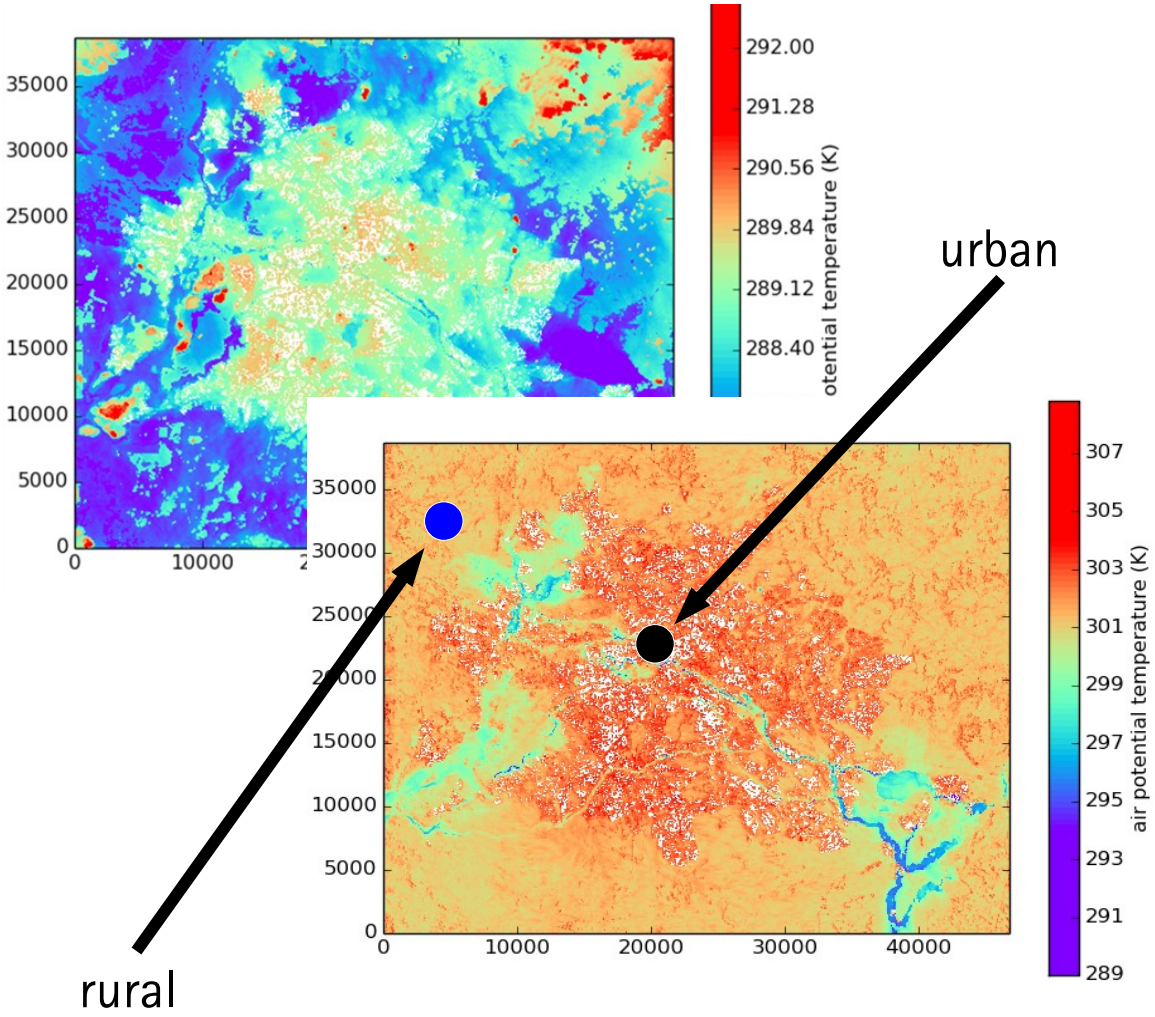
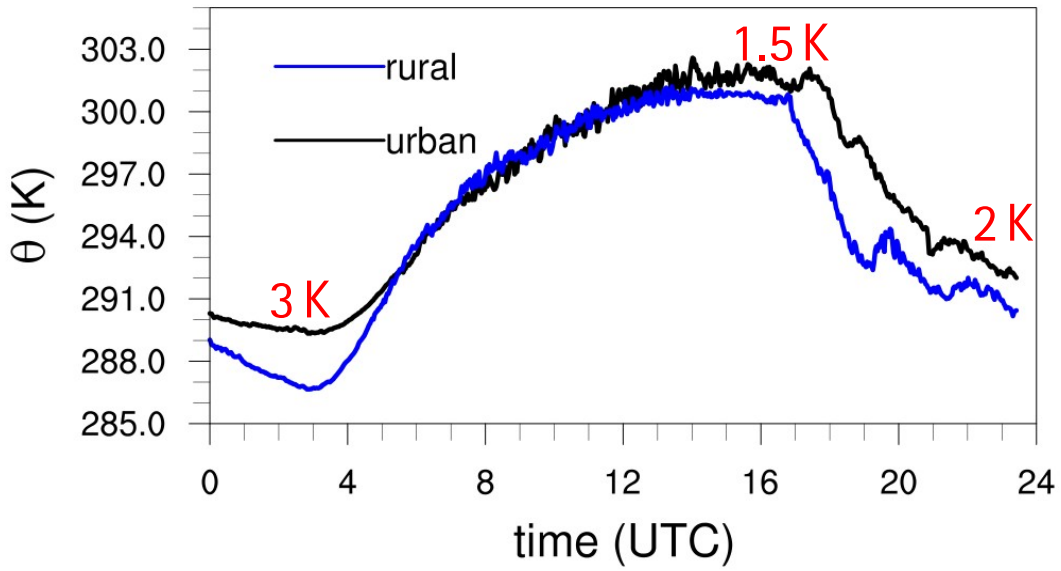
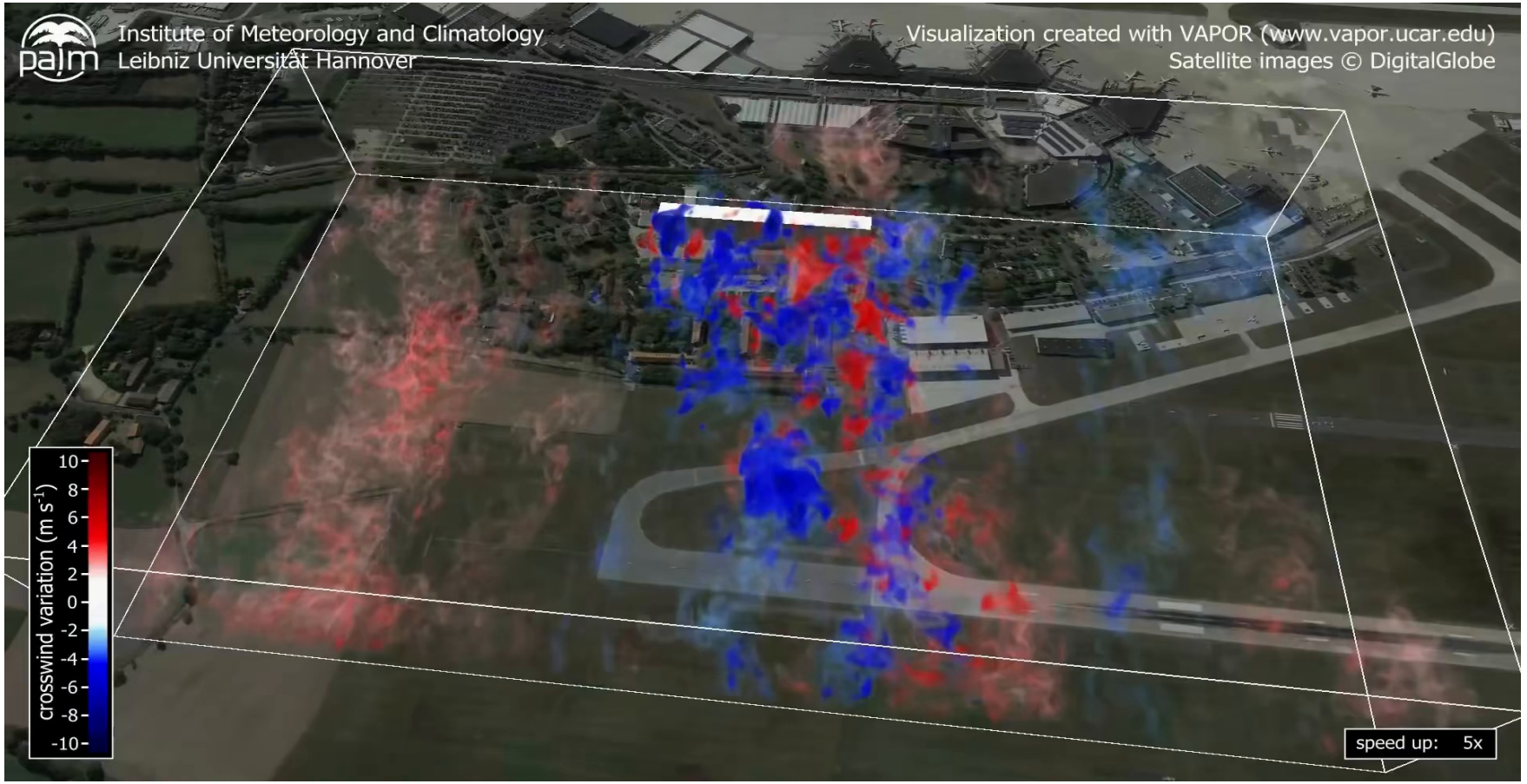
24 Hours in Berlin – the Urban Heat Island



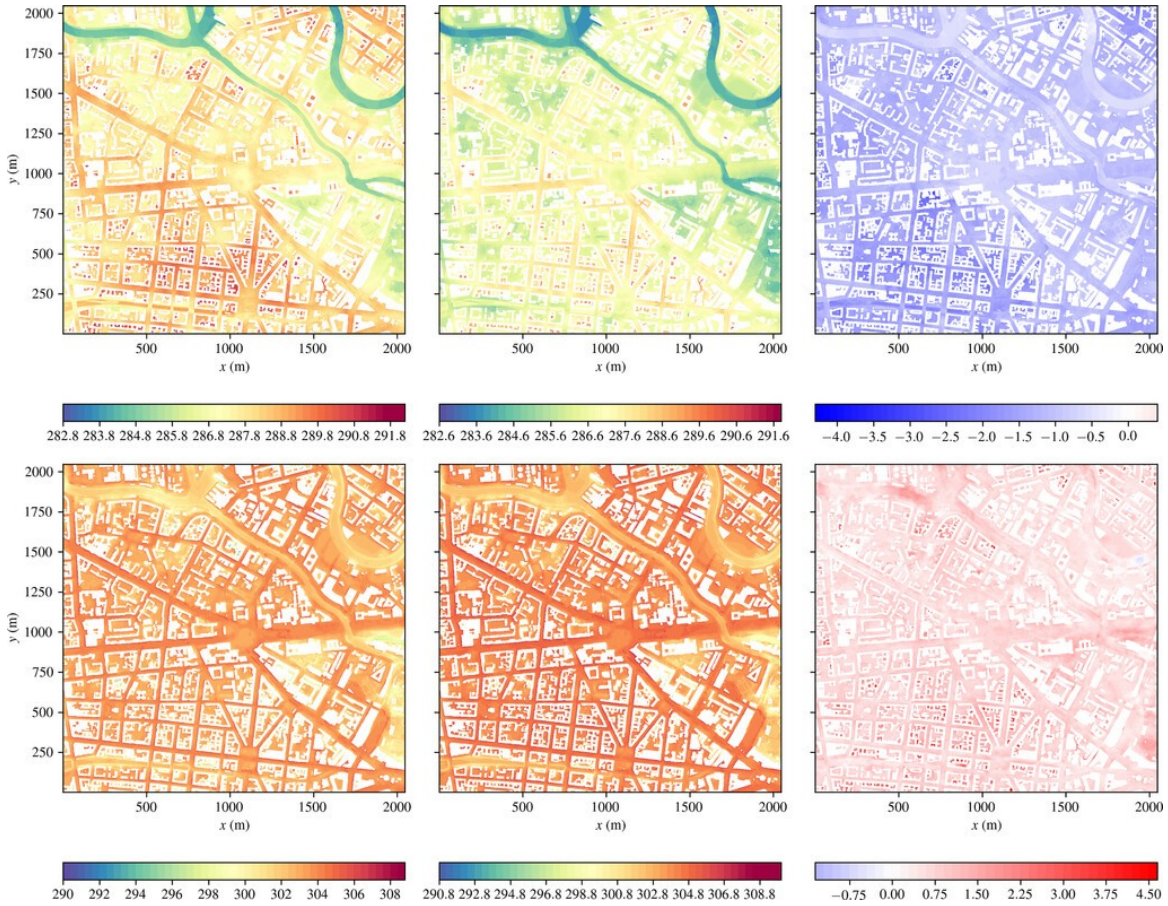


Localized Pollutant – Dispersion in the City

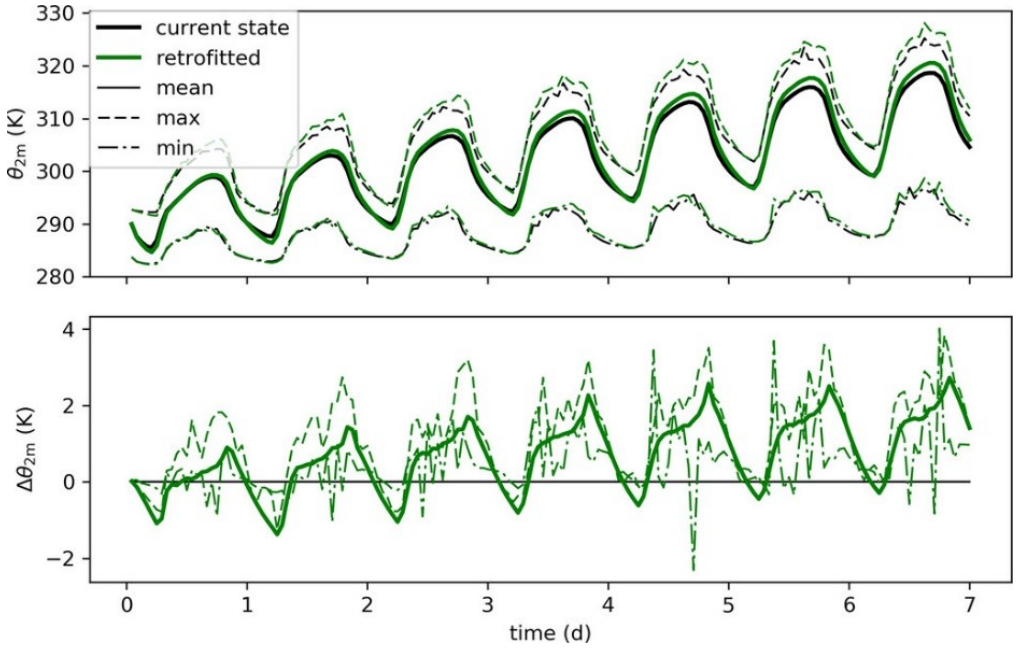
Airport Planning – Risk Weather Analysis



Building Retrofitting – Unexpected Consequences



- Colder late-night hours
- Warmer evening hours
- Warming trend in cyclic simulations



Maronga et al., 2022

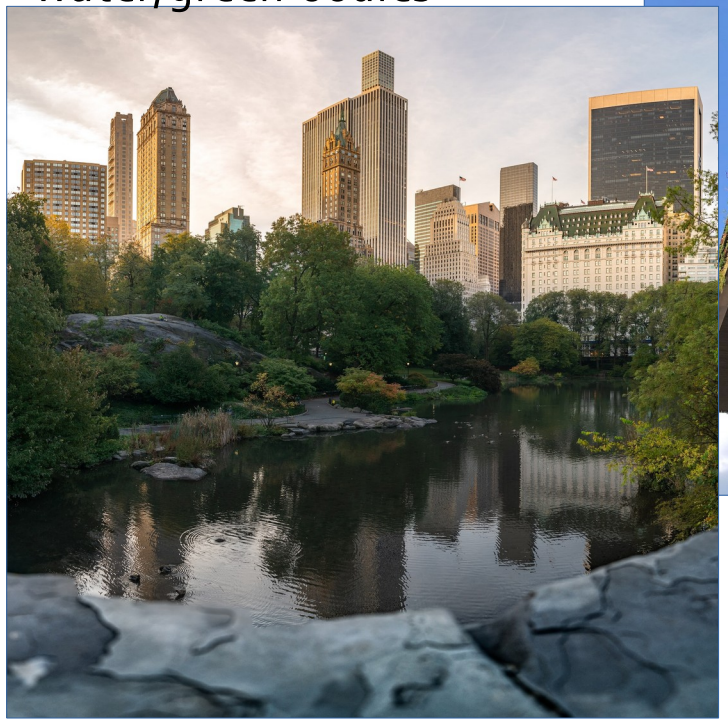
Building Retrofitting – Unexpected Consequences

- Can we avoid higher outdoor temperatures?

reflective colors

green surfaces

water/green bodies



Maybe!

https://unsplash.com

What can PALM provide?

- Simulate physical processes in the urban canopy layer
- Study feedback processes between urban and rural areas
- Investigate and develop parameterizations
- Evaluate mitigation and adaption strategies for cities
- Help planning and building
- Risk weather prediction

Berlin's Governmental District