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Building-resolving large-eddy simulations for entire Berlin

First results using the high-performance urban microscale model PALM-4U

Björn Maronga[1] and:
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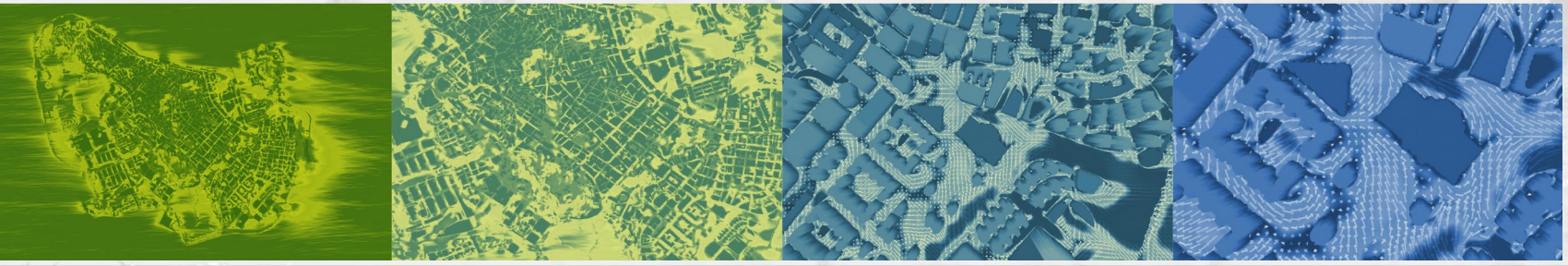


PALM-4U

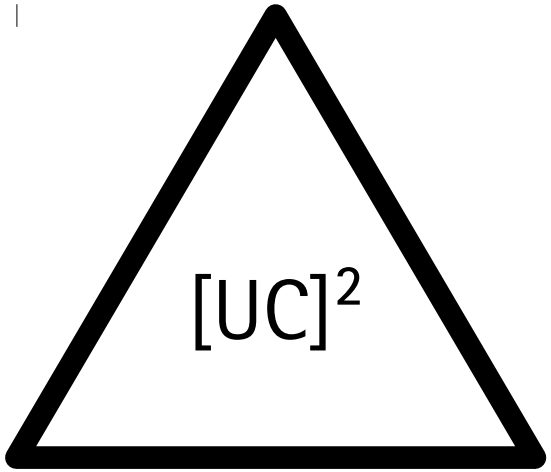
Introduction

Development framework and (planned) capabilities

From PALM to PALM-4U: Project structure

- **Urban Climate Under Change [UC]^2:** Research project funded by the German Federal Ministry of Education and Research (BMBF), 2016-2019
- **Goal:** Development of a new (building resolving) urban model for scientific research and applied urban planning

Module A
Model development
MOSAIK

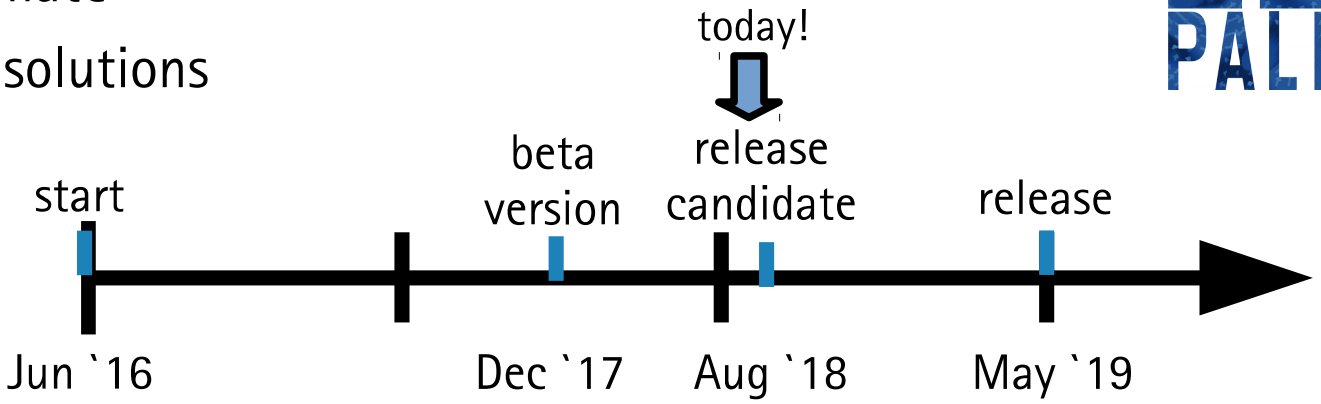


Module B
Observations & wind tunnel
3DO (2A.5 *Scherer et al.)*

Module C
Practicability & user-friendliness
UseUClim/KliMoPrax (11C.3 Steuri et al.)

From PALM to PALM-4U: Overview of capabilities

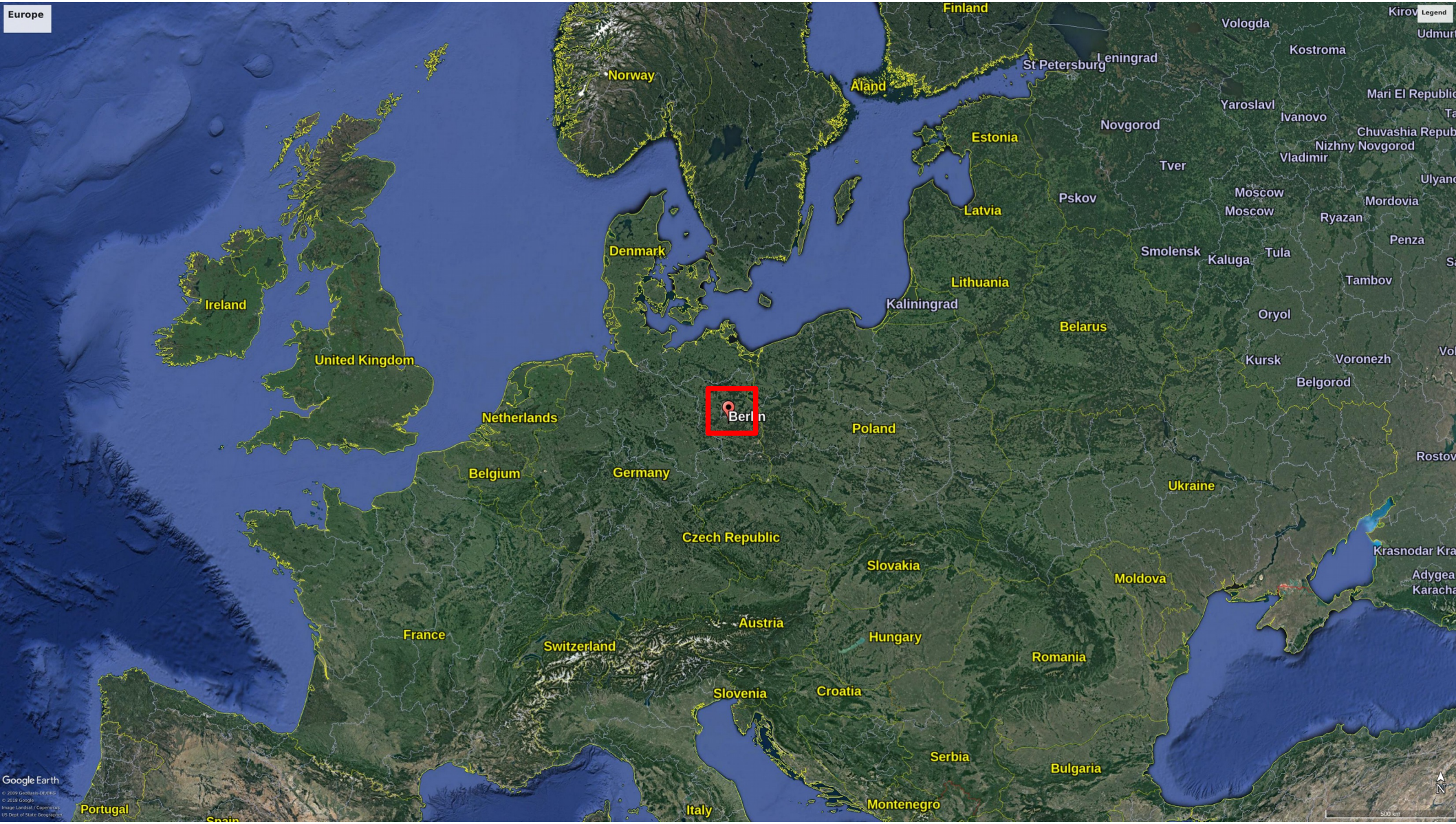
- **PALM**: the model core (*Maronga et al. 2015, GMD*)
  - Parellelized large-eddy simulation (LES) model
  - Highly-optimized, scales up to (tested) 32 000 cores
  - Topography on Cartesian grid
  - Interactive land surface model, coupled to RRTMG
  - Embedded models
- **PALM-4U: PALM + additional components**
  - Energy transfer in the urban canopy layer
  - Chemistry and emissions
  - Indoor climate
  - Technical solutions



Setup

The Berlin showcase

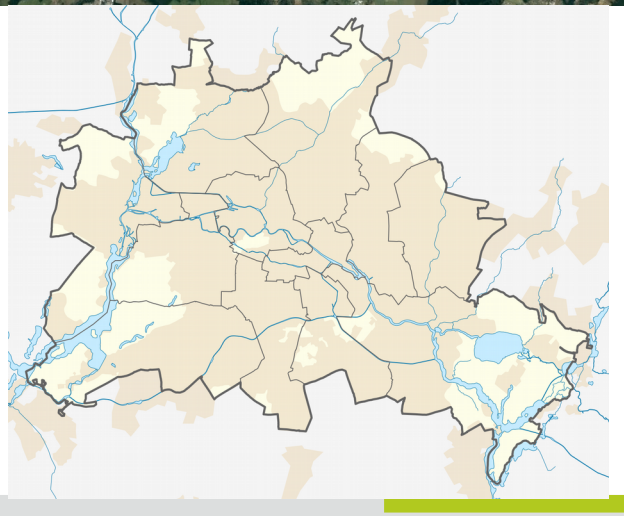
Berlin showcase: Setup



Berlin showcase: Setup – the parent domain

Berlin showcase: Setup – the parent domain

Domain (x x y x z)	46.8 km x 38.6 km x 3.5 km
Grid spacing	15 m
Forcing	COSMO-DE initial profiles, 21 July 2013 at midnight
Synoptic situation	weak winds, clear sky, COSMO-DE near-surface temperatures of > 303 K
Lateral boundaries	cyclic
Simulation time (Spinup)	24 h (surface and radiation)
Simulation time (LES)	24 h



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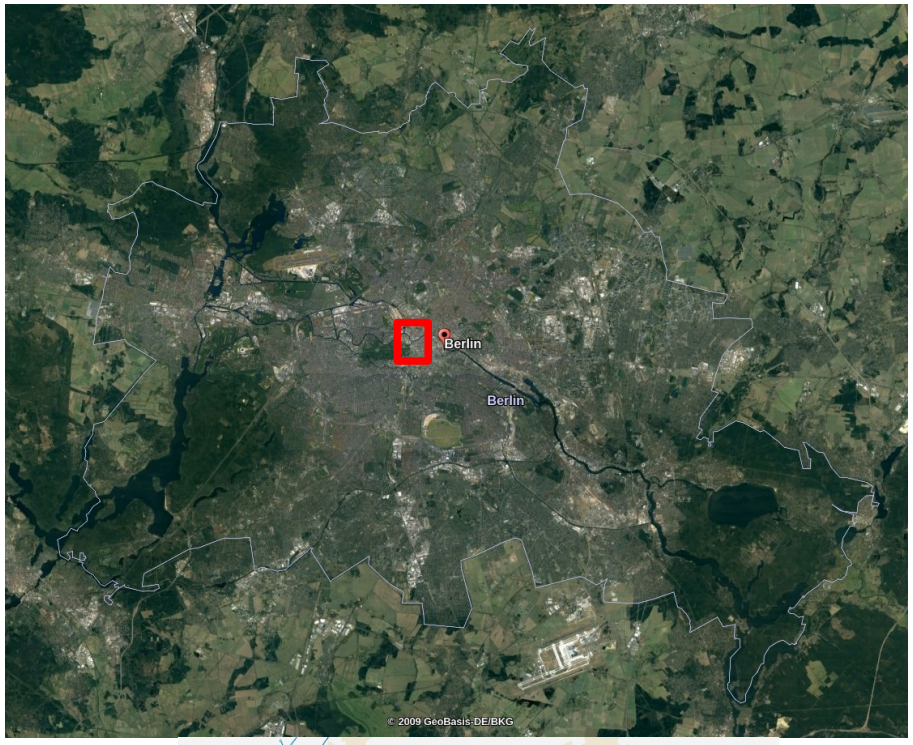
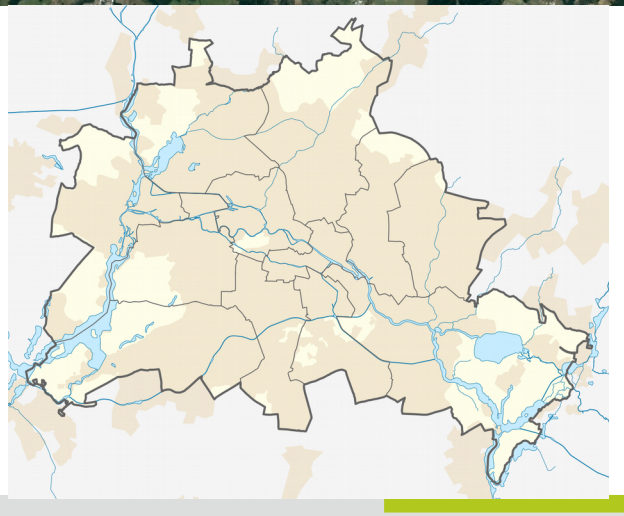




Berlin showcase: Setup – the child domain

Berlin Central Station

Reichstag building
(2nd most visited attraction in Germany)

Berlin showcase: Setup – the child domain

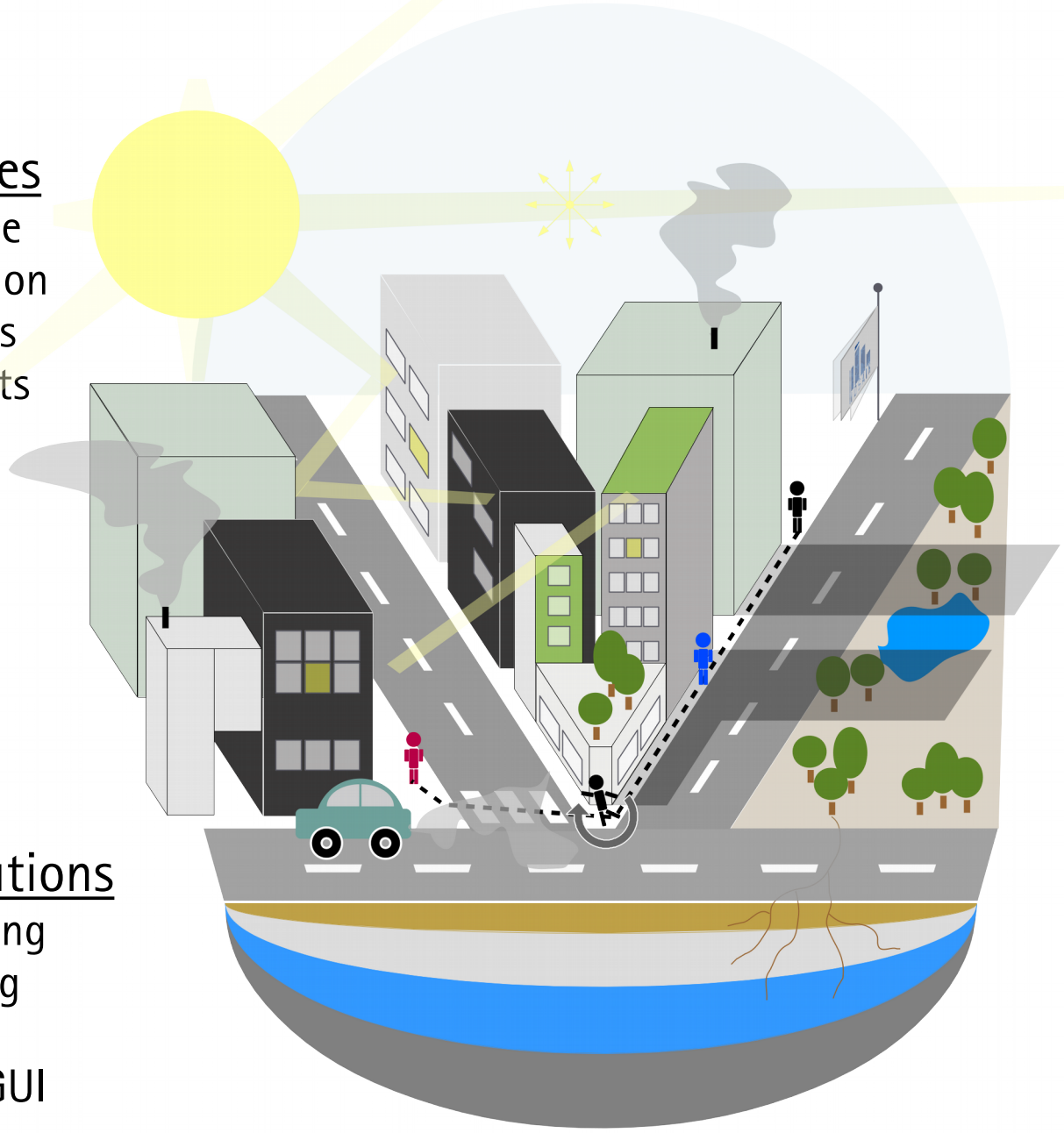
Domain (x x y x z)	1 km x 1 km x (0.3) 3 km
Grid spacing	1 m
Forcing	as parent
Synoptic situation	as parent
Lateral boundaries	(from parent) cyclic
Simulation time (Spinup)	24 h (surface and radiation)
Simulation time (LES)	24 h

Processes in PALM-4U

Urban surfaces
- Energy balance
- Heat conduction
- Solid materials
- Green elements

Chemistry
- Transport
- Reactions
- Photolysis
- Emissions

Technical solutions
- Mesocale nesting
- LES-LES nesting
- RANS mode
- User-friendly GUI



Radiation
- Energy balance
- Shading
- Reflections

Vegetation & Soil
- Energy balance
- Sink for momentum
- Shading
- Roots
- Soil moisture

Impact
- Multi-agent system
- Biometeorological analysis

Berlin showcase: model physics

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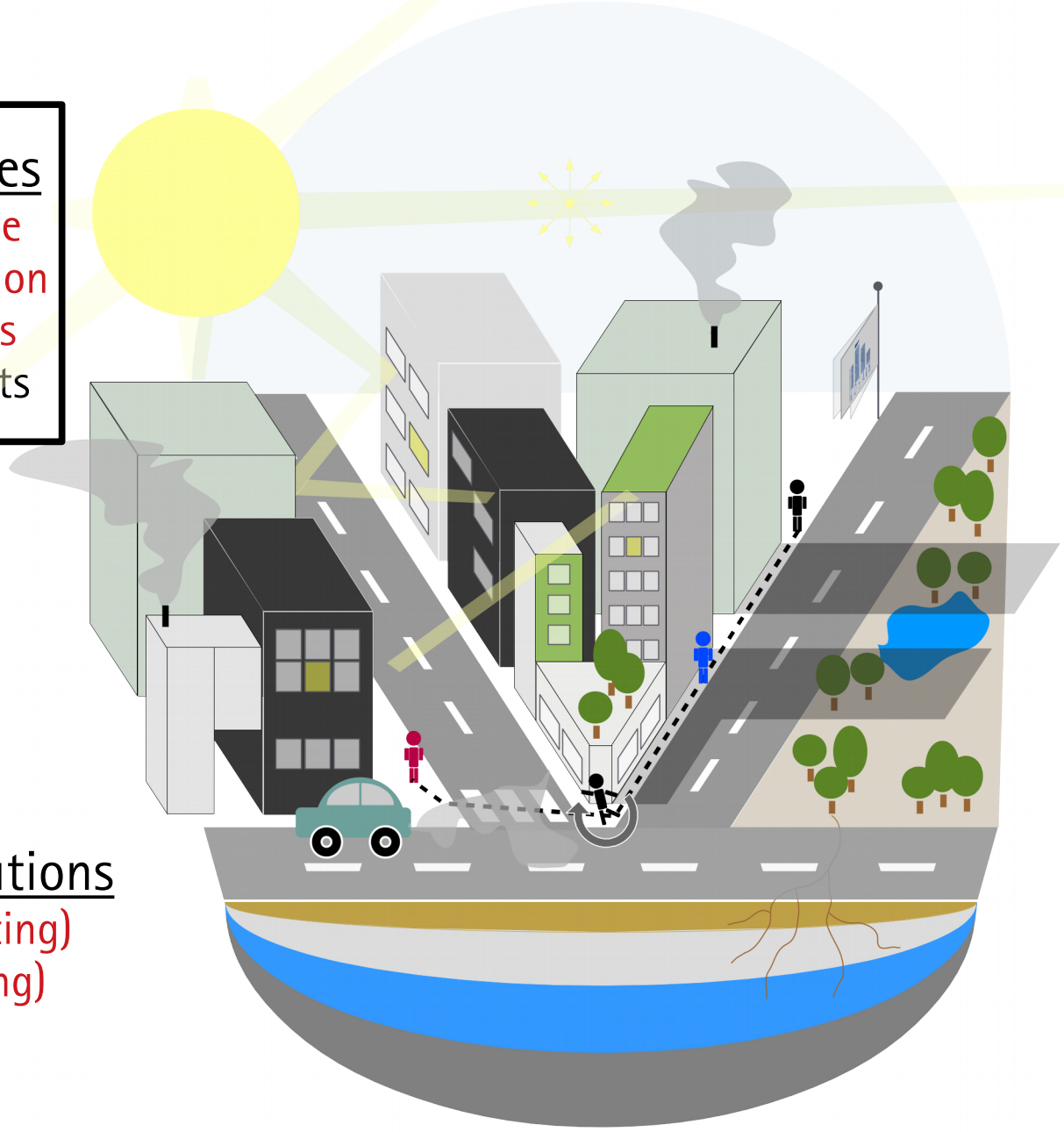

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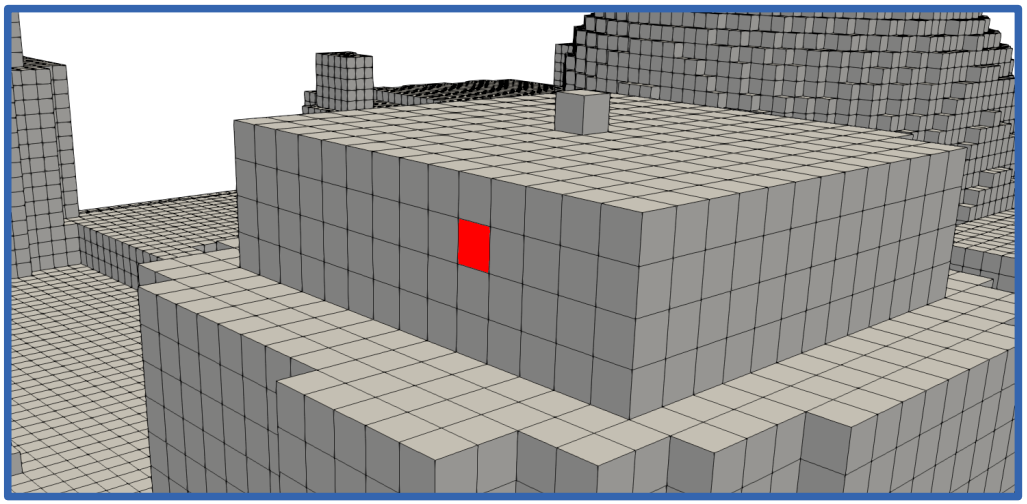

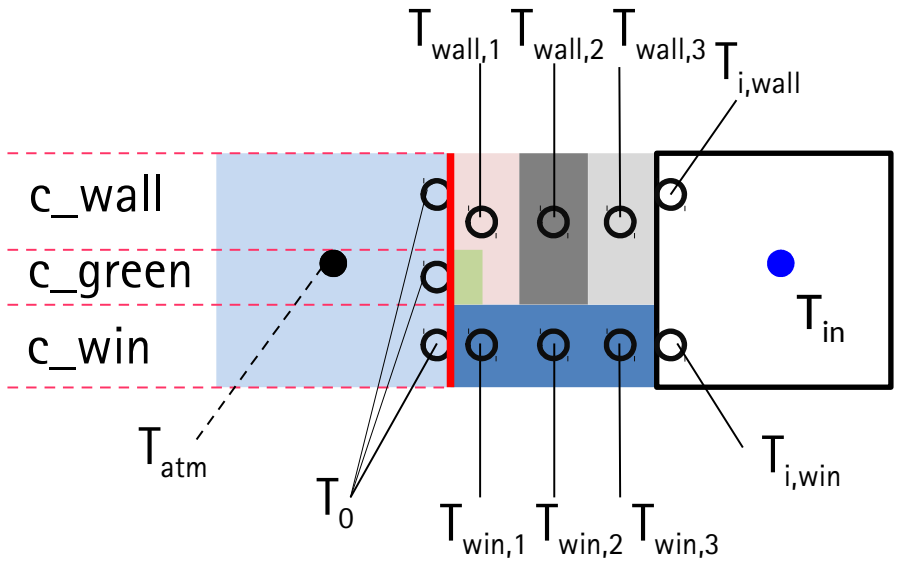

Resler et al., 2017, GMD
12D.8 (*Resler et al.*, Friday)

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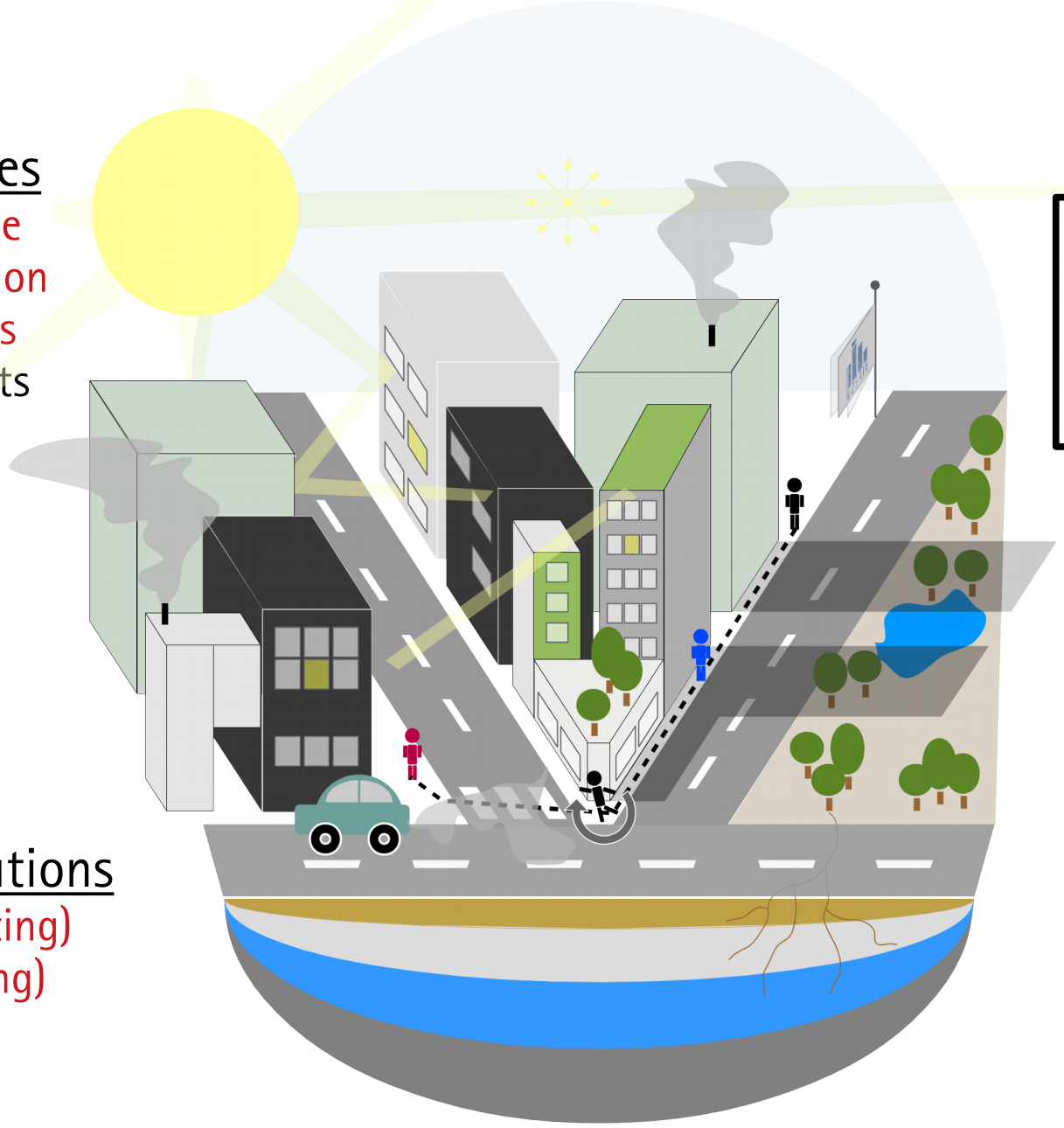

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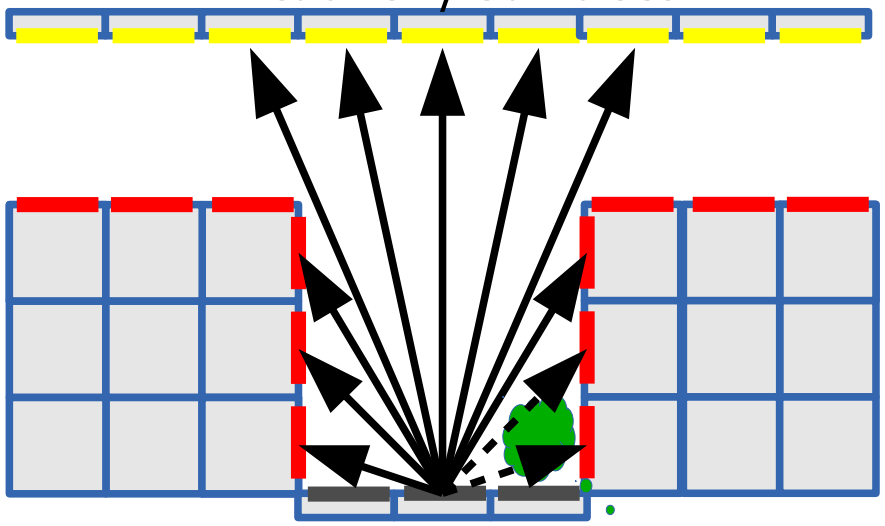

Shadows, reflections
coupled to RRTMG

Details:
Resler et al., 2017, GMD
12D.8 (*Resler et al.*, Friday)
13D.4 (*Salim et al.*, Friday)

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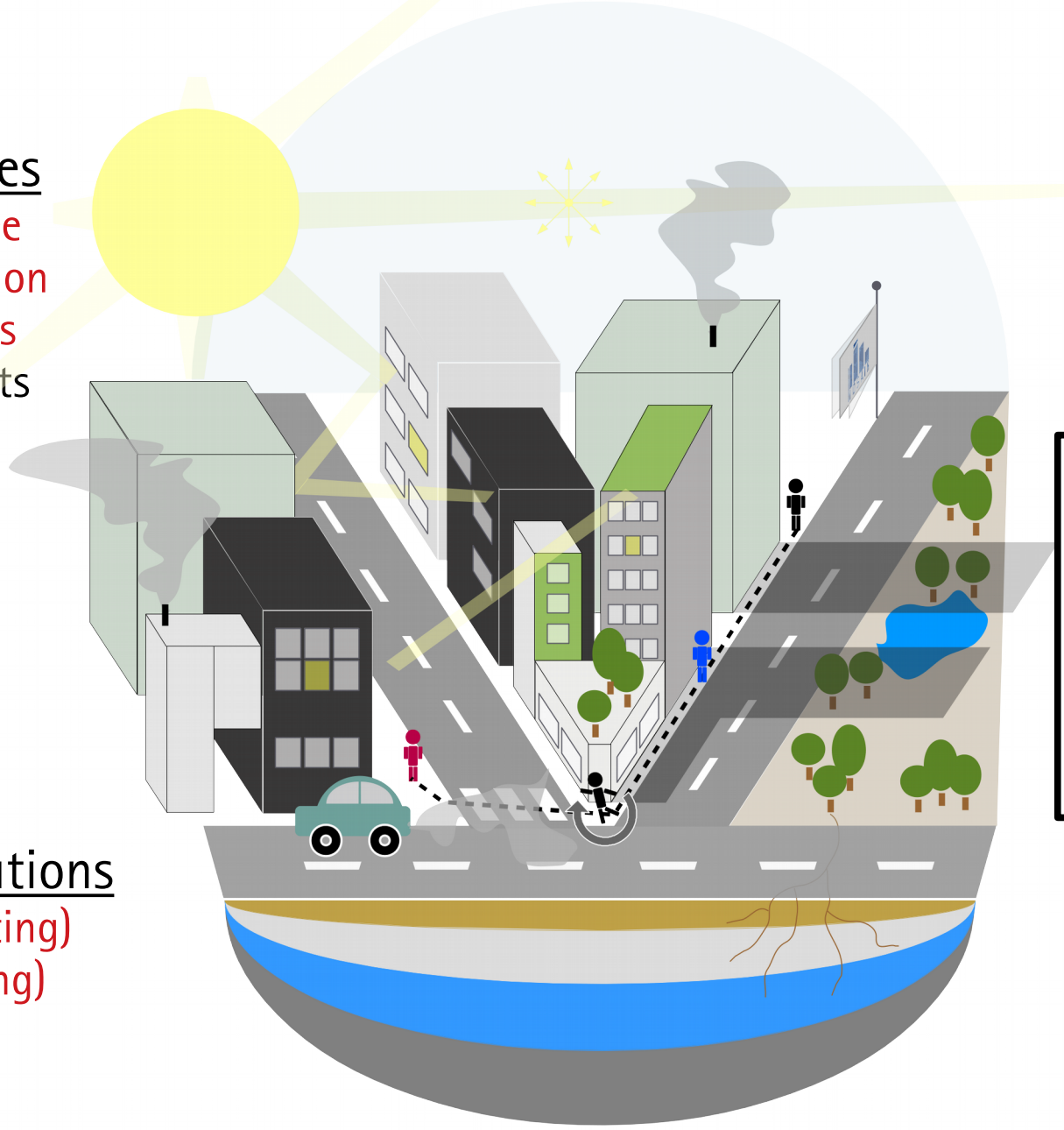

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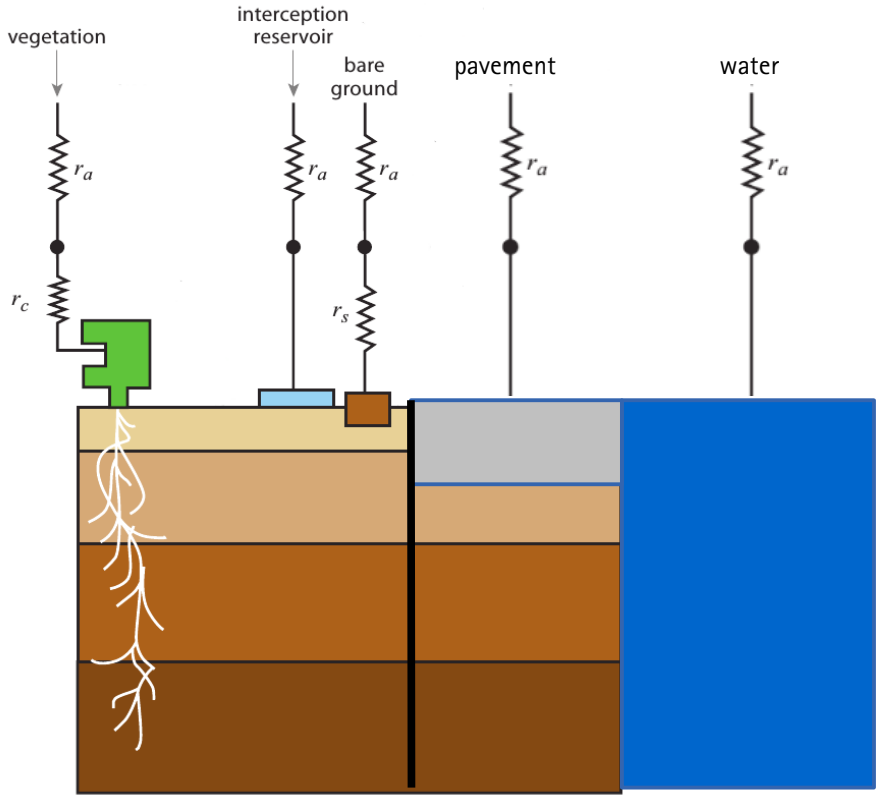

energy balance solver
Vegetation, pavement, (water)
8 layer soil model

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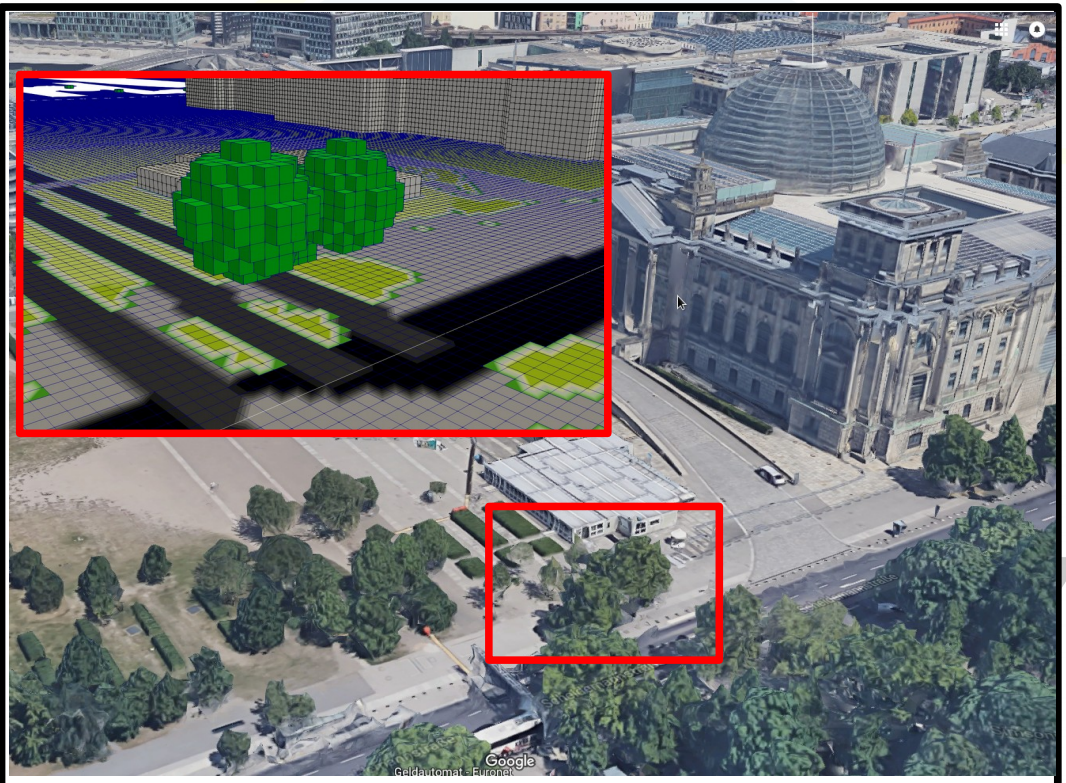

3D leaf area density
shading
sink for momentum
source of heat
source of water vapor

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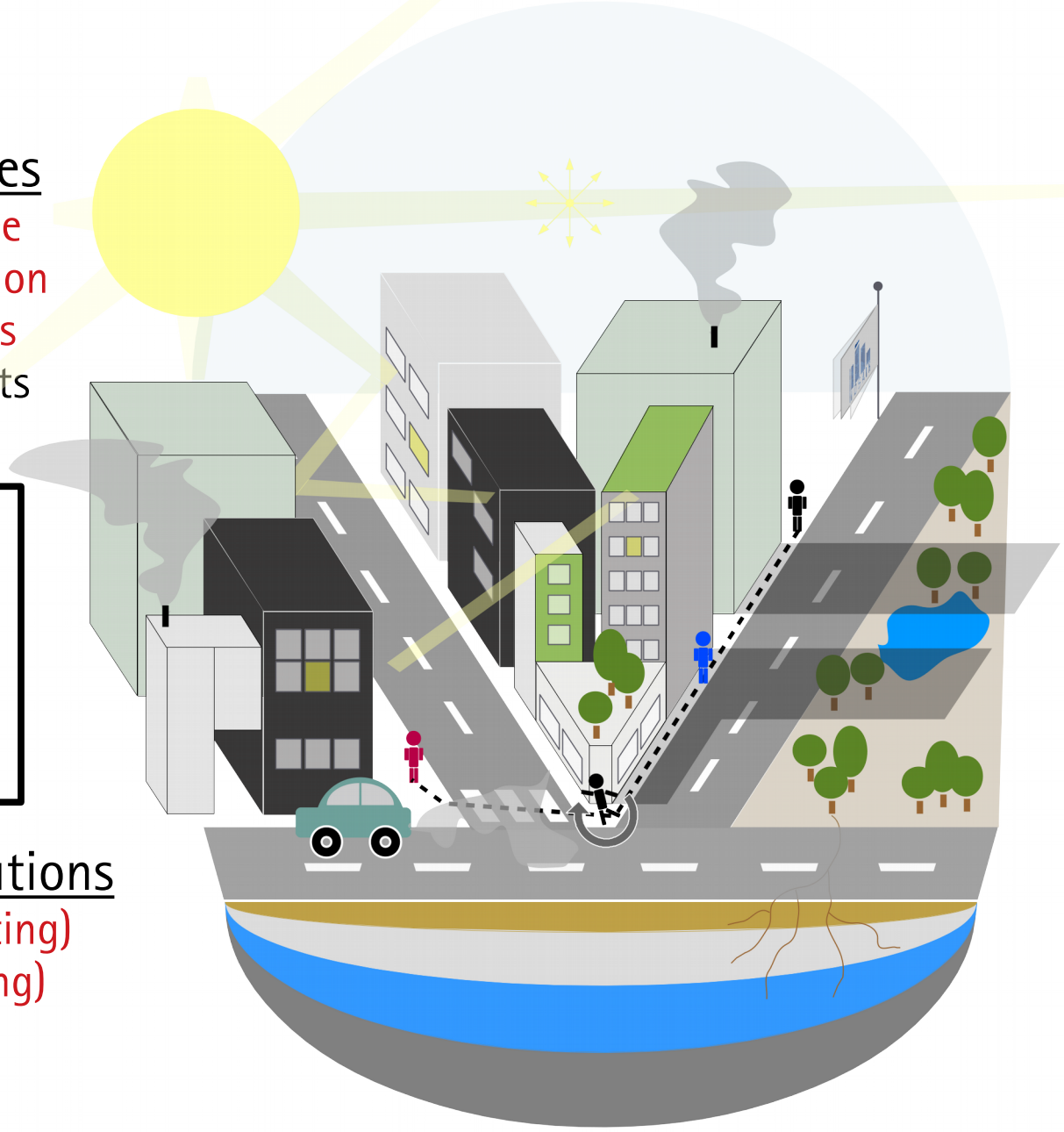

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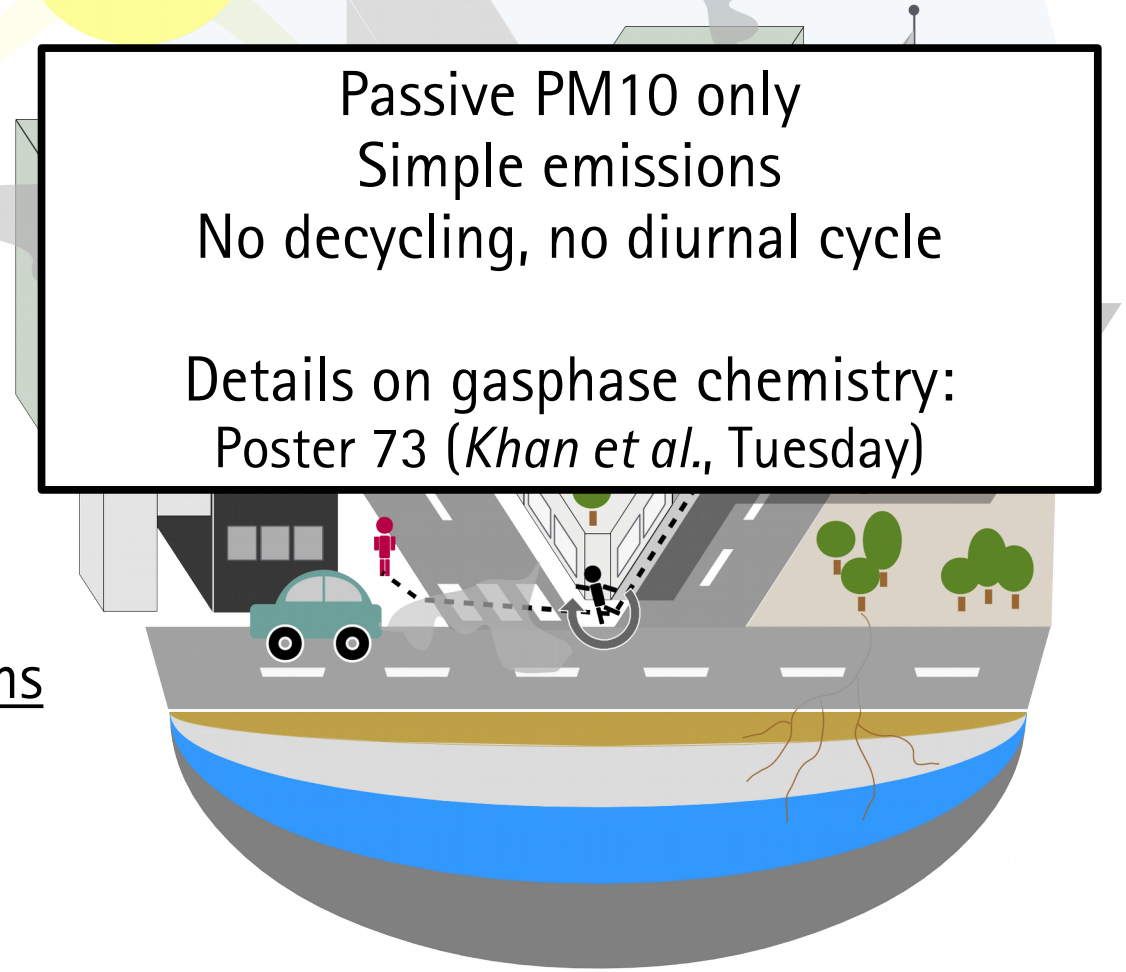

Passive PM10 only
Simple emissions
No decycling, no diurnal cycle

Details on gasphase chemistry:
Poster 73 (*Khan et al.*, Tuesday)

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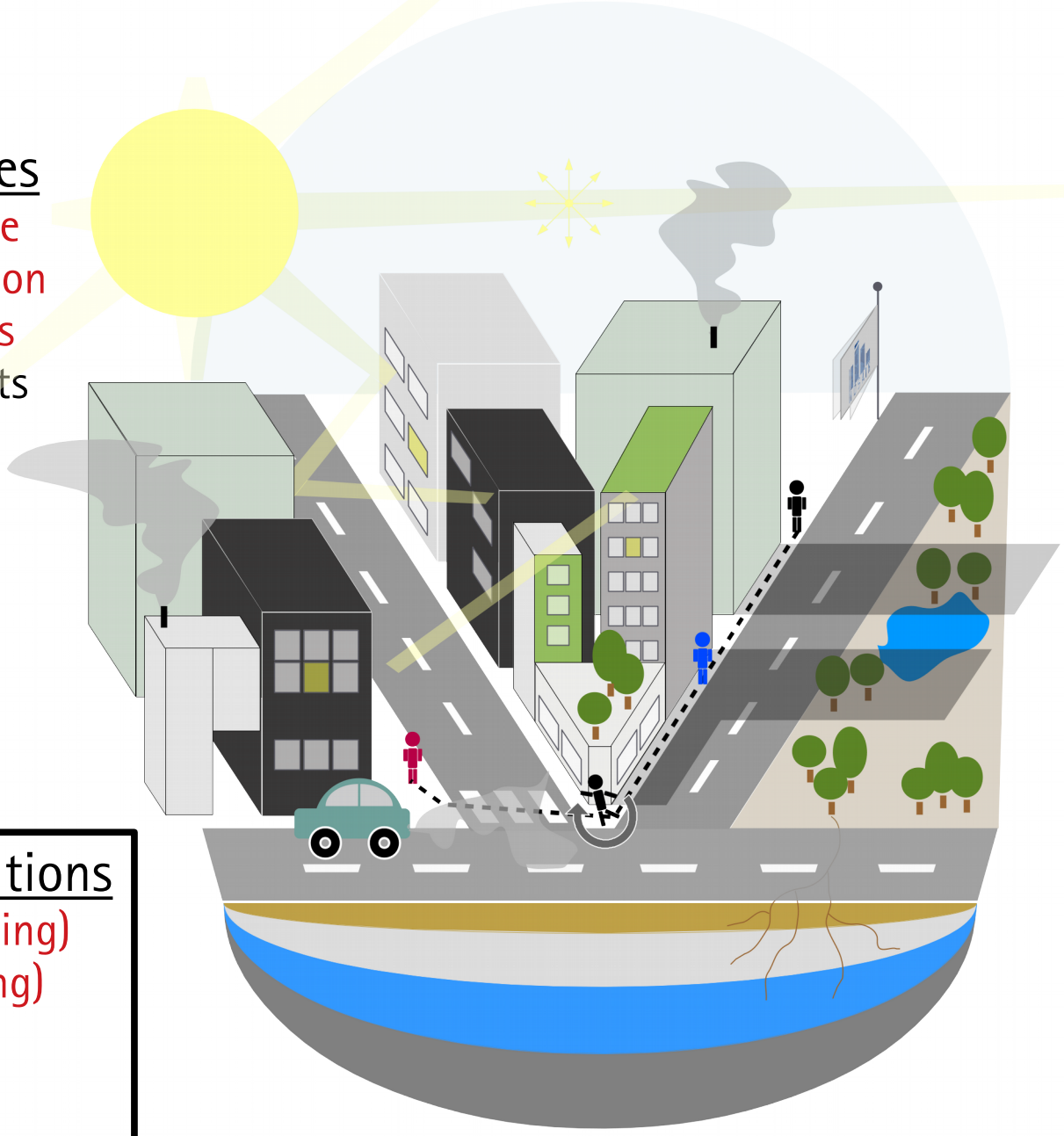

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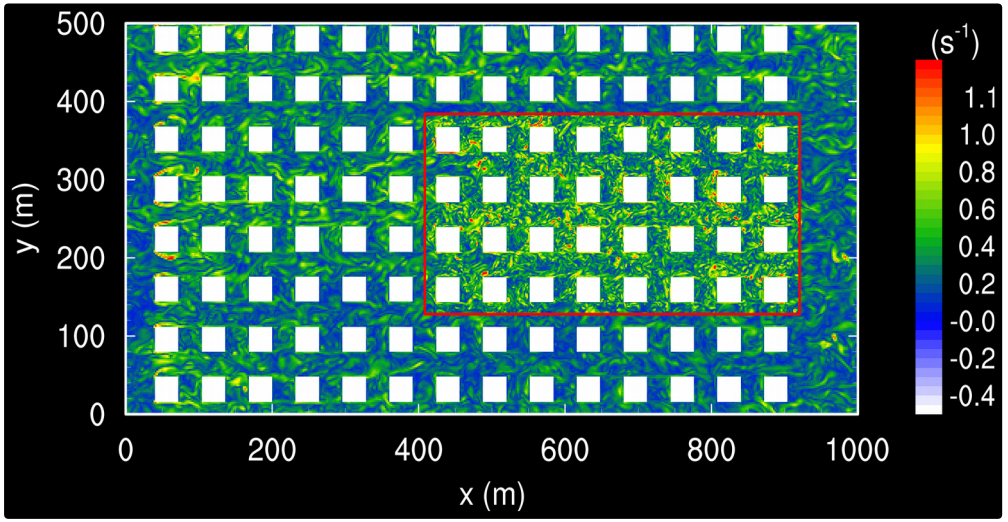
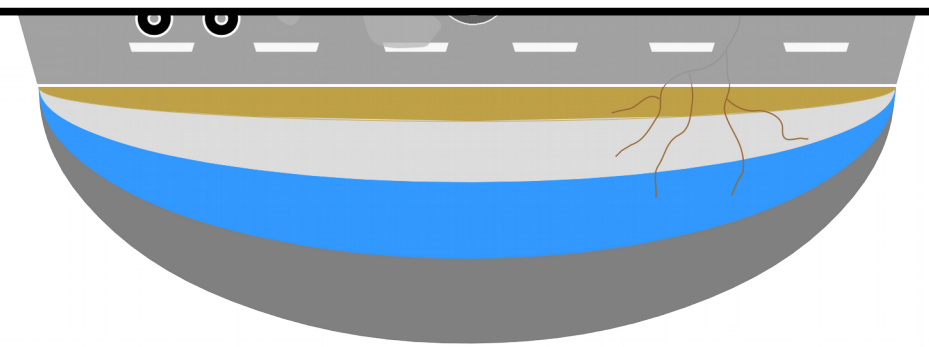


COSMO-DE forcing
LES-LES nesting (switched off - debugging)

Poster 52, *Sühring et al.*, Tuesday



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Berlin showcase: surface representation / input data

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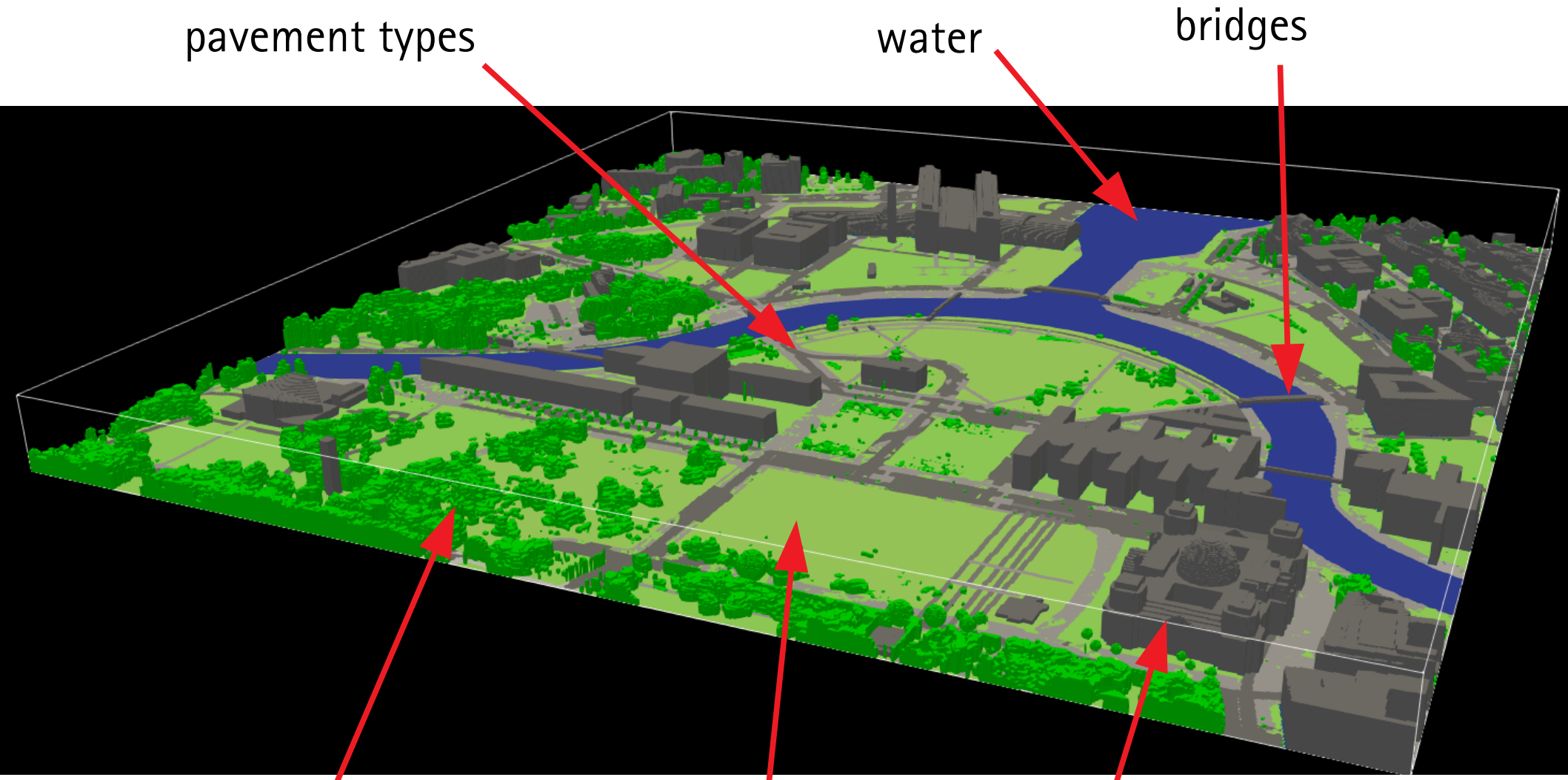
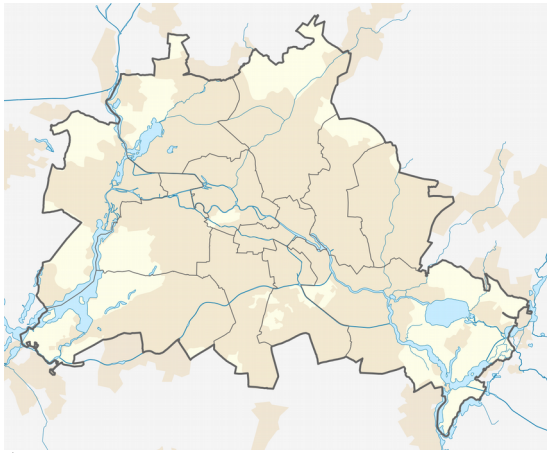


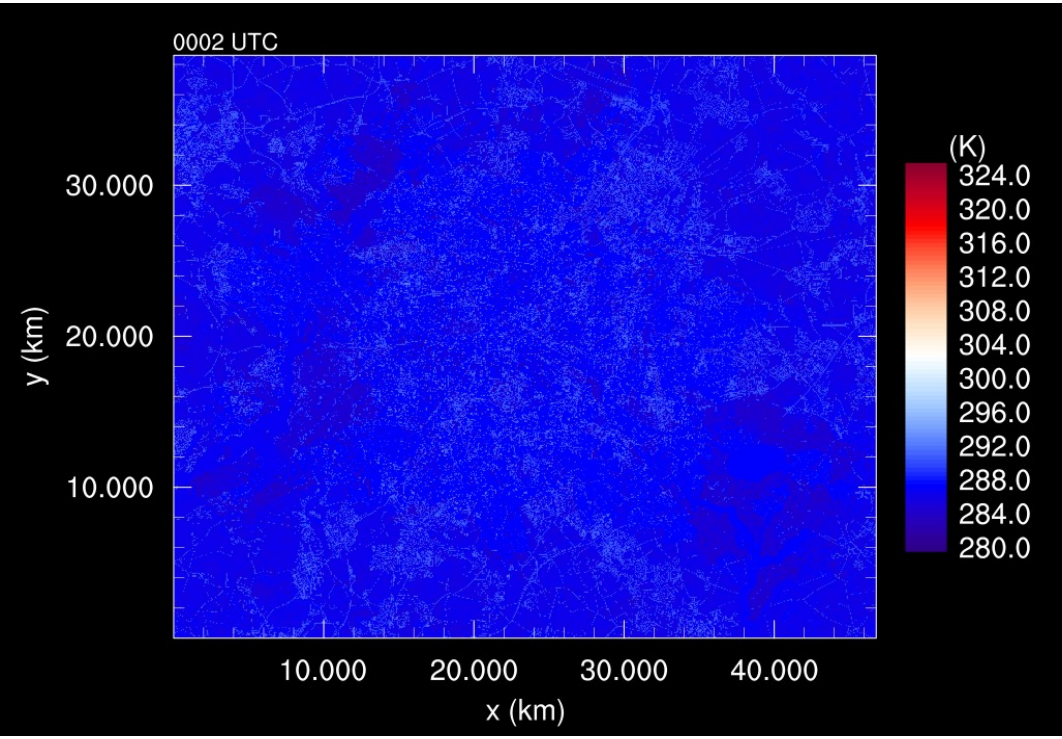
First Results

The Berlin showcase

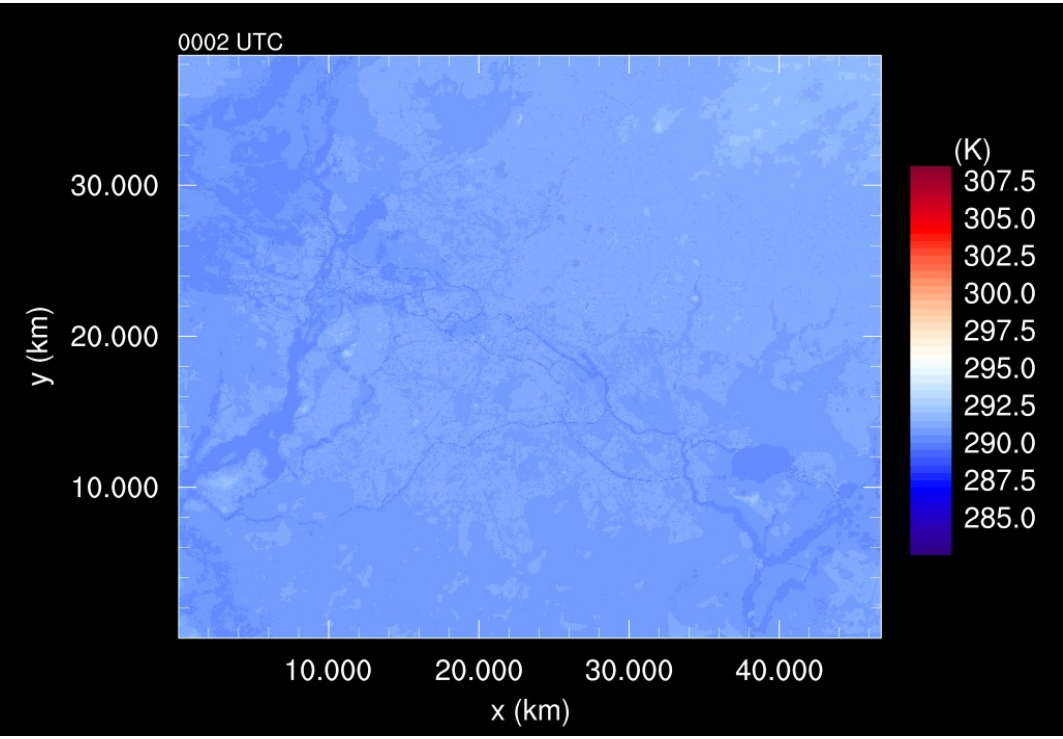
Results: Temperature – diurnal cycle



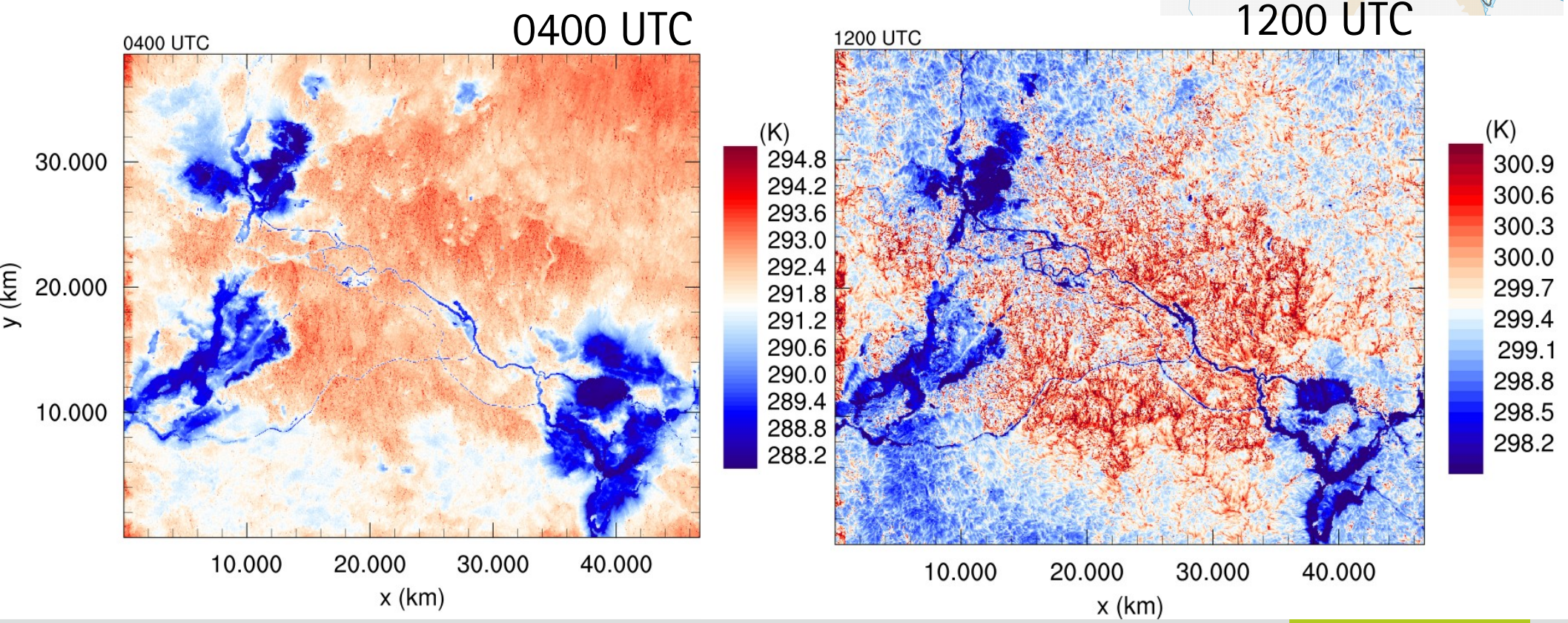
surface temperature



(near-surface) air temperature



Results: Air temperature – night vs. day



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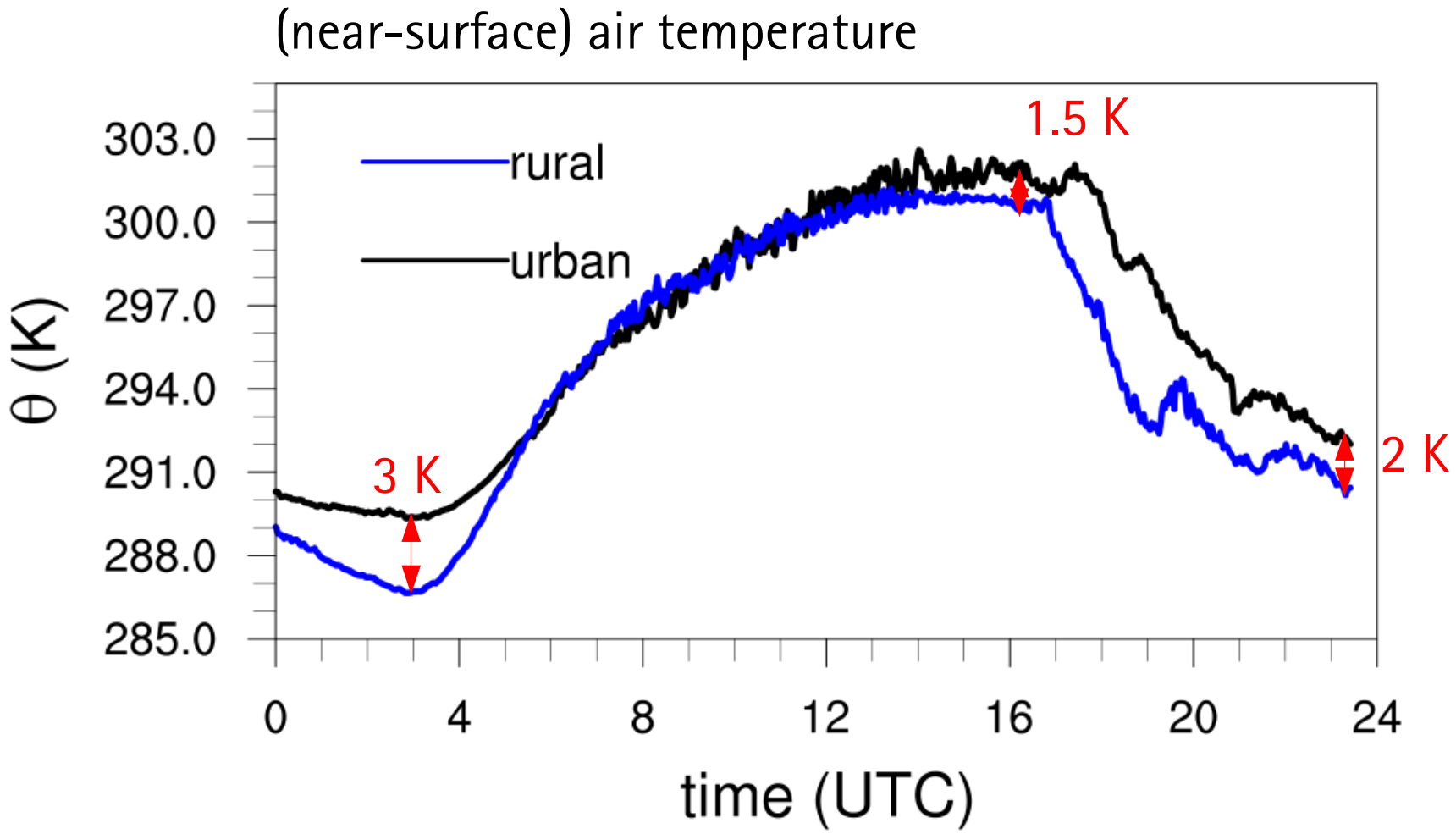

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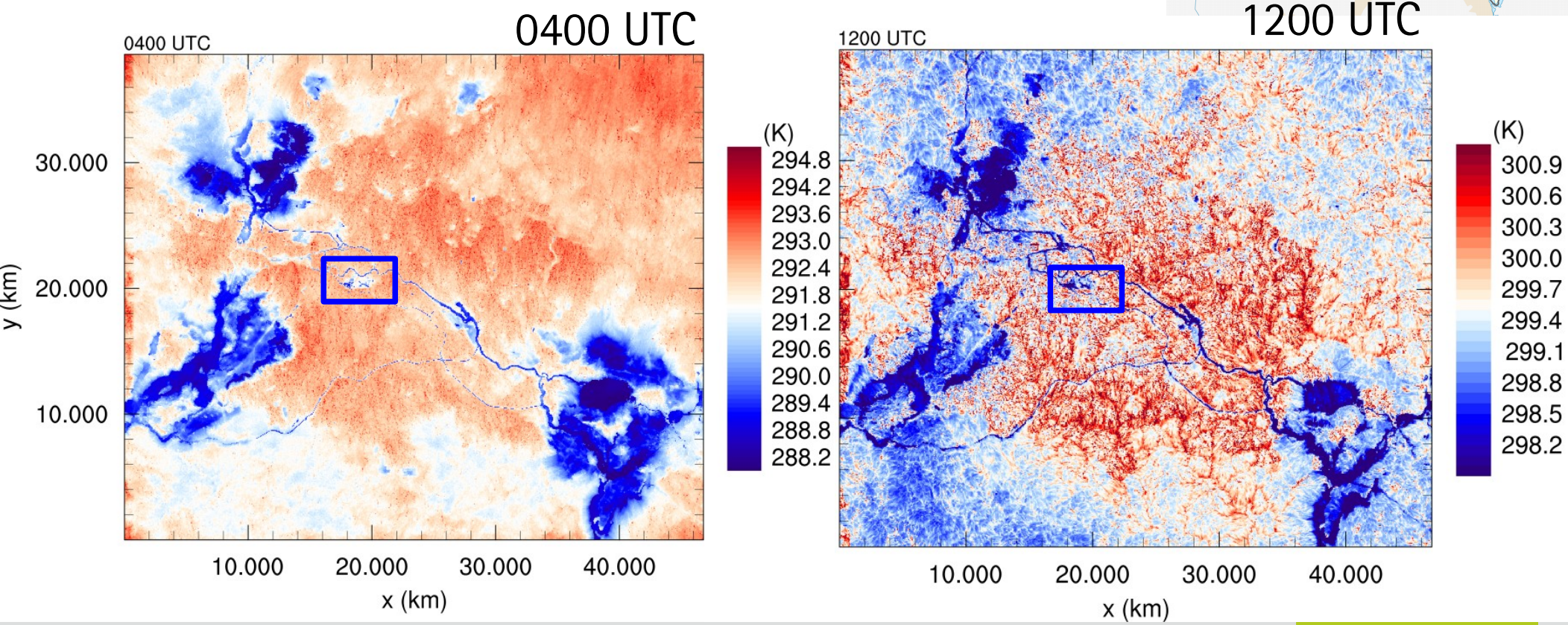
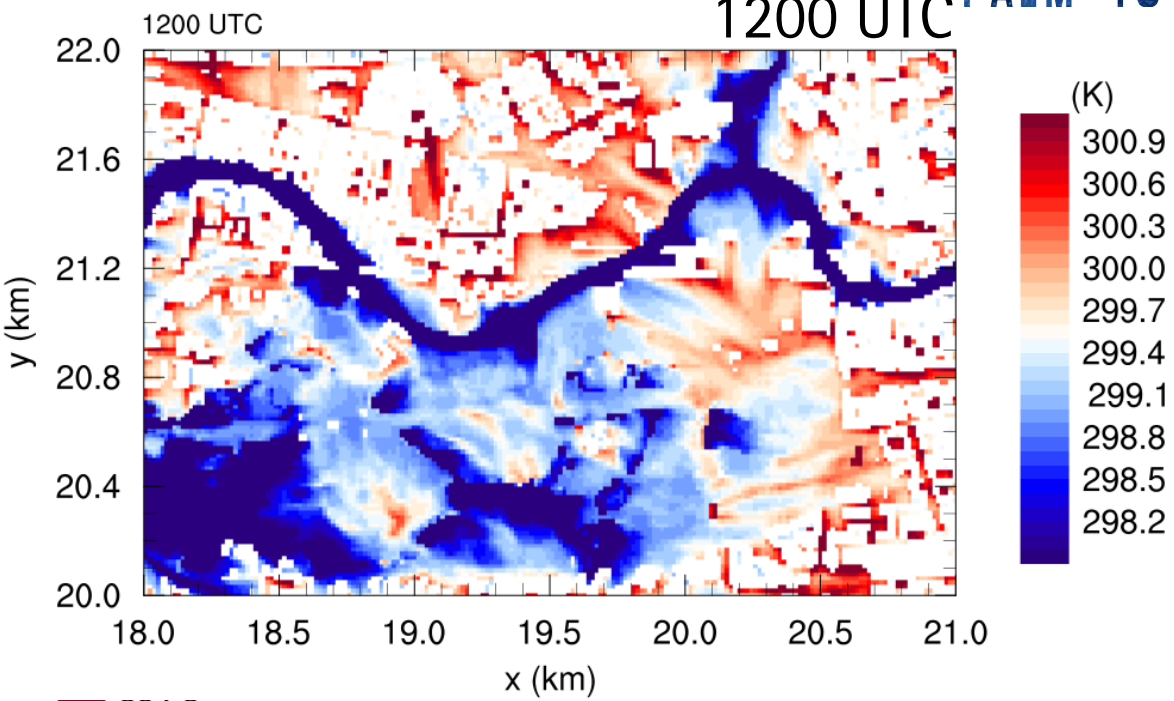
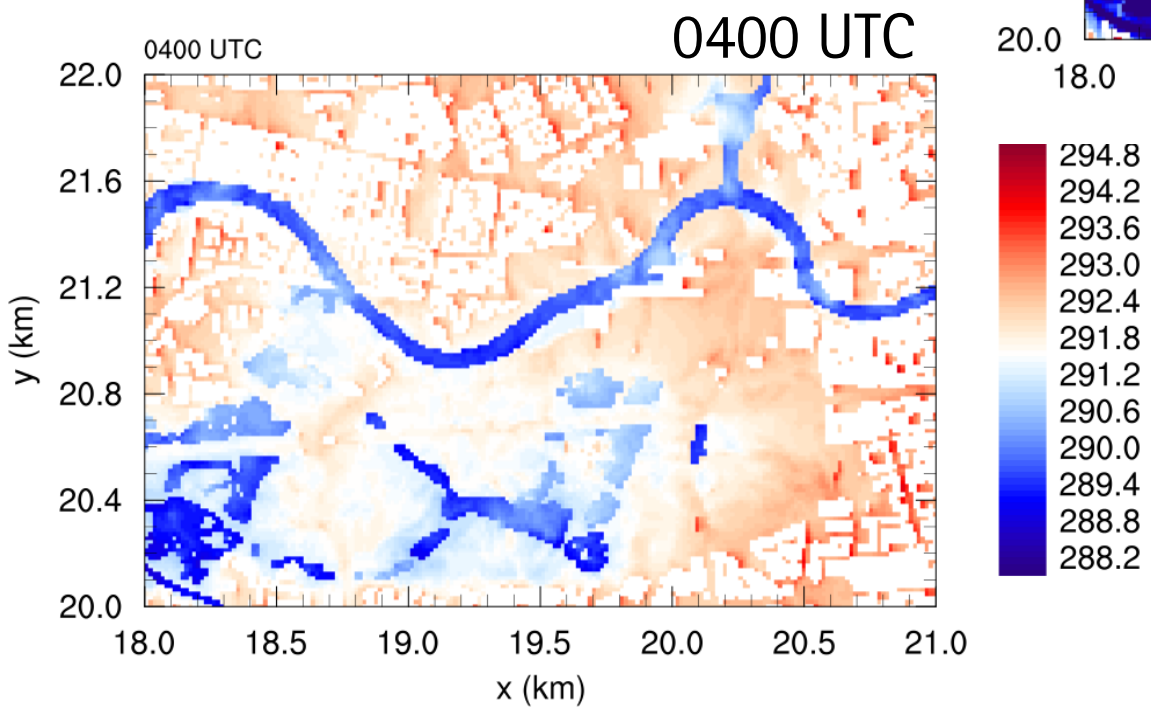
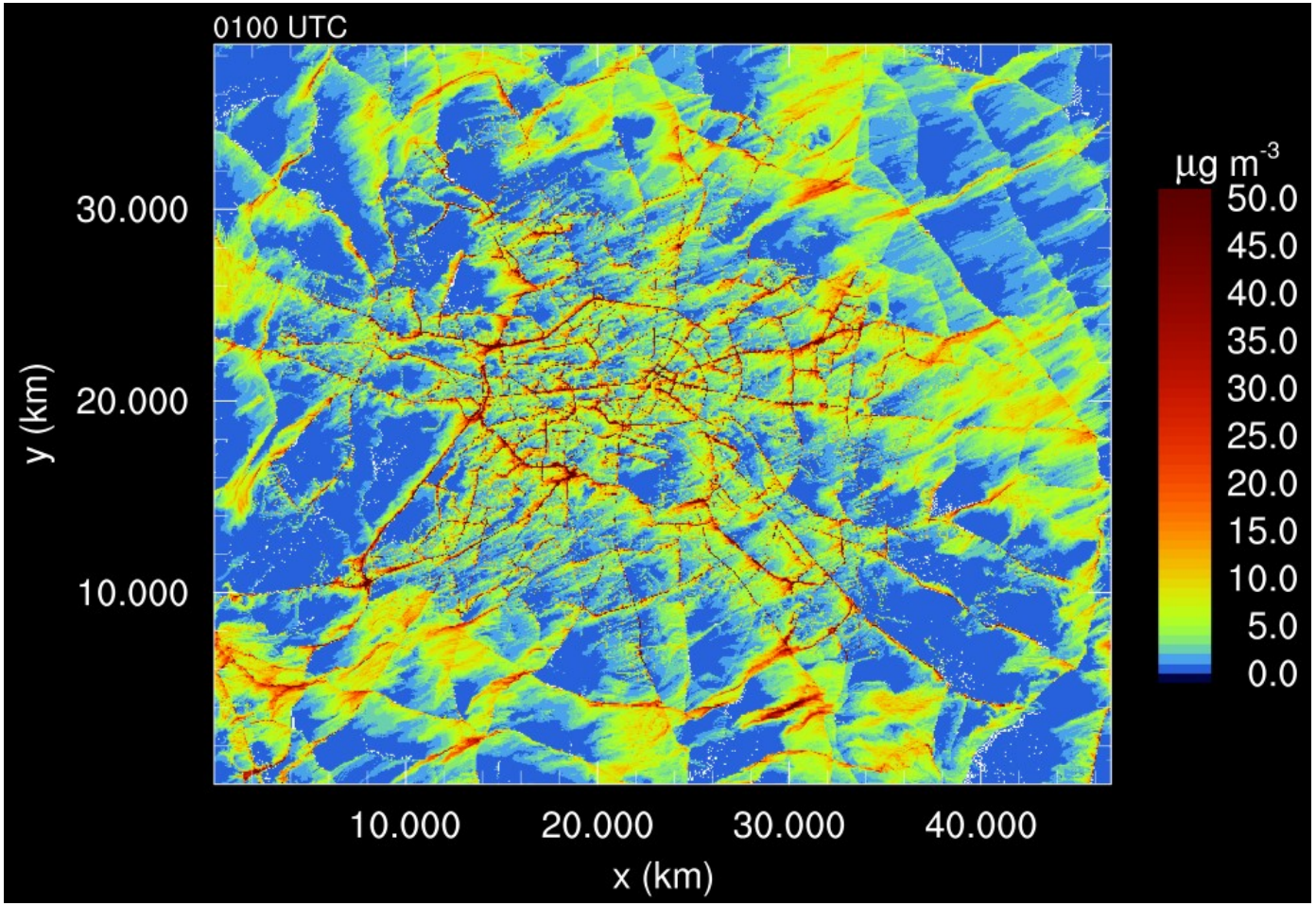


Results: Air temperature – night vs. day – Tiergarten



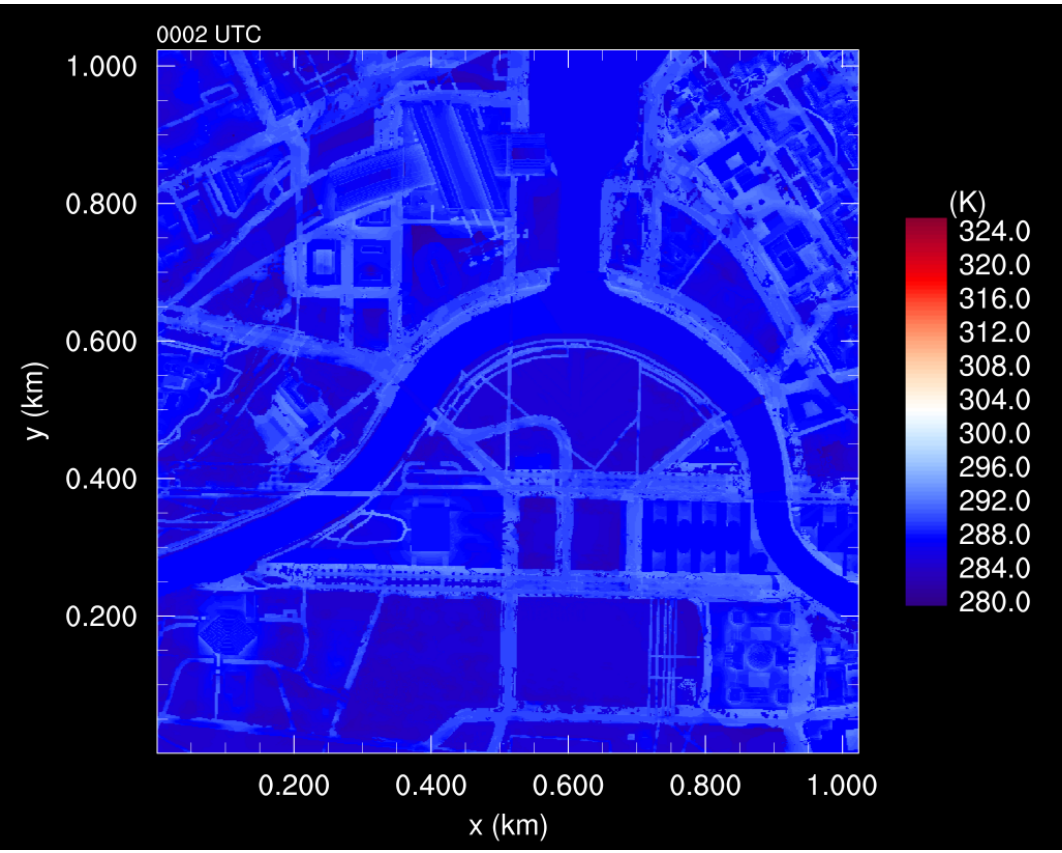


Results: PM10 – diurnal cycle

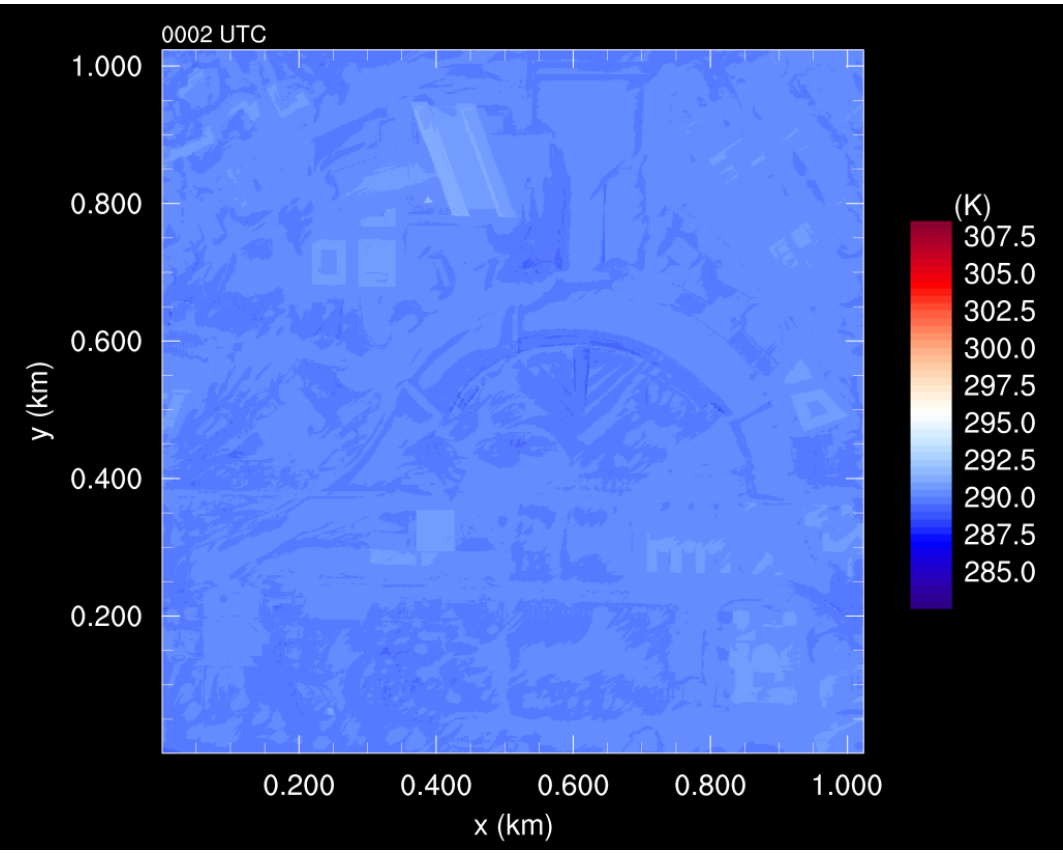


Results: Temperature – diurnal cycle – child domain

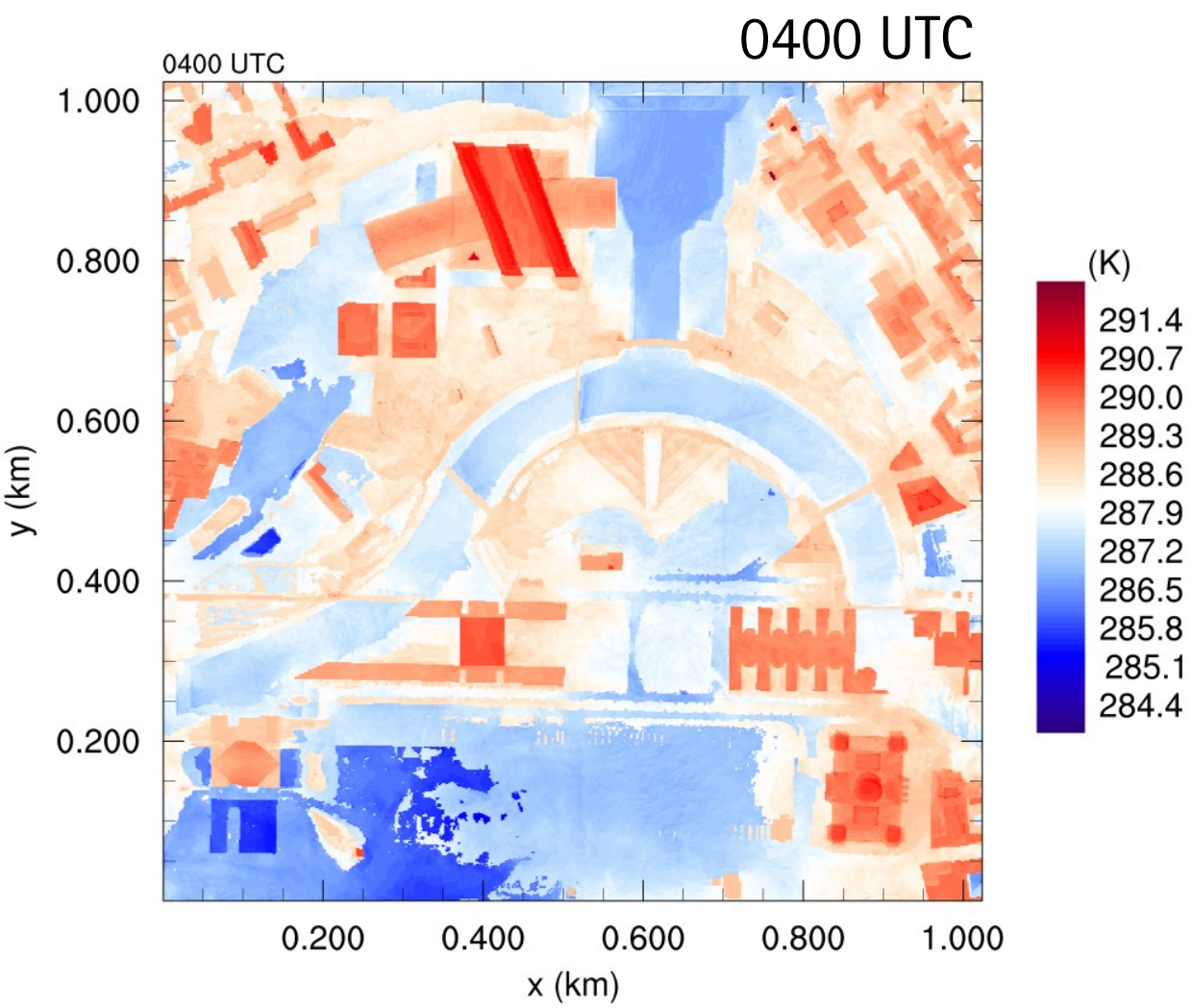
surface temperature



(near-surface) air temperature



Results: Temperature – diurnal cycle – child domain



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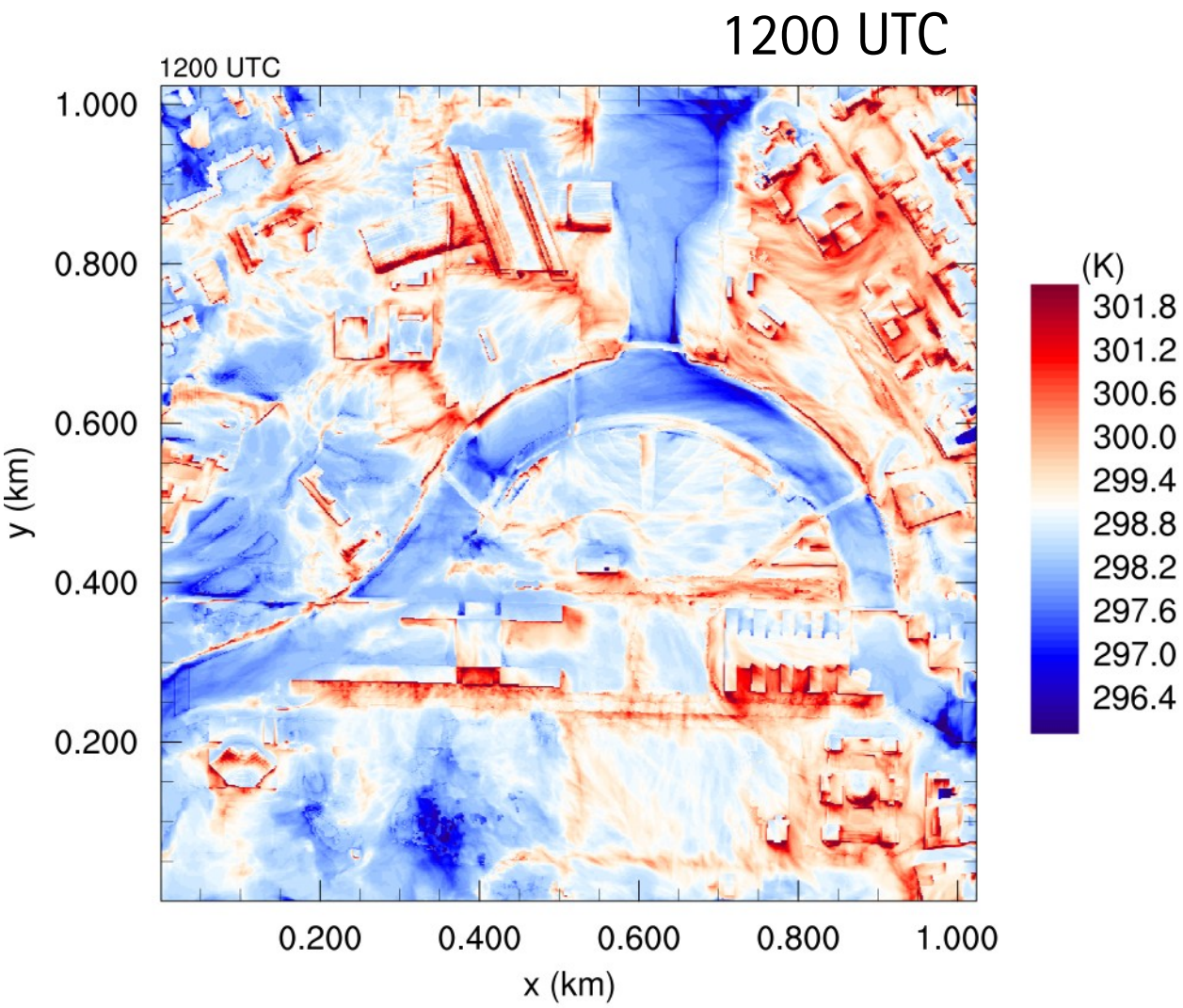
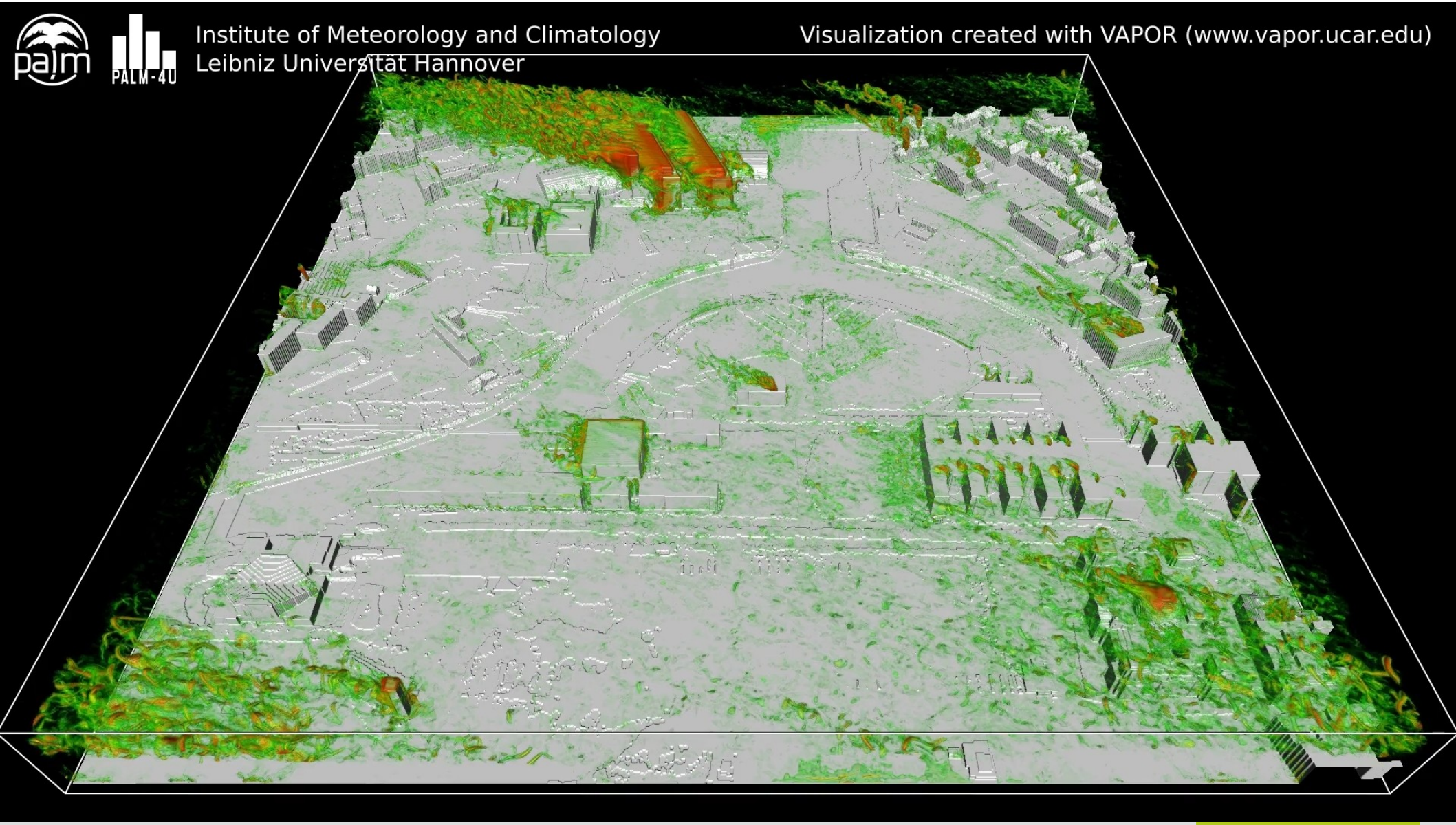


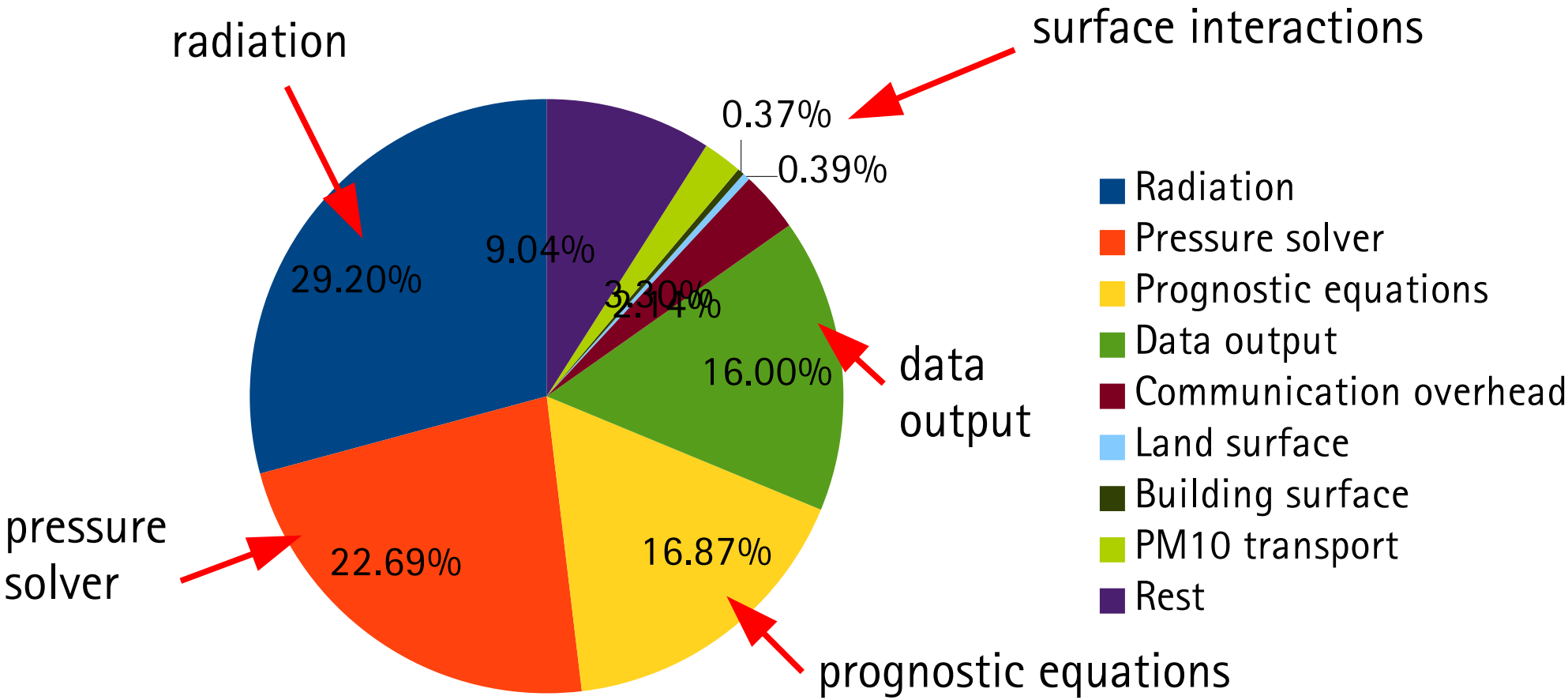
Results: Wind flow around buildings – child domain

Turbulence intensity



Results: Computational aspects

- Parent domain: 24 h @ 6048 PEs
- Child domain: 96 h @ 1024 PEs



What's next?

Outlook and summary

Outlook: PALM-4U release

- **Improvements (until May 2019):**
  - Bugfixes in new code components
  - Improved radiative transfer model
  - Green facades and roofs
  - Sophisticated emissions
  - Biometeorological analysis (UV, PET, ...), coupled to multi-agent system
  - Indoor climate module (indoor temperature, energy demand, waste heat)
  - Aerosol chemistry
- **Limitations:**
  - No clouds (in urban area)
  - No ice phase (clouds and soil)
  - No energy balance solver for individual trees
  - No reliable emission model
  - Expensive chemistry

    → 2nd $[UC]^2$ phase?

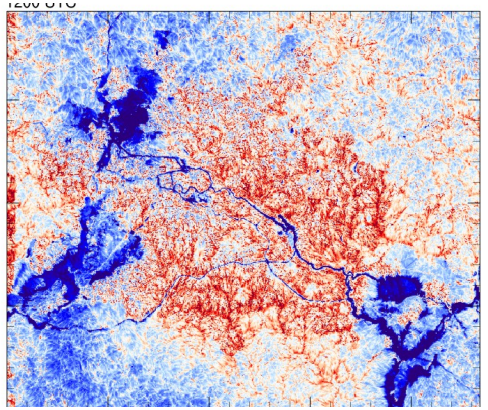
Outlook: Model evaluation

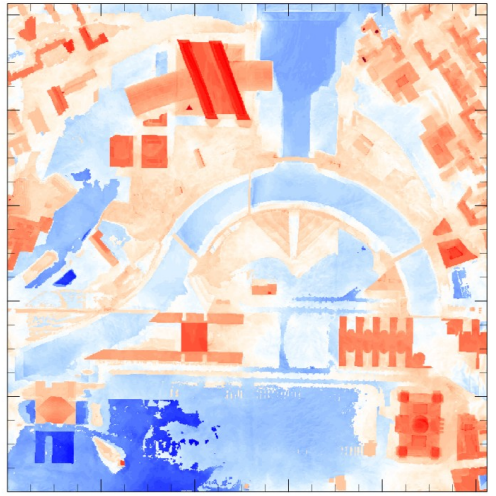
- **Evaluation:**
  - **Parameter studies:** Sensitivity due to (inaccurate) input data
  - **Wind tunnel** (City of Hamburg)
  - **Intensive observations** (Berlin, Hamburg, and Stuttgart):
    - 2A.5 *Scherer et al.*, Monday
    - 35 *Fehrenbach et al.*, Tuesday
    - 127 *Holtmann et al.*, Tuesday
    - 12B.3 *Queck et al.*, Friday
    - 4E.5 *Langer et al.*, Tuesday
    - 10C.3 *Emeis et al.*, Thursday
    - 1E.6 *Jagatha et al.*, Monday
    - 11A.2 *Samad et al.*, Friday

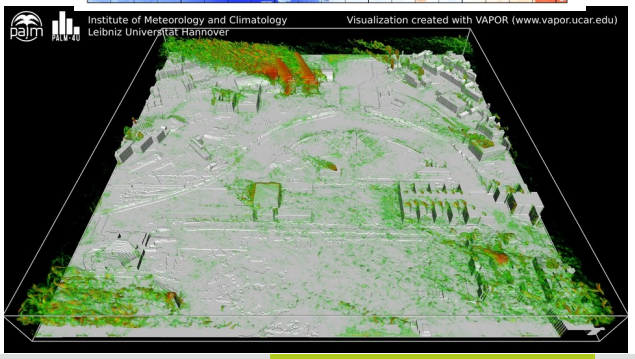
Summary

- PALM-4U: a new building-resolving urban climate model
- Turbulence-resolving simulations of entire cities
- Varying grid spacings and boundary conditions
- Model physics:
  - Buildings on Cartesian grid
  - Energy balance solvers for all urban surfaces
  - Radiative transfer
  - Model (self-) nesting
  - 3D trees
  - Chemistry
  - Multi-agent system

- **First results:** successful first application for Berlin
- **But:** still… work to do!







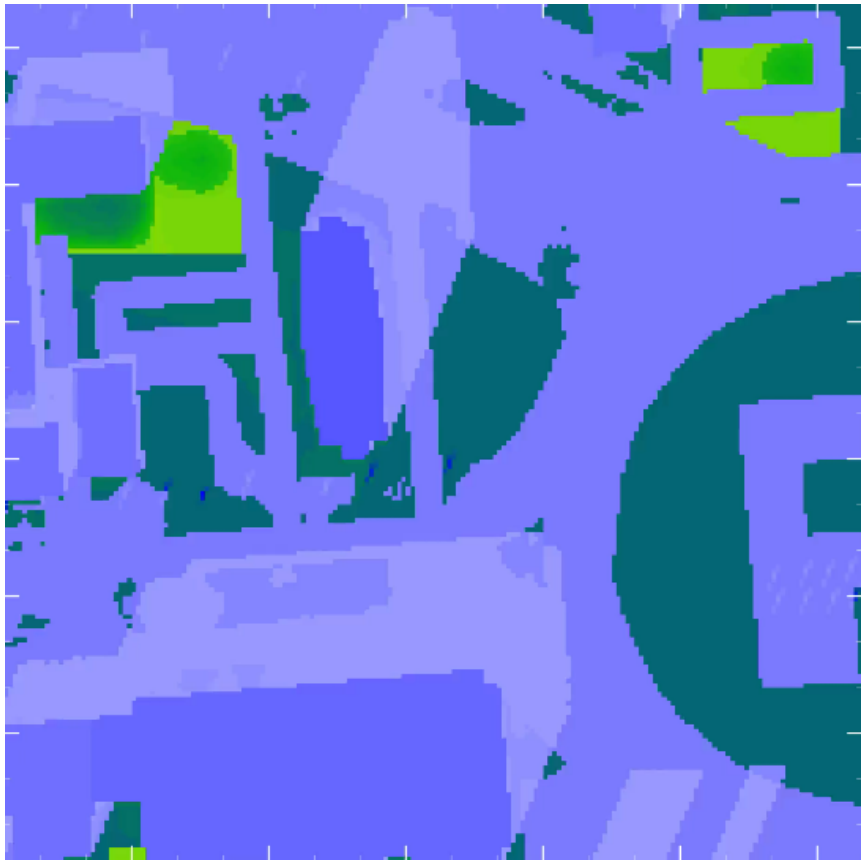
Thank you!

http://palm4u.org

http://palm-model.org

Additional material: Spinup-Mechanism

Technical test
Component: Spinup-mechanism
Spinup time: 48 h
Time step: 60 s
Animation:
surface temperature
CPU time: 200 s



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Technical test

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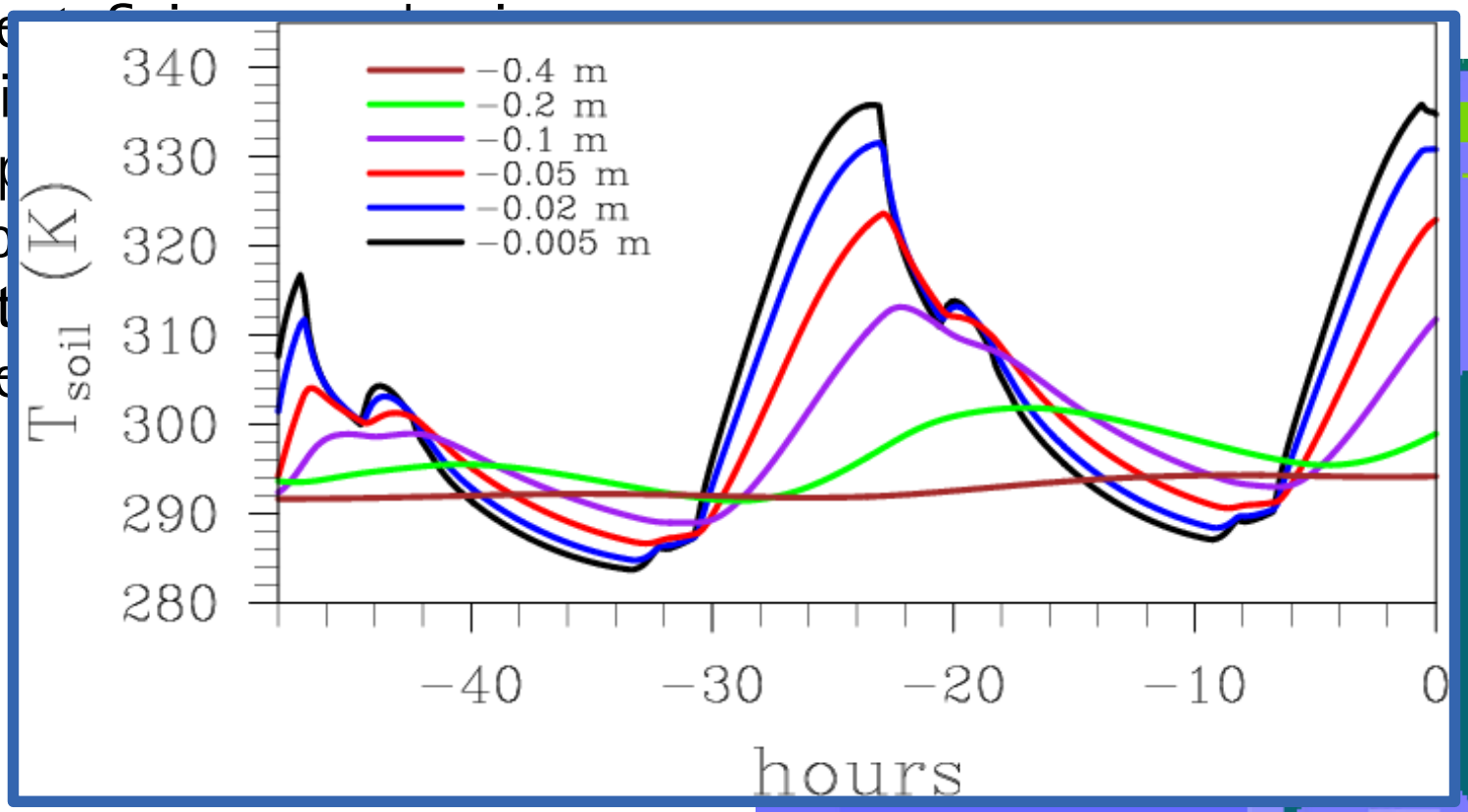

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Technical test

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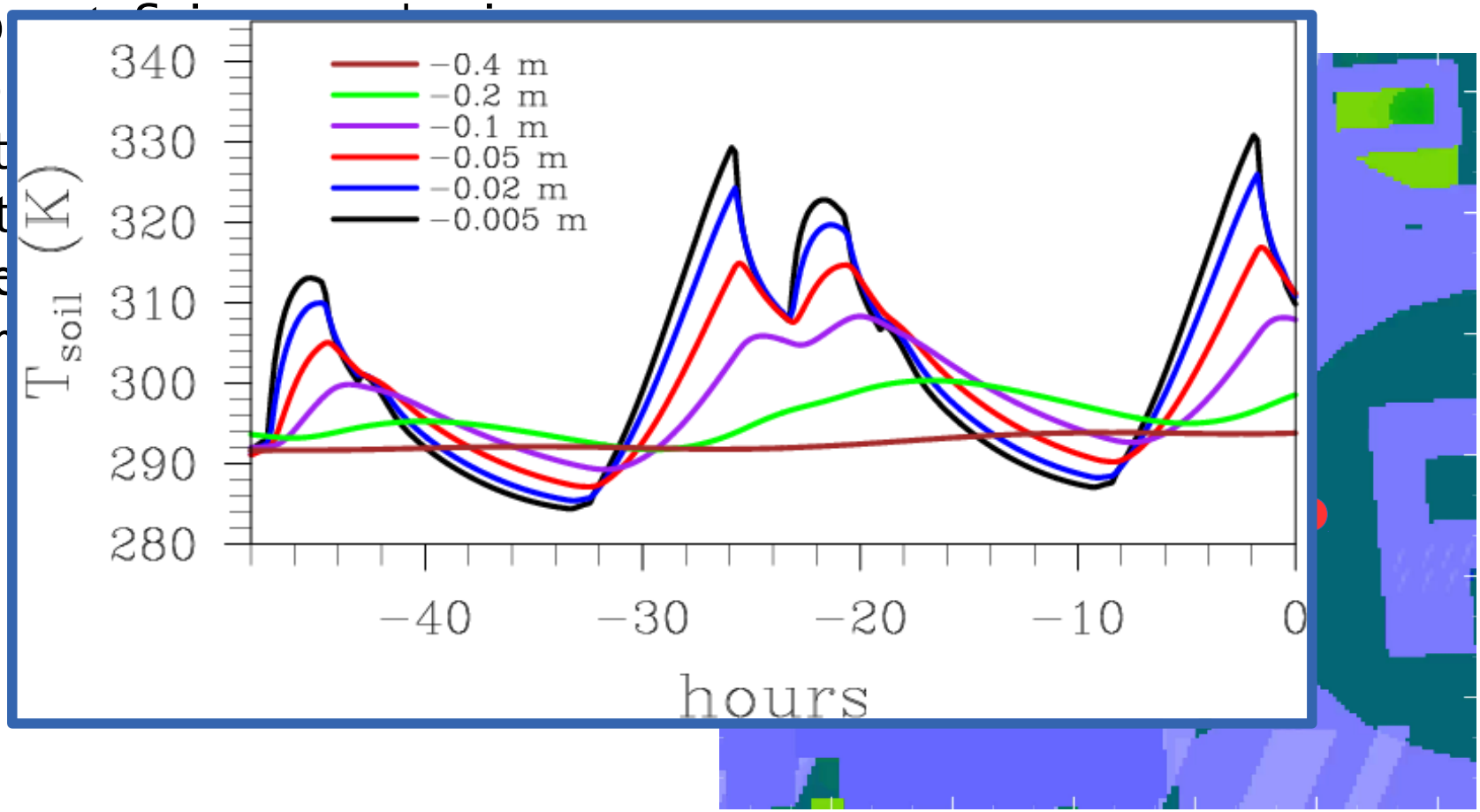
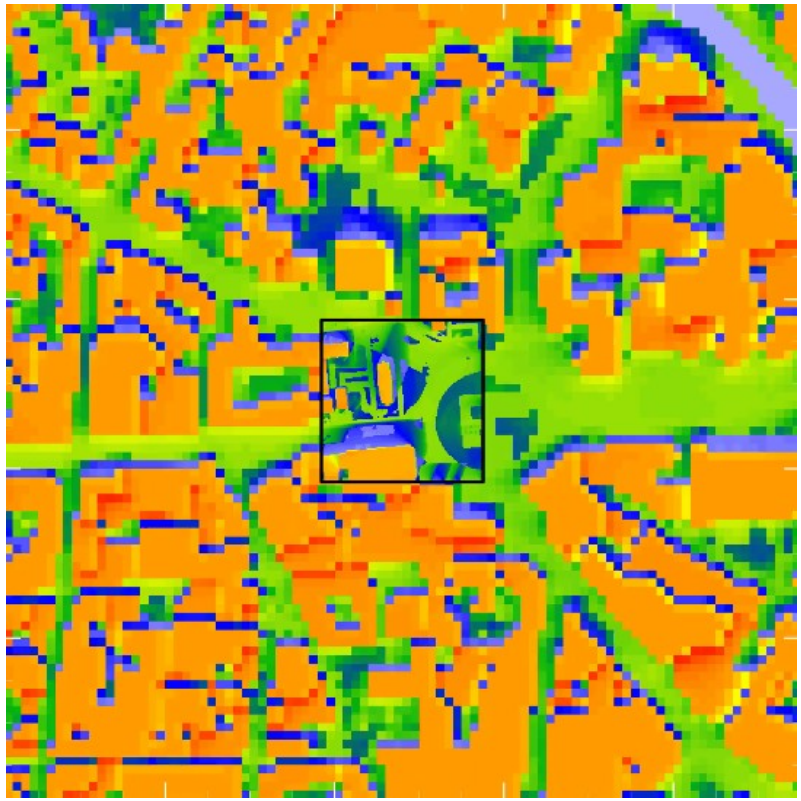
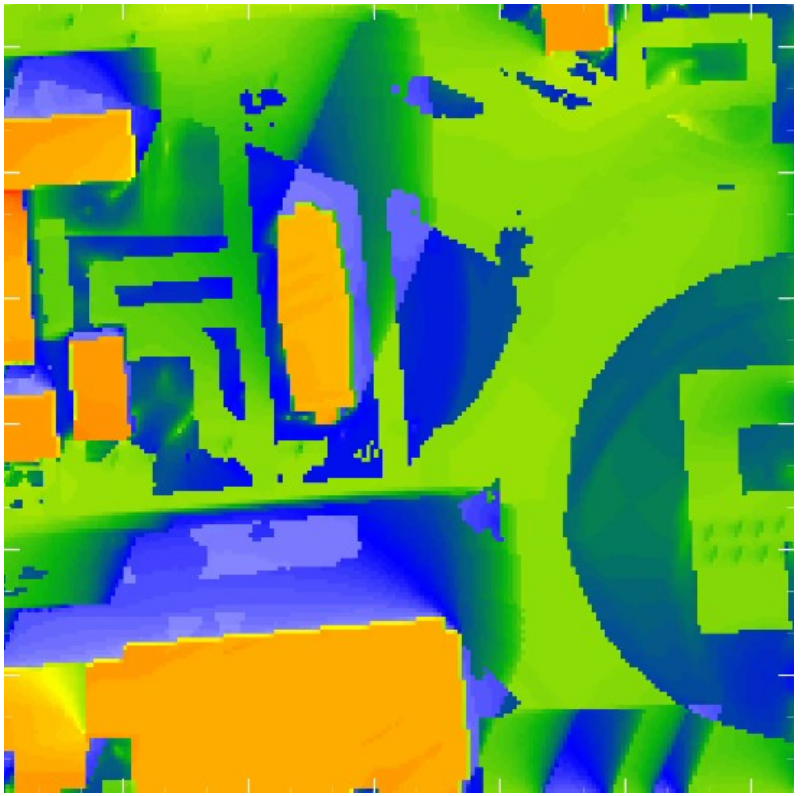


Additional material: Nesting 10 m – 1 m

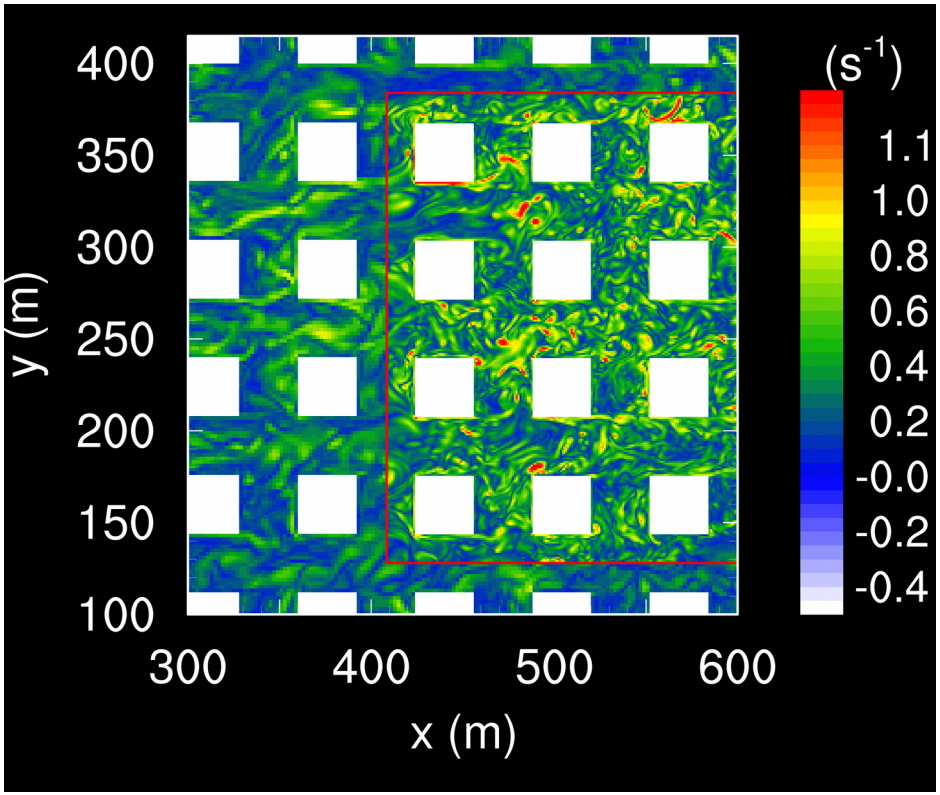




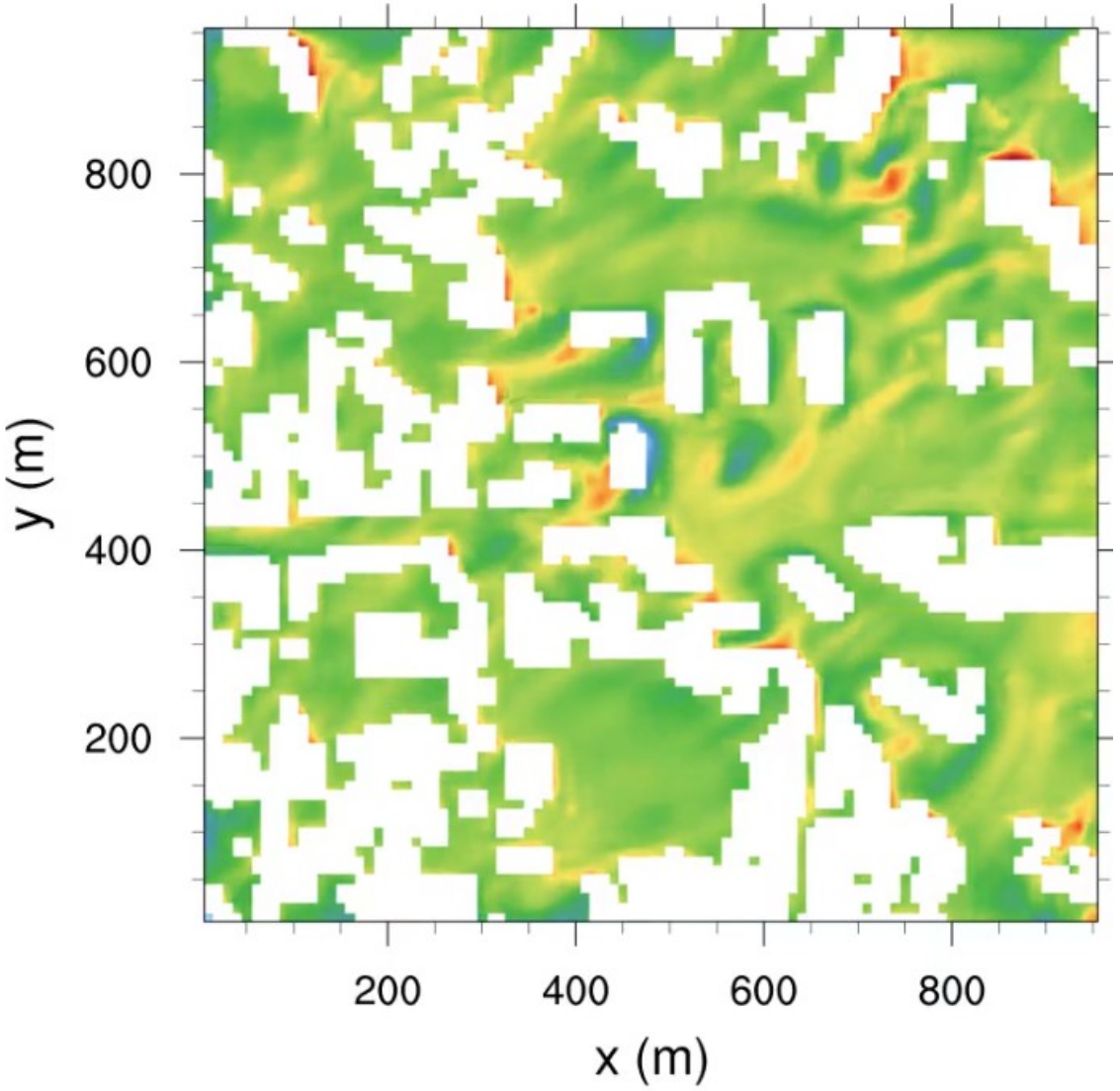
Additional material: LES-LES nesting

Forcing and model nesting

- Mesoscale interface for COSMO-DE (details in: 12D.2,*Kadasch*, Friday)
- For now: initial profiles only
- LES-LES nesting (details in: Poster 52, *Sühring et al.*, Tuesday)



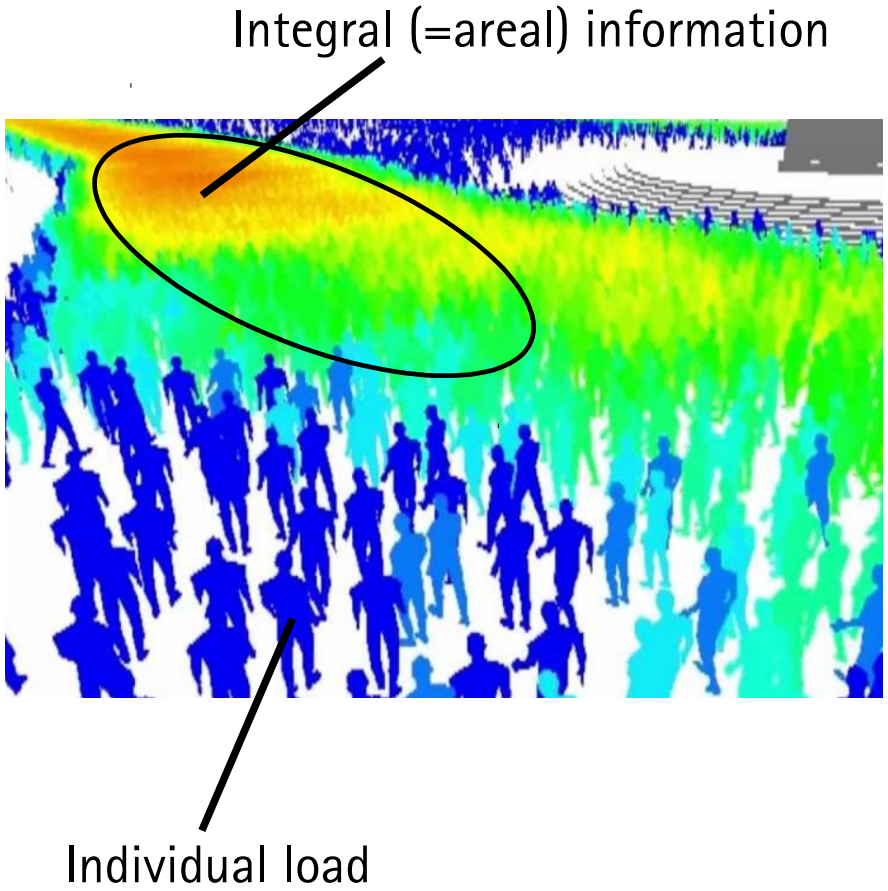
Additional material: COSMO-DE forcing



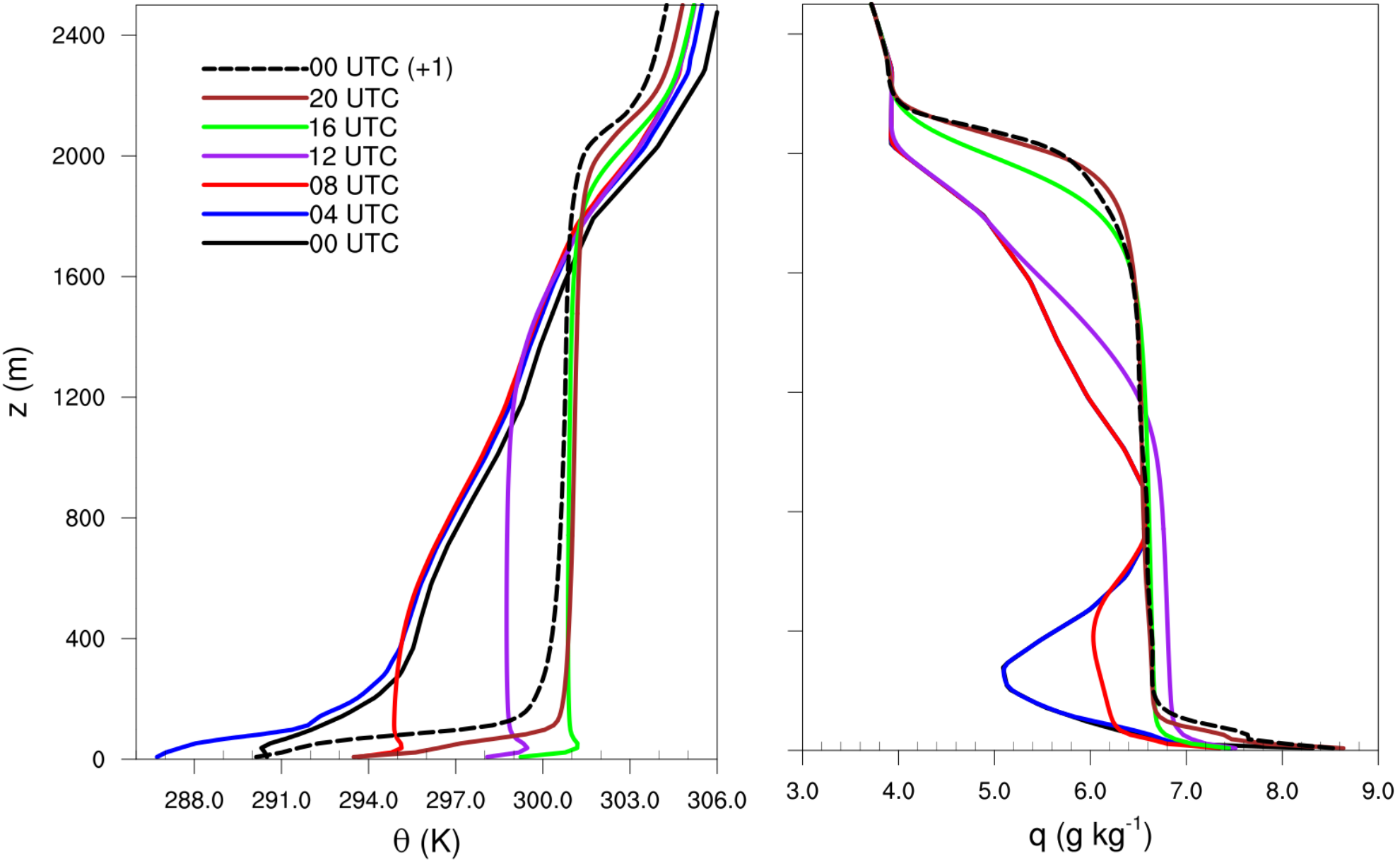
Multi-agent system (MAS)

- Alternative approach for evaluation of human comfort
- "agents" walk through the simulation domain, feel the atmosphere
- Analysis possibilities:
  - UV load (see 12B.2, *Schrempf et al.*, Friday)
  - Biometeorological indices (MRT, PET, UTCI, etc.)
  - Individual pollutant load
  - Planning of escape routes

- MAS consists of:
  - Creating navigation mesh
  - Plan routes
  - Move and track agents



Results: Mean profiles



Berlin showcase: model physics

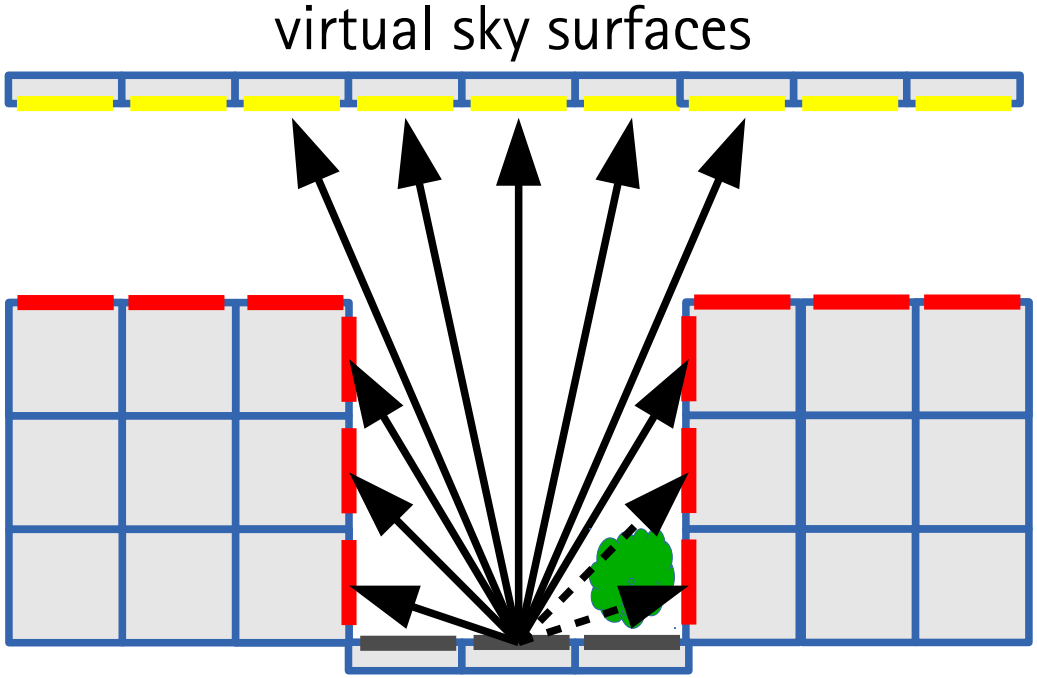
Radiative transfer

Atmospheric radiation:
- RRTMG (single column)

Urban canopy radiative transfer:
- Direct & diffuse radiation
- Incoming SW radiation for each SE
- Longwave emission for each SE
- Finite reflections
- Individual absorption
- Realized by SVF and CSF

Details in:
- Resler et al., 2017, GMD
- 12D.8 (*Resler et al.*, Friday)
- 13D.4 (*Salim et al.*, Friday)

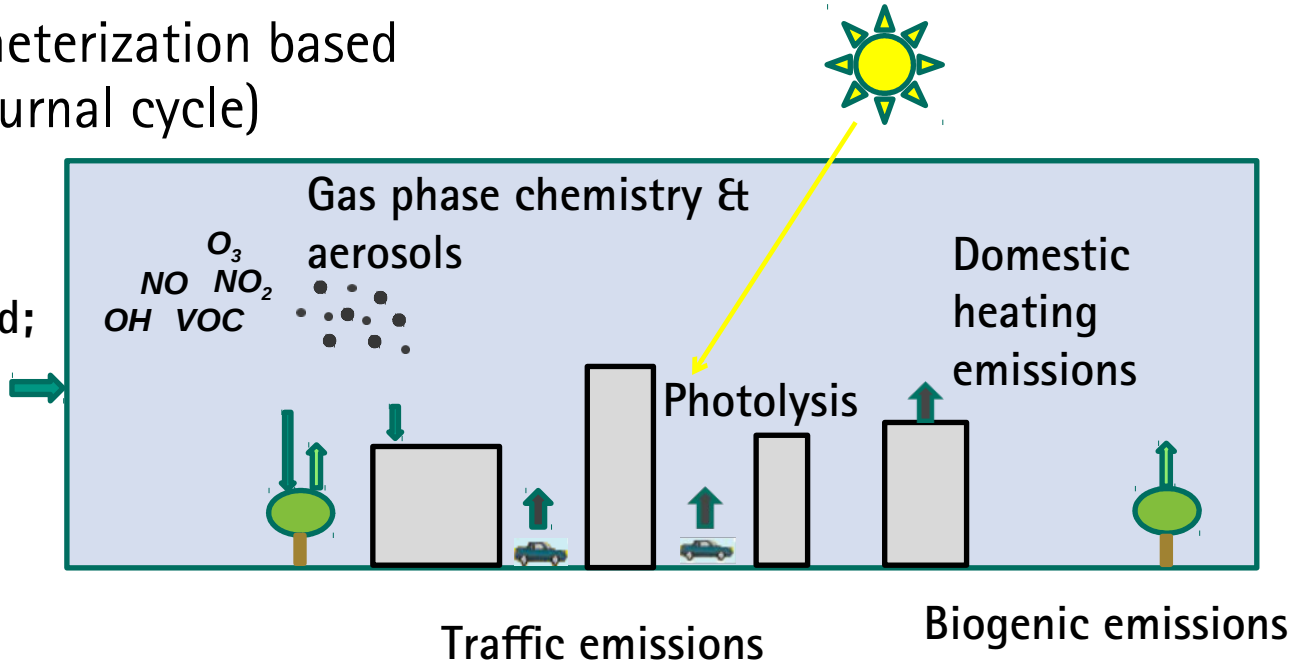
Urban radiation basics:
- Shadowing
- Surface reflections
- 3D vegetation as sink for radiation



Berlin showcase: model physics

Chemistry

- "online" coupled model for gas phase chemistry implemented
- Kinetic PreProcessor (KPP) are preprocessing
- Different mechanisms possible
- For now: (passive) PM10 only
- No background concentration
- Simple traffic emission parameterization based on street classification (no diurnal cycle)
- No deposition/decycling

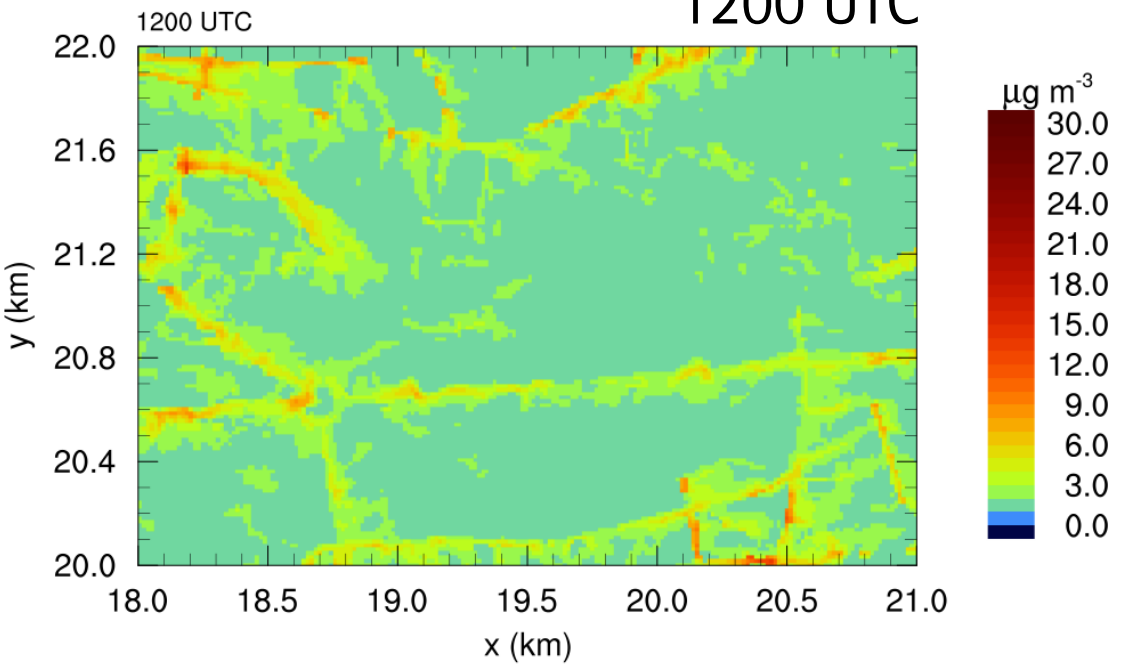


Details:

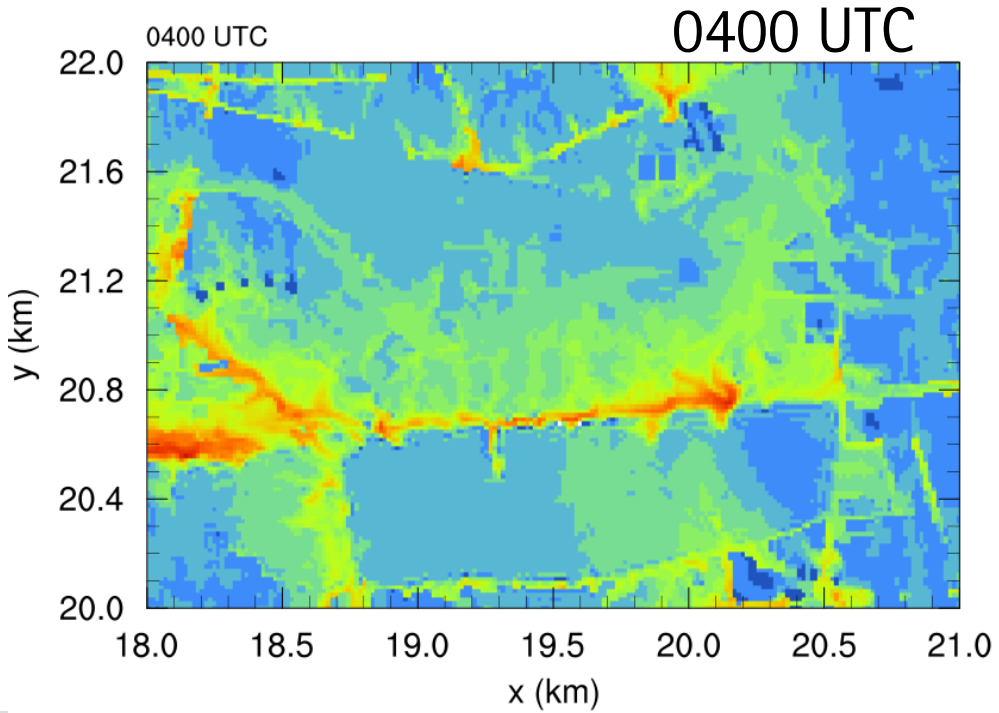
- Poster 73 (*Khan et al.*, Tuesday)

Results: PM10 – day vs. night – Tiergarten

1200 UTC

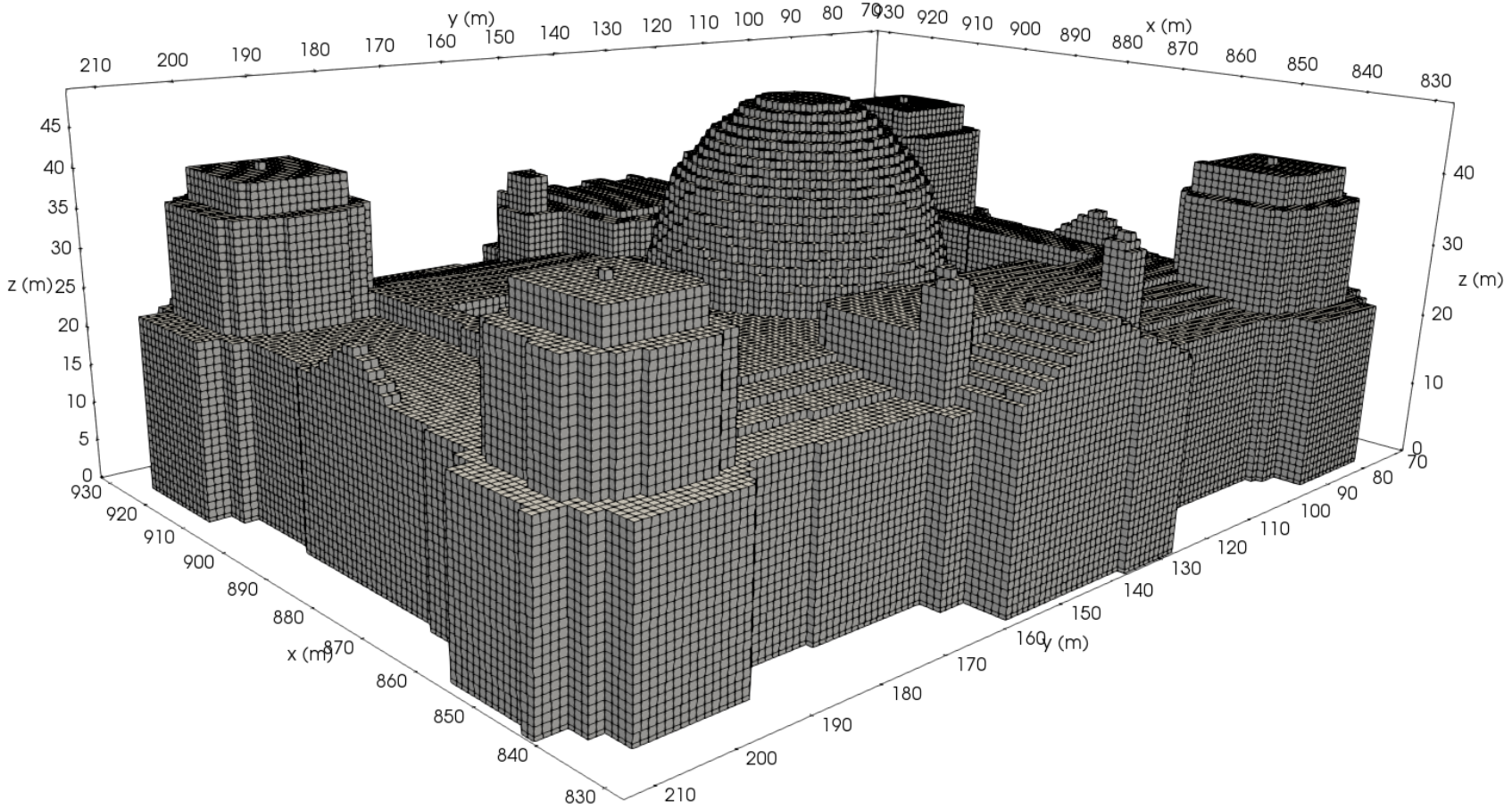


0400 UTC



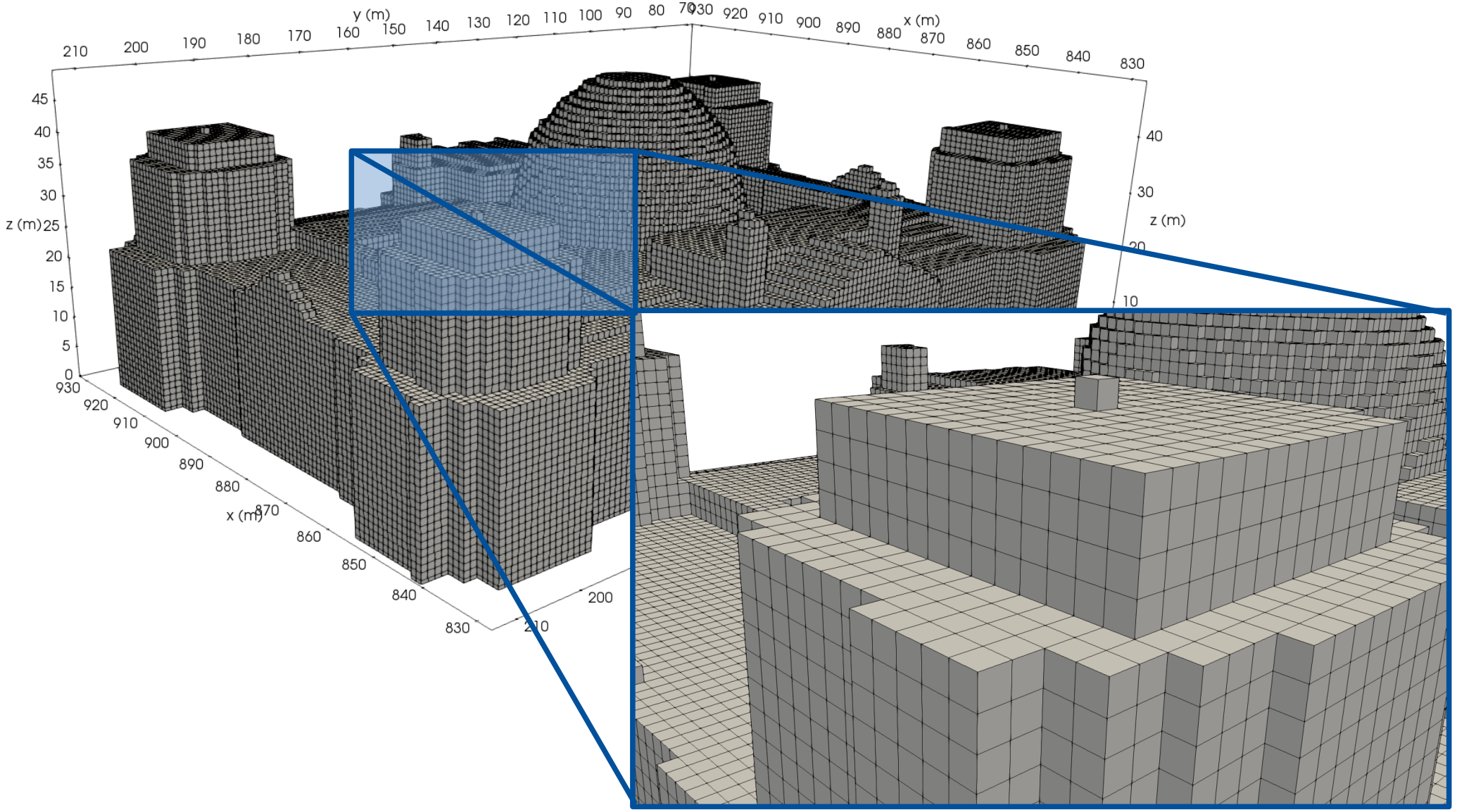
Berlin showcase: model physics

Building surfaces



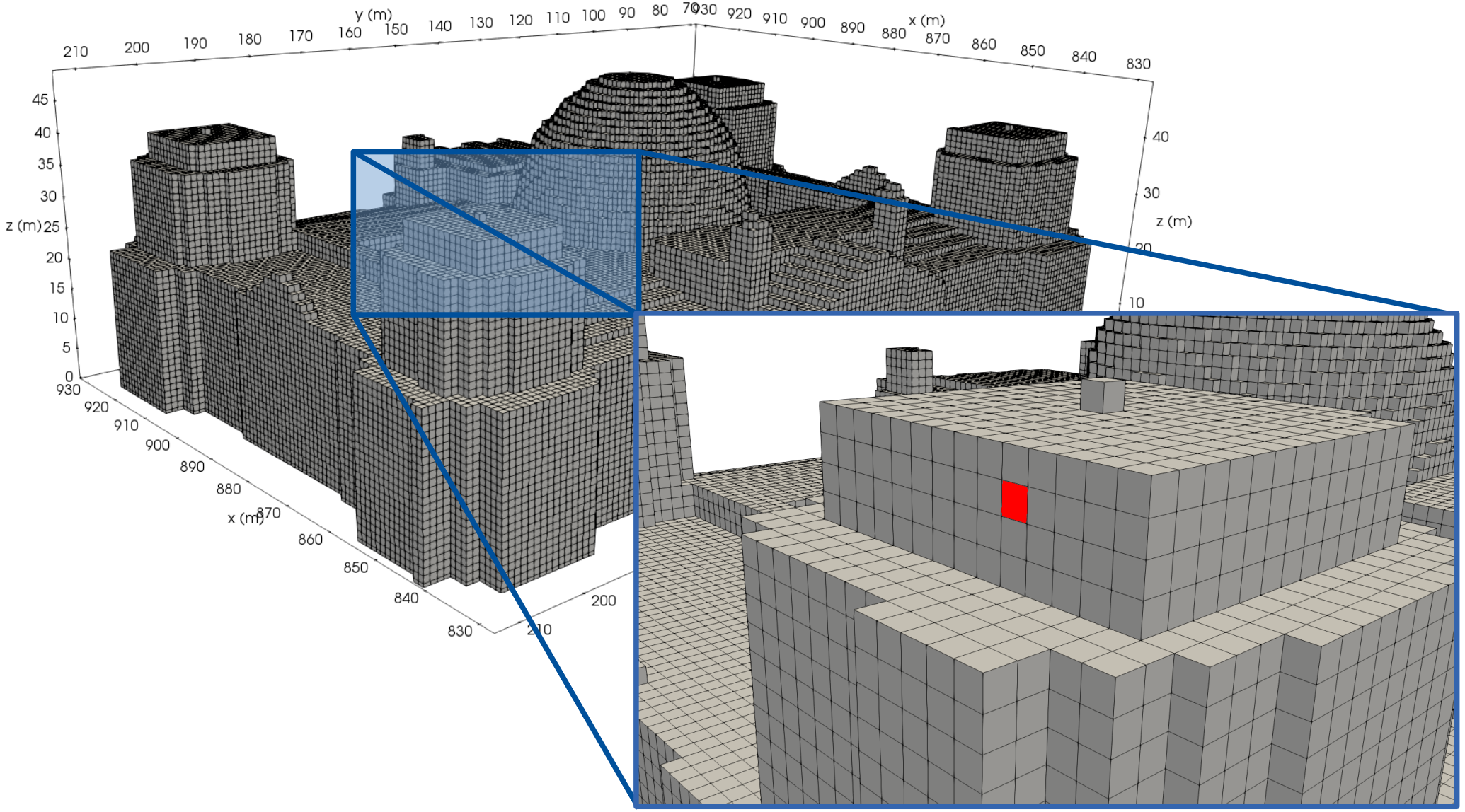
Berlin showcase: model physics

Building surfaces



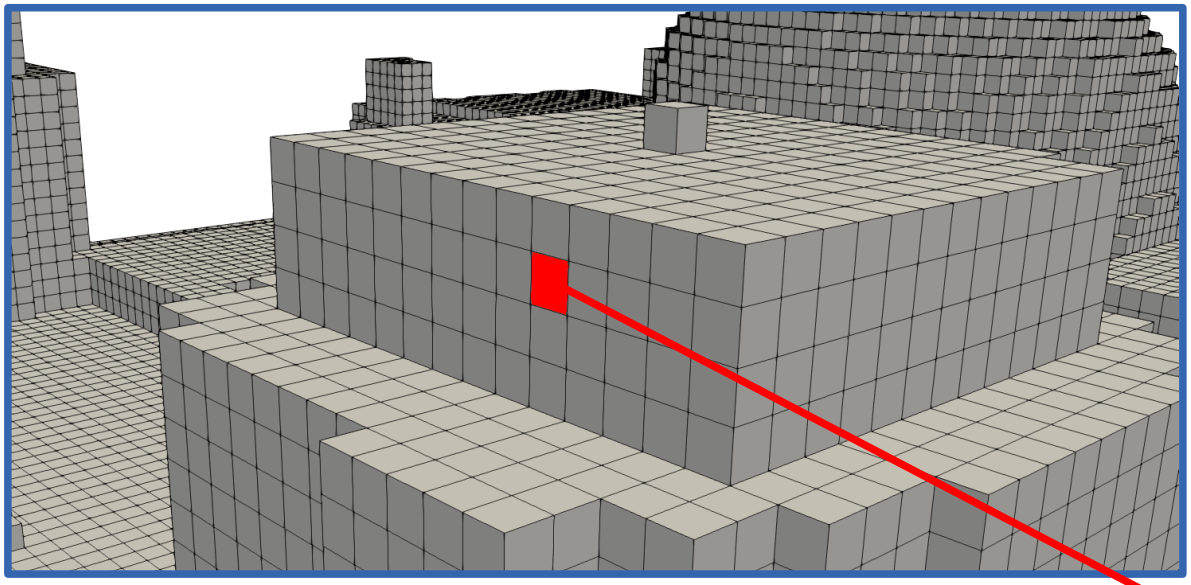
Berlin showcase: model physics

Building surfaces



Berlin showcase: model physics

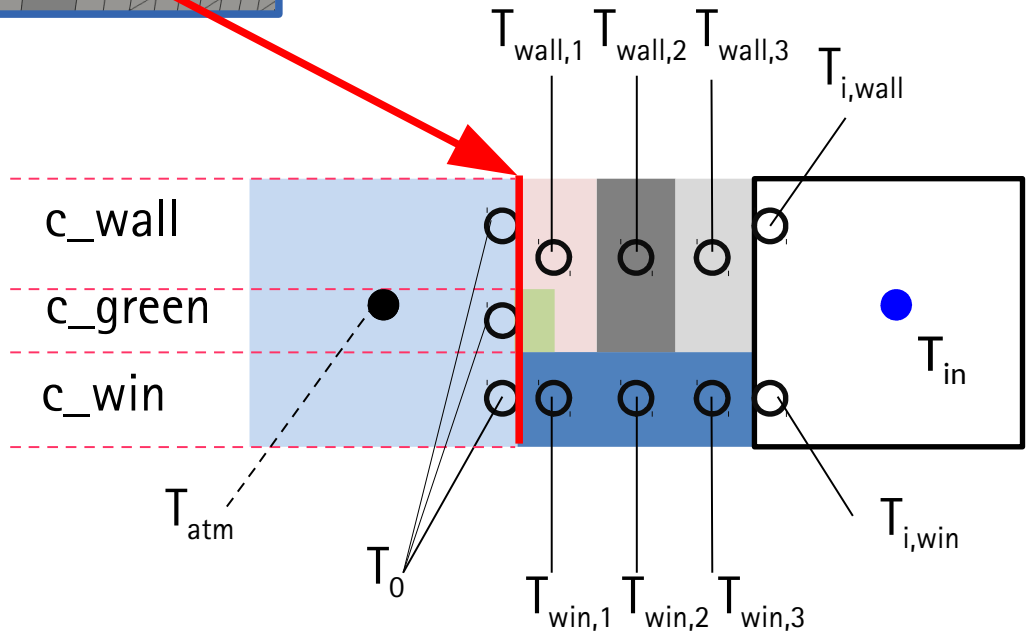
Building surfaces



- Tile approach
  - wall fraction
  - window fraction
  - green fraction
- Energy balance solver for T_0
- Heat conduction through 3 wall/window layers

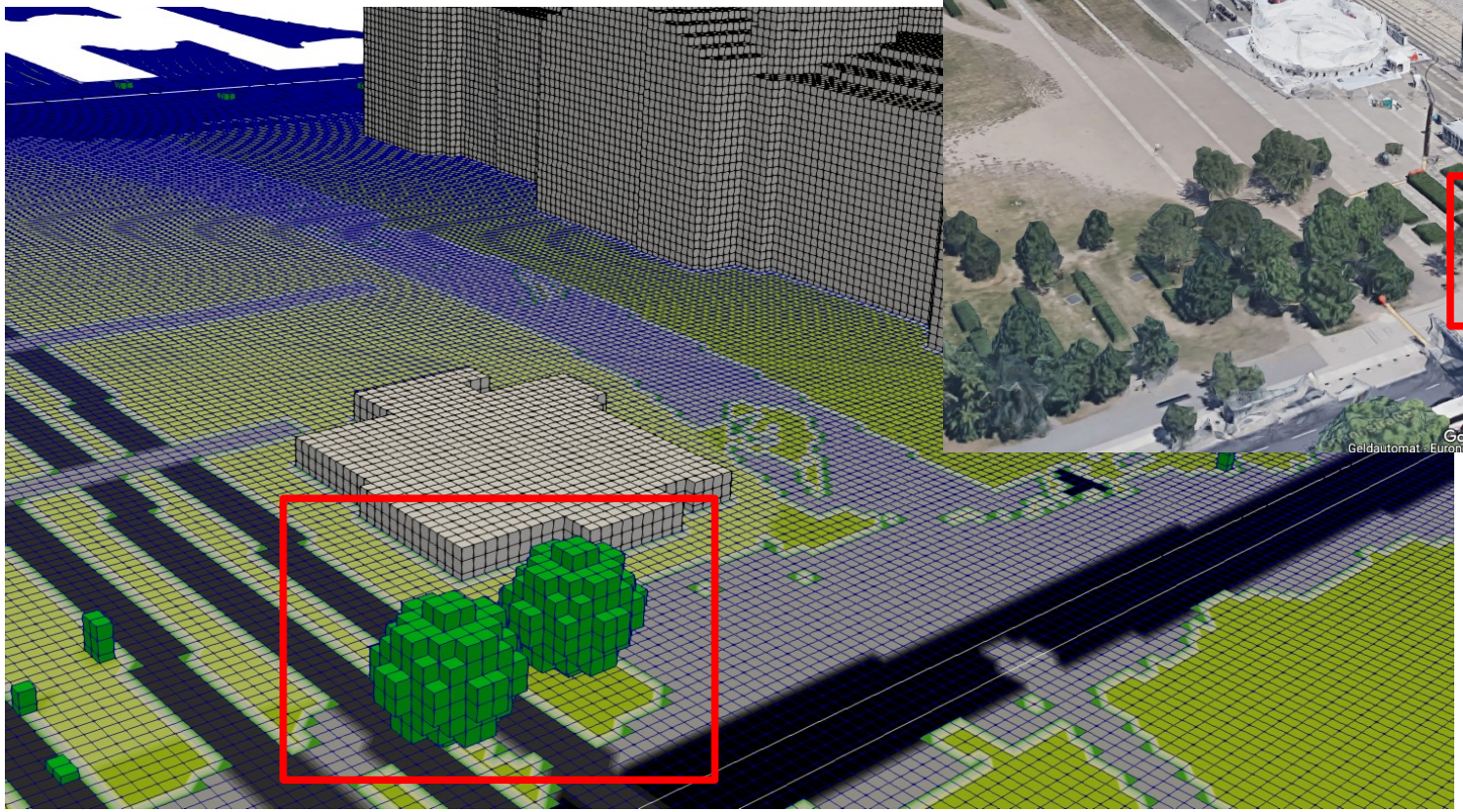
- Resistance parameterization
  - horizontal: Monin-Obukhov
  - vertical: Krayenhoff & Voogt (2007)

- For more:
12D.8 (*Resler et al.*, Friday)



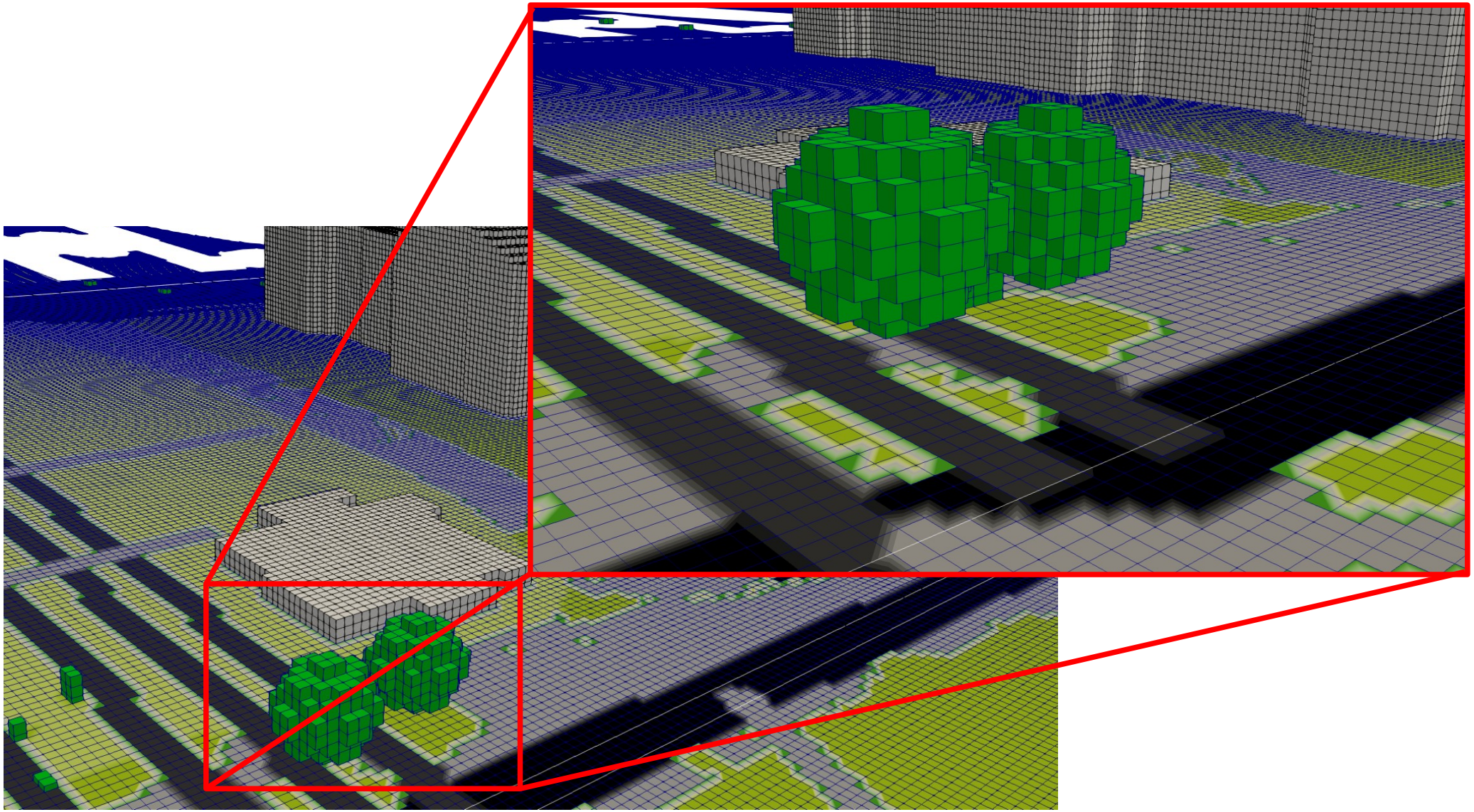
Berlin showcase: model physics

Land surface, pavements and vegetation



Berlin showcase: model physics

Land surface, pavements and vegetation



Berlin showcase: model physics

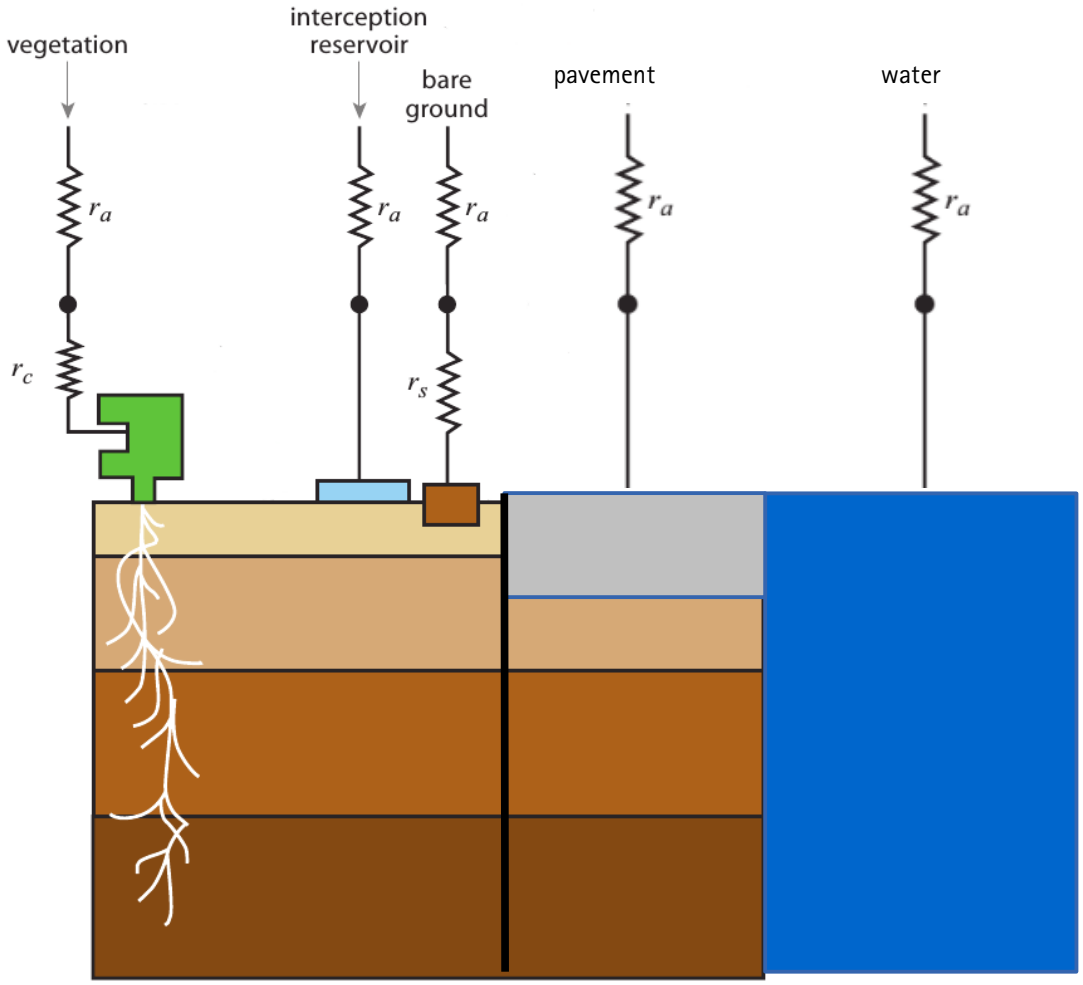
Land surface, pavements and vegetation

- 3D “resolved“ vegetation
    - sink for momentum
    - sink for radiation
    - source of heat
    - source of water vapor

Berlin showcase: model physics

Land surface, pavements and vegetation

- Similar to TESSEL (IFS)
- Energy balance solver for T0
- Resistance parameterization using Monin-Obukhov
- Multi-layer soil model (default: 8)
- Vertical transport of heat and water
- Surface classification:
  - Water (fixed temperature)
  - Vegetation (low)
  - Bare soil
  - Pavement
  - Precipitation water possible on vegetation and pavement



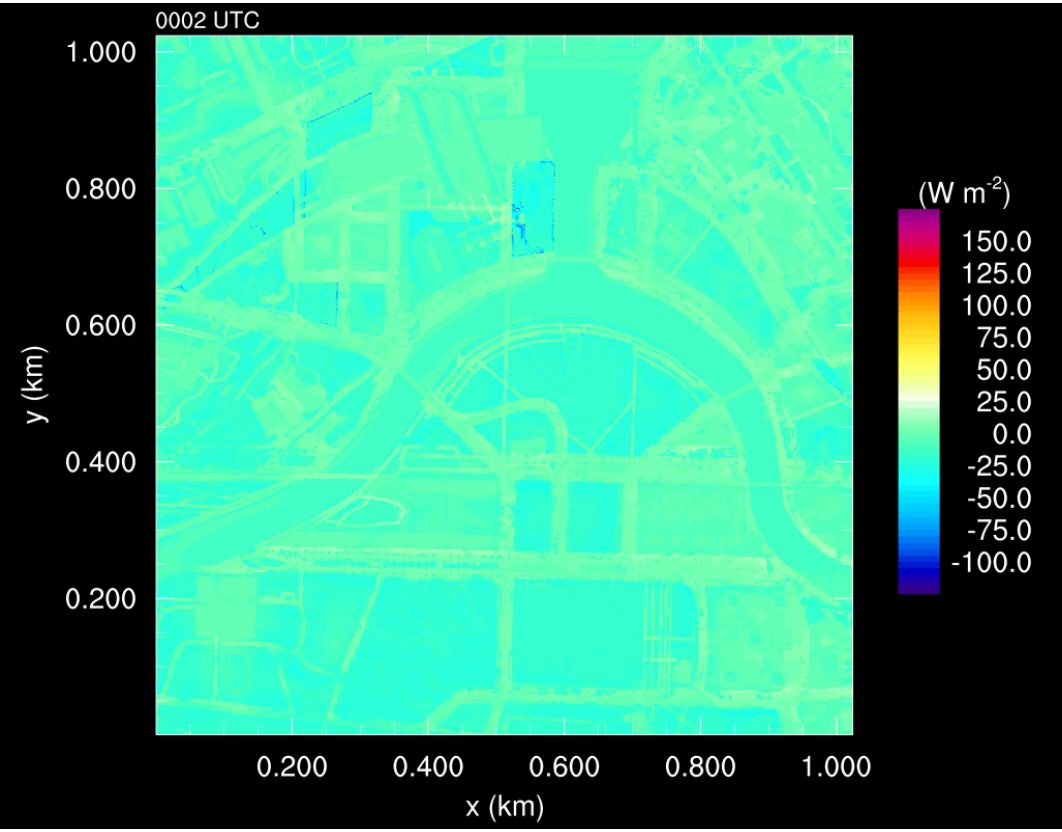
Berlin showcase: model physics

Forcing and model nesting

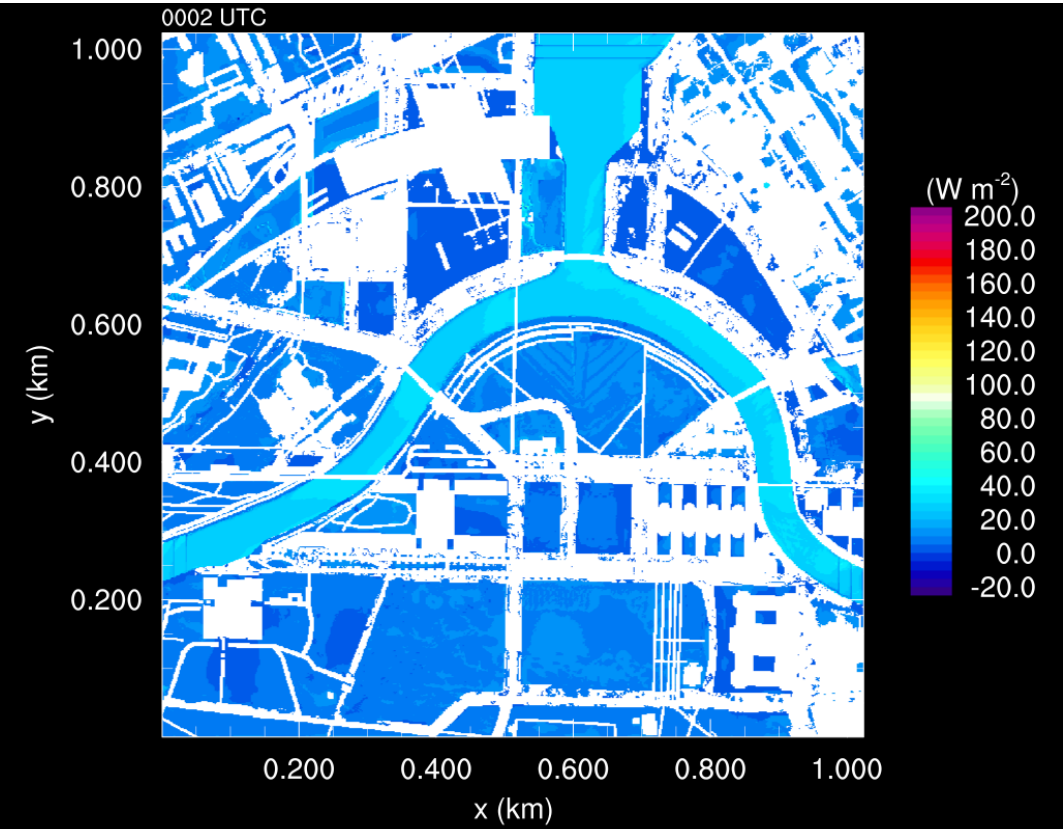
- Mesoscale interface for COSMO-DE (details in: 12D.2,*Kadasch*, Friday)
- For now: initial profiles only
- LES-LES nesting (details in: Poster 52, *Sühring et al.*, Tuesday)

Results: Surface fluxes – diurnal cycle – child domain

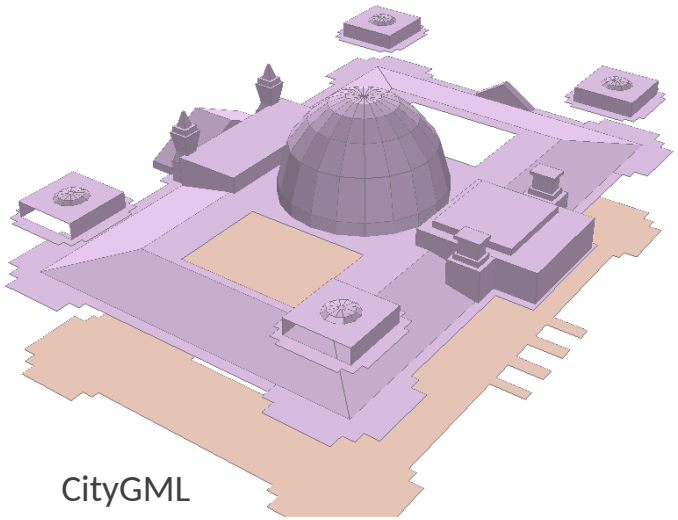
surface sensible heat flux



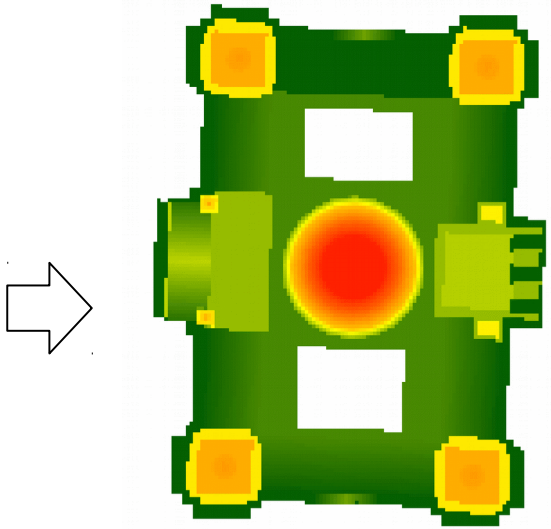
surface latent heat flux

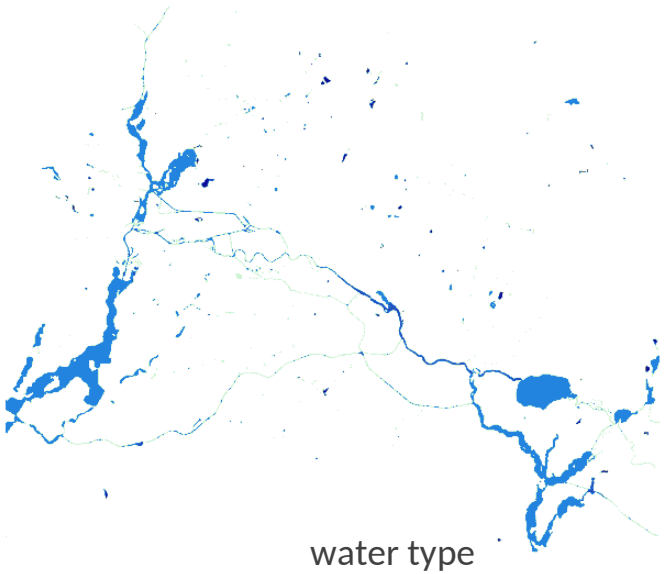


Berlin showcase: input data processing

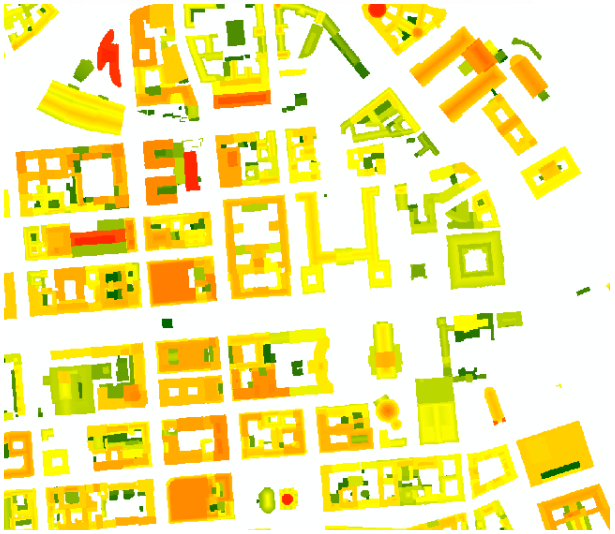


CityGML





water type



building height, 1 m grid

Used input data:

topography
- terrain height
- building id
- building height
- bridges

surfaces
- building type
- vegetation type
- pavement type
- water type

vegetation
- vegetation height
- leaf area index
- tree height
- crown diameter
- tree species*

Additional material: Multi-agent system