Leibniz Universität Hannover

GEFÖRDERT VOM

Bundesministe
für Bildung
und Forschu

Gebäudeauflösende Large-Eddy Simulation von Berlin

Erste Ergebnisse des leistungsstarken mikroskaligen Stadtklimamodells PALM-4U

Björn Maronga[1] und:
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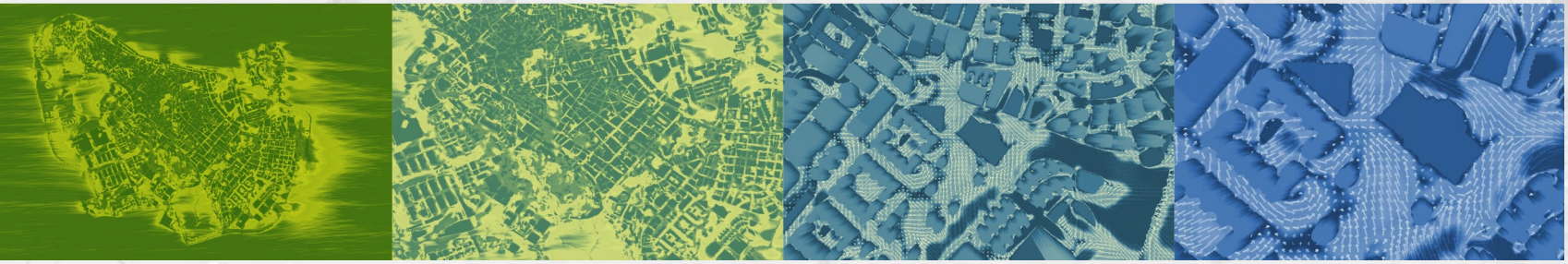
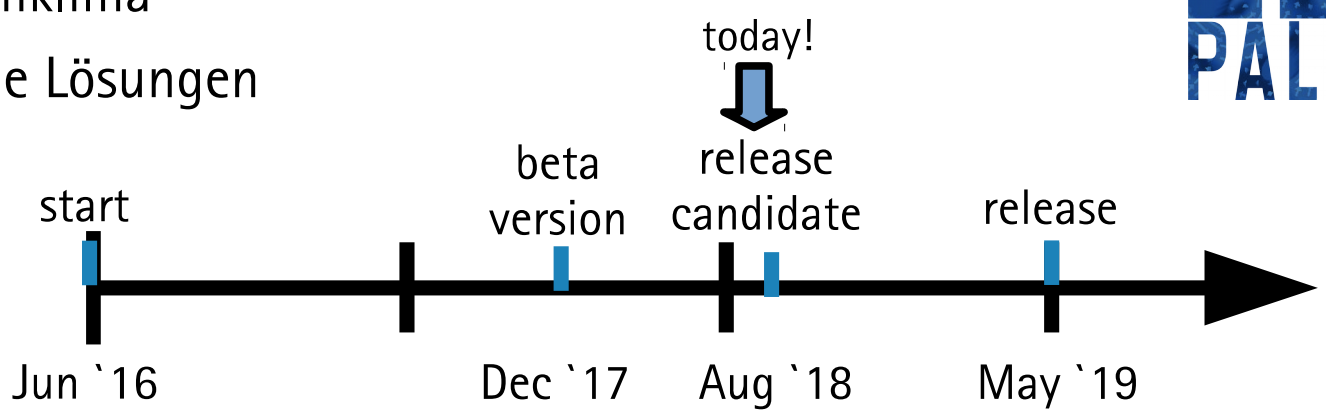
[4] Deutsches Zentrum für Luft- und Raumfahrt | [5] Karlsruher Institut für Technologie | [6] Deutscher Wetterdienst | [7]Hochschule Offenburg |
[9]Ingenieurgesellschaft Prof. Dr. Sieker mbH | [10] Humbold-Universität zu Berlin | [11]Finnish Meteorological Institute | [12]Software Consultant | [13] Czech Academy of Sciences,Czech Rebublic | [4]Charles University, Prague, Czech Republic



PALM-4U

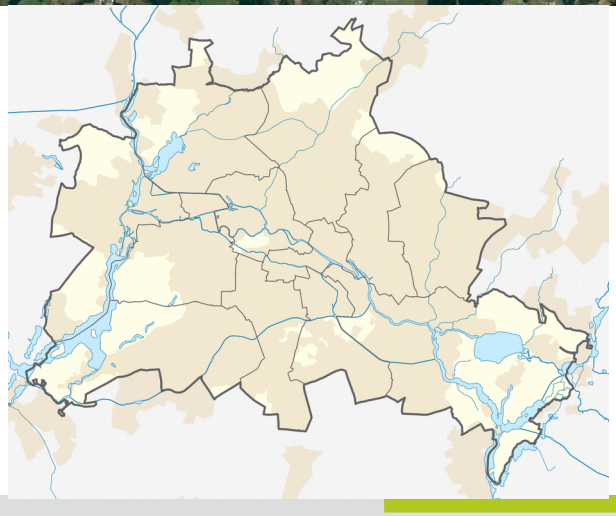
Von PALM zu PALM-4U: Überblick

- **PALM**: Modellkern (*Maronga et al. 2015, GMD*)
  - Parallelisiertes Large-eddy Simulations- (LES) Modell
  - Hochoptimisieert, skaliert bis zu > 32 000 Rechenkerne
  - Topographie auf kartesischem Gitter
  - Interaktives Landoberflächenmodell + Kopplung an RRTMG
  - Eingebettete Modelle
- **PALM-4U: PALM + zusätzliche Komponenten**
  - Energietransfer in der städtischen Grenzschicht
  - Luftchemie und Emissionen
  - Innenraumklima
  - Technische Lösungen



Berlin showcase: Setup – Das „parent“ Gebiet

Gebiet (x x y x z)	46.8 km x 38.6 km x 3.5 km
Gitterweite	15 m
Antrieb	COSMO-DE Initialprofile 21.07.2013, 00:00 Uhr
Synoptik	Schwachwind, wolkenlos, COSMO-DE 2m -Temperatur > 303 K
Laterale Randbedingungen	zyklisch
Simulationszeit (Spinup)	24 h (Oberflächen + Strahlung)
Simulationszeit (LES)	24 h



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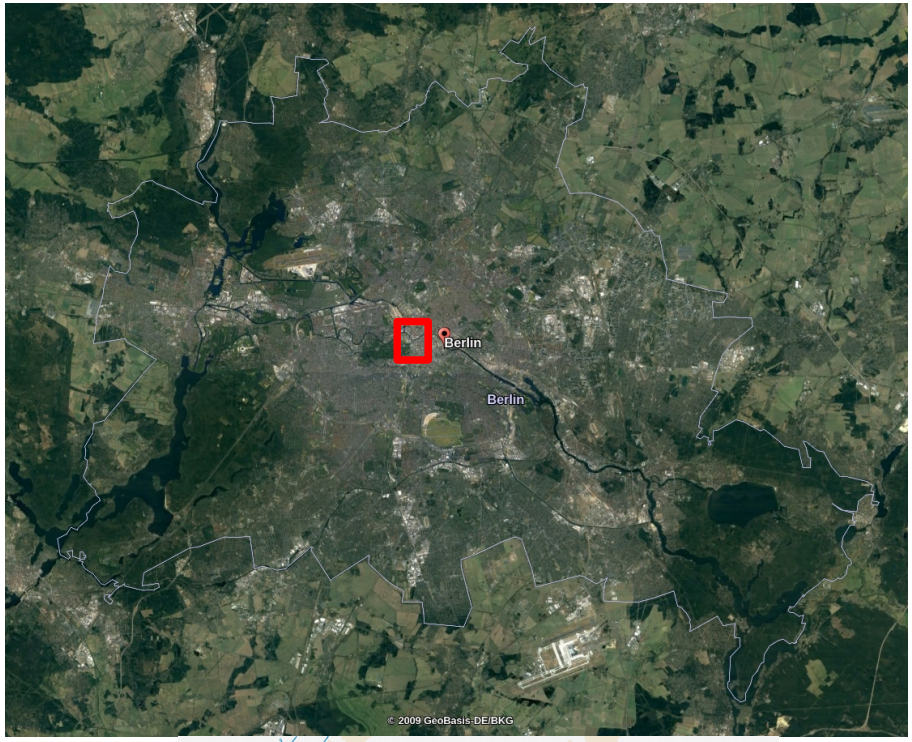
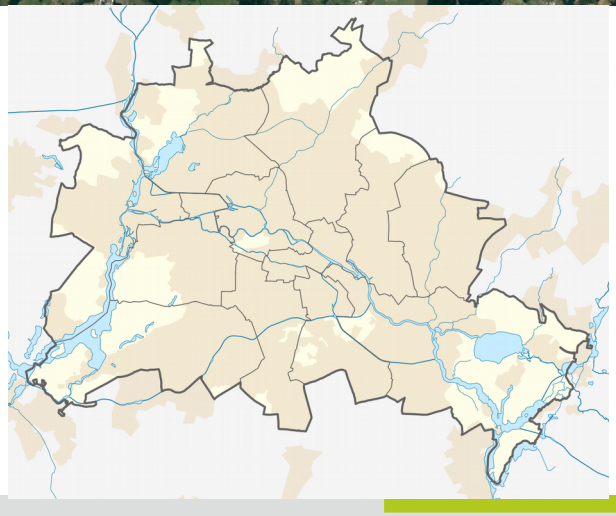




Berlin showcase: Setup – das „child“ Gebiet

Berlin Hbf

Reichstagsgebäude

Berlin showcase: Setup – das „child“ Gebiet

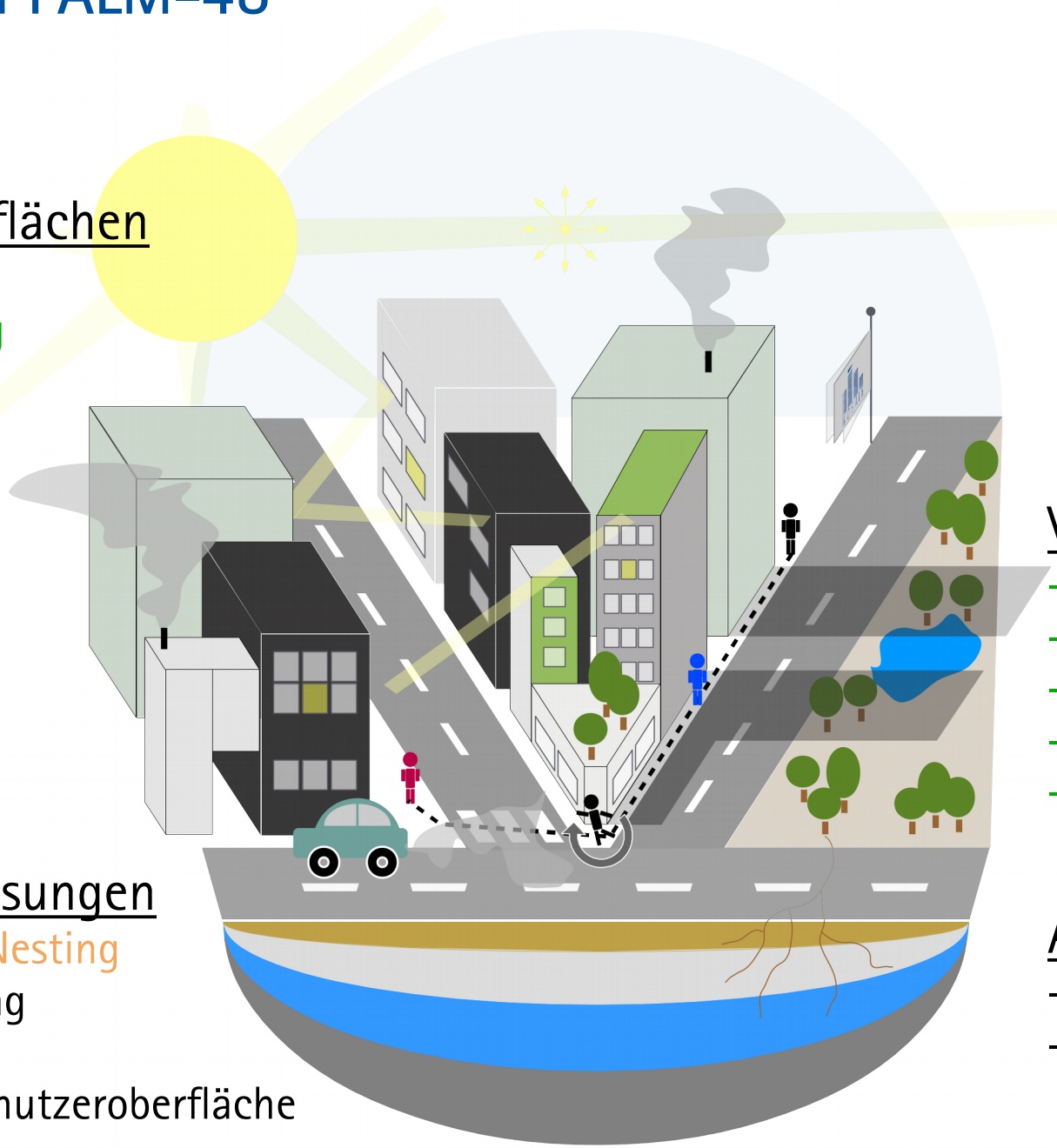
Gebiet (x x y x z)	1 km x 1 km x (0.3) 3 km
Gitterweite	1 m
Antrieb	wie parent
Synoptik	wie parent
Laterale Randbedingungen	(from parent) cyclic
Simulationszeit (Spinup)	24 h (Oberflächen und Strahlung)
Simulationszeit (LES)	24 h

Prozesse in PALM-4U

Urbane Oberflächen
- Energiebilanz
- Wärmeleitung
- Begrünung

Chemie
- Transport
- Reaktionen
- Photolyse
- Emissionen

Technische Lösungen
- Mesoskaliges Nesting
- LES-LES Nesting
- RANS Modus
- Graphische Benutzeroberfläche



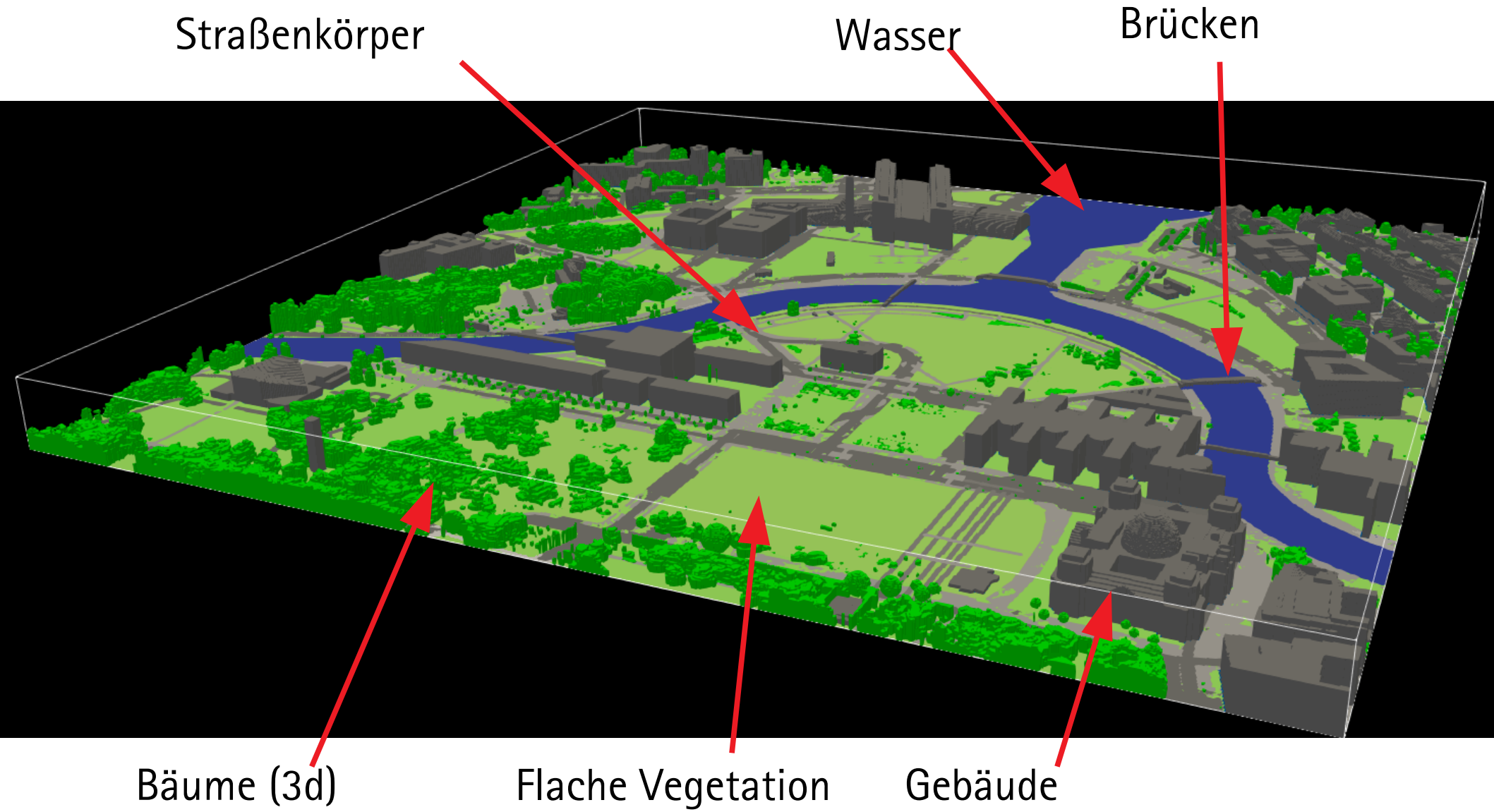
Strahlung
- Strahlungsbilanz
- Schattenwurf
- Reflektionen

Vegetation & Boden
- Energiebilanz
- Impulssenke
- Schattenwurf
- Wurzeln
- Bodenfeuchte

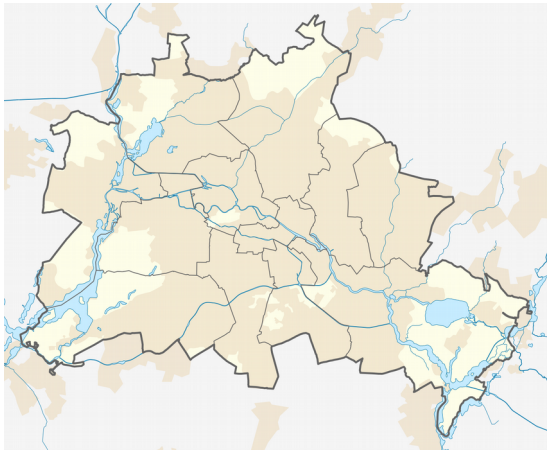
Auswirkungen
- Multiagentensystem
- Biometeorologie

Berlin showcase: Oberflächendaten

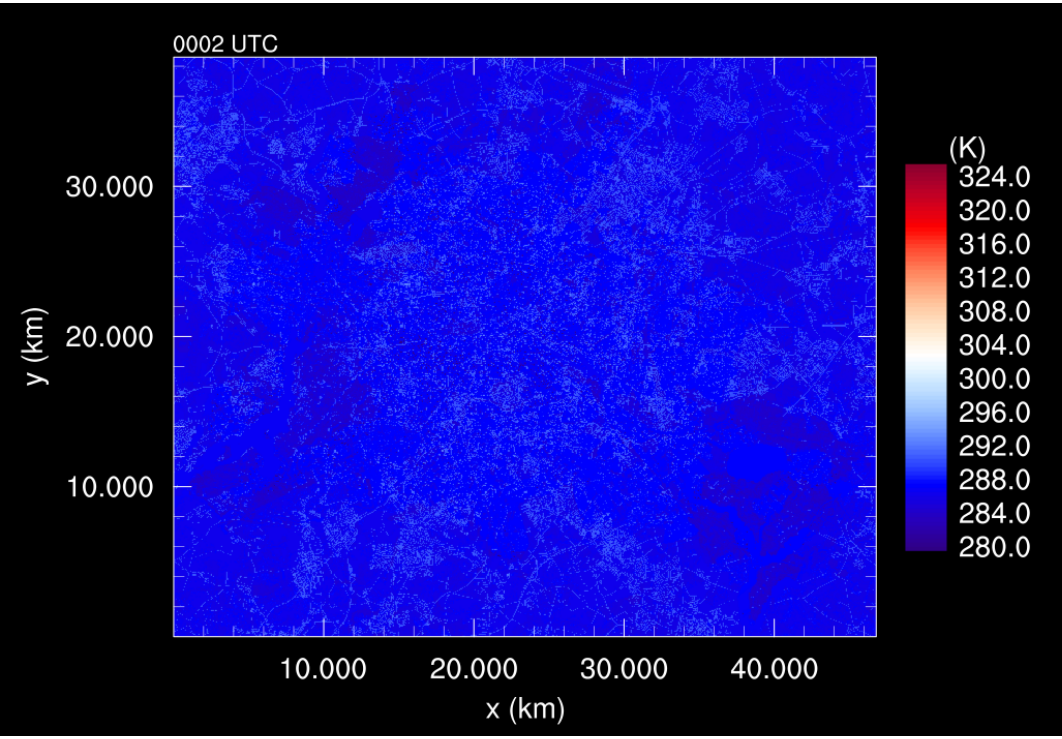
Berlin showcase: Oberflächendaten



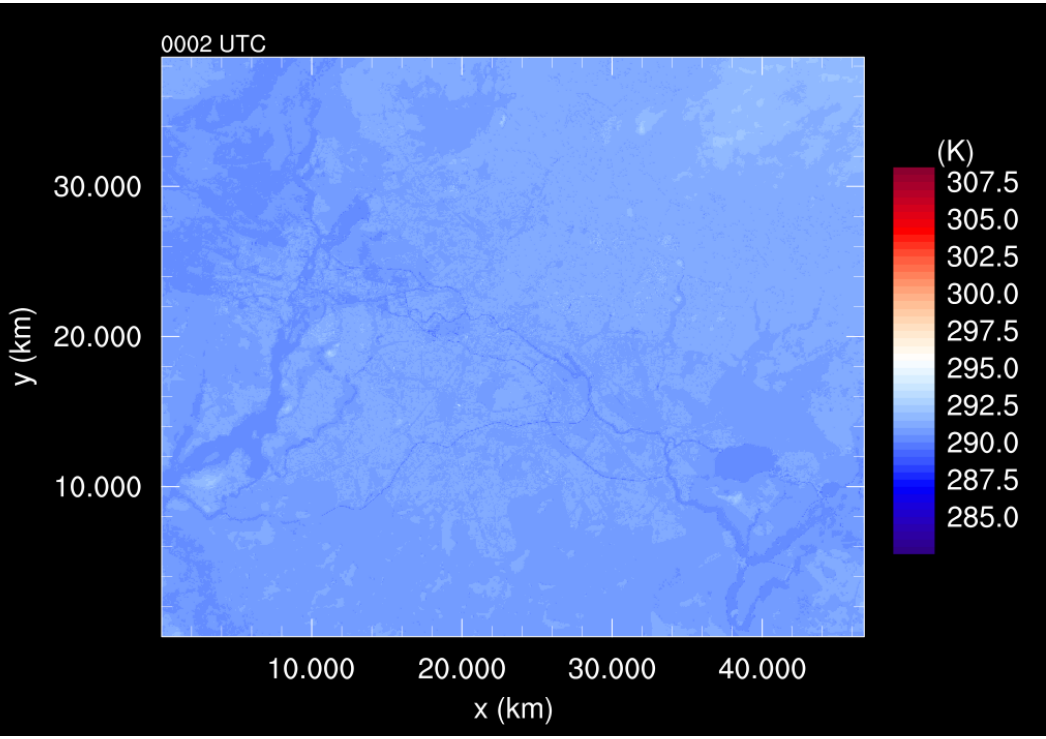
Ergebnisse: Tagesgang der Temperatur



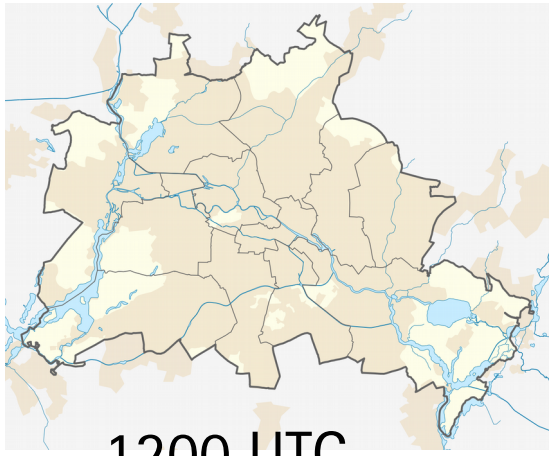
Oberflächentemperatur

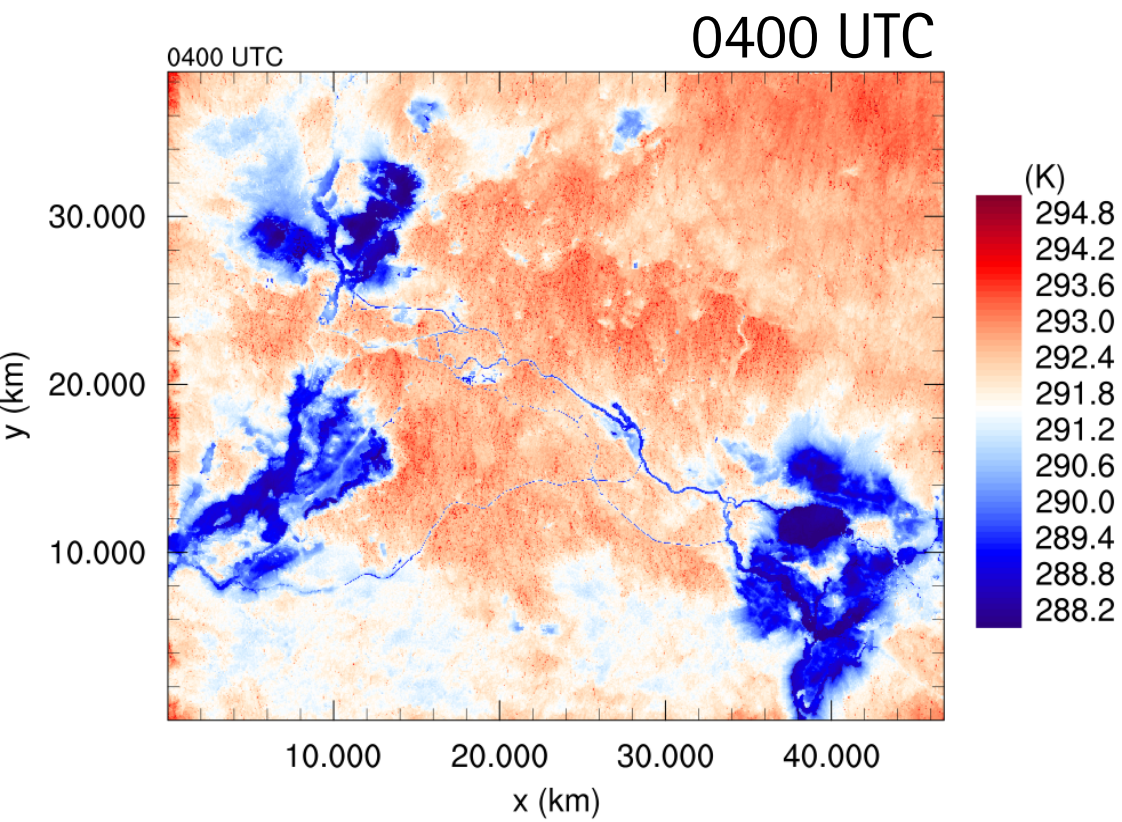


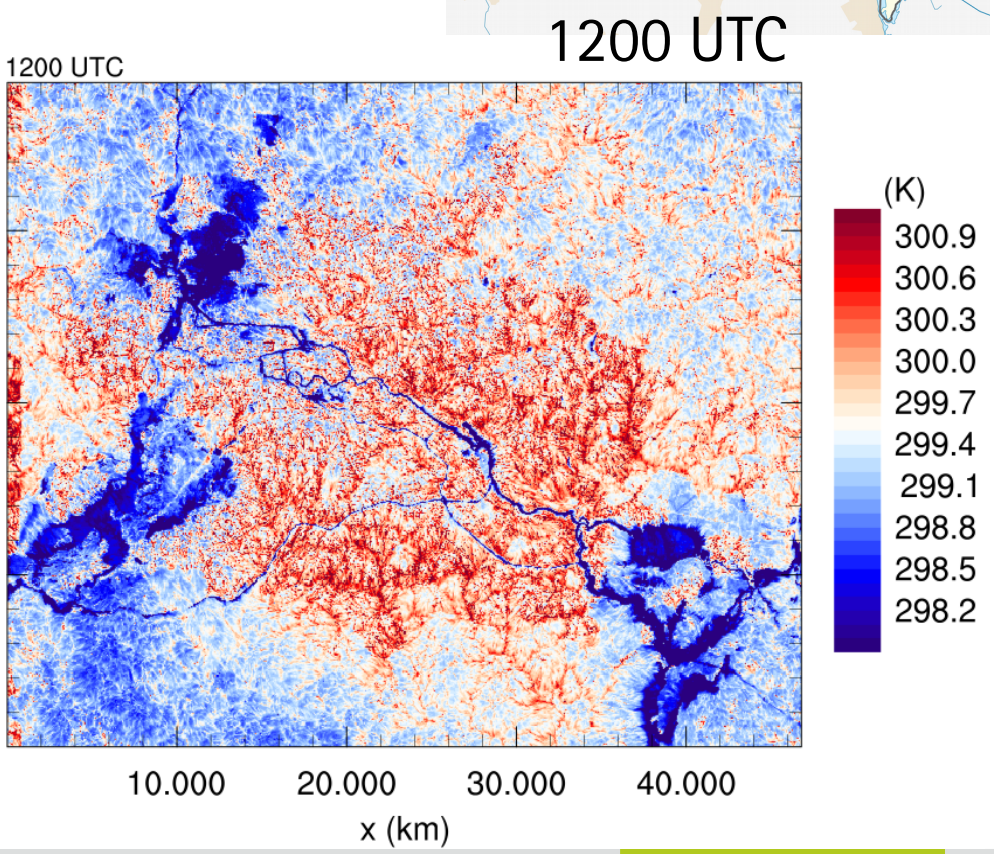
Lufttemperatur



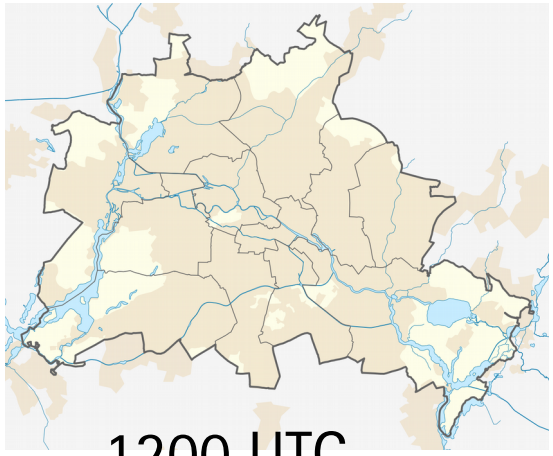
Ergebnisse: Lufttemperatur (Tag vs Nacht)

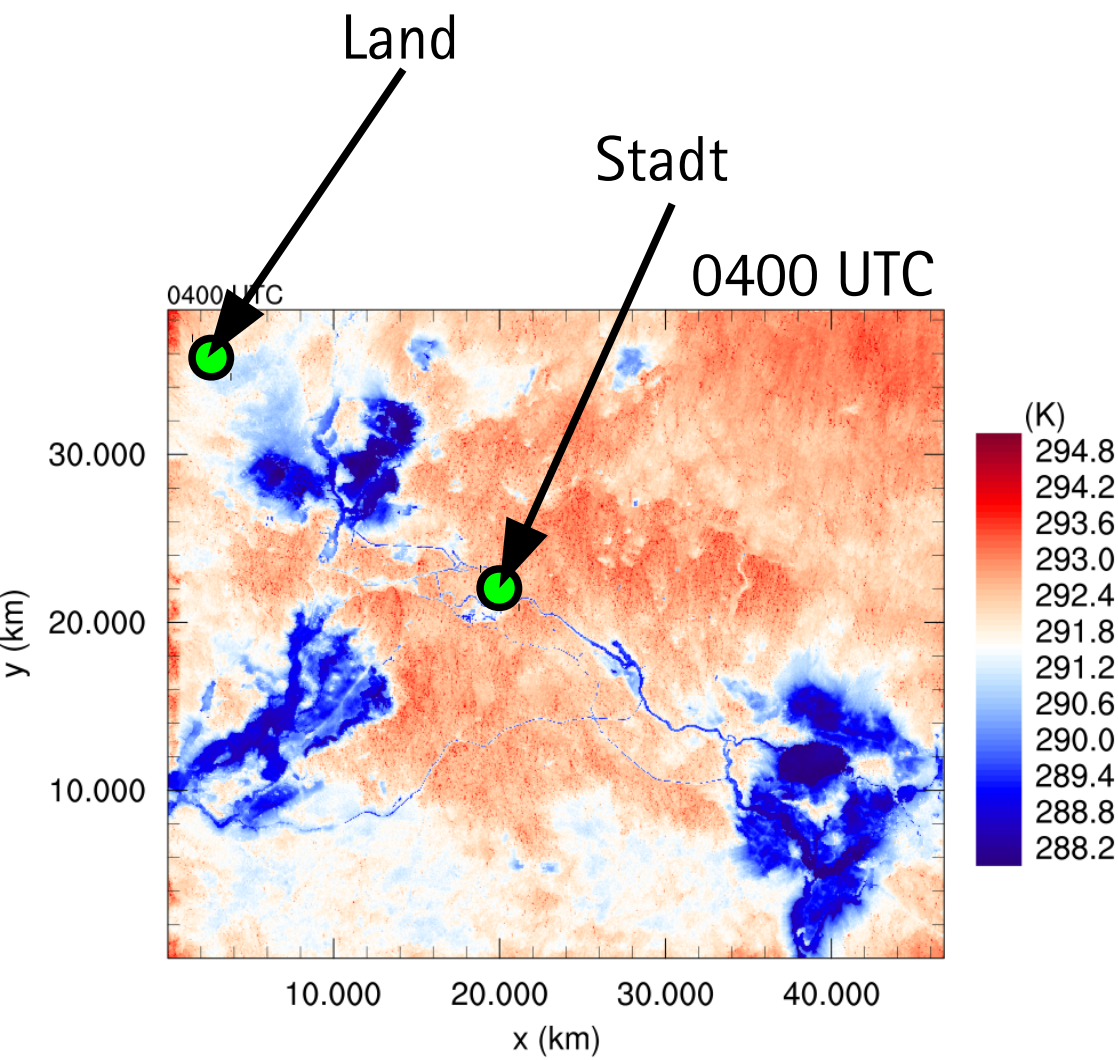


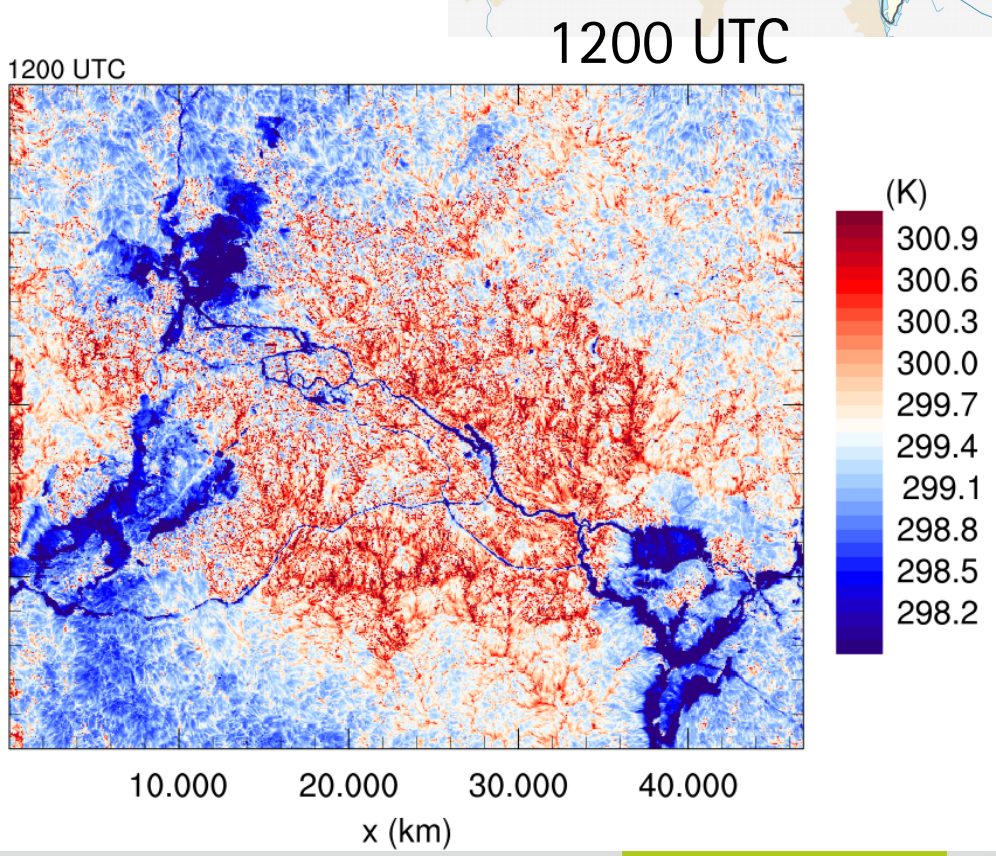




Ergebnisse: Lufttemperatur (Tag vs Nacht)







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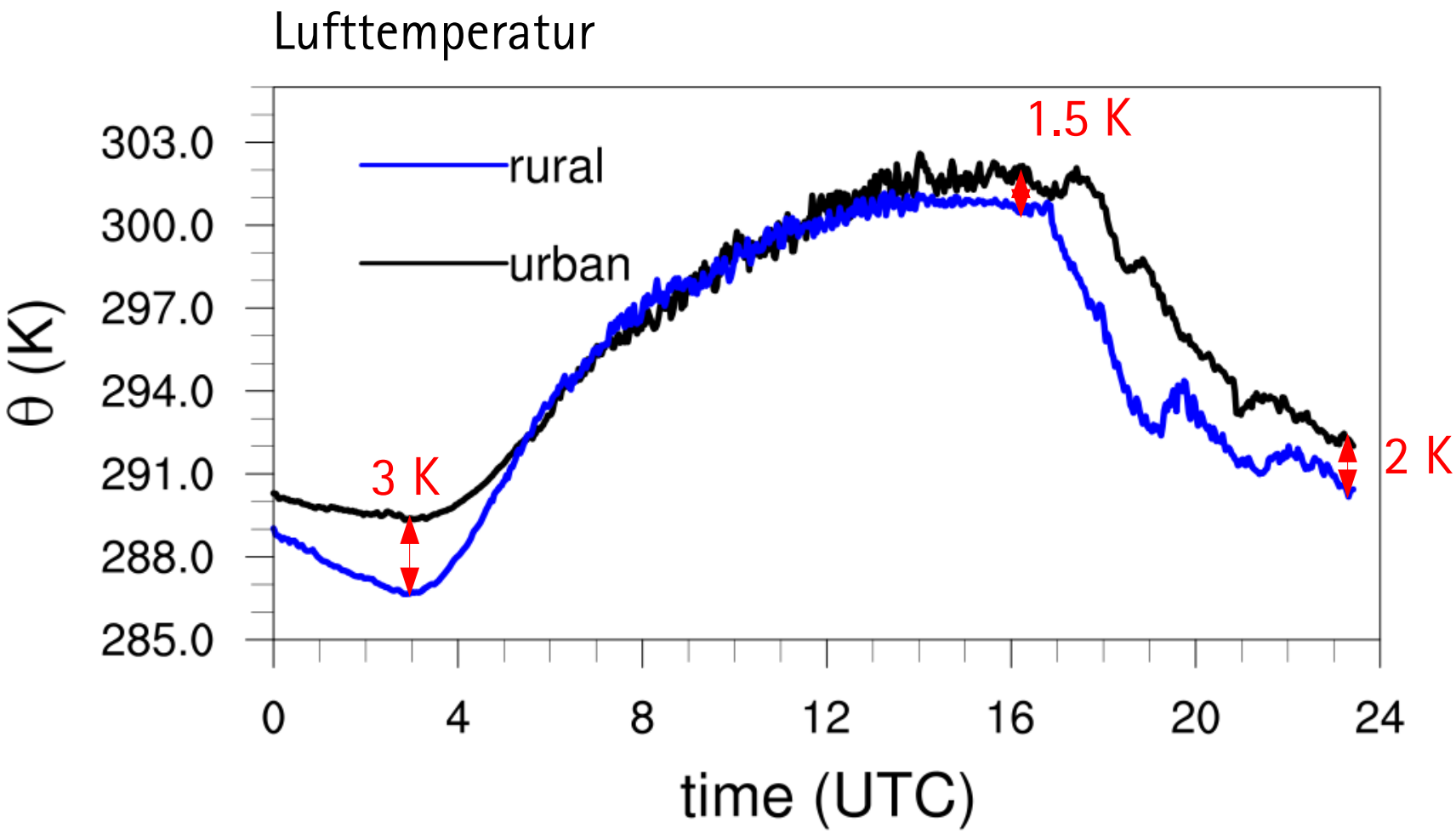
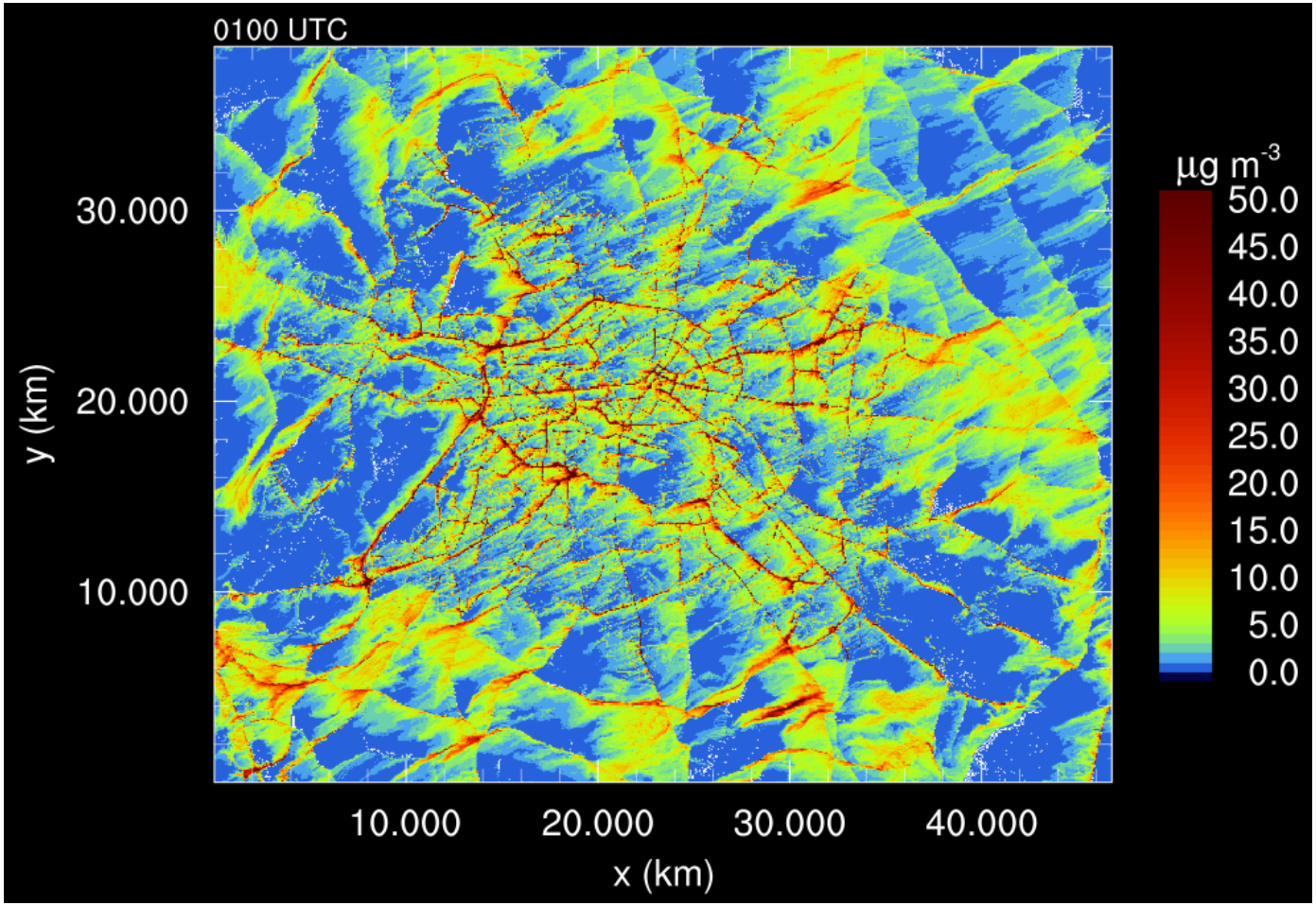
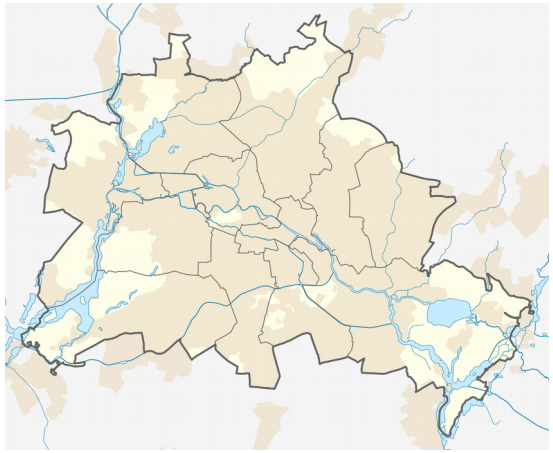


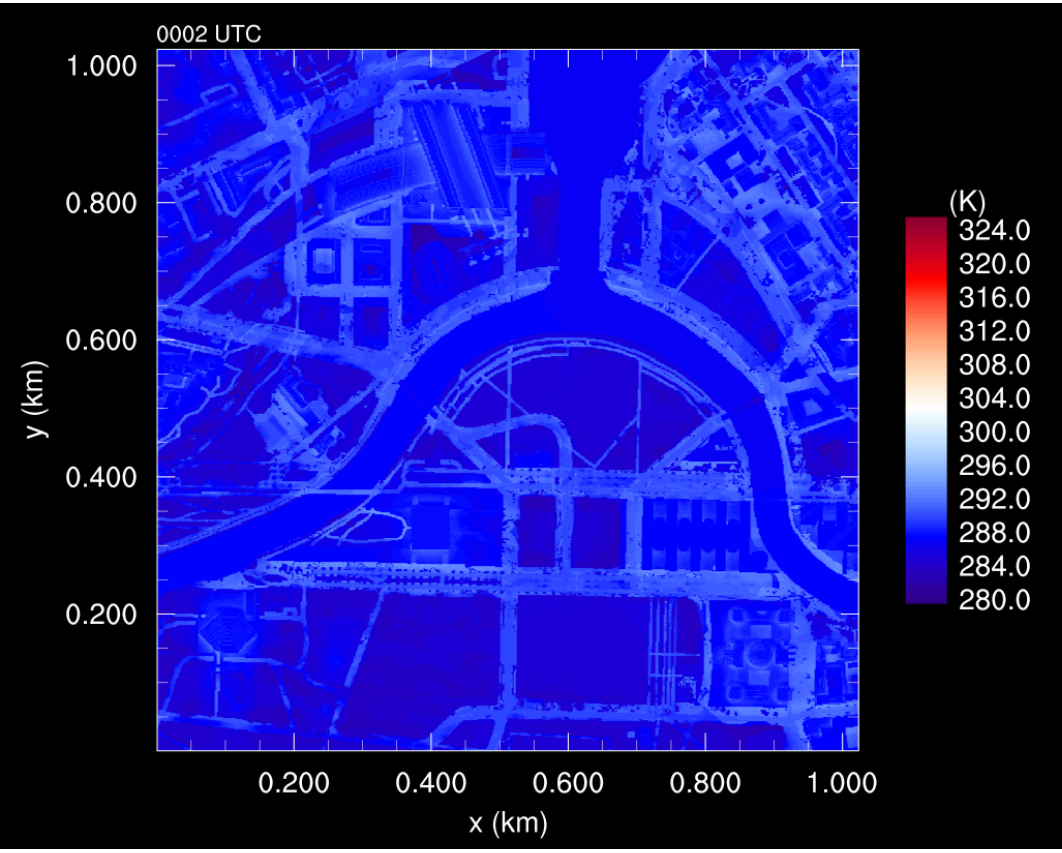
Ergebnisse: PM10 – Tagesgang



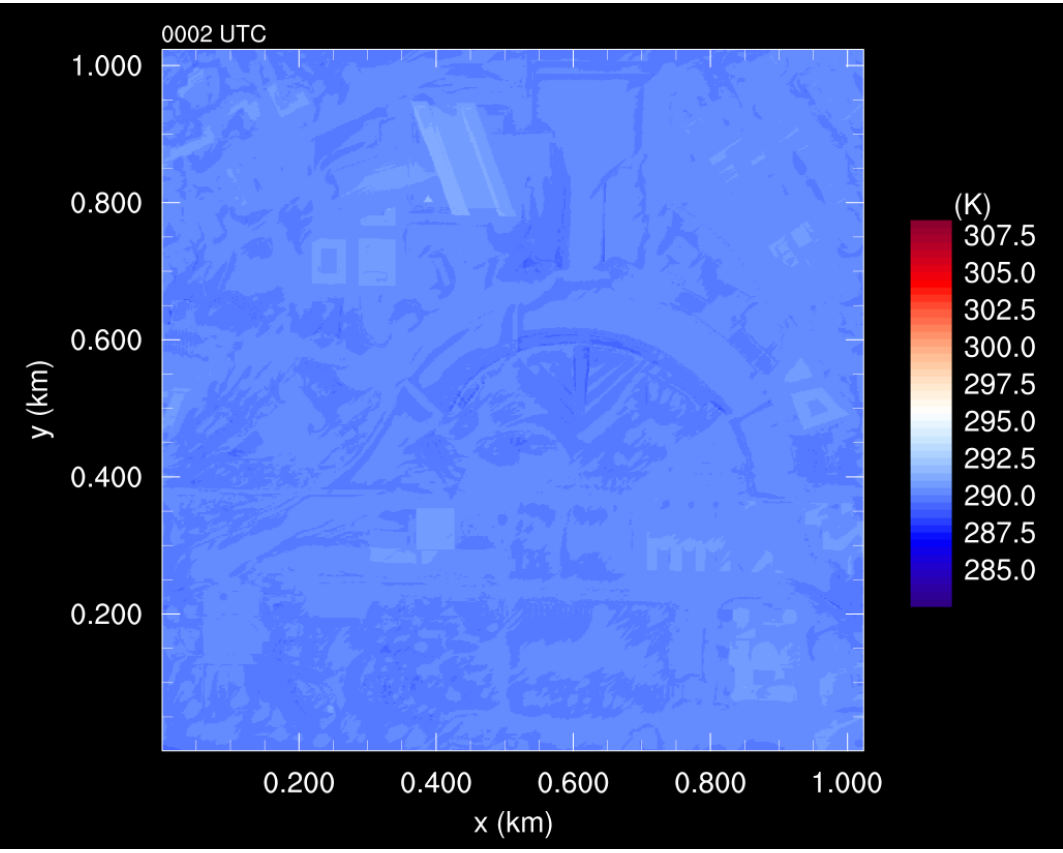


Ergebnisse: Tagesgang der Temperatur („child“)

Oberflächentemperatur



Lufttemperatur



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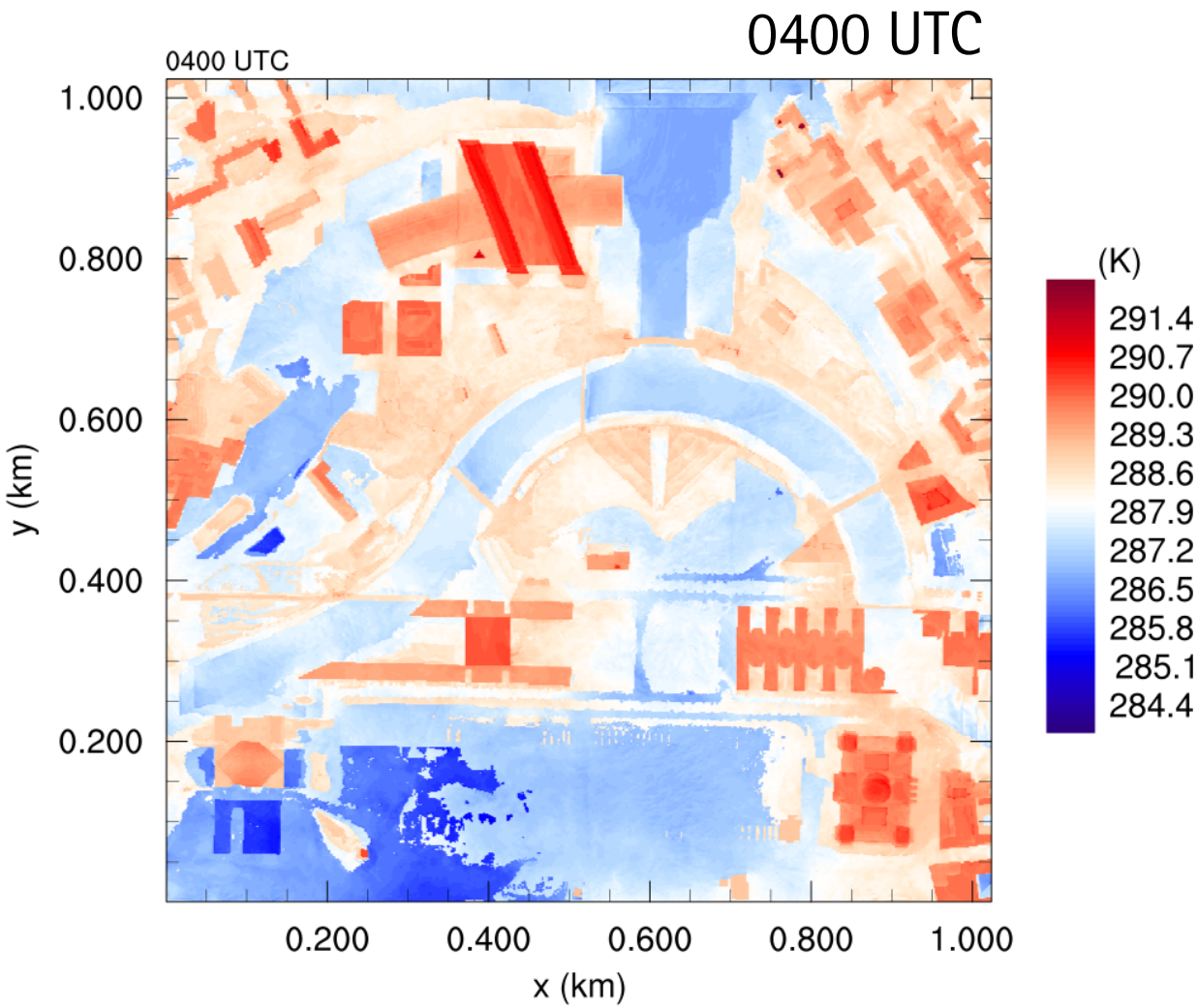

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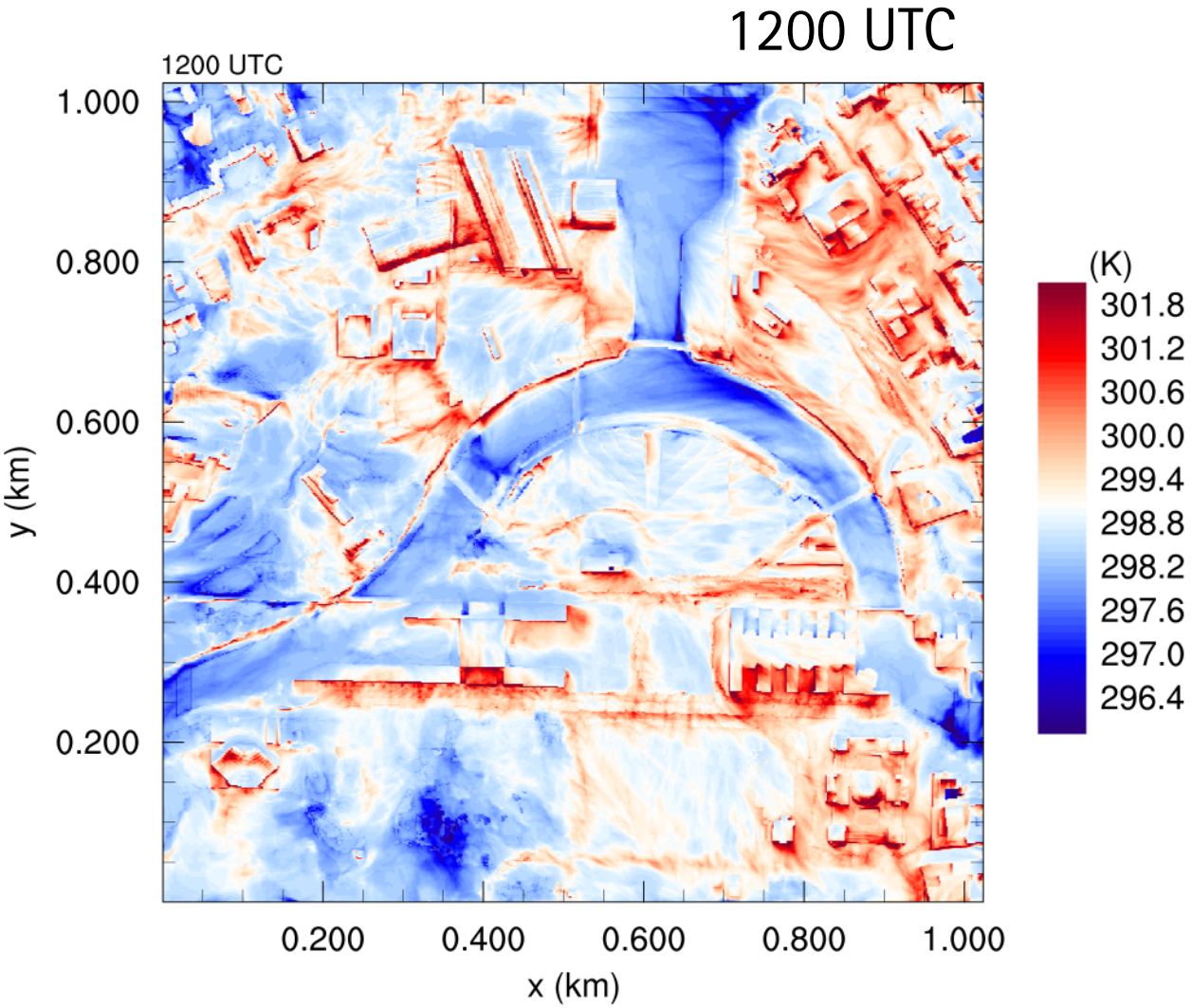
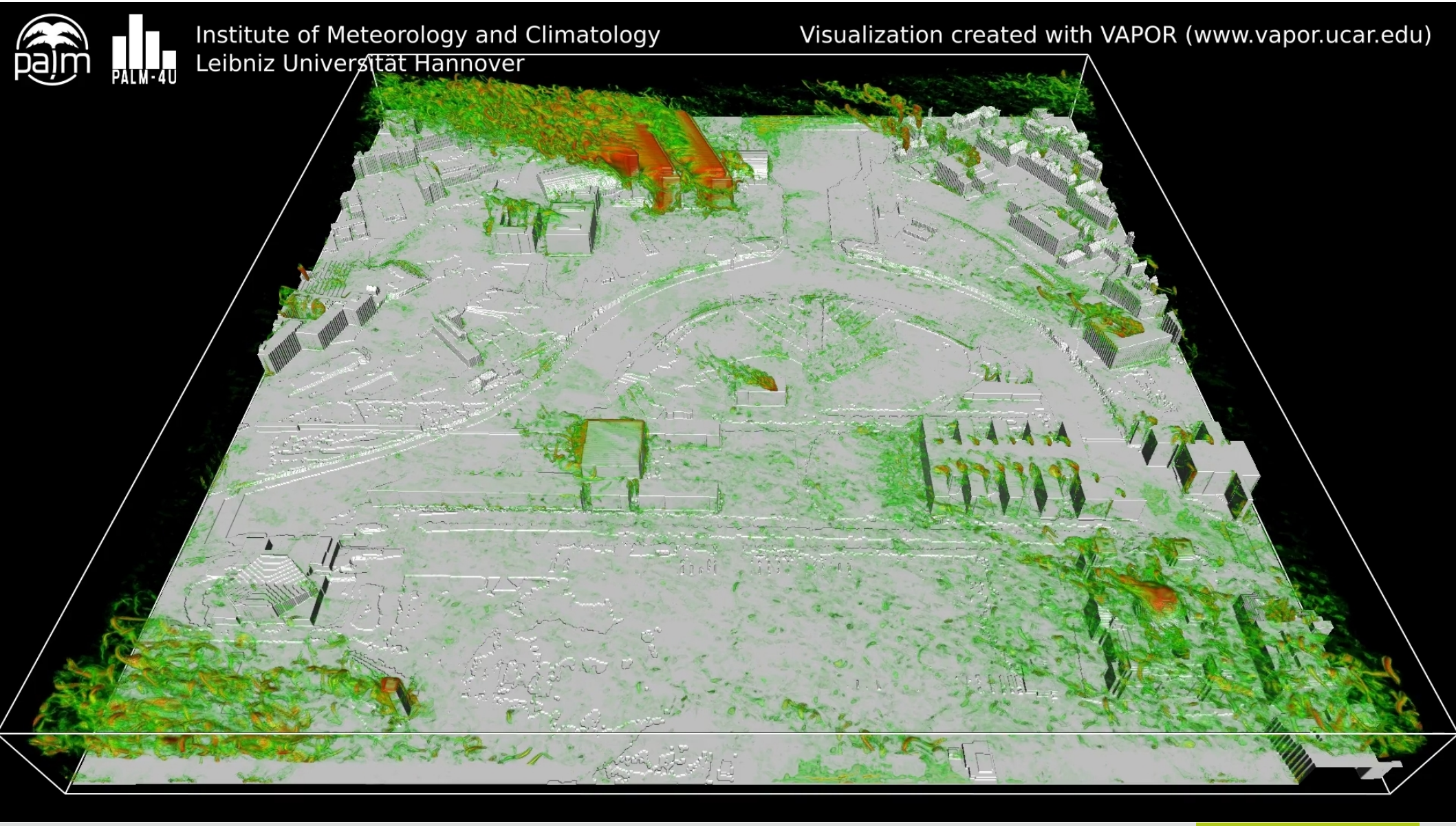


Ergebnisse: Gebäudeumströmung („child“)

Betrag des Vorticityvektors



Ausblick: PALM-4U release

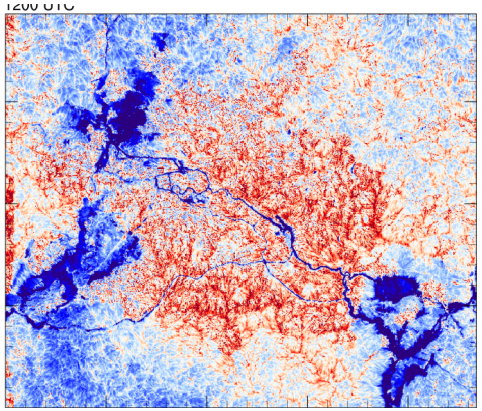
- „Release candidate“ (**Ende September**)
- Weiterentwicklungen **(until May 2019):**
  - Bugfixing der neuen Komponenten
  - Verbesserter Strahlungstransfer
  - Dach- und Fassadenbegrünung
  - Realistische Emissionen
  - Biometeorologische Analysen (UV, PET, ...) + Multiagentensystem
  - Innenraumkloma (Raumtemperatur, Energiebedarf, Abwärme)
  - Aerosolchemie (SALSA)
- Limitierungen:
  - Keine Wolken (in der Stadt)
  - Kein Eisphase (Boden + Wolken)
  - Kein Energiebilanzlöser für 3d-Bäume
  - Kein eigenständiges Emissionsmodell
  - Teure Chemie

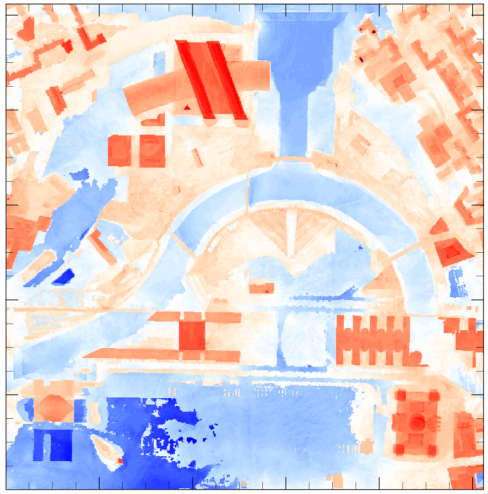
→ Zweite Förderphase ?!

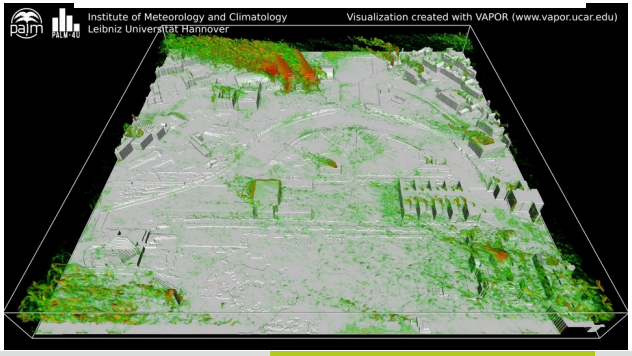
Zusammenfassung

- **PALM-4U**: neues gebäudeauflösendes Stadtklimamodell
- Erlaubt Simulation **ganzer Stadtgebiete**
- Variable Gitterweiten und Randbedingungen
- **Modellphysik:**
  - Gebäude auf kartesischem Gitter
  - Energiebilanzlöser für alle urbanen Oberflächen
  - Strahlungstansfer in der UCL
  - Modellnesting + Selbstnesting
  - 3d Bäume
  - Chemie
  - Multiagentensystem

- **Erste Ergebnisse:** Erfolgreiche Simulation von Berlin!
- **Aber:** ... noch viel zu tun!







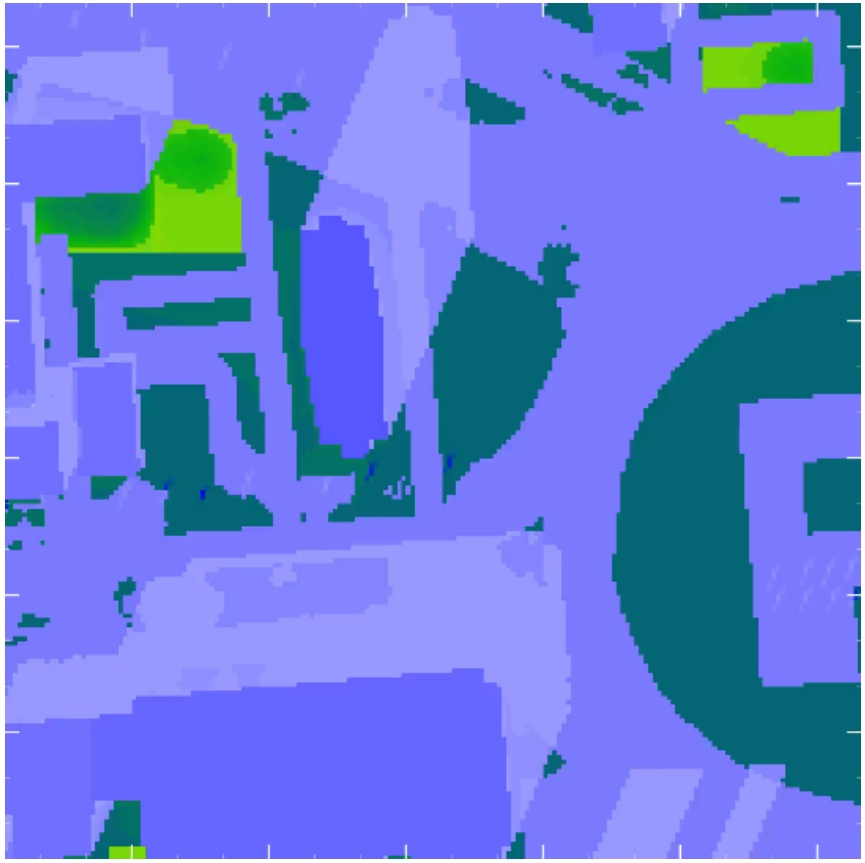
Vielen Dank für die Aufmerksamkeit!

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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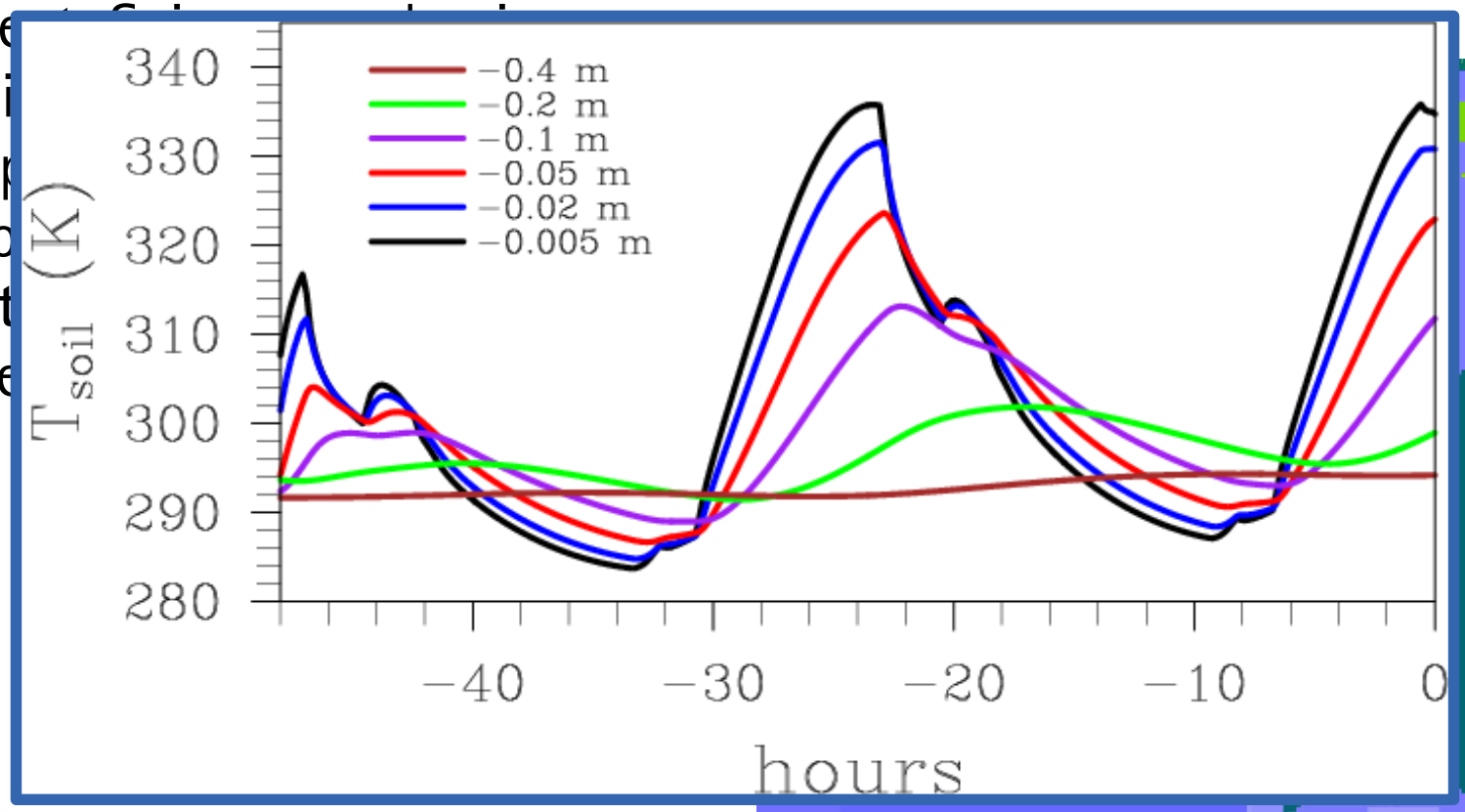

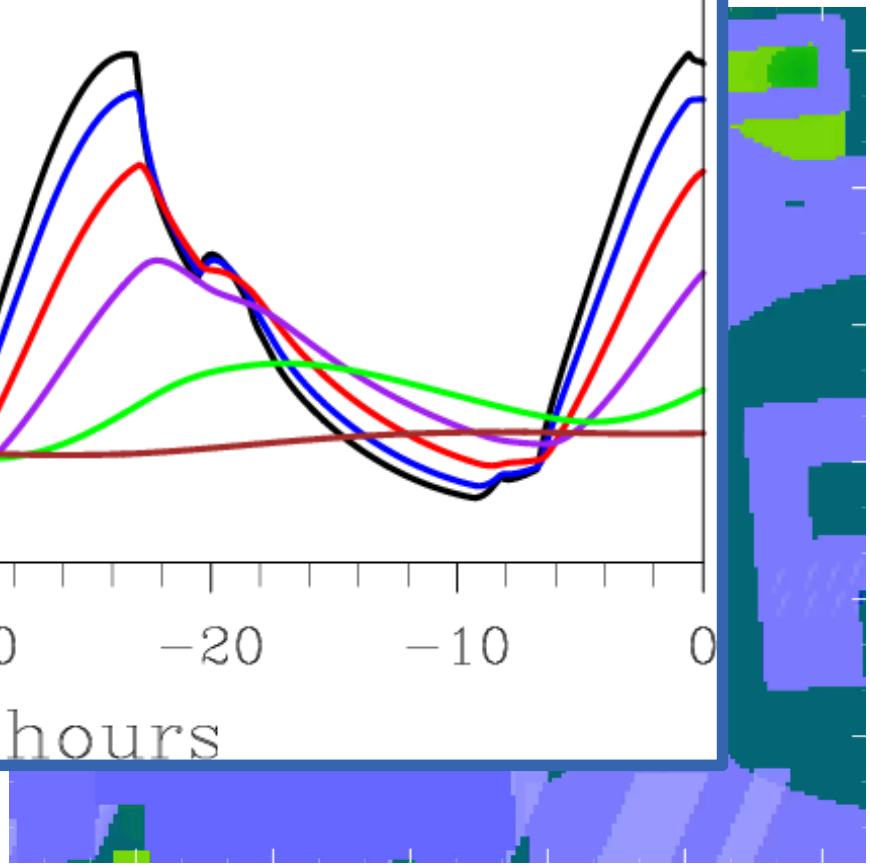

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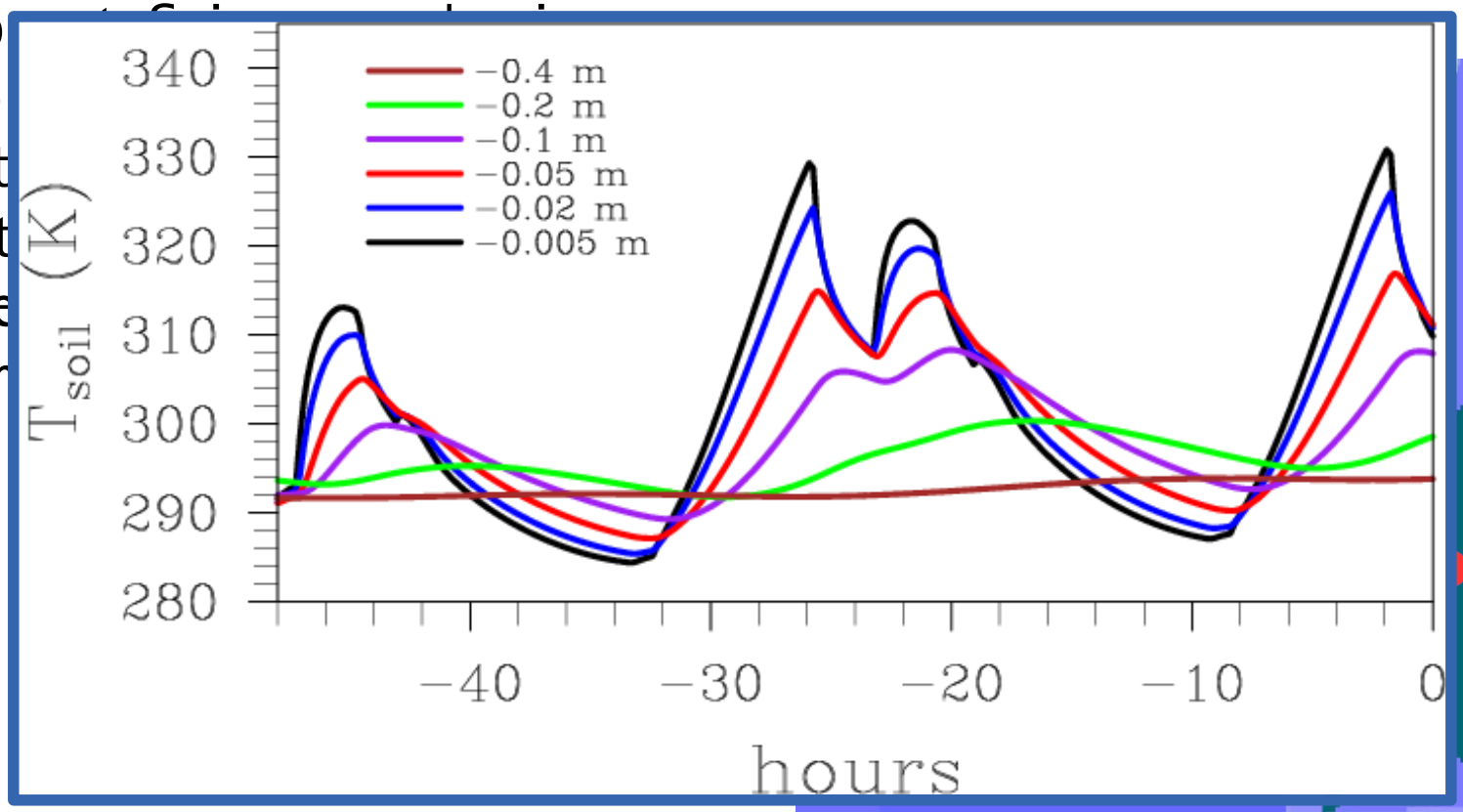
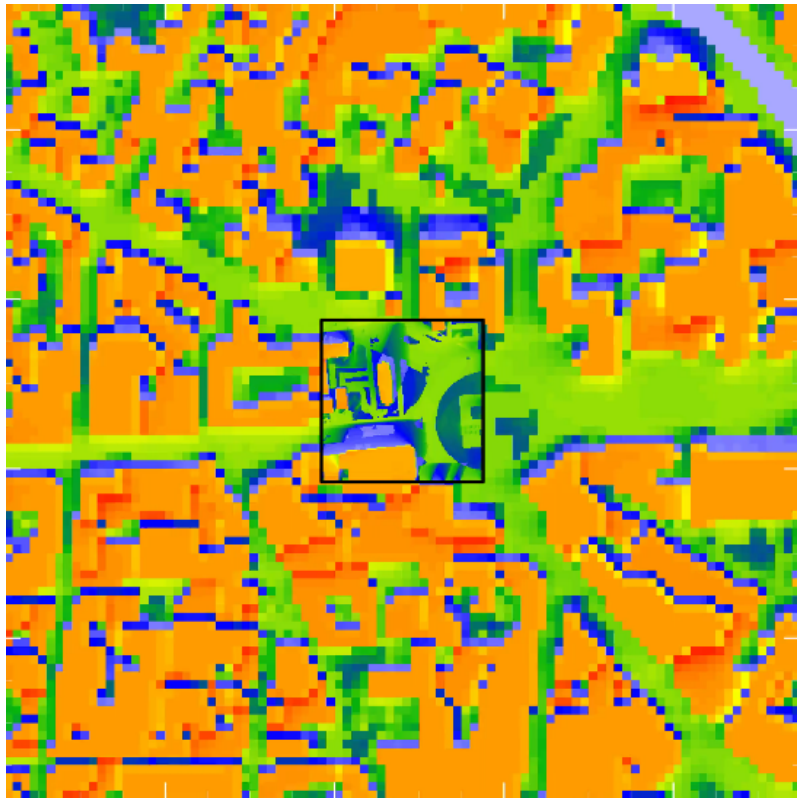
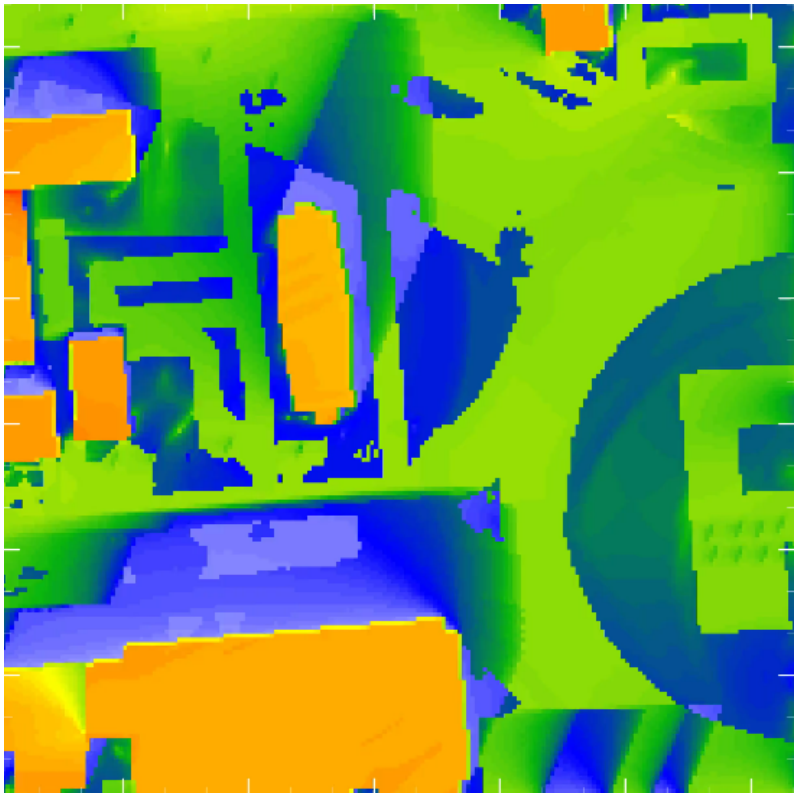


Additional material: Nesting 10 m – 1 m

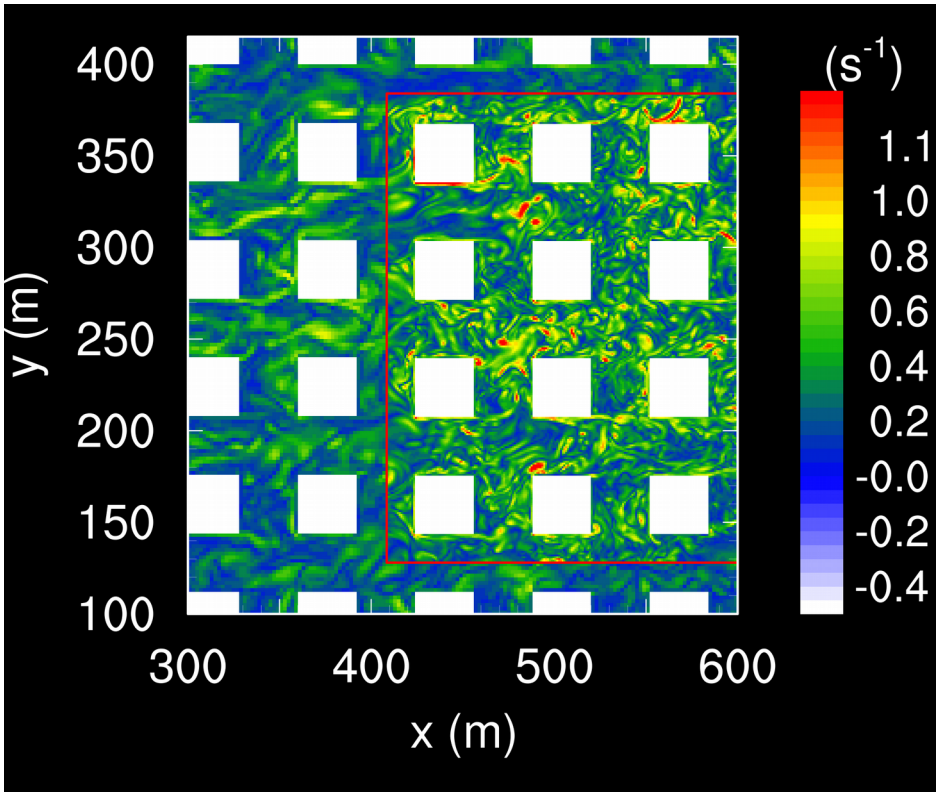




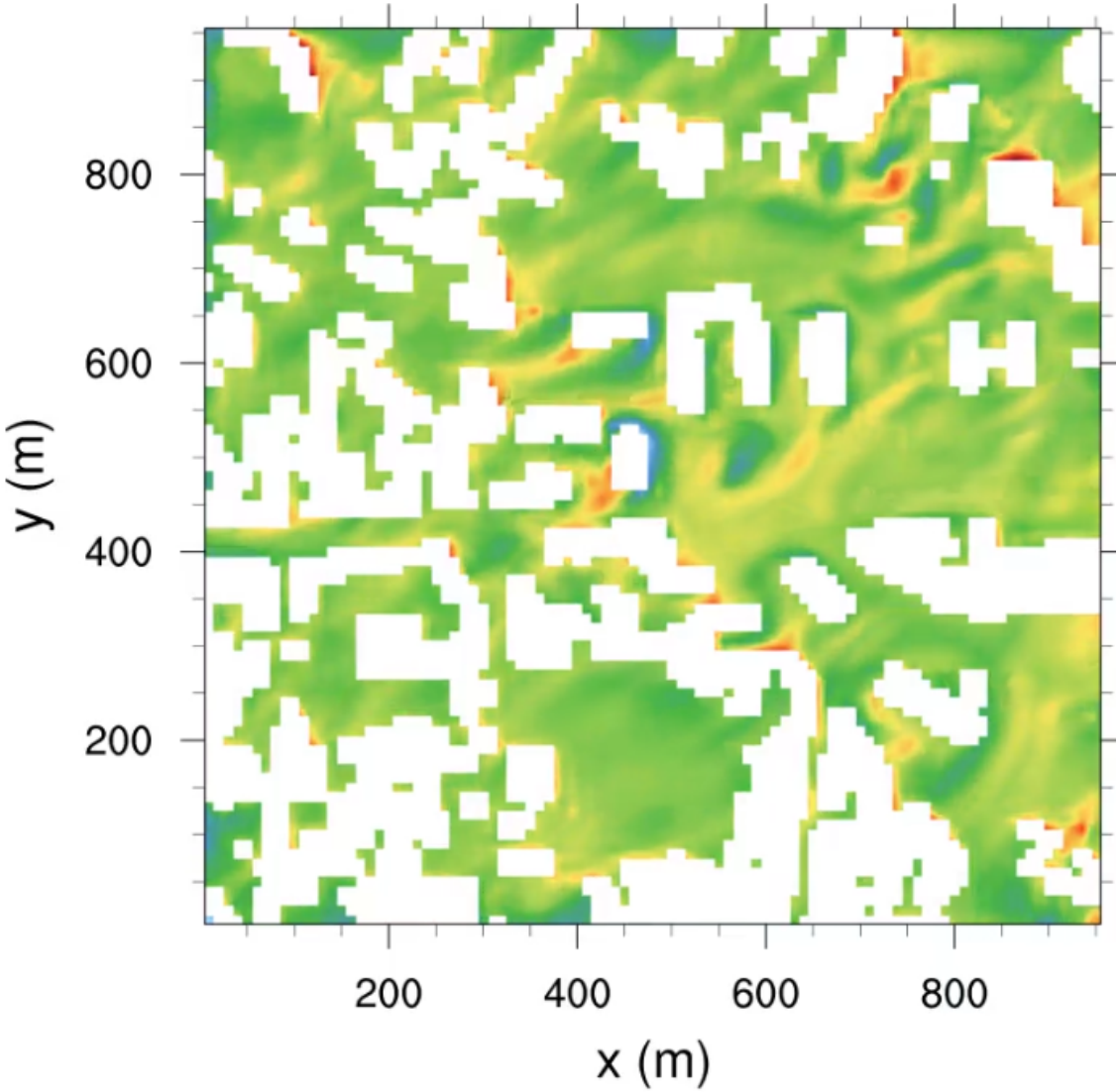
Additional material: LES-LES nesting

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)



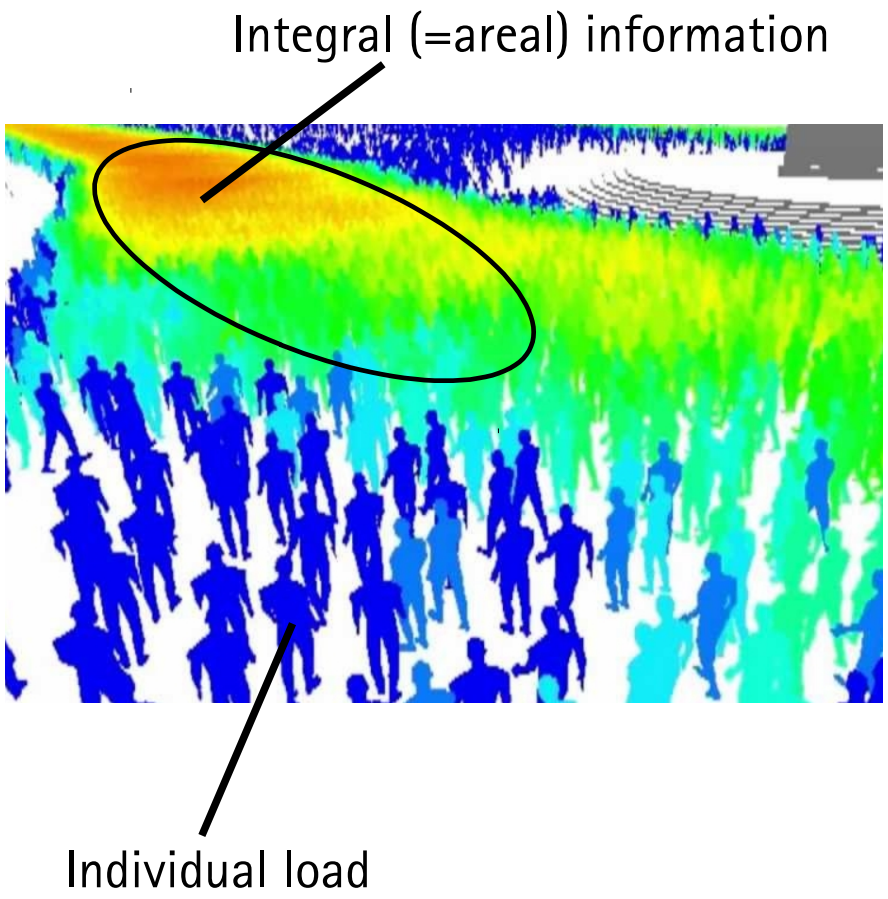
Additional material: COSMO-DE forcing



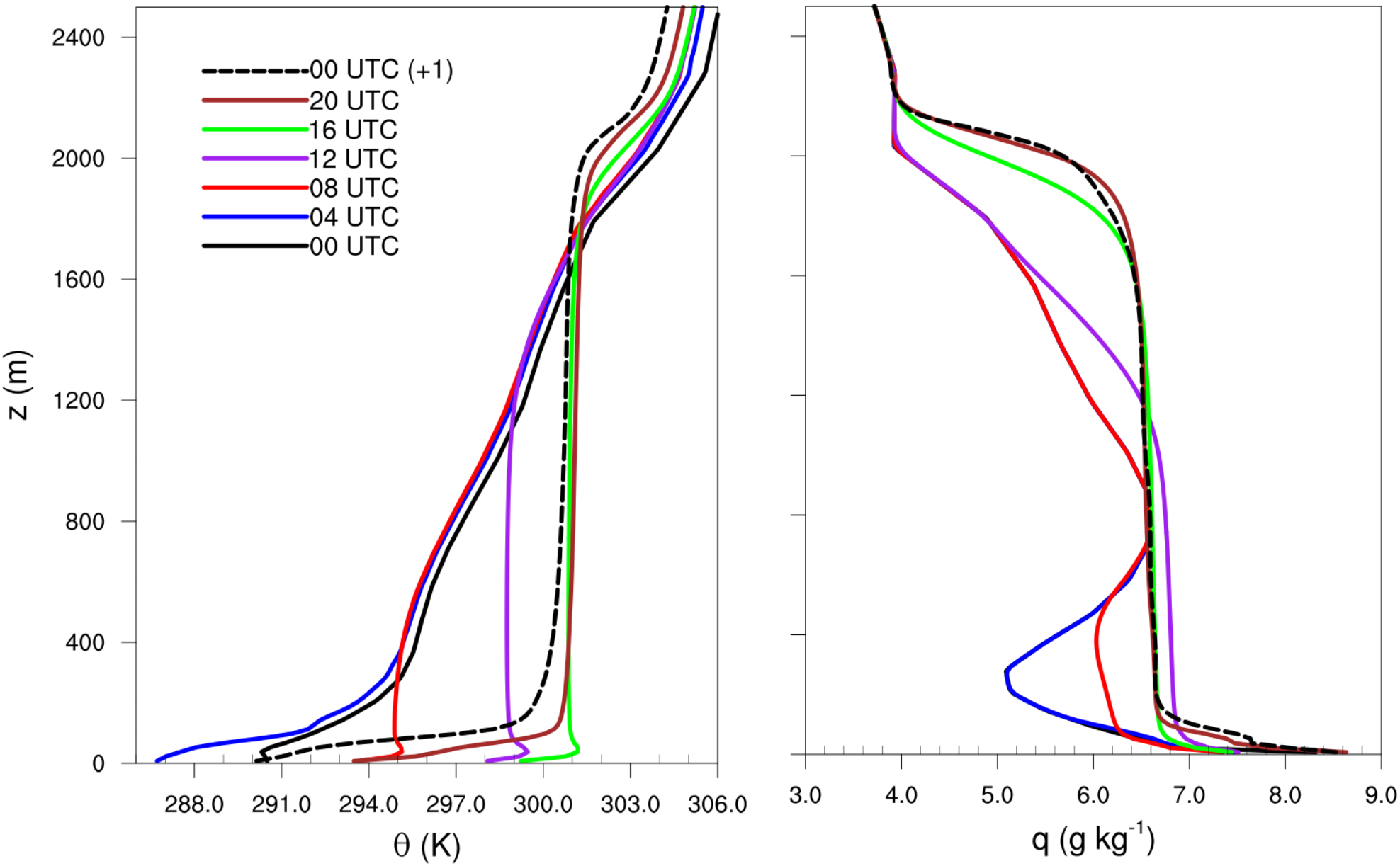
Multi-agent system (MAS)

- 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

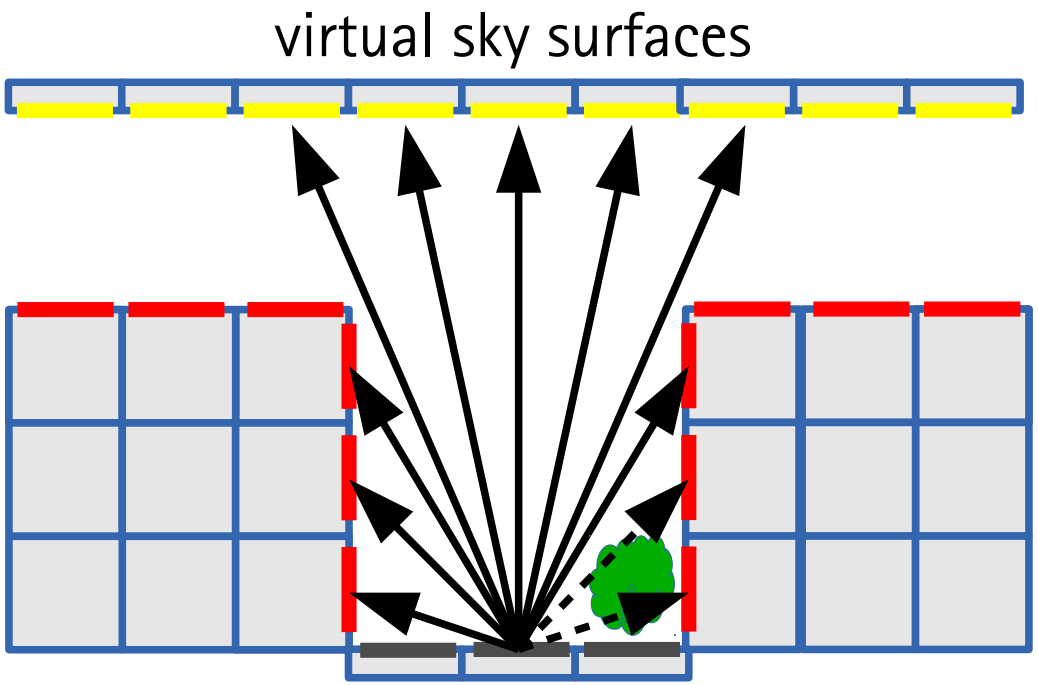
Radiative transfer

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
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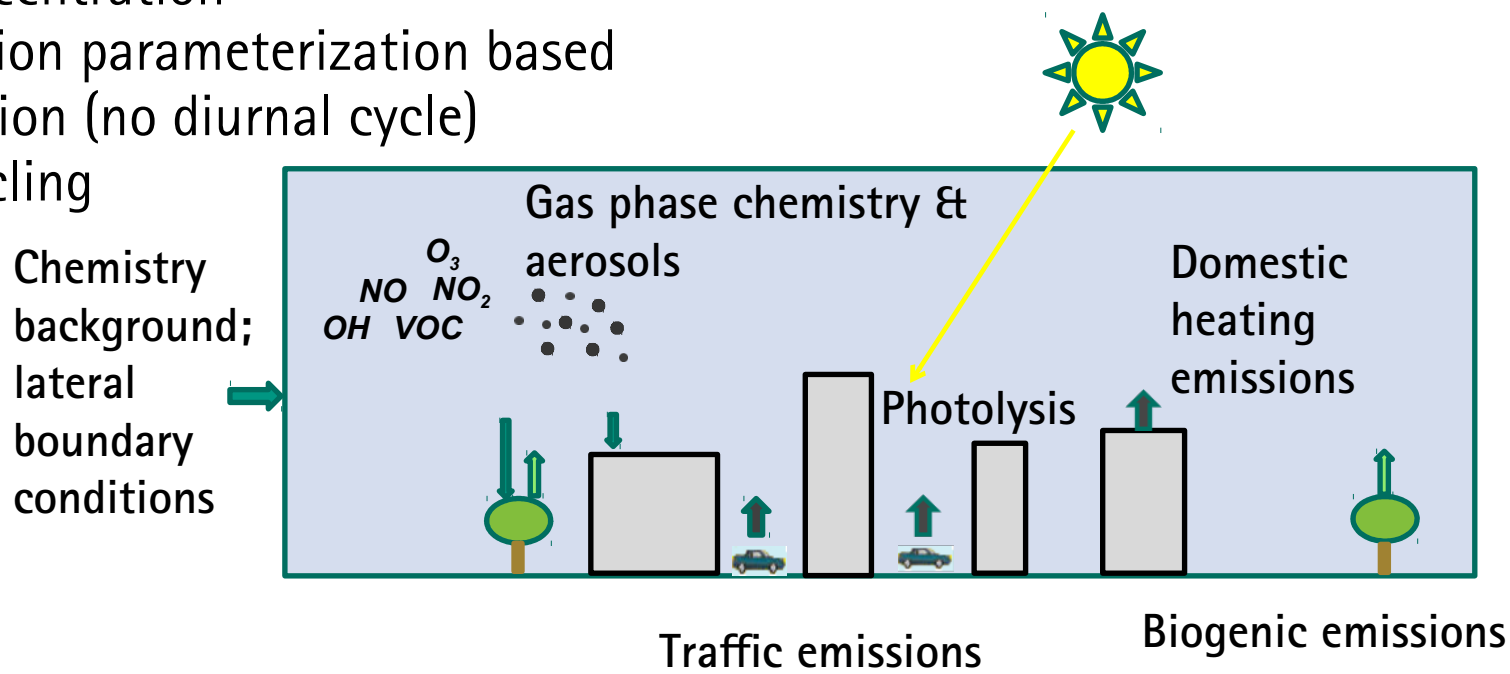
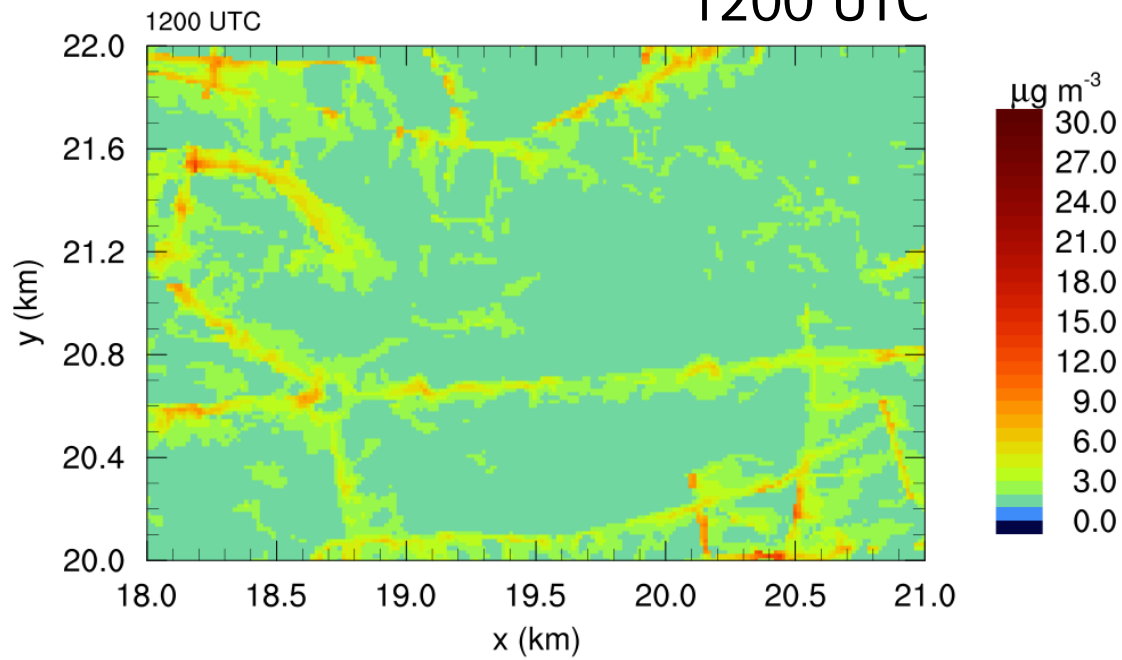


Details:

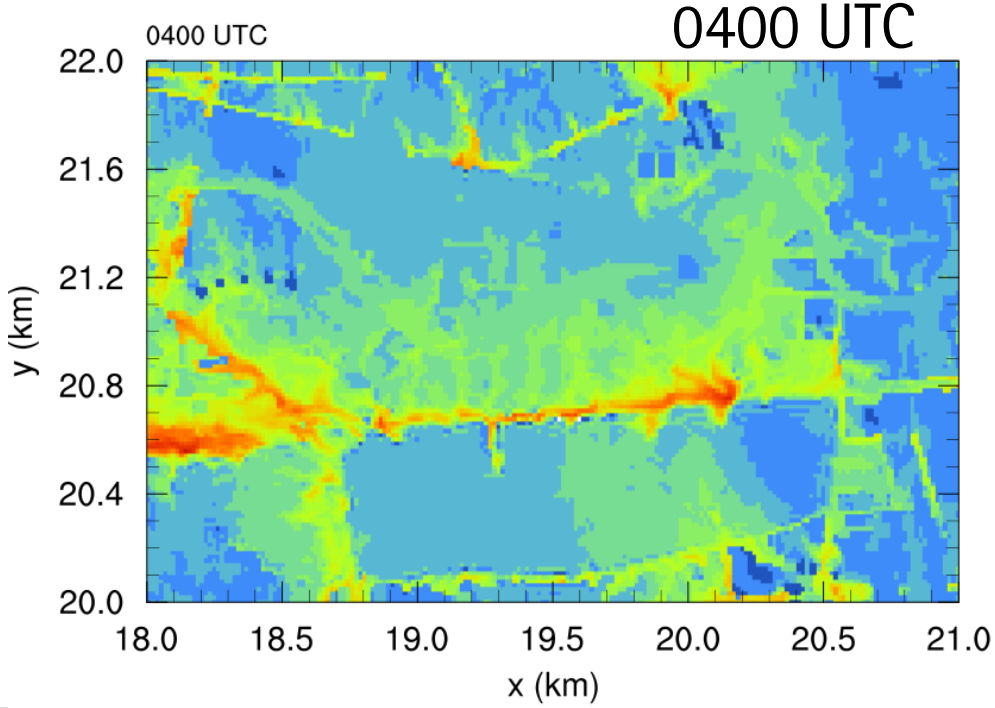
- Poster 73 (*Khan et al.*, Tuesday)

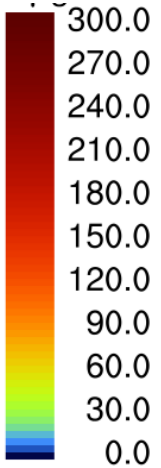
Results: PM10 – day vs. night – Tiergarten

1200 UTC



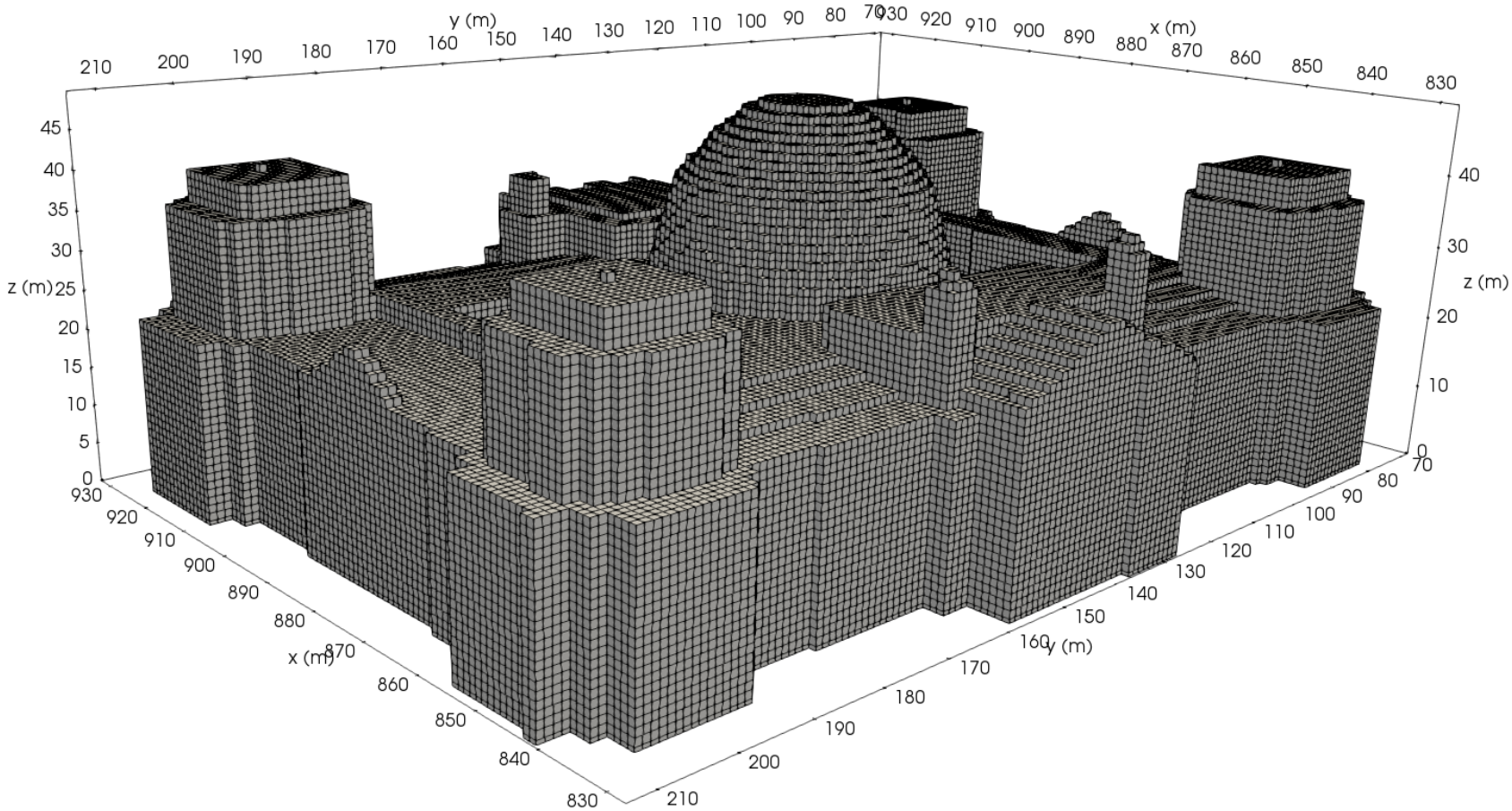
0400 UTC





Berlin showcase: model physics

Building surfaces



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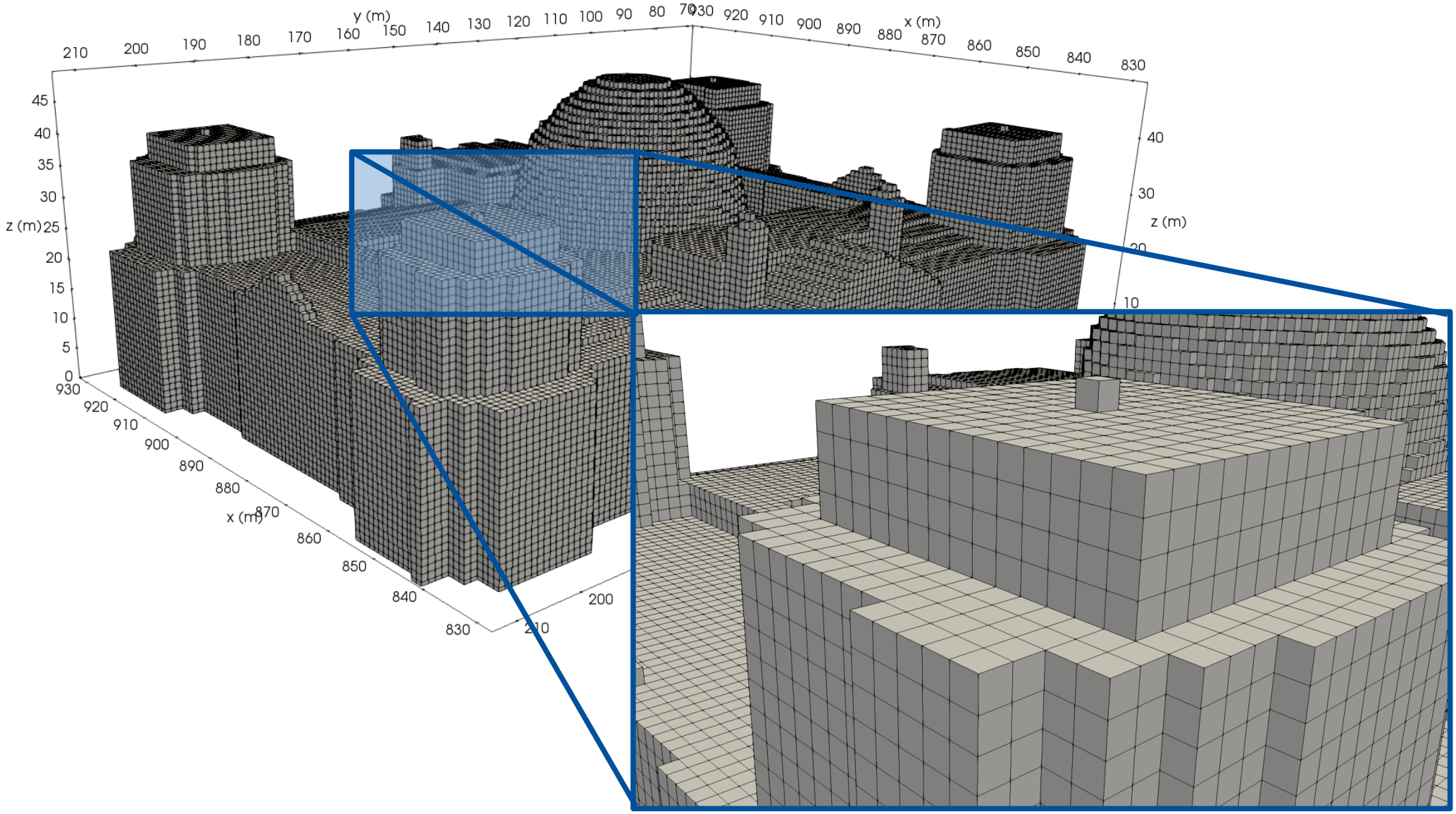

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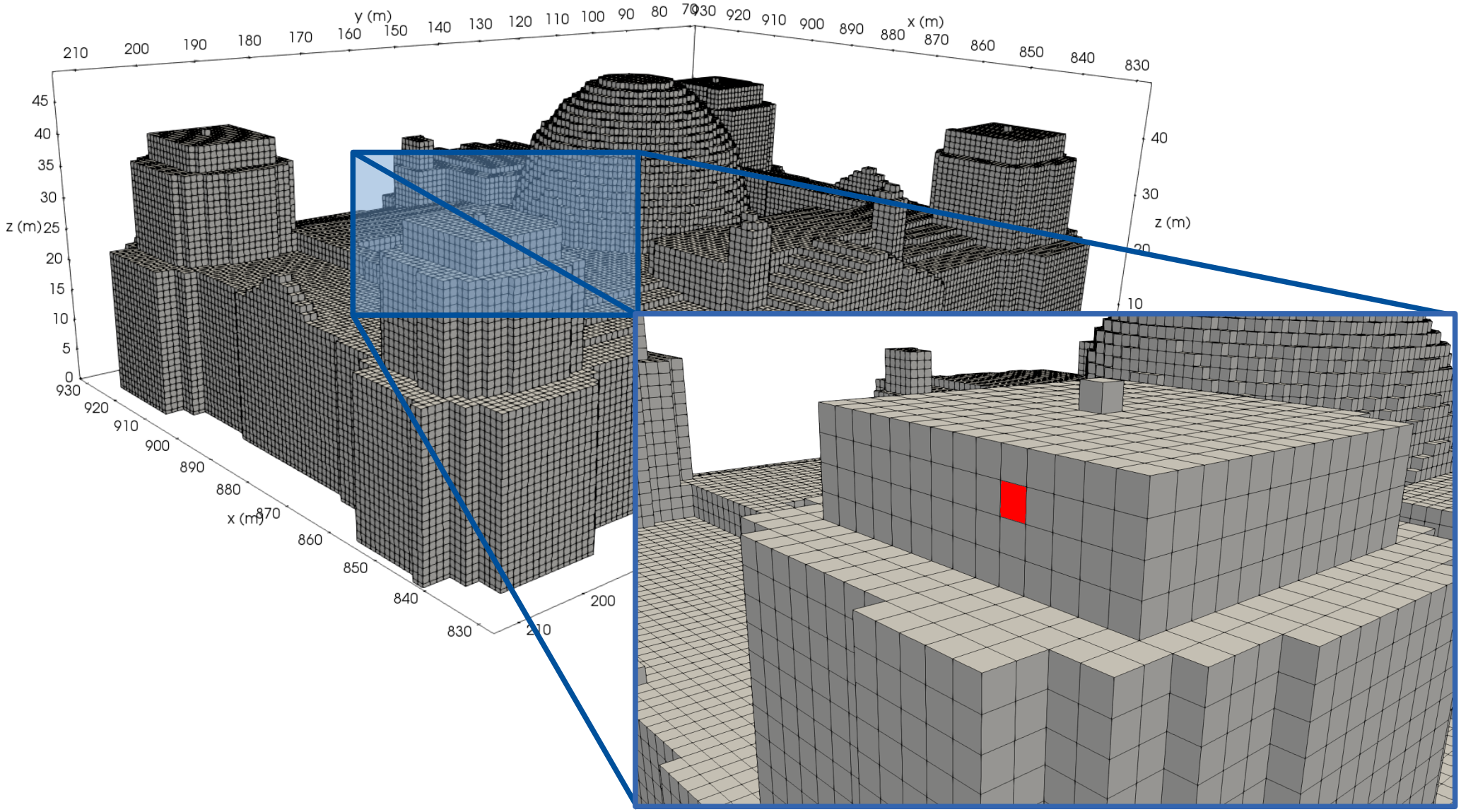

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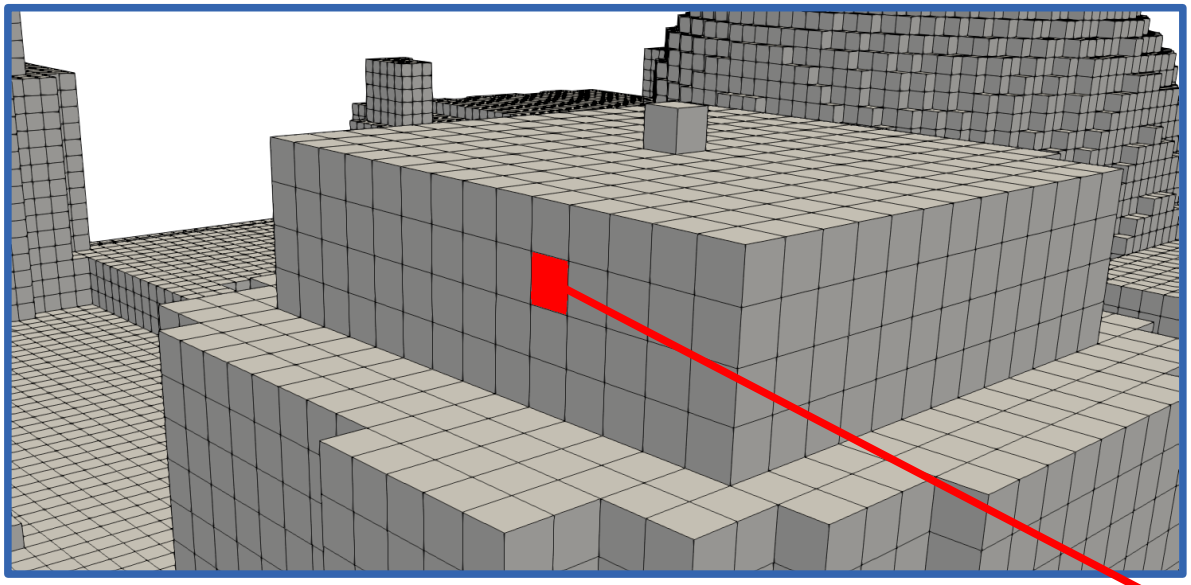

- Tile approach
  - wall fraction
  - window fraction
  - green fraction
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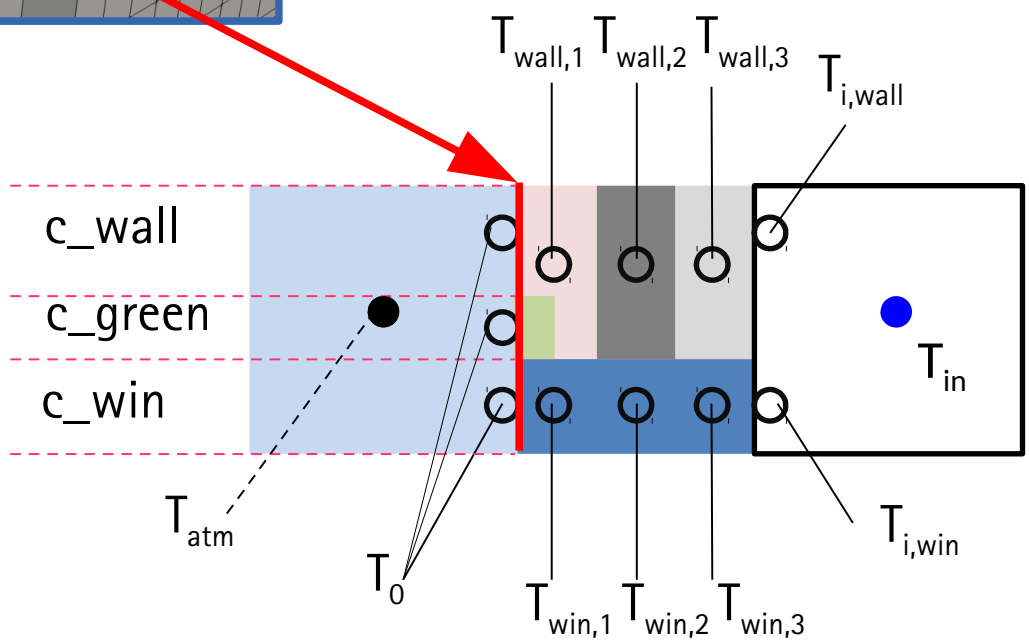
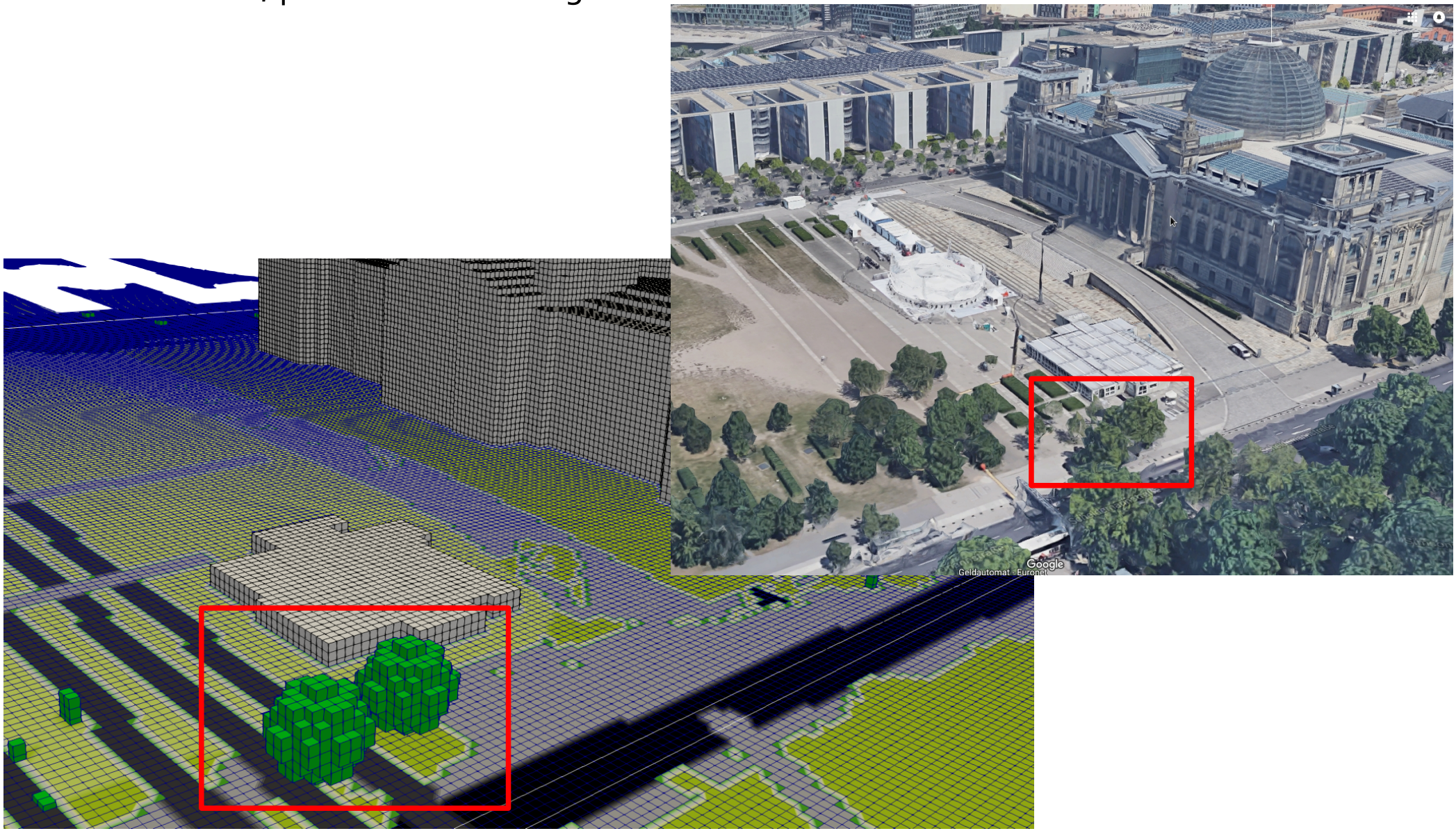
- Resistance parameterization
  - horizontal: Monin-Obukhov
  - vertical: Krayenhoff & Voogt (2007)

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



Berlin showcase: model physics

Land surface, pavements and vegetation



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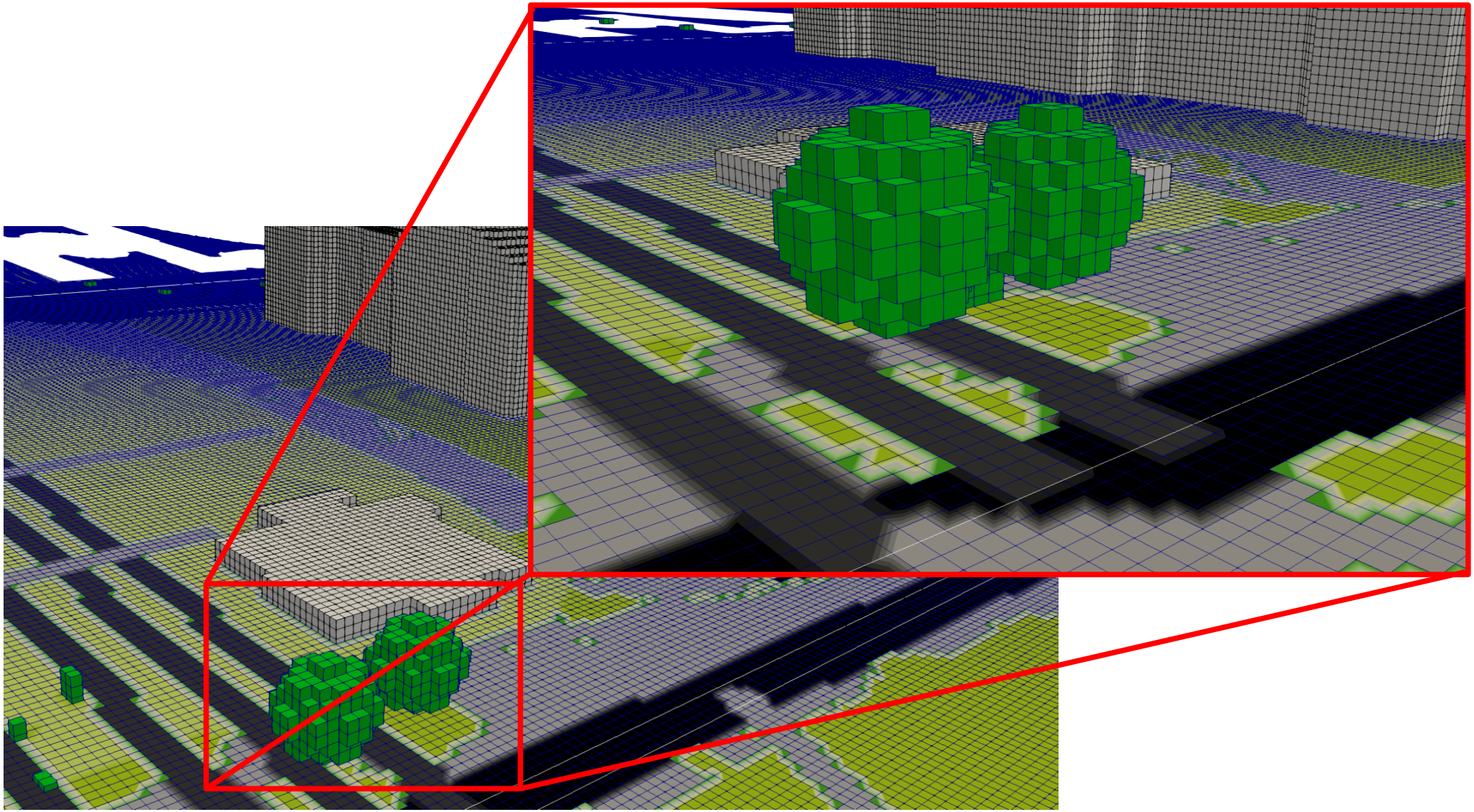

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Land surface, pavements and vegetation

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

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Land surface, pavements and vegetation

- Similar to TESSEL (IFS)
- Energy balance solver for T0
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- Multi-layer soil model (default: 8)
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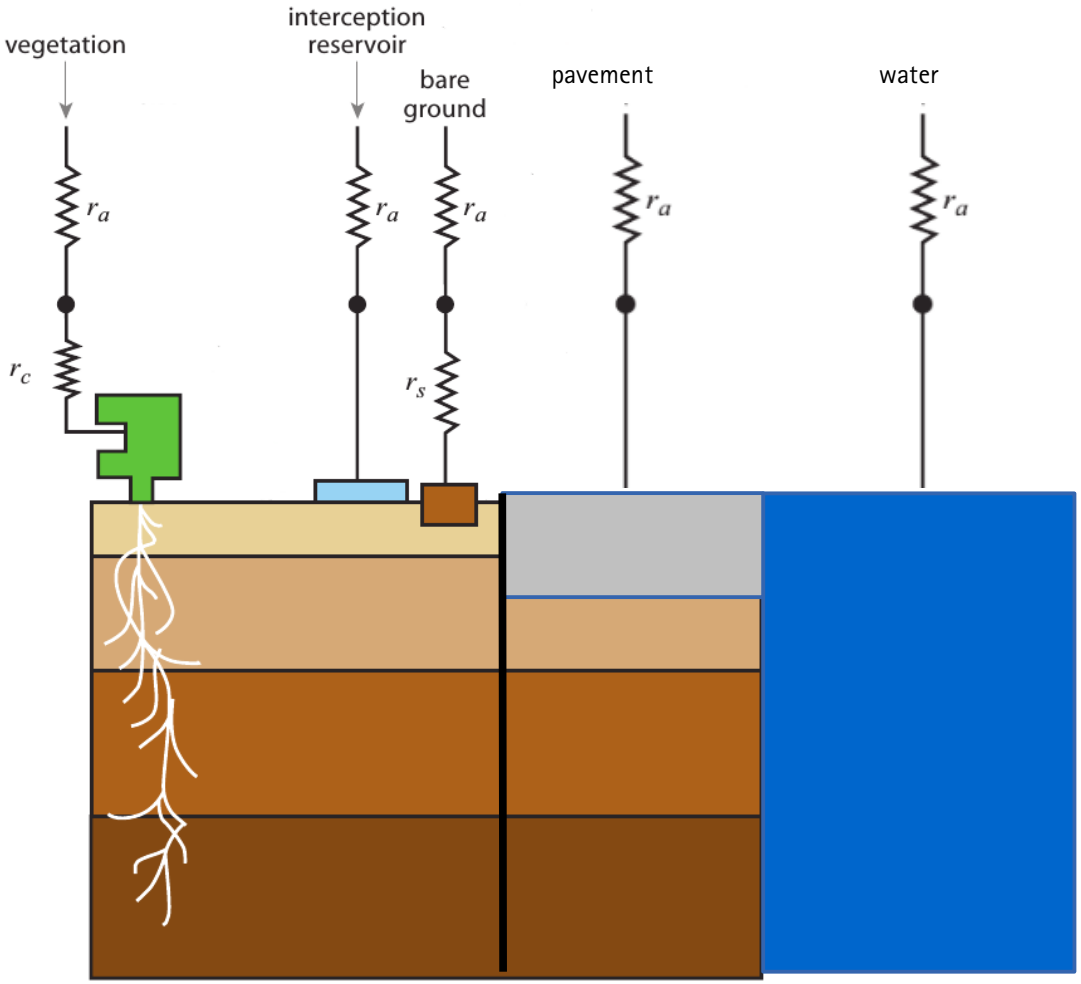

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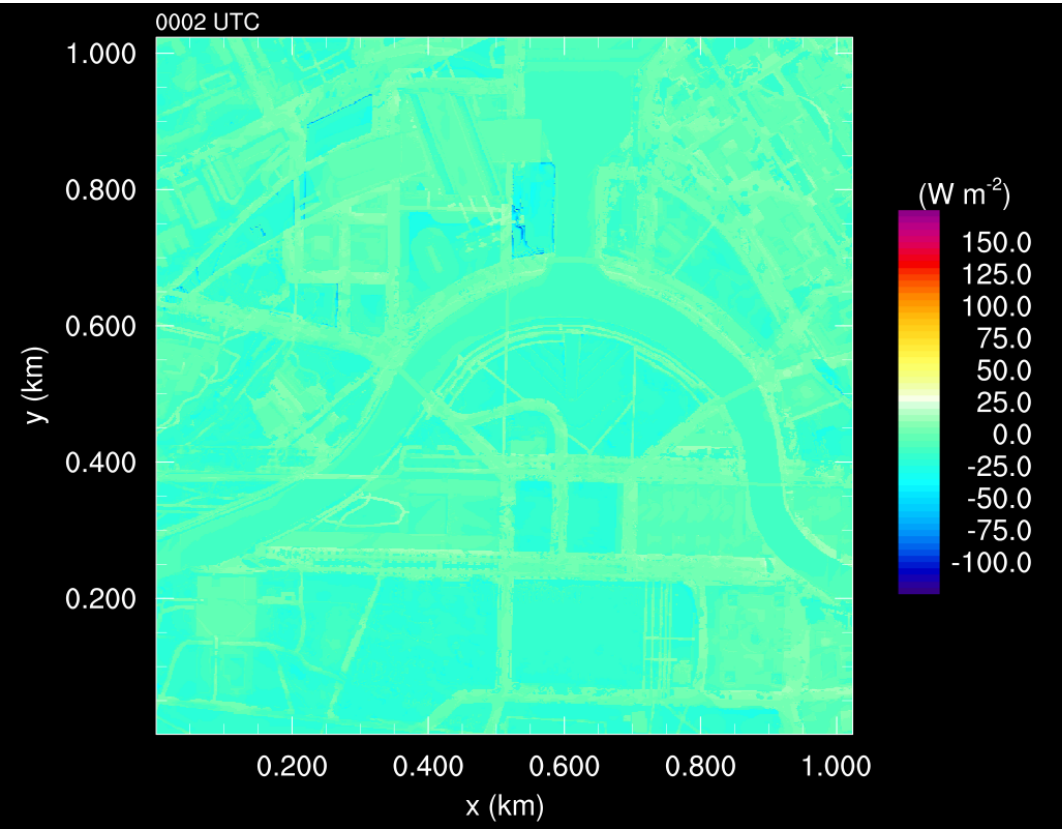
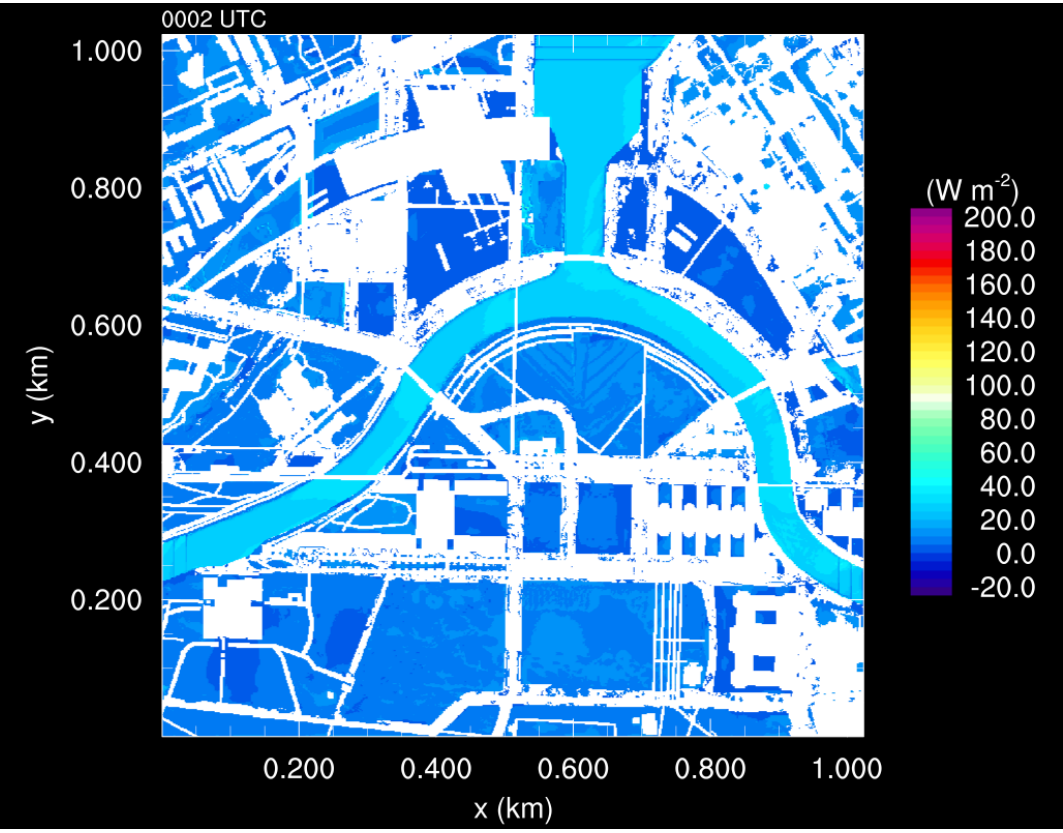
- Mesoscale interface for COSMO-DE (details in: 12D.2,*Kadasch*, Friday)
- For now: initial profiles only
- LES-LES nesting (details in: Poster 52, *Sühring et al.*, Tuesday)

Results: Surface fluxes – diurnal cycle – child domain

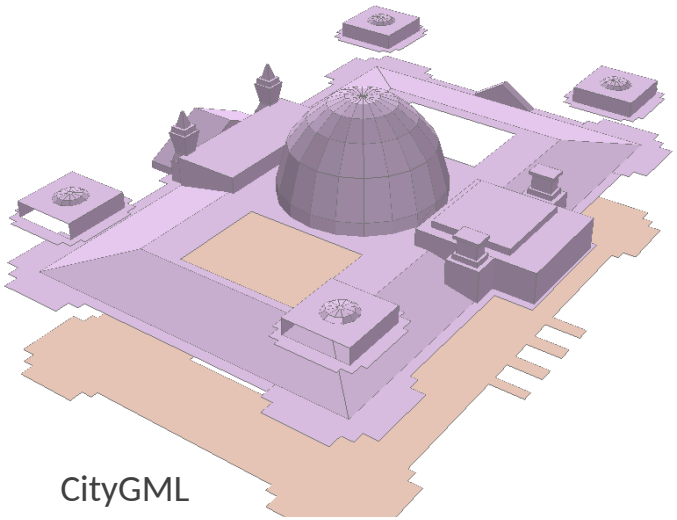
surface sensible heat flux



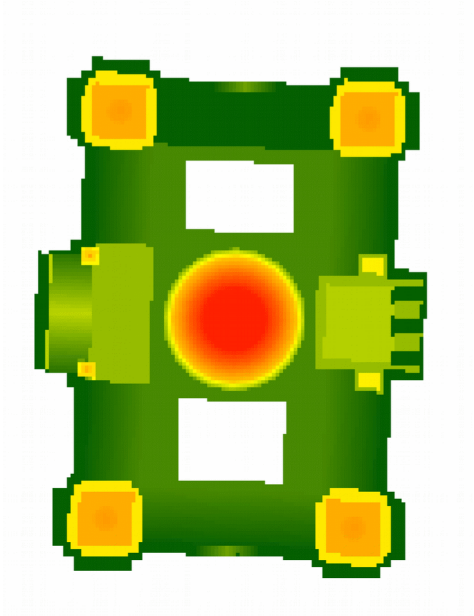
surface latent heat flux

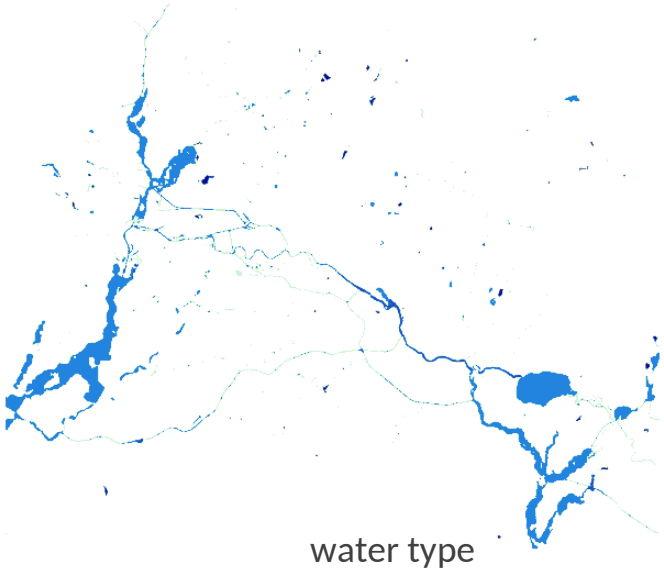


Berlin showcase: input data processing

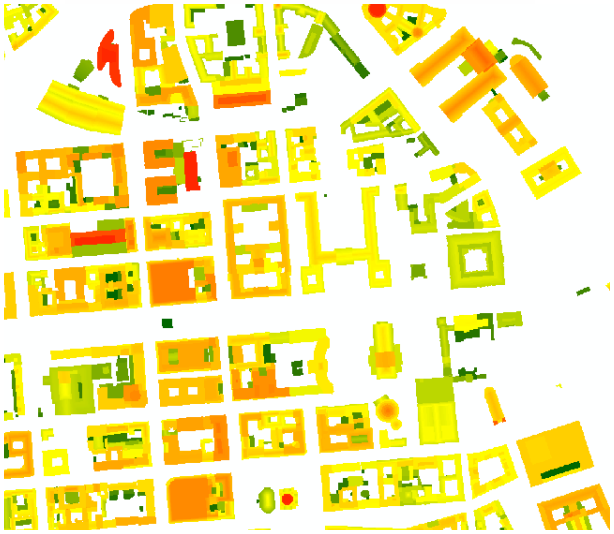


CityGML





water type



building height, 1 m grid

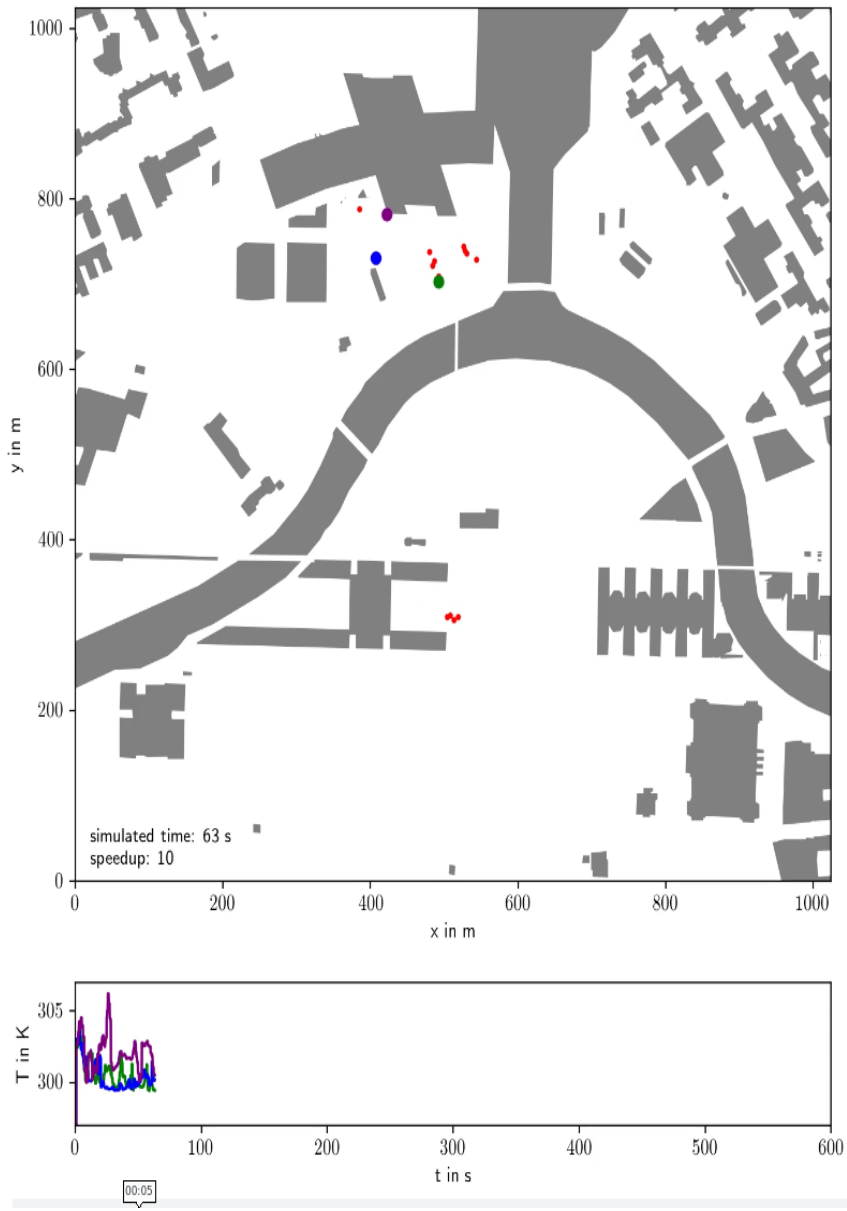
Used input data:

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

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

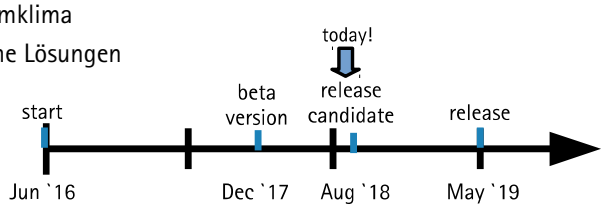
vegetation
- vegetation height
- leaf area index
- tree height
- crown diameter
- tree species*

Additional material: Multi-agent system



Von PALM zu PALM-4U: Überblick

- **PALM**: Modellkern (*Maronga et al. 2015, GMD*)
  - Parallelisiertes Large-eddy Simulations- (LES) Modell
  - Hochoptimisieert, skaliert bis zu > 32 000 Rechenkerne
  - Topographie auf kartesischem Gitter
  - Interaktives Landoberflächenmodell + Kopplung an RRTMG
  - Eingebettete Modelle
- **PALM-4U: PALM + zusätzliche Komponenten**
  - Energietransfer in der städtischen Grenzschicht
  - Luftchemie und Emissionen
  - Innenraumklima
  - Technische Lösungen



Berlin showcase: Setup – Das „parent" Gebiet

Gebiet (x x y x z)	46.8 km x 38.6 km x 3.5 km
Gitterweite	15 m
Antrieb	COSMO-DE Initialprofile 21.07.2013, 00:00 Uhr
Synoptik	Schwachwind, wolkenlos, COSMO-DE 2m -Temperatur > 303 K
Laterale Randbedingungen	zyklisch
Simulationszeit (Spinup)	24 h (Oberflächen + Strahlung)
Simulationszeit (LES)	24 h

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Berlin showcase: Setup – das „child“ Gebiet

Berlin Hbf

(c) D. Schwen

(c) AVDA

Reichstagsgebäude

Berlin showcase: Setup – das „child“ Gebiet

Gebiet (x x y x z)	1 km x 1 km x (0.3) 3 km
Gitterweite	1 m
Antrieb	wie parent
Synoptik	wie parent
Laterale Randbedingungen	(from parent) cyclic
Simulationszeit (Spinup)	24 h (Oberflächen und Strahlung)
Simulationszeit (LES)	24 h

Prozesse in PALM-4U

Urbane Oberflächen
- Energiebilanz
- Wärmeleitung
- Begrünung

Chemie
- Transport
- Reaktionen
- Photolyse
- Emissionen

Technische Lösungen
- Mesoskaliges Nesting
- LES-LES Nesting
- RANS Modus
- Graphische Benutzeroberfläche

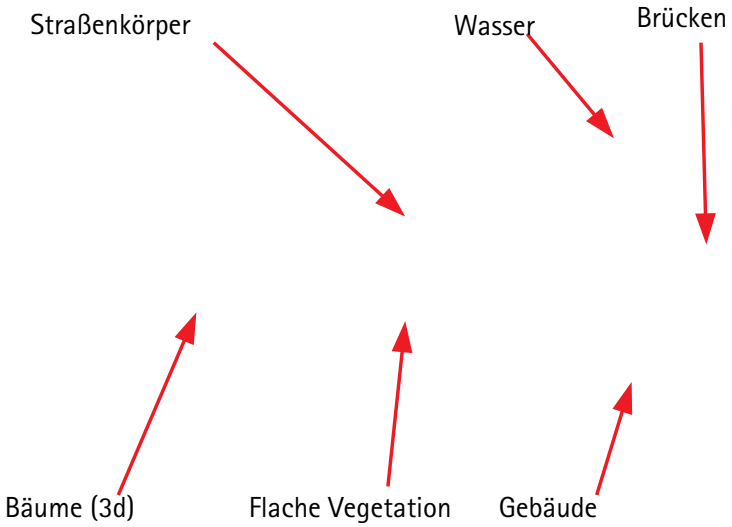
Strahlung
- Strahlungsbilanz
- Schattenwurf
- Reflektionen

Vegetation & Boden
- Energiebilanz
- Impulssenke
- Schattenwurf
- Wurzeln
- Bodenfeuchte

Auswirkungen
- Multiagentensystem
- Biometeorologie

Berlin showcase: Oberflächendaten

Berlin showcase: Oberflächendaten



Ergebnisse: Tagesgang der Temperatur

Oberflächentemperatur

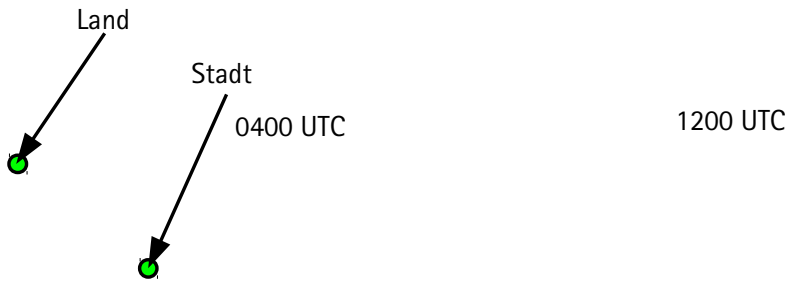
Lufttemperatur

Ergebnisse: Lufttemperatur (Tag vs Nacht)

0400 UTC

1200 UTC

Ergebnisse: Lufttemperatur (Tag vs Nacht)



Ergebnisse: Lufttemperatur (Tag vs Nacht)

Lufttemperatur

1.5 K

3 K

2 K

Ergebnisse: PM10 – Tagesgang

Ergebnisse: Tagesgang der Temperatur („child“)

Oberflächentemperatur

Lufttemperatur

Ergebnisse: Tagesgang der Temperatur („child“)

0400 UTC

Ergebnisse: Tagesgang der Temperatur („child“)

1200 UTC

Ergebnisse: Gebäudeumströmung („child“)

Betrag des Vorticityvektors

Ausblick: PALM-4U release

- „Release candidate" **(Ende September)**
- Weiterentwicklungen **(until May 2019):**
  - Bugfixing der neuen Komponenten
  - Verbesserter Strahlungstransfer
  - Dach- und Fassadenbegrünung
  - Realistische Emissionen
  - Biometeorologische Analysen (UV, PET, ...) + Multiagentensystem
  - Innenraumkloma (Raumtemperatur, Energiebedarf, Abwärme)
  - Aerosolchemie (SALSA)
- Limitierungen:
  - Keine Wolken (in der Stadt)
  - Kein Eisphase (Boden + Wolken)
  - Kein Energiebilanzlöser für 3d-Bäume
  - Kein eigenständiges Emissionsmodell
  - Teure Chemie

→ Zweite Förderphase ?!

Zusammenfassung

- **PALM-4U**: neues gebäudeauflösendes Stadtklimamodell
- Erlaubt Simulation **ganzer Stadtgebiete**
- Variable Gitterweiten und Randbedingungen
- **Modellphysik:**
  - Gebäude auf kartesischem Gitter
  - Energiebilanzlöser für alle urbanen Oberflächen
  - Strahlungstansfer in der UCL
  - Modellnesting + Selbstnesting
  - 3d Bäume
  - Chemie
  - Multiagentensystem

- **Erste Ergebnisse:** Erfolgreiche Simulation von Berlin!
- **Aber:** ... noch viel zu tun!

Vielen Dank für die Aufmerksamkeit!

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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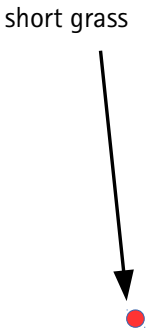

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surface temperature
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Additional material: Nesting 10 m – 1 m

Additional material: LES-LES nesting

Forcing and model nesting

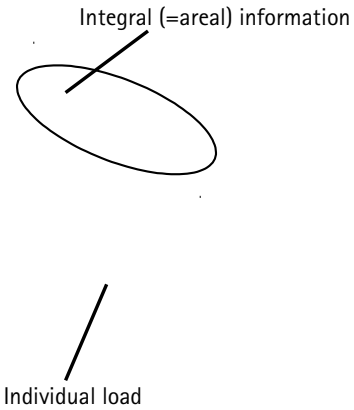
- Mesoscale interface for COSMO-DE (details in: 12D.2,*Kadasch*, Friday)
- For now: initial profiles only
- LES-LES nesting (details in: Poster 52, *Sühring et al.*, Tuesday)

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

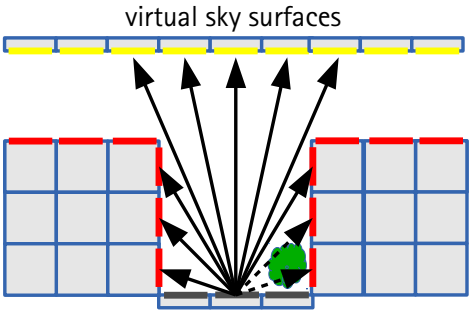
Radiative transfer

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)

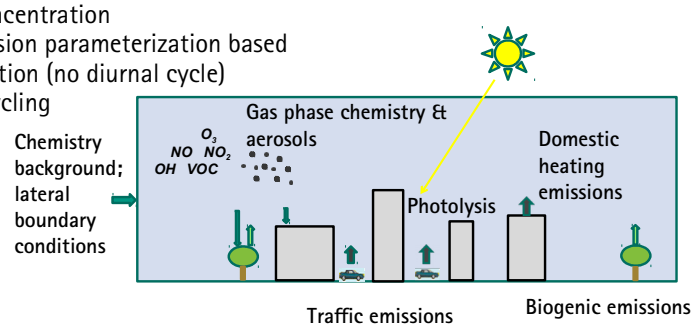
Urban radiation basics:
- Shadowing
- Surface reflections
- 3D vegetation as sink for radiation



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:

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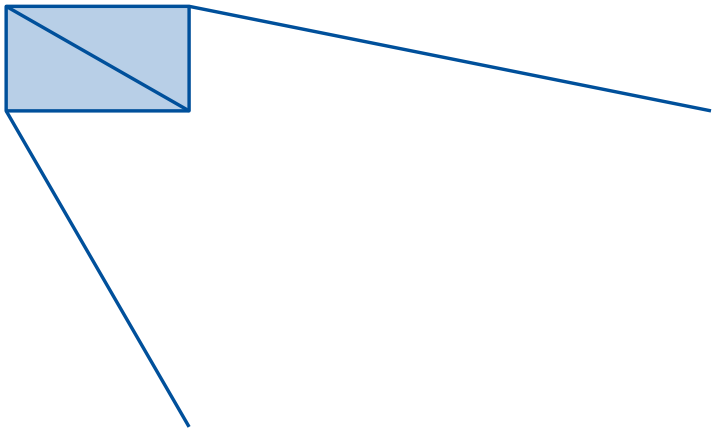
0400 UTC

Berlin showcase: model physics

Building surfaces

Berlin showcase: model physics

Building surfaces



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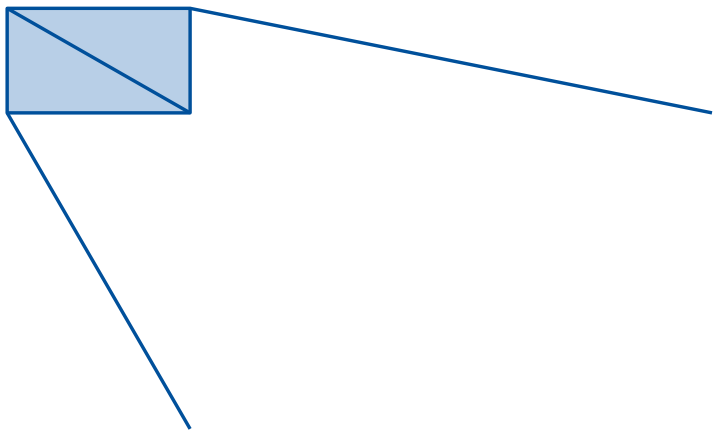

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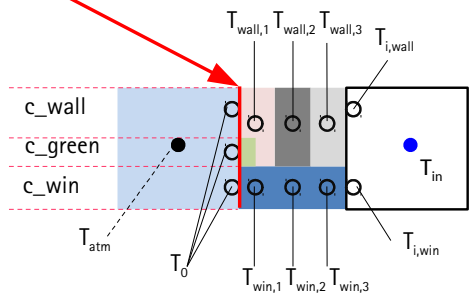
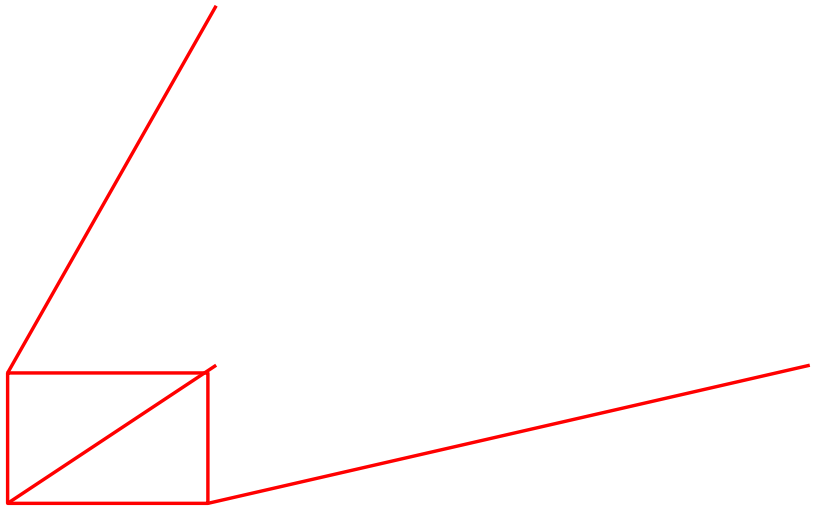


Berlin showcase: model physics

Land surface, pavements and vegetation

Berlin showcase: model physics

Land surface, pavements and vegetation



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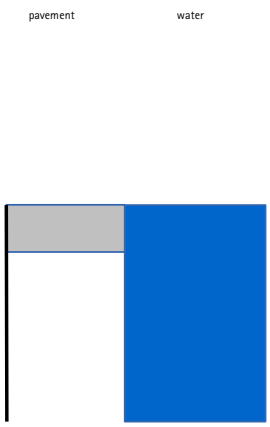

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surface sensible heat flux

surface latent heat flux

Berlin showcase: input data processing

CityGML

water type

building height, 1 m grid

Used input data:

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- terrain height
- building id
- building height
- bridges

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

vegetation
- vegetation height
- leaf area index
- tree height
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Additional material: Multi-agent system