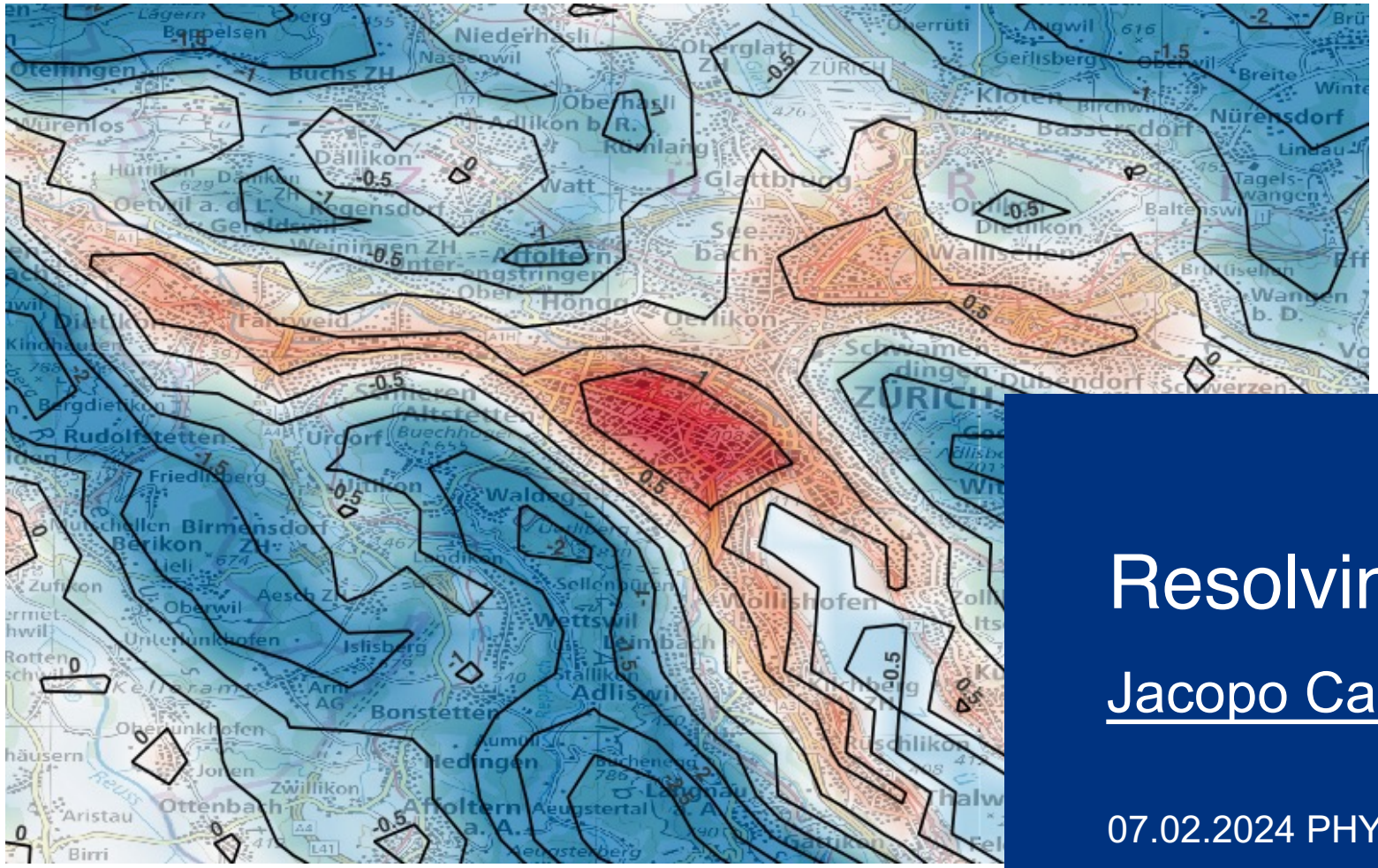
Resolving cities in a global model

ETH zürich

EXCLAIM



Resolving cities in a global model

Jacopo Canton & Anurag Dipankar

07.02.2024 PHY-EPS hectometric Workshop

C2SM Center for Climate Systems Modeling

CSCS

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Home Affairs FDHA
Federal Office of Meteorology and Climatology MeteoSwiss

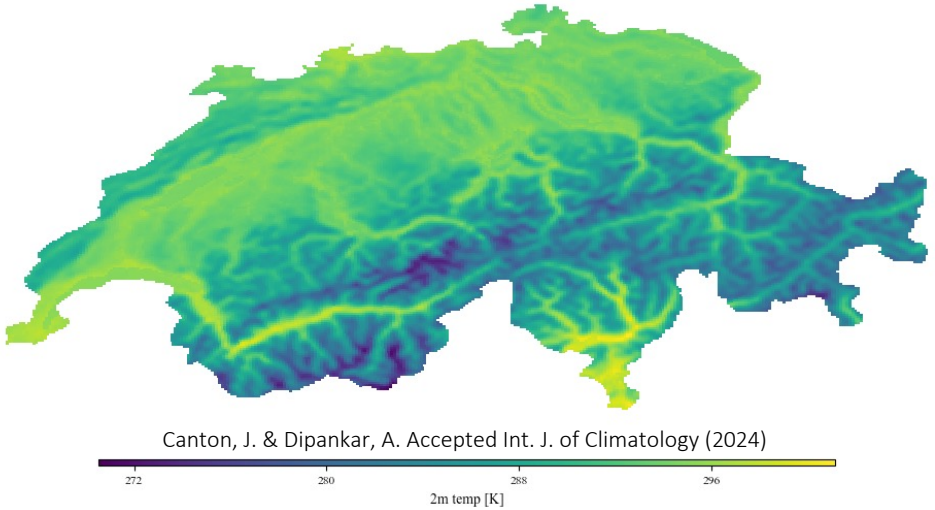
MeteoSwiss

SDSC

Empa
Materials Science and Technology

Overview

More than 50% of people live in cities.
In Switzerland and EU the average is 70%[1]

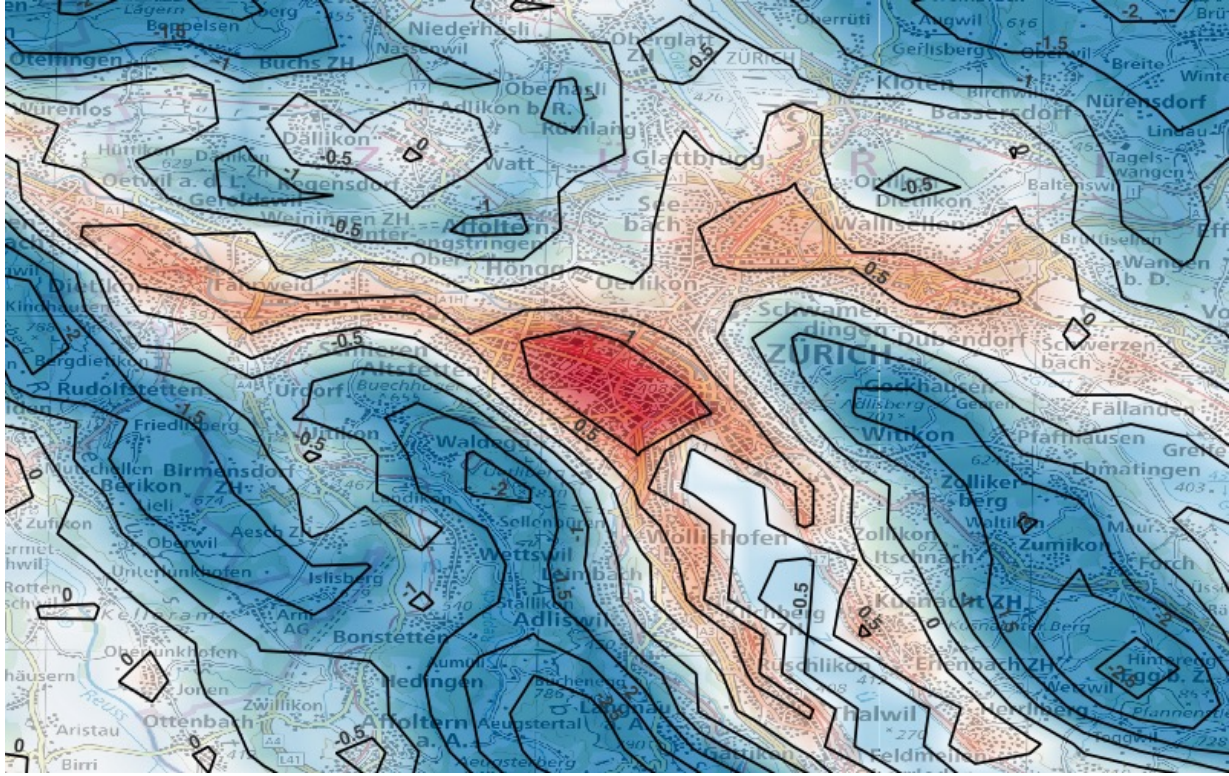


Our plan:

- Investigate the current state-of-the-art at km-scale
- Develop high-resolution capabilities to simulate weather/climate extremes
    - attention to steep terrain (B. Goger)
    - and urban areas (J. Canton)

Thunderstorm effects in Zürich. July 2021

1. United Nations. World Urbanization Prospects: The 2018 Revision. NewYork (2018).



What we did so far

km-scale

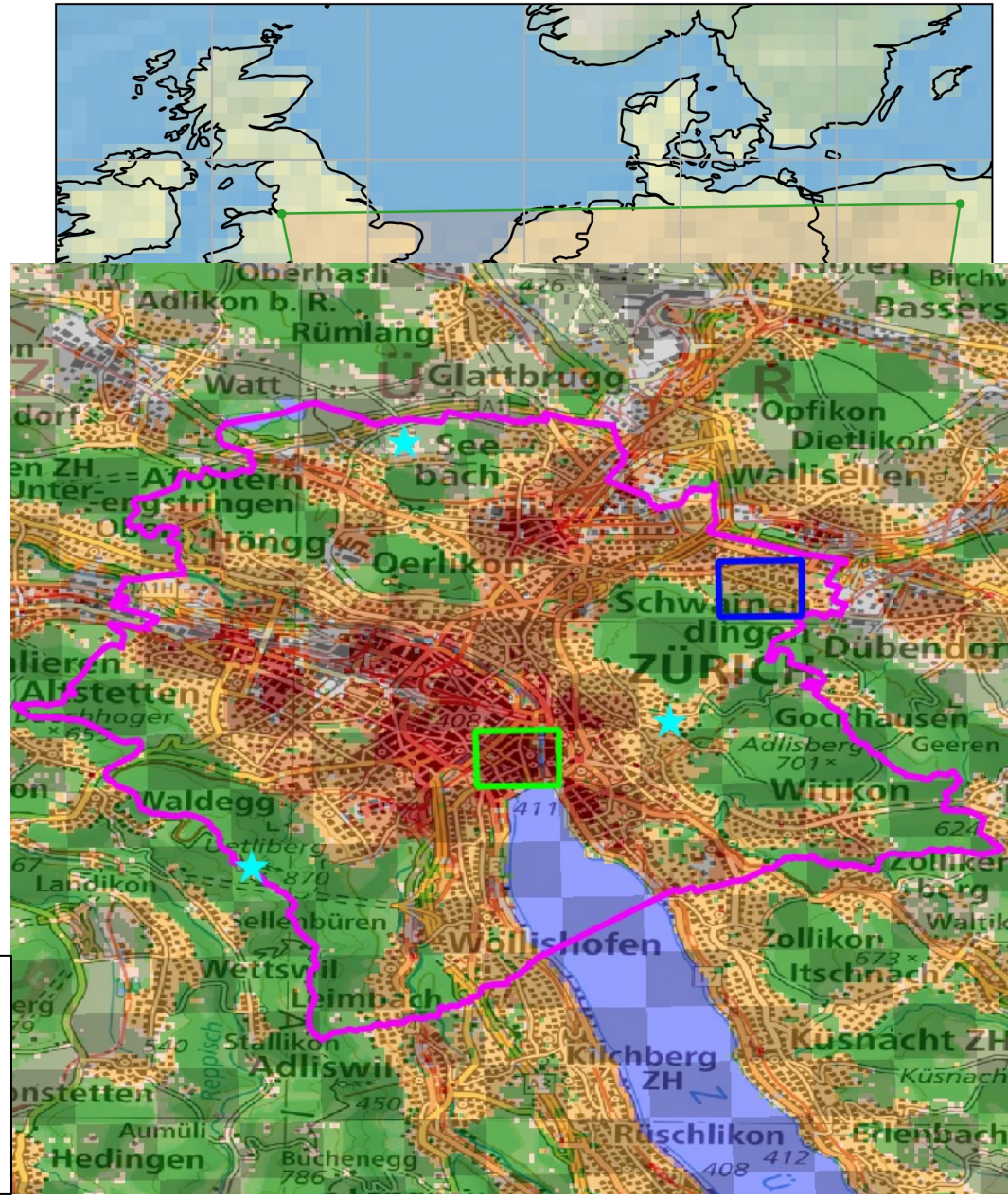
Numerical setup COSMO v6

↓ERA-5 data at hourly interval

↓Nest 1 at 11 km res. 10 years spinup

↓Nest 2 at 3.3 km res.

- Study domain at 1.1 km res. Monthly spinup
  - 6 years: 01.01.2017—31.12.2022
  - 1D turbulence parametrization (Raschendorfer)
  - Explicit convection
  - TERRA_URB + SURY urban parametrization[1]
  - 100m global local climate zones database[2]

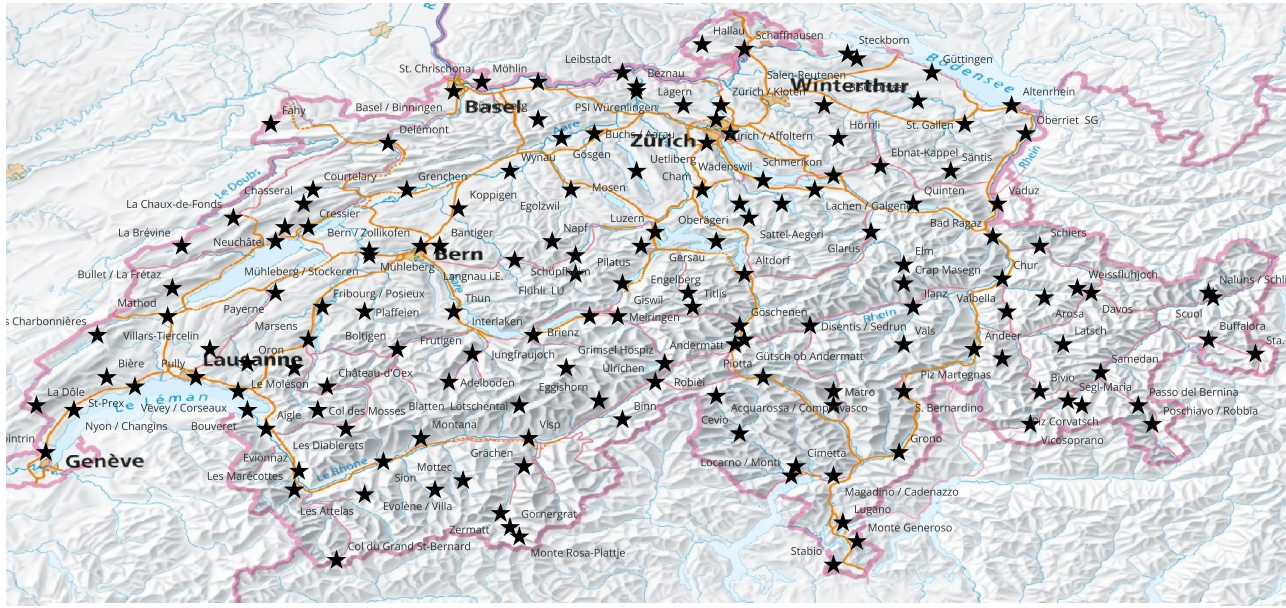


Many thanks to Jan-Peter and the PP CITTÁ group

1. Wouters, H. et al.: User Guide for TERRA URB v2.2: The Urban-Canopy Land-Surface Scheme of the COSMO Model. (2017)
2. Demuzere, M. et al.: A global map of local climate zones to support earth system modelling and urban-scale environmental science. Earth Syst. Sci. Data 14, 3835–3873, (2022).

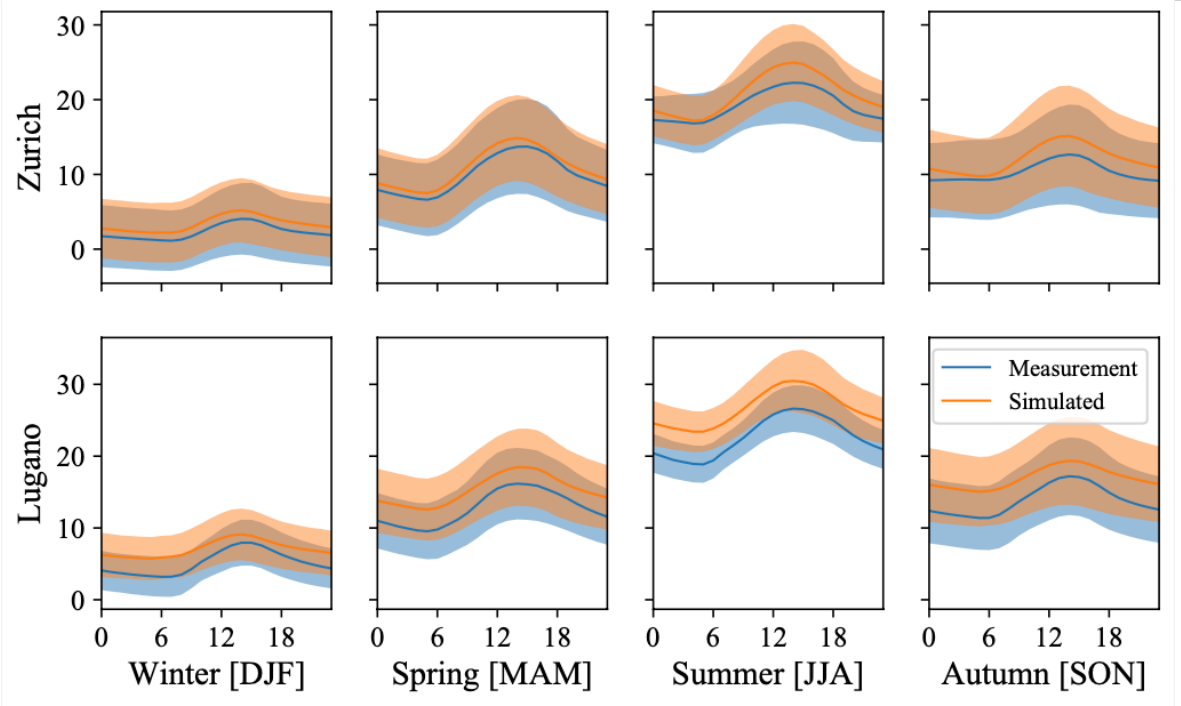
Validation

Hourly measurements from 156 automatic measurement towers (MeteoSwiss): T, P, humidity, wind



2 m temperature

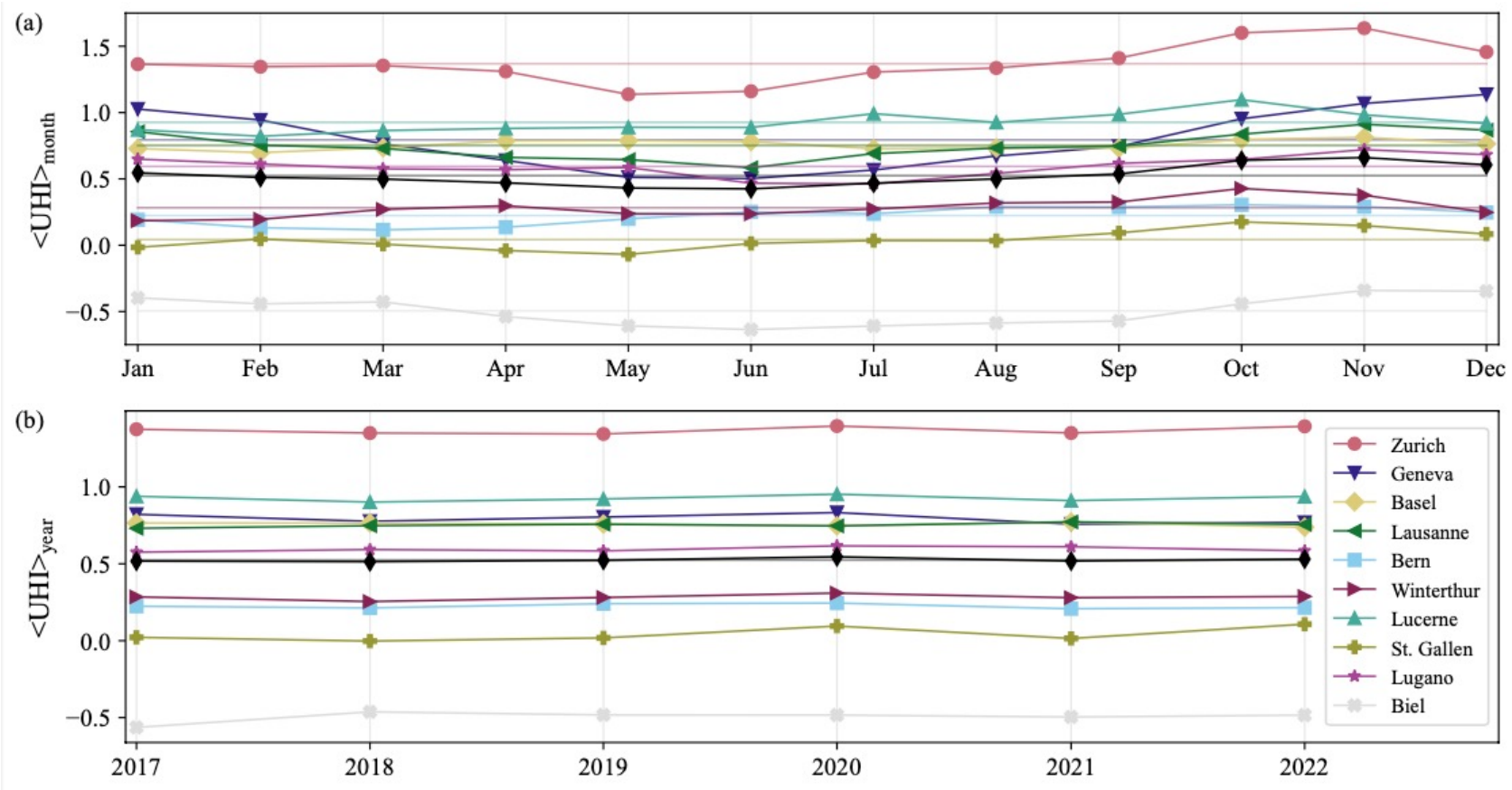
- The temporal variability is very well captured
- Mean bias at some stations within expected values[1]



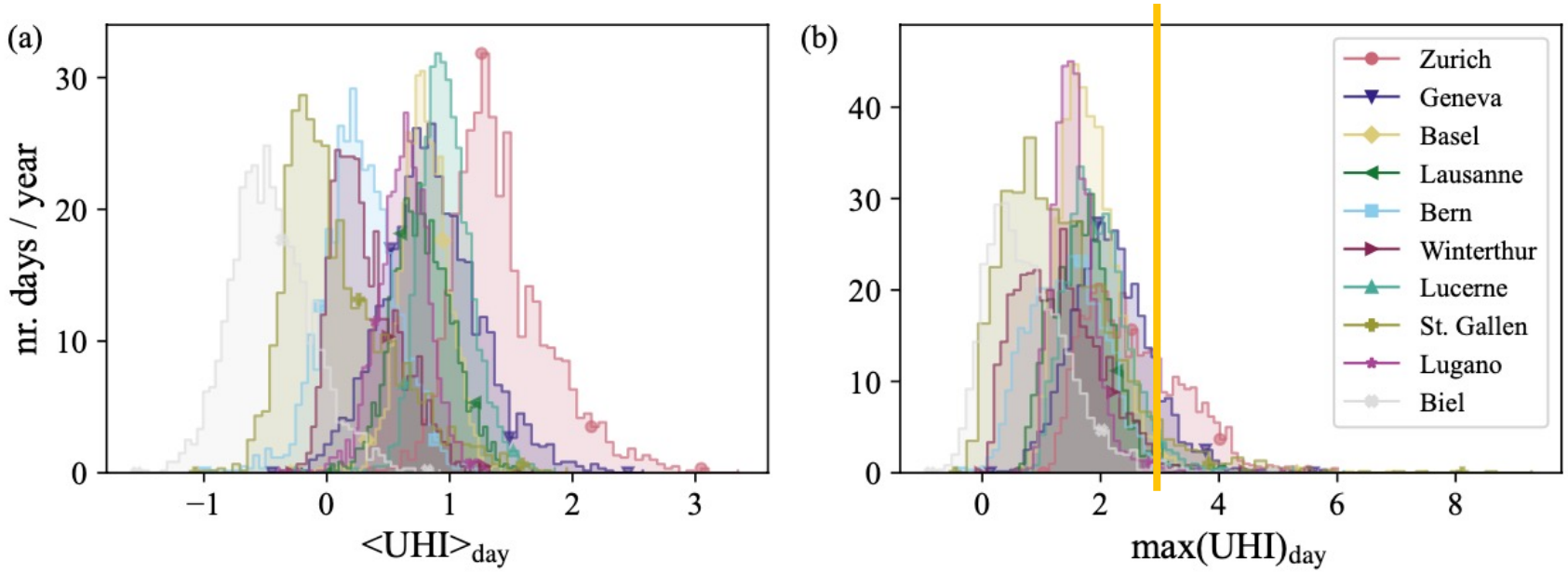
1. Leutwyler D, Lüthi D, Ban N, Fuhrer O, Schär C. Evaluation of the Convection-Resolving Climate Modeling Approach on Continental Scales. J. Geophys. Res.-Atmos. (2017)

Urban heat island (UHI): temporal dynamics

- Monthly variations are relatively similar across cities
- Yearly variations *of the mean value* are almost absent



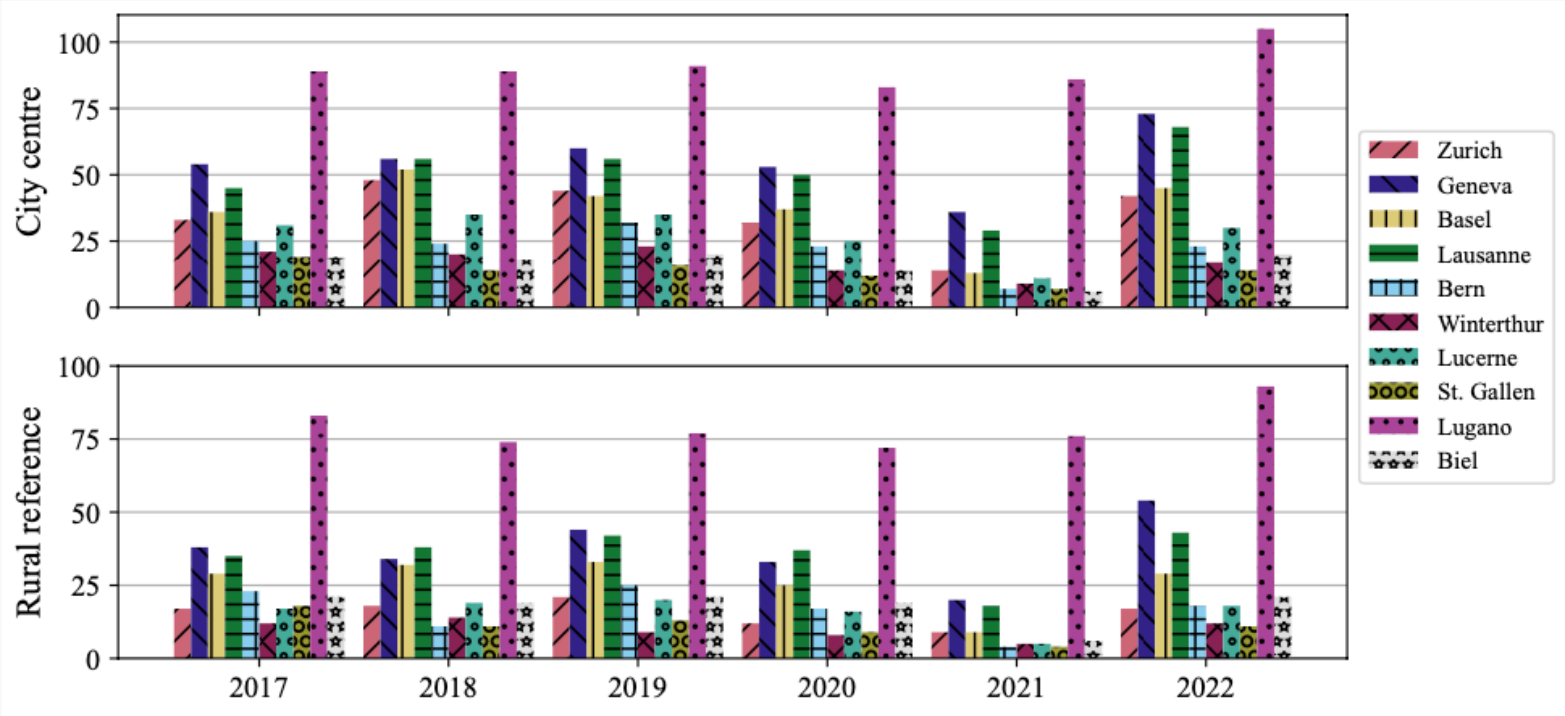
UHI histograms and extreme events



- Many cities almost only positive <UHI> (Zurich and Lausanne only <UHI> > 0)
- All cities present UHI_{max} exceeding 3°C
- Extreme values will increase more in cities[1]

1. Li D, Bou-Zeid E. Synergistic Interactions between Urban Heat Islands and Heat Waves: The Impact in Cities Is Larger than the Sum of Its Parts. J Appl Meteorol Clim. (2013)

Extreme events 2: tropical nights (T_{min} ≥ 20°C)

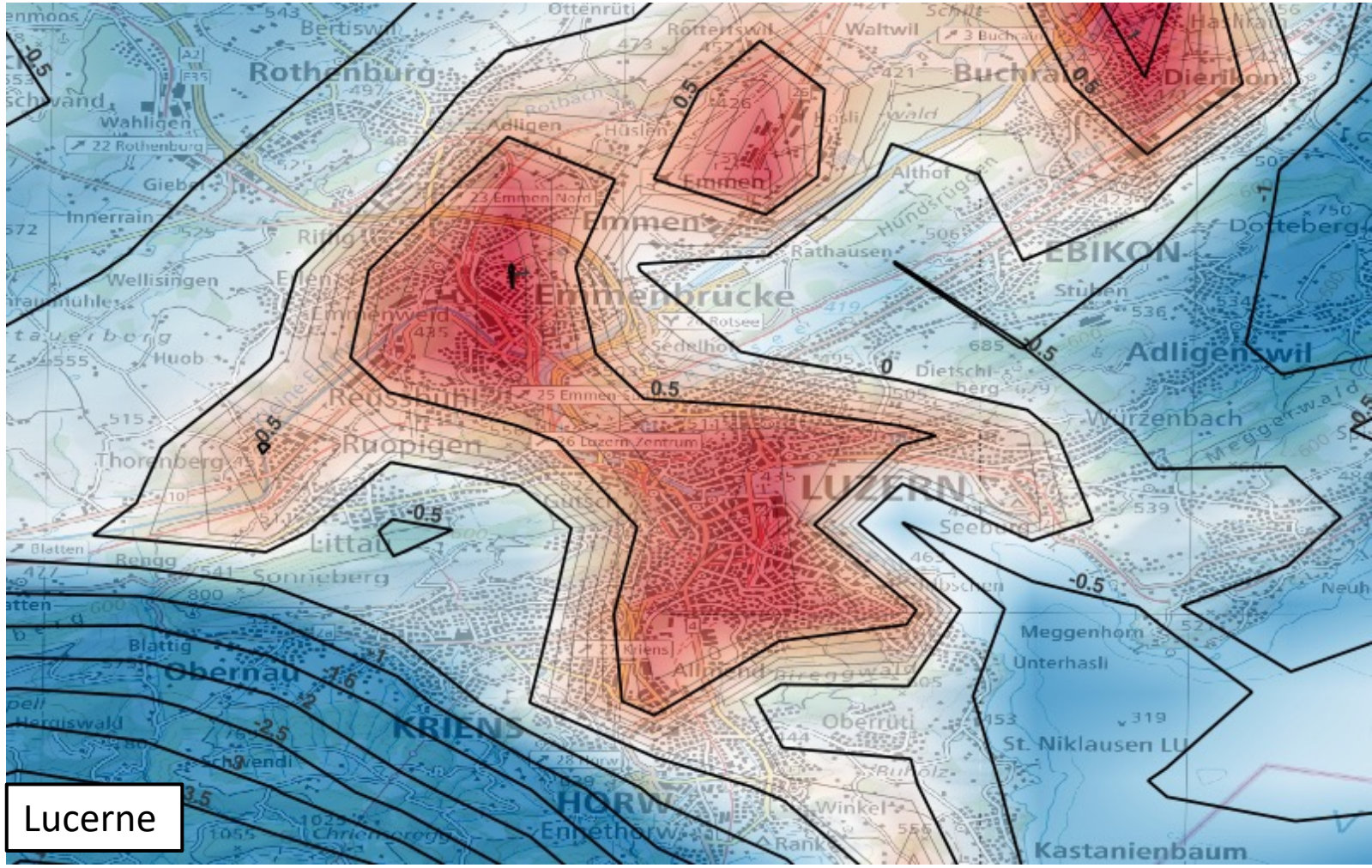


- Connected with a change in the mortality rate in Switzerland[1]
- Lugano (south of the Alps) has more than 2x
- Highly influenced by local climate (e.g., Geneva Lausanne)
- Not connected to UHI intensity

1. Rippstein V, de Schrijver E, Eckert S, Vicedo-Cabrera AM. Trends in Tropical Nights and Their Effects on Mortality in Switzerland across 50 Years. PLOS Climate (2023)

Spatial maps

- Large features can be readily identified by steep gradients (e.g., mountains)
- Clearly shows the spatial nature of the phenomenon
- Highlights that downtown ≠ heat centre



<UHI> over the summer season (June, July, August). Blue=neg, Red=pos

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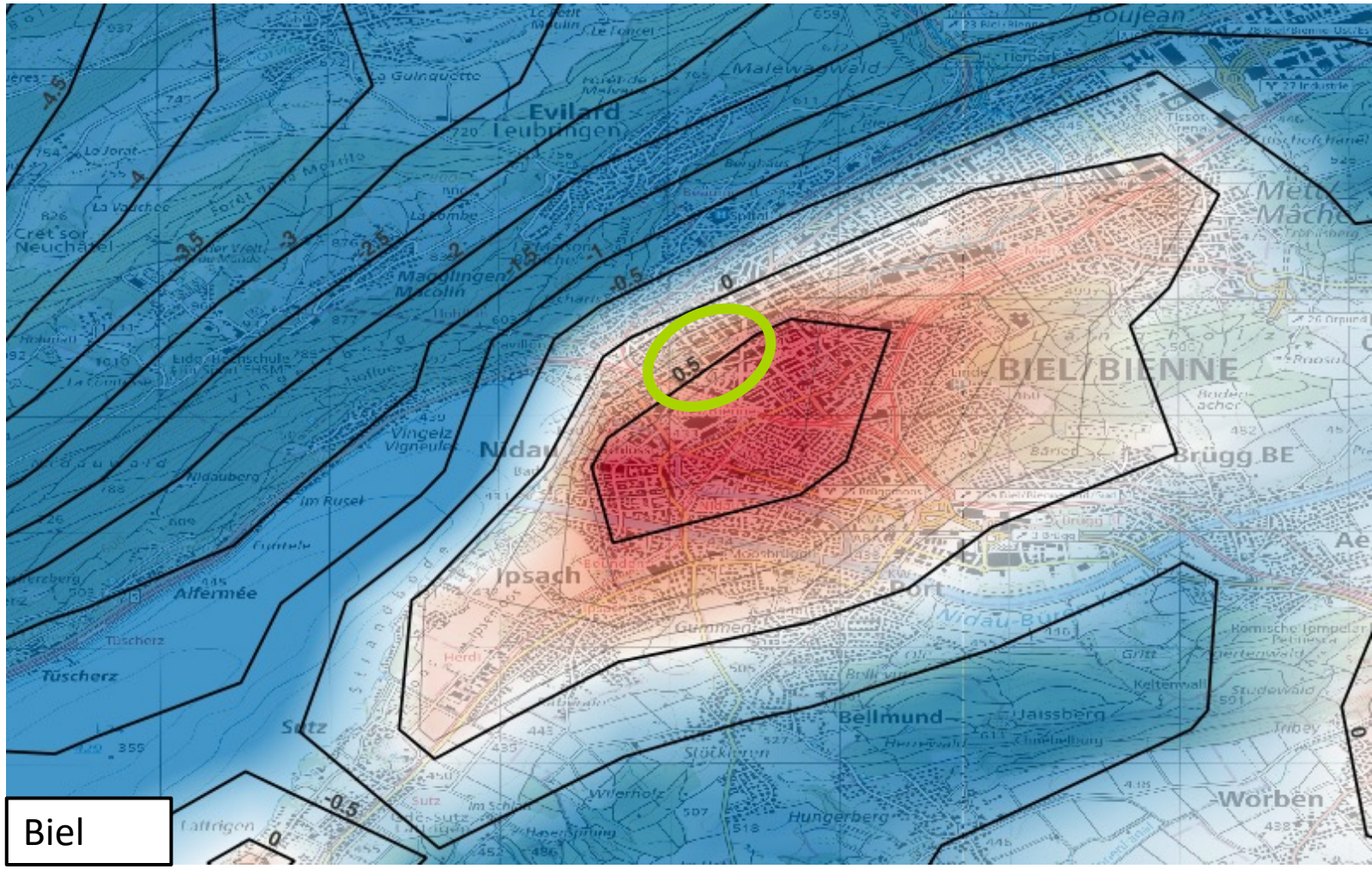

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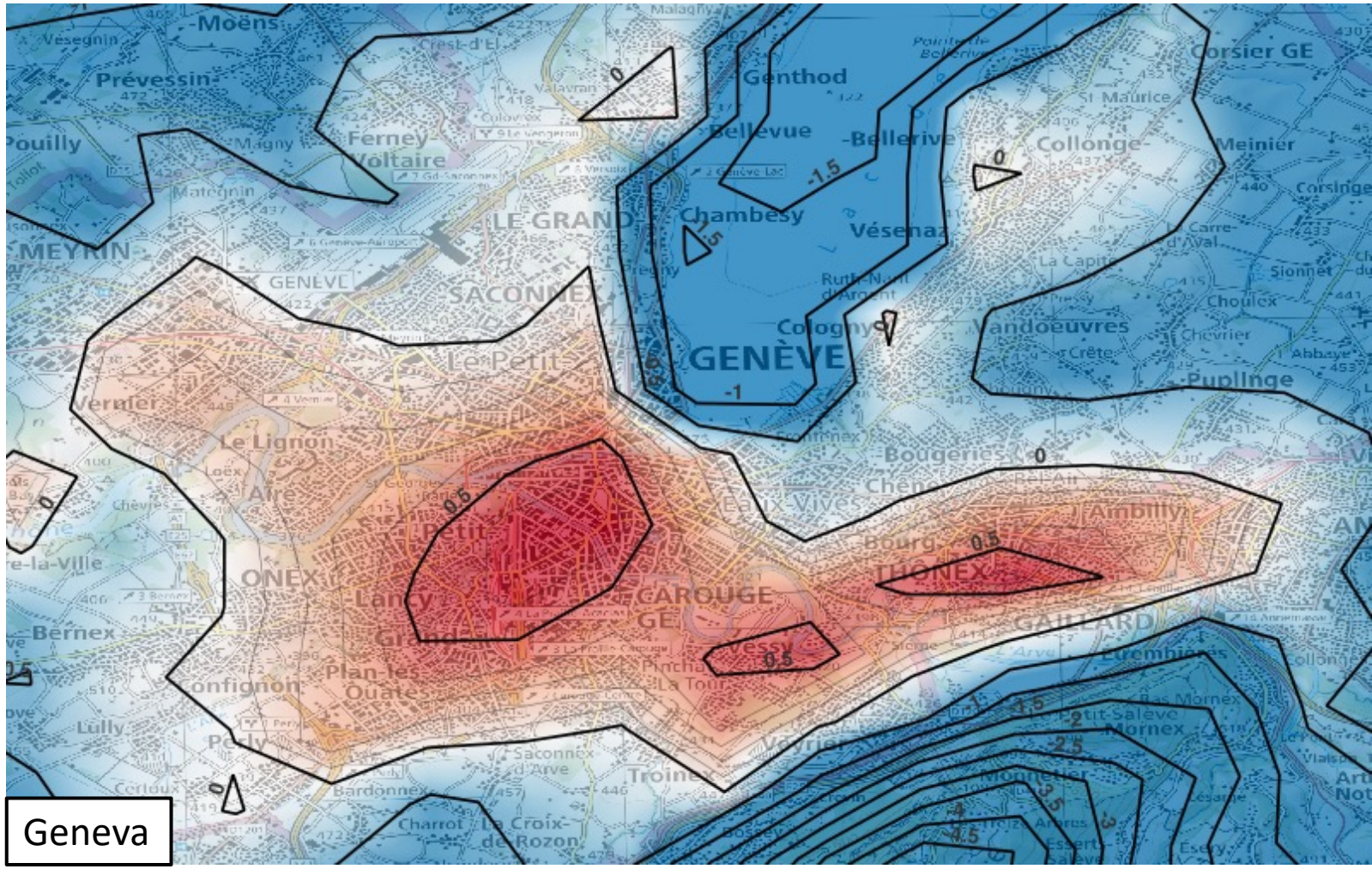

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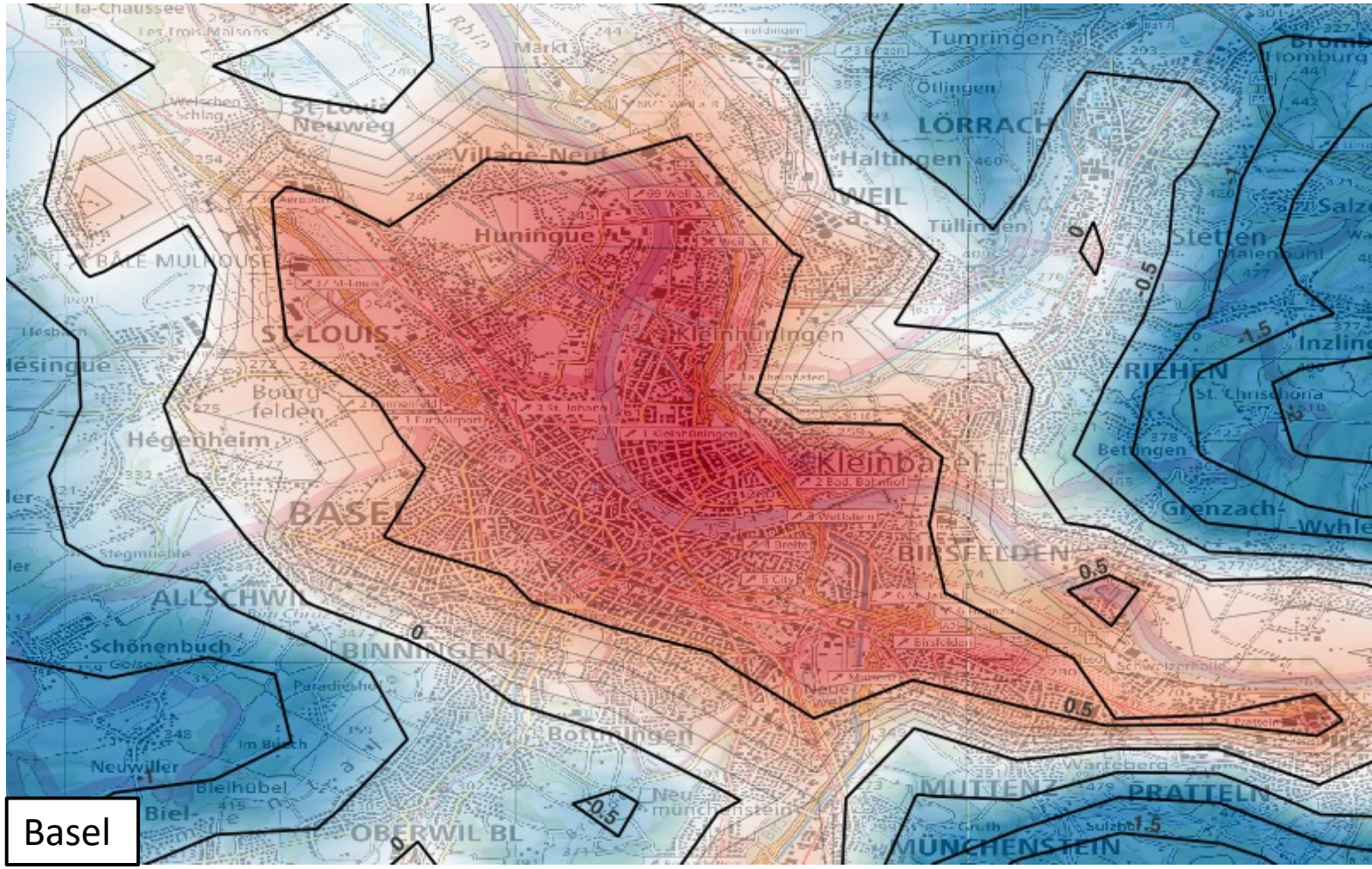

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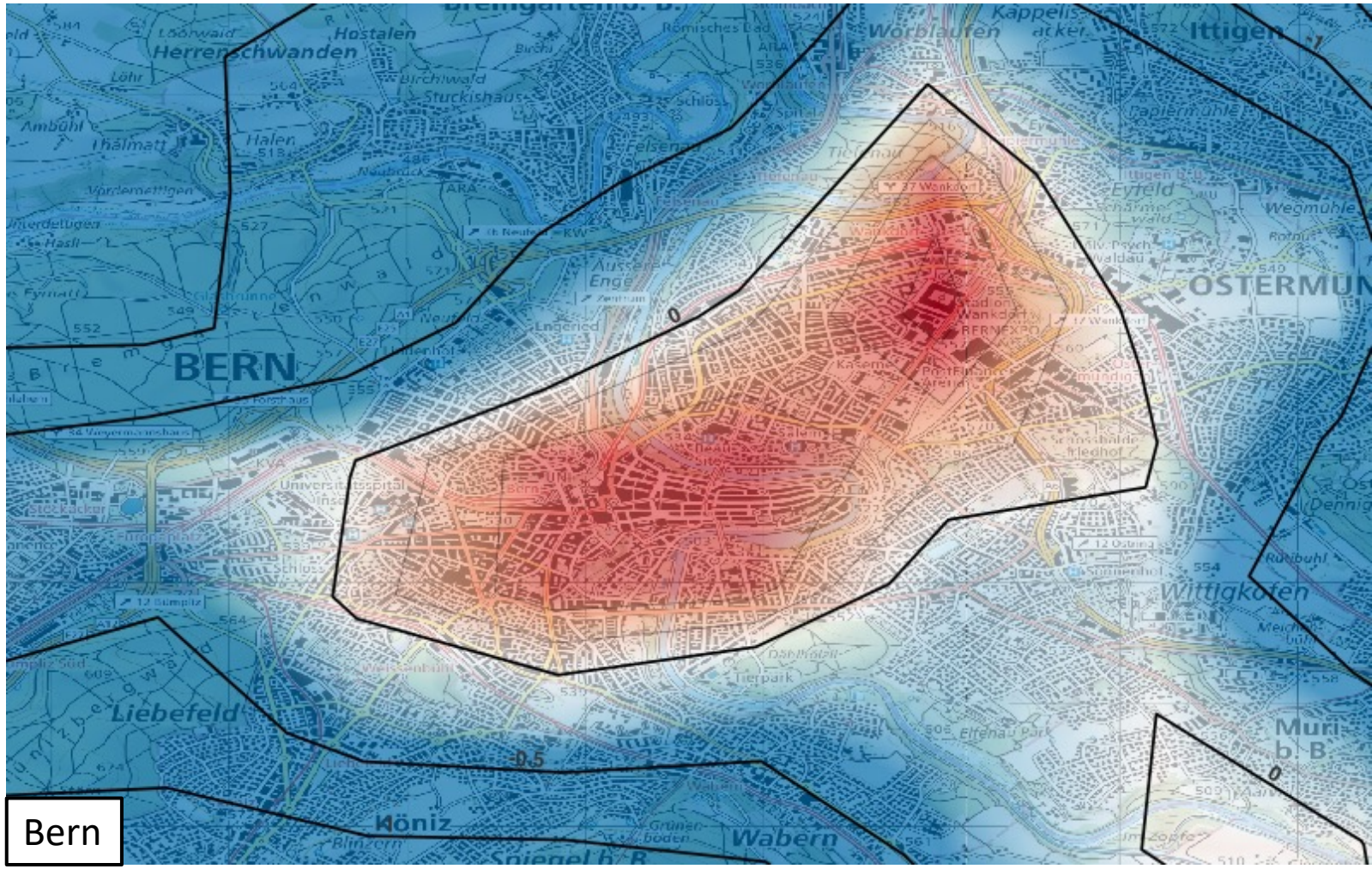

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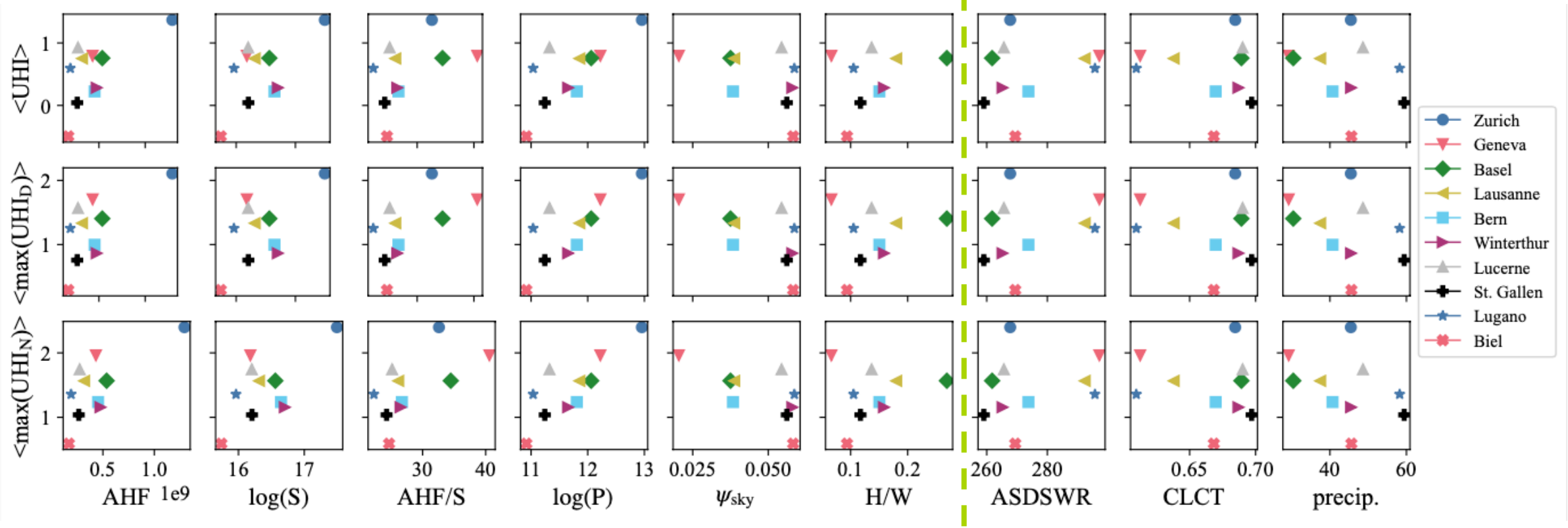
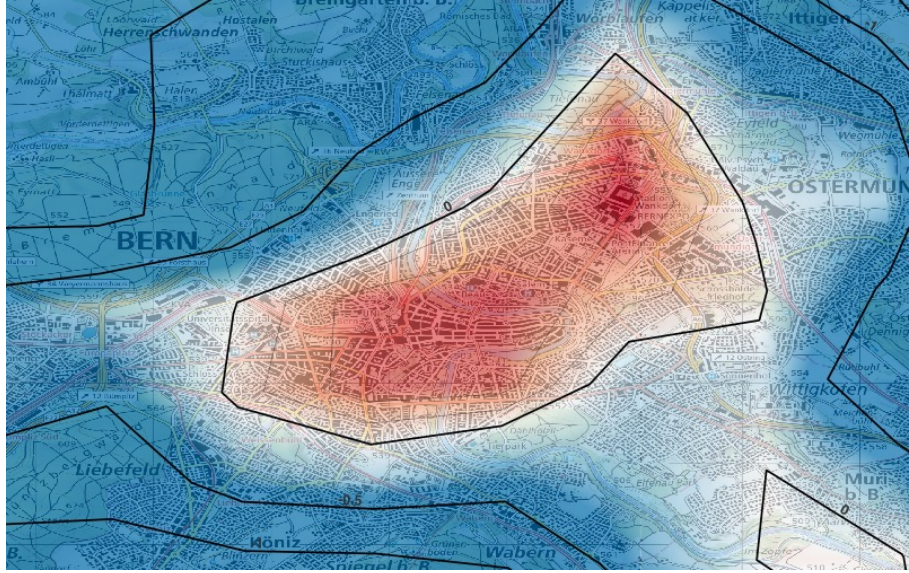
UHI as a function of bulk parameters



- Empirical relationships between UHI and geometrical parameters[1,2,3]
- Does not apply to any UHI measurement and any parameter investigated

1. Zhou B, Rybski D, Kropp JP. The Role of City Size and Urban Form in the Surface Urban Heat Island. Sci Rep (2017)
2. Zhao L, Lee X, Smith RB, Oleson K. Strong Contributions of Local Background Climate to Urban Heat Islands. Nature (2014)
3. Oke TR. Canyon Geometry and the Nocturnal Urban Heat Island: Comparison of Scale Model and Field Observations. J. Clim. (1981)

km-scale summary



- First comprehensive analysis over CH
- Data publicly available for further analysis

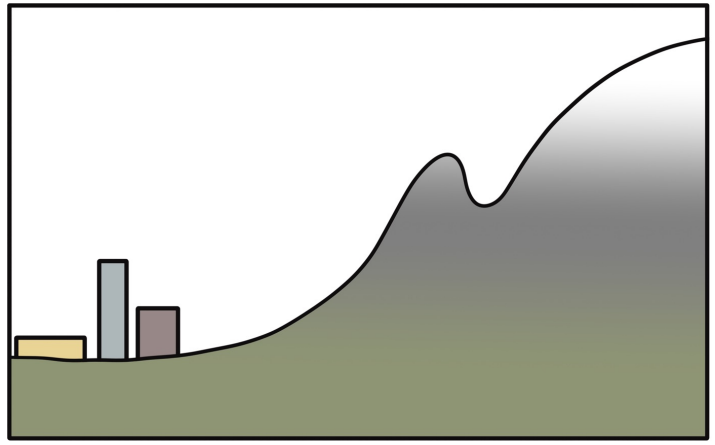
- Higher UHI effect than expected (more than 3°C)
- Spatial analyses needed

1. Canton, J. & Dipankar, A. *Climatologial analysis of urban heat island effects in Swiss cities*. Accepted Int. J. of Climatology (2024)

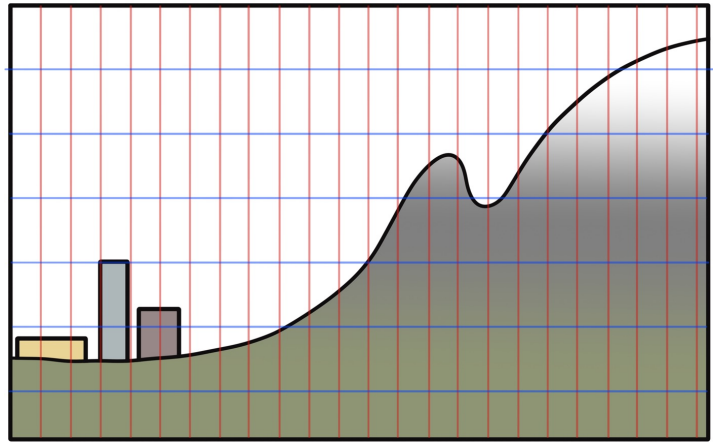
What we are working on

High resolution plans

High resolution plans

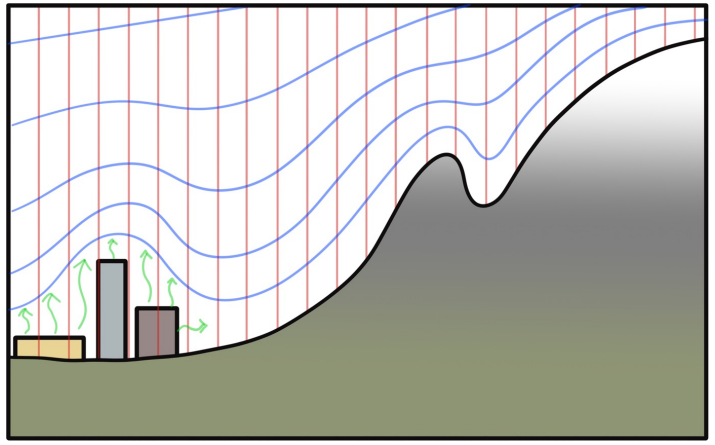


Regular grid + immersed boundary



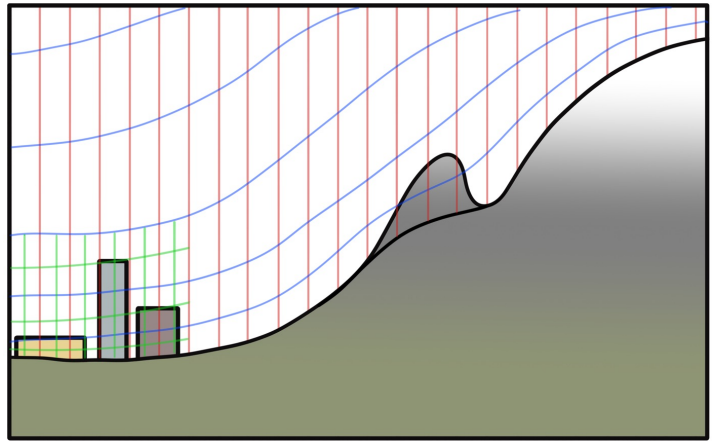
PALM
uDALES

Terrain-following "terra-urb++"



Option for improvements with CFD simulations / ML / statistical methods

Terrain-following + immersed boundary

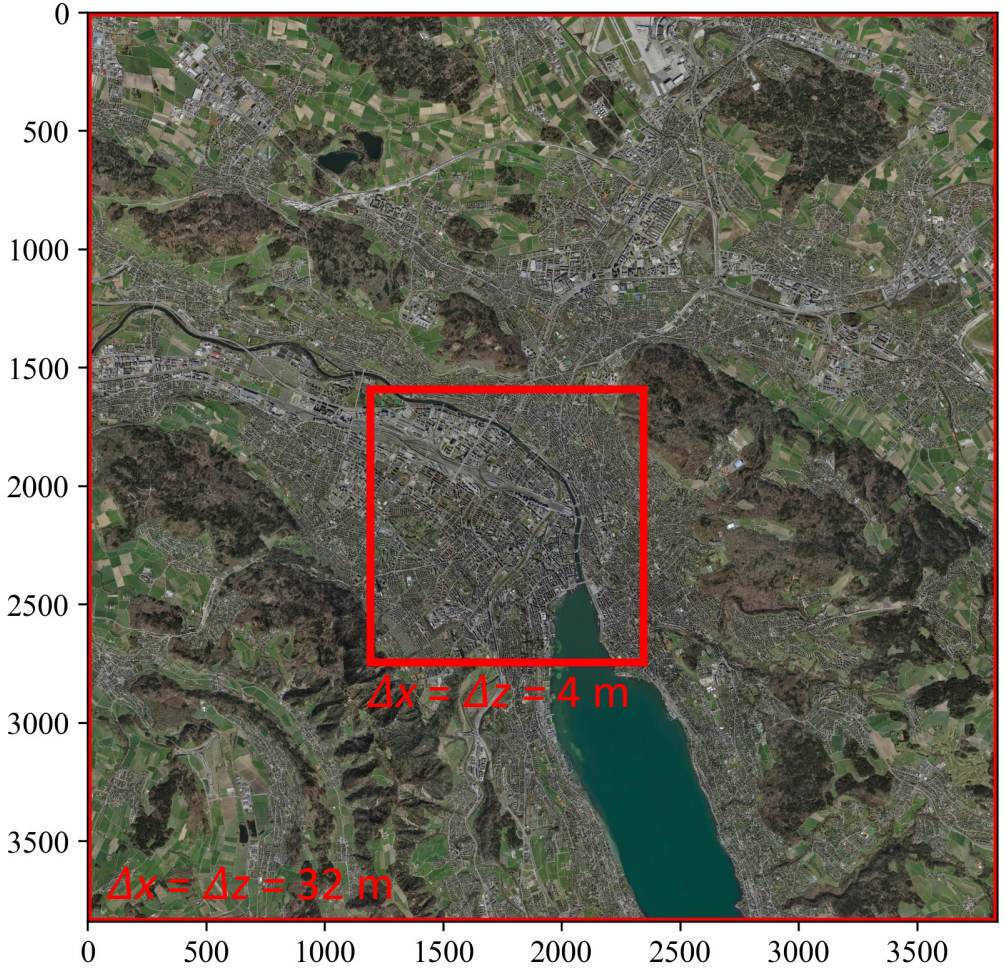


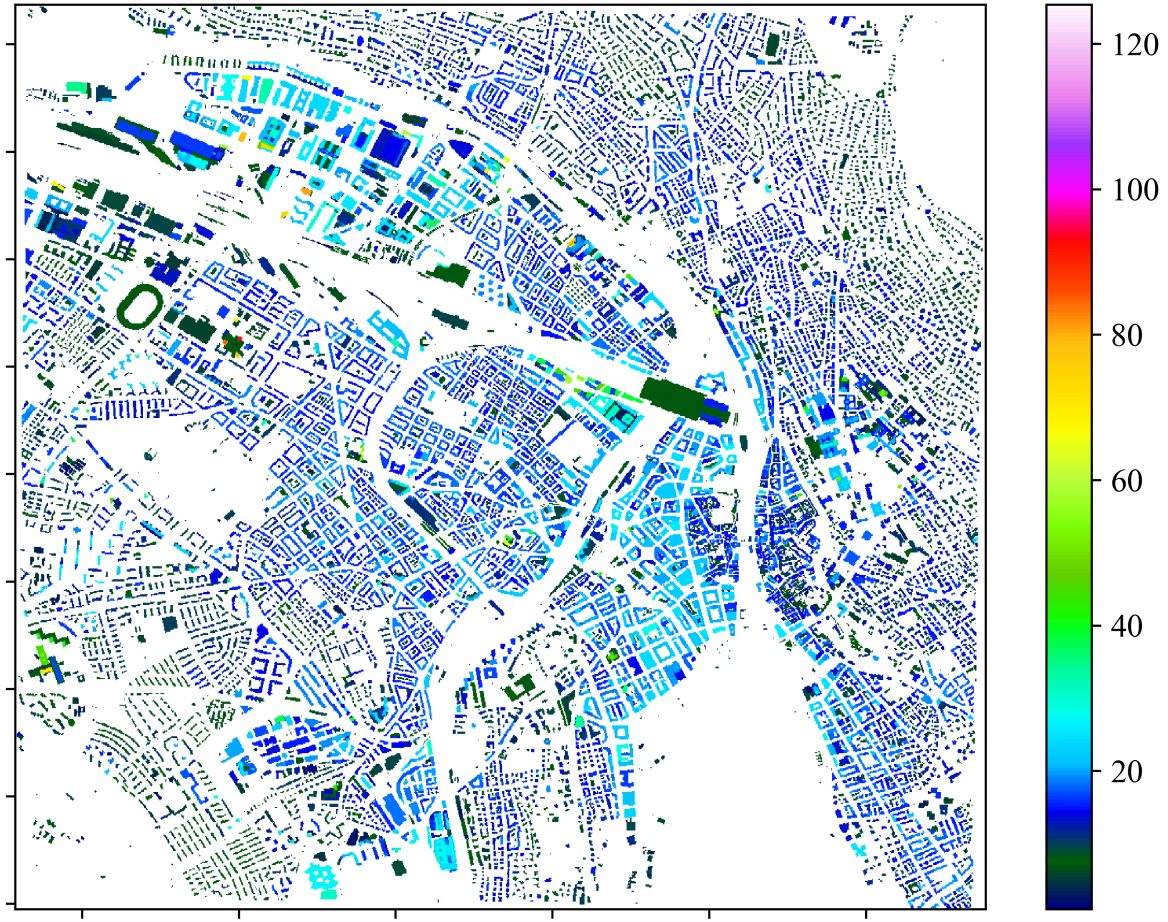
Vertical nesting
Buildings and complex terrain
WRF

Swiss 3D buildings data

Precision: ±30cm to 50cm planimetric and altimetric

Preliminary investigation with PALM





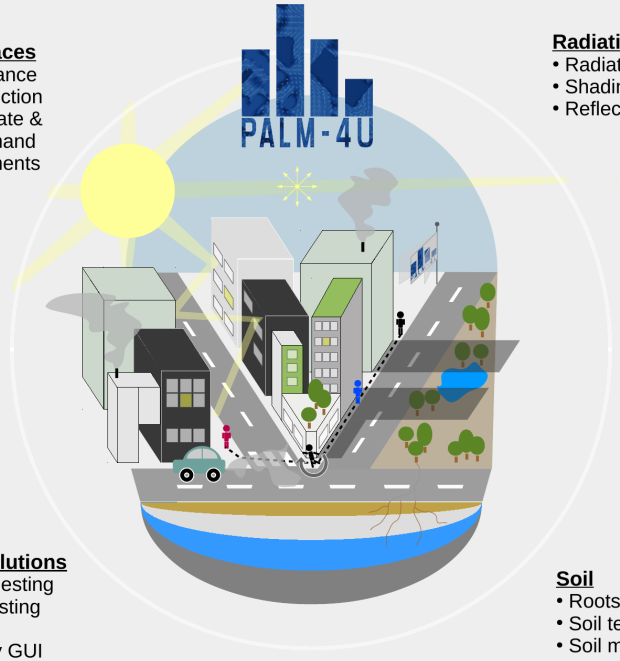
Building height [m]

Preliminary PALM

Urban surfaces
- Energy balance
- Heat conduction
- Indoor climate & energy demand
- Green elements

Chemistry
- Transport
- Reactions
- Photolysis
- Emissions
- Aerosols

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

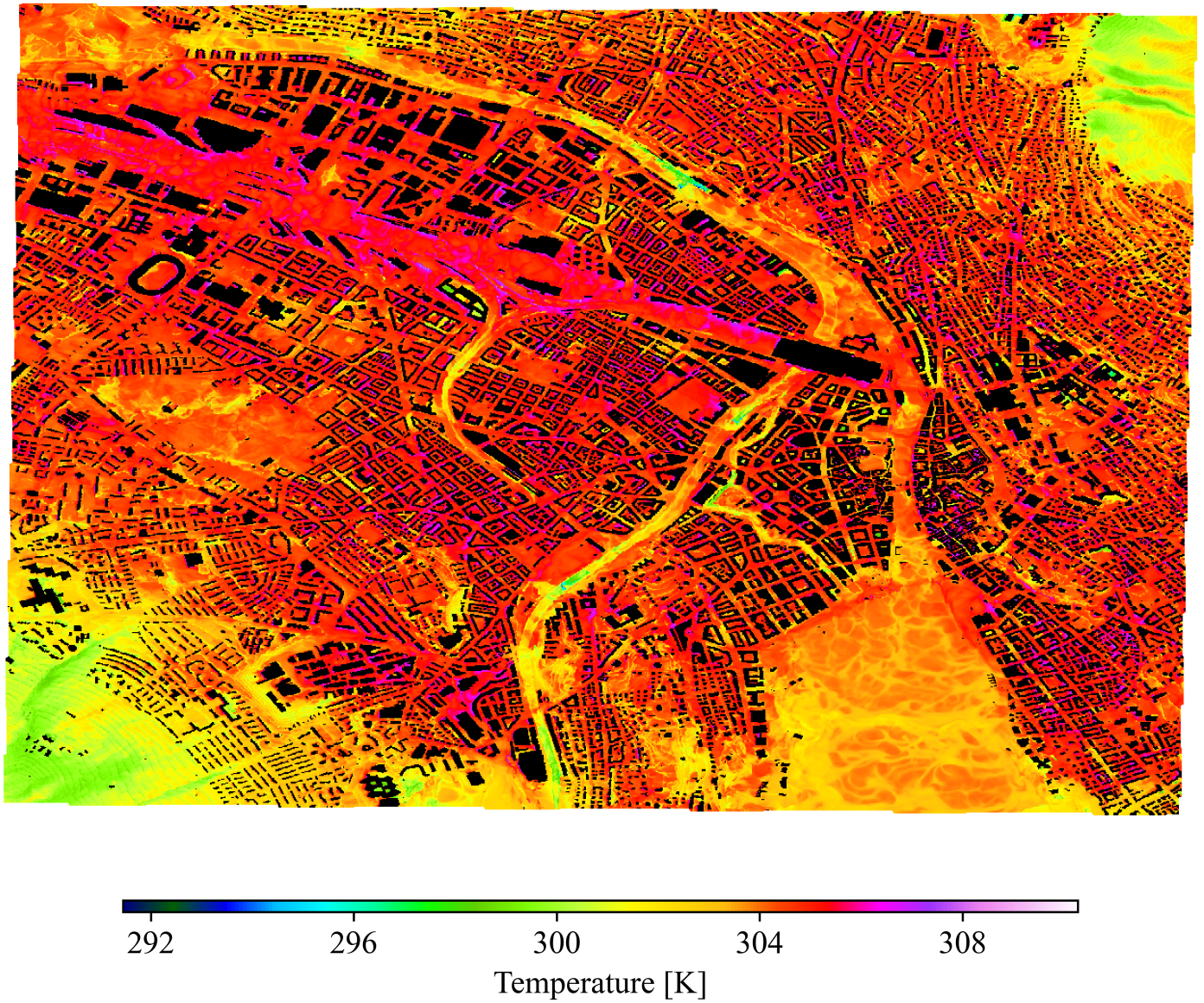


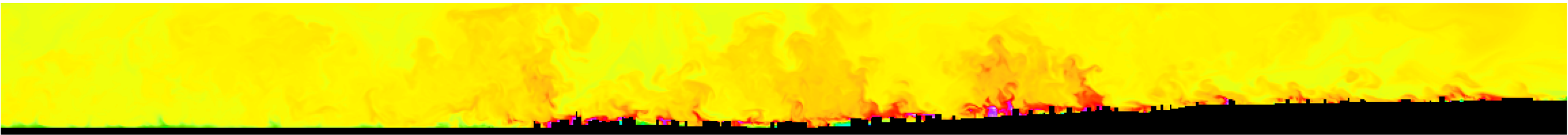
Radiation
- Radiation budget
- Shading
- Reflections

Impact
- Multi-agent system
- Biometeorological analysis

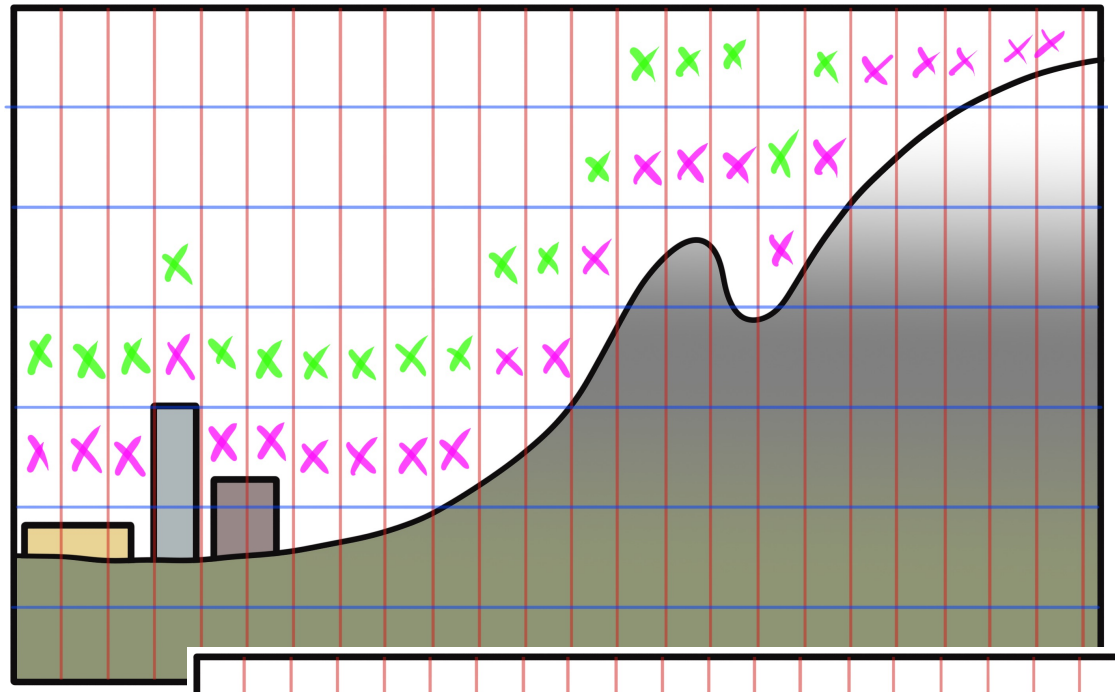
Vegetation
- Energy balance
- Momentum sink
- Shading

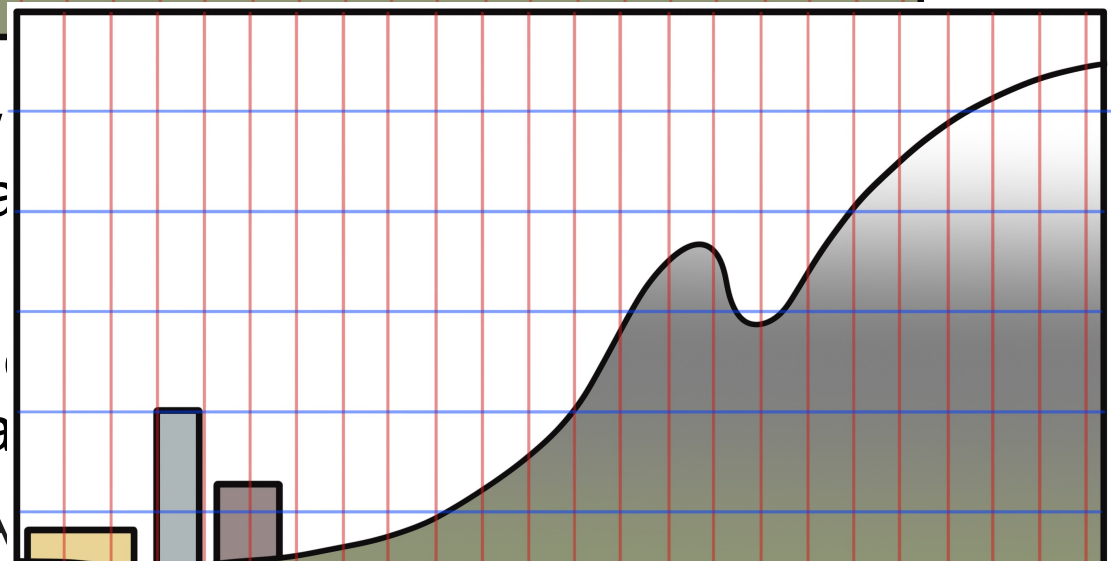
Soil
- Roots
- Soil temperature
- Soil moisture





Regular -> terrain following





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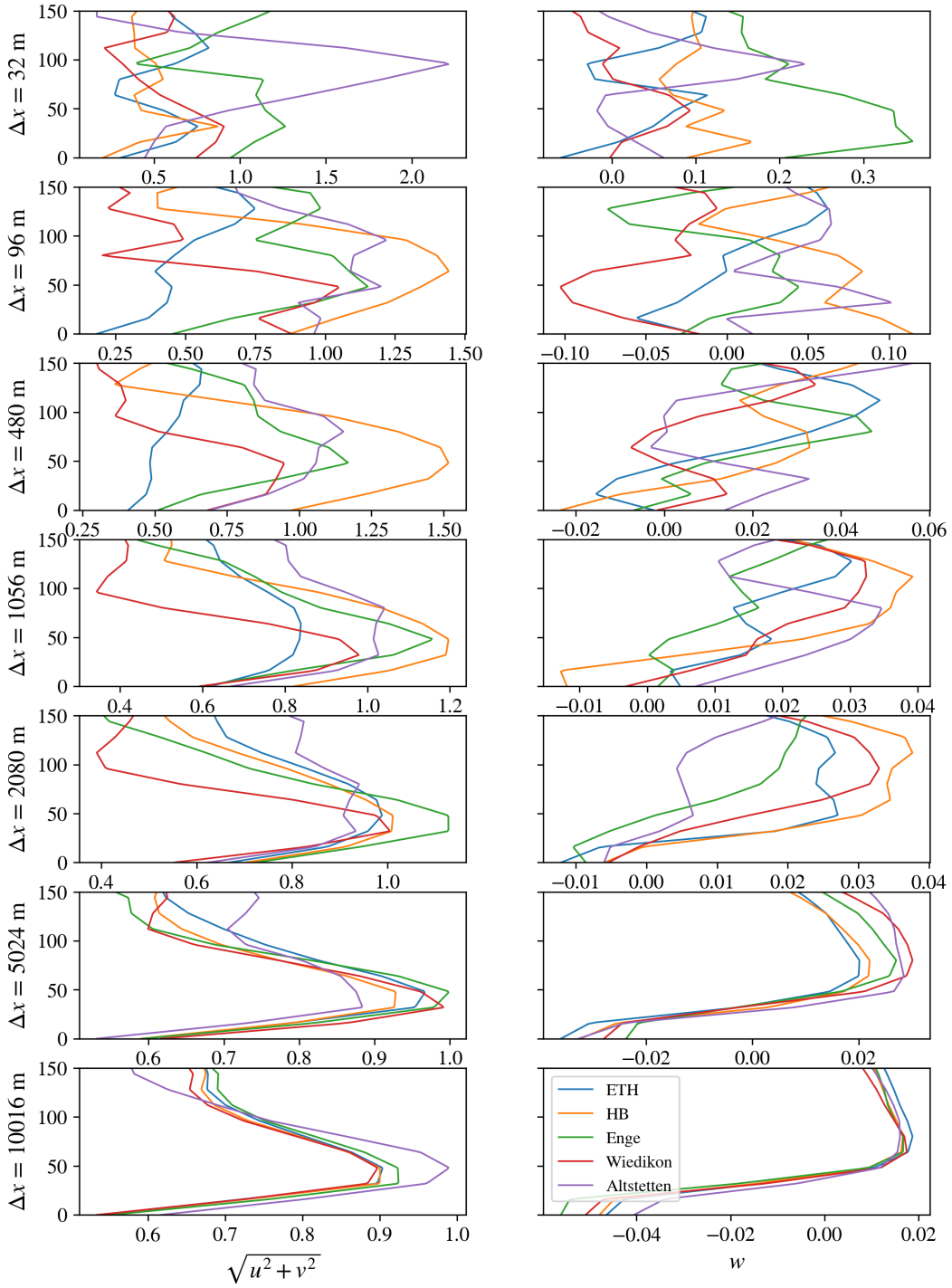
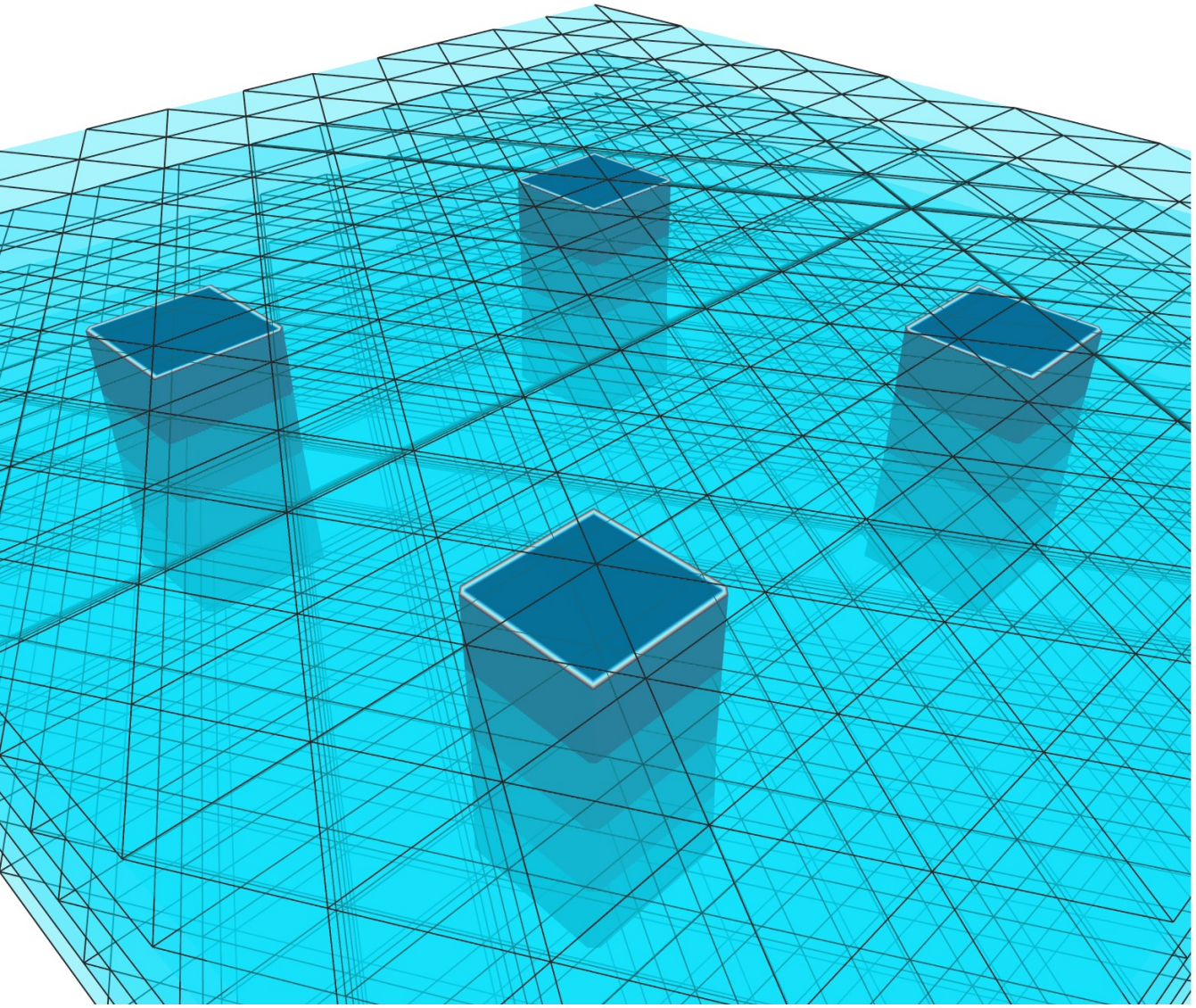
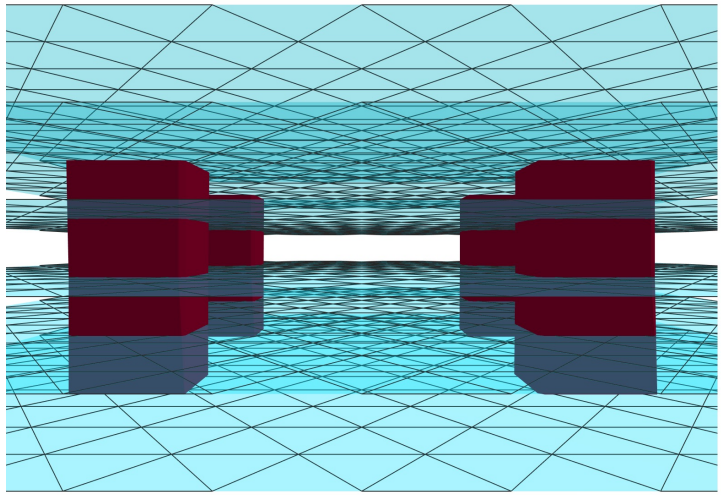


Immersed boundary method in a global model

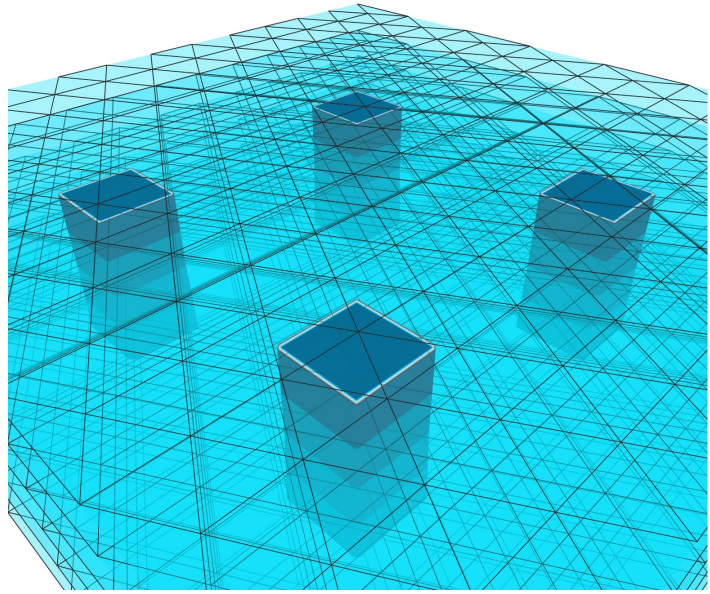




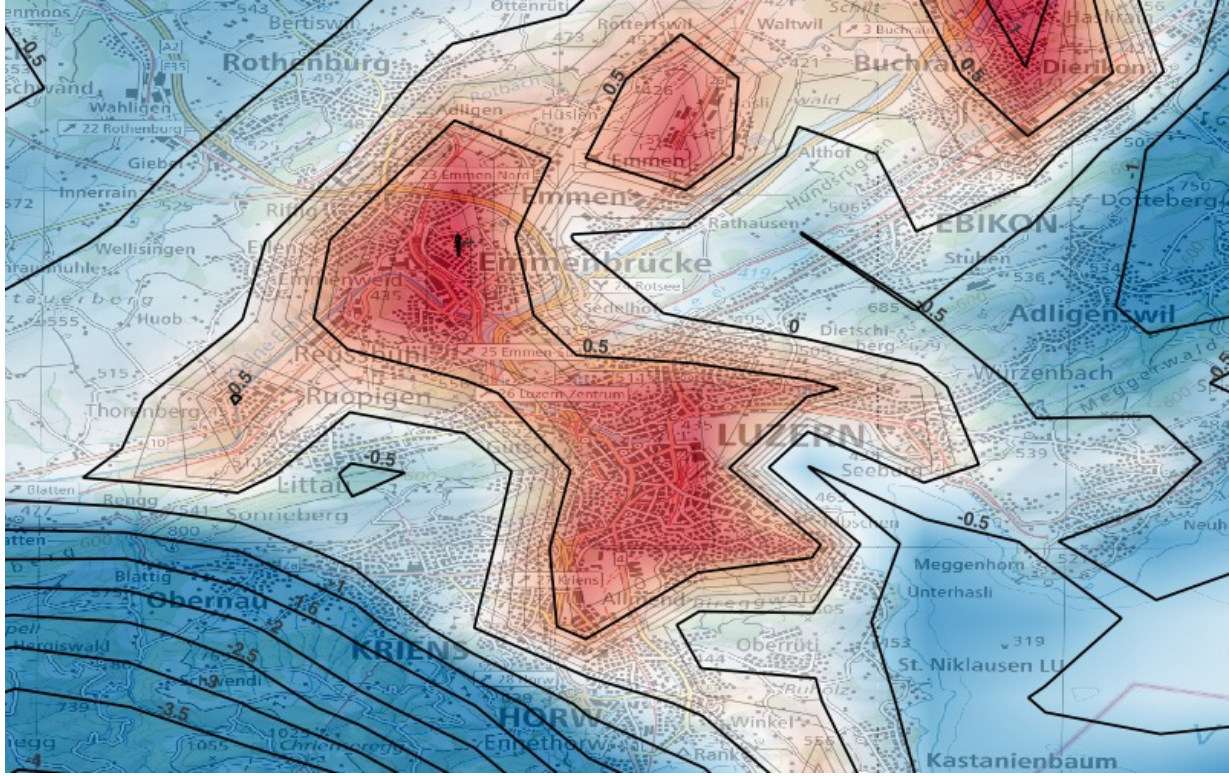
- IBM implemented with good results in the WRF model[1]
- Promising literature on IBM in unstructured triangular grids

1. K. A., Lundquist, F. K. Chow, and J. K. Lundquist. *An Immersed Boundary Method for the Weather Research and Forecasting Model*. Monthly Weather Review (2010)

Questions for you



- Is anyone else working on this? Or planning to?
- Any pros / cons about the methodology?
- Any issues specific to ICON?
- Any criticism of existing options (e.g. PALM-4U, WRF-IBM, …)
- Dynamics / parametrizations / numerics of particular interest?
- Scaling laws / similarities / assumptions...
- How to validate all this?
  Comparisons with PALM / WRF-IBM, crowd-sourced measurements, high-res measurement campaigns
- Non-CH databases for surface / buildings?



Thank you for your attention

Any questions?