

# Bochum Urban Climate Summer School 2022

## WRF Hands-on

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# Challenges of the day

- Familiarize yourself with Google Colab and the output from the Weather Research Forecasting (WRF) climate model
- Evaluation, visualisation, ... of WRF output using observations from citizen weather stations
- The role of the urban description therein (Local Climate Zones)
- Investigate the impact of rooftop mitigation strategies, that include cool roofs, green roofs and photovoltaics

# WRF

- Weather Research Forecasting (WRF) model is a state-of-the-art atmospheric modeling system
- Supported “community model”, i.e free and open source code with distributed development and centralized support.
- Development is lead by National Centre Atmospheric Research (NCAR) and National Oceanic and Atmospheric Administration (NOAA)
- Idealized simulations, real-time forecasting, weather and climate research (including urban applications!)
- Suitable for a broad spectrum of applications across scales ranging from meters to thousands of kilometers (typically used at ~1 km)
- [WRF users page](#)

<b>MODELS (settings)</b>	<b>WRF 4.4</b>
Period	19-28/07/2019
Analysis Period	20-28/07/2019
Number of domains	3
Parent grid ratio	1, 3, 3
Lat, long (grid center)	51.24, 6.97
Horizontal resolution	9, 3, 1 km
Domain size	(99x99), (100x100), (133x133) pixels
Vertical levels	44
Model / Forcing time step	54s / 6h, 18s , 6s / 1h
Forcing data	ERA-5 (30 km resolution)
Urban descriptor	Local climate zones (LCZs) (10 urban classes), interpolated . List of parameter values <a href="#">here</a> .
Vegetation	MODIS
Urban	BEP+BEM & RMS (Martilli 2002, Zonato 2021)
Spectral nudging	OFF
Air Conditioning	ON

# Available WRF simulations

geo_em name	Simulation name	Description
geo_em.d03		
geo_em.d03_NoUrban	NOURBAN_SIM	Basic run, where the urban land cover is replaced by its neighbouring natural land cover ( <i>W2W</i> )
geo_em.d03_LCZ_extent	LCZ_NORMS_EXTENT_SIM	<i>LCZ</i> extent only, yet binary urban class with default urban parameters ( <i>W2W</i> )
geo_em.d03_LCZ_params	LCZ_NORMS_SIM	<i>LCZ</i> urban description, including intra-urban heterogeneity and spatially explicit urban parameters ( <i>W2W</i> )
geo_em.d03_LCZ_params	LCZ_CR_SIM	<i>LCZ</i> urban description, <u>cool roofs</u> , total coverage ( <i>Zonato et al., 2021</i> )
geo_em.d03_LCZ_params	LCZ_GR_SIM	<i>LCZ</i> urban description, <u>green roofs</u> , total coverage ( <i>Zonato et al., 2021</i> )
geo_em.d03_LCZ_params	LCZ_PVP_SIM	<i>LCZ</i> urban description, <u>rooftop photovoltaic panels</u> , total coverage ( <i>Zonato et al., 2021</i> )

# Variable in output from the simulations:

- XLAT, XLONG: Coordinates of the center of the grid cell
- T2, TSK, T: 2m air temperature, skin temperature, vertical potential temperature
- HGT: Terrain Height
- U10,V10,U,V: 10-m wind speeds, vertical profiles
- CM\_AC\_URB3D: Energy consumption by air conditioning
- EP\_PV\_URB3D: Energy produced by RPVPs
- HFX,LH: Sensible/Latent heat fluxes
- PBLH: PBL height
- SWDOWN,GLW: Short/Long-wave radiation at the surface
- TKE\_PBL: Turbulent kinetic energy

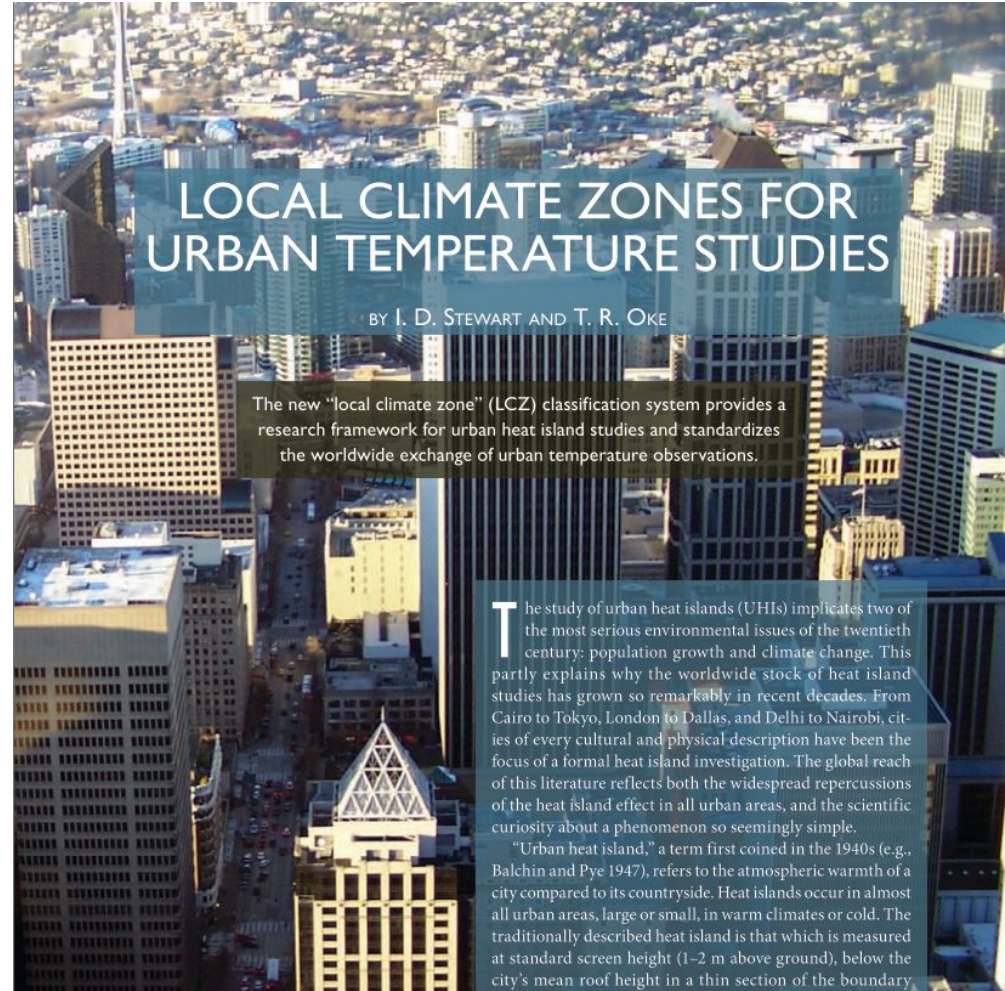
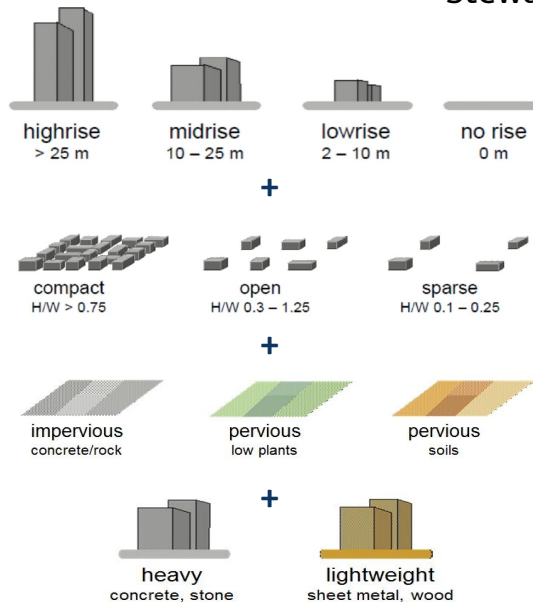
How to setup WRF ...



# Local Climate Zones

75% of the 190 reviewed urban heat island studies published between 1950-2007 **failed to communicate basic metadata** regarding instrumentation and field site characteristics.

Stewart et al. (2011)





# Local Climate Zones

## Built types

1



**Compact highrise**

Dense mix of tall buildings to tens of stories. Few or no trees. Land cover mostly paved. Concrete, steel, stone, and glass construction materials.

2



**Compact midrise**

Dense mix of midrise buildings (3-9 stories). Few or no trees. Land cover mostly paved. Stone, brick, tile, and concrete construction materials.

3



**Compact lowrise**

Dense mix of lowrise buildings (1-3 stories). Few or no trees. Land cover mostly paved. Stone, brick, tile, and concrete construction materials.


4



**Open highrise**

Open arrangement of tall buildings to tens of stories. Abundance of pervious land cover (low plants, trees). Concrete, steel, stone, and glass construction materials.


5



**Open midrise**

Open arrangement of midrise buildings (3-9 stories). Abundance of pervious land cover (low plants, scattered trees). Concrete, steel, stone, and glass construction materials.

6



**Open lowrise**

Open arrangement of lowrise buildings (1-3 stories). Abundance of pervious land cover (low plants, scattered trees). Wood, brick, stone, tile, and concrete construction materials.

7



**Lightweight lowrise**

Dense mix of single-story buildings. Few or no trees. Land cover mostly hard-packed. Lightweight construction materials (e.g., wood, thatch, corrugated metal).

8



**Large lowrise**

Open arrangement of large lowrise buildings (1-3 stories). Few or no trees. Land cover mostly paved. Steel, concrete, metal, and stone construction materials.

9



**Sparsely built**

Sparse arrangement of small or medium-sized buildings in a natural setting. Abundance of pervious land cover (low plants, scattered trees).

10




**Heavy industry**

Lowrise and midrise industrial structures (towers, tanks, stacks). Few or no trees. Land cover mostly paved or hard-packed. Metal, steel, and concrete construction materials.

## Land cover types


A



**Dense trees**

Heavily wooded landscape of deciduous and/or evergreen trees. Land cover mostly pervious (low plants). Zone function is natural forest, tree cultivation or urban park.


B



**Scattered trees**

Lightly wooded landscape of deciduous and/or evergreen trees. Land cover mostly pervious (low plants). Zone function is natural forest, tree cultivation, or urban park.


C



**Bush, scrub**

Open arrangement of bushes, shrubs, and short, woody trees. Land cover mostly pervious (bare soil or sand). Zone function is natural scrubland or agriculture.


D



**Low plants**

Featureless landscape of grass or herbaceous plants/crops. Few or no trees. Zone function is natural grassland, agriculture, or urban park.


E



**Bare rock or paved**

Featureless landscape of rock or paved cover. Few or no trees or plants. Zone function is natural desert (rock) or urban transportation.


F



**Bare soil or sand**

Featureless landscape of soil or sand cover. Few or no trees or plants. Zone function is natural desert or agriculture.

G



**Water**

Large, open water bodies such as seas and lakes, or small bodies such as rivers, reservoirs, and lagoons.

**VARIABLE LAND COVER PROPERTIES**

Variable or ephemeral land cover properties that change significantly with synoptic weather patterns, agricultural practices, and/or seasonal cycles.

b. bare trees

Leafless deciduous trees (e.g., winter). Increased sky view factor. Reduced albedo.

s. snow cover

Snow cover >10 cm in depth. Low admittance. High albedo.

d. dry ground

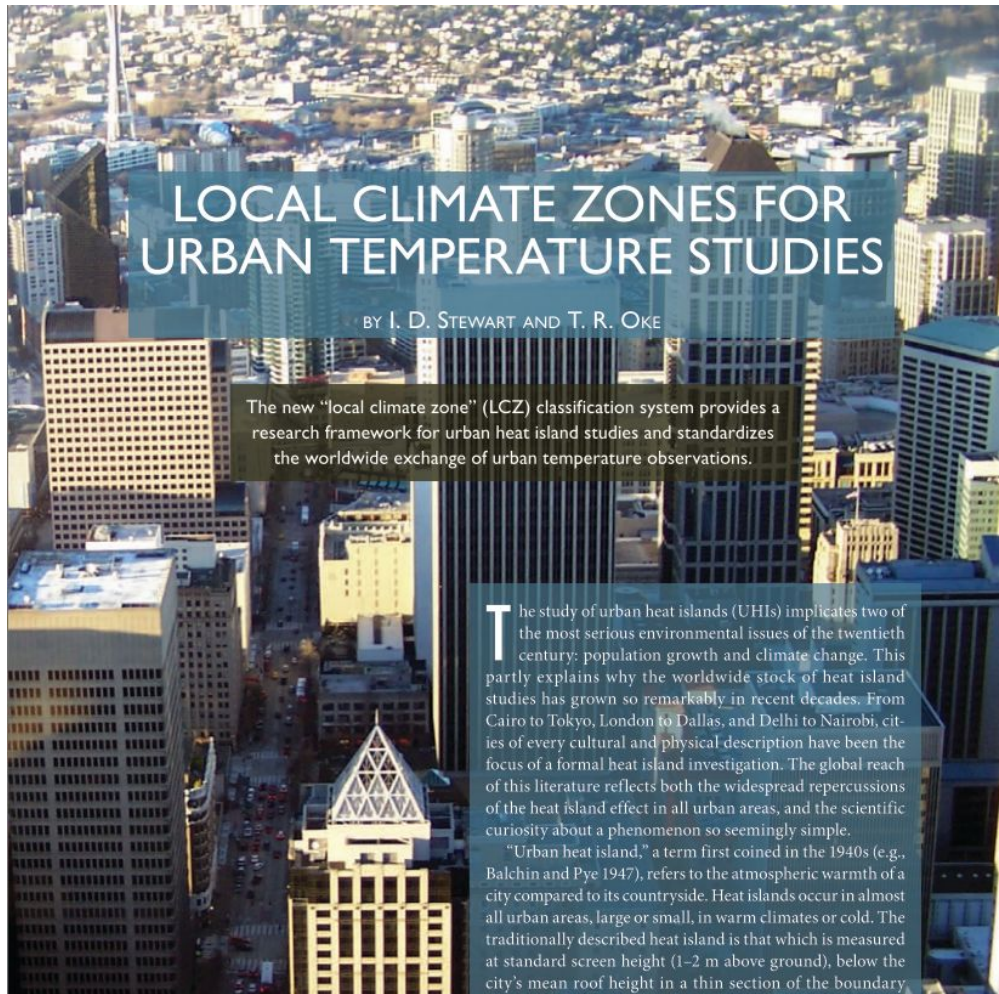
Parched soil. Low admittance. Large Bowen ratio. Increased albedo.

w. wet ground

Waterlogged soil. High admittance. Small Bowen ratio. Reduced albedo.



Stewart et al. (2012), Demuzere et al. (2020)



## LOCAL CLIMATE ZONES FOR URBAN TEMPERATURE STUDIES

BY I. D. STEWART AND T. R. OKE

The new "local climate zone" (LCZ) classification system provides a research framework for urban heat island studies and standardizes the worldwide exchange of urban temperature observations.

The study of urban heat islands (UHIs) implicates two of the most serious environmental issues of the twentieth century: population growth and climate change. This partly explains why the worldwide stock of heat island studies has grown so remarkably in recent decades. From Cairo to Tokyo, London to Dallas, and Delhi to Nairobi, cities of every cultural and physical description have been the focus of a formal heat island investigation. The global reach of this literature reflects both the widespread repercussions of the heat island effect in all urban areas, and the scientific curiosity about a phenomenon so seemingly simple.

"Urban heat island," a term first coined in the 1940s (e.g., Balchin and Pye 1947), refers to the atmospheric warmth of a city compared to its countryside. Heat islands occur in almost all urban areas, large or small, in warm climates or cold. The traditionally described heat island is that which is measured at standard screen height (1-2 m above ground), below the city's mean roof height in a thin section of the boundary



# Local Climate Zones

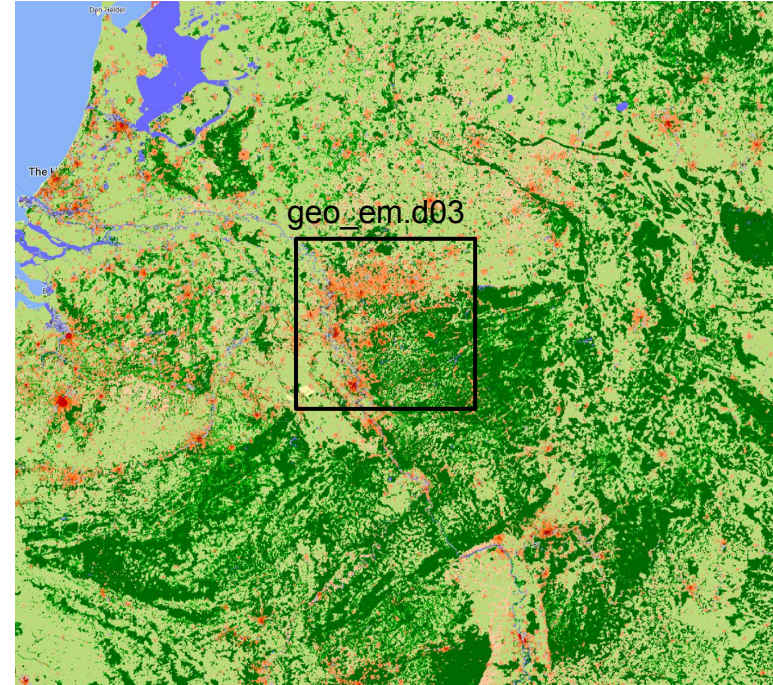
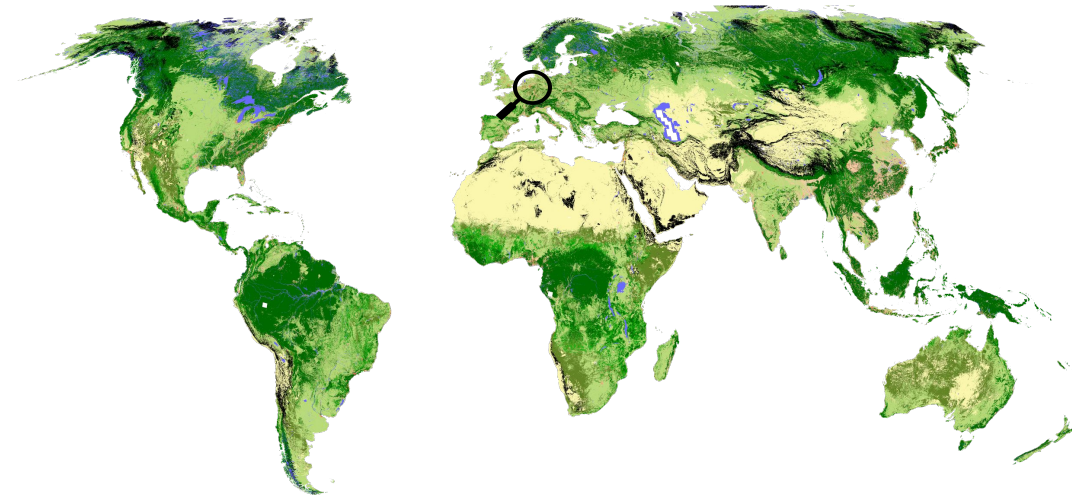
Earth Syst. Sci. Data, 14, 3835–3873, 2022  
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Open Access  
Earth System  
Science  
Data

## A global map of local climate zones to support earth system modelling and urban-scale environmental science

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Iain D. Stewart<sup>4</sup>, Jasper van Vliet<sup>5</sup>, and Benjamin Bechtel<sup>1</sup>




# W2W: WUDAPT-to-WRF



## W2W: A Python package that injects WUDAPT's Local Climate Zone information in WRF

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DOI: [10.21105/joss.04432](https://doi.org/10.21105/joss.04432)

### Software

- [Review](#) 
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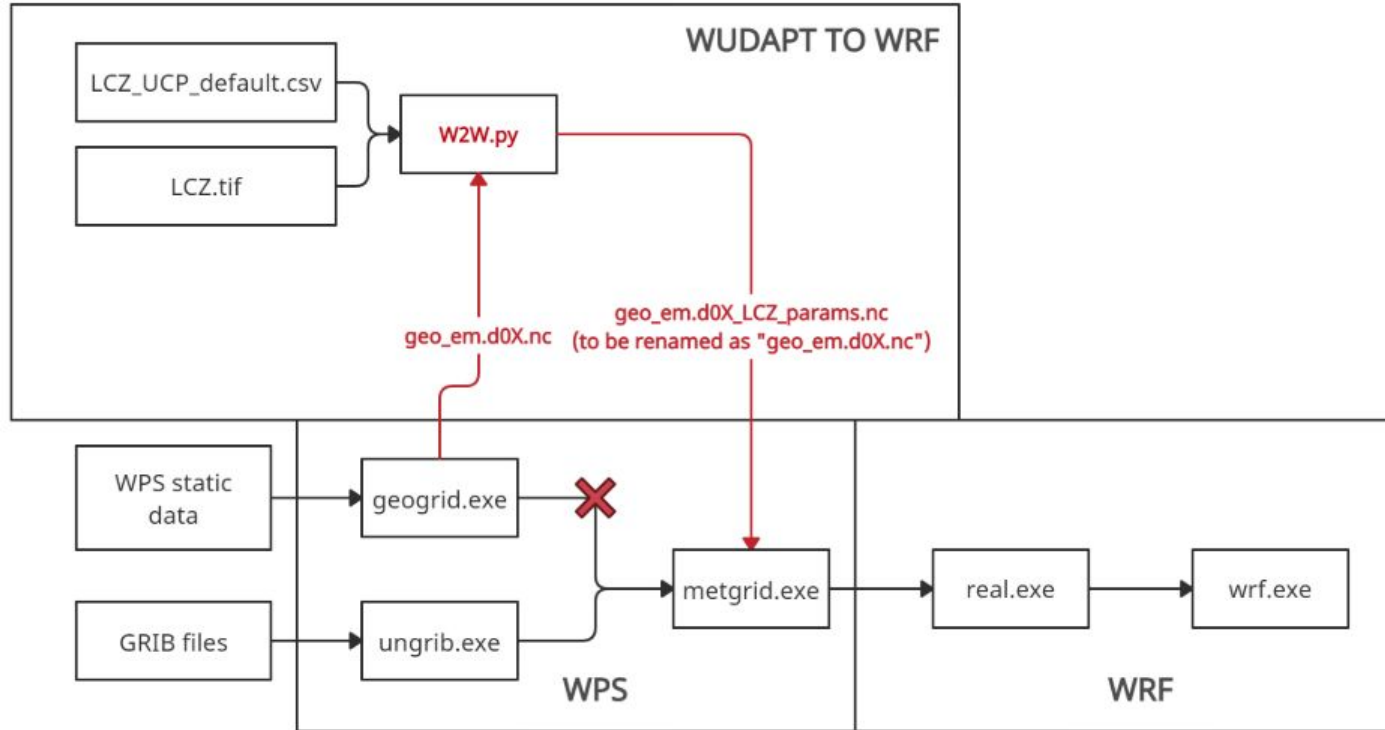
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## Summary

The Python-based WUDAPT-to-WRF (w2w) package is developed to translate Local Climate Zone (LCZ) maps into urban canopy parameters readable by WRF, the community “Weather Research and Forecasting” model ([Skamarock et al., 2021](#)). It is the successor of the Fortran-based w2w package developed by Brousse et al. (2016) and Martilli et al. (2016), and provides an improved, simpler, and more efficient procedure to use LCZ information in WRF. Some important changes include direct manipulation of the geogrid files without the creation of temporary files, and the use of average LCZ-based urban morphological parameters instead of assigning them to the modal LCZ class.

This development of this package is in line with the objectives of WUDAPT, the World Urban Database and Access Portals Tools community project, that aims to 1) acquire and make accessible coherent and consistent information on the form and function of urban morphology relevant to climate weather and environmental studies, and 2) provide tools that extract relevant urban parameters and properties for models and model applications at appropriate scales for various climate, weather, environment, and urban planning purposes ([Ching et al., 2018](#)).

# W2W: WUDAPT-to-WRF

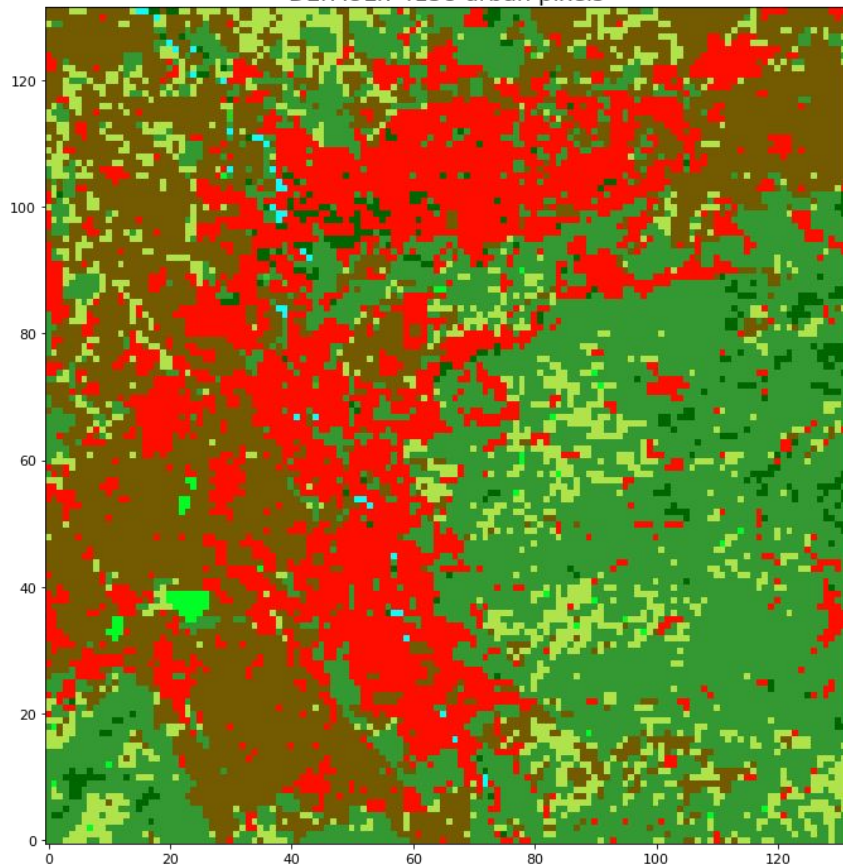


**Figure 1:** Modified workflow to set up and run a WRF simulation including urban parameters derived from LCZs using W2W.



# W2W: WUDAPT-to-WRF

DEFAULT: 4158 urban pixels

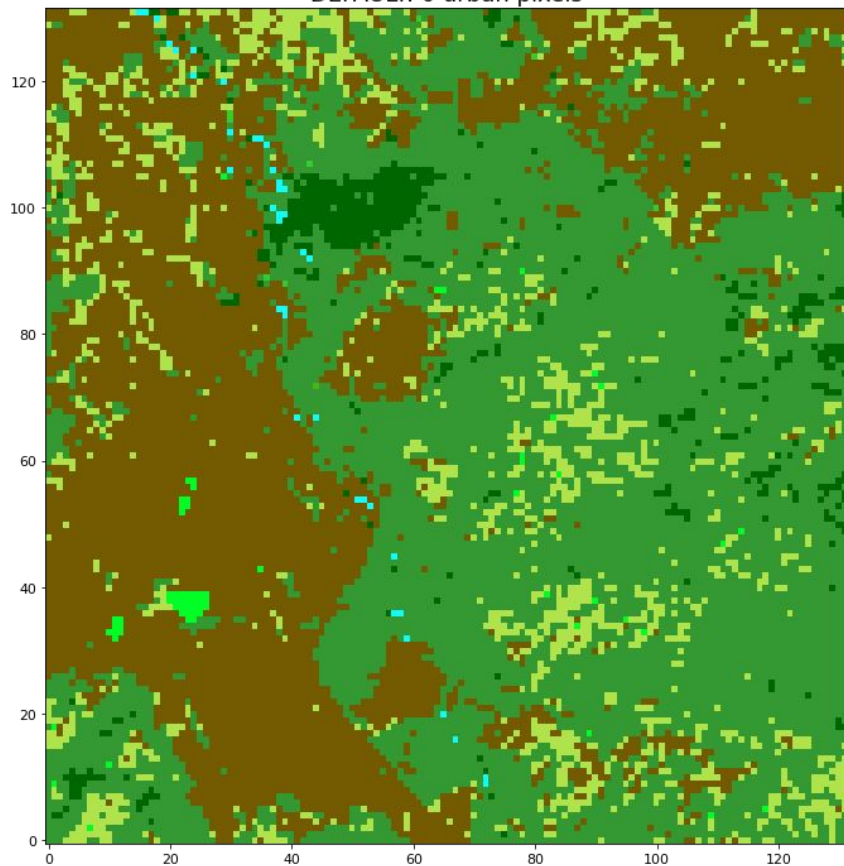


W\_INDEX

geo\_em.d03

# W2W: WUDAPT-to-WRF

DEFAULT: 0 urban pixels

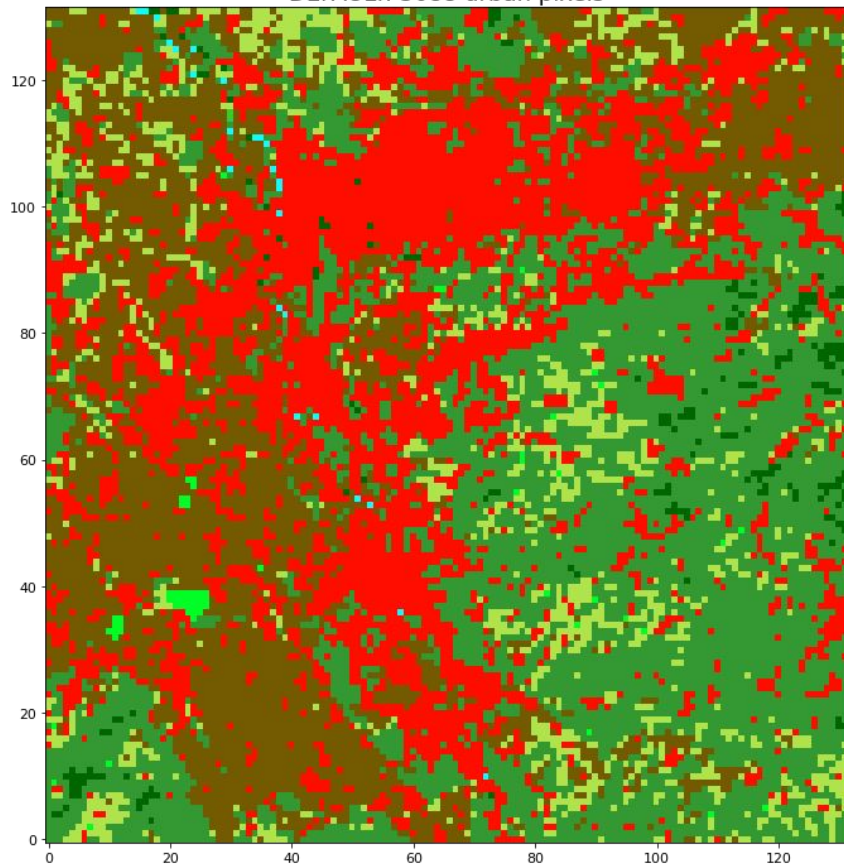


W\_INDEX

geo\_em.d03\_NoUrban

# W2W: WUDAPT-to-WRF

DEFAULT: 5088 urban pixels



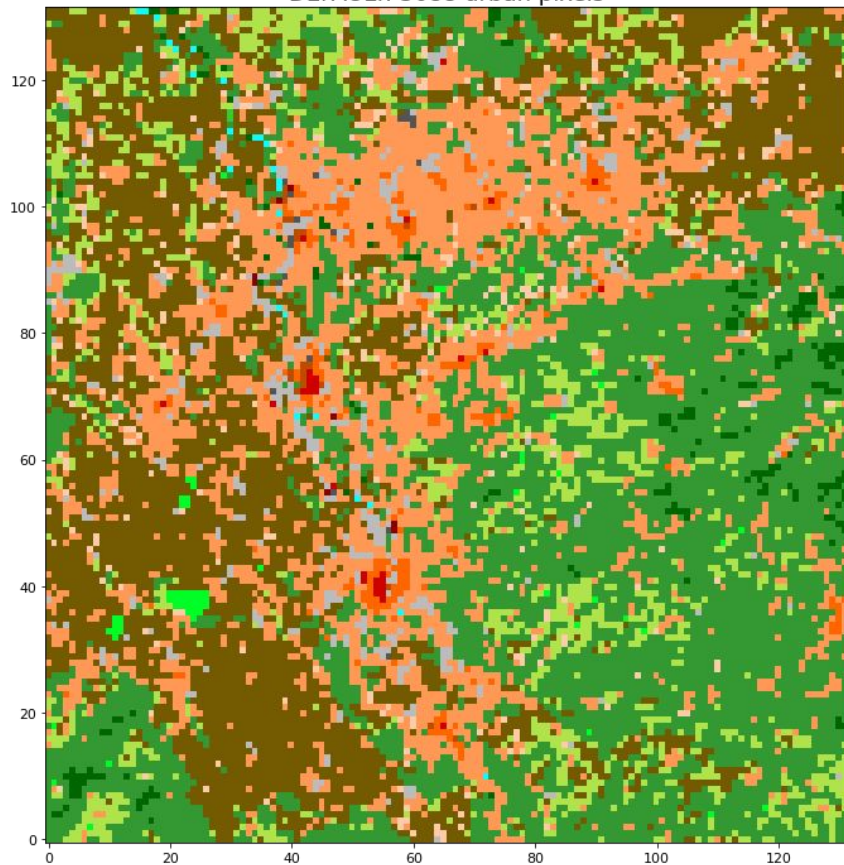
W\_INDEX

geo\_em.d03\_LCZ\_extent



# W2W: WUDAPT-to-WRF

DEFAULT: 5088 urban pixels



W\_INDEX

geo\_em.d03\_LCZ\_params

# WRF rooftop mitigation strategies

## JGR Atmospheres



### RESEARCH ARTICLE

10.1029/2021JD035002

#### Key Points:

- New parameterizations of rooftop mitigations strategies are developed and implemented into the Weather Research and Forecasting (WRF) model
- The new implementations include green roofs and photovoltaic panels, coupled with the BEP + BEM urban canopy models
- Sensitivity tests are conducted in order to evaluate the effect of RMSs on near-surface air temperature and energy consumption

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## Exploring the Effects of Rooftop Mitigation Strategies on Urban Temperatures and Energy Consumption

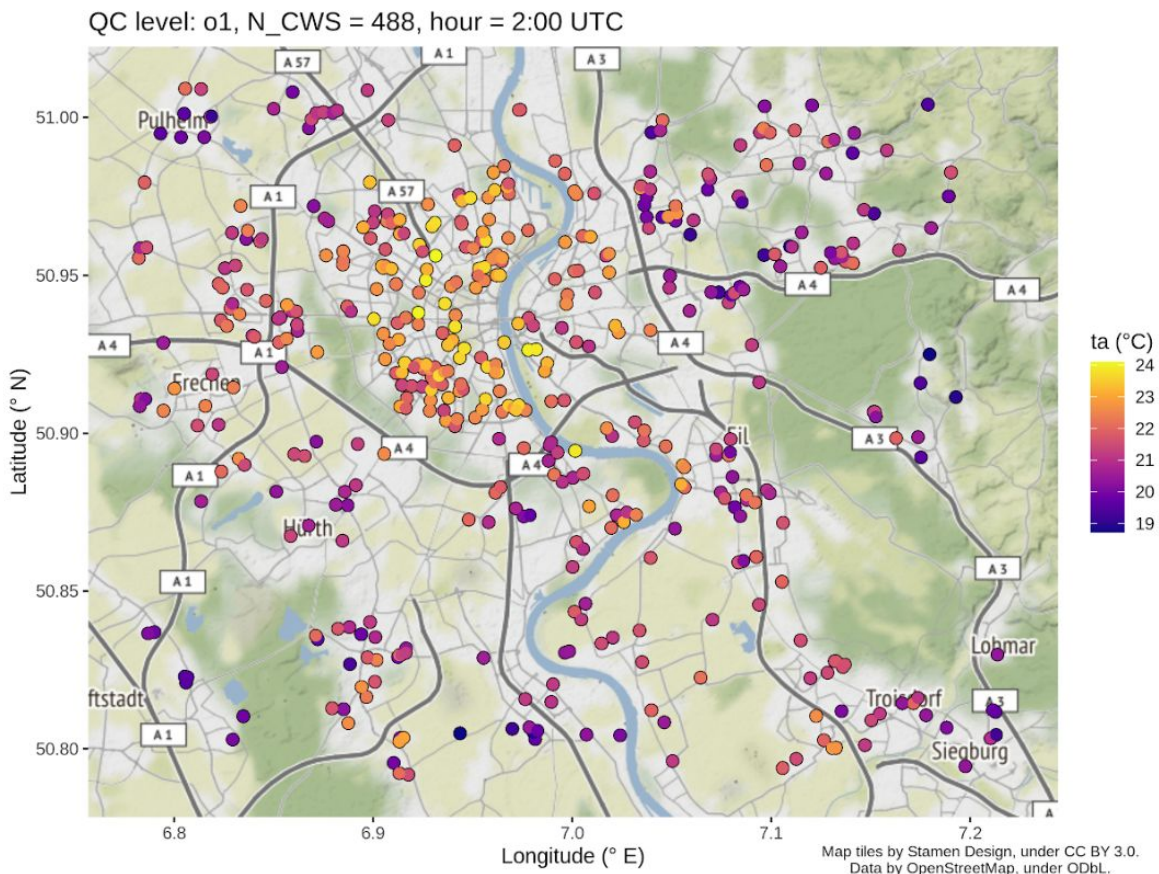
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**Abstract** This paper describes and evaluates physical parameterizations accounting for the effect of rooftop mitigation strategies (RMSs) on the urban environment, in the context of the mesoscale model Weather Research and Forecasting (WRF). Through the new implementation, the sensitivity of near-surface air temperature and building energy consumption to different RMSs is evaluated by means of numerical simulations in idealized urban areas, for typical summer and winter conditions. **Rooftop mitigation strategies considered include cool roofs, green roofs, and rooftop photovoltaic panels.** The reference case simulations are performed assuming buildings made by bricks, with roof composed of clay tiles. Results indicate that near-surface air temperature is reduced by cool and green roofs during summer: cool roofs are the most efficient in decreasing air temperature, followed by irrigated green roofs. Photovoltaic panels, instead, induce a temperature increase during daytime and a small decrease during nighttime. Cool roofs reveal to be the most efficient strategy in reducing the energy consumption by air conditioning systems. During wintertime, green roofs maintain a higher near-surface air temperature than clay tile roofs and largely decrease energy consumption. Even PVPs increase air temperature, as in the summer case. On the other hand, cool roofs reduce near-surface air temperature during daytime, inducing an increase in energy consumption. The results presented here show that the parameterization schemes implemented in the WRF model can be a valuable tool to evaluate the effects of mitigation strategies in the urban environment.

# Observations

## Quality-controlled Netatmo observations (N=5000+)



# Visualizations

- A number of python routines are available to plot various WRF input/output, where possible together with available observations.
- These scripts will be explained in Google Colab directly!

# Student presentations

At the end of the WRF hands-on session, we'd like all of you to present some of your results. This does not have to be done individually, but can be done as a team (4 to 5 people).

Some guidance:

- What are the research question(s) you tried to address?
- How did you tackle this (these) questions
- What are the results?
- Can you provide a physical interpretation of these results?
- What are the caveats? E.g. what type of information would have been beneficial to interpret the results, but that was not available?

Feel free to use the above-mentioned guidelines to prepare a ~ 3 to 5 slide presentation, as a team!

# Potential research questions?

- Understand the urban morphology features at the mesoscale meteorological model scale
- Understand the dependence of UHI on LCZs from netatmo measurements
- Evaluate the model skills and weaknesses in reproducing observed temperatures
- Estimate the city-wide impact of various rooftop mitigation strategies
- Estimate the dependence of rooftop mitigation strategies on LCZs
- Identify the effect of various rooftop mitigation strategies on the consumption by air conditioning systems (ACS)
- Estimate the modification induced by rooftop mitigation strategies on land-surface and boundary layer variables (Sensible/Latent heat flux, PBL height...)