

A global map of Local Climate Zones

to support earth system modelling and urban scale environmental science

Matthias Demuzere

Benjamin bechtel

Jonas Kittner

& many more



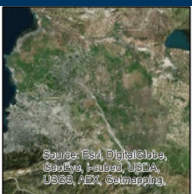
matthias.demuzere@rub.de



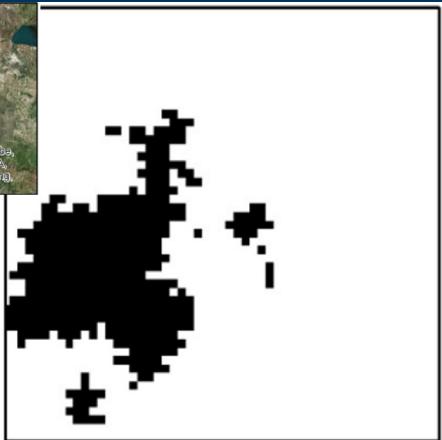
[mdemuzere](#)



Context



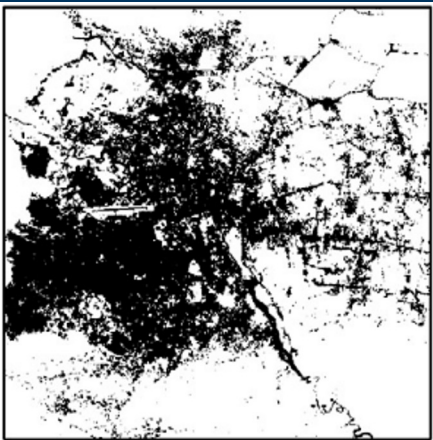
Port-au-prince



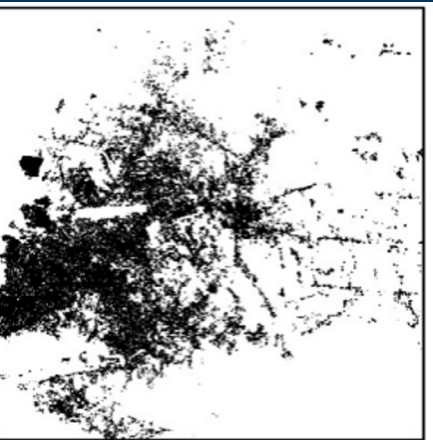
MODIS 500



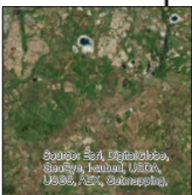
GlobeLand30



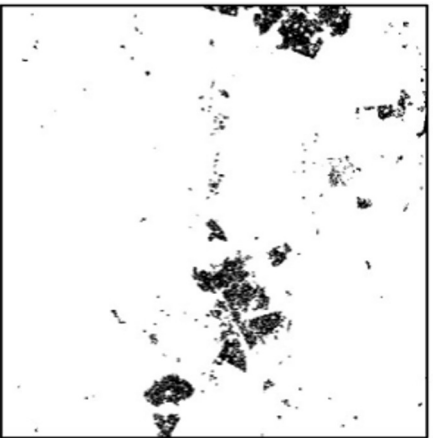
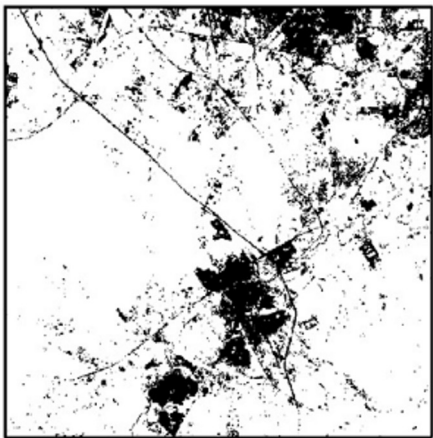
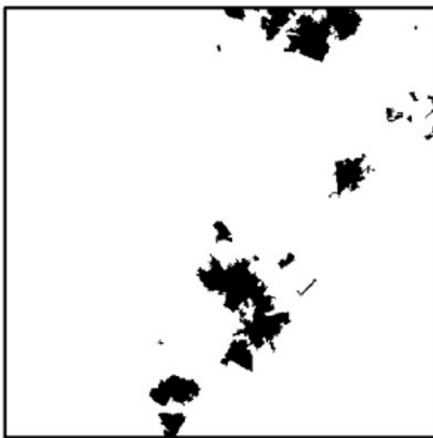
GHSL



GUF



Johannesburg



Esch et al. (2017)

WUDAPT

An Urban Weather, Climate, and Environmental Modeling Infrastructure for the Anthropocene

J. CHING, G. MILLS, B. BECHTEL, L. SEE, J. FEDDEMA, X. WANG, C. REN, O. BROUSSE, A. MARTILLI,
M. NEOPHYTOU, P. MOUZOURIDES, I. STEWART, A. HANNA, E. NG, M. FOLEY, P. ALEXANDER, D. ALIAGA,
D. NIYOGI, A. SHREEVASTAVA, P. BHALACHANDRAN, V. MASSON, J. HIDALGO, J. FUNG, M. ANDRADE,
A. BAKLANOV, W. DAI, G. MILCINSKI, M. DEMUZERE, N. BRUNSELL, M. PESARESI, S. MIAO, Q. MU,
F. CHEN, AND N. THEEUWES

→ world Urban Database and Access Portal Tools

WUDAPT is an international community-generated urban canopy information and modeling infrastructure to facilitate urban-focused climate, weather, air quality, and energy-use modeling application studies

WUDAPT Levels 0, 1 & 2 features and their potential applications.

| Product | Level 0 | Level 1 | Level 2 |
|--------------|--|---|---|
| Coverage | Over 120 cities and regions | Data gathering methods; and testing to refine Level 0 based on crowdsourcing APPS and Building Typology approaches as in MAppUCE | Any city by using our new 3-D mapping technology, DSC |
| Data source | Landsat + Google Earth + local data & expert evaluation | Landsat + Google Earth + local data & expert evaluation | World-view Stereo Data + Terra-SAR data |
| Resolution | 100–500 m | 100–500 m | 2 m |
| Format | kml, tiff | GIS shapefiles | GIS shapefiles |
| Applications | Environment and Energy (Weather Research and Forecasting (WRF) Modeling, Urban heat island) Urban and Regional planning (population density) | Environment and Energy (weather and climate, urban air flows, urban radiation, mean radiant temperature, urban energy consumption, air pollution, CO2 and GHG emission) Ecology (biodiversity) Urban and Regional planning (master plan, land use plan, green master plan, new town plan) | Environment and Energy (building energy cost) Building and community design (visibility analysis, building development) Disaster and risk management (Flooding, heatwave) Pedestrian and citizen's mobility (walkability, thermal comfort) Public health (polluted areas) |


WUDAPT?


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| | Local Climate Zone maps | | |


Local Climate Zones (LCZs)?


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.

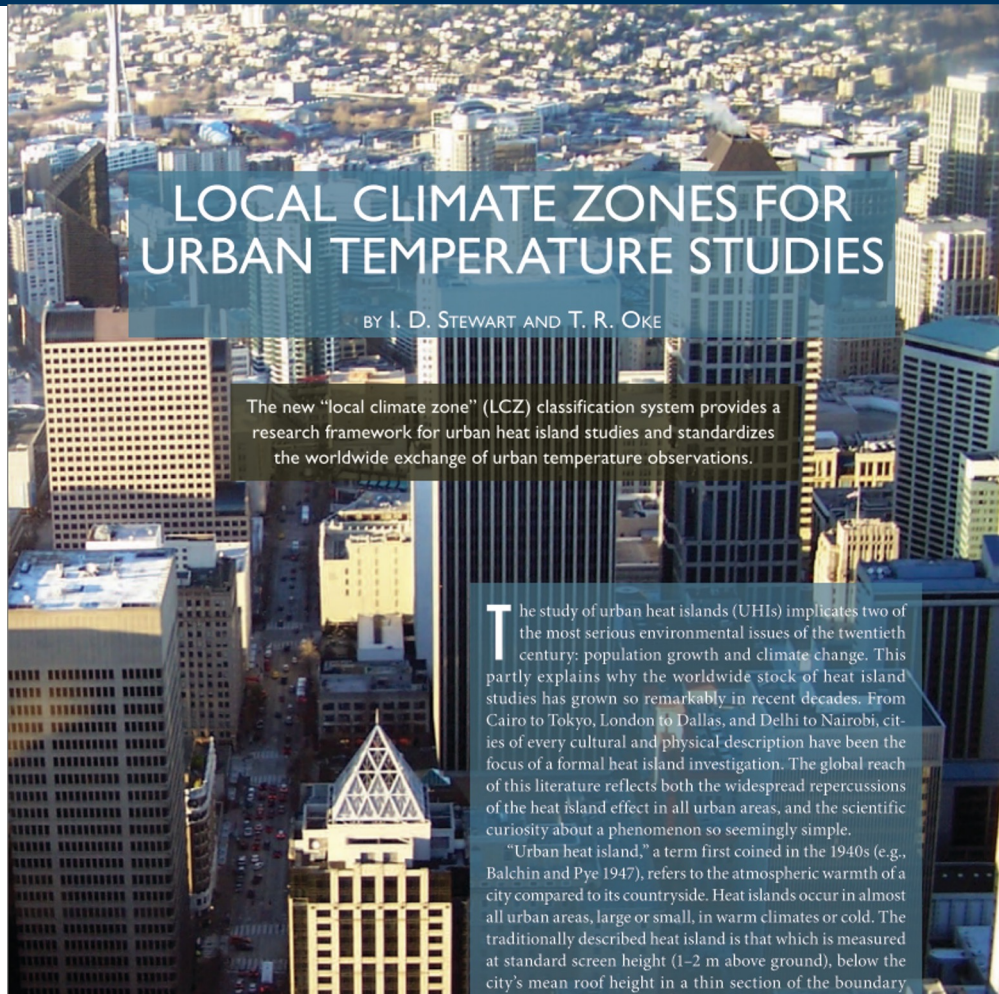
VARIABLE LAND COVER PROPERTIES

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

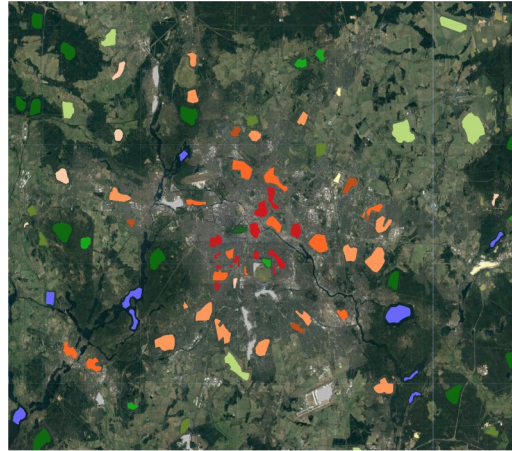
BY I. D. STEWART AND T. R. OKE

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.

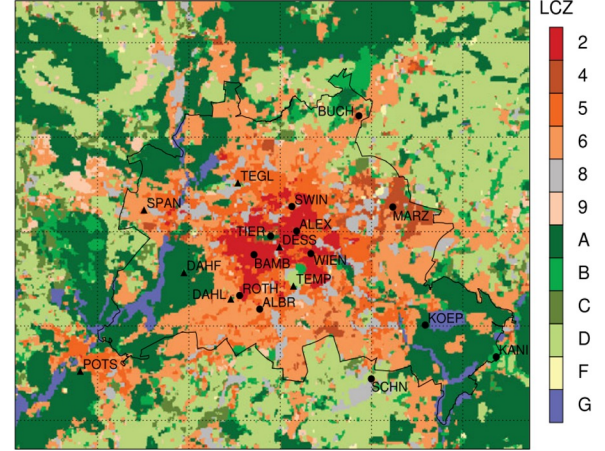
“Urban heat island,” a term first coined in the 1940s (e.g., Balchin and Pye 1947), refers to the atmospheric warmth of a city compared to its countryside. Heat islands occur in almost all urban areas, large or small, in warm climates or cold. The traditionally described heat island is that which is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

LCZ maps?



SAGA

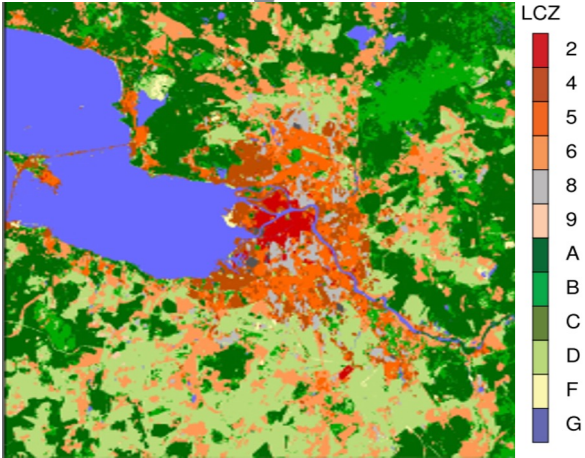
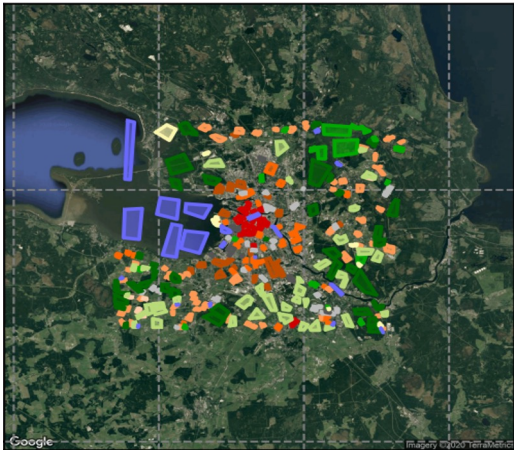
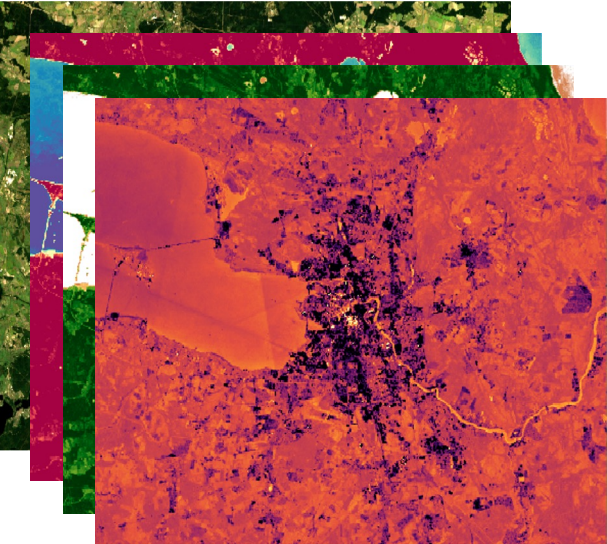
System for Automated Geoscientific Analyses



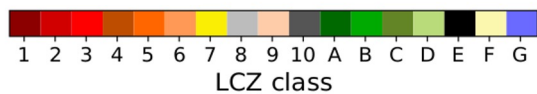
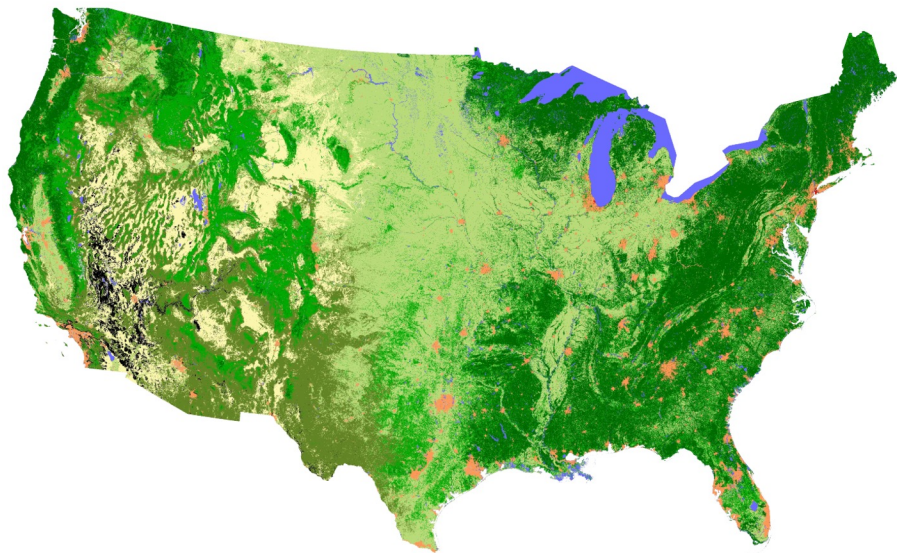
+ This method is universal, simple and objective

- It requires the download of large satellite images, and lacks an automated quality control and sufficient resources to keep dissemination up-to-date

LCZ maps in the cloud



Continental-scale LCZ maps



More LCZ maps: <https://www.wudapt.org/lcz-maps/>

LCZ database?

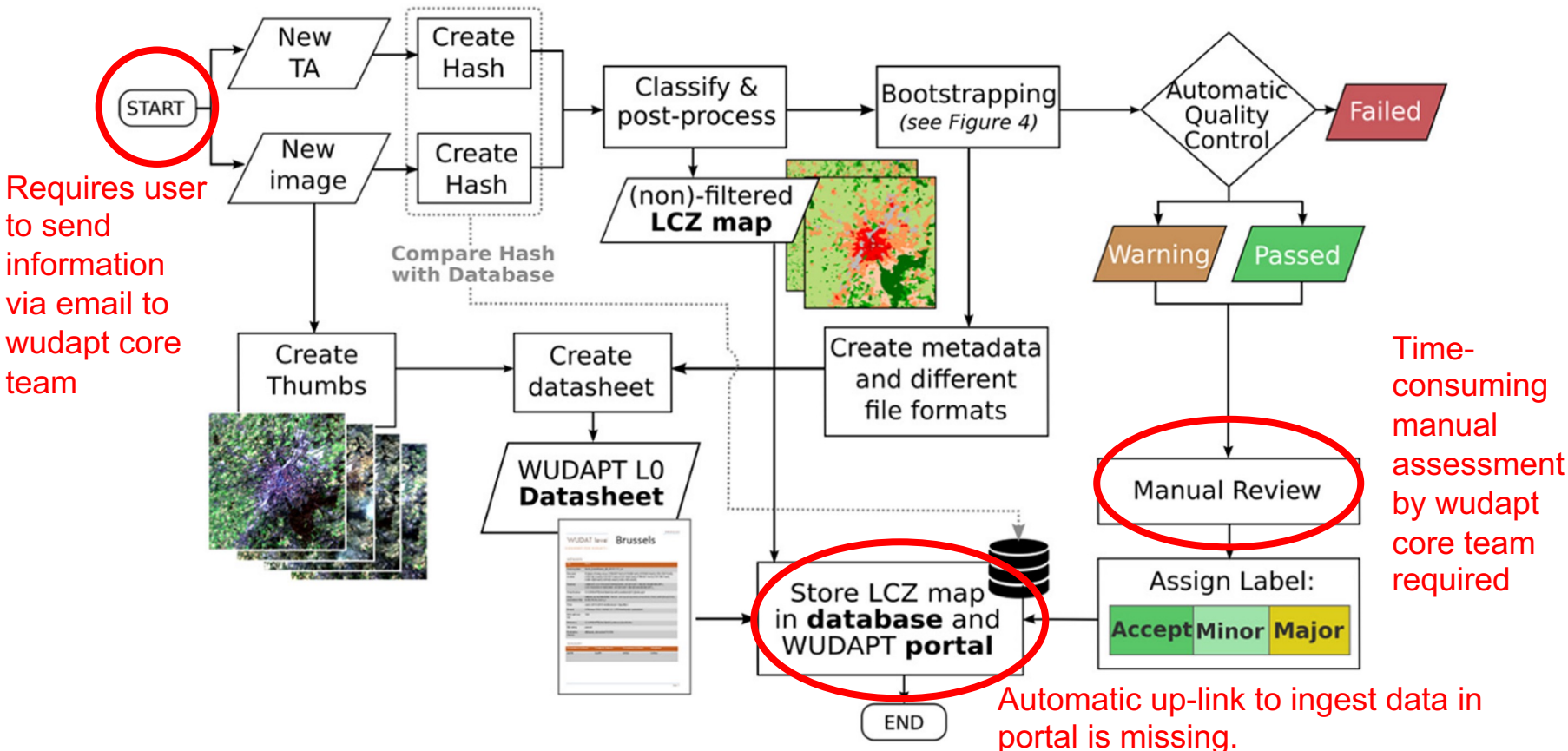
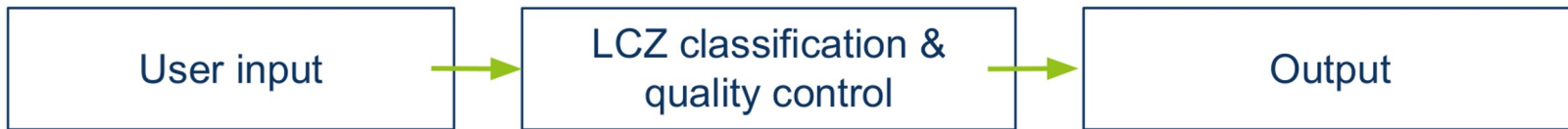


Fig. 2. The LCZ production and quality assessment workflow.

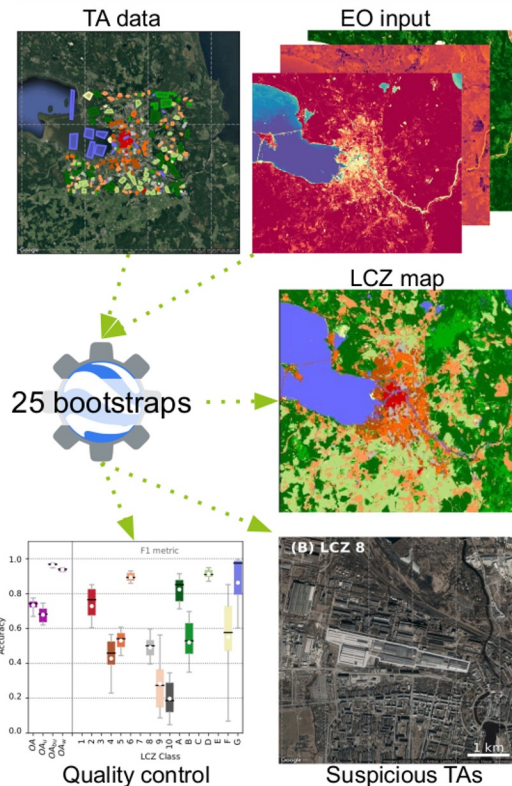


1. Personal information

- First Name
- Last Name
- E-mail Address

2. Training area information

- Continent
- Country
- City Name
- **Upload training area file**
- Representative Date
- Reference
- Remarks



1. Compressed results (e-mail)

- Factsheet
- LCZ map
- QGIS/ArcGIS colormaps

- data/
 - *ID.kml*
 - *ID_TA_statistics.csv*
 - *ID_auto_qc_polygon.shp*
 - *ID_auto_qc_point.shp*
 - *ID_cm_average_formatted.csv*
- figures/
 - *ta_freq.png*
 - *lcz_map.jpg*
 - *lcz_oa.jpg*

2. Online submission table

Improve training area data

Welcome to the LCZ Generator!

Fast and easy Local Climate Zone mapping

Getting started:

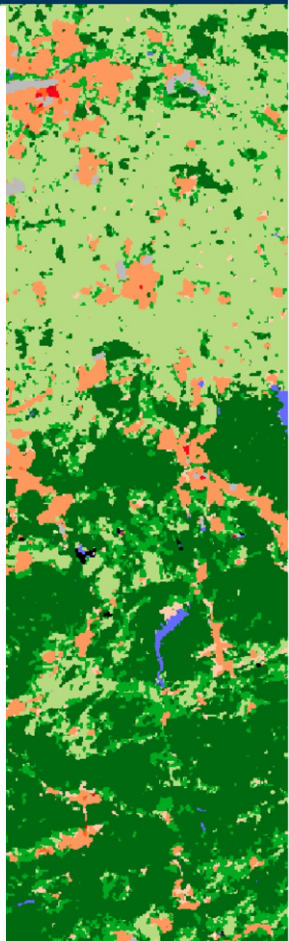
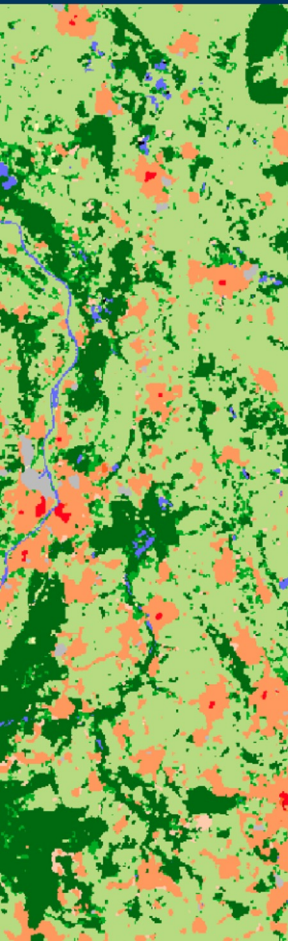
1. Read [Demuzere et al. \(2021\)](#) it serves as the primary user guide
2. Download the [Training Area Template kml](#) file
3. Create your Training Areas following the [guidelines](#)
4. Once finished, use the [submission form](#) to submit your file.
5. Fill out the fields in the submission form; fields with an asterisk (*) are required.
 - ▶ [Show detailed information](#)
6. Submit the form. If you see a green box appear on the top of the page after clicking the submit button, your submission was successful and will be processed. If a red box appears, there was a problem with your Training Area file. Check out the [FAQ](#) for more information.
7. You will be notified via email once the processing has finished. Depending on the current load of the system it should take ~20 minutes.
8. After you received the email, your submission is also available in the [submission table](#).

[Submit your Training Area](#)

[Show generated LCZ maps](#)

Please cite the tool using:

Demuzere, M., Kittner, J., Bechtel, B. (2021). LCZ Generator: a web application to create Local Climate Zone maps. *Frontiers in Environmental Science* 9:637455. <https://doi.org/10.3389/fenvs.2021.637455>

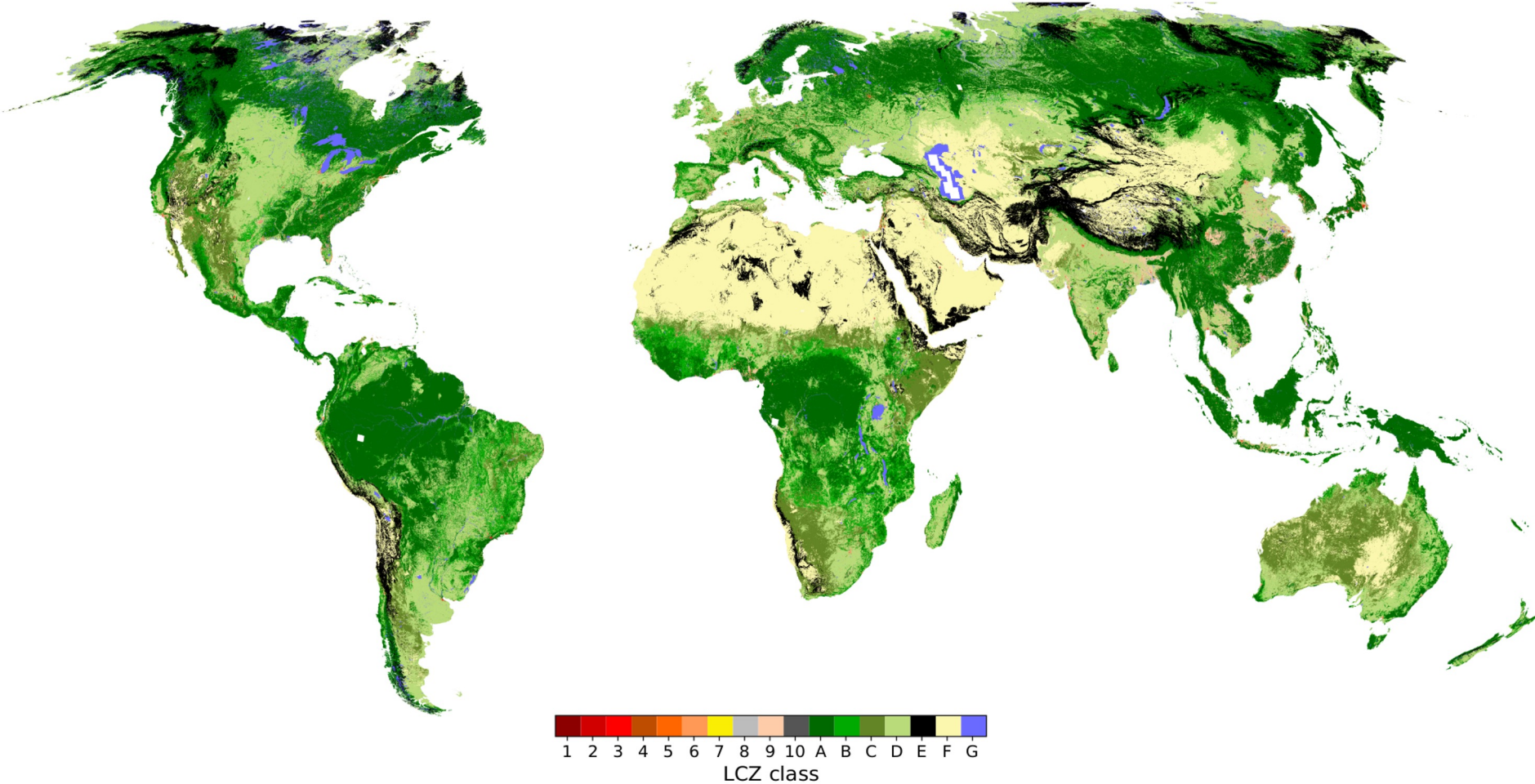


[Download Selected](#) [Show best submissions](#) Search:

| <input type="checkbox"/> | City | Country | Continent | Date Submitted | Author | Accuracy | |
|--------------------------|----------------|--------------------------------|---------------|---------------------|----------------------|----------|--------------------------------|
| <input type="checkbox"/> | Barcelona | Spain, Kingdom of | Europe | 2022-06-08 07:26:11 | Majdi Hunter-Batal | 0.69 | Show Factsheet |
| <input type="checkbox"/> | NANJING | China, People's Republic of | Asia | 2022-06-08 00:26:51 | Yokey Tang | 0.81 | Show Factsheet |
| <input type="checkbox"/> | Salt Lake City | United States of America | North America | 2022-06-07 17:53:05 | Natalie White | 0.52 | Show Factsheet |
| <input type="checkbox"/> | SÃO PAULO | Brazil, Federative Republic of | South America | 2022-06-07 14:42:41 | Sara Lopes De Moraes | 0.65 | Show Factsheet |
| <input type="checkbox"/> | Piatra Neamt | Romania | Europe | 2022-06-07 11:58:14 | Dragos Butnaru | 0.70 | Show Factsheet |
| <input type="checkbox"/> | Bhubaneswar | India, Republic of | Asia | 2022-06-07 11:40:03 | | 0.43 | Show Factsheet |
| <input type="checkbox"/> | São Paulo | Brazil, Federative Republic of | South America | 2022-06-07 11:00:13 | Sara Lopes De Moraes | 0.65 | Show Factsheet |
| <input type="checkbox"/> | nanjing | China, People's Republic of | Asia | 2022-06-07 01:53:29 | Yokey Tang | 0.82 | Show Factsheet |
| <input type="checkbox"/> | São Paulo | Brazil, Federative Republic of | South America | 2022-06-06 16:31:53 | Sara Lopes De Moraes | 0.65 | Show Factsheet |
| <input type="checkbox"/> | Yazd | Iran, Islamic Republic of | Asia | 2022-06-06 15:48:24 | | 0.69 | Show Factsheet |

Showing 1 to 10 of 2,175 entries

Global map of LCZs



LCZ maps ~ climate modelling?

Table: LCZ-class specific urban canopy parameter values

| LCZ | λ_B | λ_I | λ_V | H | SVF | AHF | IMD |
|-------------------------|-------------|-------------|-------------|-------|---------|--------|-------|
| 1. Compact high-rise | 40–60 | 40–60 | <10 | >25 | 0.2–0.4 | 50–300 | >80 |
| 2. Compact midrise | 40–70 | 30–50 | <20 | 10–25 | 0.3–0.6 | <75 | >70 |
| 3. Compact low-rise | 40–70 | 20–50 | <30 | 3–10 | 0.2–0.6 | <75 | >60 |
| 4. Open high-rise | 20–40 | 30–40 | 30–40 | >25 | 0.5–0.7 | <50 | 50–80 |
| 5. Open midrise | 20–40 | 30–50 | 20–40 | 10–25 | 0.5–0.8 | <25 | 50–80 |
| 6. Open low-rise | 20–40 | 20–50 | 30–60 | 3–10 | 0.6–0.9 | <25 | 40–90 |
| 7. Lightweight low-rise | 60–90 | <20 | <30 | 2–4 | 0.2–0.5 | <35 | >60 |
| 8. Large low-rise | 30–50 | 40–50 | <20 | 3–10 | >0.7 | <50 | >70 |
| 9. Sparsely built | 10–20 | <20 | 60–80 | 3–10 | >0.8 | <10 | 10–40 |
| 10. Heavy industry | 20–30 | 20–40 | 40–50 | 5–15 | 0.6–0.9 | >300 | >40 |
| A. Dense trees | <10 | <10 | >90 | 3–30 | <0.4 | 0 | <20 |
| B. Scattered trees | <10 | <10 | >90 | 3–15 | 0.5–0.8 | 0 | <20 |
| C. Bush, scrub | <10 | <10 | >90 | <2 | 0.7–0.9 | 0 | <20 |
| D. Low plants | <10 | <10 | >90 | <1 | >0.9 | 0 | <20 |
| E. Bare rock or paved | <10 | >90 | <10 | <0.25 | >0.9 | 0 | >90 |
| F. Bare soil or sand | <10 | <10 | >90 | <0.25 | >0.9 | 0 | <20 |
| G. Water | <10 | <10 | >90 | – | >0.9 | 0 | <20 |

+ Radiative and thermal properties such as emissivity, albedo, heat capacity, heat conductivity etc ...

Stewart & Oke (2012); Demuzere et al. (2019a, 2022)

LCZ maps ~ climate modelling?

Table: LCZ-class specific urban canopy parameter values

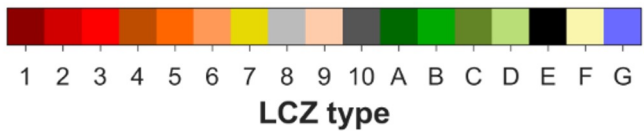
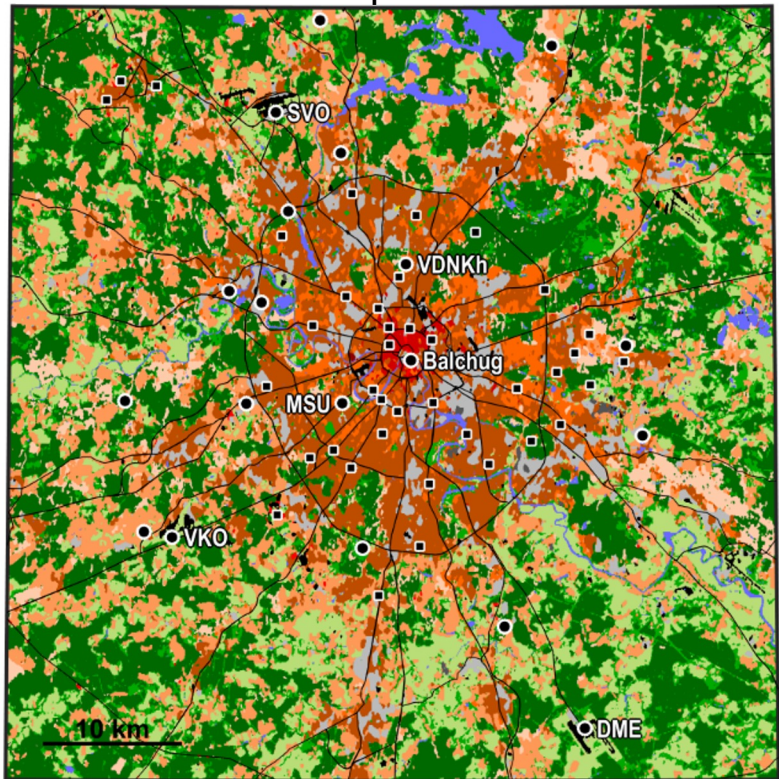
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|-------------------------|-------------|-------------|-------------|-------|---------|--------|-------|
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| 7. Lightweight low-rise | 60–90 | <20 | <30 | 2–4 | 0.2–0.5 | <35 | >60 |
| 8. Large low-rise | 40–70 | 10–20 | <20 | 3–10 | >0.7 | <50 | >70 |
| 9. Sparsely built-up | 10–20 | 10–20 | 10–20 | 3–10 | 0.5–0.8 | <10 | 10–40 |
| 10. Heavy industry | 20–30 | 20–40 | 40–50 | 5–15 | 0.6–0.9 | >300 | >40 |
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| D. Low plants | <10 | <10 | >90 | <1 | >0.9 | 0 | <20 |
| E. Bare rock or paved | <10 | >90 | <10 | <0.25 | >0.9 | 0 | >90 |
| F. Bare soil or sand | <10 | <10 | >90 | <0.25 | >0.9 | 0 | <20 |
| G. Water | <10 | <10 | >90 | - | >0.9 | 0 | <20 |



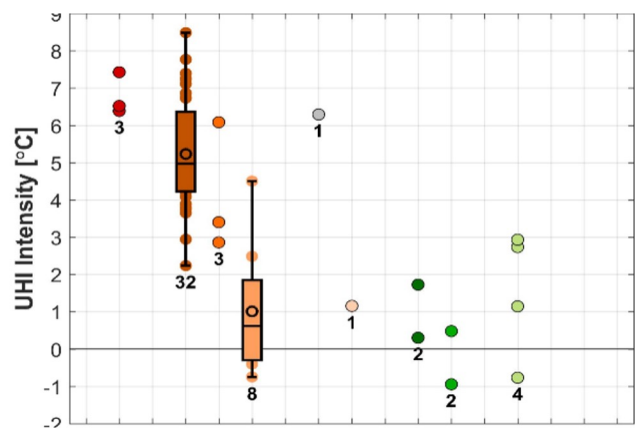
The global LCZ map describes all the cities of the world, in the same, universal language, but interested users can read it in their own dialect

+ Radiative and thermal properties such as emissivity, albedo, heat capacity, heat conductivity etc ...

LCZ map Moscow

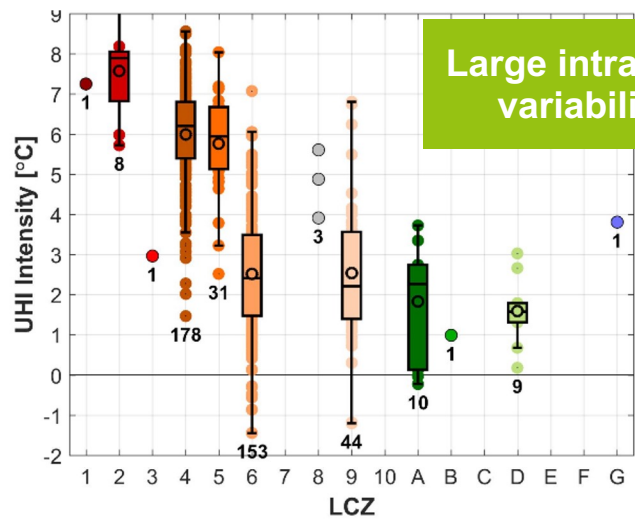


Reference weather stations



Summer 2019

Citizen weather stations (netatmo)



Large intra-LCZ variability

The LCZ approach provides a consistent and comprehensive framework for SUHI analysis.

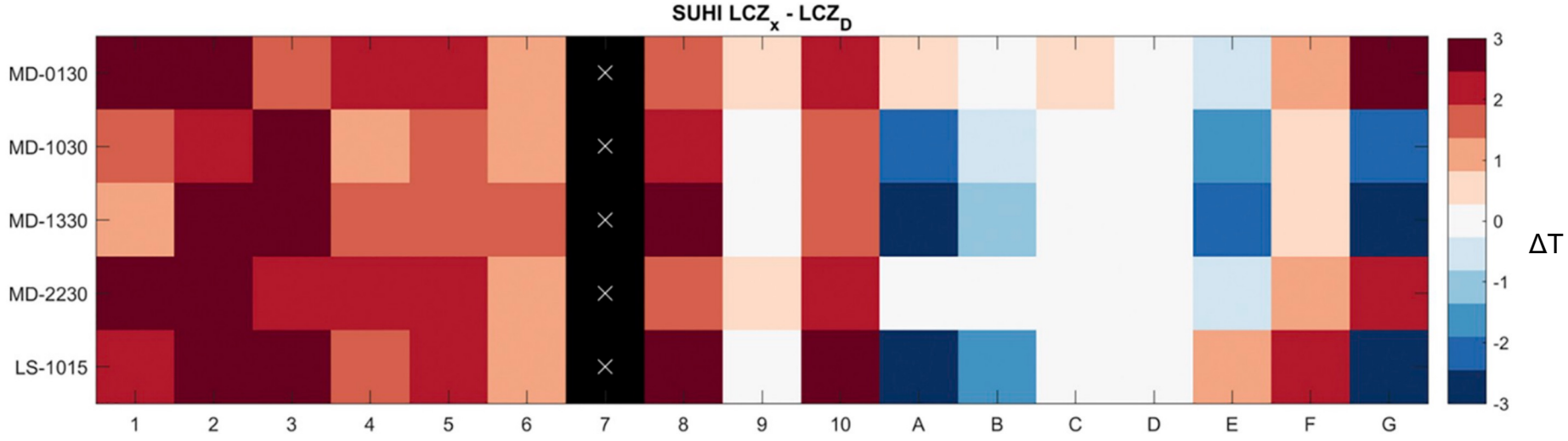
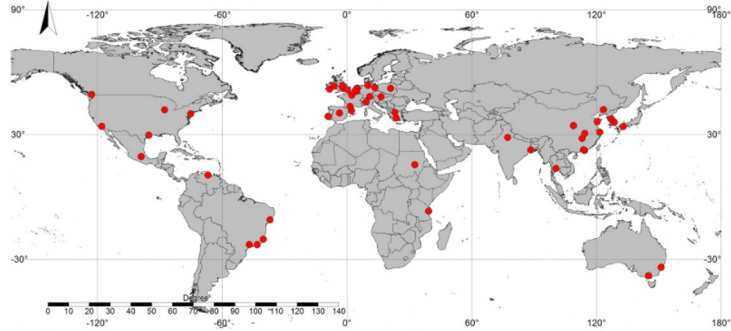


Fig. 11. Average SUHI intensity in K for all cities and LCZ compared to LCZ D for different acquisition times and sensors. Black with white x (LCZ 7) indicates that the LCZ type is not present in the study.

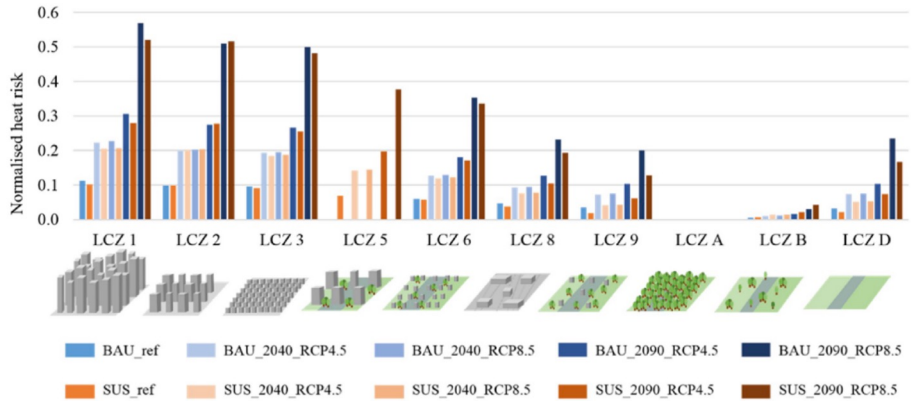
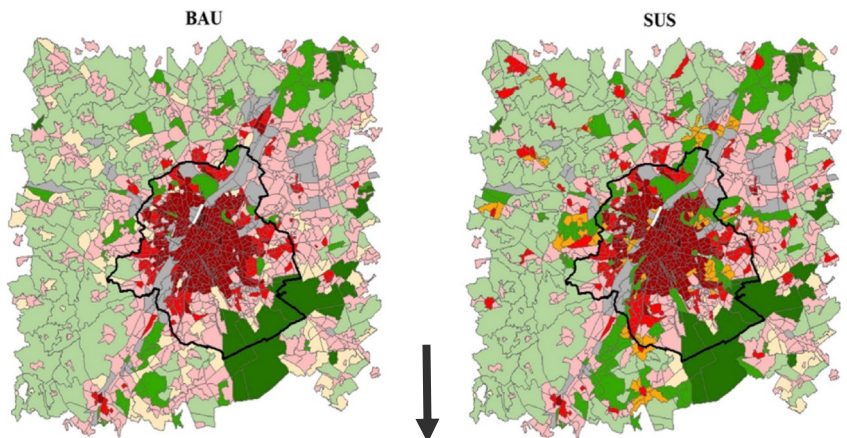
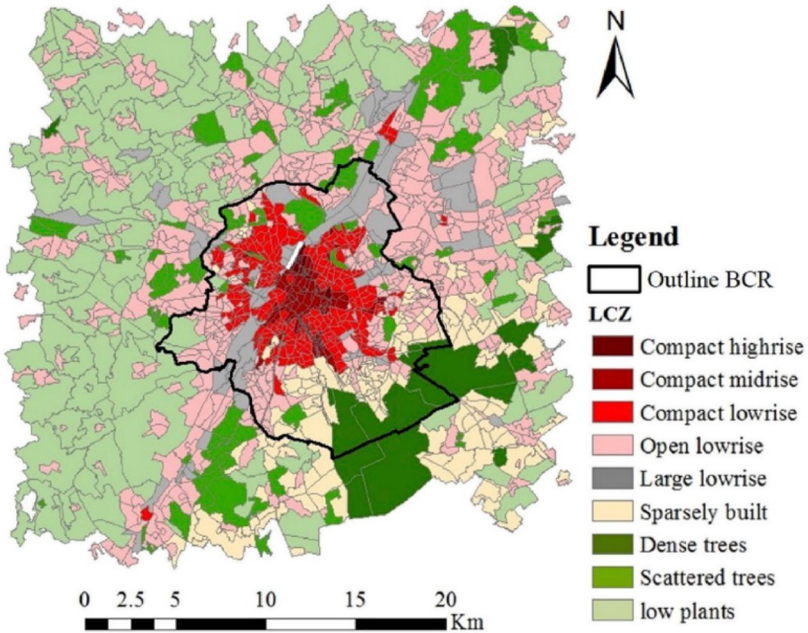
Applications

Urbanisation - Future heat risk

PRESENT-DAY



FUTURE



Future planning policies can be translated into LCZ maps, that in term can serve as boundary conditions to model intra-urban heat risk

“This study compares three different approaches to define the urban canopy parameters for Moscow (Russia), using the COSMO numerical weather prediction and climate model coupled to TERRA_URB urban parameterization”

“ ... for the summer period, the LCZ-based and ‘Reference’ urban parameters show almost similar performance in terms of the modelled thermal environment, and provide noticeable improvements with respect to default urban description.”



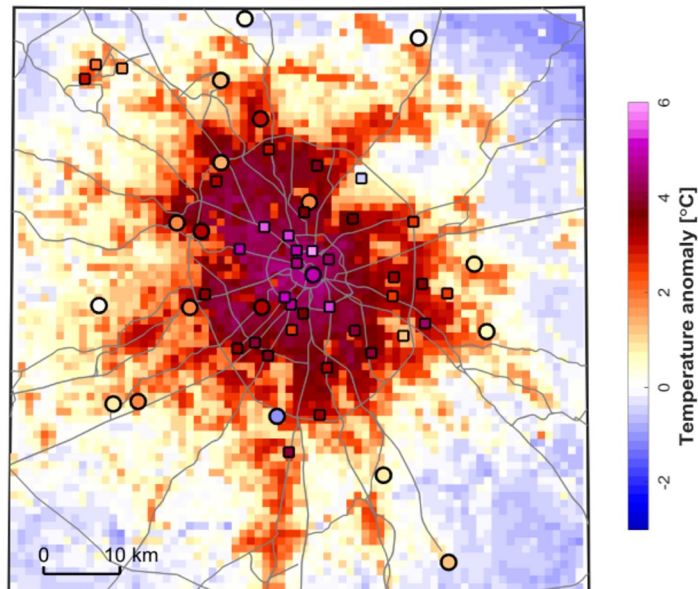
atmosphere

COSMO-CLM

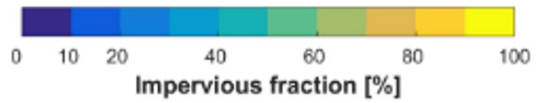
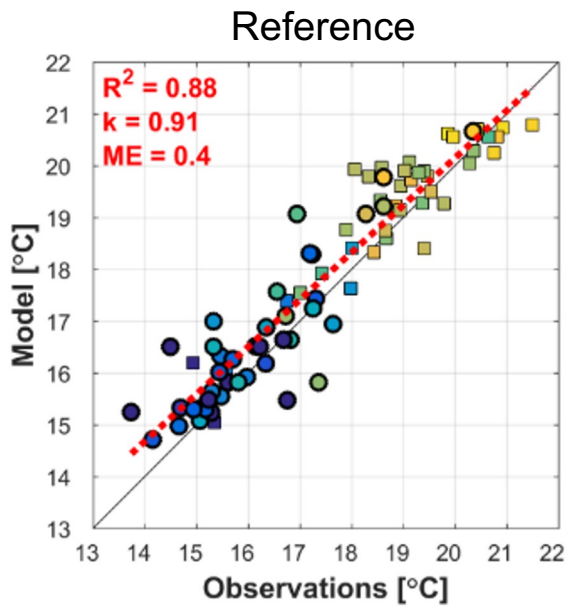
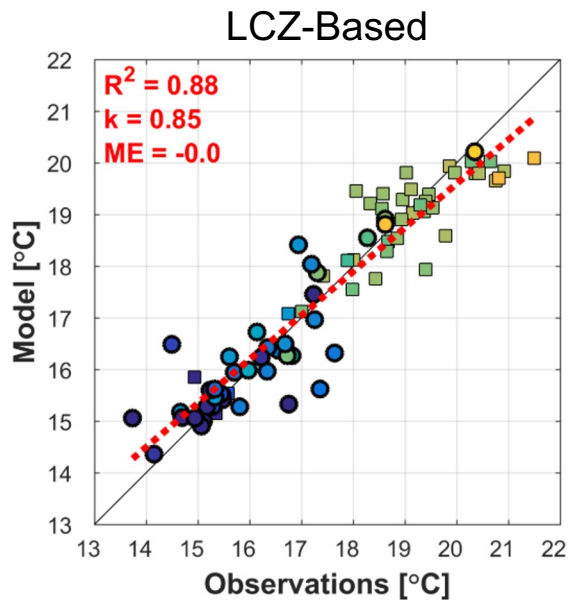
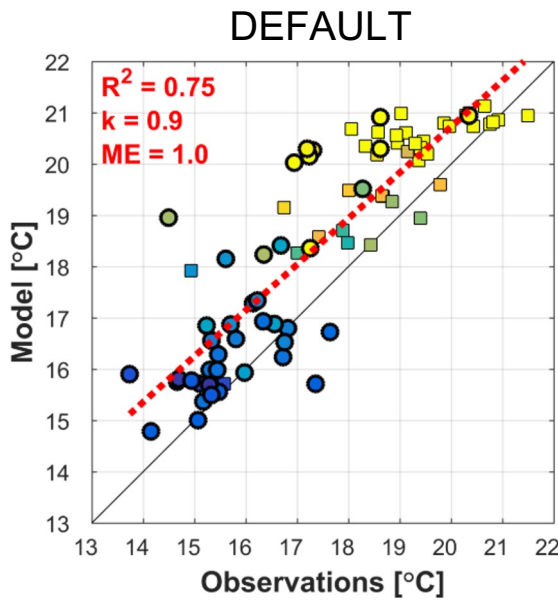
Article

Impact of Urban Canopy Parameters on a Megacity's Modelled Thermal Environment

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Evaluation of nocturnal 2m air temperature averaged for August 2017



TOOLS

WUDAPT offers tools to generate data on form and function of urban areas and to apply them in different models and procedures.

Generate LCZ map (*LO* data)

- **Generate LCZ training data**
- **Classify your city**

Use WUDAPT data in models

- **WRF**
- **COSMO-CLM**
- **UMEP**

Generate Urban Canopy Parameters

- **Convert cityGML and sealing data to UCPS** (by Sebastian Schubert)

Summary, gaps, potential?

Local Climate Zone (maps) can serve as a **first-order proxy describing the heterogeneity of urban areas**, which in turn can serve as boundary conditions for urban parameterizations embedded within climate models. Various **tools are available / being developed** to facilitate this process.



Data-driven reading of LCZ map in local dialect (= Level-1 and -2 information)?
Improve representation of informal settlements?



Collaboration to explore this big dataset!

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<https://www.climate.ruhr-uni-bochum.de/>



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Selected references

- Bechtel B, Alexander P, Böhner J, et al. Mapping Local Climate Zones for a Worldwide Database of the Form and Function of Cities. *ISPRS Int J Geo-Information*. 2015;4(1):199-219. doi:10.3390/ijgi4010199
- Bechtel B, Alexander PJ, Beck C, et al. Generating WUDAPT Level 0 data – Current status of production and evaluation. *Urban Clim*. 2019a;27:24-45. doi:10.1016/j.uclim.2018.10.001
- Bechtel B, Demuzere M, Mills G, et al. SUHI analysis using Local Climate Zones—A comparison of 50 cities. *Urban Clim*. 2019b;28:100451. doi:10.1016/j.uclim.2019.01.005
- Brousse O, Georganos S, Demuzere M, et al. Can we use local climate zones for predicting malaria prevalence across sub-Saharan African cities? *Environ Res Lett*. 2020;15(12):124051. doi:10.1088/1748-9326/abc996
- Ching J, Mills G, Bechtel B, et al. WUDAPT: An Urban Weather, Climate, and Environmental Modeling Infrastructure for the Anthropocene. *Bull Am Meteorol Soc*. 2018;99(9):1907-1924. doi:10.1175/BAMS-D-16-0236.1
- Ching J, Aliaga D, Mills G, et al. Pathway using WUDAPT's Digital Synthetic City tool towards generating urban canopy parameters for multi-scale urban atmospheric modeling. *Urban Clim*. 2019;28:100459. doi:10.1016/j.uclim.2019.100459
- Demuzere M, Bechtel B, Middel A, Mills G. Mapping Europe into local climate zones. *PLoS One*. 2019a;14(4):e0214474. doi:10.1371/journal.pone.0214474
- Demuzere M, Bechtel B, Middel A, Mills G. European LCZ map. Figshare. 2019b; doi:10.6084/m9.figshare.13322450.v1
- Demuzere M, Hankey S, Mills G, Zhang W, Lu T, Bechtel B. Combining expert and crowd-sourced training data to map urban form and functions for the continental US. *Sci Data*. 2020a; 7(1):264. doi:10.1038/s41597-020-00605-z
- Demuzere M, Hankey S, Mills G, Zhang W, Lu T, Bechtel B. CONUS-WIDE LCZ map and Training Areas. Figshare. 2020b. doi:10.6084/m9.figshare.11416950
- Demuzere M, Kittner J, Bechtel B. LCZ Generator: A Web Application to Create Local Climate Zone Maps. *Front Environ Sci*. 2021;9. doi:10.3389/fenvs.2021.637455
- Demuzere M, Kittner J, Martilli A, et al. A global map of Local Climate Zones to support earth system modelling and urban scale environmental science. *Earth Syst Sci Data Discuss*. 2022.
- Esch T, Heldens W, Hirne A, et al. Breaking new ground in mapping human settlements from space -The Global Urban Footprint-. *ISPRS J Photogramm Remote Sens*. 2017;134:30-42. doi:10.1016/j.isprsjprs.2017.10.012
- Fenner D, Meier F, Bechtel B, Otto M, Scherer D. Intra and inter 'local climate zone' variability of air temperature as observed by crowdsourced citizen weather stations in Berlin, Germany. *Meteorol Zeitschrift*. 2017;26(5):525-547. doi:10.1127/metz/2017/0861
- Hertwig D, Ng M, Grimmond S, Vidale PL, McGuire PC. High-resolution global climate simulations: Representation of cities. *Int J Climatol*. 2021;41(5):3266-3285. doi:10.1002/joc.7018
- Lipson MJ, Thatcher M, Hart MA, Pitman A. A building energy demand and urban land surface model. *Q J R Meteorol Soc*. 2018;(April):1572-1590. doi:10.1002/qj.3317
- Lu T, Marshall JD, Zhang W, et al. National Empirical Models of Air Pollution Using Microscale Measures of the Urban Environment. *Environ Sci Technol*. 2021. doi:10.1021/acs.est.1c04047
- Patel P, Jamshidi S, Nadimpalli R, et al. Modeling Large-Scale Heatwave by Incorporating Enhanced Urban Representation. *J Geophys Res Atmos*. 2022;127(2):1-33. doi:10.1029/2021JD035316
- Stewart ID. A systematic review and scientific critique of methodology in modern urban heat island literature. *Int J Climatol*. 2011;31(2):200-217. doi:10.1002/joc.2141
- Stewart ID, Oke TR. Local Climate Zones for Urban Temperature Studies. *Bull Am Meteorol Soc*. 2012;93(12):1879-1900. doi:10.1175/BAMS-D-11-00019.1
- Sun T, Grimmond S. A Python-enhanced urban land surface model SuPy (SUEWS in Python, v2019.2): development, deployment and demonstration. *Geosci Model Dev*. 2019;12(7):2781-2795. doi:10.5194/gmd-12-2781-2019
- Varentsov M, Samsonov T, Demuzere M. Impact of Urban Canopy Parameters on a Megacity's Modelled Thermal Environment. *Atmosphere (Basel)*. 2020;11(12):1349. doi:10.3390/atmos11121349
- Varentsov M, Fenner D, Meier F, Samsonov T, Demuzere M. Quantifying Local and Mesoscale Drivers of the Urban Heat Island of Moscow with Reference and Crowdsourced Observations. *Front Environ Sci*. 2021;9(November):1-21. doi:10.3389/fenvs.2021.716968