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A study on the spatial patterns of the Moscow megacity urban heat island

based on the dense official and crowdsourcing observations

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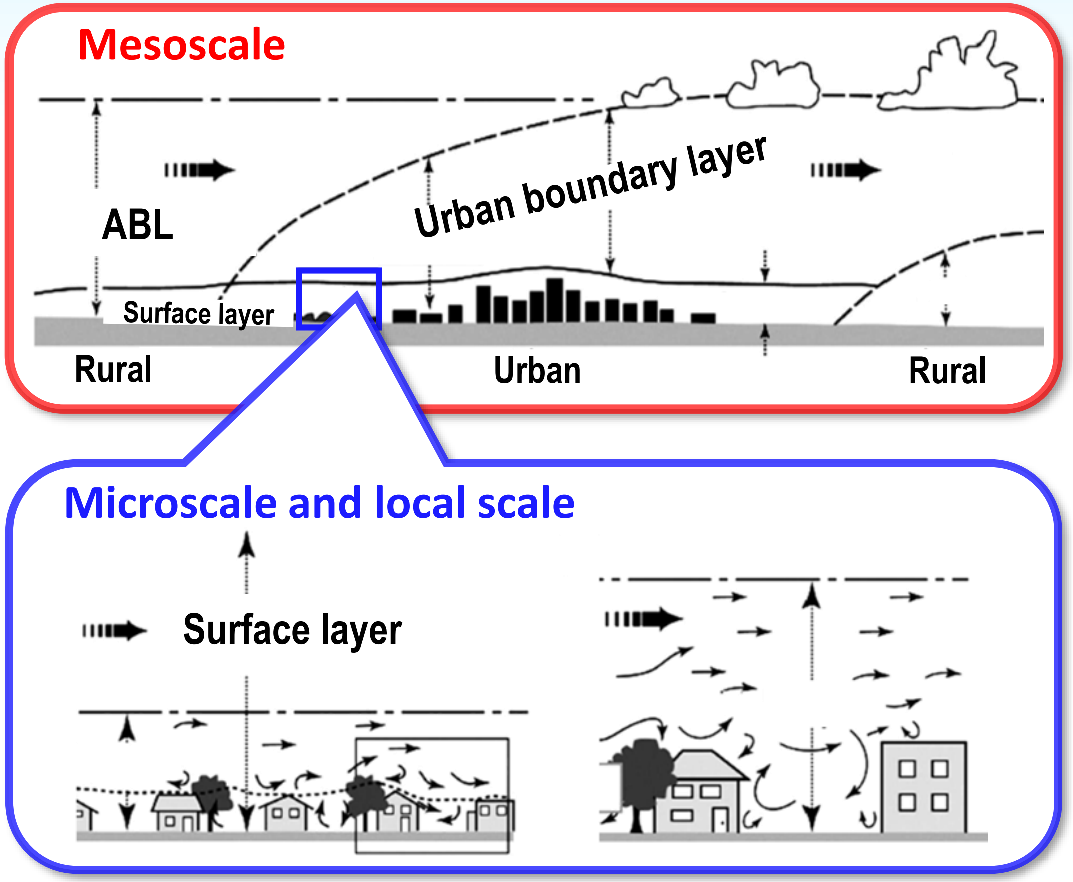
Technische Universität Berlin

Motivation: scales of urban climate processes

The scientific problems:

- A lot of studies are devoted to the dependence between the local climate features and surface properties (SVF, AHF, impervious area, etc.).
- Urban-induced mesoscale effects (ABL UHI, urban breeze, heat plumes, etc.) are known.
- The non-local effects are in general poorly studies, and often are not taken into consideration.
- Moreover, urban climate is often considered as only a variety of local climates.
- **We try to analyze the contribution of the local and non-local effects to the development of Moscow UHI.**



Scales of urban-atmosphere interaction (Oke, 1987)

Mesoclimatic
features of a big city
(non-local effects)

Microclimate or local climate
of certain streets, yards, parks, etc....

Motivation: citizen weather stations (CWSs)

- ❑ **Crowdsourced CWS networks as part of "Internet of things" concept**
- ❑ **The world's biggest CWS network Netatmo (www.netatmo.com)**
- ❑ **Already used for urban climate studies** (e.g. Chapman et al., 2017; Fenner et al., 2017; Meier et al., 2017)

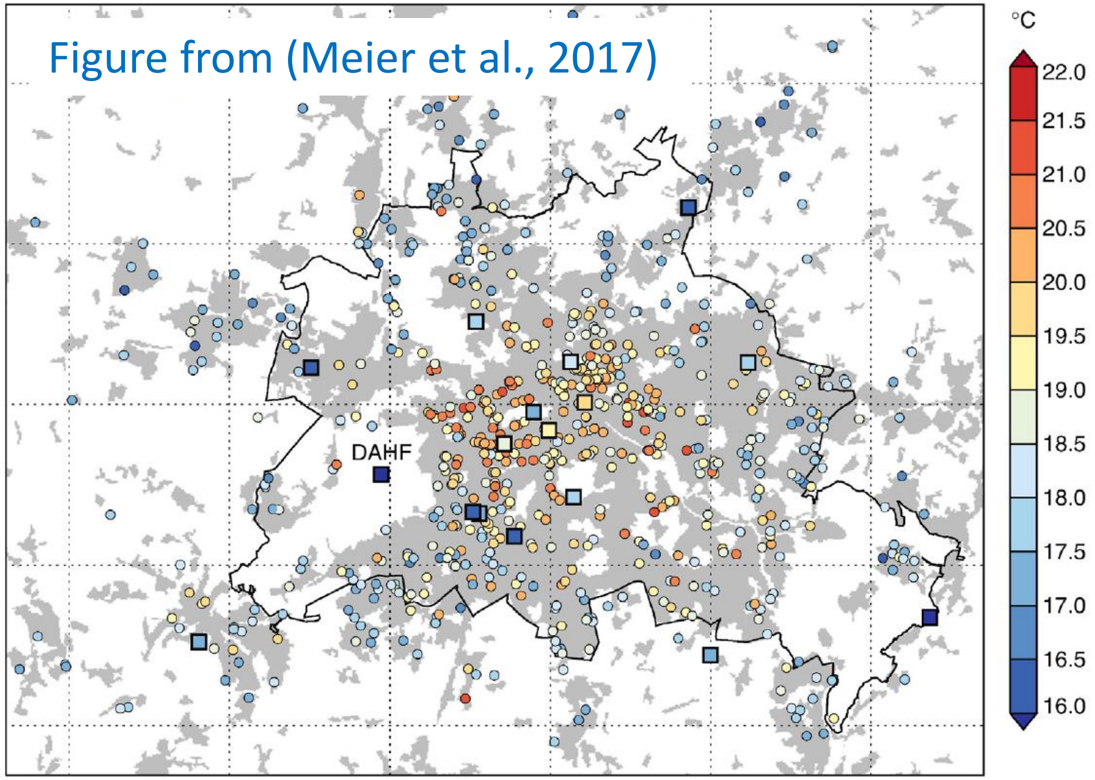


Figure from (Meier et al., 2017)

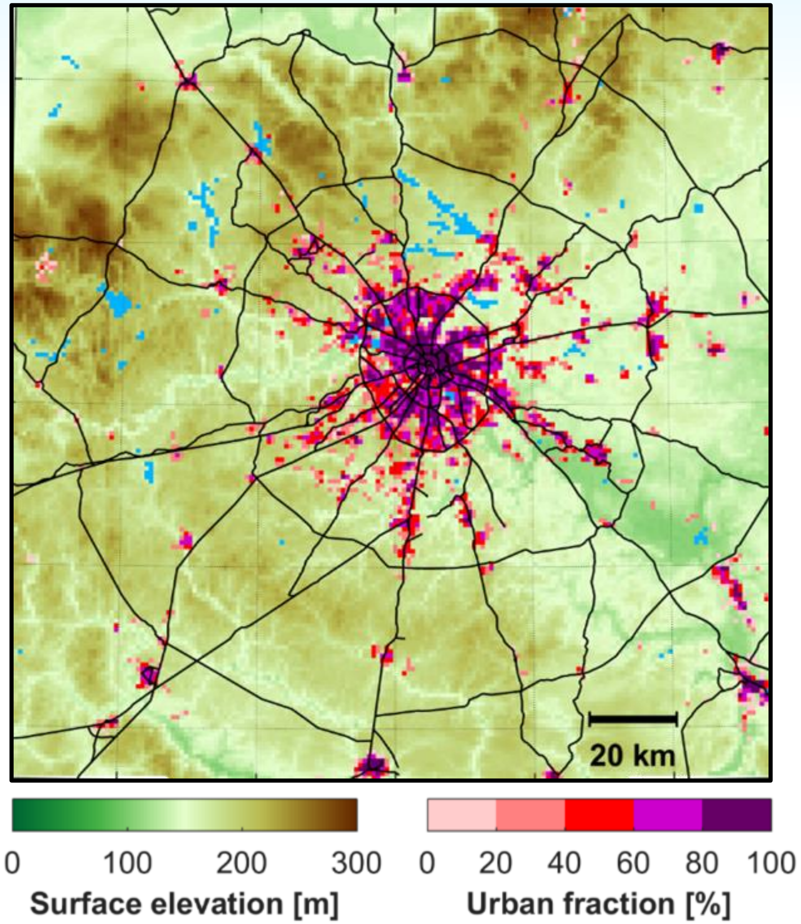
City	# CWS June 2018
Basel	940
Berlin	2100
Bern	650
Gothenburg	410
Hamburg	1190
Lisbon	150
London	830
Moscow	730
Paris	6380
Toulouse	720
Stuttgart	840
Atlanta	90
New York City	210
Phoenix	160
Santiago de Chile	130
Vancouver	150
Seoul	20

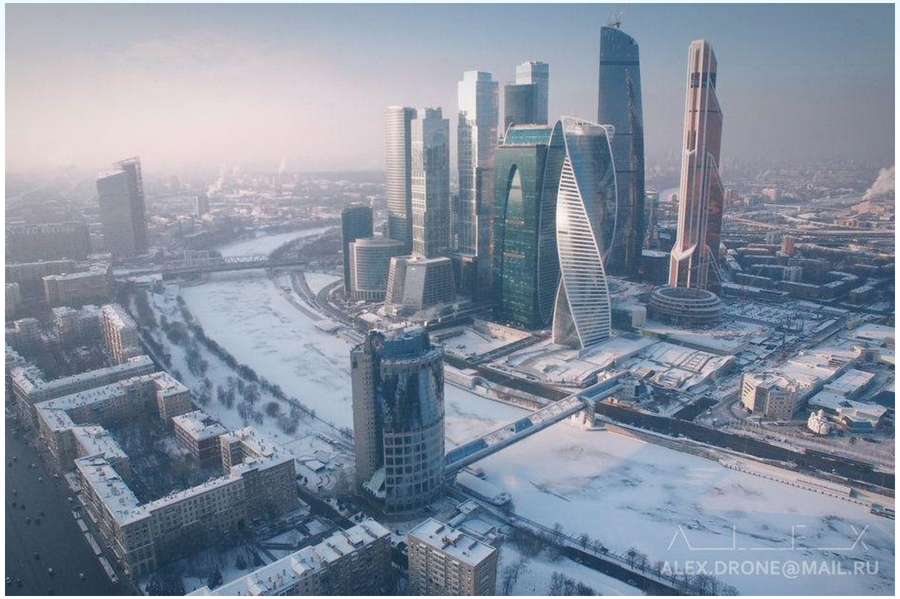
Data from (Meier et al., 2018)

Why Moscow megacity?

Benefits of urban climate studies in Moscow:

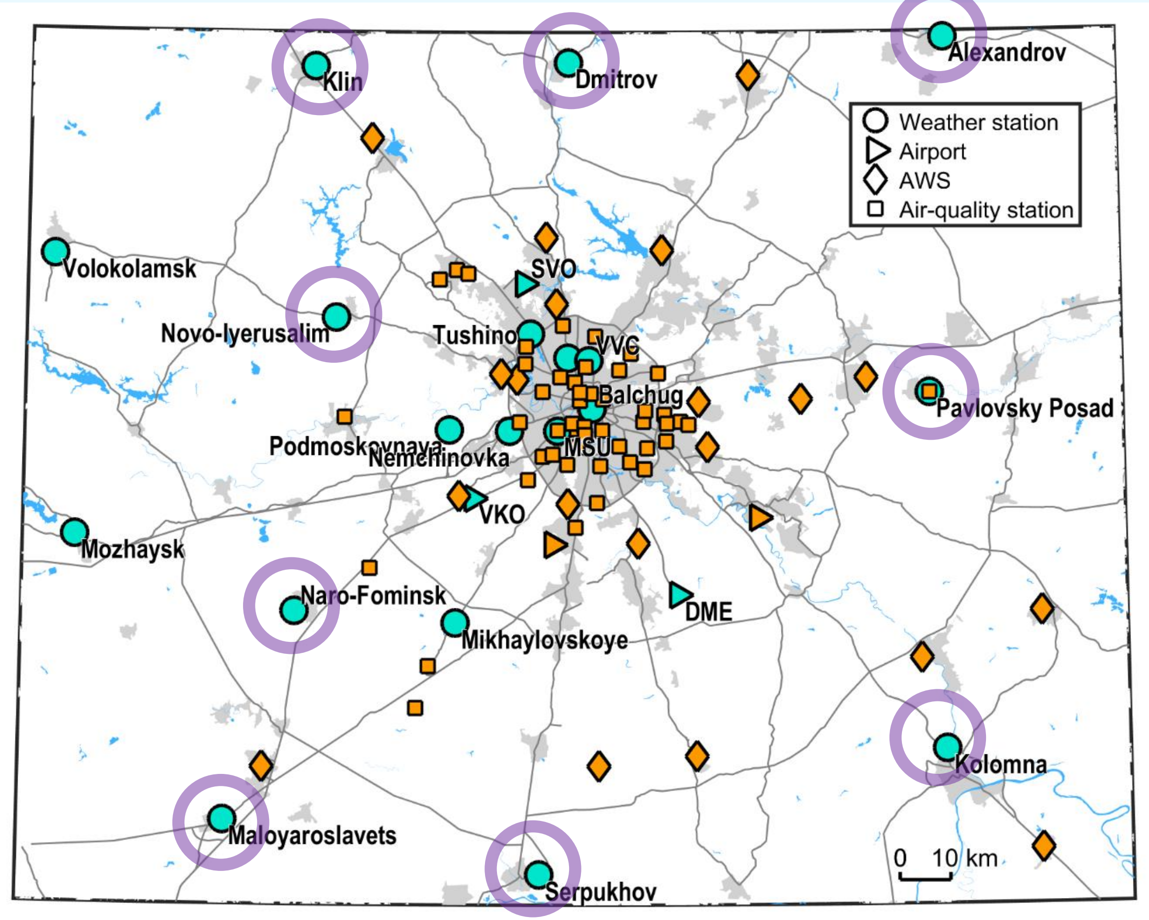
- ✓ The biggest agglomeration in Europe (≈$17 \cdot 10^6$ people)
- ✓ The world's northernmost and coldest megacity with continental climate
- ✓ Compact and symmetric shape of the city
- ✓ Flat and homogenous surrounding landscape
- ✓ **Dense official meteorological network**





Data from a recent modelling study (Varentsov et al., 2018)

Official weather observations in Moscow



UHI intensity – **a temperature anomaly with respect to the mean rural value, averaged over 9 stations around Moscow**

Balchug station
(downtown, 500 m from Kremlin)

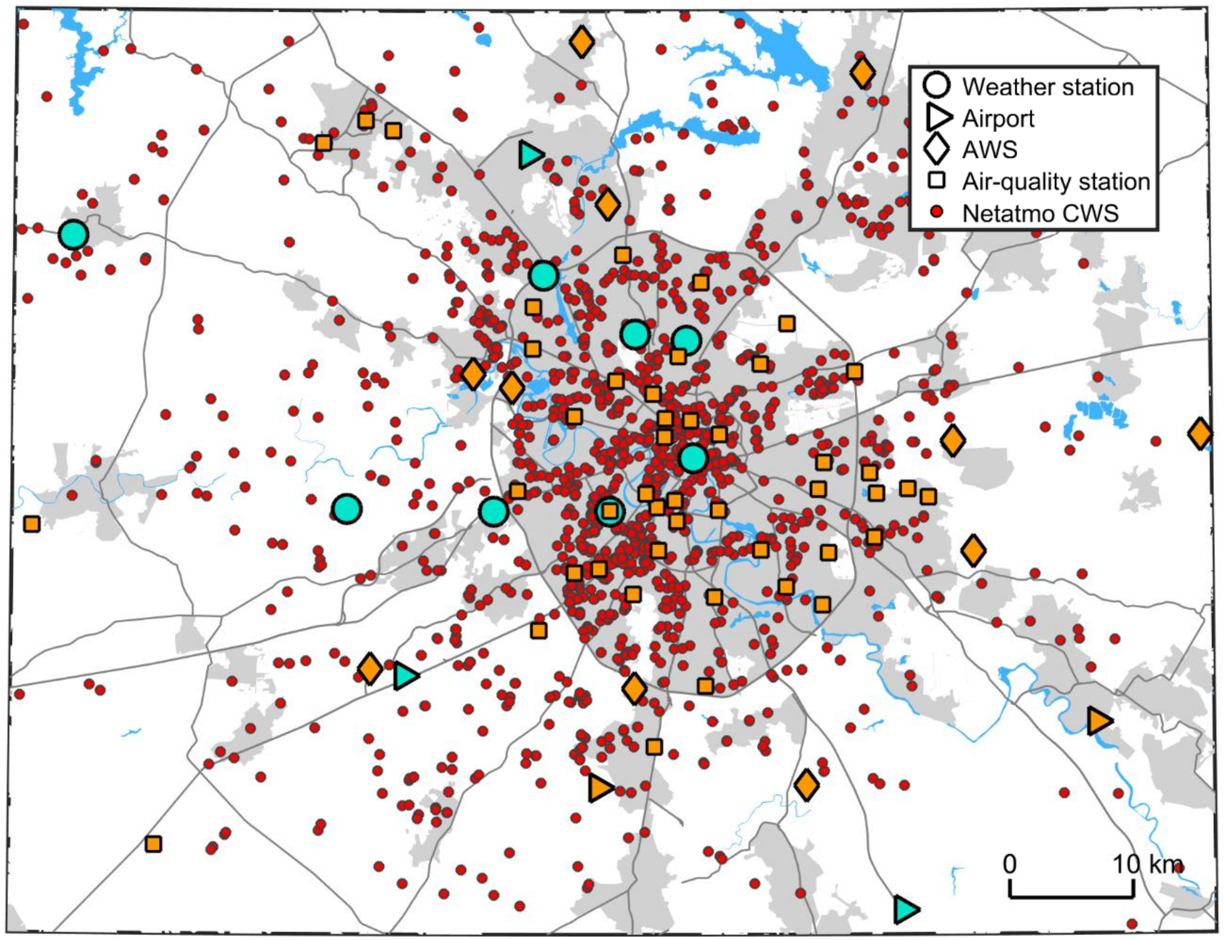
Meteorological observatory of Moscow State University (MSU)

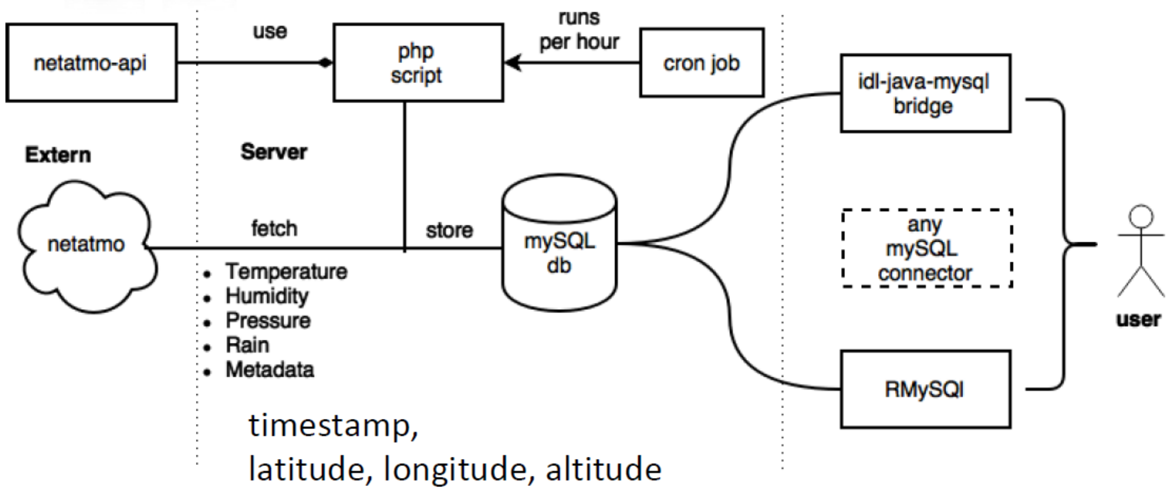
New automatic weather stations (since 2013)

Air-quality monitoring stations (since 1990th)

Citizen weather stations in Moscow

- The data for Moscow is automatically collected using Netatmo API and stored at Berlin Technical University (Meier et al., 2017; Fenner et al., 2017)
- Considered periods: Winter 2018/19, Summer 2019
- Study area: aprox. 100 km around Moscow center
- More than 1600 CWSs available for each of the periods
- What part of this data could be used?





Quality control of CWS data

- Quality control (QC) is essential part of the work with CWS data
- QC algorithm for Moscow is based on the ideas from previous studies (Meier et al., 2017; Napoly et al., 2018), but involve more intensively the reference (official) data

L0: CWSs with same locations are removed

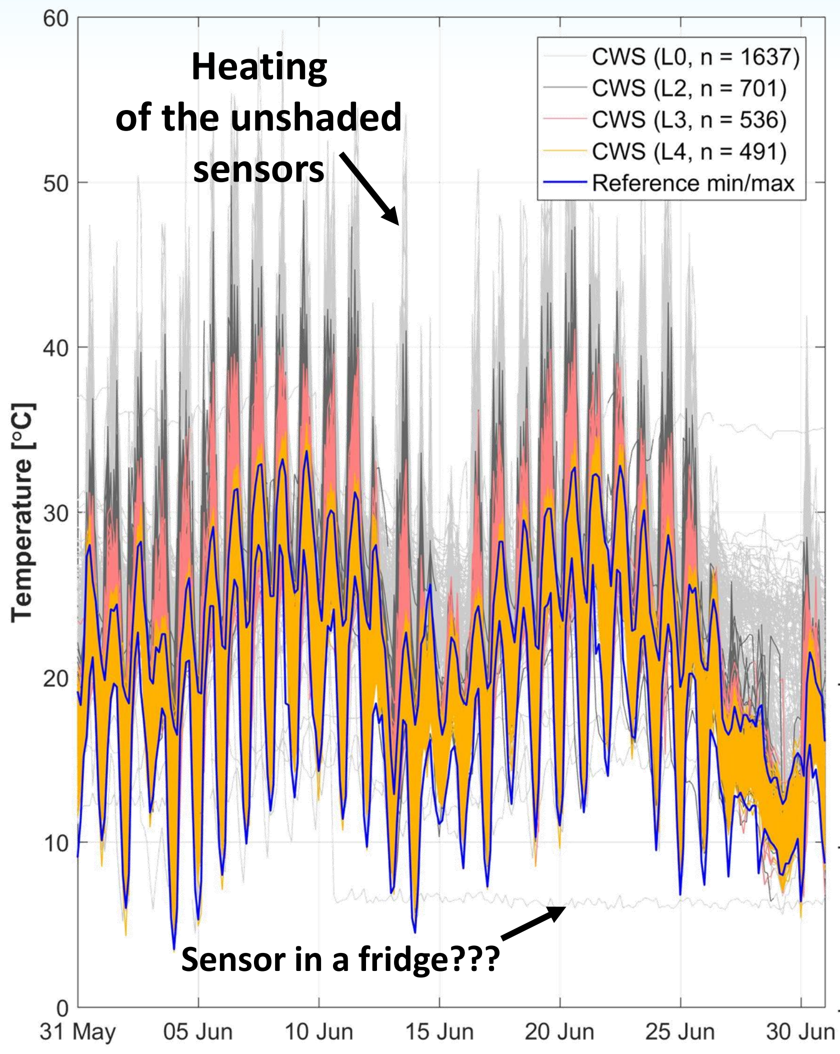
L1: CWSs with high ration of missing data are removed

L2: filtering based on temperature means and STDs for given intervals (14 days). Acceptable ranges are determined by the reference data set.

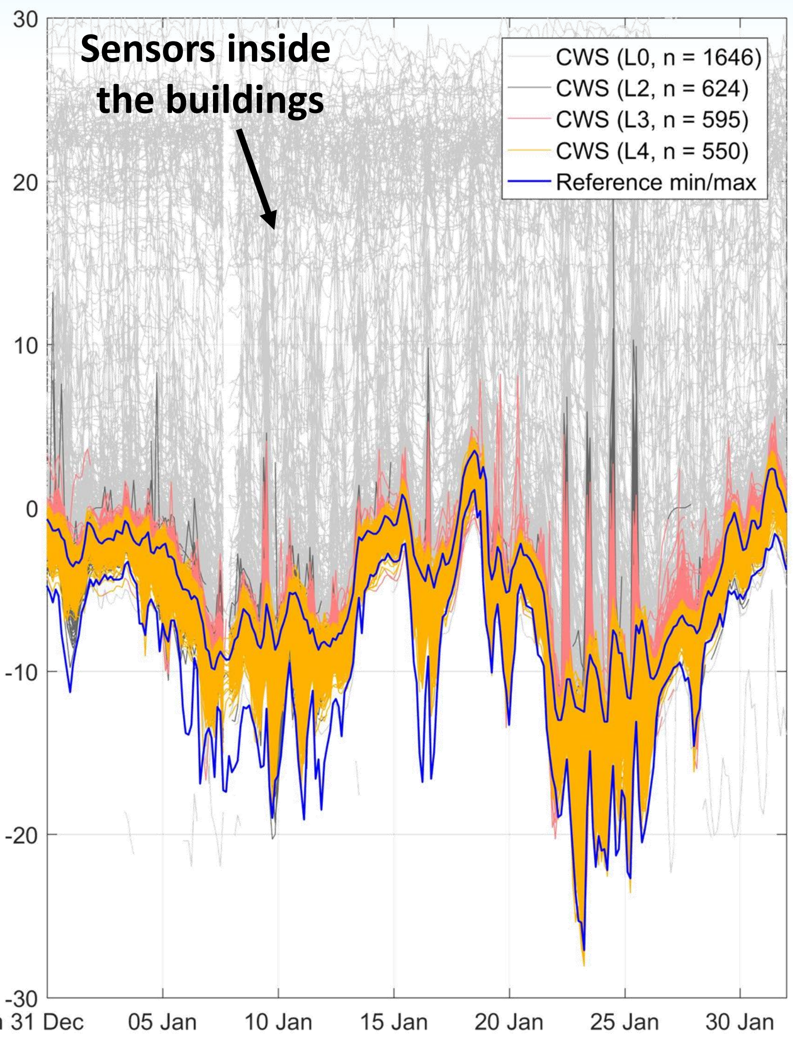
L3: filtering based on correlation between CWS and reference temperature time series STDs for given intervals (14 days).

L4: filtering of the data for specific moments based on the ranges of the reference data in Moscow city and surrounding (100 km)

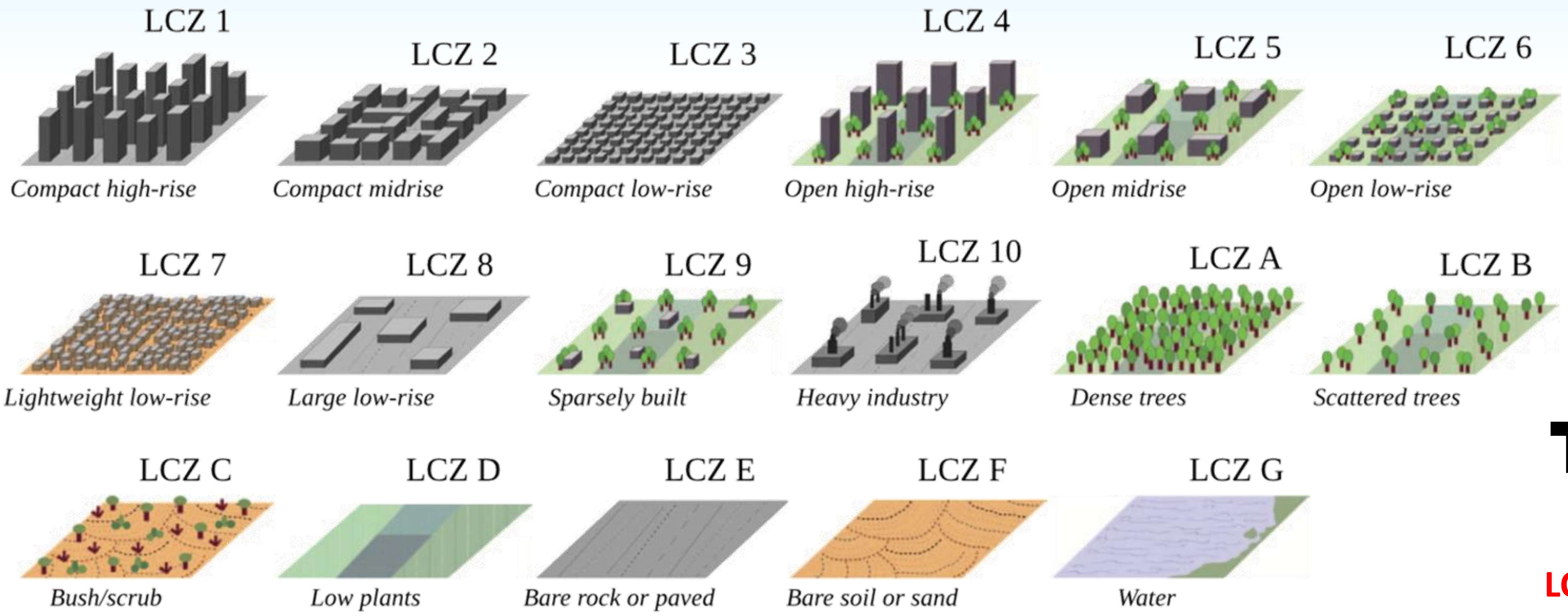
May-June 2019



Dec 2018 – Jan 2019



Describing the city: **Local Climate Zones**



Local climate zones (LCZs) for urban **temperature** studies
by Stewart and Oke (2012)

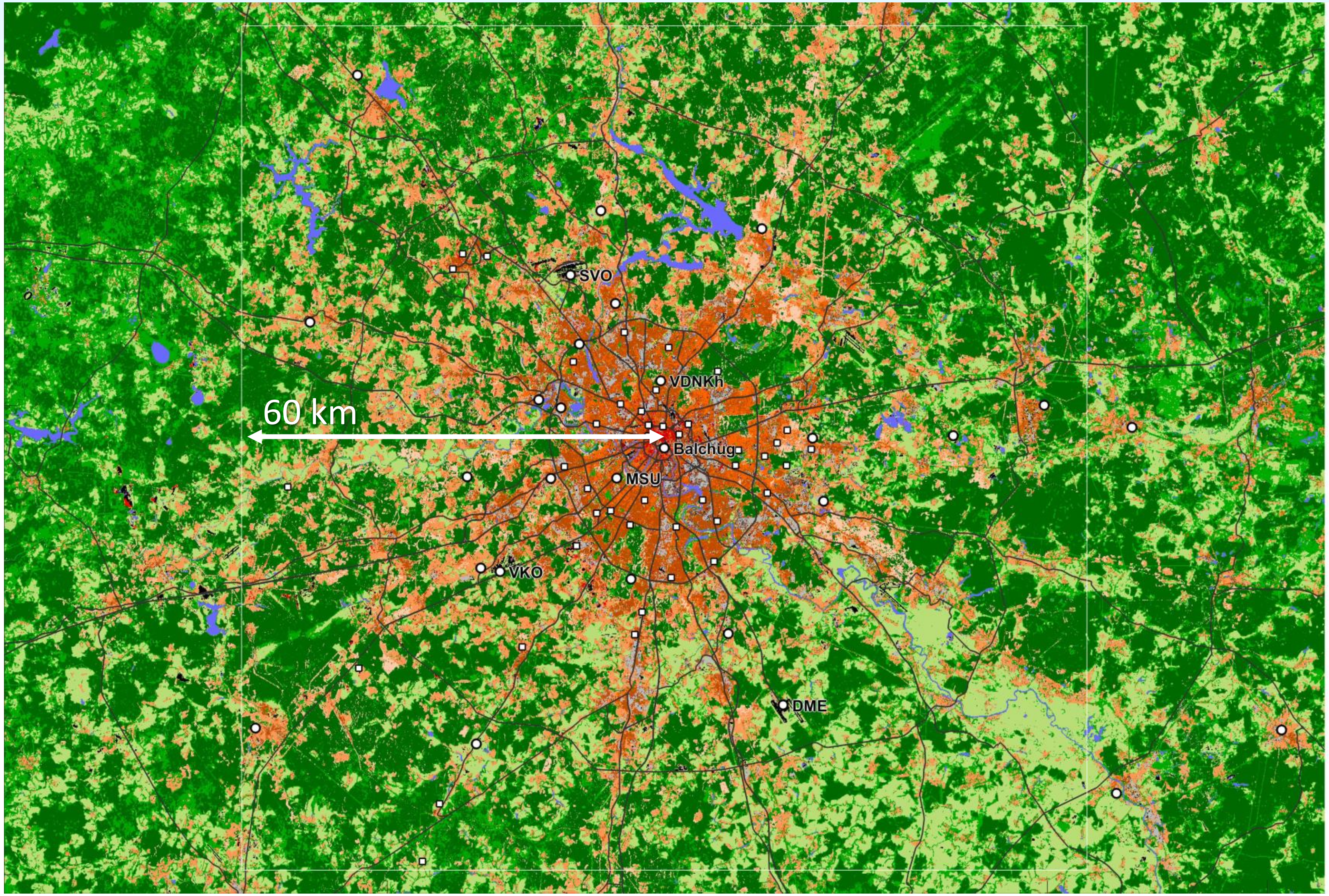
LCZ

?

T_a/LST [°C]

LCZs are often considered as major driver shaping the local climates in a city

Describing the city: **Local Climate Zones**



LCZ type

- 1 Compact high-rise
- 2 Compact midrise
- 3 Compact low-rise
- 4 Open high-rise
- 5 Open midrise
- 6 Open low-rise
- 7 Lightweight low-rise
- 8 Large low-rise
- 9 Sparsely Built
- 10 Heavy Industry
- A Dense trees
- B Scattered trees
- D Low plants
- E Bare rock or paved
- G Water
- Major highways and streets

Open high-rise

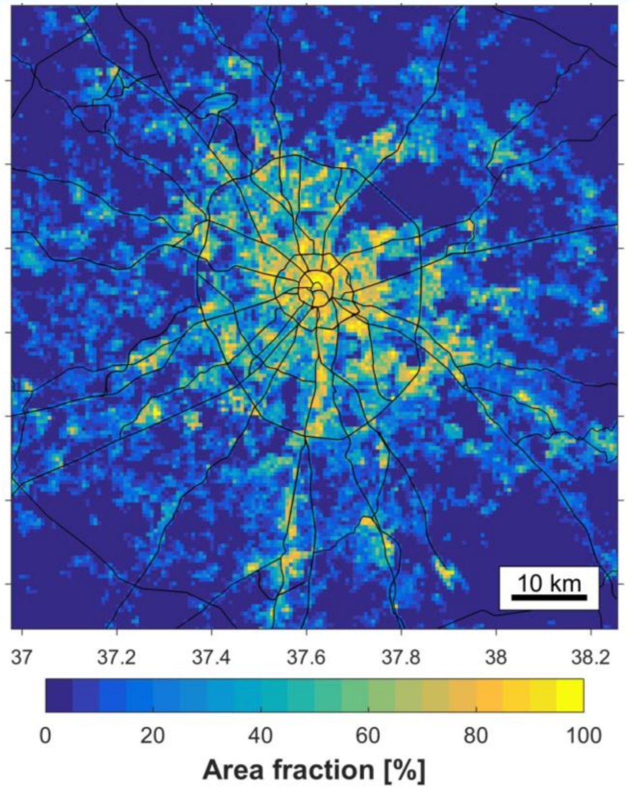
Sparsely built

Low plants

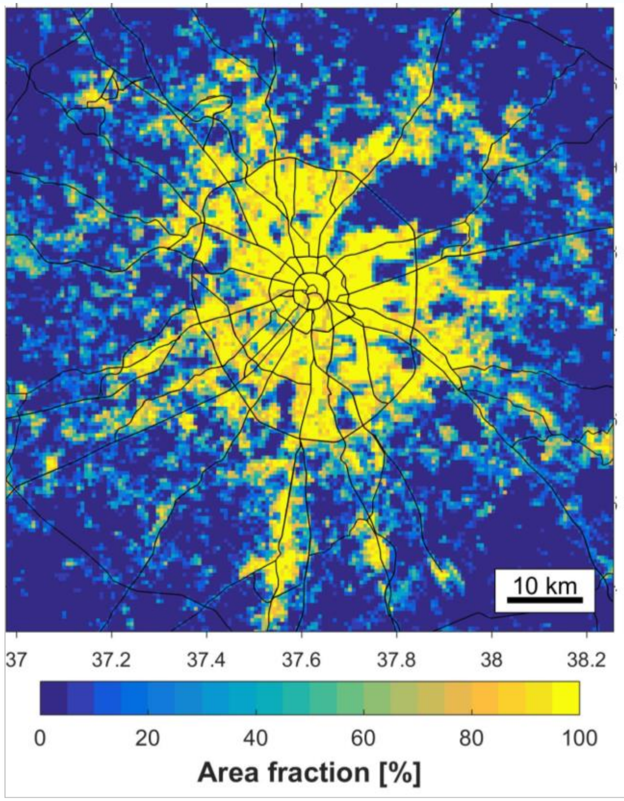
LCZ map for Moscow region from (Samsonov, Trigub, 2017) was recently re-classified and extended for a wider area by Matthias Demuzere (Ruhr University Bochum)

Describing the city: **quantitative parameters**

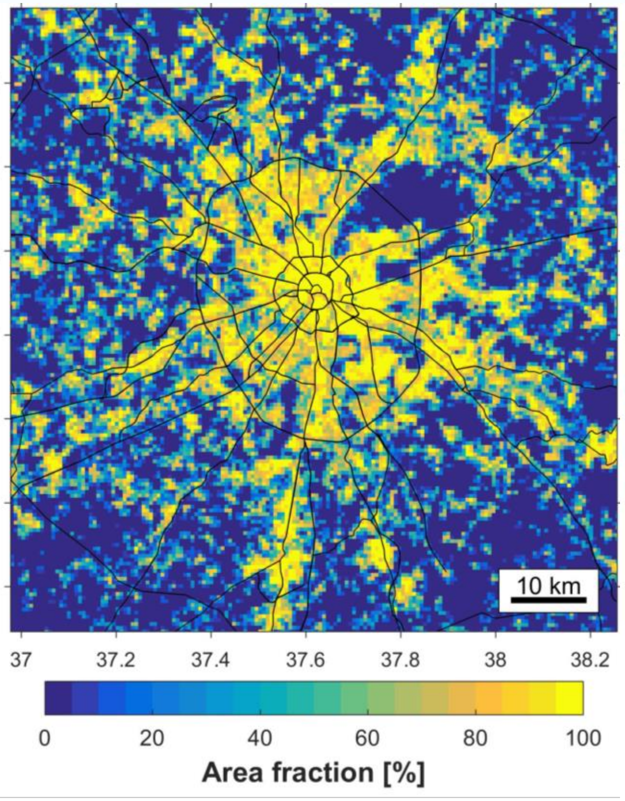
The problem: high uncertainty between different data sets on urban/impervious fraction



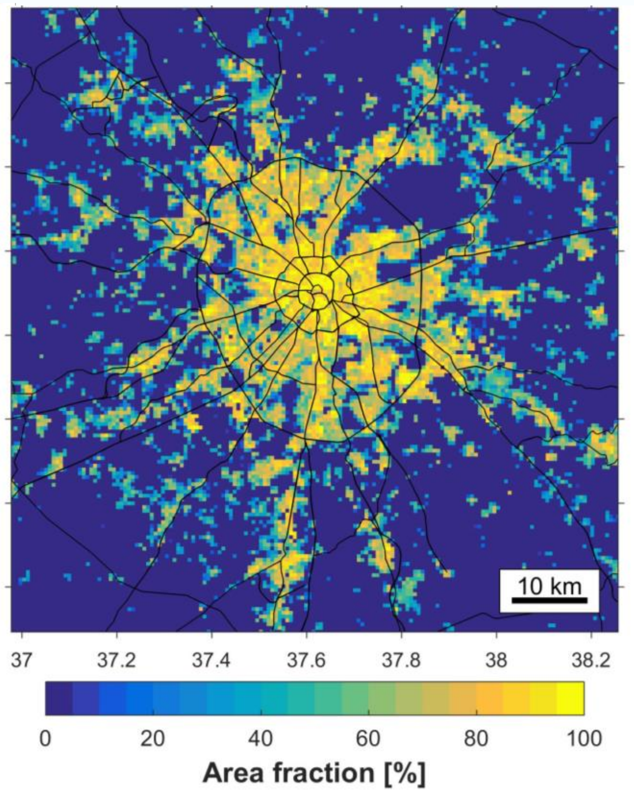
Impervious area fraction (GMIS-2010)



Impervious area fraction (GAIA-2018, Gong et al., 2020)

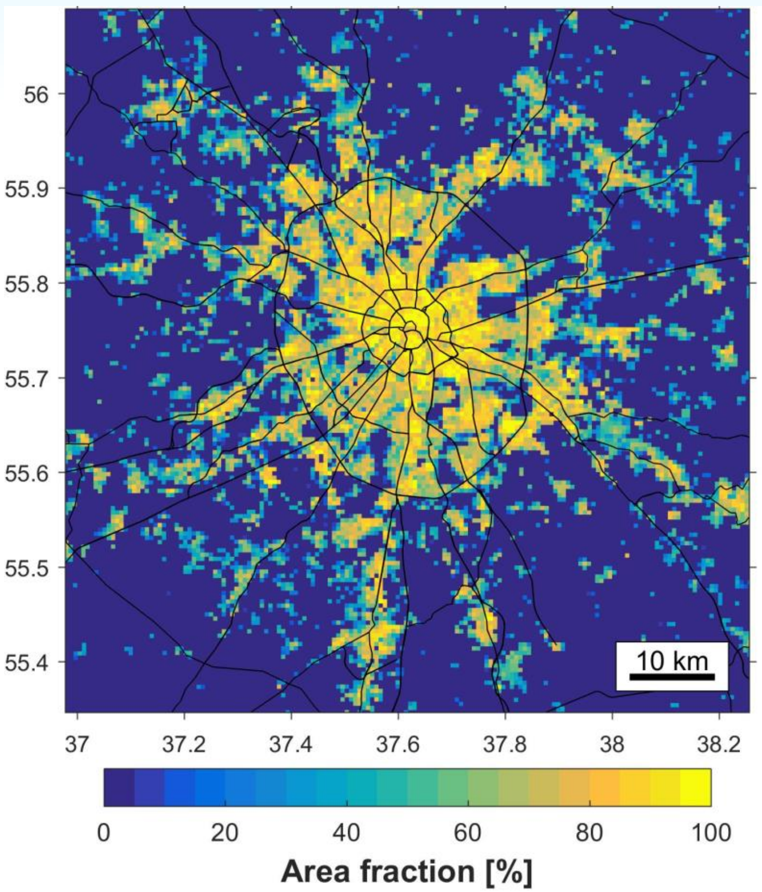


Built-up area fraction from Copernicus Global Land Cover (CGLC, Buchhorn et al., 2020)



Impervious & built-up area fraction (our estimate for based on CGLC data, OSM and Sentinel-2 Images)

Describing the city: **quantitative parameters**



Impervious & built-up area fraction
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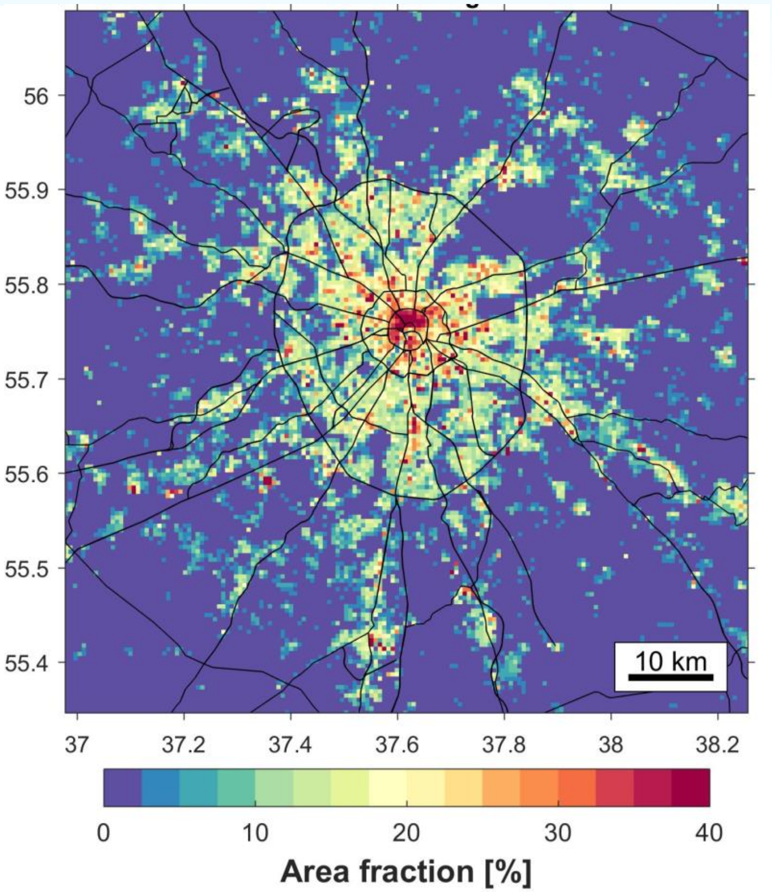
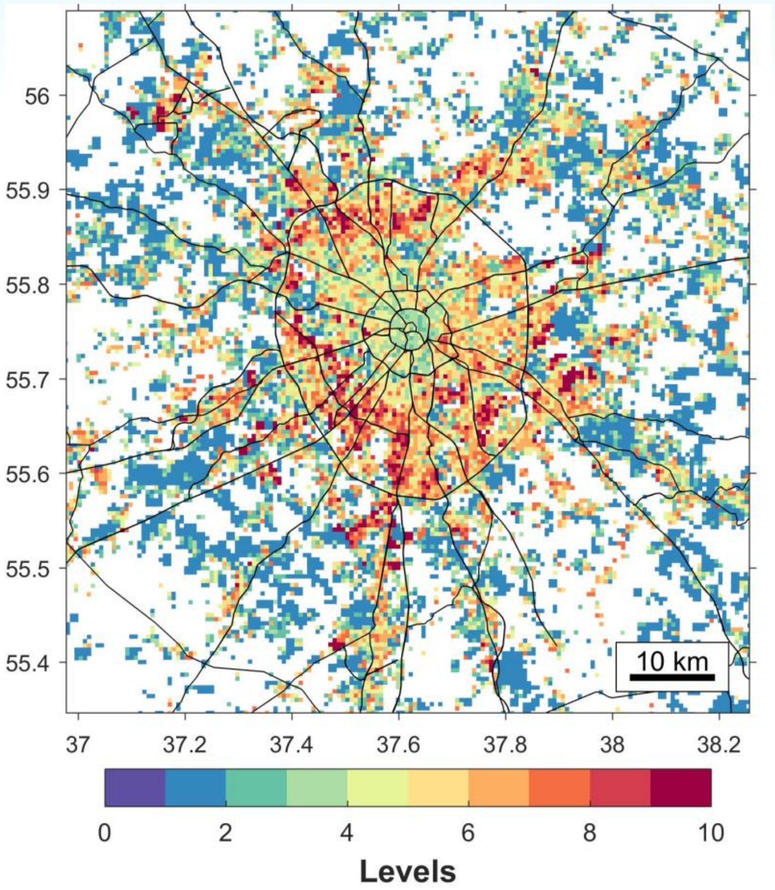


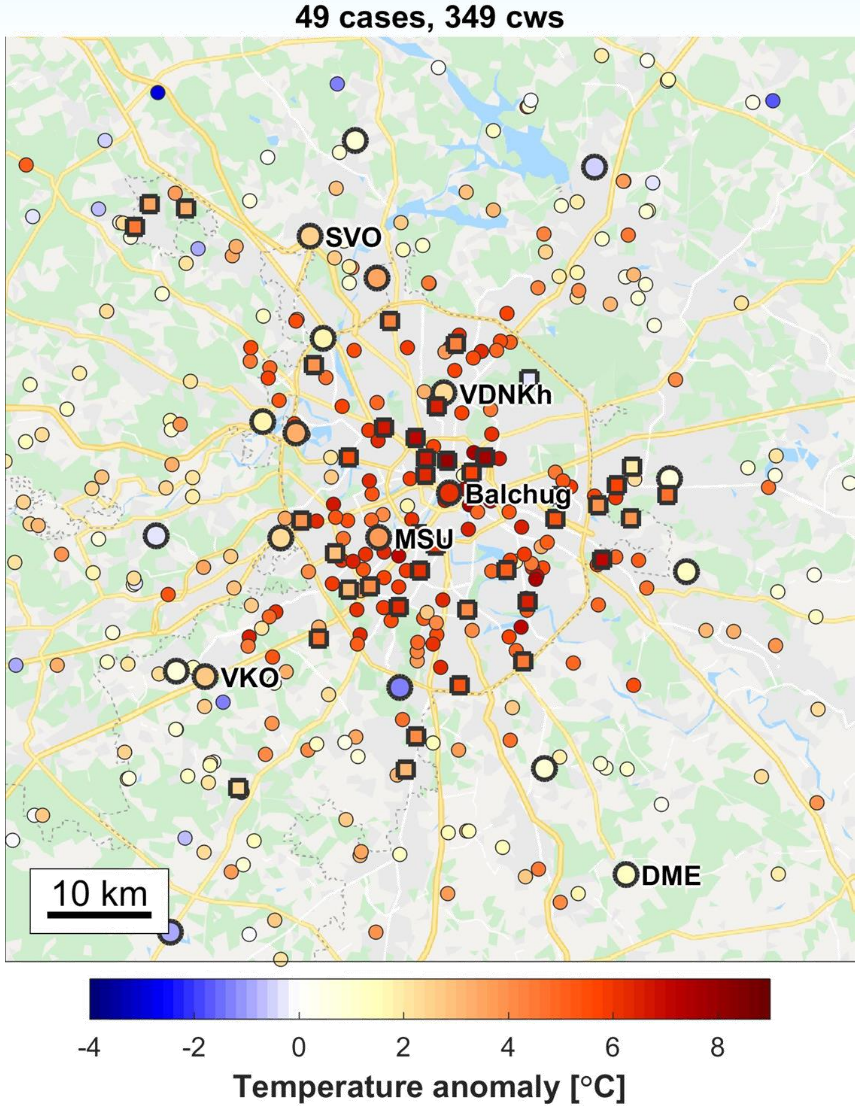
Building fraction based on OSM data



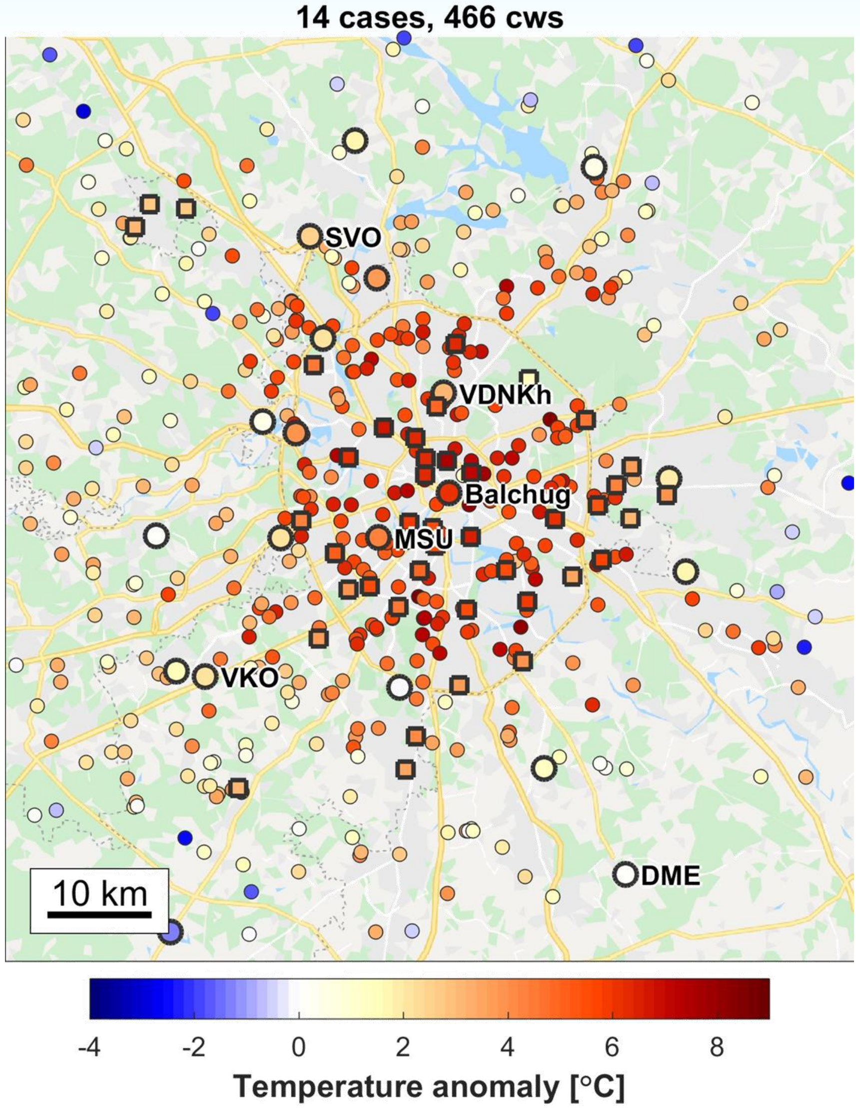
Building height (in levels) based on OSM data

Spatial patents of the UHI: reference and CWS data

Summer (May-June 2019)



Winter (Dec-Jan 2018/19)



◯ Reference weather station

□ Reference air-quality station

○ Netatmo CWS

UHI intensity: temperature anomaly with respect to the mean rural value, averaged over 9 stations around Moscow

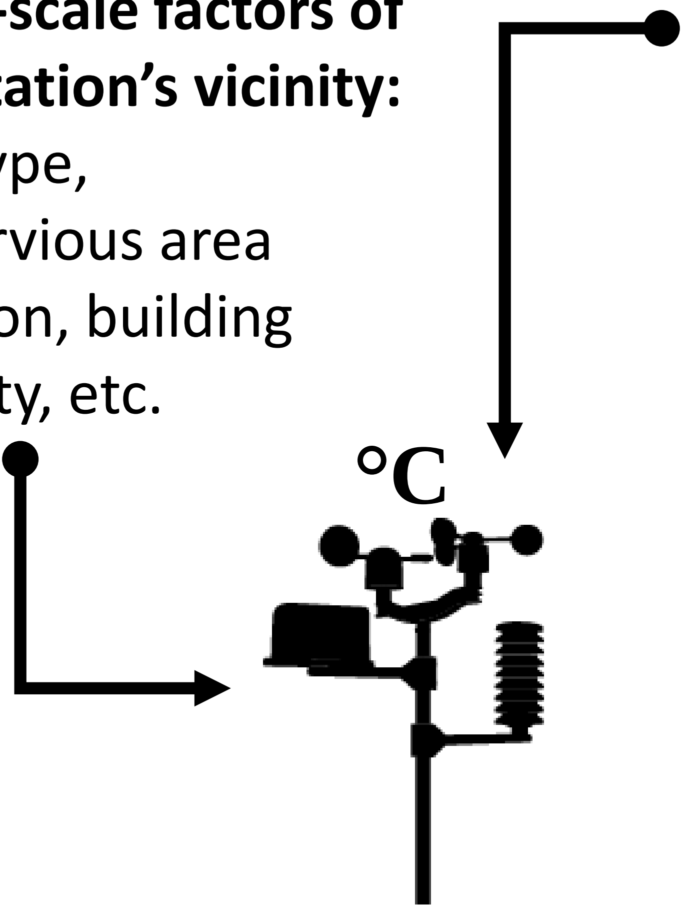
These and all further results are shown for the selection of nocturnal cases when $UHI_{center} > 4°C$

General idea: to analyze the contribution from local and non-local drivers

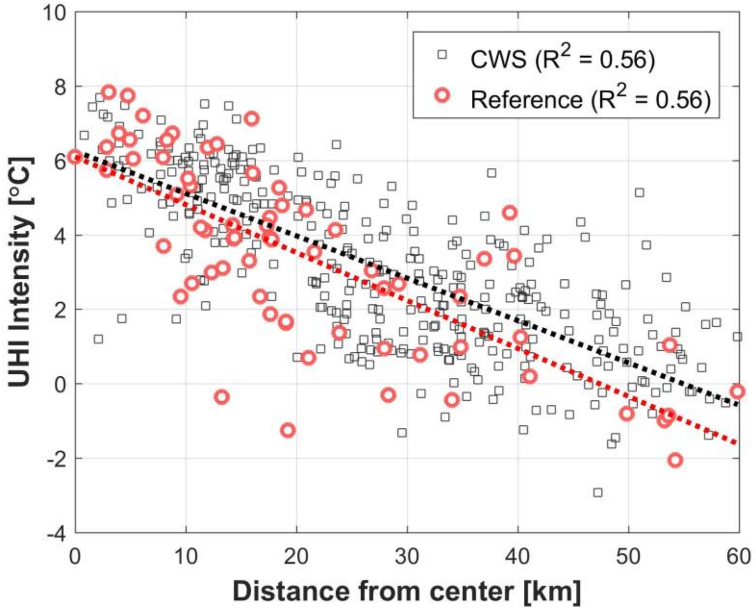
Local-scale factors of the station's vicinity:
LCZ type,
Impervious area fraction, building density, etc.

Non-local factors:
Mesoscale influence from the rest of the city.

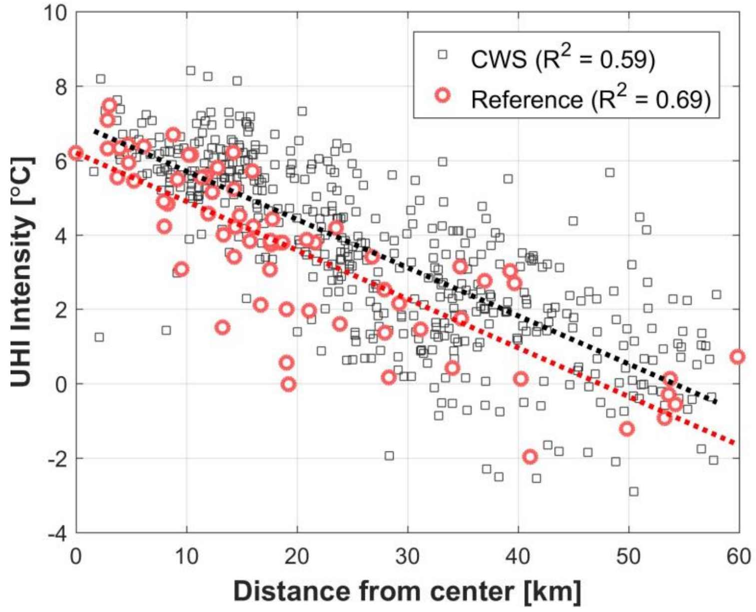
Extreme simplification: dependence from the distance from the city center (reasonable for Moscow)



Summer (May-June 2019)



Winter (Dec-Jan 2018/19)



Temperature vs LCZ type: official data

Summer

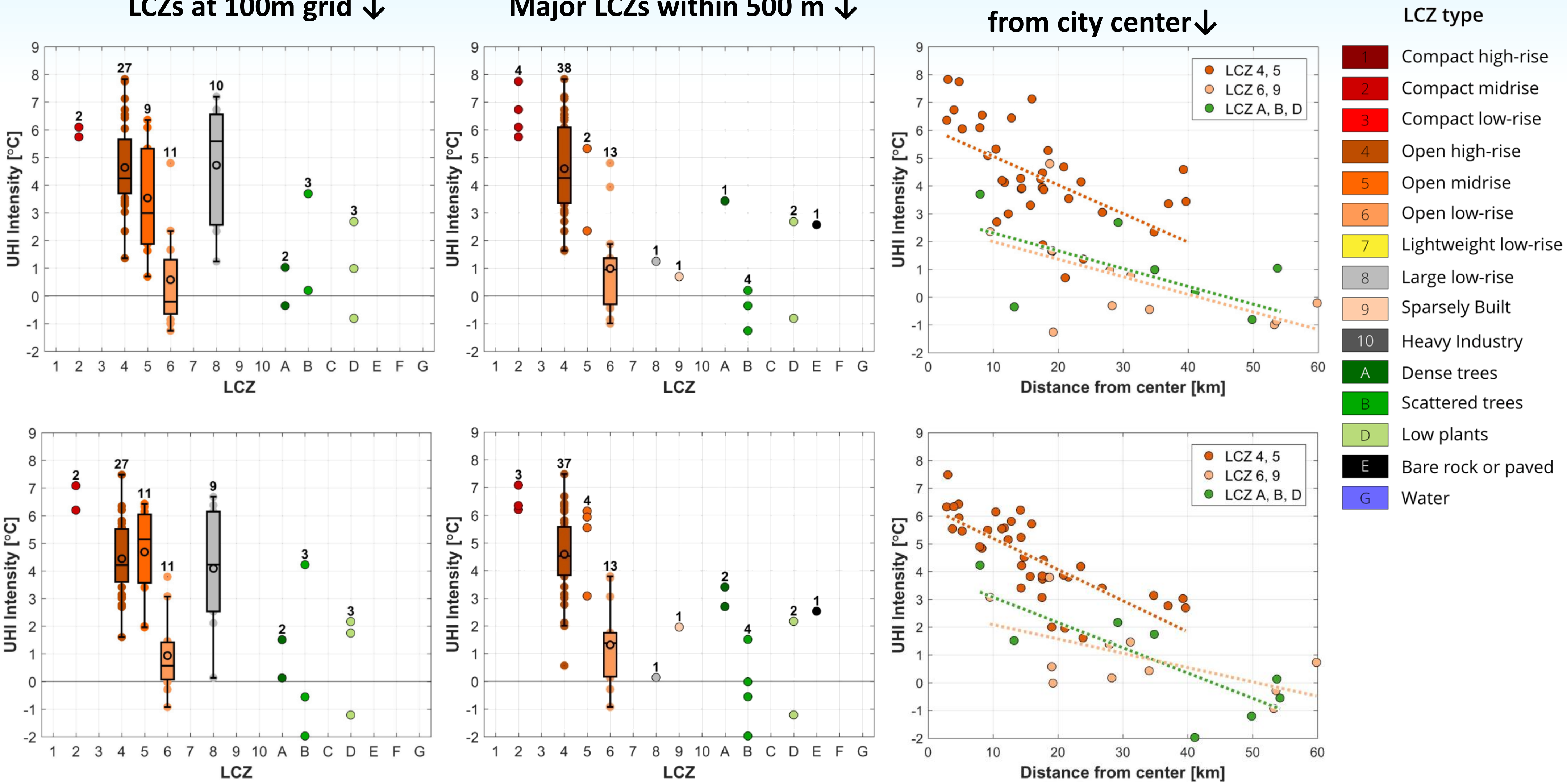
(May-June 2019)

Winter

(Dec-Jan 2018/19)

Results for the selection of nocturnal cases when UHI_{center} > 4°C

LCZs at 100m grid ↓ | **Major LCZs within 500 m ↓** | **LCZs at 100m grid vs distance from city center↓**



Temperature vs LCZ type: CWS data

LCZs at 100m grid ↓

Major LCZs within 500 m ↓

LCZs at 100m grid vs distance from city center↓

LCZ type

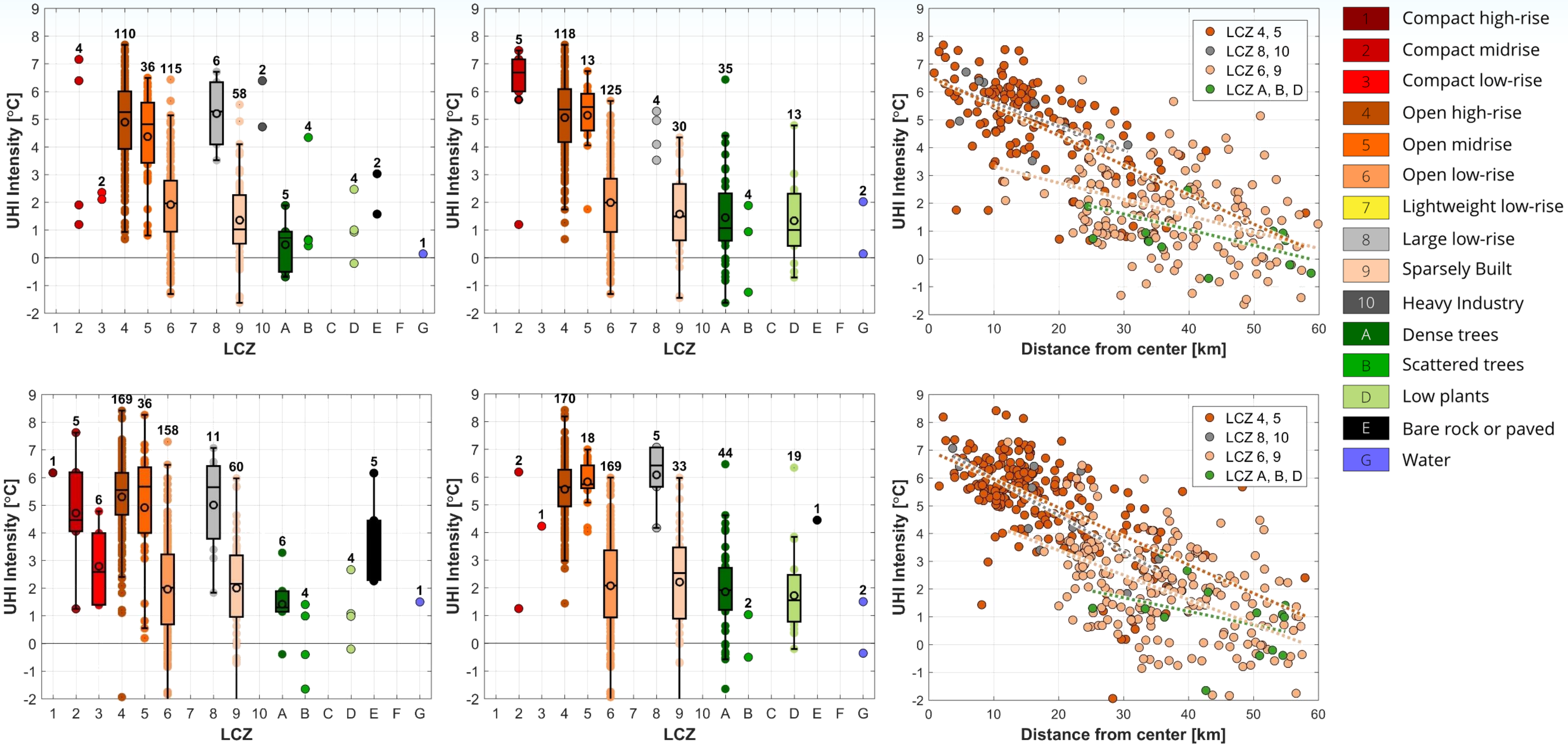
Summer

(May-June 2019) →

Winter

(Dec-Jan 2018/19) →

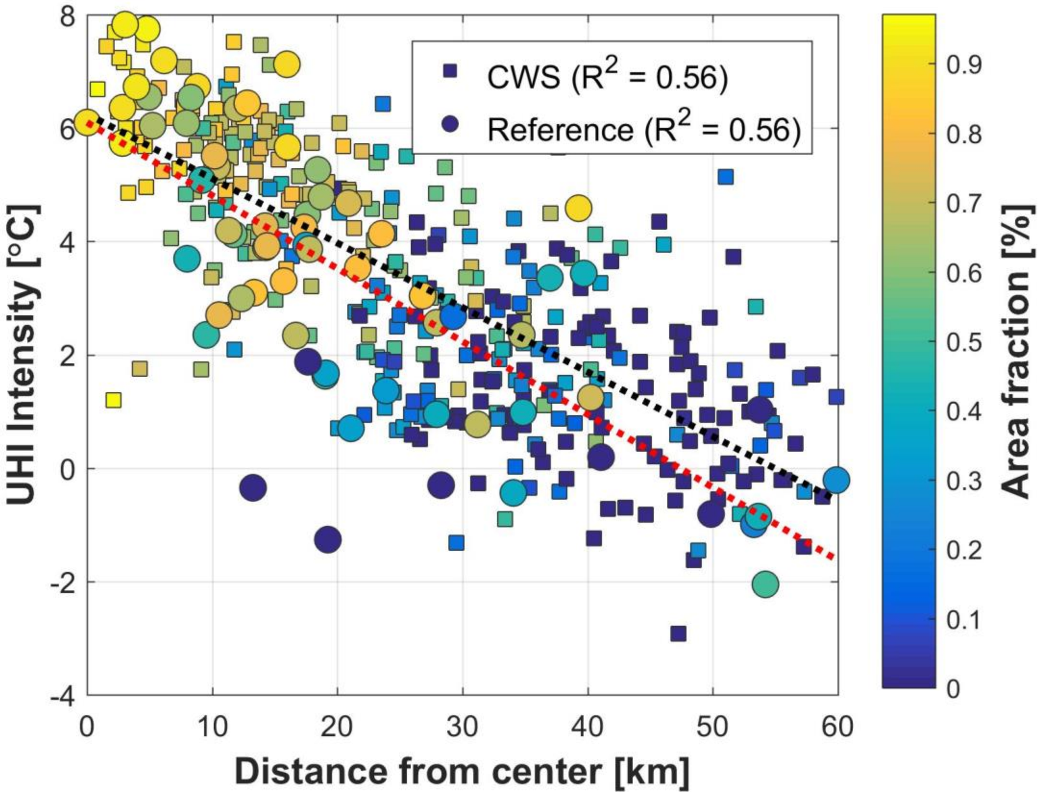
Results for the selection of nocturnal cases when UHI_{center} > 4°C



Summary: high temperature variety within similar LCZs. High sensitivity to size of the area where major LCZ is defined. Dependence between temperature and distance from city center exists within different LCZs.

Towards understanding the driving factors

Relation between UHI intensity, distance from city center and impervious & built-up area fraction (our estimate for based on CGLC data, OSM and Sentinel-2 Images) **for summer**



Preliminary results of the statistical analysis of the relationships between temperature anomaly (Ta), different local predictors (surface properties in the point's surroundings) and non-local predictor (distance from the city center)

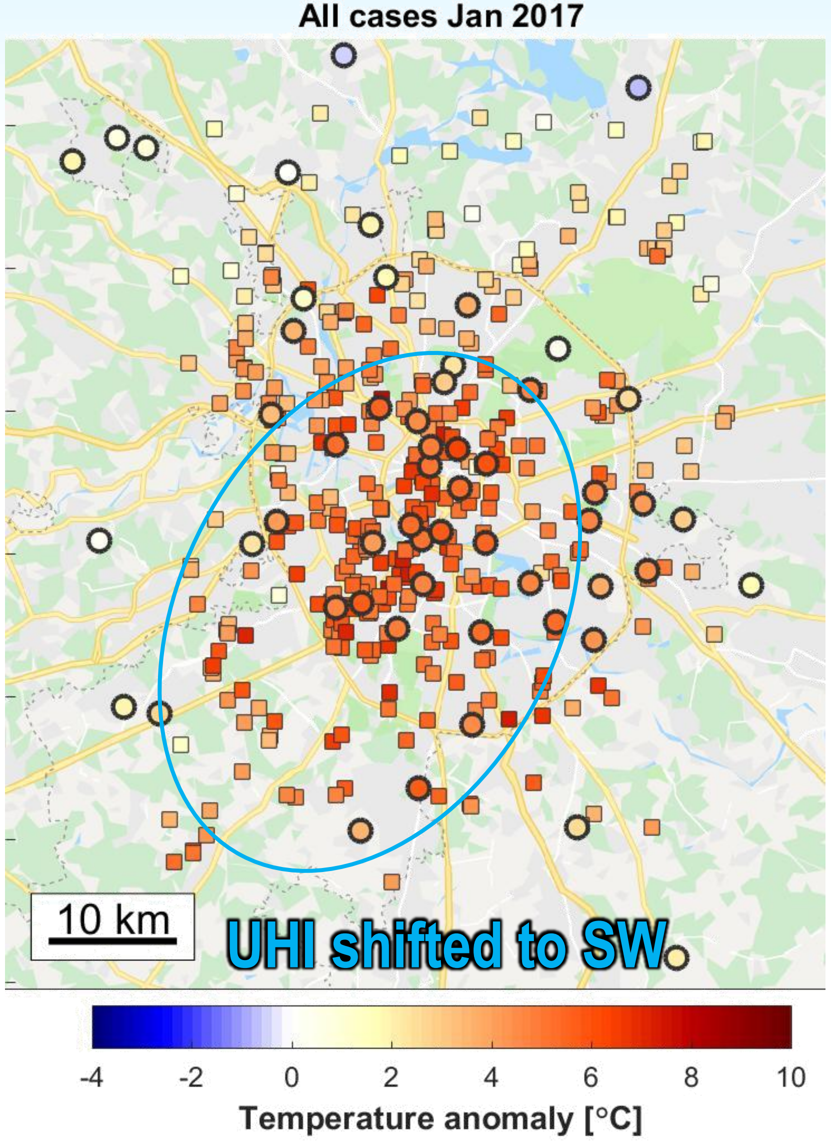
CWSs, summer			
Local predictor	**R_p (Ta, Local predictor)**	**R_p (Ta, distance)**	**R_{MLR}**
Paved & built-up fraction (corrected CGLC)	**0.36**	**-0.44**	**0.78**
Built-up fraction (CGLC)	**0.27**	**-0.62**	**0.77**
Paved fraction (GMIS)	**0.34**	**-0.46**	**0.78**
Paved fraction (GAIA)	**0.41**	**-0.31**	**0.79**
Building fraction (OSM)	**0.29**	**-0.48**	**0.77**
Reference weather stations, summer			
Local predictor	**R_p (Ta, Local predictor)**	**R_p (Ta, distance)**	**R_{MLR}**
Paved & built-up fraction (corrected CGLC)	**0.61**	**-0.62**	**0.85**
Built-up fraction (CGLC)	**0.53**	**-0.67**	**0.83**
Paved fraction (GMIS)	**0.55**	**-0.57**	**0.83**
Paved fraction (GAIA)	**0.53**	**-0.50**	**0.83**
Building fraction (OSM)	**0.56**	**-0.57**	**0.83**

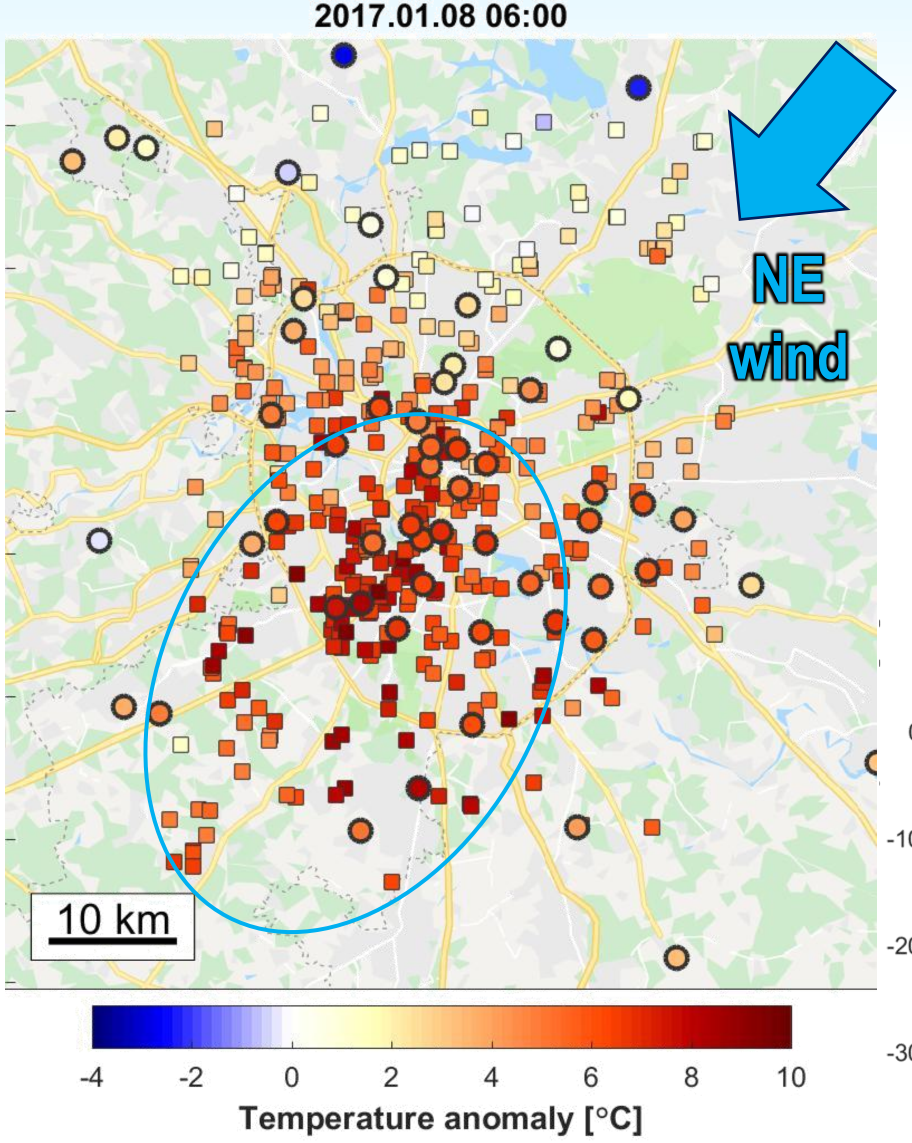
R_p – multiple correlation coefficient for Ta, distance and one of the local predictors

R_{MLR} – correlation between Ta and its MLR predition based on one non-local predictor (distance) and one of local predictors

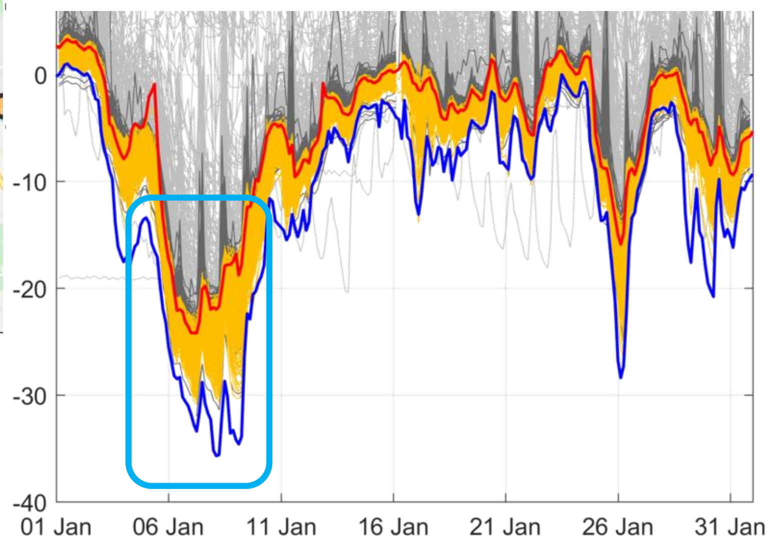
Further research is going...

Spatial patterns of the winter UHI

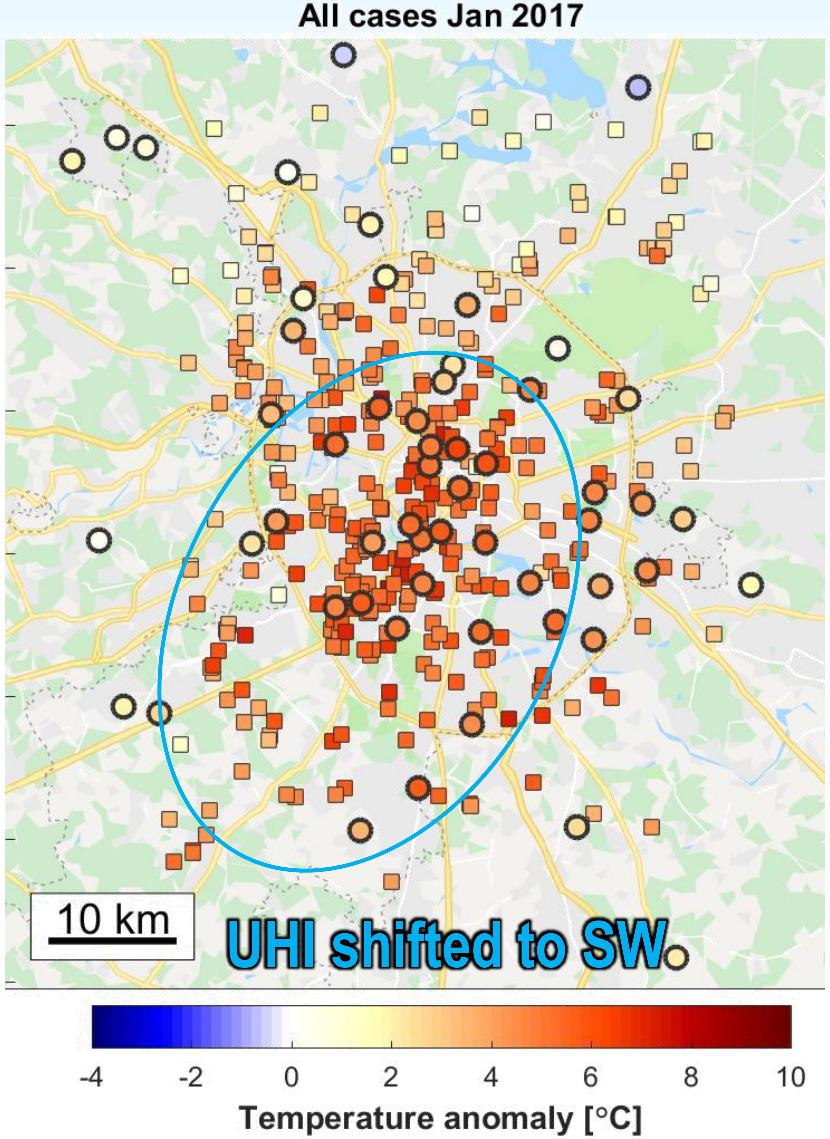


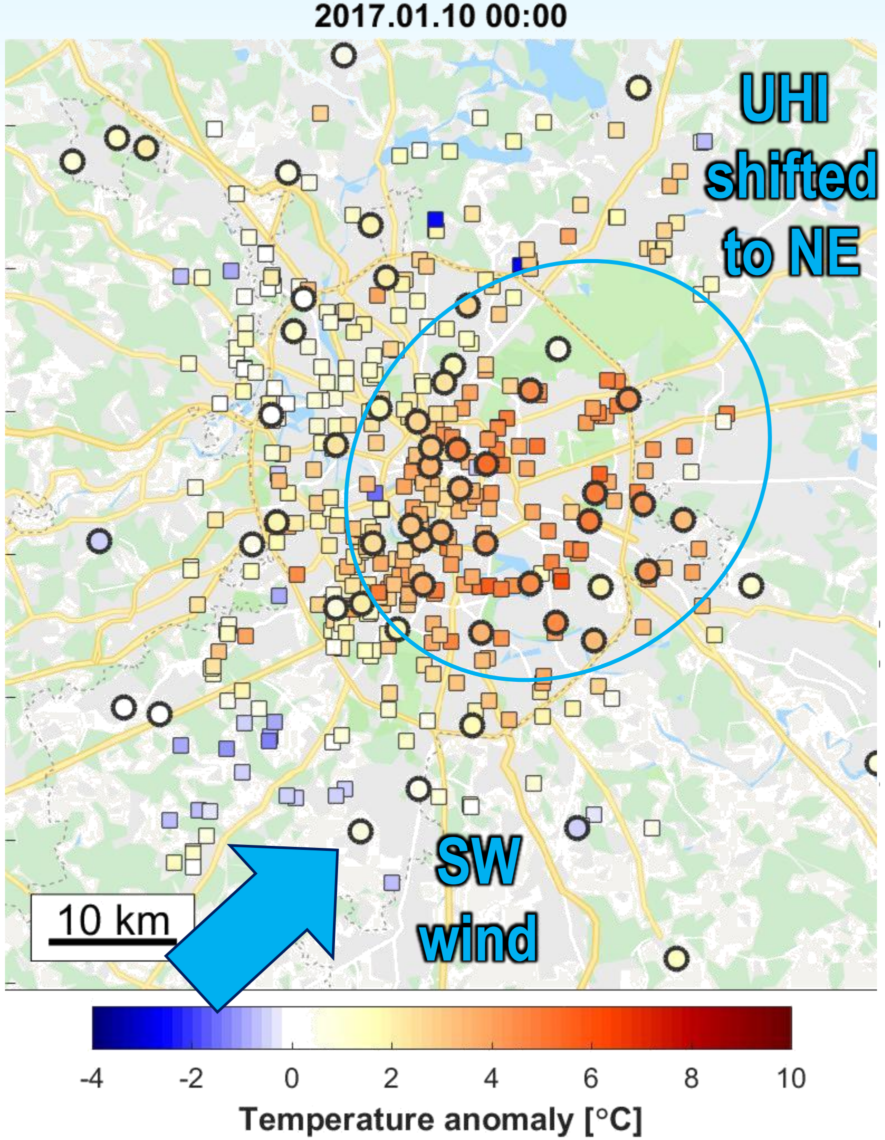


7-9 Jan 2017 – one of the coldest periods in Moscow in XXI century (Yushkov et al., 2019)



Spatial patterns of the winter UHI





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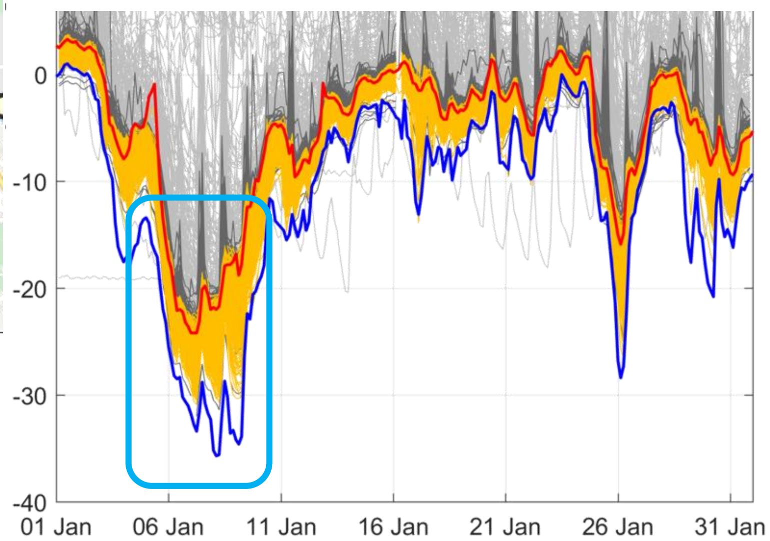

Key results

- ✓ **Urban climate is not just a variety of local climates**
- ✓ **LCZs concept is a great invention, but it could not explain the real variety of local climates in a megacity (at least in Moscow)**
- ✓ **The non-local (mesoscale) effects are important**
- ✓ **The simplest reflections of the non-local effects:**
  - Dependence between the temperature and distance from the city center
  - Temperature differences between the similar LCZs in the different parts of the city
  - Heat advection to the leeward side of the city
- ✓ **The data of Netatmo CWSs could open a new era in the spatially-resolved urban climate studies, but a lot of further research is needed**

Preliminary results will be published soon: Varentsov M.I., Konstantinov P.I., Shartova N.V., Samsonov T. E., Kargashin P. E., Varentsov A.I., Fenner D., Meier F. *Urban heat island of the Moscow megacity: the long-term trends and new approaches for monitoring and research based on crowdsourcing data*// IOP Conference Series: Earth and Environmental Science. 2020. (accepted)

Any questions, ideas or suggestions?

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