CLM-Assembly 2020, 15.09.2020

High-resolution weather and climate simulations for Moscow megacity with TERRA_URB scheme: **the recent developments and new challenges**

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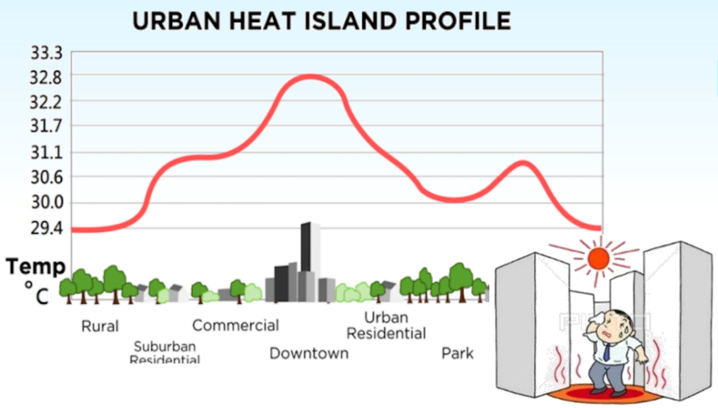
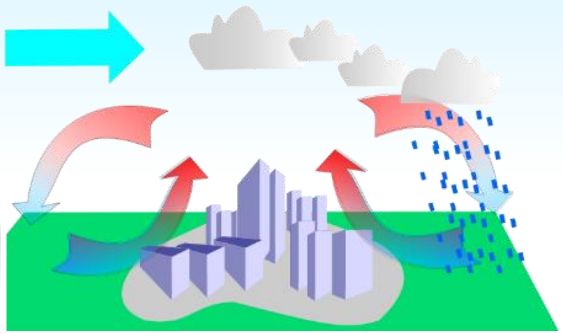
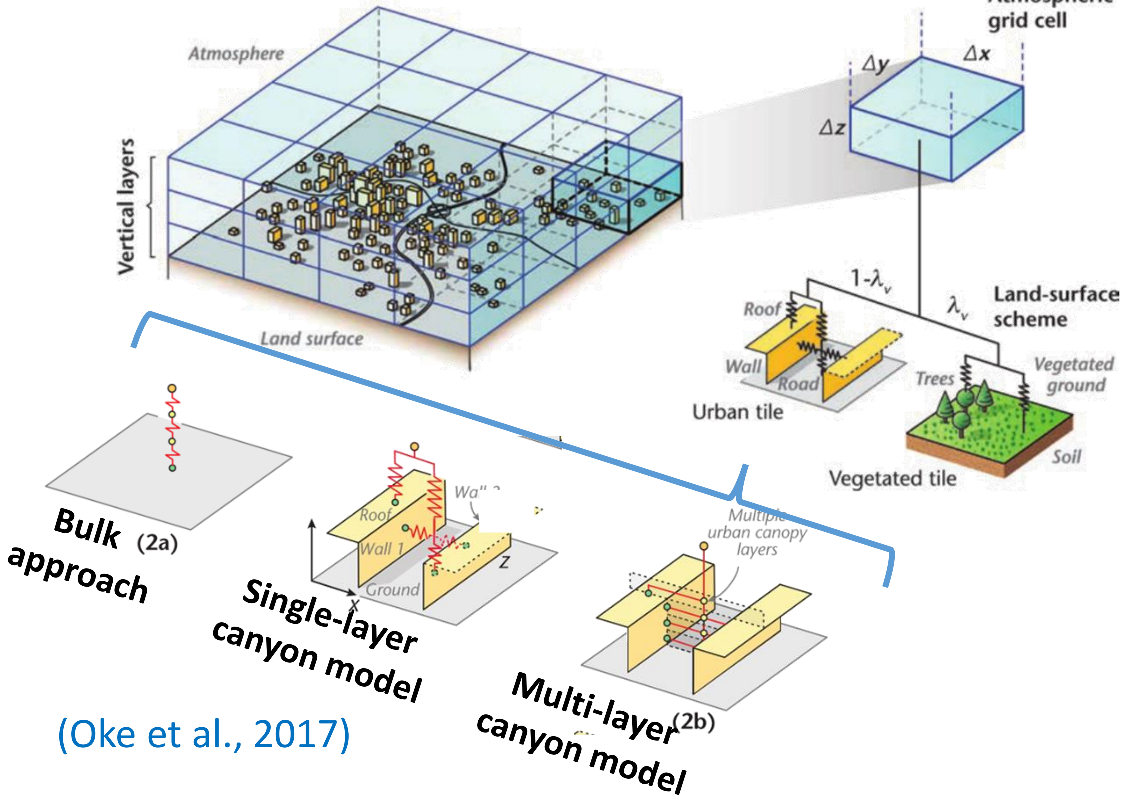
2) Hydrometeorologycal Research Center of Russia, Moscow
3) A.M. Obukhov Institute of Atmospheric Physics
4) RUDN University
5) Ruhr University Bochum

Urban climate & urban parameterizations





Urban parameterizations for mesoscale models



(Oke et al., 2017)

What's available in COSMO?

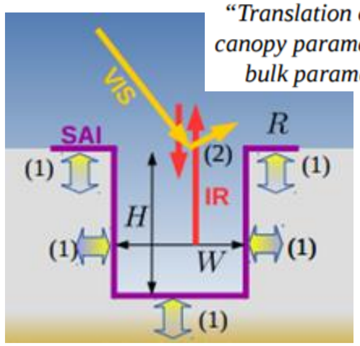
1) TEB (Town Energy Balance) – single layer scheme (Trusilova et al., 2013), problems in coupling revealed (Varentsov et al., 2017)

2) DCEP (Shubert et al., 2012) and **BEP-Tree** (Musetti et al., 2019): the most advanced multi-layer schemes for COSMO

3) TERRA_URB (Wouters et al.,2016), simple and fast bulk scheme

- Surface properties in TERRA are modified by **SURY (Semi-empirical Urban canopy parameterization)**
- Impervious urban tile with puddles
- Pre-defined anthropogenic heat flux according to (Flanner, 2009)

"Translation of urban canopy parameters into bulk parameters"



Geosci. Model Dev., 9, 3027–3054, 2016
www.geosci-model-dev.net/9/3027/2016/
doi:10.5194/gmd-9-3027-2016

Geoscientific Model Development
Open Access

The efficient urban canopy dependency parametrization (SURY) v1.0 for atmospheric modelling: description and application with the COSMO-CLM model for a Belgian summer

Hendrik Wouters[1], Matthias Demuzere[1], Ulrich Blahak[2], Krzysztof Fortuniak[3], Bino Maiheu[4], Johan Camps[5], Daniël Tielemans[6], and Nicole P. M. van Lipzig[1]

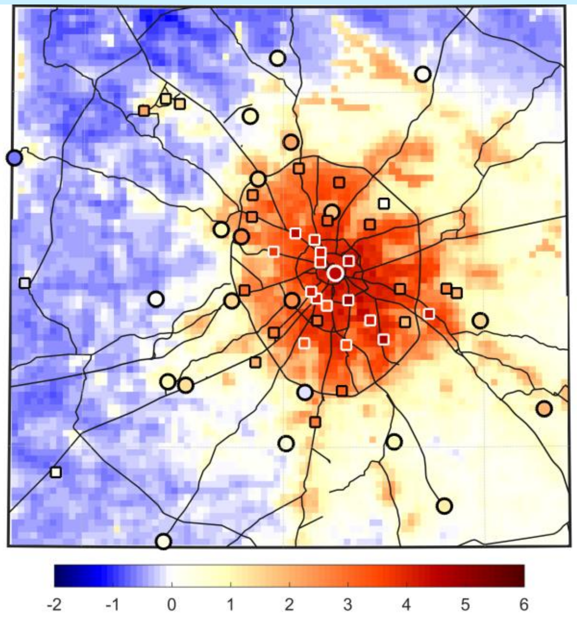
Previous studies for Moscow

Moscow as a test-bed for urban climate studies:

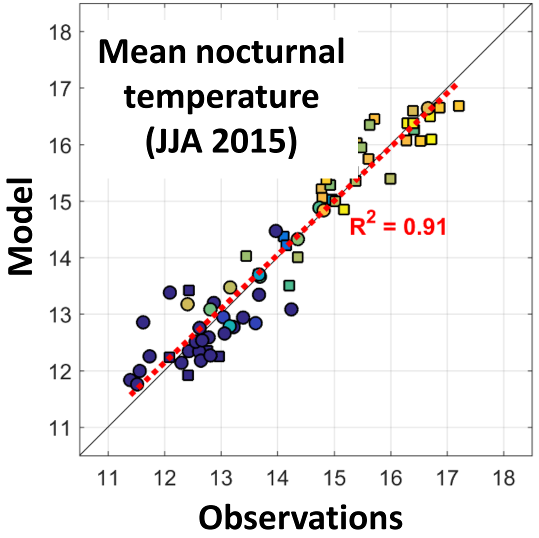
- ✓ The biggest agglomeration in Europe ($\approx 17 \cdot 10^6$ people)
- ✓ Compact and symmetric shape of the city, flat and homogenous surrounding landscape
- ✓ Intense UHI
- ✓ Dense observational network

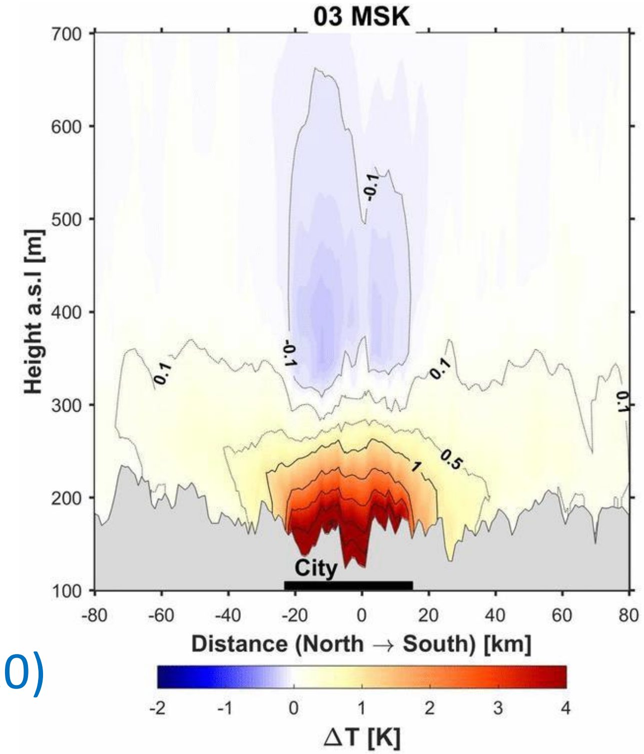
Previous studies with TERRA_URB for Moscow:

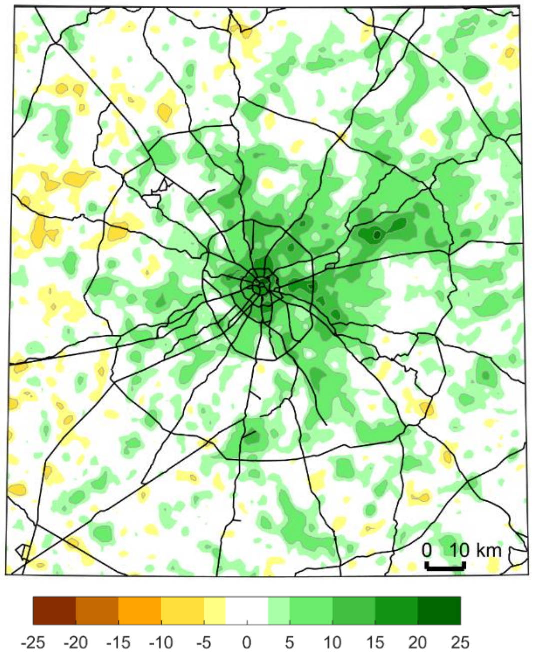
- ❑ Urbanization scenarios (Varentsov et al. 2017b)
- ❑ Urban-induced effects in lower atmosphere (Varentsov et al. 2018)
- ❑ Verification based on in-situ and remote-sensing data (Varentsov et al., 2019)
- ❑ COSMO-Ru NWP for Moscow (Rivin et al., 2019; 2020)



Simulated vs observed UHI [°C]







Summer precipitation anomaly [%]

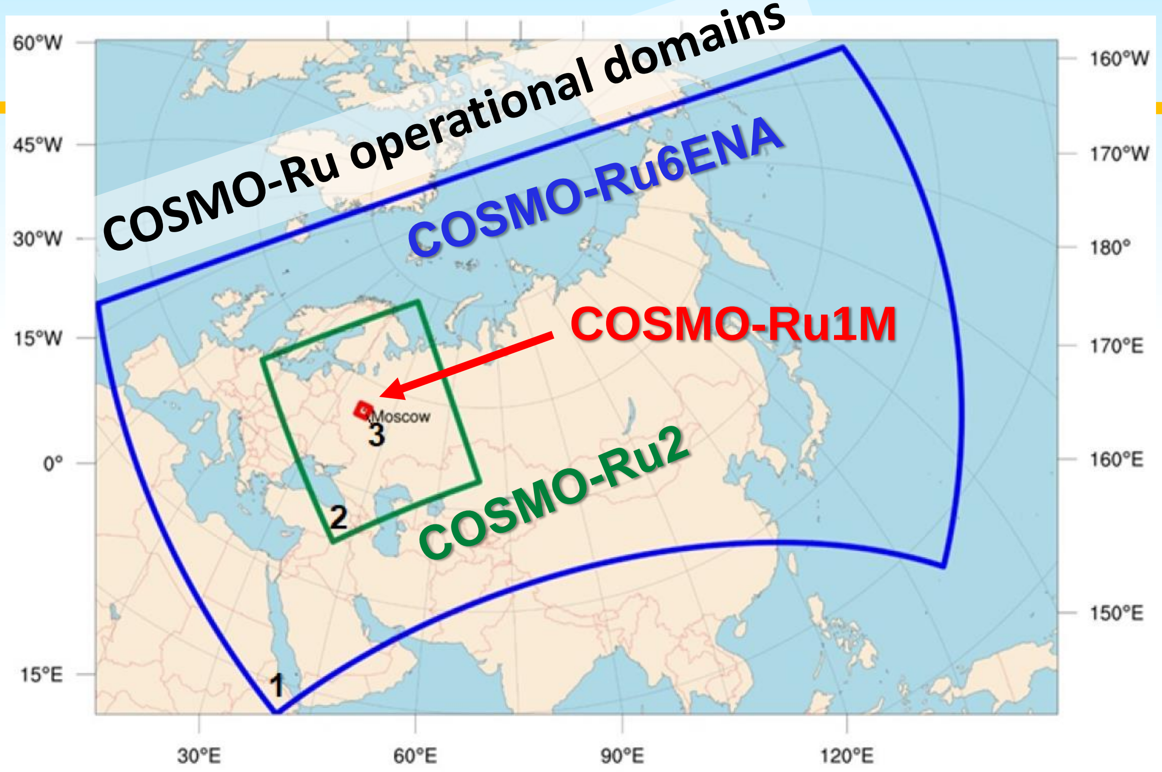
Ongoing studies

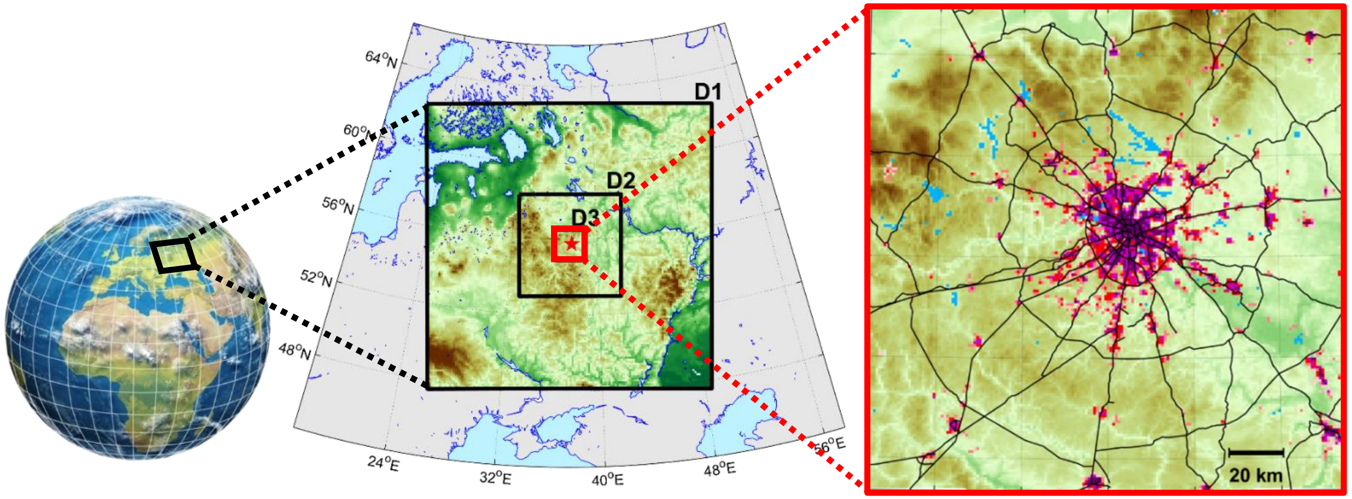
Applications:

- Testing new developments for improving the numerical weather forecast for urban areas
- Historical hindcasts to provide high-resolution meteorological data for interdisciplinary studies (biometeorology, soil ecology, etc.)

New challenges:

- New model developments
- City-descriptive external parameters
- Increasing the model resolution towards the “gray zone” (1 km → 500 m)
- Model tuning and other improvements (firstly the soil physics)





Dynamical downscaling chain for hindcast simulations

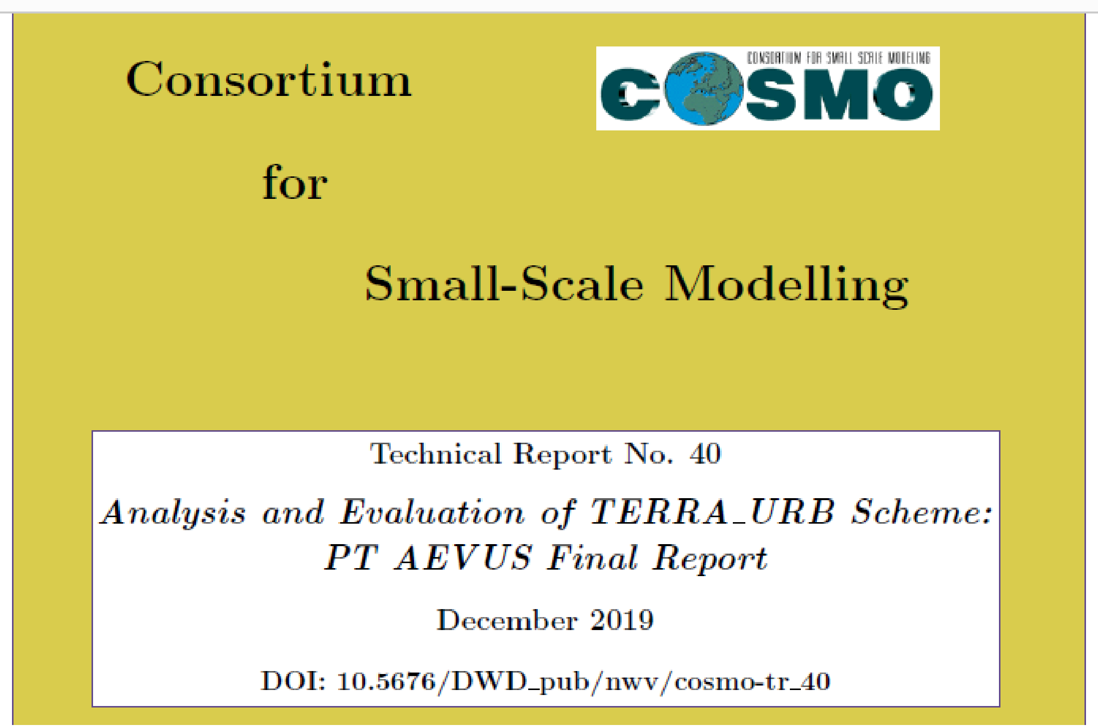
Recent developments of the TERRA_URB scheme

2016: parallel branch of **COSMO 5.0_clm9** with TERRA_URB became available (Wouters et al., 2016).

2016-2017: first tests of COSMO + TERRA_URB for Moscow megacity. Some code developments additionally performed.

2017: start of AEVUS PT, aimed to the implementation of the TERRA_URB scheme to the recent COSMO version (5.04, 5.05). **This versions include new ICON-based physics!**

2019: AEVUS PT successfully finished with a stable, debugged and tested model version **5.05urb5** with TERRA_URB (report is available)


Consortium

for

Small-Scale Modelling

Technical Report No. 40

Analysis and Evaluation of TERRA_URB Scheme: PT AEVUS Final Report

December 2019

DOI: 10.5676/DWD_pub/nwv/cosmo-tr_40

2019: start of AEVUS 2 with following aims:
1) Development of the more flexible version with less hard-coded parameters
2) In-depth testing and verification
3) First steps towards TERRA_URB implantation to ICON

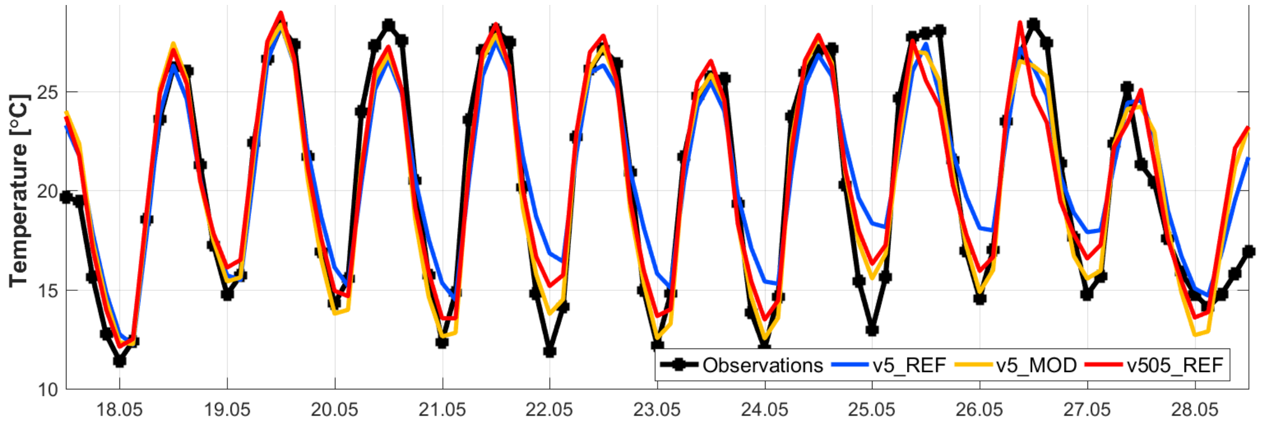
2020: developments towards implementing additional external parameters for TERRA_URB (**5.05urb6up)**

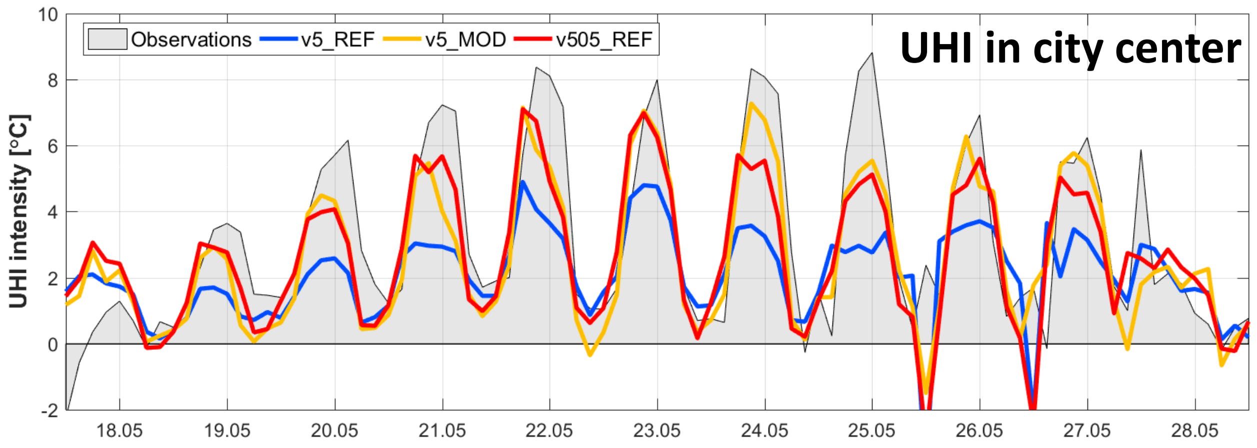
2020 (?): last unified COSMO update, version 6.0, will include TERRA_URB

2020-2023 (?): PP CITTA proposal is prepared for moving TERRA_URB to ICON

New and old COSMO versions with TERRA_URB

Mean rural temperature (averaged over 9 stations)





Simulations for May 2014

Parameter	v5_REF	v5_MOD	v505_REF*
PHYCTL			
Itype_rootdp	1	2	2
Itype_evsl	1	4	4
Itype_heatcond	1	2	3
Itype_canopy	1	2	1*
calamrur	-	30	-
londtur	-	-	FALSE
TUNNING			
tkmmin & tkhmin	0.4	0.1 or 0.05	0.75
pat_len	500	100 or 50	100

New COSMO version with “new” physics and default settings behaves as good as carefully tuned old version

(PT AEVUS report, 2019; Rivin et al., 2020)

New city-descriptive external parameters

- **Basic external parameters for TERRA_URB in (Wouters et al., 2016):**
  - Impervious area fraction (ISA)
  - Annual-mean anthropogenic heat flux (AHF)

- **Additional 2D external parameters to replace hard-coded values:**

Urban canopy parameters (input of SURY)		
Parameter name	Symbol	Default values
Surface albedo	α	0.101
Surface emissivity	ϵ	0.86
Surface heat conductivity	λ_s	$0.767\,\mathrm{W\,m^{-1}\,K^{-1}}$
Surface heat capacity	$C_{v,s}$	$1.25 \times 10^6\,\mathrm{J\,m^{-3}\,K^{-1}}$
Building height	H	15 m
Canyon height-to-width ratio	$\frac{h}{w_c}$	1.5
Roof fraction	R	0.667

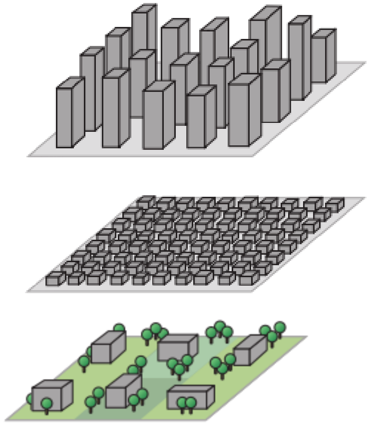
Thermal and radiative parameters of urban materials (surface albedo, emissivity, heat conductivity, heat capacity)

Building morphology parameters (building height, canyon height-to-width ratio, roof fraction)

LCZ 1 Compact highrise

LCZ 3 Compact lowrise

LCZ 5 Open midrise

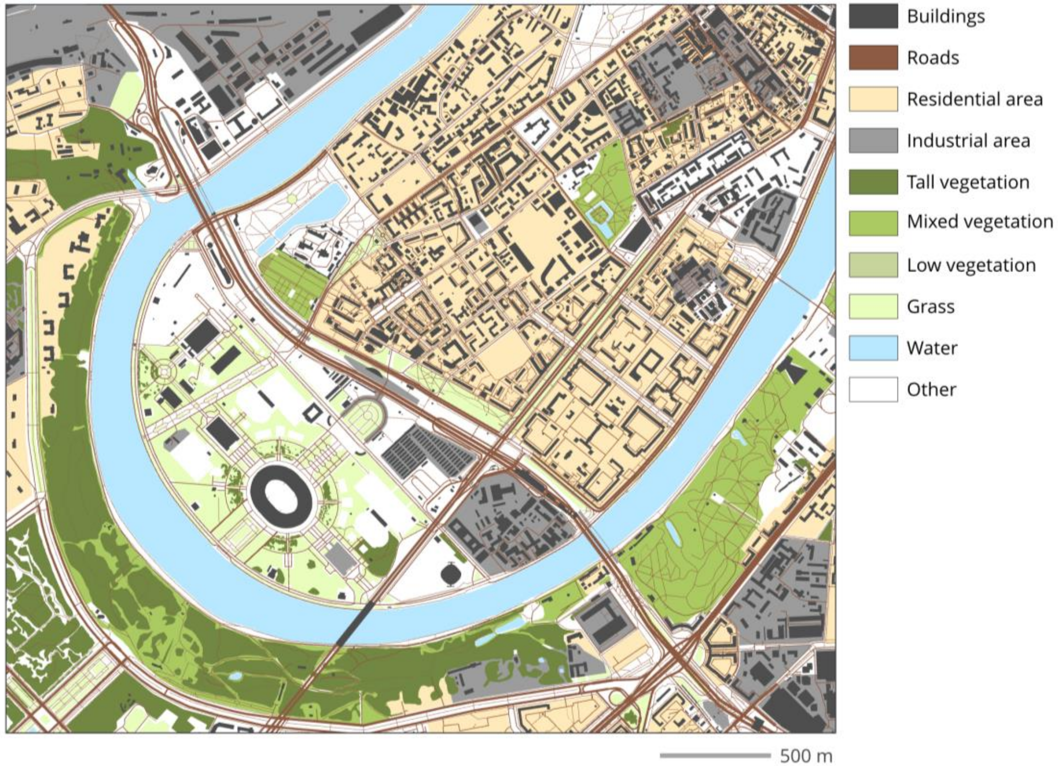


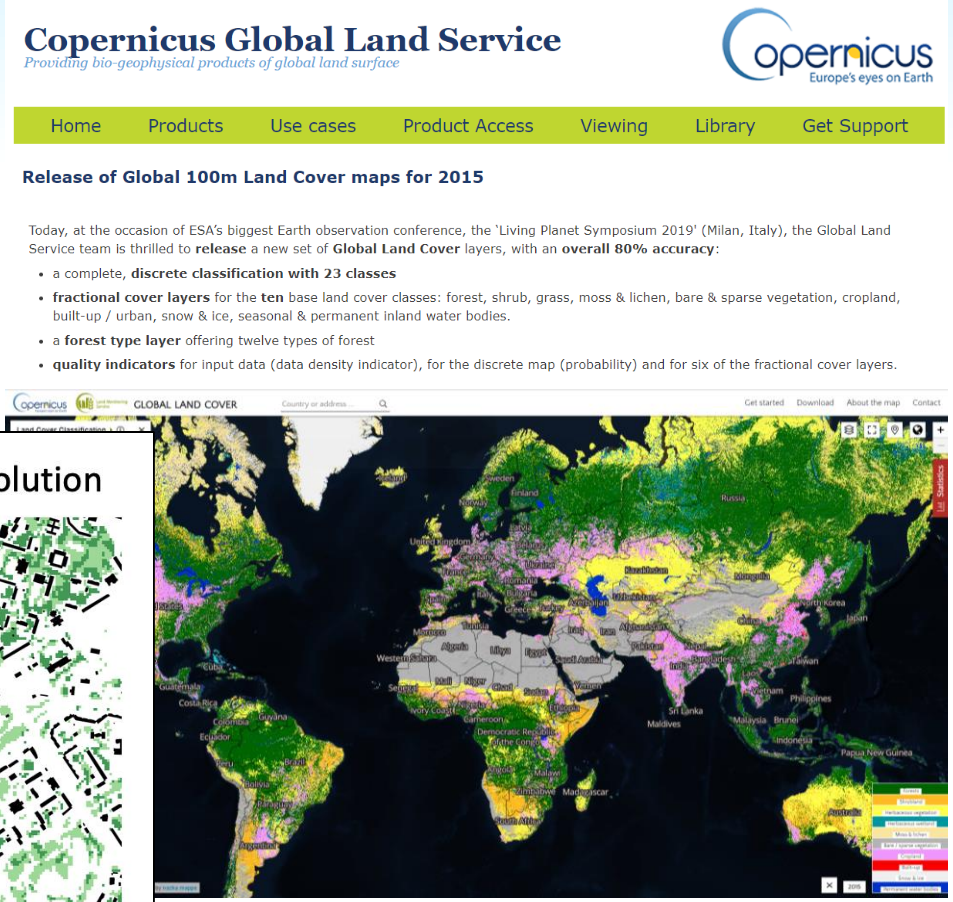
But how to define the values of new parameters?

Comprehensive GIS-based approach

Based on combined use of different <u>global</u> data sets

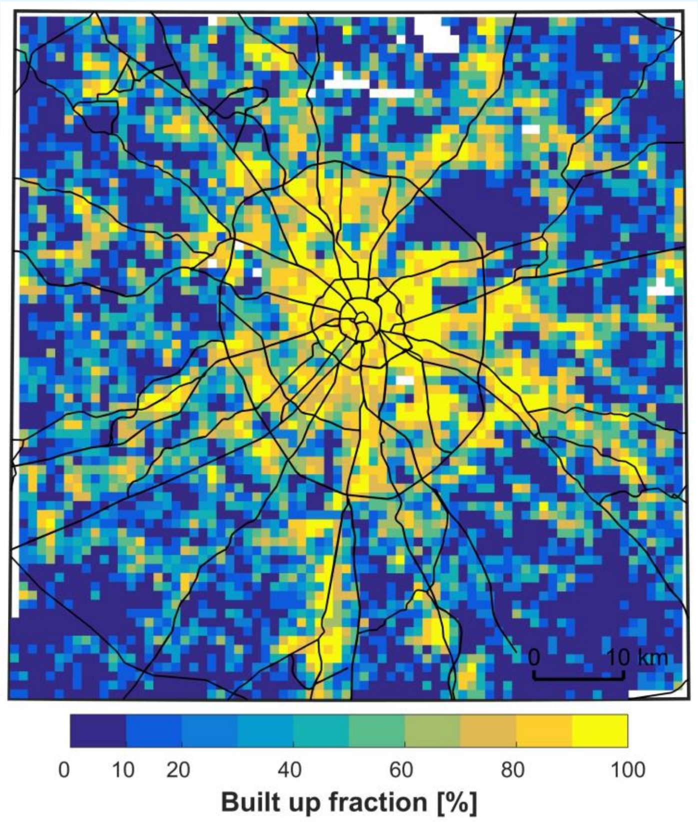
- Built up fraction area from ***Copernicus Global Land Cover*** with 100 m resolution
- Data on buildings and roads from ***OpenStreetMap***
- Data on vegetation derived from ***Sentinel-2 satellite images*** with 10 m resolution
- Literature AHF estimates (Stewart, Kennedy, 2017)





More details in (Samsonov, Varentsov, 2020)

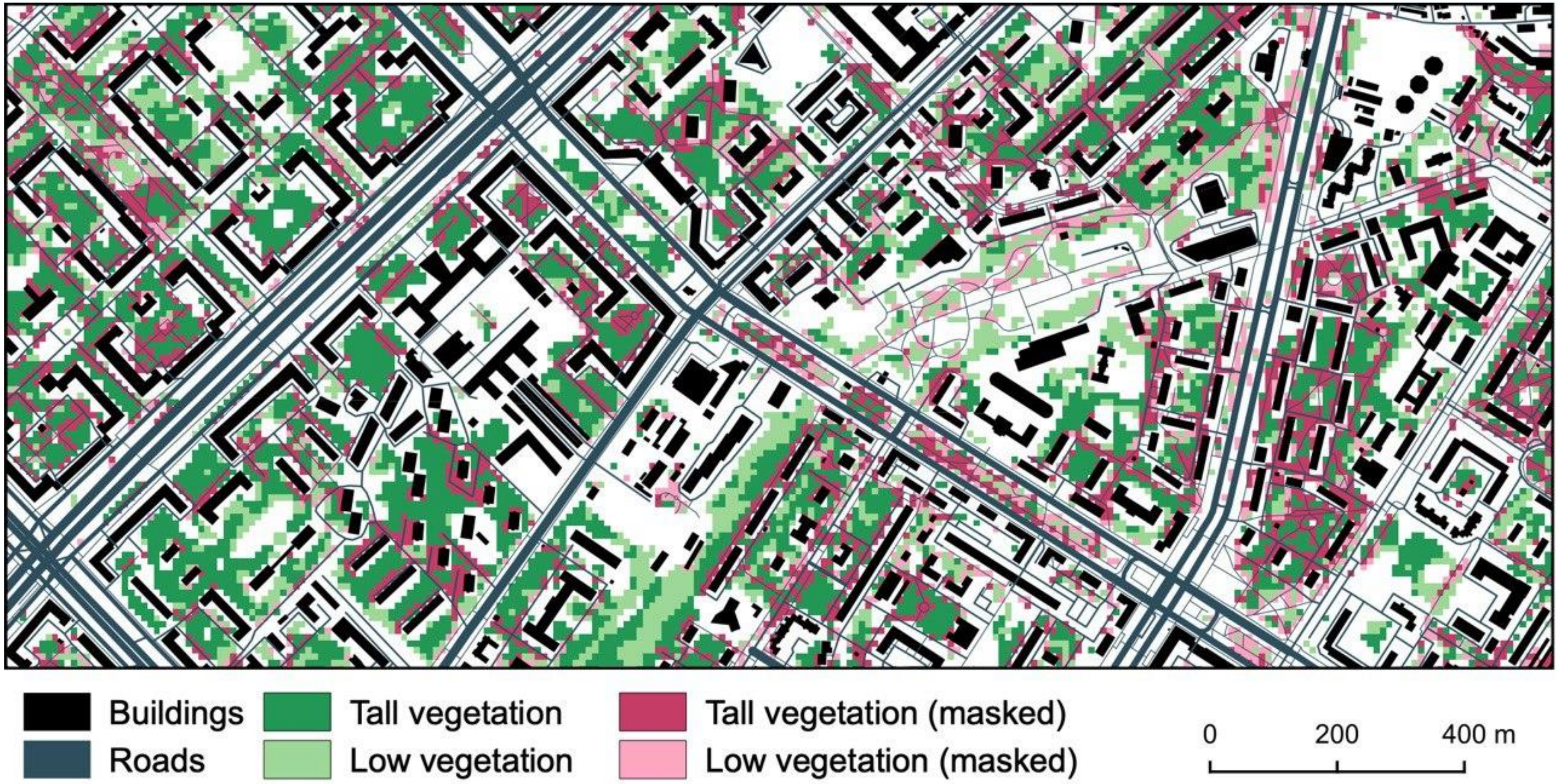
ISA in GIS-based approach



↑ Urban fraction in CGLC includes urban vegetation, but we need ISA for TERRA_URB

ISA = max (min (URBAN_FR$_{CGLC}$, 1 – GREEN_FR), BLDF_FR$_{OSM}$ + ROAD_FR$_{OSM}$)

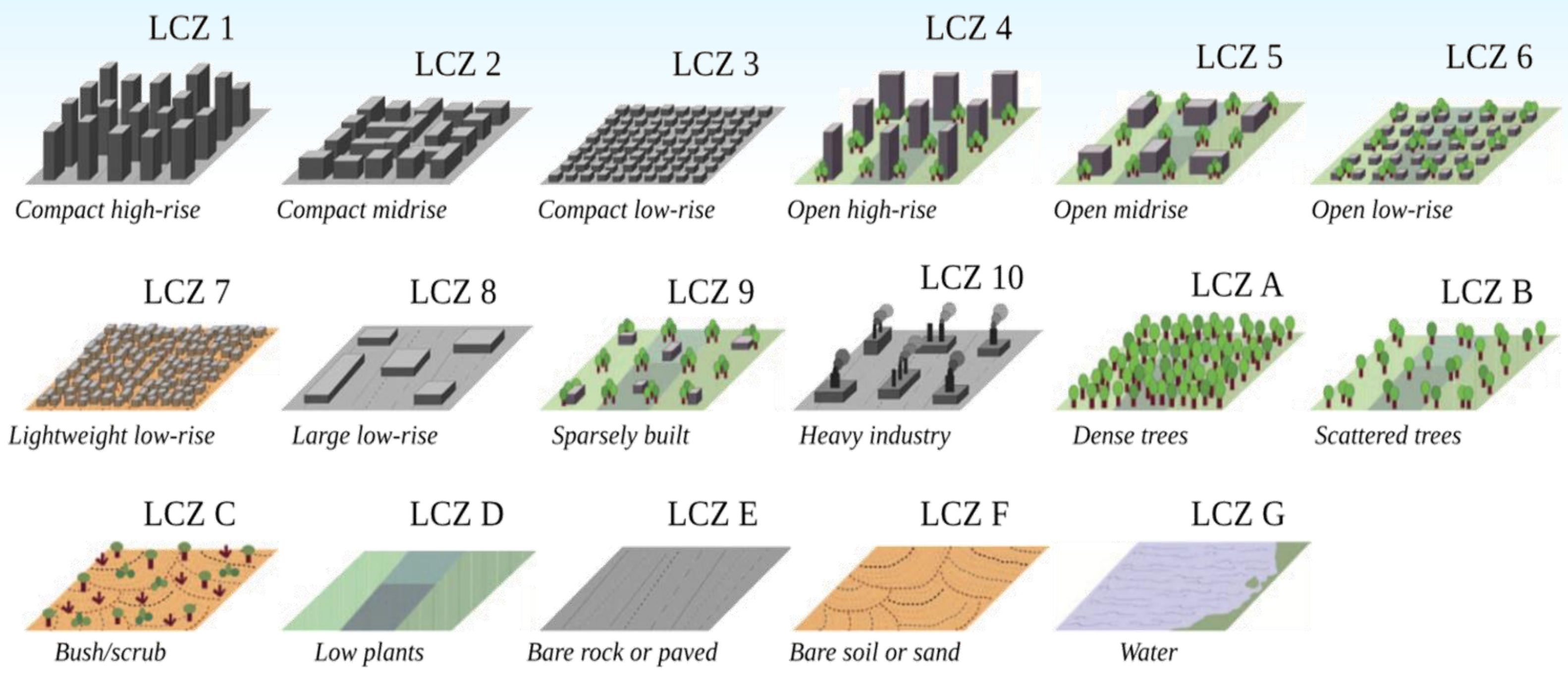
GREEN_FR = max (GREEN_FR$_{OSM}$, GREEN_FR$_{SENTINEL}$)

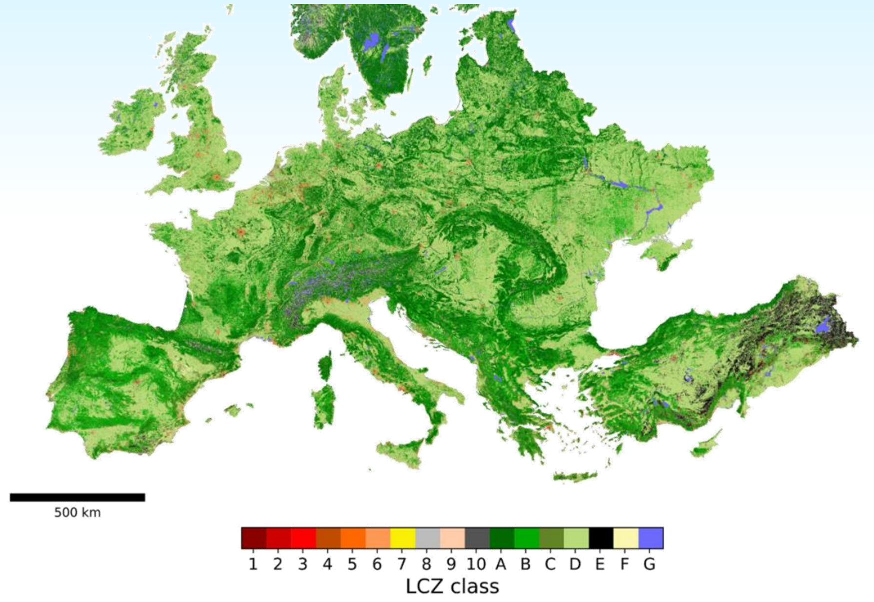


Uncertainty: what to do with vegetation, that intersects with buildings/roads?

(Samsonov, Varentsov, 2020)

LCZ-based approach





- ❑ Local climate zones (LCZs) concept by Stewart and Oke (2012)
- ❑ WUDAPT crowdsourcing initiative (Ching et al., 2018) to generate LCZ maps for the world's cities
- ❑ European and US LCZ maps is available (Demuzere et al., 2019, 2020)

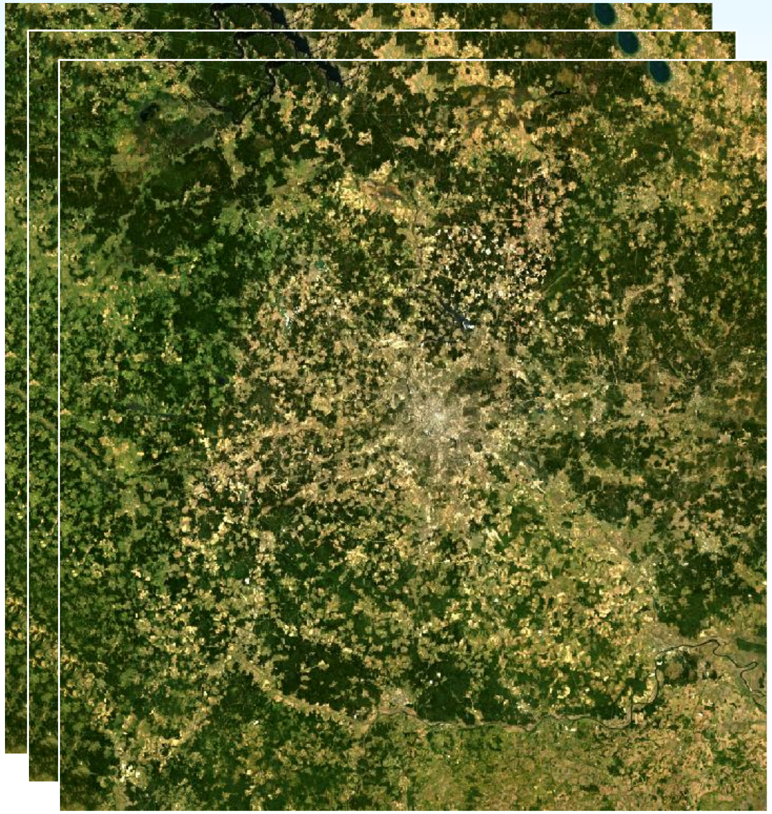
WUDAPT

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

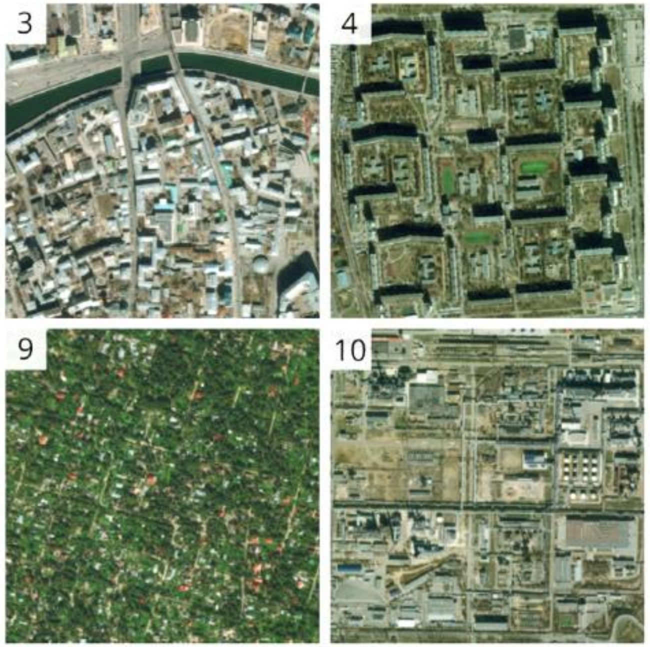
WUDAPT is an international community-generated urban canopy information and modeling infrastructure to facilitate urban-focused climate, weather, air quality, and energy-use modeling application studies

LCZ-based approach

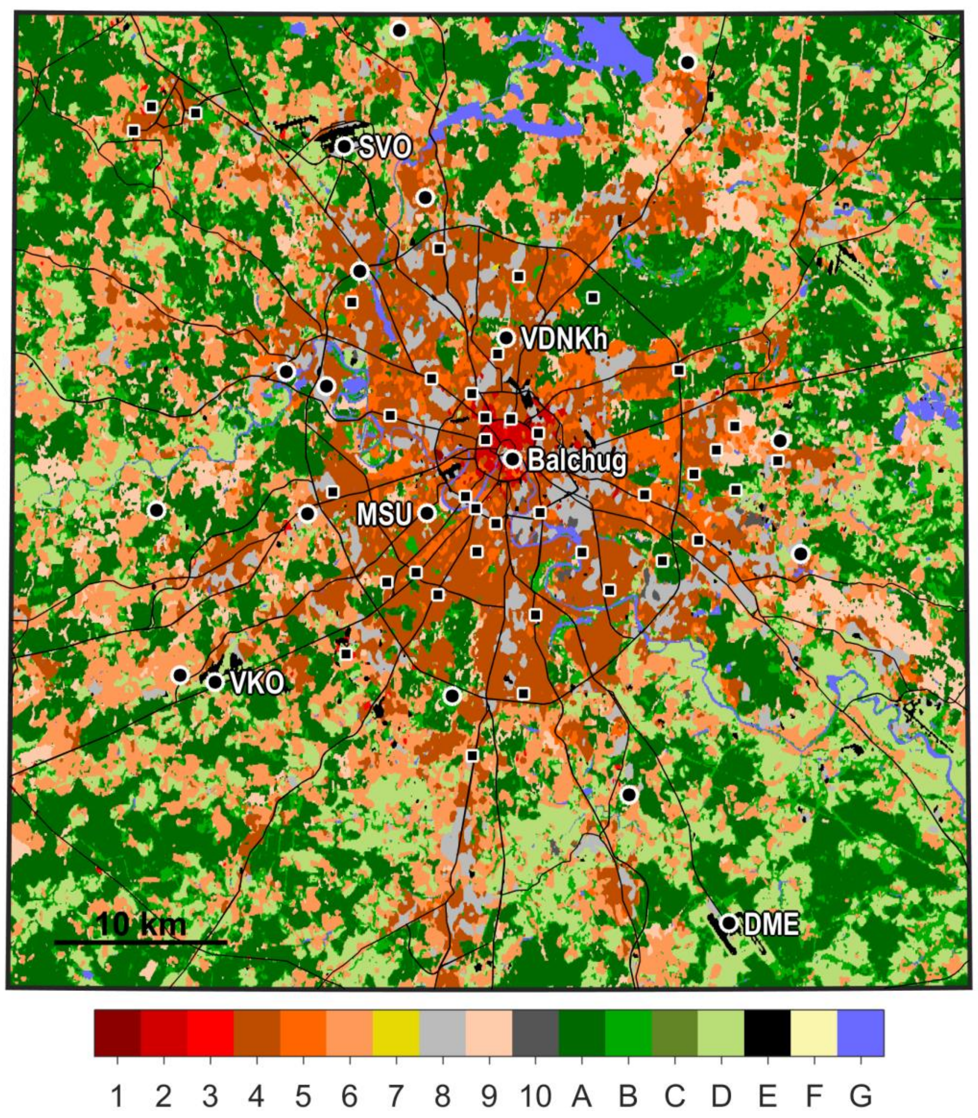


Input features: Landsat 8, Sentinel 1 & 2, Other ...

Training Polygons
(Samsonov, Trigub, 2018)



Random forest classifier



LCZ Map for Moscow

LCZ-based approach

Table 3. Values of geometric and surface cover properties for local climate zones. All properties are unitless except height of roughness elements (m).

Local climate zone (LCZ)	Sky view factor[a]	Aspect ratio[b]	Building surface fraction[c]	Impervious surface fraction[d]	Pervious surface fraction[e]	Height of roughness elements[f]	Terrain roughness class[g]
LCZ 1 *Compact high-rise*	0.2–0.4	> 2	40–60	40–60	< 10	> 25	8
LCZ 2 *Compact midrise*	0.3–0.6	0.75–2	40–70	30–50	< 20	10–25	6–7
LCZ 3 *Compact low-rise*	0.2–0.6	0.75–1.5	40–70	20–50	< 30	3–10	6
LCZ 4 *Open high-rise*	0.5–0.7	0.75–1.25	20–40	30–40	30–40	>25	7–8
LCZ 5 *Open midrise*	0.5–0.8	0.3–0.75	20–40	30–50	20–40	10–25	5–6
LCZ 6 *Open low-rise*	0.6–0.9	0.3–0.75	20–40	20–50	30–60	3–10	5–6
LCZ 7 *Lightweight low-rise*	0.2–0.5	1–2	60–90	< 20	<30	2–4	4–5
LCZ 8 *Large low-rise*	>0.7	0.1–0.3	30–50	40–50	<20	3–10	5
LCZ 9	> 0.8	0.1–0.25	10–20	< 20	60–80	3–10	5–6

Table 4. Values of thermal, radiative, and metabolic properties for local climate zones. All values are representative of the local scale.

Local climate zone (LCZ)	Surface admittance[a]	Surface albedo[b]	Anthropogenic heat output[c]
LCZ 1 *Compact high-rise*	1,500–1,800	0.10–0.20	50–300
LCZ 2 *Compact midrise*	1,500–2,200	0.10–0.20	<75
LCZ 3 *Compact low-rise*	1,200–1,800	0.10–0.20	<75
LCZ 4 *Open high-rise*	1,400–1,800	0.12–0.25	<50
LCZ 5 *Open midrise*	1,400–2,000	0.12–0.25	<25
LCZ 6 *Open low-rise*	1,200–1,800	0.12–0.25	<25
LCZ 7 *Lightweight low-rise*	800–1,500	0.15–0.35	<35
LCZ 8 *Large low-rise*	1,200–1,800	0.15–0.25	<50
LCZ 9	1,000–1,800	0.12–0.25	<10
[illegible]	[illegible]–2,500	0.12–0.20	>300

WUDAPT2COSMO tool developed by M. Demuzere:

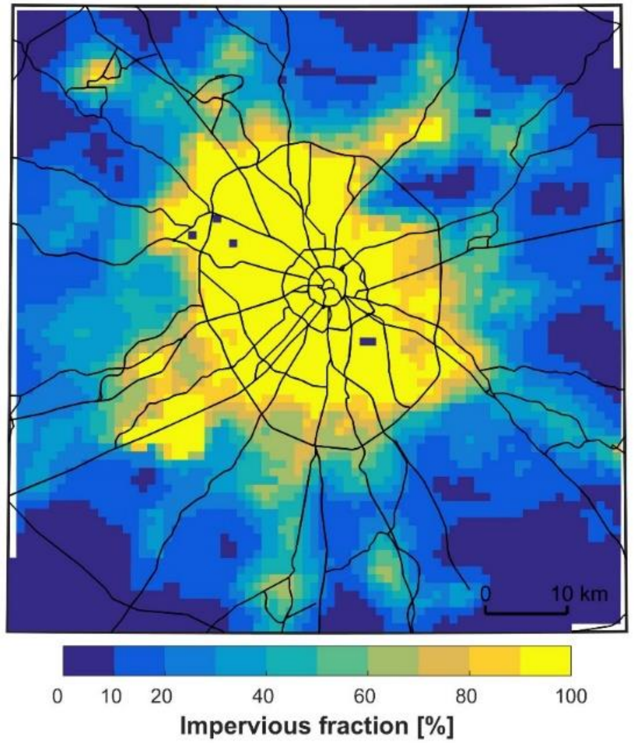
LCZ map (*.tiff) → urban canopy parameters for TERRA_URB (*.nc)

(Varentsov et al., 2020, in preparation)

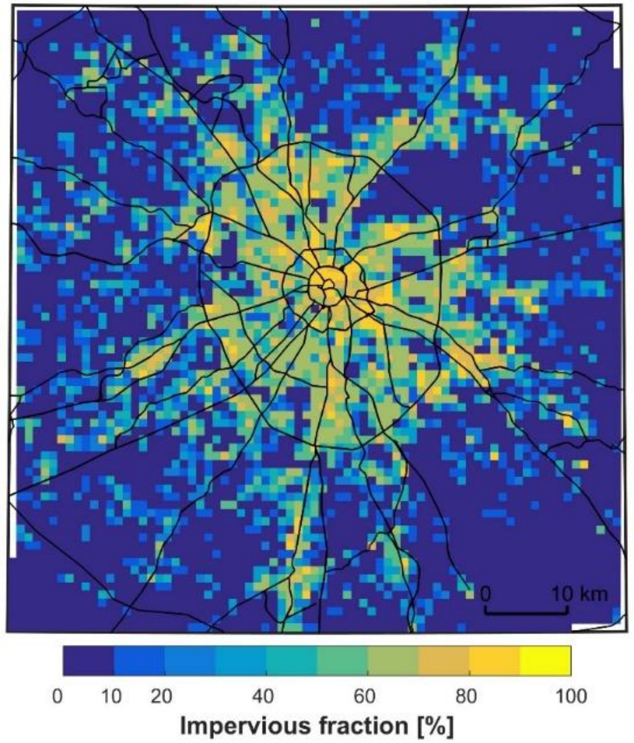
Stewart & Oke (2012)

Comparison between LCZ-based and GIS-based approaches

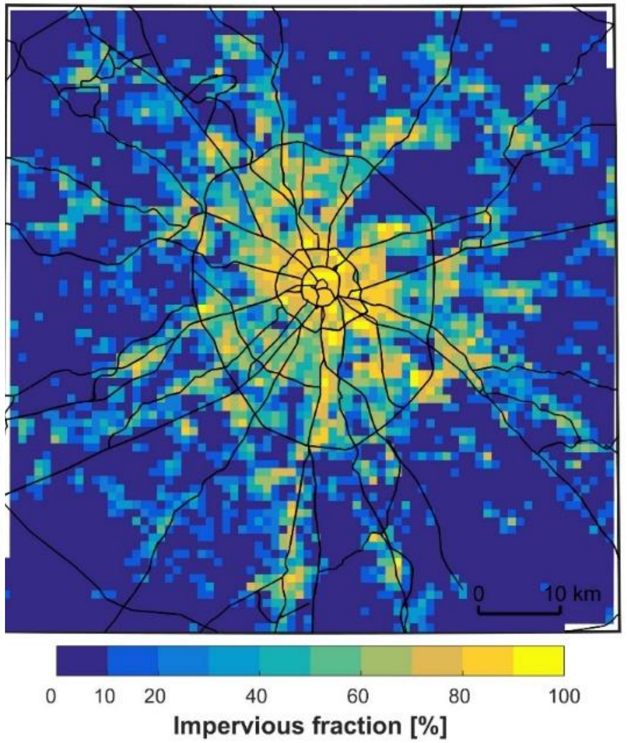
Default values from EXTPAR (DEF)



LCZ-derived ISA



REF1



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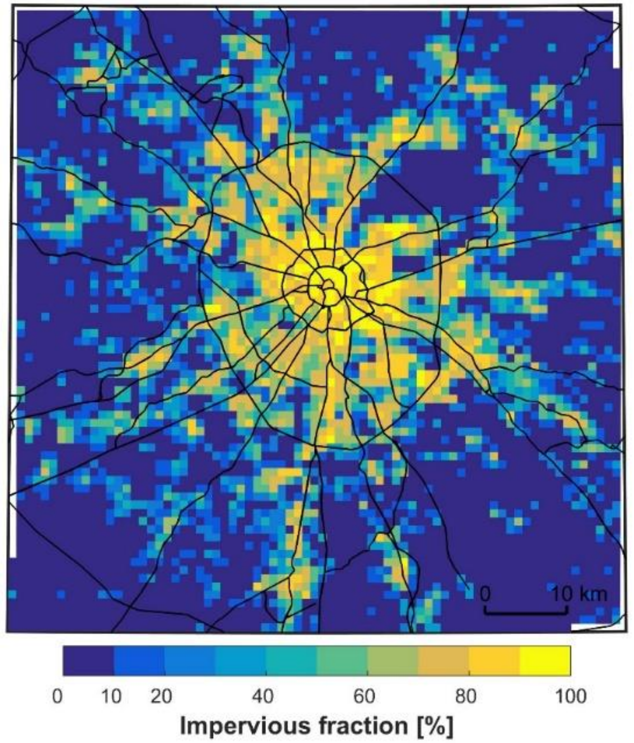
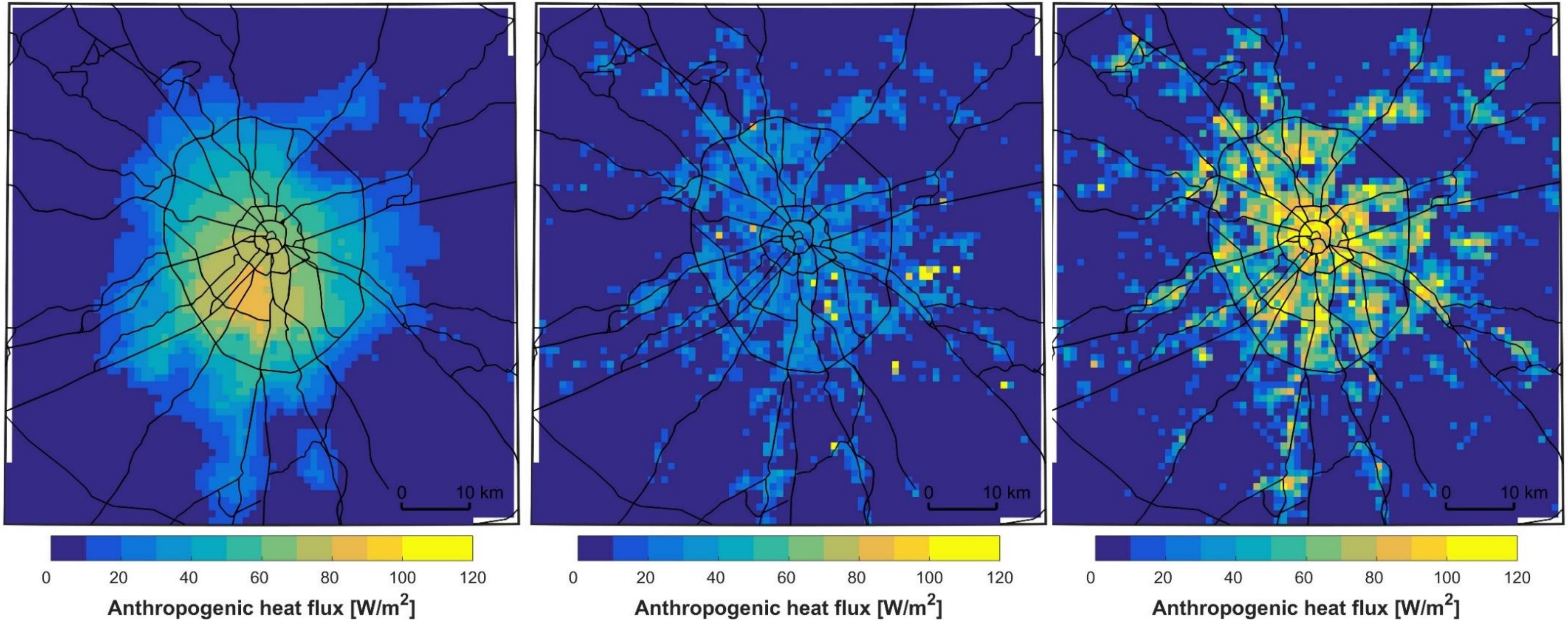


Comparison between LCZ-based and GIS-based approaches

Default values from EXTPAR (Flanner et al., 2009)

LCZ-based AHF

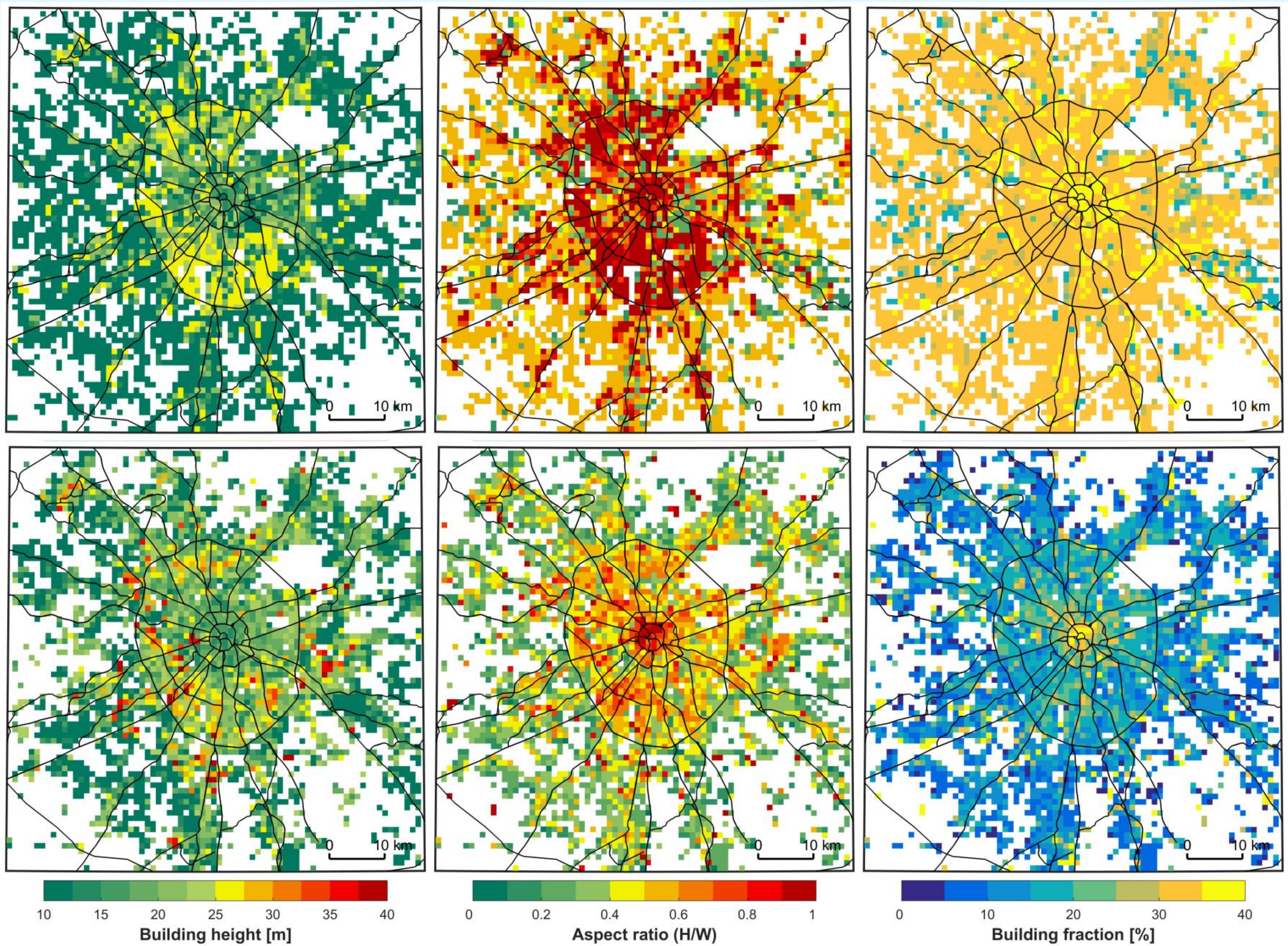
Custom estimate (REF)



Comparison between LCZ-based and GIS-based approaches

LCZ-based UCP
→

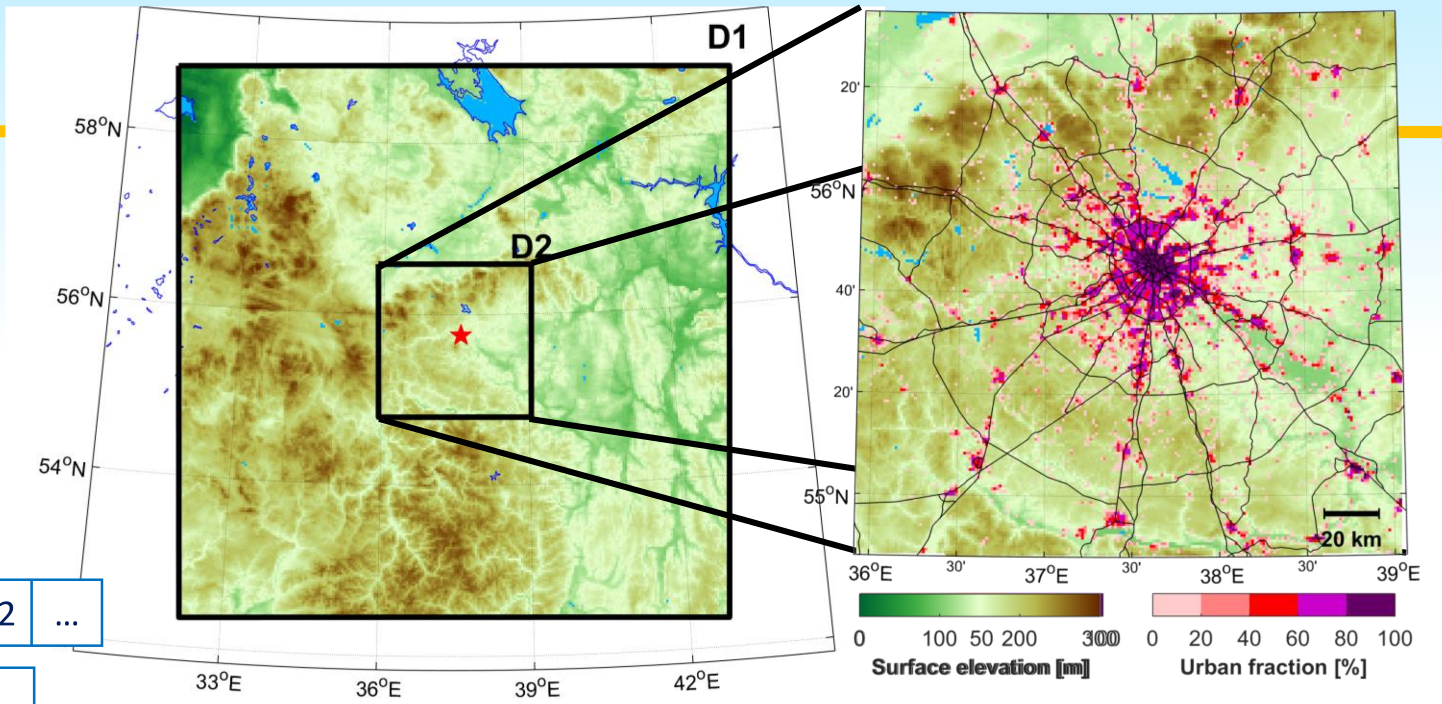
Custom-made UCPs
(based on
OpenStreetMap data)
→



Simulation set up

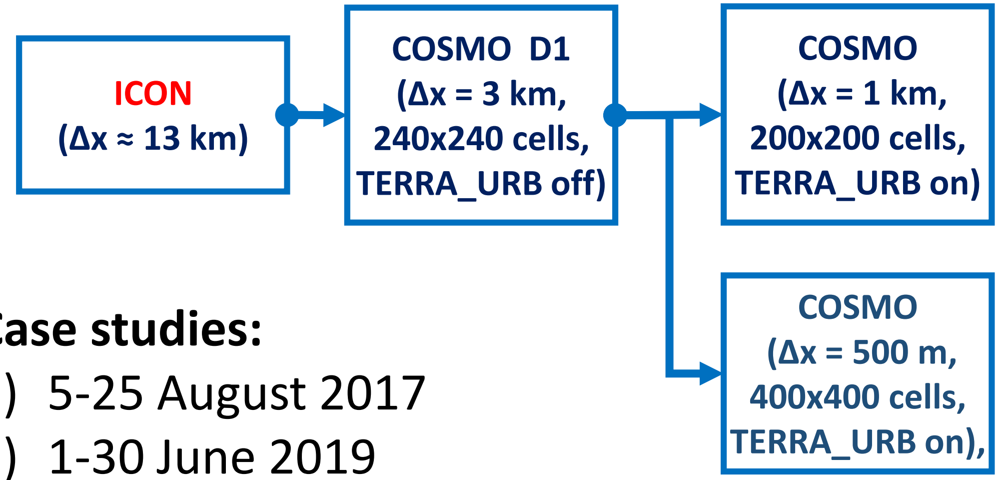
Initial and boundary conditions:
Continuous data set, constructed from ICON forecasts for 3 and 6 hours:

Forecast from 0 UTC	0	3	6	9	12	...					
Forecast from 6 UTC			0	3	6	9	12	...			
Forecast from 12 UTC					0	3	6	9	12	...	
Continuous data:					6	9	12	15	18	21	...



Namelist setting: almost all recent COSMO developments switched on, including:

- loldtur = false
- Itype_rootdp=2
- Itype_evsl=4, itype_canopy=2 (Schults, Vogel, 2020)
- Itype_aerosol=2
- Additional tuning for rooting depth (scaling factor of 2.5 introduced)



Case studies:

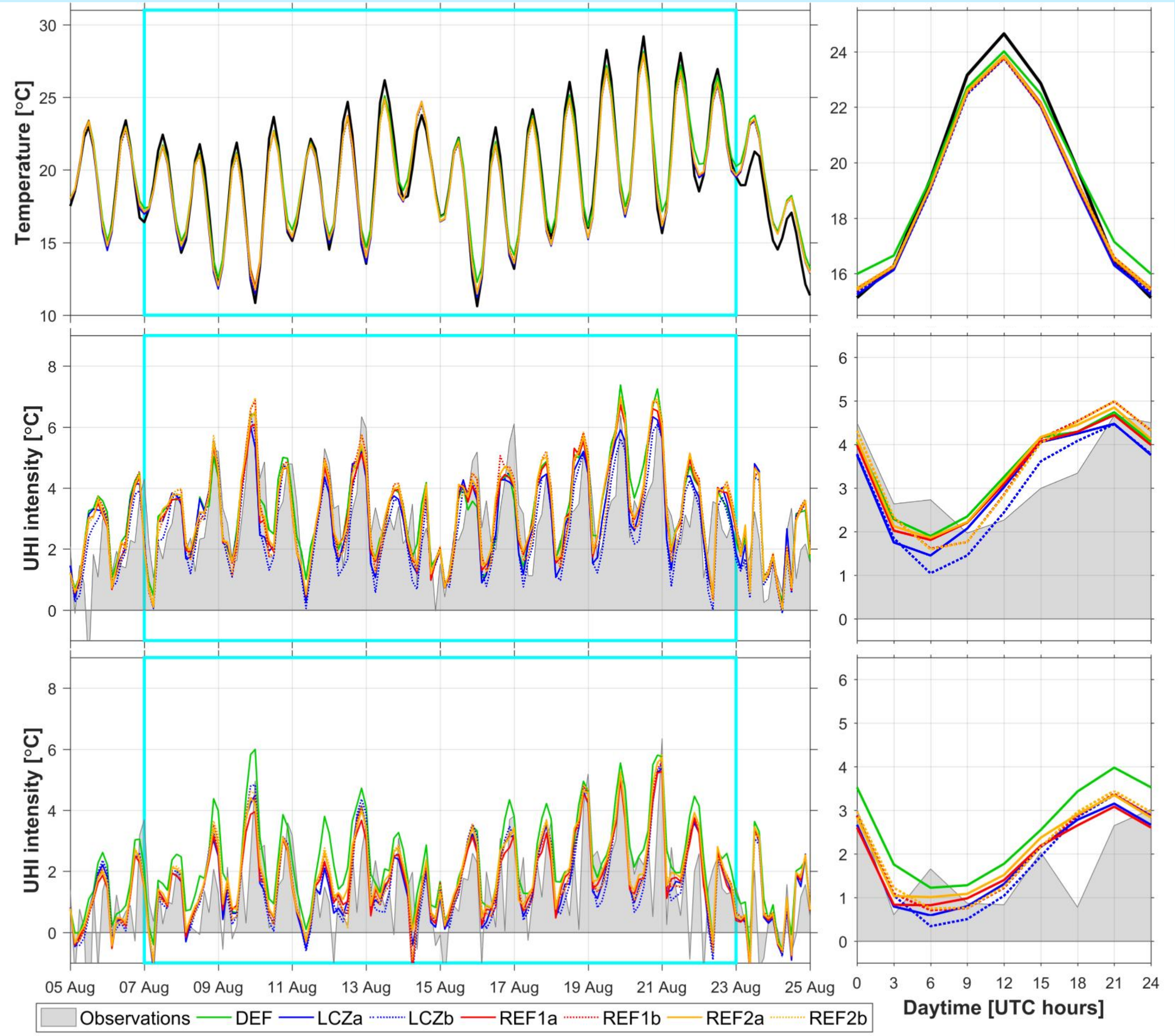
1) 5-25 August 2017
2) 1-30 June 2019
3) 1-30 Jan 2017

Summer case, August 2017

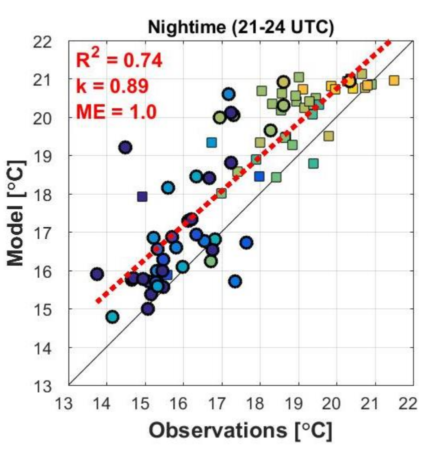
Mean rural temperature →

UHI intensity, city center →

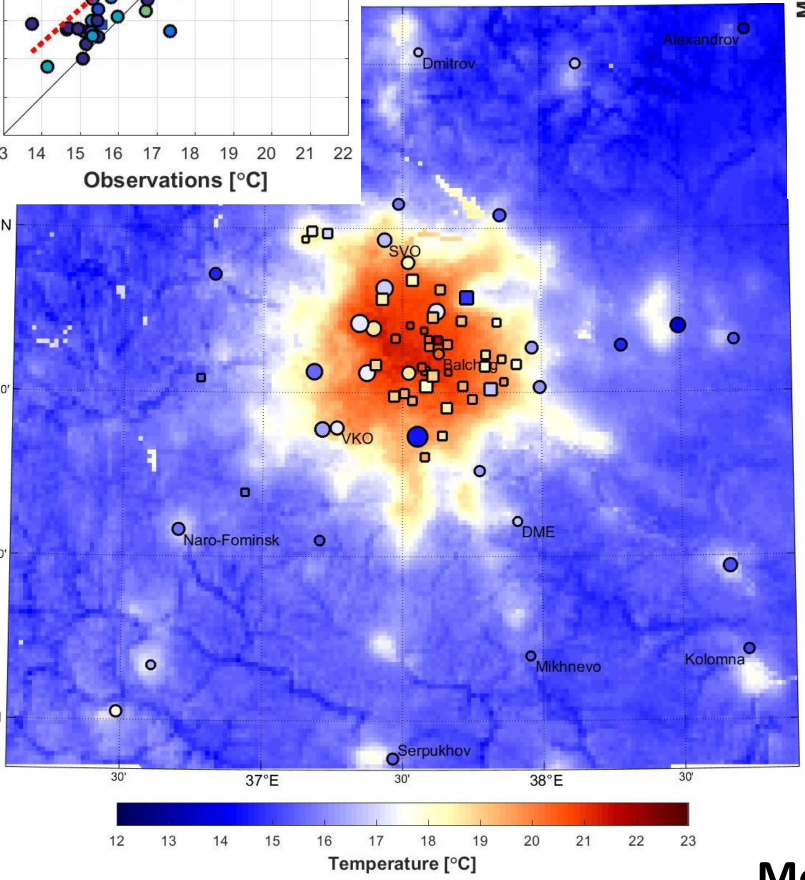
UHI intensity, urban park →

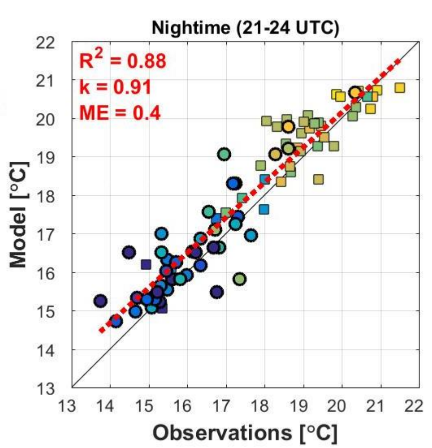


Summer case, August 2017

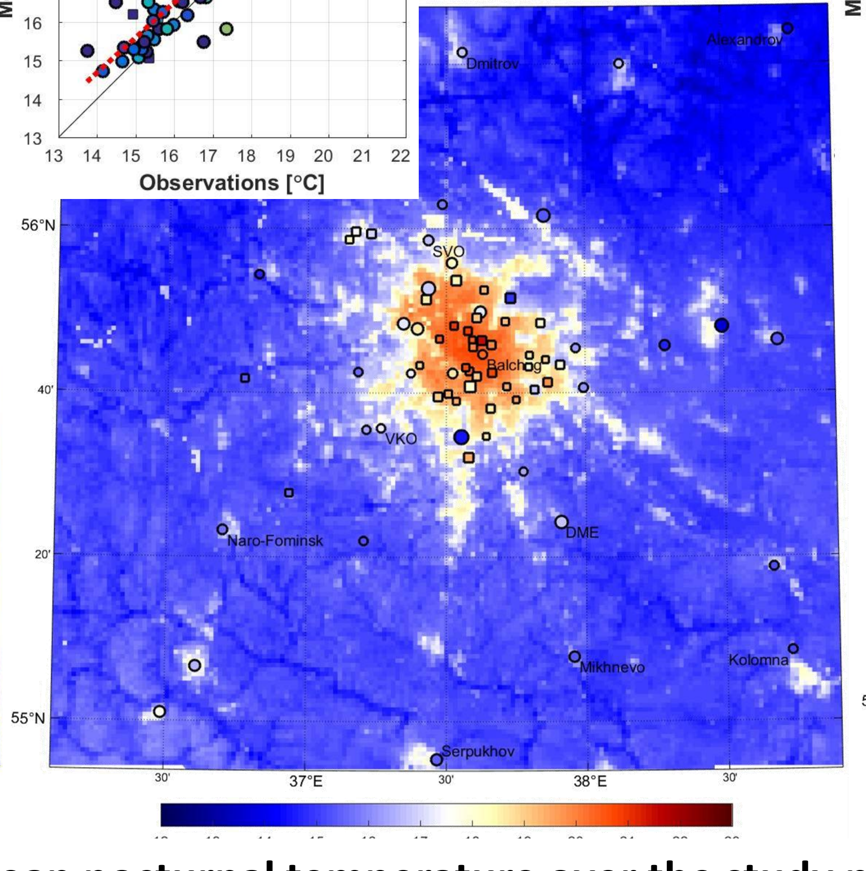


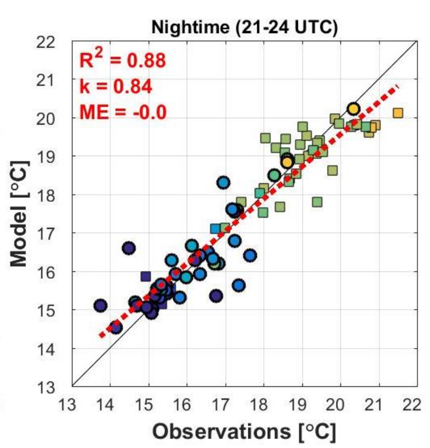
Default EXTPAR fields and constants



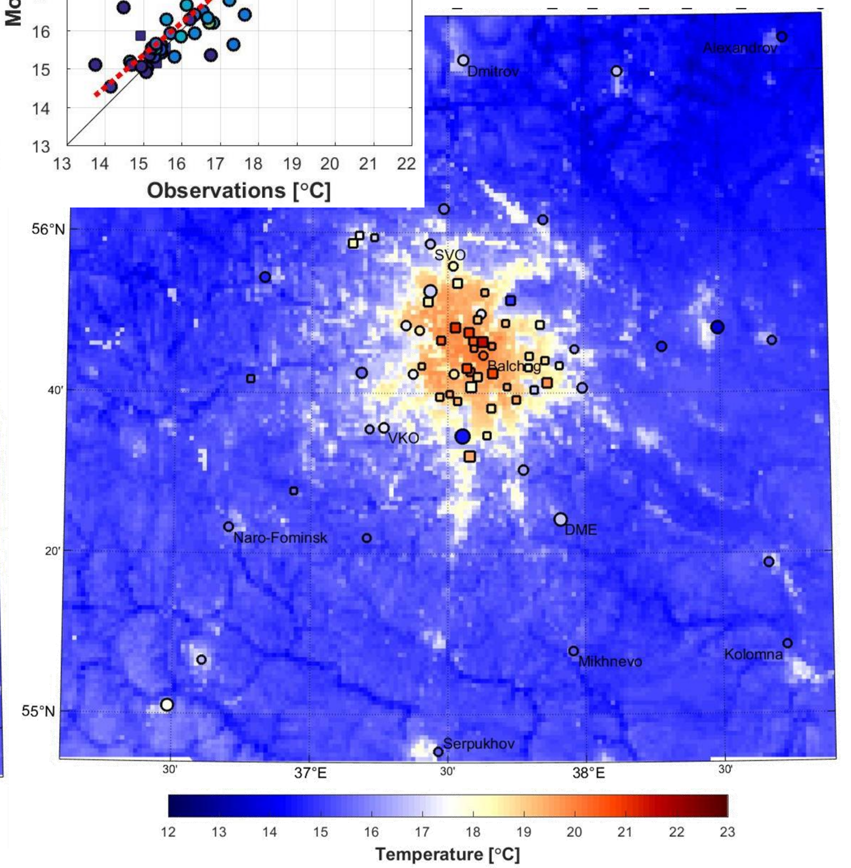


LCZ-based approach





Reference GIS-based approach



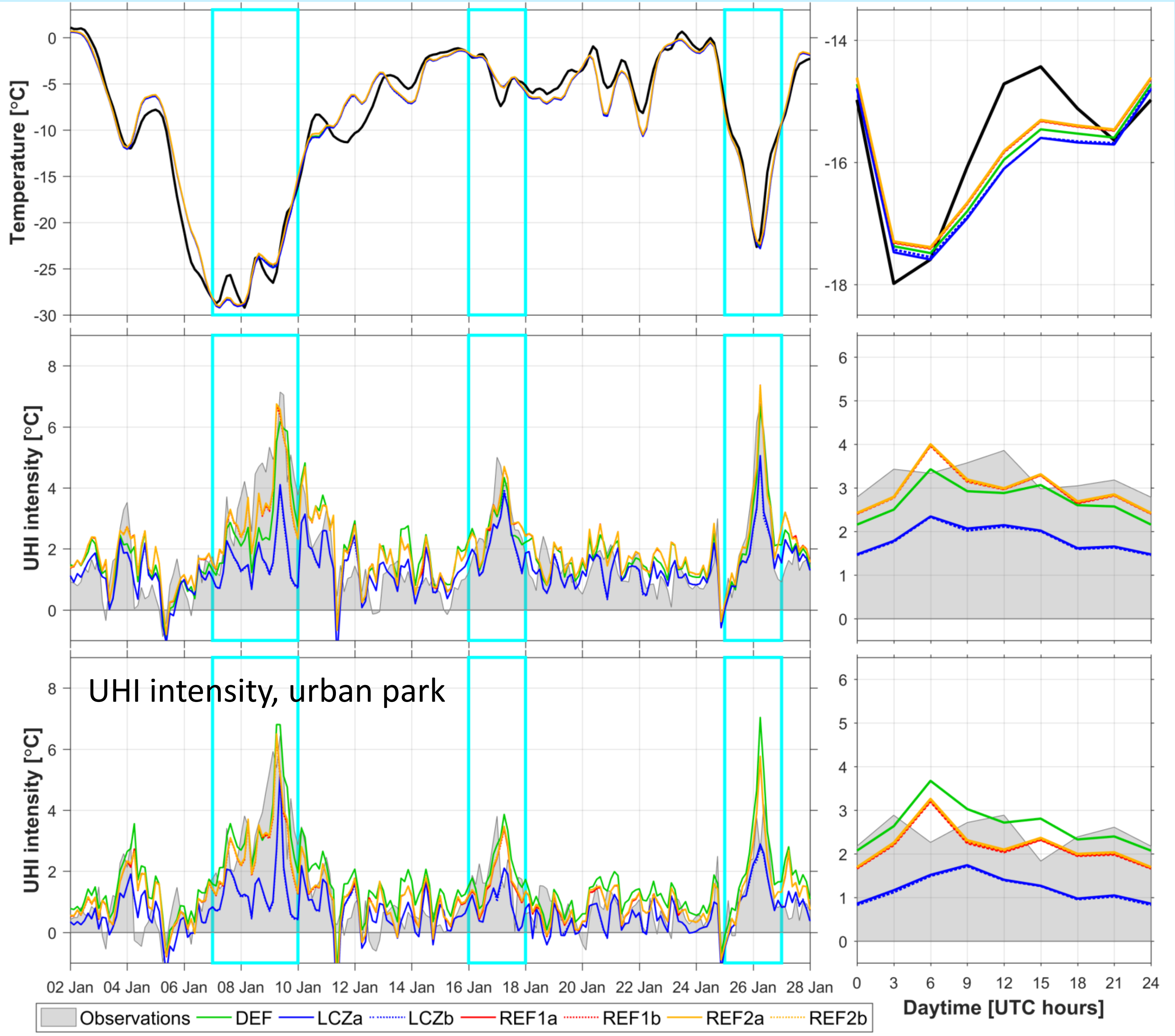
Mean nocturnal temperature over the study period

Winter case, January 2017

Mean rural temperature →

UHI intensity, city center →

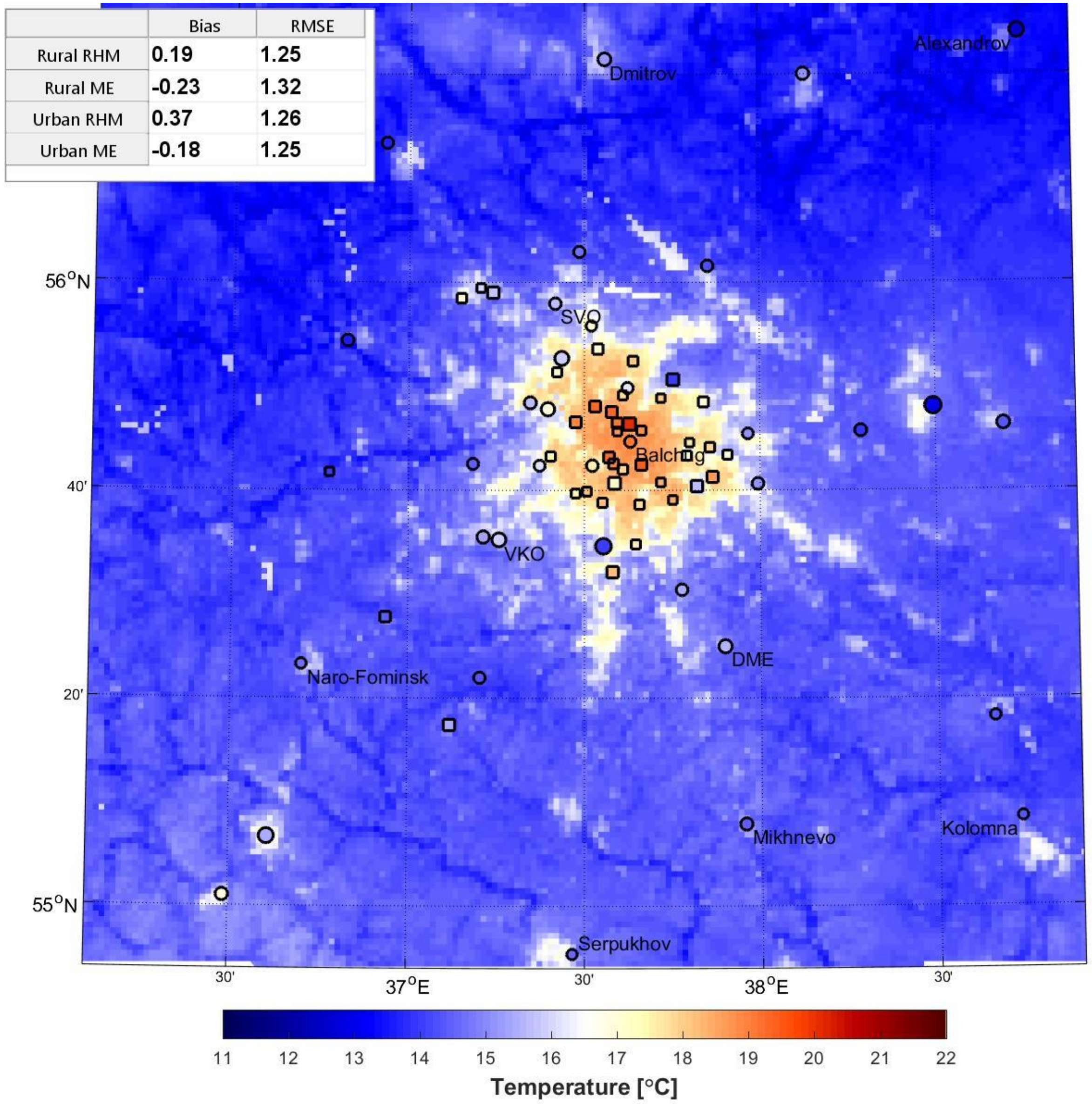
UHI intensity, urban park →



Towards the higher-resolution simulations (1 km → 500 m)

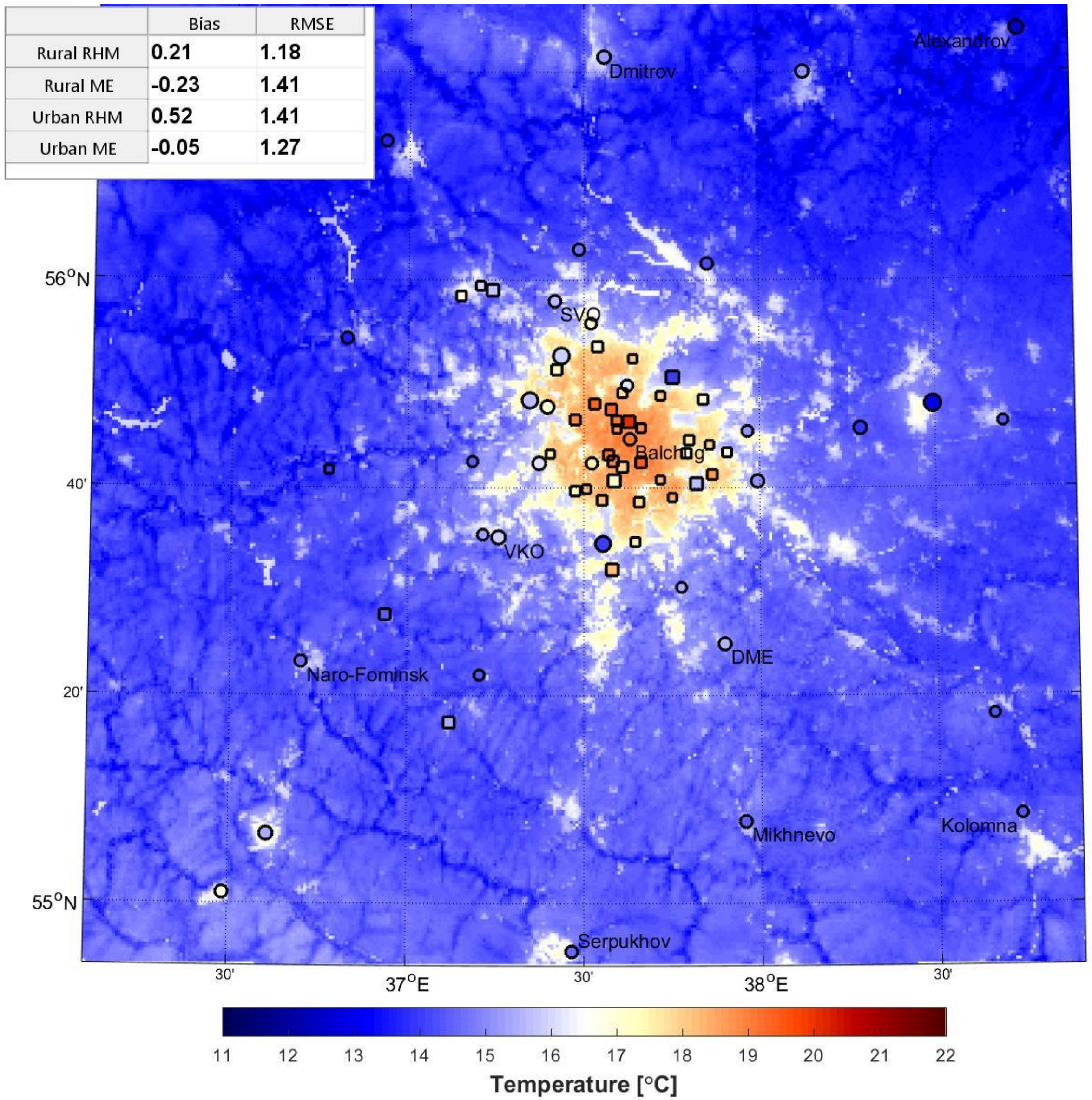
Daytime nocturnal (0 UTC), 1 km grid step

	Bias	RMSE
Rural RHM	0.19	1.25
Rural ME	-0.23	1.32
Urban RHM	0.37	1.26
Urban ME	-0.18	1.25



Daytime nocturnal (0 UTC), 500 m grid step

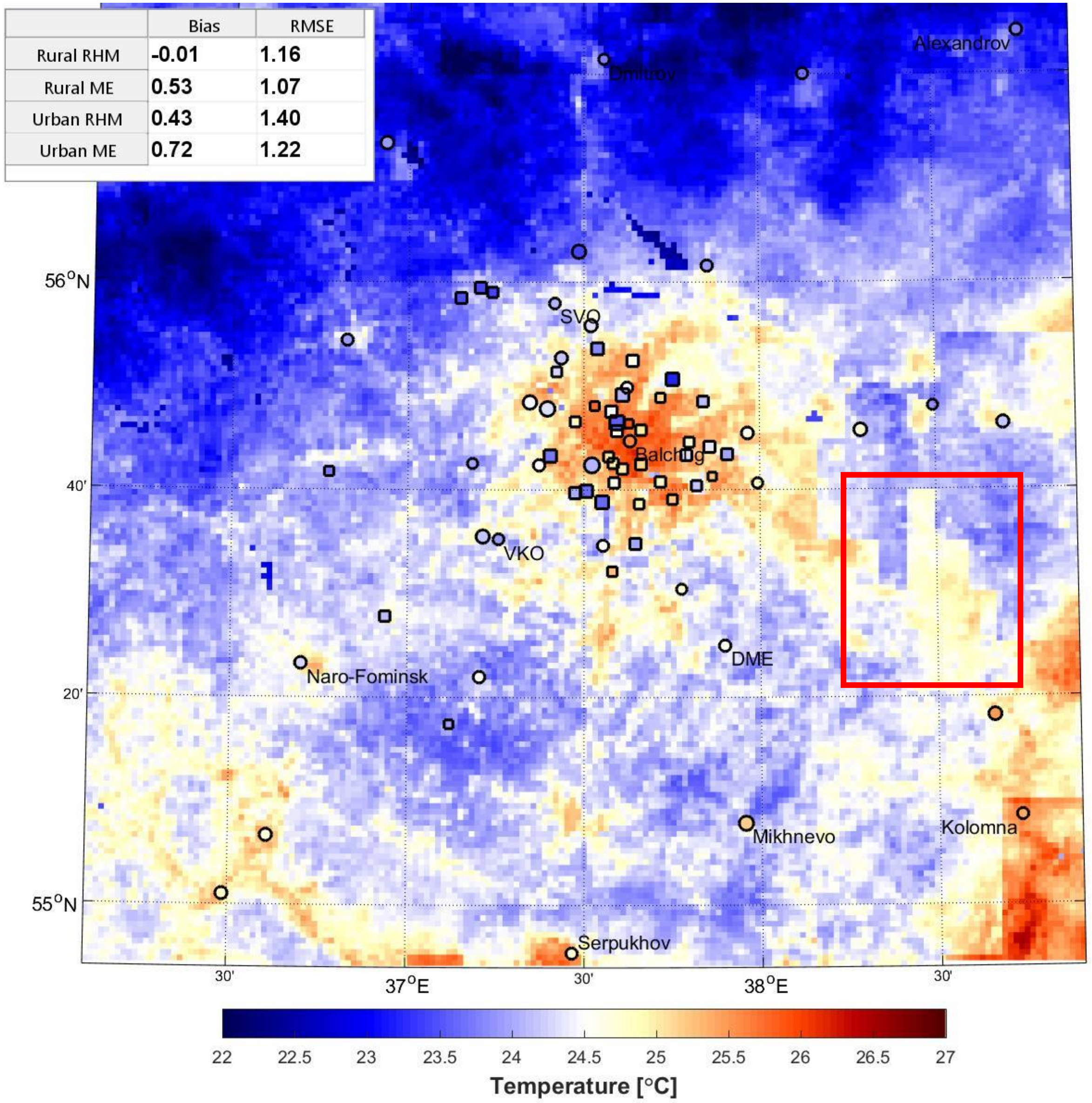
	Bias	RMSE
Rural RHM	0.21	1.18
Rural ME	-0.23	1.41
Urban RHM	0.52	1.41
Urban ME	-0.05	1.27



Towards the higher-resolution simulations (1 km → 500 m)

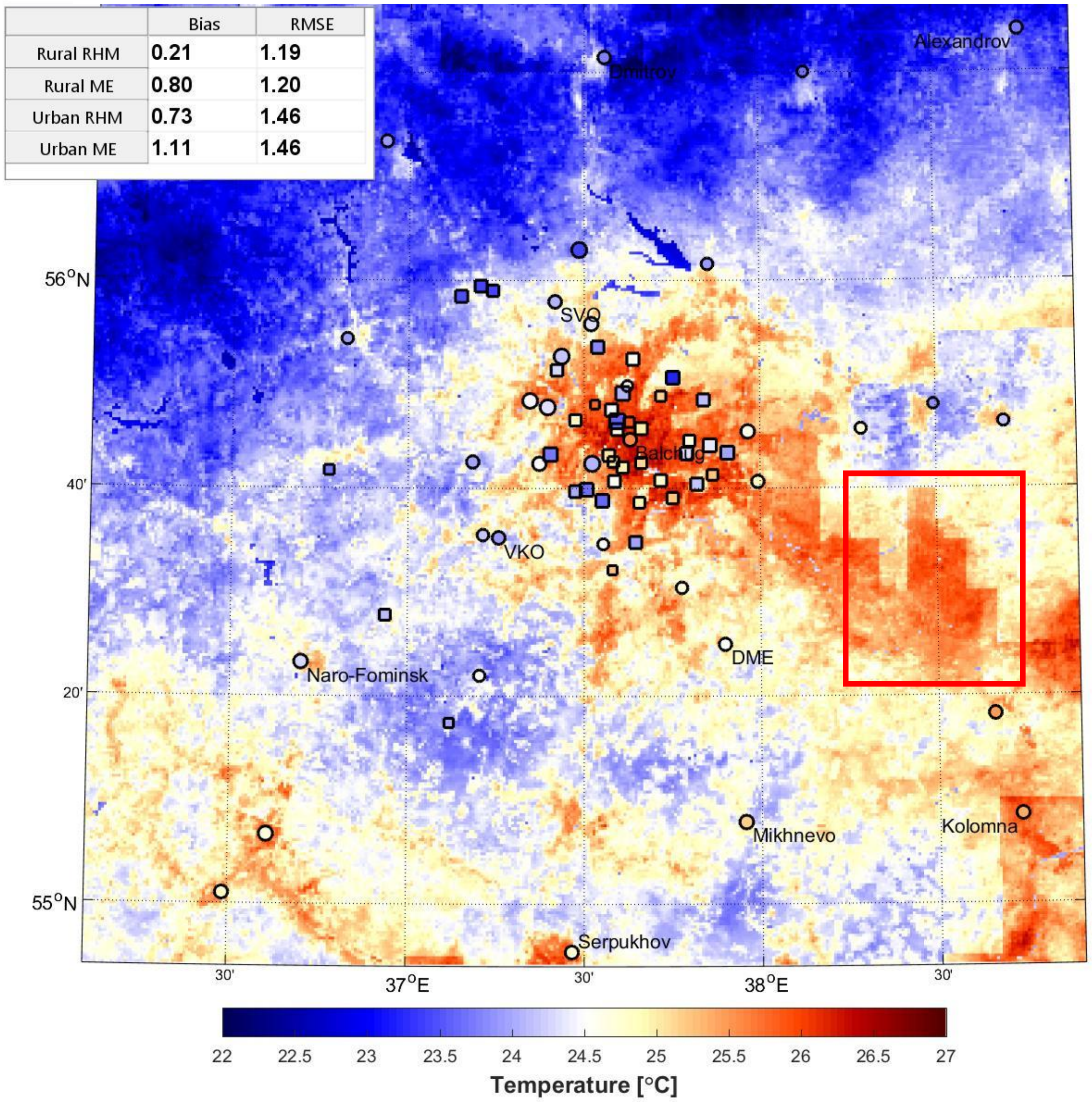
Daytime temperature (12 UTC), 1 km grid step

	Bias	RMSE
Rural RHM	-0.01	1.16
Rural ME	0.53	1.07
Urban RHM	0.43	1.40
Urban ME	0.72	1.22



Daytime temperature (12 UTC), 500 m grid step

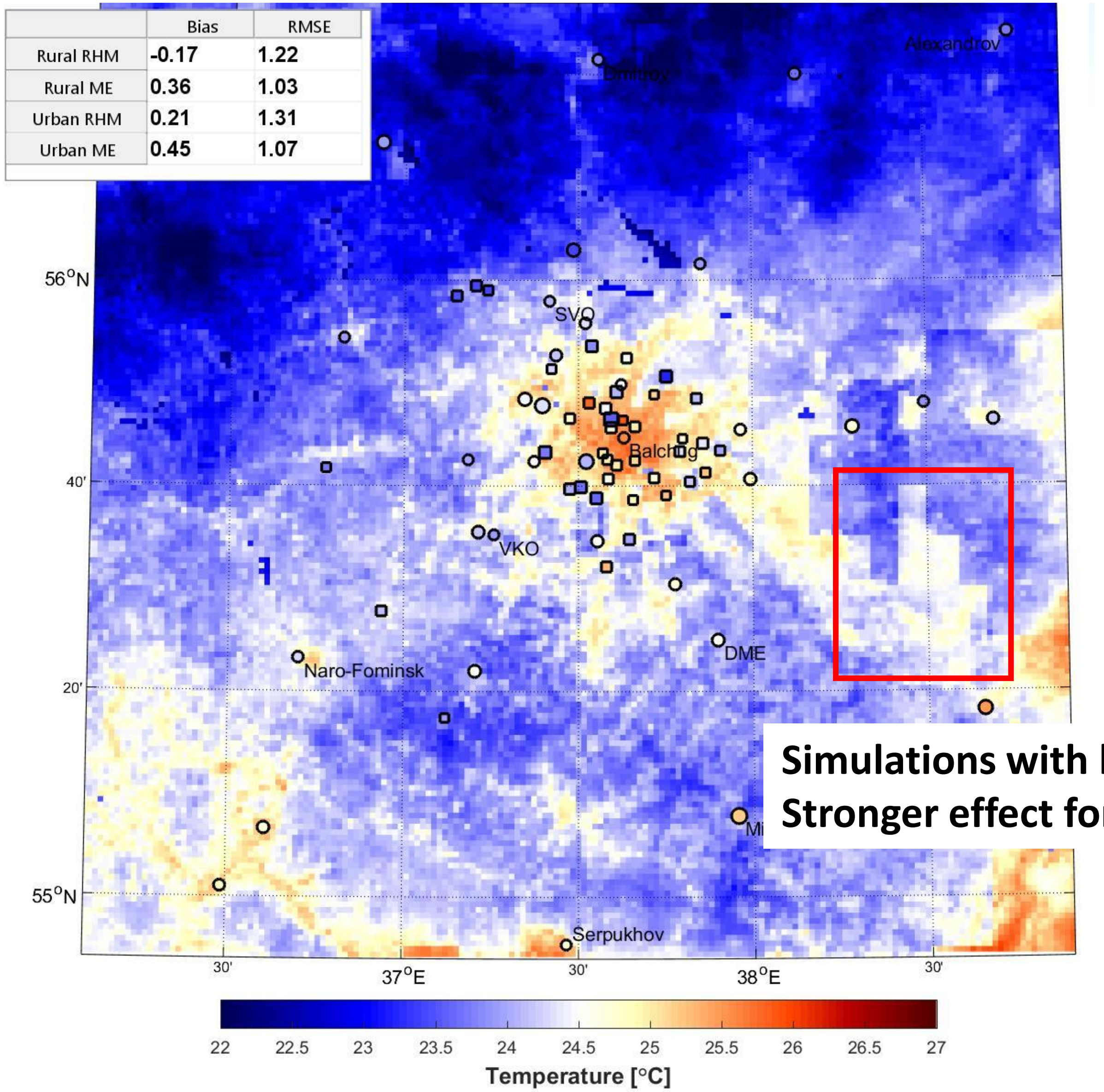
	Bias	RMSE
Rural RHM	0.21	1.19
Rural ME	0.80	1.20
Urban RHM	0.73	1.46
Urban ME	1.11	1.46



Towards the higher-resolution simulations (1 km → 500 m)

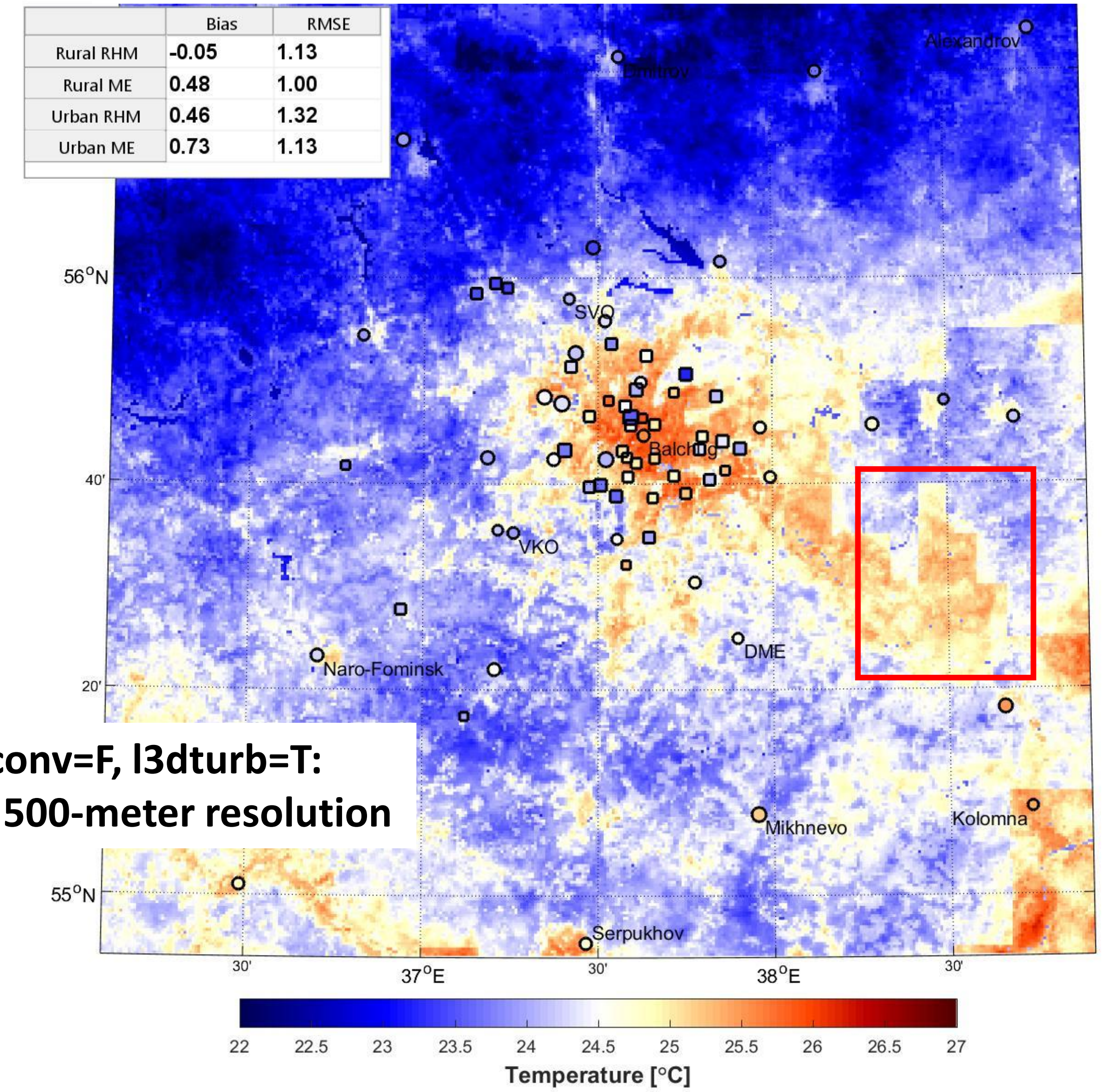
Daytime temperature (12 UTC), 1 km grid step

	Bias	RMSE
Rural RHM	-0.17	1.22
Rural ME	0.36	1.03
Urban RHM	0.21	1.31
Urban ME	0.45	1.07



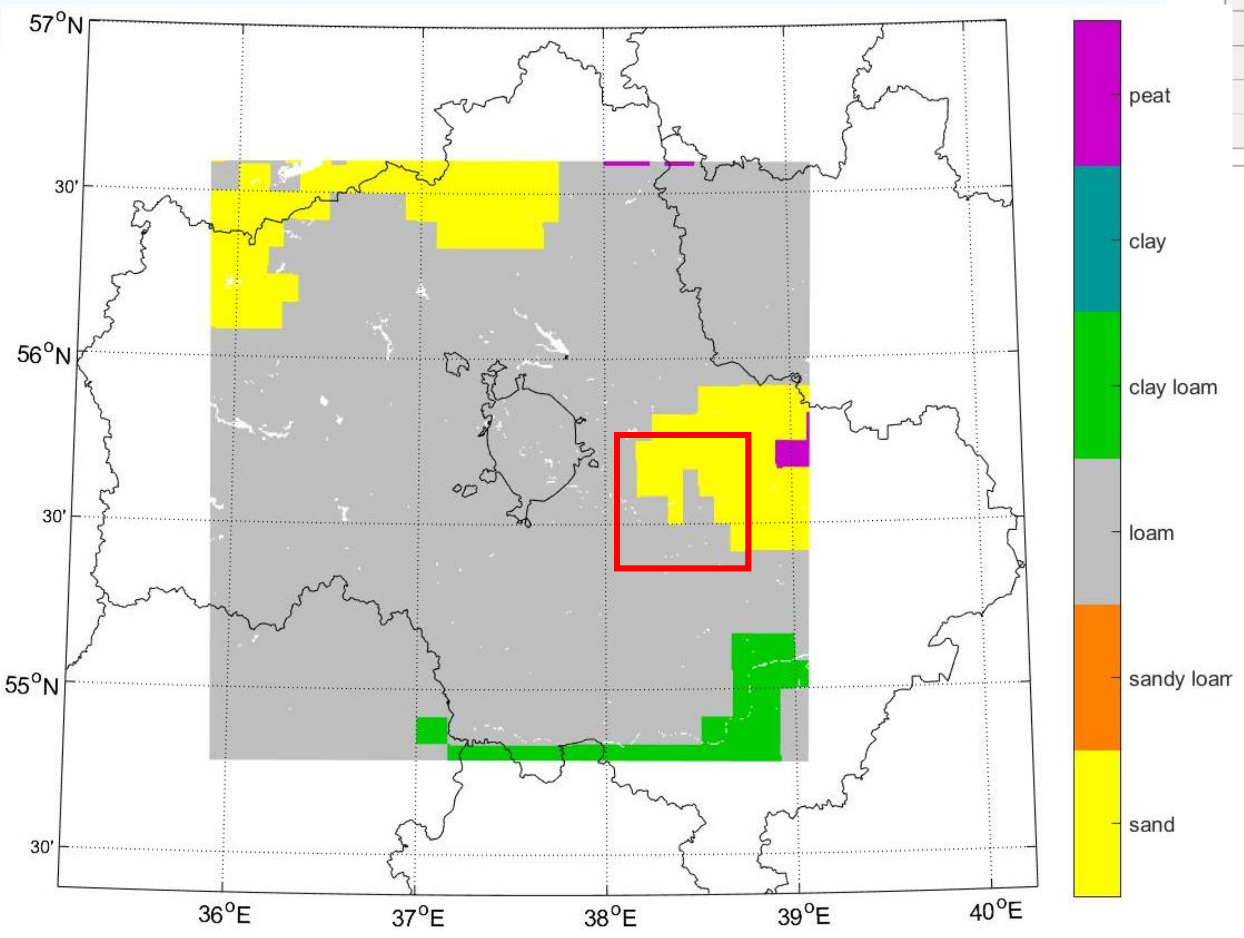
Daytime temperature (12 UTC), 500 m grid step

	Bias	RMSE
Rural RHM	-0.05	1.13
Rural ME	0.48	1.00
Urban RHM	0.46	1.32
Urban ME	0.73	1.13



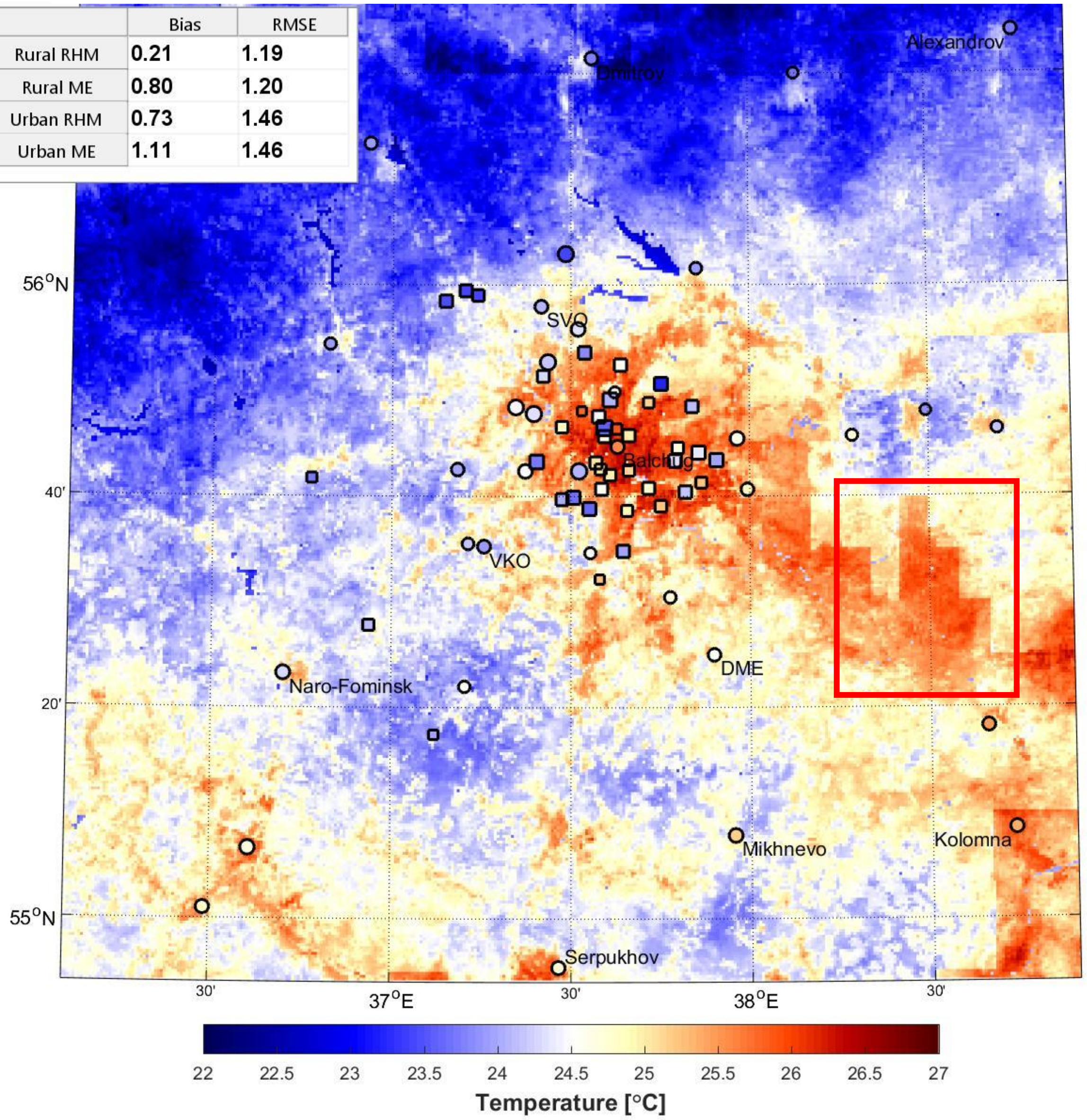
Simulations with lconv=F, l3dturb=T:
Stronger effect for 500-meter resolution

Need for high-resolution external parameters (non-urban)



Daytime temperature (12 UTC), 500 m grid step

	Bias	RMSE
Rural RHM	0.21	1.19
Rural ME	0.80	1.20
Urban RHM	0.73	1.46
Urban ME	1.11	1.46

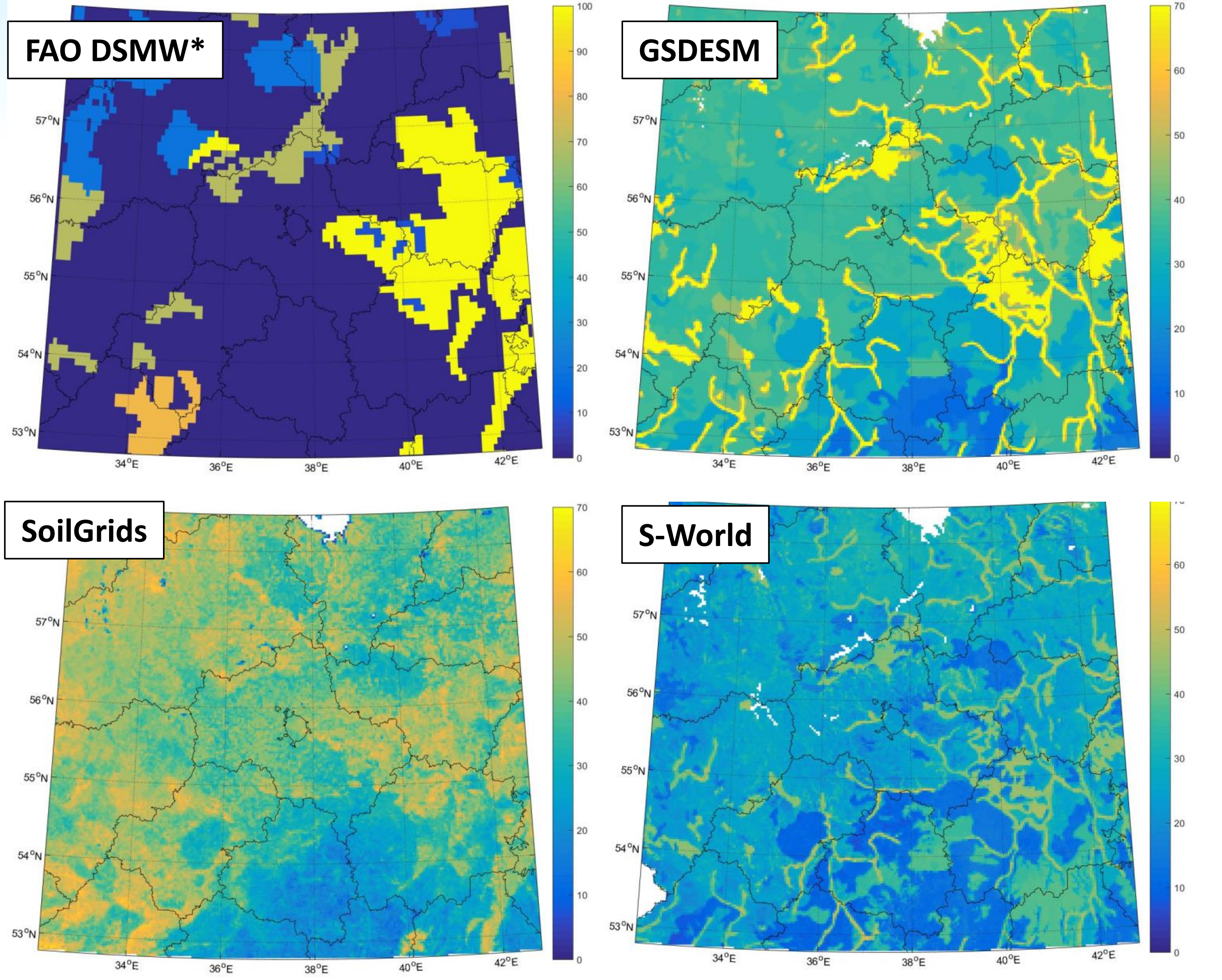


Towards improving the soil texture map

Considered data sets:

- FAO DSMW (EXTPAR default)
- GSDESM (The Global Soil Dataset for Earth System Modeling, Shangguan et al., 2014)
- Soil Grids (https://soilgrids.org/)
- S-World (Stoorvogel et al., 2017)

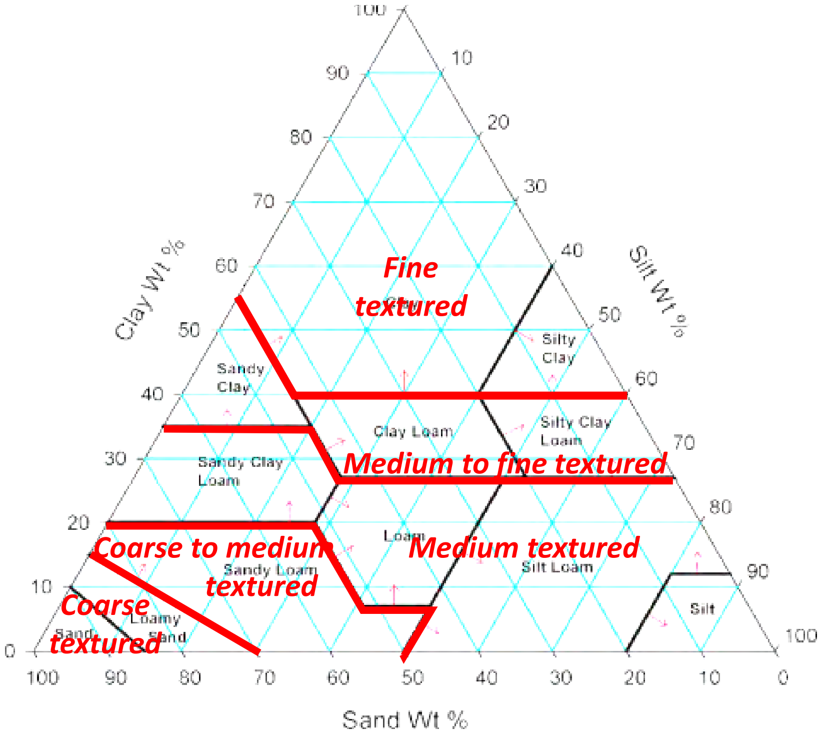
Uncertainties
of the input data:
sand fraction (%) →



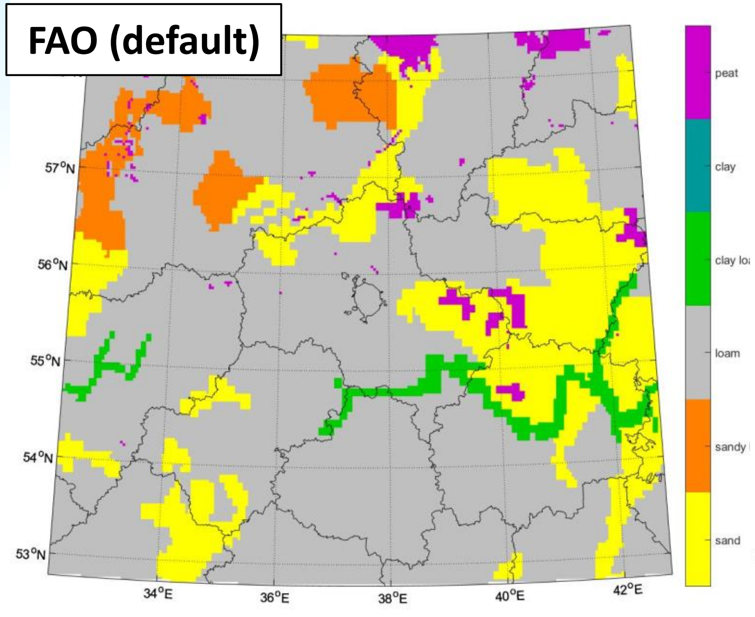
Thanks to collaboration with Juergen Helmert

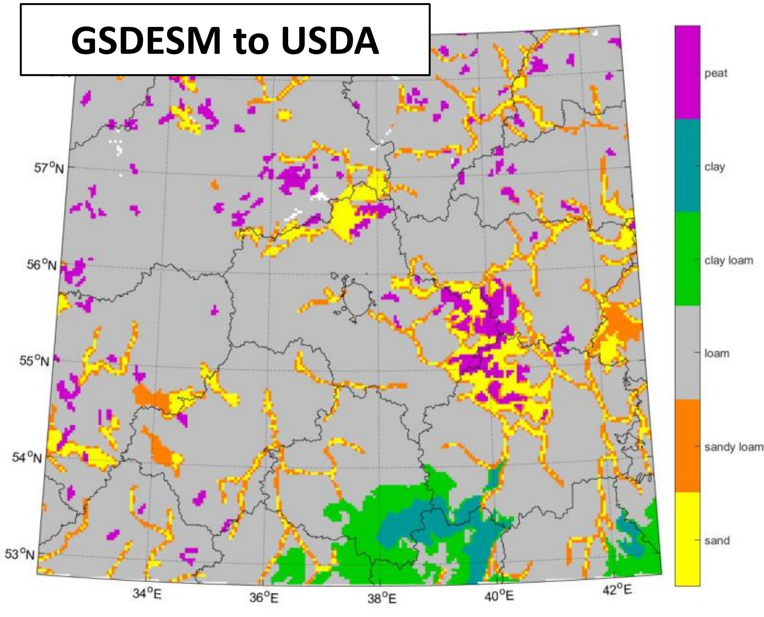
Towards improving the soil texture map

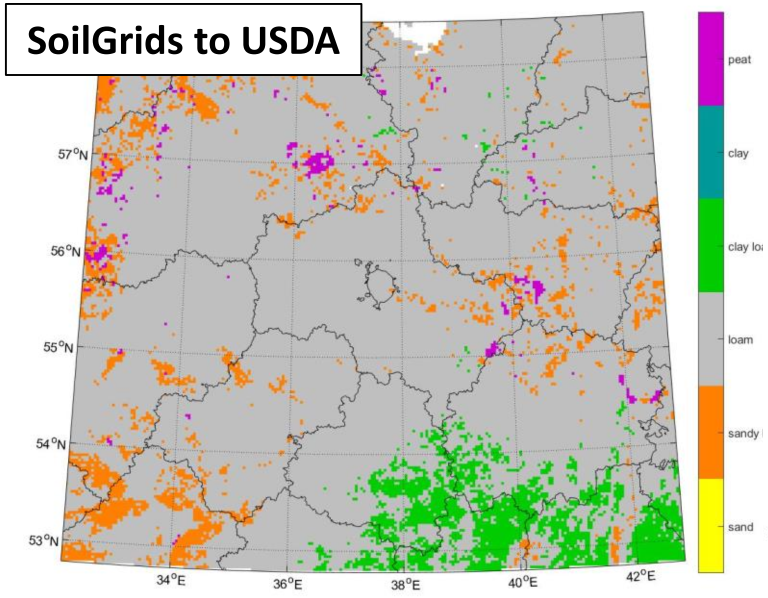
USDA triangle to 5 COSMO texture classes

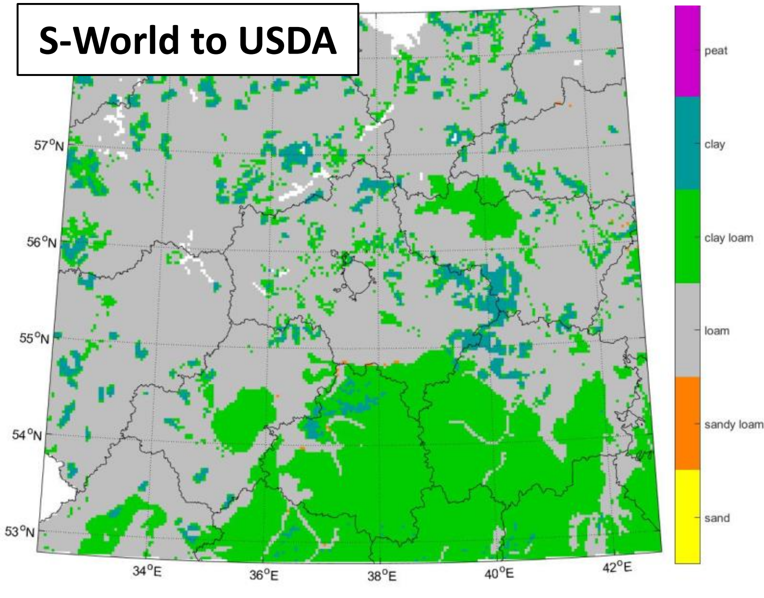


Uncertainties of resulting classification →









Conclusion and outlook

- **New developments:** COSMO 5.05urb with recent physical developments, TERRA_URB scheme and extended opportunities for setting the city-descriptive parameters
- **External city-descriptive parameters:**
  - Comprehensive GIS-based approach and faster LCZ-based approach were developed
  - For summer, both approaches provide a noticeable impartments in comparison to default configuration with urban fields from EXTPAR
  - For the winter, LCZ-based approach demonstrates worse results due to underestimation of anthropogenic heat flux
  - ***Paper under preparation:*** *Varentsov M., Samsonov T., Demuzere M. Impact of urban canopy parameters on a megacity'smodelled thermal environment. Will be submitted to Atmosphere SI (thanks Eduardo for extending the deadline!)*
- **Questions for further research:**
  - Need for higher-resolution soil texture data (and likely other natural parameters)
  - Questions on the physical set up for "gray zone" simulations (do we need shallow convection, 3D diffusion, etc.?)

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