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Lomonosov Moscow State University

High-resolution weather and climate simulations for urban areas: experience with COSMO model for Moscow megacity

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and

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2) Hydrometeorologicall Research Center of Russia

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Self-introduction

Graduated from Lomonosov Moscow State University, Faculty of Geography, Department of Meteorology and Climatology.

PhD candidate since May 2018.
The thesis **"Analysis and modelling of mesoclimatic features of Moscow agglomeration"** (scientific supervisor – Prof., Dr. Alexander Kislov)

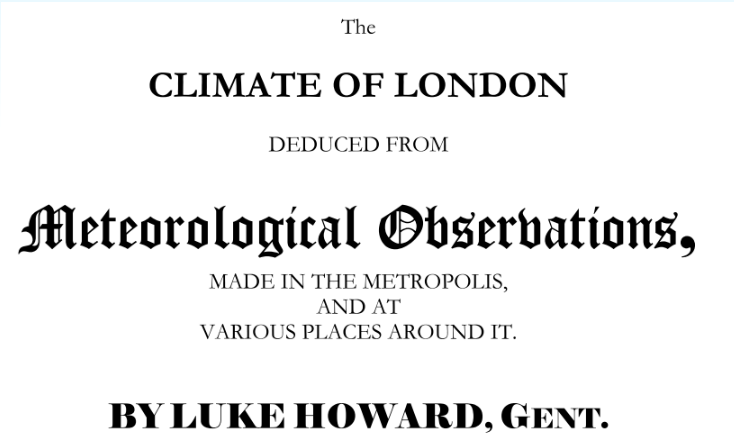
Scientific background and skills:

- Urban climate
- Regional mesoscale modelling (COSMO)
- Data analysis in Matlab
- Model-to-observation comparison
- Experimental studies (incl. eddy-covariance, UAV applications, etc.).
- Urban climate research research in the Arctic cities

Outline

1. Brief introduction to urban climatology and meteorology
2. Approaches for urban atmospheric modelling
3. Urban climate studies in Moscow megacity
4. Experience of using COSMO model for Moscow: problems, applications and recent developments
    - External parameters
    - Verification & tuning
    - Applications
    - Recent developments

Urban climatology and meteorology


The

CLIMATE OF LONDON

DEDUCED FROM

Meteorological Observations,

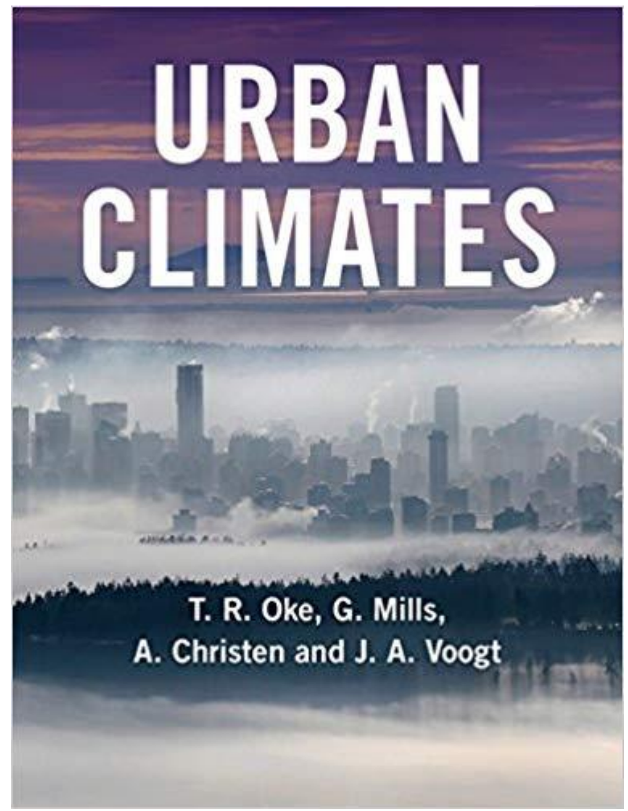
MADE IN THE METROPOLIS,
AND AT
VARIOUS PLACES AROUND IT.

BY LUKE HOWARD, GENT.

Climate of London (Luke Howard, 1833)

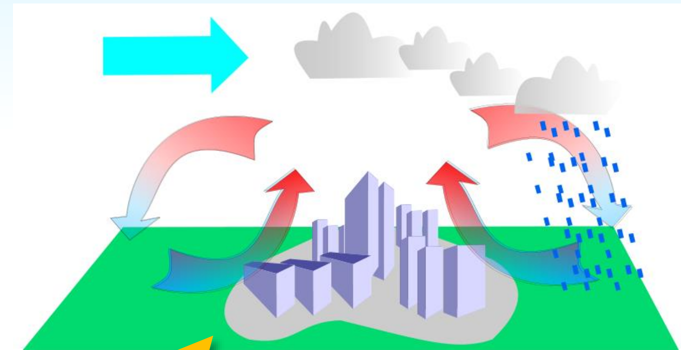
IAUC

INTERNATIONAL ASSOCIATION FOR URBAN CLIMATE

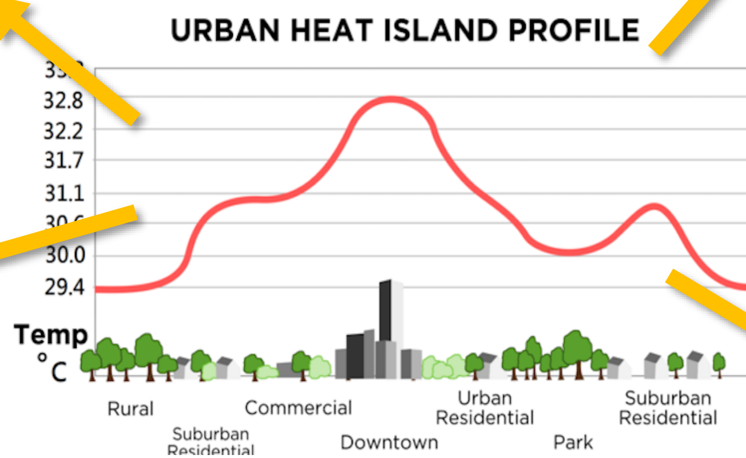


Motivation for urban climate studies

Ecosystems
(e.g. plants' phenology



Mesoscale circulation, precipitation, air quality, etc.



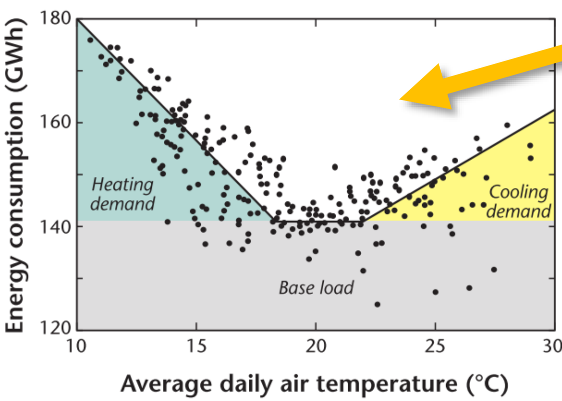
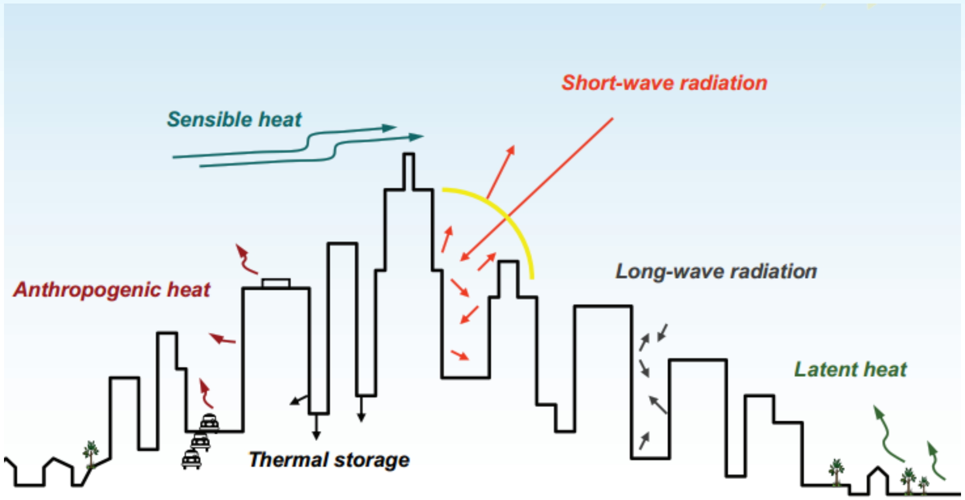


Figure 6.4 Daily energy demand by Sidney, Australia, as met by electrical power on the grid in 1990–91 (Source: Modified based on data by Pacific Power Inc.).

Energy demands for cooling/heating

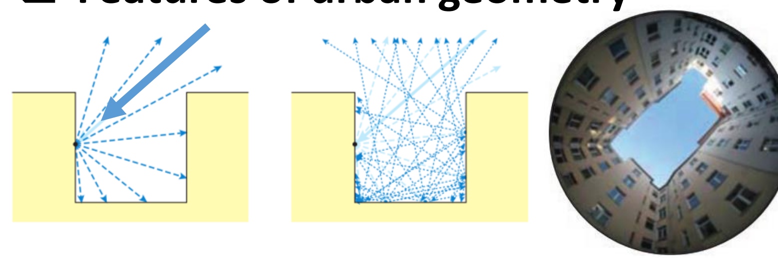
Outdoor thermal comfort

Driving factors

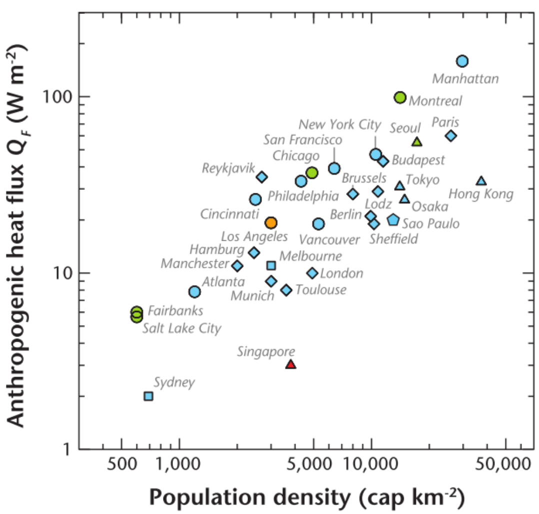


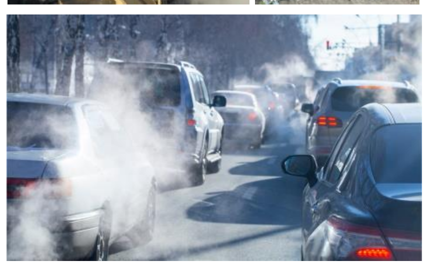
- Man-made materials

- Features of urban geometry

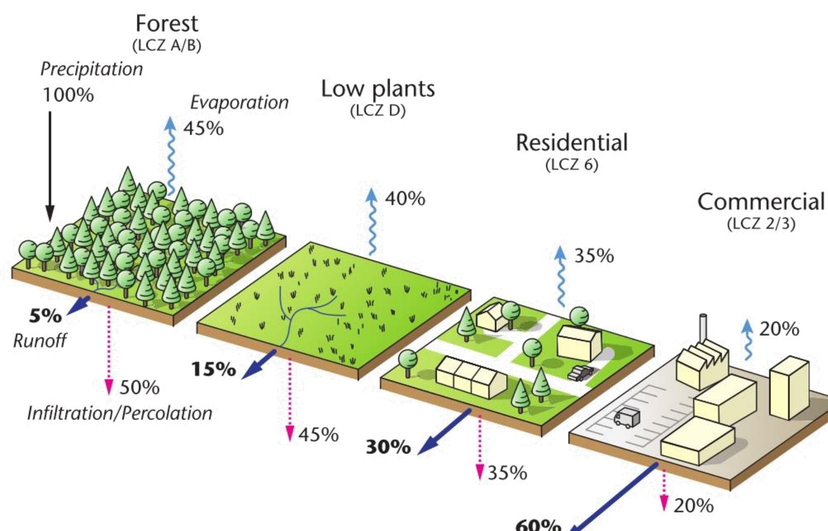


- Anthropogenic heat emissions

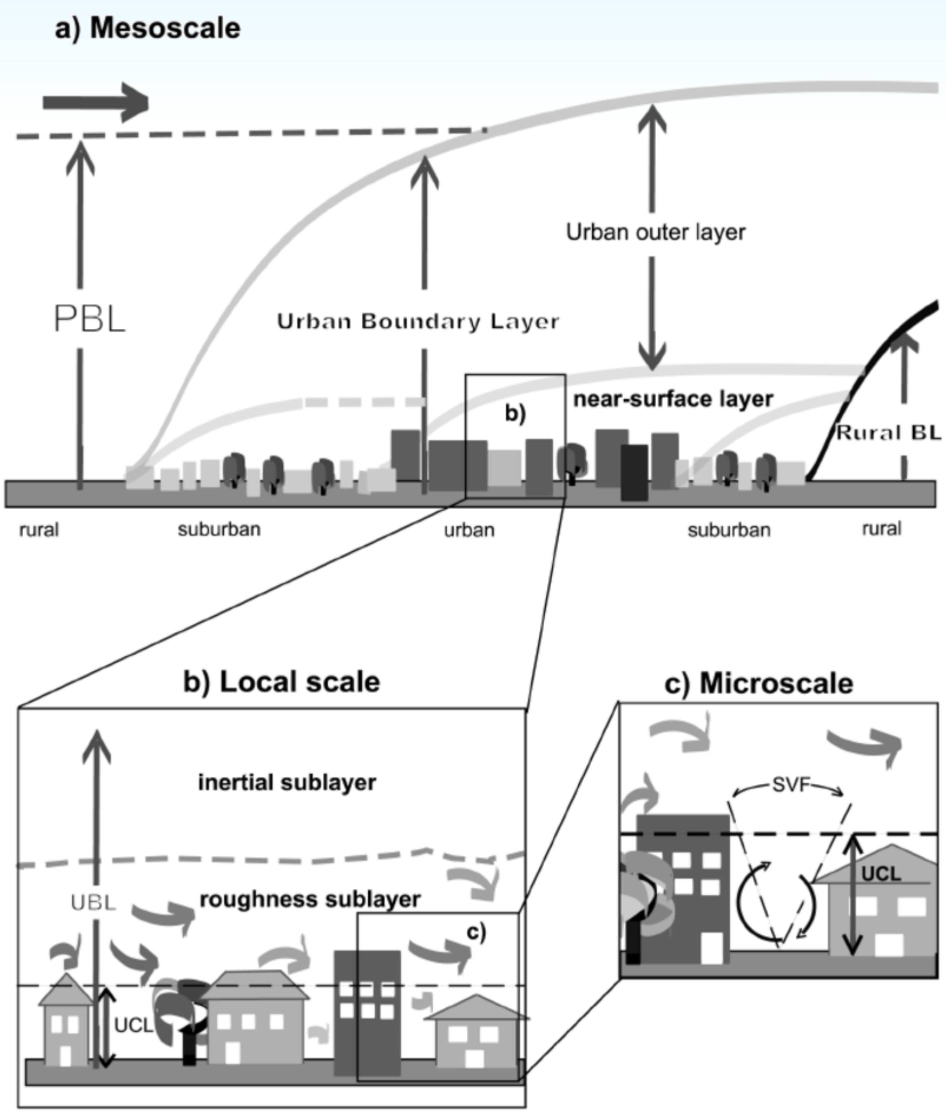


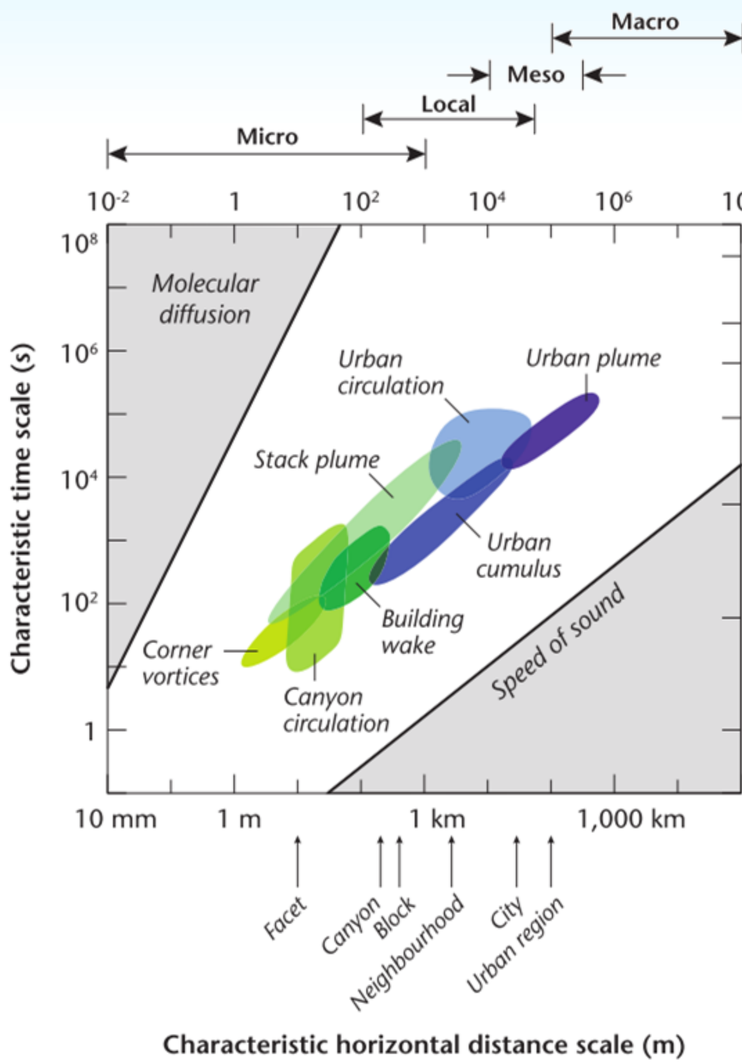


- Urban vs rural water balance

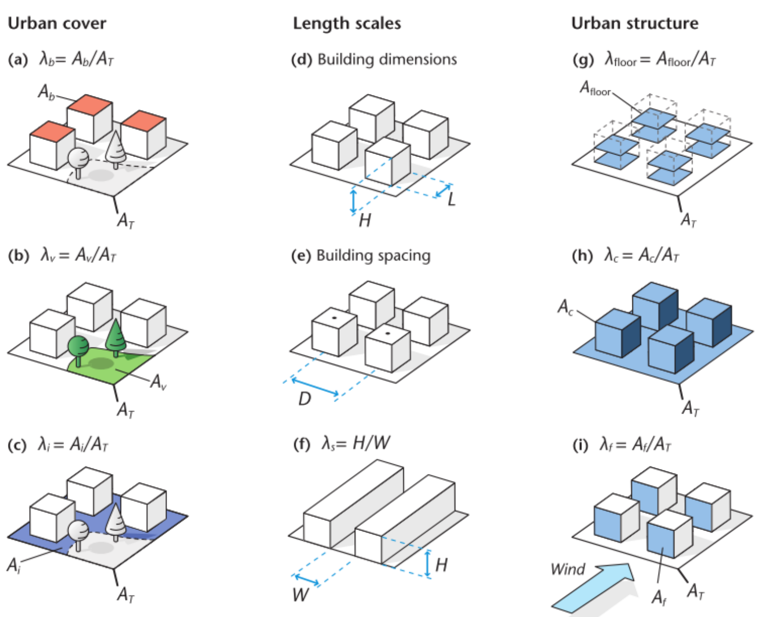


Complexity of urban climate system

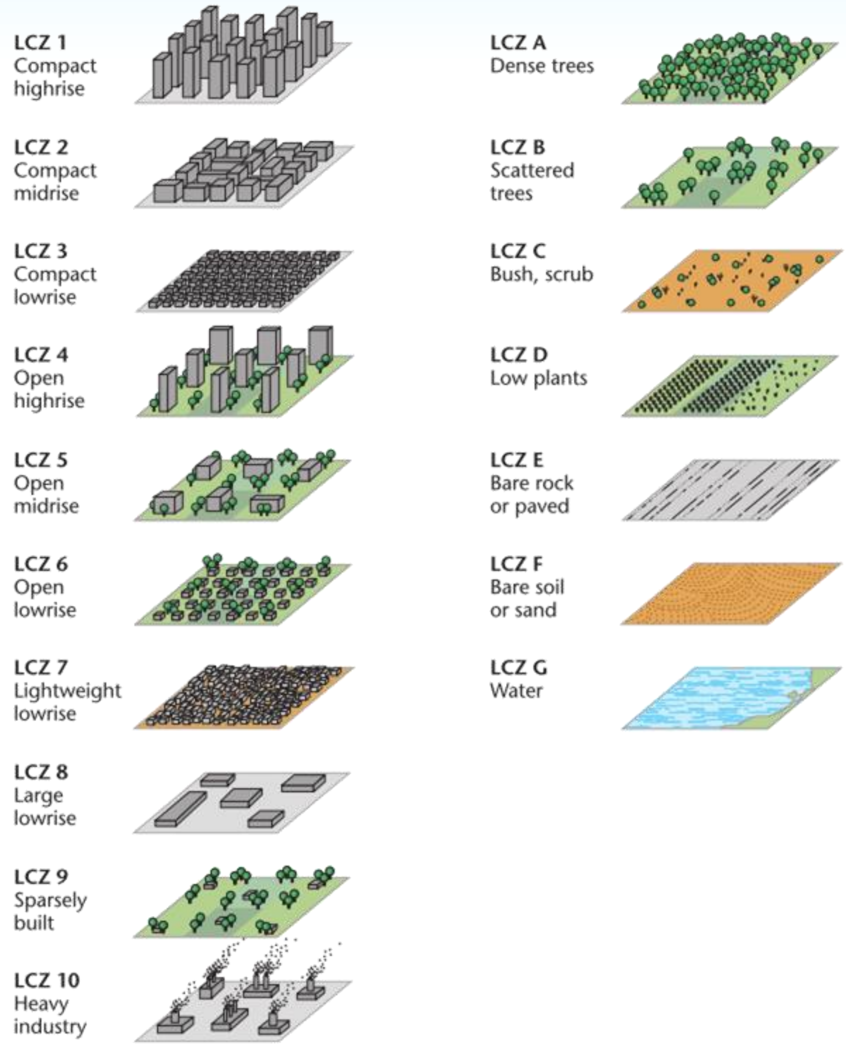




How to describe the urban environment?

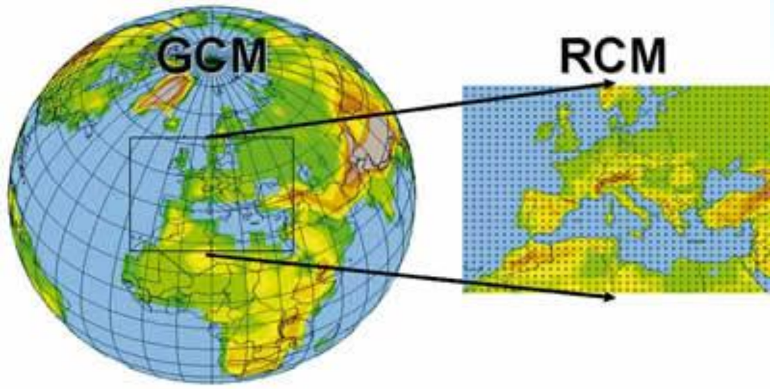


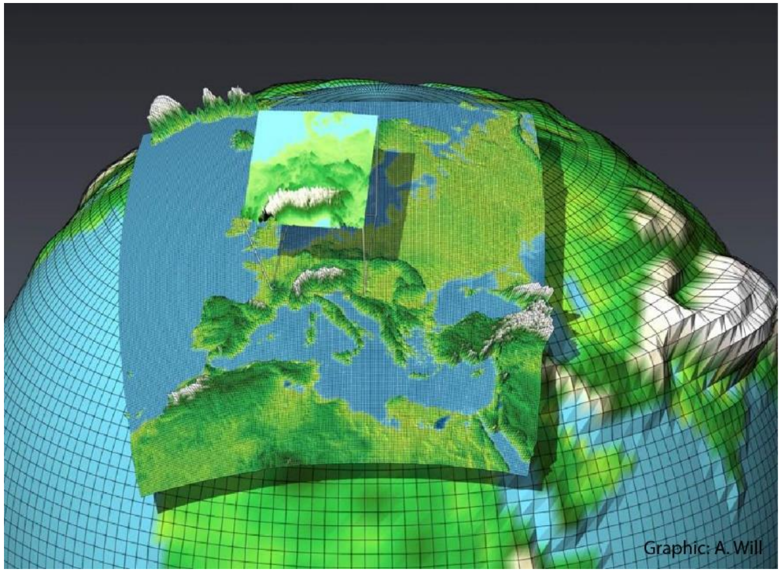
Local climate zones (LCZs)
by Stewart and Oke (2012)



Numerical atmospheric models

$$
\begin{aligned}
\frac{\partial u}{\partial t} + \mathbf{v}\cdot\nabla u - \frac{uv}{a}\tan\varphi - fv &= -\frac{1}{\rho a\cos\varphi}\left(\frac{\partial p'}{\partial\lambda} + \frac{J_\lambda}{\sqrt{G}}\frac{\partial p'}{\partial\zeta}\right) + M_u \\
\frac{\partial v}{\partial t} + \mathbf{v}\cdot\nabla v + \frac{u^2}{a}\tan\varphi + fu &= -\frac{1}{\rho a}\left(\frac{\partial p'}{\partial\varphi} + \frac{J_\varphi}{\sqrt{G}}\frac{\partial p'}{\partial\zeta}\right) + M_v \\
\frac{\partial w}{\partial t} + \mathbf{v}\cdot\nabla w &= \frac{1}{\rho\sqrt{G}}\frac{\partial p'}{\partial\zeta} + B + M_w \\
\frac{\partial p'}{\partial t} + \mathbf{v}\cdot\nabla p' - g\rho_0 w &= -(c_{pd}/c_{vd})pD + (c_{pd}/c_{vd} - 1)\rho c_{pd}Q_T \\
\frac{\partial T}{\partial t} + \mathbf{v}\cdot\nabla T &= \frac{1}{\rho c_{pd}}\left(\frac{\partial p'}{\partial t} + \mathbf{v}\cdot\nabla p' - g\rho_0 w\right) + Q_T \\
\frac{\partial q^v}{\partial t} + \mathbf{v}\cdot\nabla q^v &= -(S^l + S^f) + M_{q^v} \\
\frac{\partial q^{l,f}}{\partial t} + \mathbf{v}\cdot\nabla q^{l,f} + \frac{1}{\rho\sqrt{G}}\frac{\partial P_{l,f}}{\partial\zeta} &= S^{l,f} + M_{q^{l,f}}.
\end{aligned}
$$



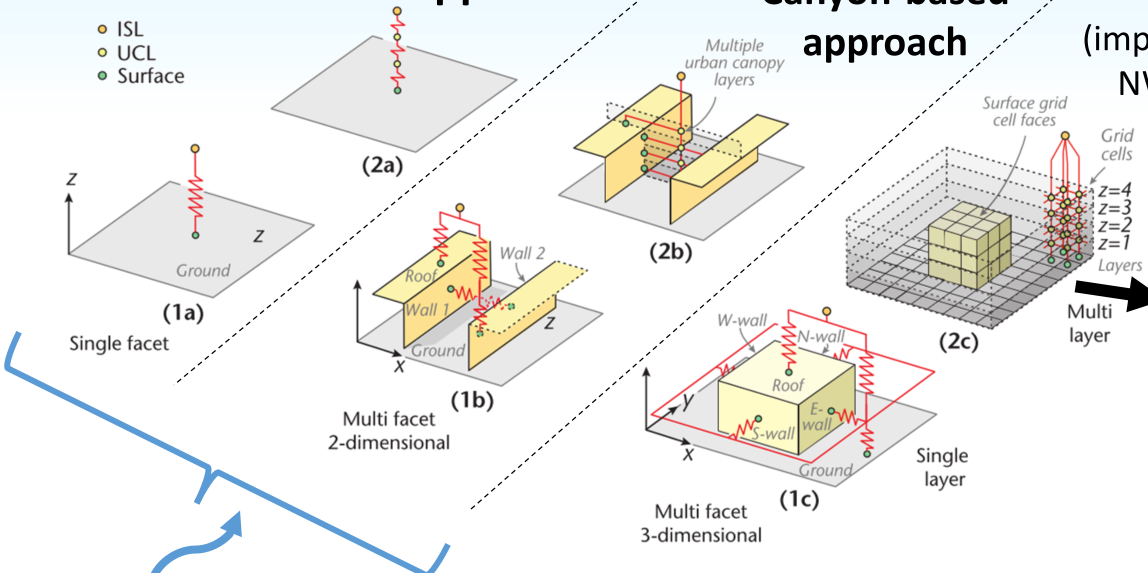


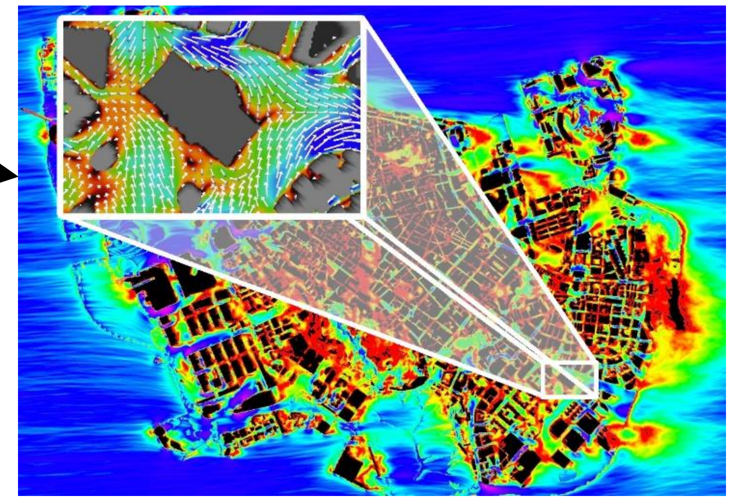
How to model the urban-atmosphere interactions?

Bulk approach

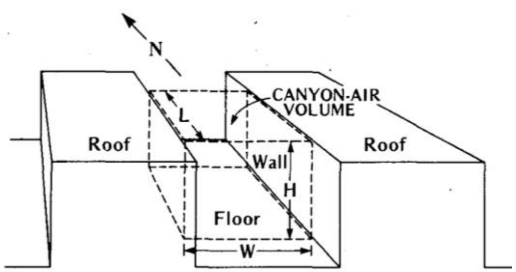
Canyon-based approach

Building-resolving approach
(impossible for long-term climate modelling and NWP tasks; example from PALM LES model)

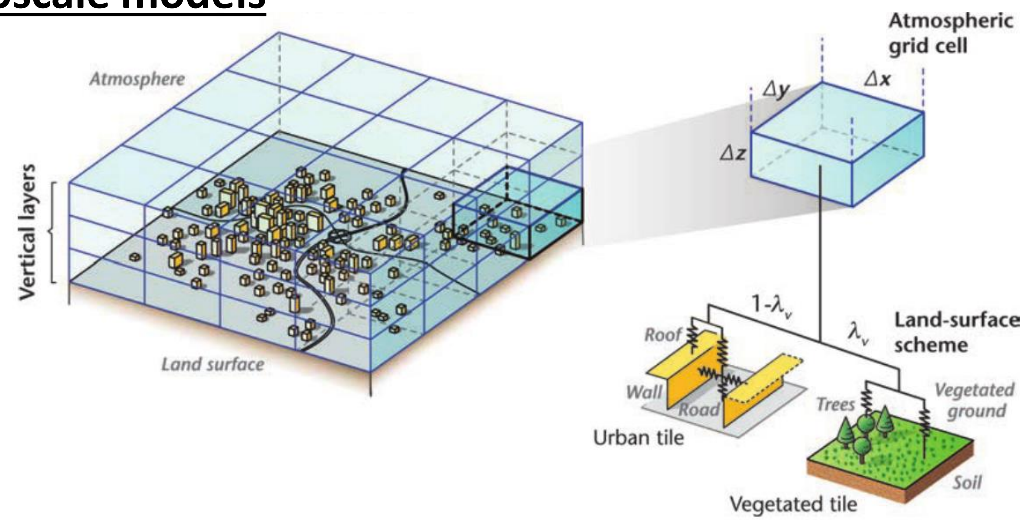




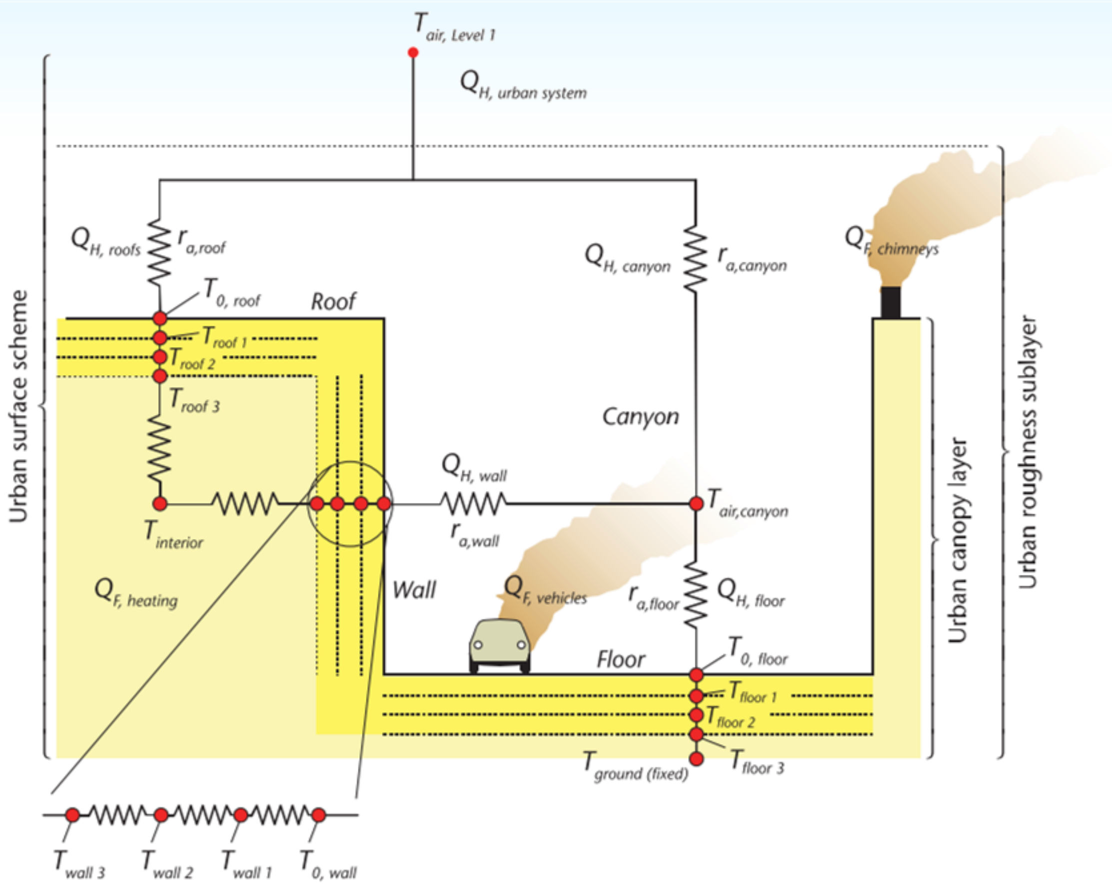
Parameterizations for mesoscale models



Street canyon concept
(Oke, Nunez, 1977)



Urban canopy parameterizations



TEB (Town Energy Balance) scheme (Masson, 2000)

Urban canopy parameterizations

Urban canopy models in WRF /HIRLAM:

Both models have three different urban schemes included in the official releases: bulk approach, SLUCM, MLUCM (Chen et al. 2011, Baklanov et al., 2008)

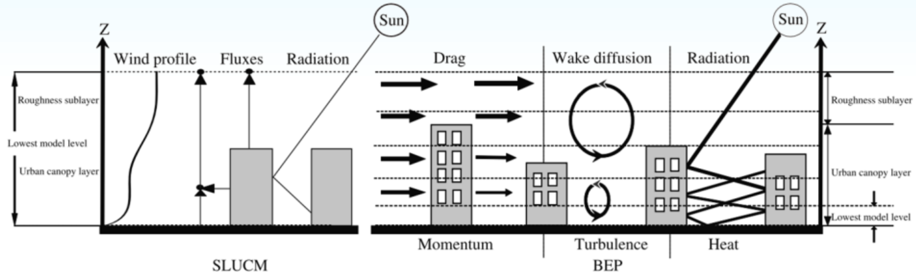
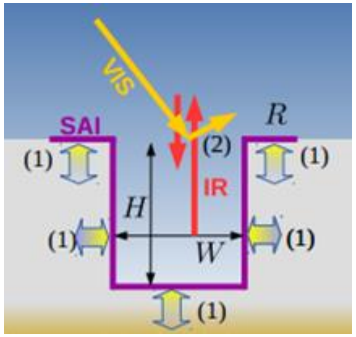


Figure 2. A schematic of the SLUCM (on the left-hand side) and the multi-layer BEP models (on the right-hand side).

Urban canopy models in COSMO:

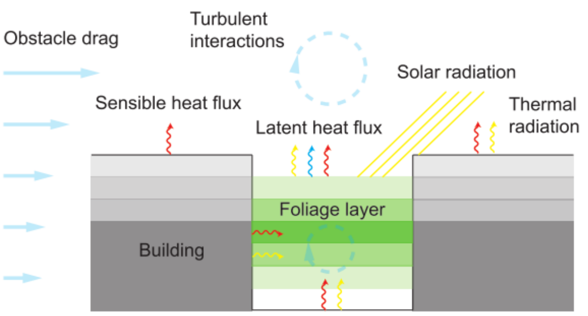
1) **TERRA_URB scheme** (Wouters et al., 2015; 2016) – fast and efficient scheme based on the bulk approach, planned be included to the official COSMO code in the last unified model version 6.0
   - Standard surface and soil properties from TERRA land model (albedo, emissivity, roughness, etc.) are modified by **SURY (Semi-empirical Urban canopy parameterization)**
   - Puddles parameterization for impervious surface
   - Pre-defined anthropogenic heat flux according to (Flanner, 2009)



"Translation of urban canopy parameters into bulk parameters"

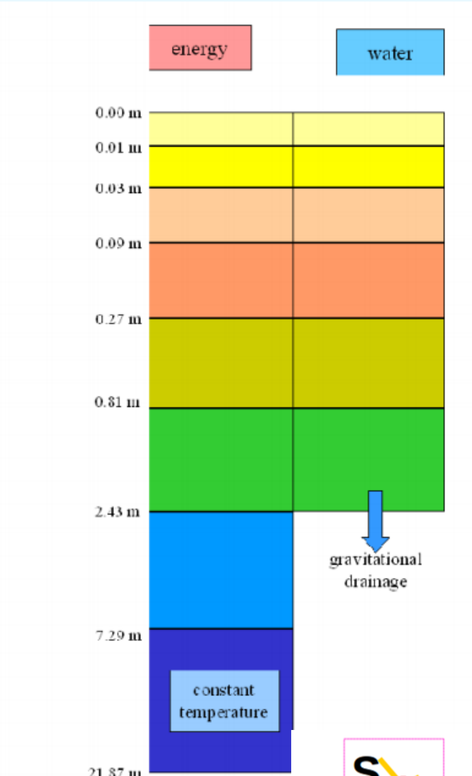
2) **TEB (Town Energy Balance)** – single layer urban canopy model (Masson, 2000; Trusilova et al., 2013), problems in coupling have been revealed

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



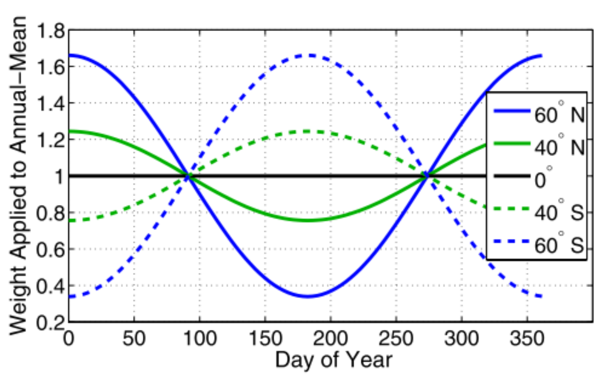
BEP-Tree

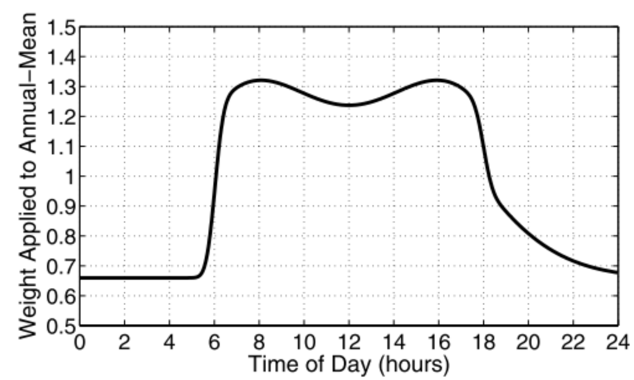
TERRA_URB scheme (Wouters et al., 2016)

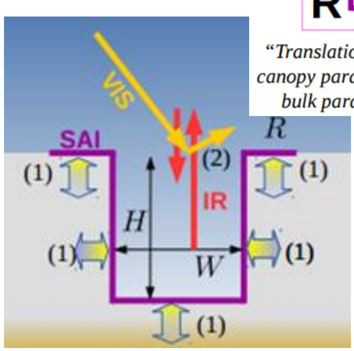


Modifications of TERRA land surface model in TERRA_URB:

1. Correction of albedo, emissivity, heat conductivity and heat capacity to take into account urban canopy effects
2. Modifications of roughness length for momentum and heat
3. Urban surface is completely impervious, puddles and rainwater drainage are parameterized
4. Tile approach: H and LE are calculated separately for urban and natural parts and then averaged
5. Anthropogenic heat flux (AHF): prescribed annual-mean value and diurnal and annual cycles according to (Flanner, 2009)







"Translation of urban canopy parameters into bulk parameters"

<u>**Necessary external parameters:**</u> 2D fields of impervious area fraction (ISA) and annual-mean AHF; + hard-coded urban canopy parameters.

Instead of implementing a computationally demanding explicit-canyon radiation scheme, an approximation for ψ_c is proposed to the numerical estimation from Fortuniak (2007). The latter applies an exact solution of the multiple-reflection problem allowing to subdivide the different facets in an urban canyon. The exact solution results in a high accuracy for low solar heights when the lower canyon parts are shaded. It could reproduce the effective-albedo observations from a scale model (Aida, 1982) and from a real canyon very well. The numerical estimation shows that the albedo reduction is most sensitive to the $\frac{h}{w_c}$ ratio, hence the following approximation is proposed:

$$\psi_c\left(\frac{h}{w_c}\right) = \exp\left(-0.6\frac{h}{w_c}\right). \quad (15)$$

Optionally, a distinction is made between the albedo of roofs, roads and walls as follows:

$$\alpha_{\text{bulk}} \simeq \frac{\left[\alpha_{\text{road,snow}} + 2\frac{h}{w_c}\alpha_{\text{wall,snow}}\right]}{(1+2\frac{h}{w_c})}\psi_c\left(\frac{h}{w_c}\right)(1-R) + \alpha_{\text{roof,snow}}R, \quad (16)$$

with

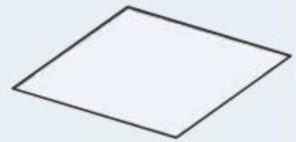
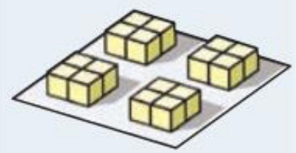
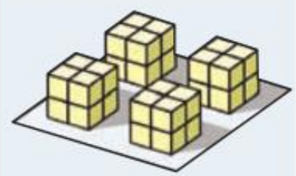
$$\alpha_{i,\text{snow}} = (1-f_{\text{snow}})\alpha_i + f_{\text{snow}}\alpha_{\text{snow}}, \quad \text{for } i \text{ in (roof, wall, road)}, \quad (17)$$

and where $\frac{\left[\alpha_{\text{road,snow}}+2\frac{h}{w_c}\alpha_{\text{wall,snow}}\right]}{(1+2\frac{h}{w_c})}$ is the averaged albedo of the roads and walls in the urban canyon. The bulk infra-red emissivity ϵ_{bulk} takes into account the same bulk albedo reduction factor ψ_{bulk} as follows:

$$\epsilon_{\text{bulk}} = 1 - \psi_{\text{bulk}}\left(1-((1-f_{\text{snow}})\epsilon + f_{\text{snow}}\epsilon_{\text{snow}})\right), \quad (18)$$

where ϵ is the emissivity and ϵ_{snow} is the snow emissivity.

Effective albedo of the urban surface

Urban form	H/W	λ_c	Albedo α	Change in absorption
	0	1	0.40	
	0.5	1.5	0.32	+17%
	1	2	0.27	+21%
	2	3	0.23	+27%

2.1.3 Surface-layer turbulent transport

Following Sarkar and De Ridder (2010), the aerodynamic roughness lengths for the urban canopy is calculated as follows:

$$z_0 = 0.075h, \tag{19}$$

with h as the building height. The thermal roughness length z_{0H} is obtained with a parametrization of the inverse Stanton number (as in De Ridder, 2006; Demuzere et al., 2008):

$$kB^{-1} = \ln\left(\frac{z_0}{z_{0H}}\right), \tag{20}$$

with k as the von Kàrmàn constant. For the urban canopy, a bluff-body thermal roughness length parametrization from Brutsaert (1982) is introduced using parameter values from Kanda et al. (2007):

$$kB^{-1} = 1.29Re_*^{0.25} - 2.0, \tag{21}$$

where $Re_* = u_* z_0/\nu$ is the roughness Reynolds number, u_* is the friction velocity and $\nu = 1.461 \times 10^{-5}\,\mathrm{m^2\,s^{-1}}$ the kinematic viscosity of air.

As before, the default value for h equal to 15 m (see also Table 1) corresponds to the recommended value in Loridan and Grimmond (2012); see their Table 4 (stage 5b). It yields $z_0 = 1.125$ m and $kB^{-1} = 13.2$ (in case that $u_* = 0.25\,\mathrm{m\,s^{-1}}$).

Roughness Lengths for Momentum and Heat Derived from Outdoor Urban Scale Models

M. KANDA, M. KANEGA, T. KAWAI, AND R. MORIWAKI

Department of International Development Engineering, Tokyo Institute of Technology, Tokyo, Japan

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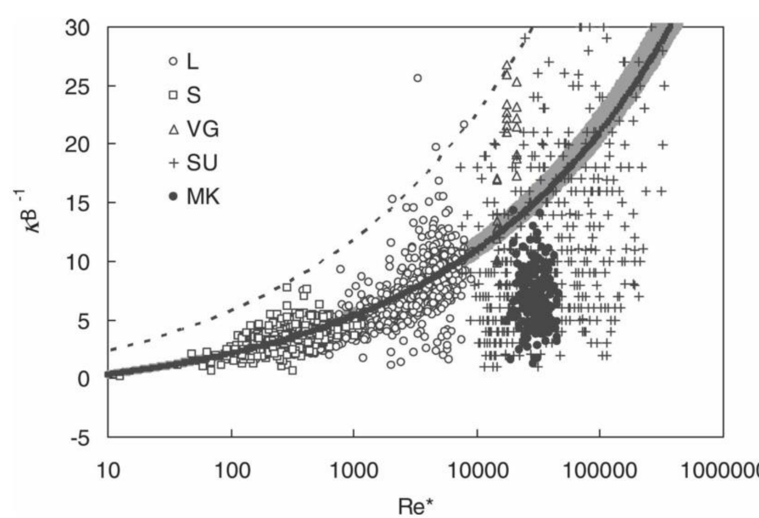
Department of Earth and Ocean Sciences, National Defense Academy of Japan, Yokosuka, Kanagawa, Japan



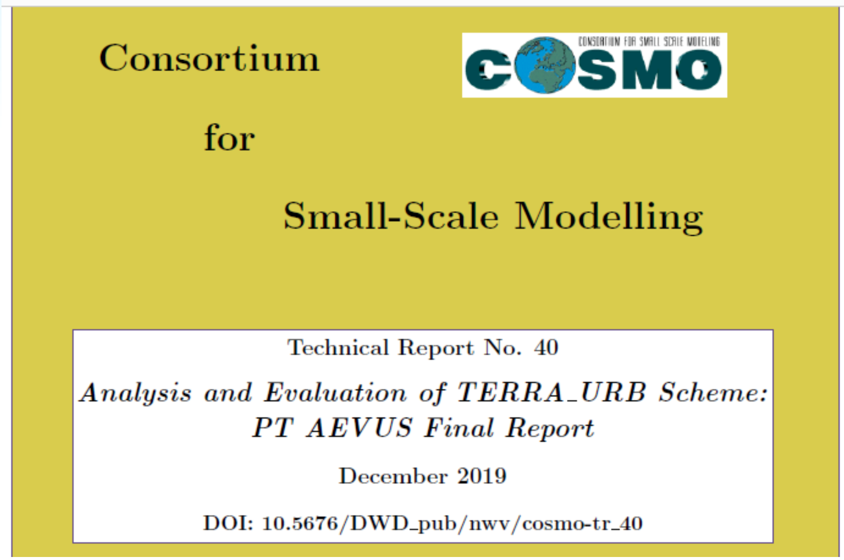
Status of TERRA_URB development

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 versions (5.04, 5.05).

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

COSMO

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:

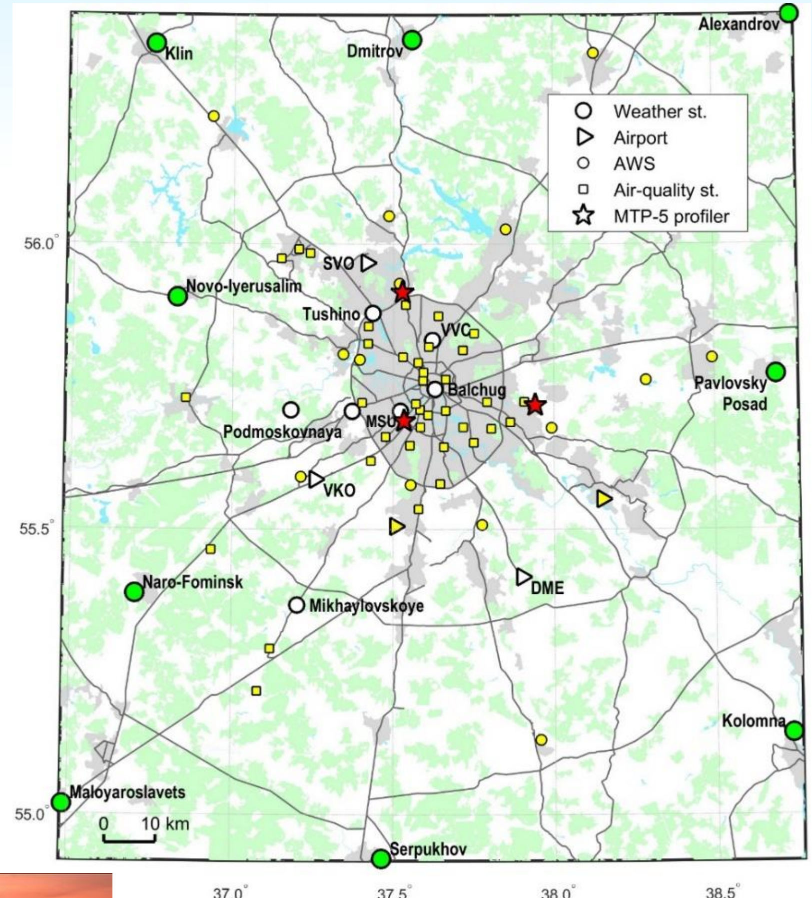
1) Development of the more flexible model version with less hard-coded parameters
2) In-depth testing and verification
3) First steps towards TERRA_URB implantation to ICON

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

Moscow as test-bed for urban climate modelling

Key features of Moscow megacity as place of urban climate research:

- ✓ Biggest agglomeration in Europe ($\approx 17 \cdot 10^6$ people)
- ✓ Flat and homogenous landscape around the city
- ✓ Continental climate with warm summer and cold winter
- ✓ Strong UHI with mean intensity of 2 °C and maximum intensity up to 13 °C (Lokoschenko, 2014)
- ✓ Spatial building features (high-rise blocks of flats, etc.)
- ✓ **Good observation network**



Meteorological observatory of Moscow University (MSU)

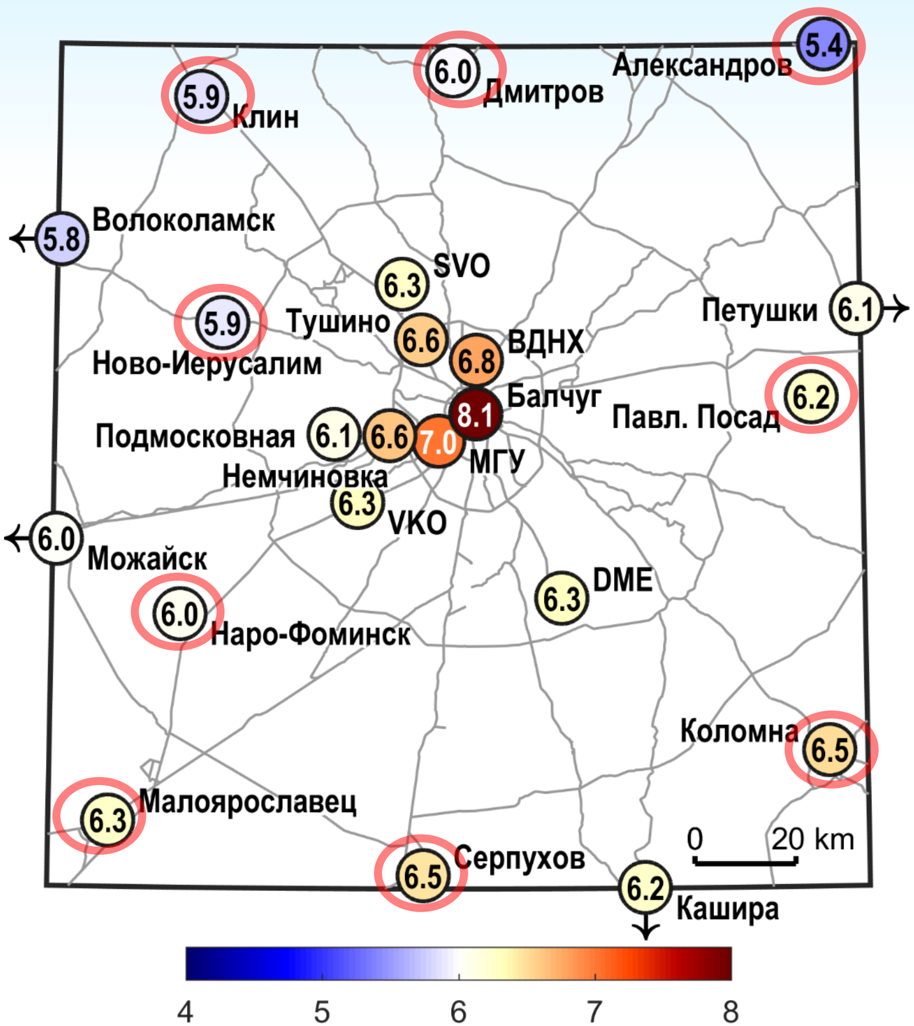
Balchug st. (city center)

Air-quality monitoring st.

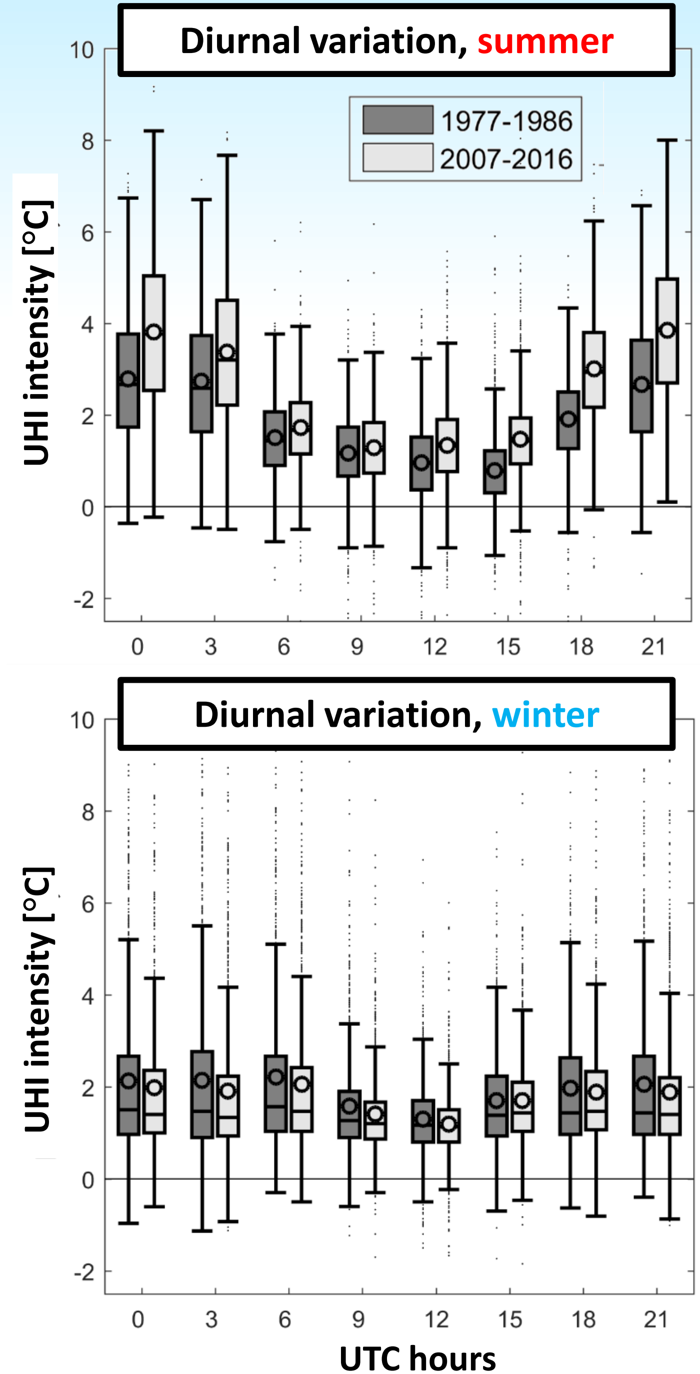
MTP-5 temperature profiler and its principle of operation

New AWS

Moscow UHI

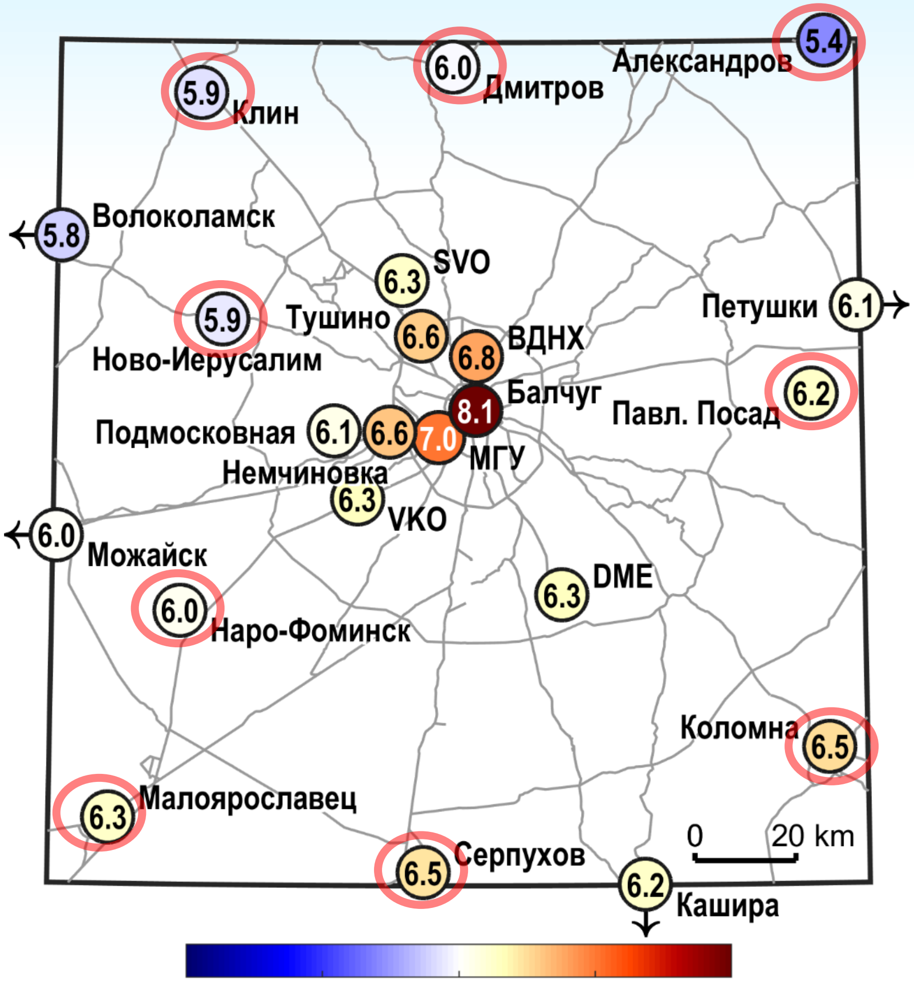


Average temperature over 2007-2016

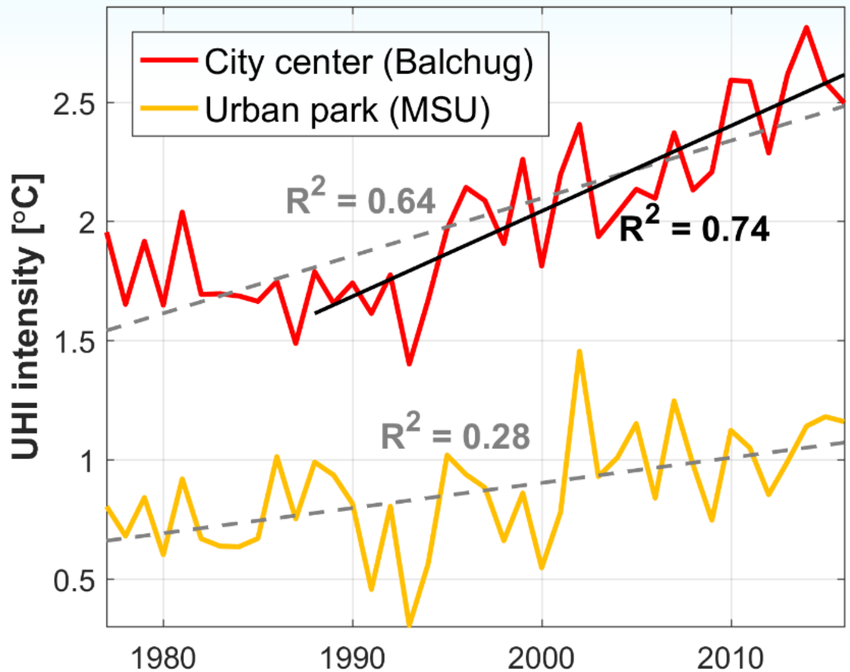


UHI intensity – temperature anomaly, calculated as a deviation from the average over 9 rural stations

Moscow UHI



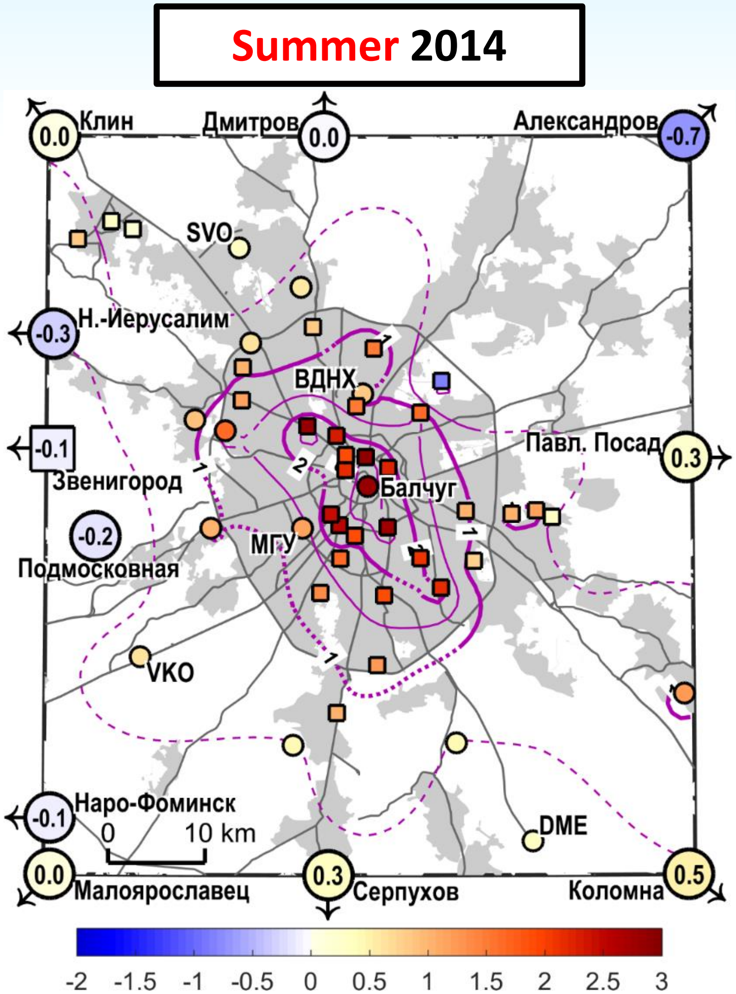
Average temperature over 2007-2016

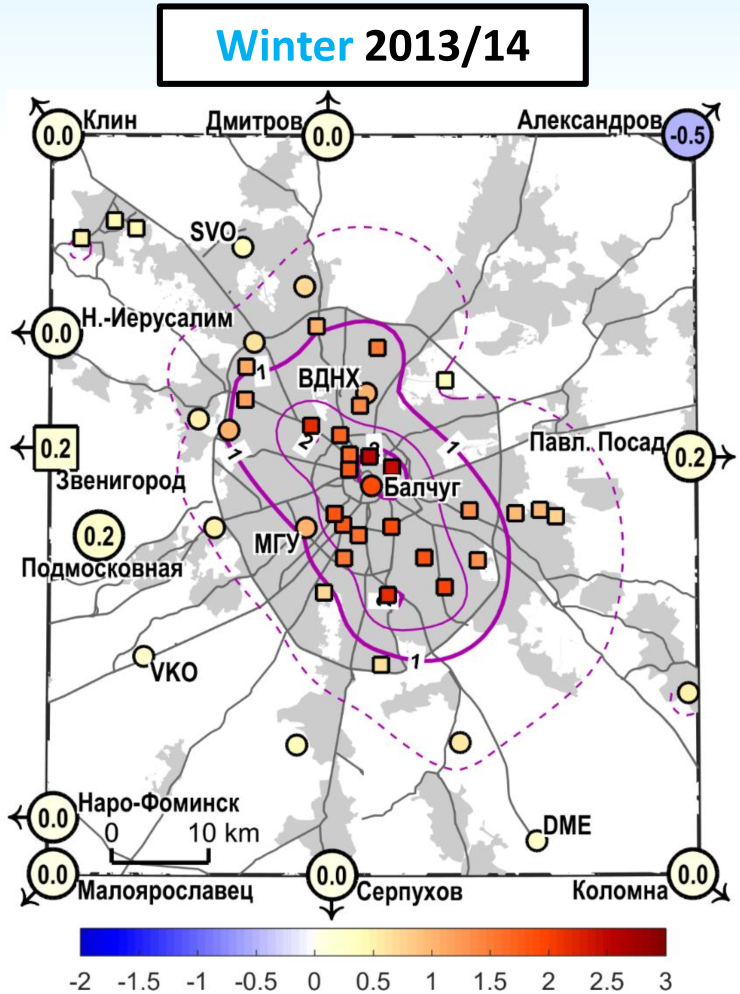


Trends of the summer UHI intensity (1977-2016)

UHI intensity – temperature anomaly, calculated as a deviation from the average over 9 rural stations

UHI spatial structure

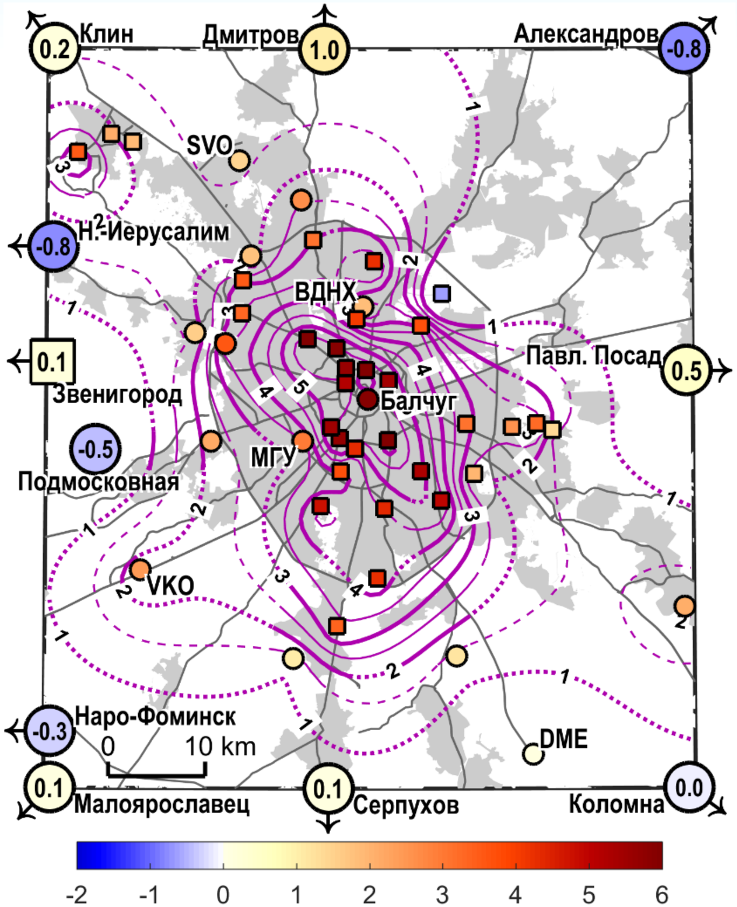




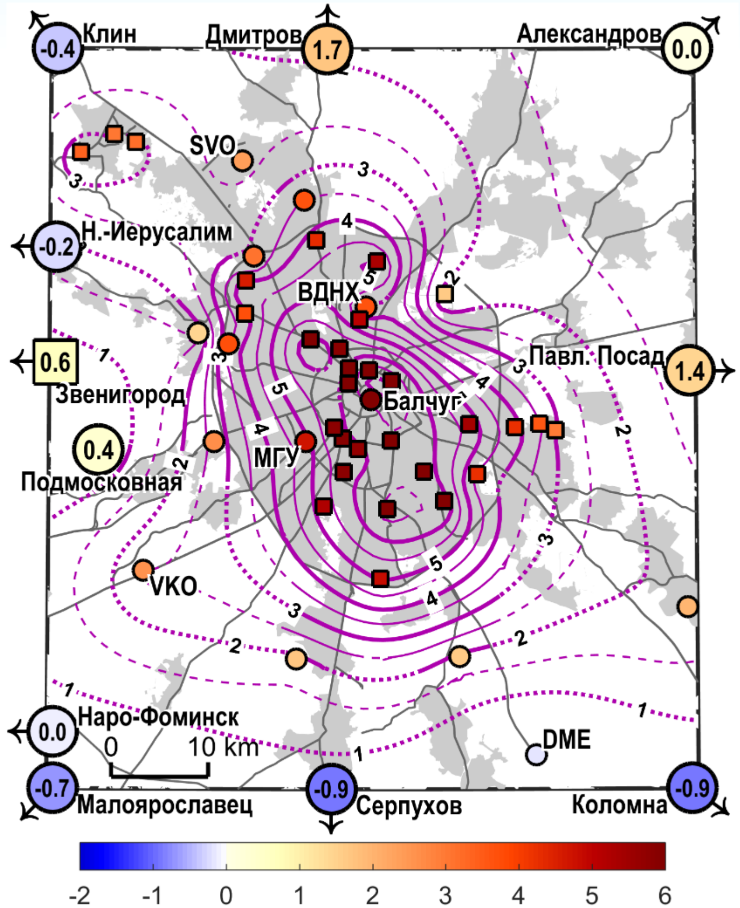
Anomaly of mean summer and winter temperature

UHI spatial structure

Summer 2014

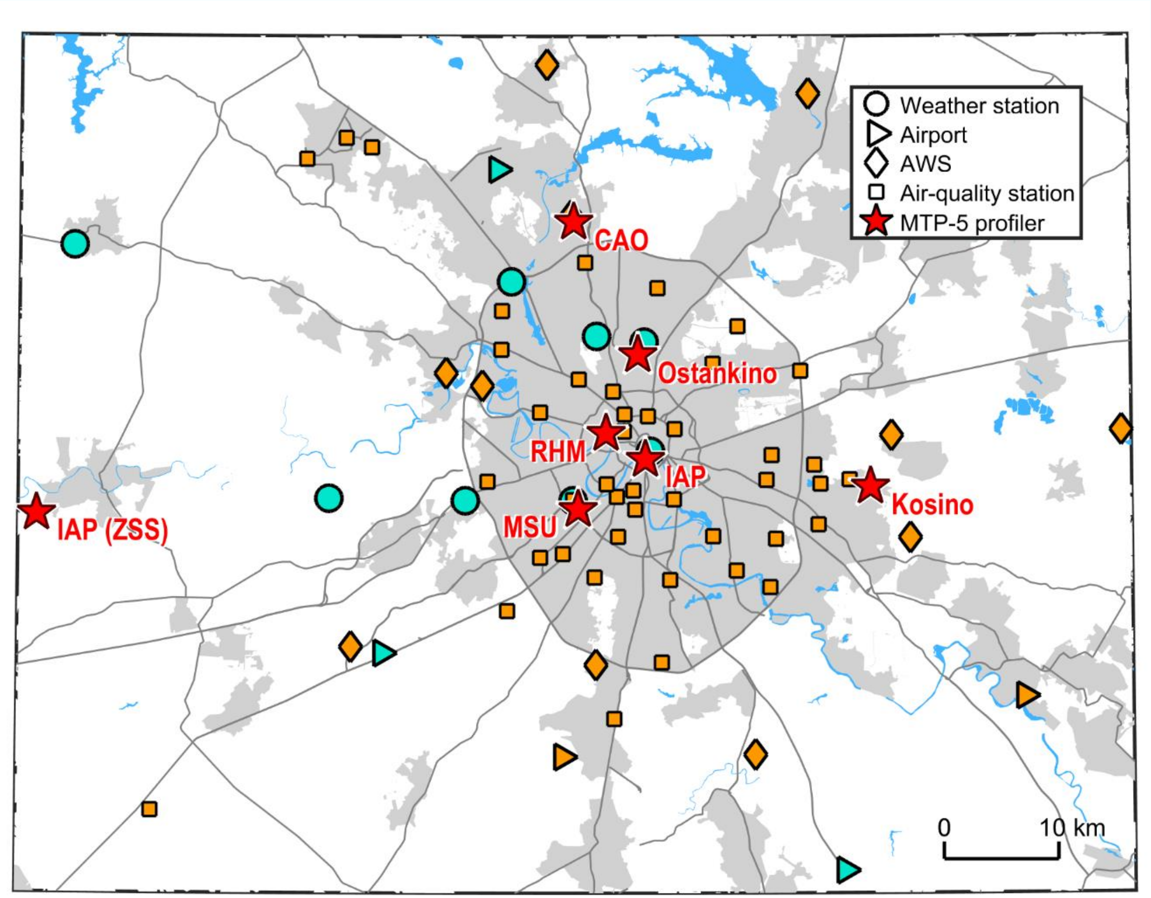


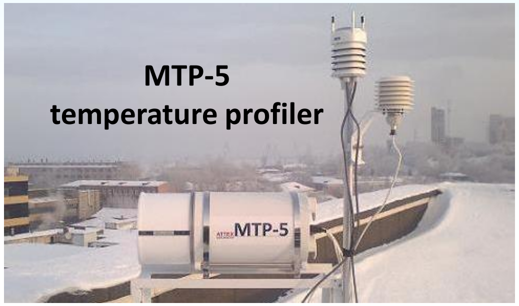
Winter 2013/14

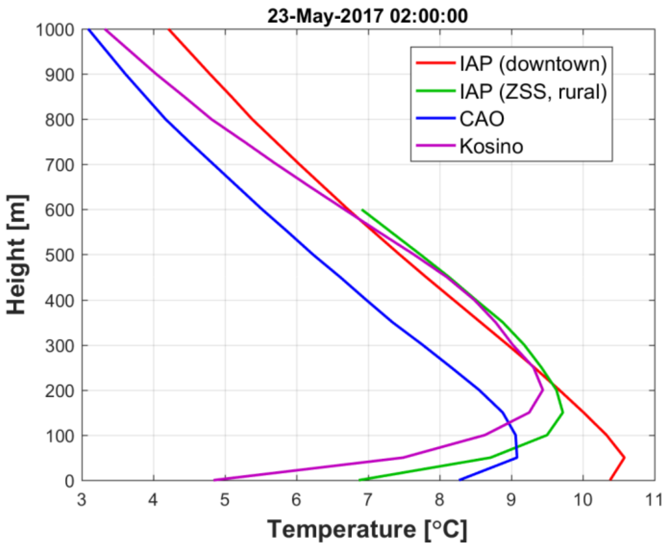


Temperature anomaly,
averaged over selections of summer and winter cases with intensive UHI

ABL observations: microwave temperature profilers







Thanks to Dr. I.A. Repina (IAP), A.Yu. Artamonov (IAP), E.A. Miller (CAO) and to Mosecomonitoring agency

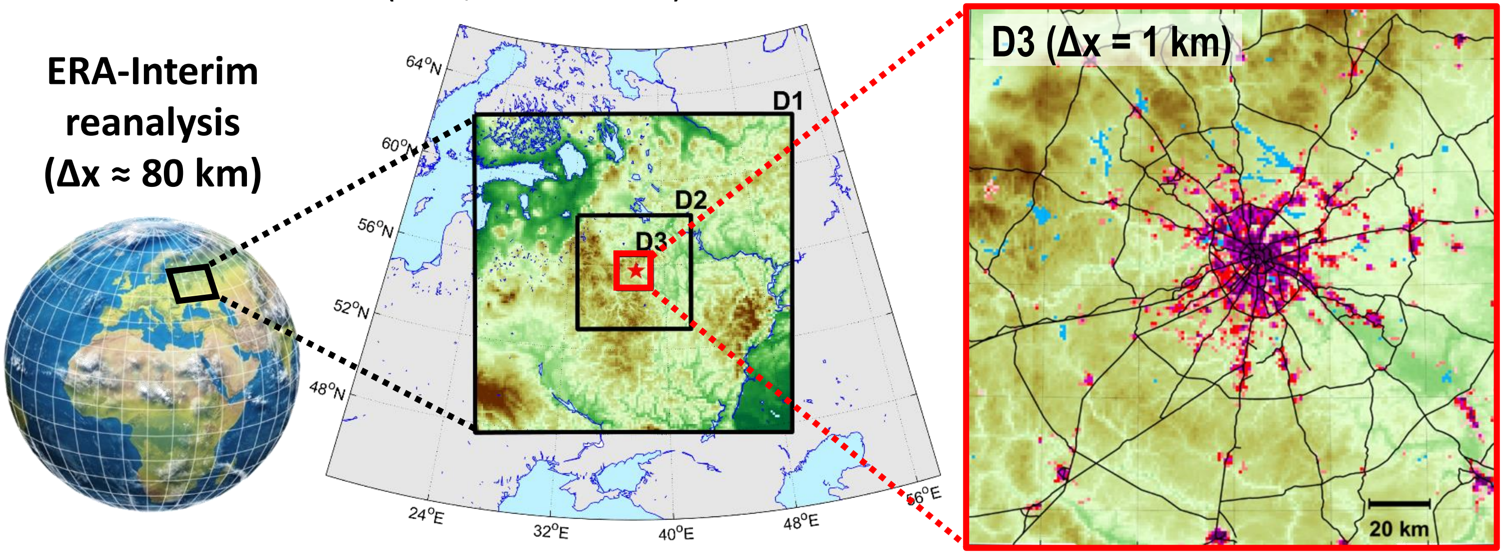
Modelling studies for Moscow

General framework of modelling studies

- ❑ **Regional mesoscale model of atmosphere COSMO-CLM**
- ❑ **Dynamic downscaling of the ERA-Interim reanalysis** for the chain of nested domains:
  D1 (Δx = 12 km) → D2 (Δx = 3 km) → D3 (Δx = 1 km)
- ❑ Carefully-tuned model configuration, including reduced turbulent mixing in stable condition according (Cerenzia et al., 2014) and new vegetation canopy schemes (Schulz, Vogel, 2017)
- ❑ **Urban canopy schemes:**
  - **TEB in COSMO 4.8_clm** (Trusiliva et al., 2013, Masson, 2000)
  - **TERRA_URB in COSMO 5.0_clm9** (Woulters et al., 2016) **and in COSMO 5.05**
- ❑ Simulations **for multiple summer and winter seasons** with and without urban canopy schemes scheme (URB/noURB runs)

MSU supercomputer "Lomonosov 2"

ERA-Interim reanalysis (Δx ≈ 80 km)



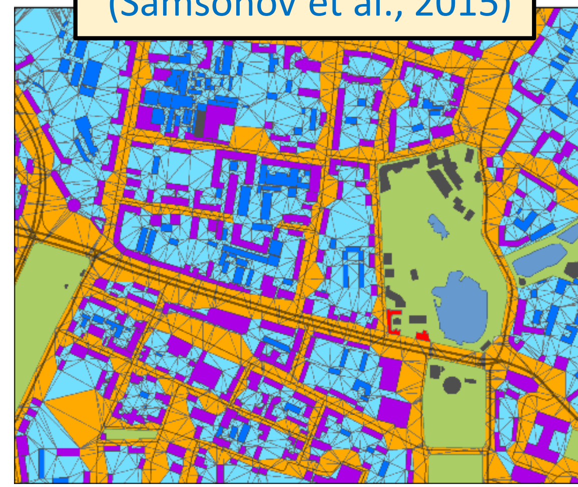
Urban canopy parameters

Required urban canopy parameters for TERRA_URB:

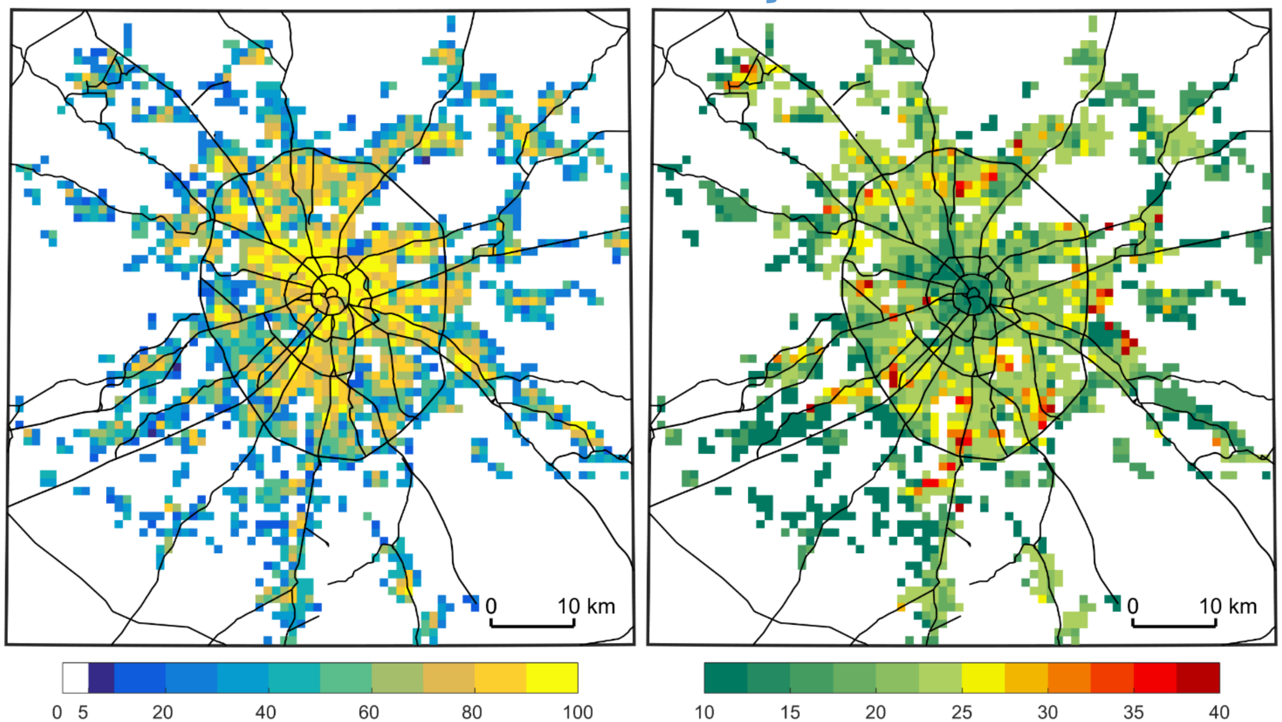
- **Urban area fraction (= impervious surface fraction, ISA)**
- **Annual-mean anthropogenic heat flux (AHF)**
- Building area fraction
- Building height H
- Street canyon aspect ration (H/W)

Additionally introduced as external parameters

1) GIS-processing of OpenStreetMaps data (Samsonov et al., 2015)



2) Averaging over given model grid cells

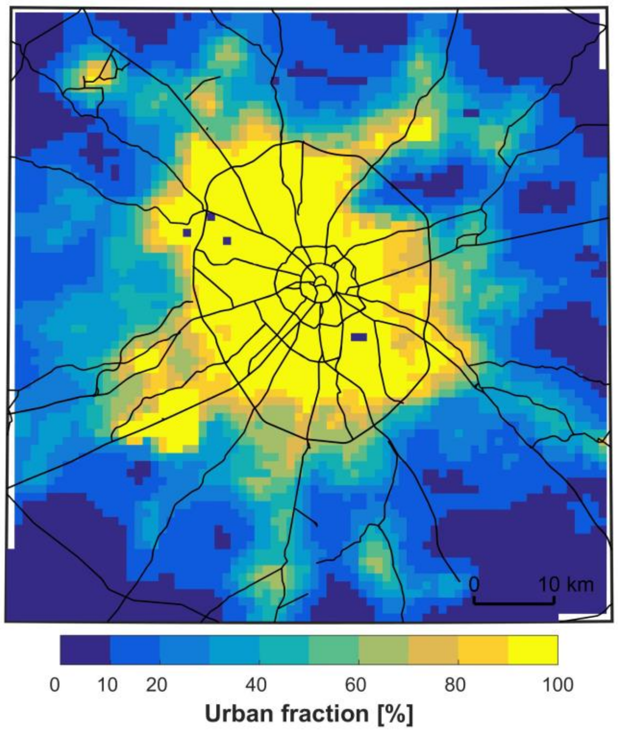


3) Calculation of the required parameters

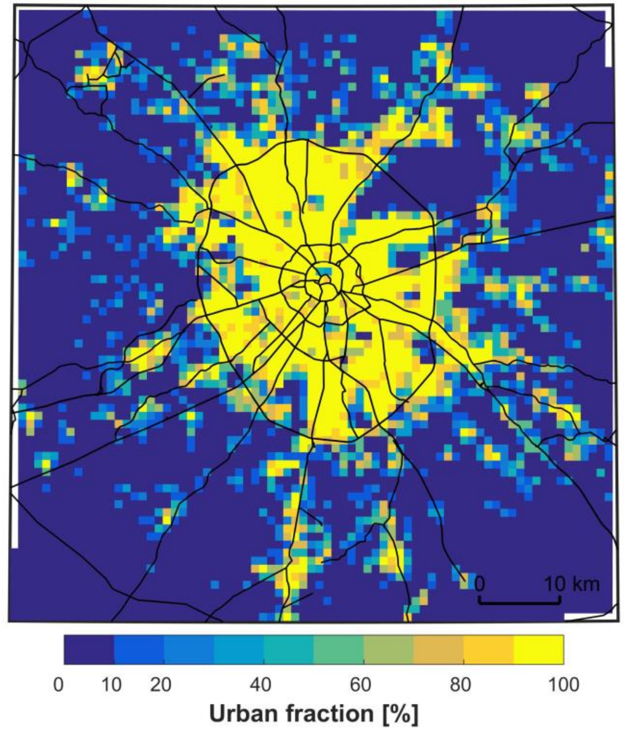
Urban canopy parameters

Urban (impervious) fraction

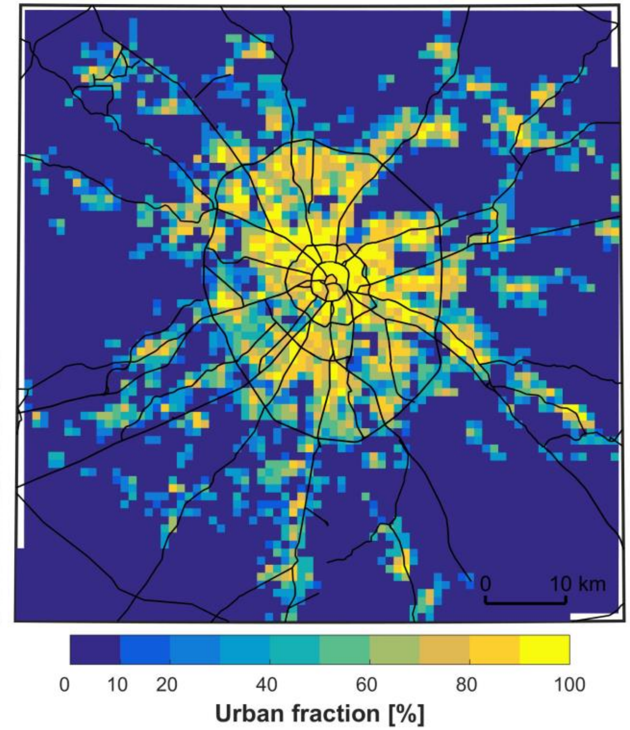
ISA/FR_PAVED field from EXTPAR



URBAN field from EXTPAR (based on Globcover LU classes)



Our empiric estimate based on OpenStreetMap data



$$F_{urb} = \min[1 - \boldsymbol{F_{nat}}, \max(\boldsymbol{F_{bld}} + \boldsymbol{F_{road}} + k_{ind} \cdot \boldsymbol{F_{ind}} + k_{res} \cdot \boldsymbol{F_{res}}; \boldsymbol{F_{bld}} + F_{can})]$$

Natural (“green”) fraction

Buildings

Roads

Industrial areas

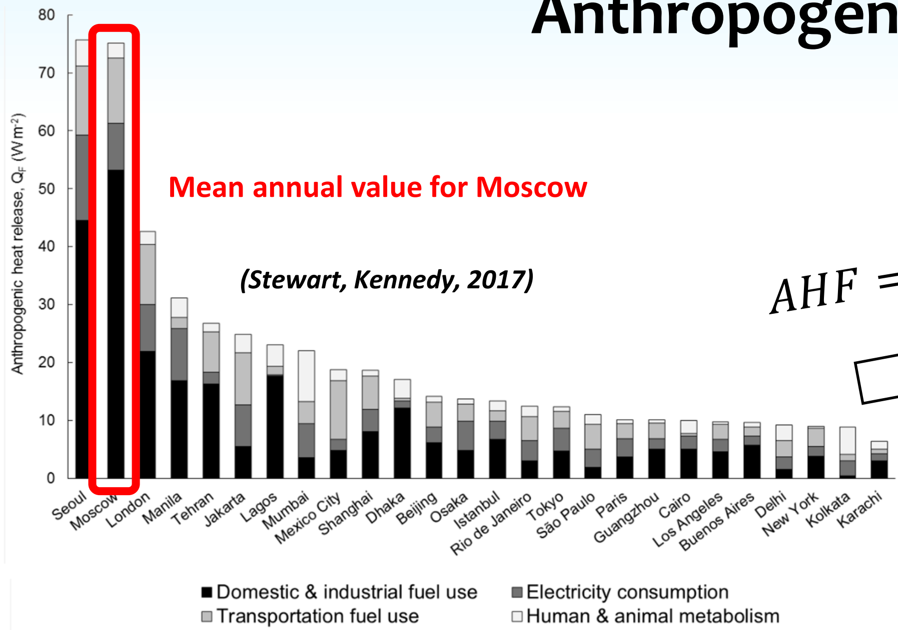
Residential areas (courtyards)

Street canyons

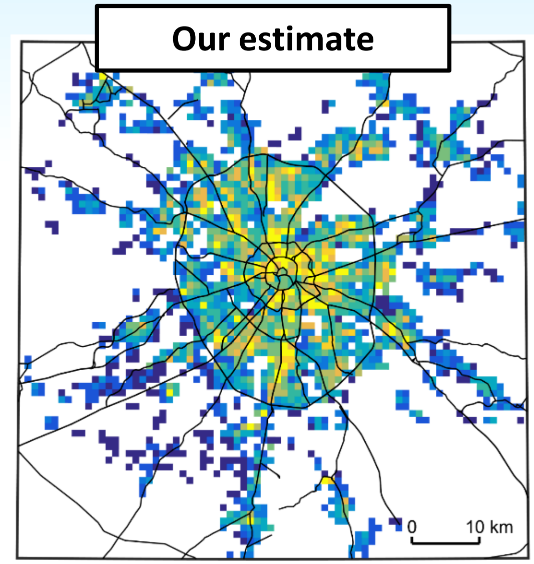
Physical sense of impervious/urban fration

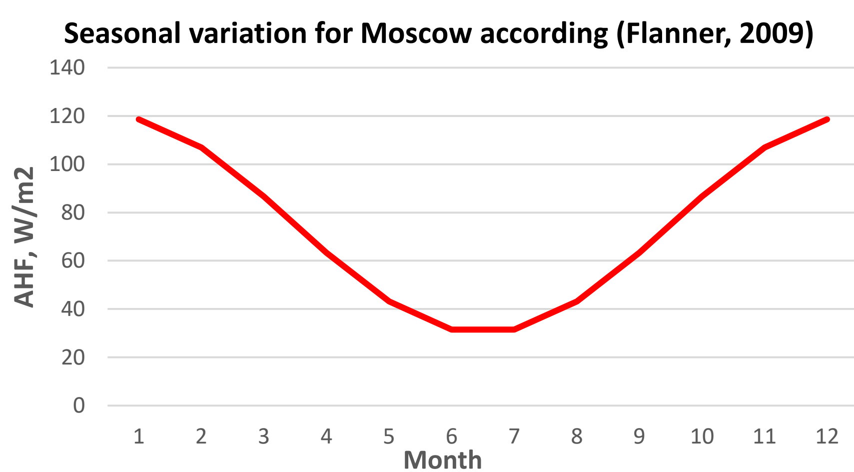
Urban canopy parameters

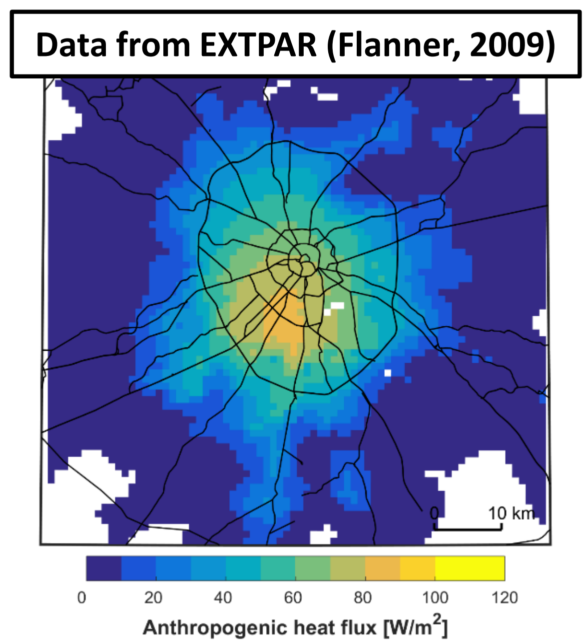
Anthropogenic heat flux



$$AHF = k \cdot F_{bld} \cdot H_{bld}$$

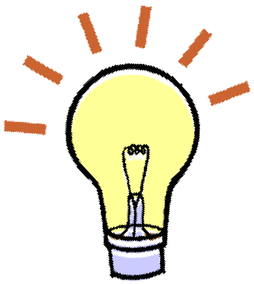






Highlights:

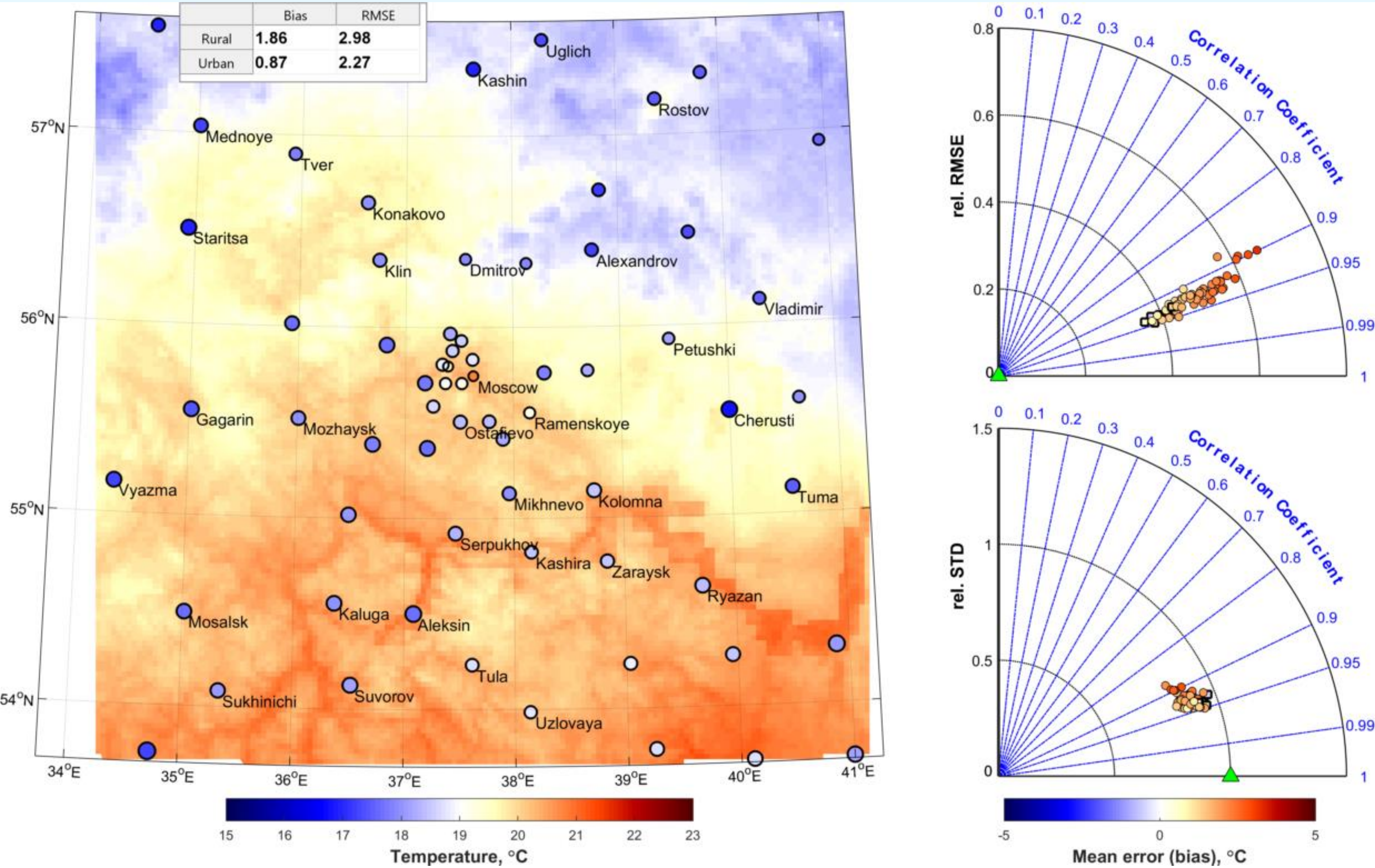
- Land-use and land-cover parameters derived from the global dataset could be surprisingly bad for a specific area
- Physical sense of the land-cover parameters is important



Model tuning and verification

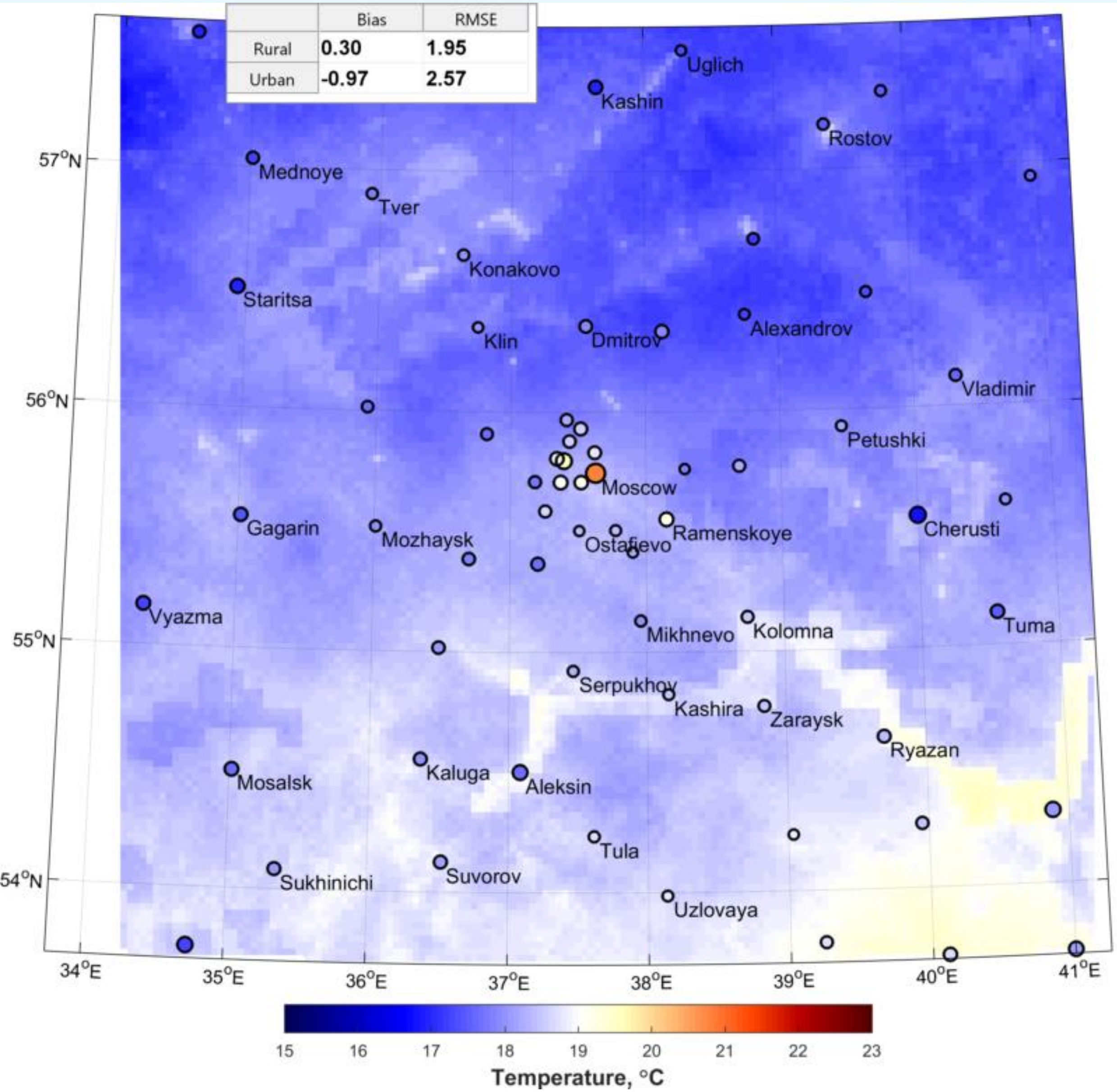
Model parameter	Default value	Modified value	Effect for summer and references	
lexpcor	off	on	T_2M_{day}↑, TOT_PREC↑	
itype_albedo	1	2	-	
itype_heatcond	1	2	T_2M_{day}↑, T_2M_{night}↓	
itype_aerosol	1	2 (Tegen et al, 1997)	T_2M↑	
itype_evsl	1	4 (Schulz, Vogel, 2016)	More realistic dynamics of T_2M, QV_2M	
itype_root	1	2	T_2M_{day}↑↑, T_2M_{night}↓↓	
itype_canopy	1	2 (Schulz, Vogel, 2017)	T_2M_{day}↑↑ T_2M_{night}↓↓↓	
pat_len	500	100	T_2M_{night}↓↓↓ Based on ideas from: (Buzzi et al., 2011; Cerenzia, 2014; Rossa et al.., 2012)	
tkhmin,tkmmin	0.4	0.1		
uc1	0.8	0.0626	CLCT↓, T_2M_{day}↑↑, T_2M_{night}↓↓	New setup from EVAL group (Ho-Hagemann et al.., 2017)
entr_sc	0.0003	0.0002	TOT_PREC↓	
soilhyd	1	1.62	**T_2M↓↓, QV_2M↑↑** (for heat waves firstly)	
fac_rootdp2	1	2.2	**T_2M↓↓, QV_2M↑↑** (for heat waves firstly)	
crsmin	150	200	**T_2M_{day}↑↑, QV_2M↓↓**	

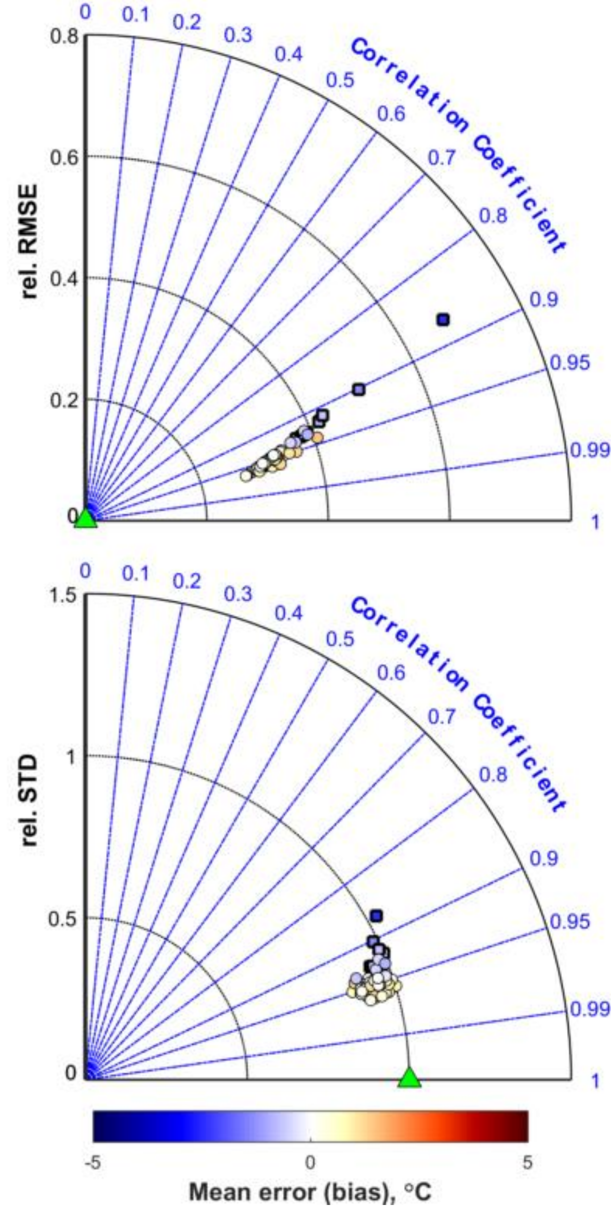
Model verification (rural T): standard options



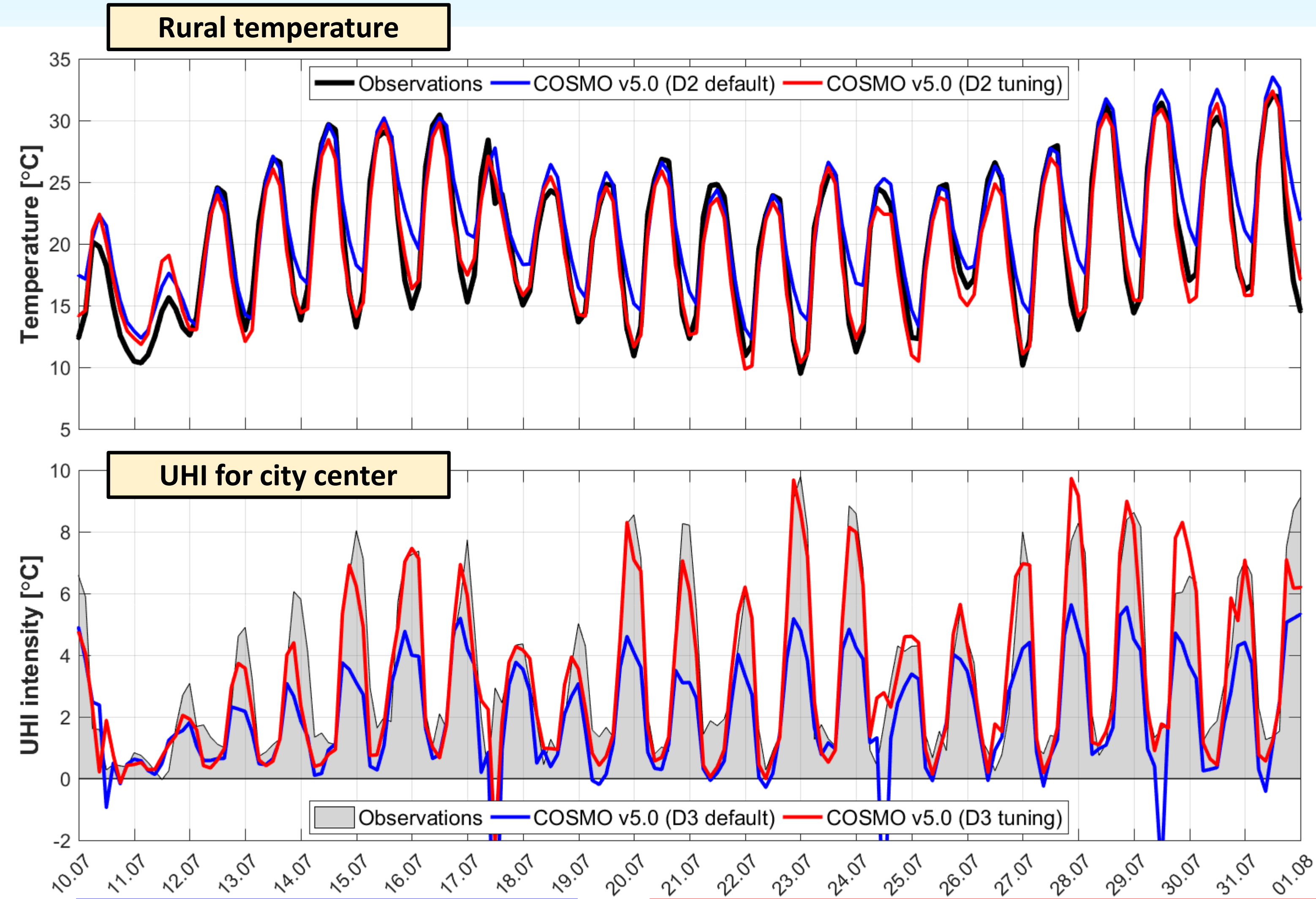
Model verification (rural T): tunned options

	Bias	RMSE
Rural	0.30	1.95
Urban	-0.97	2.57





Model verification (rural T & UHI intensity)



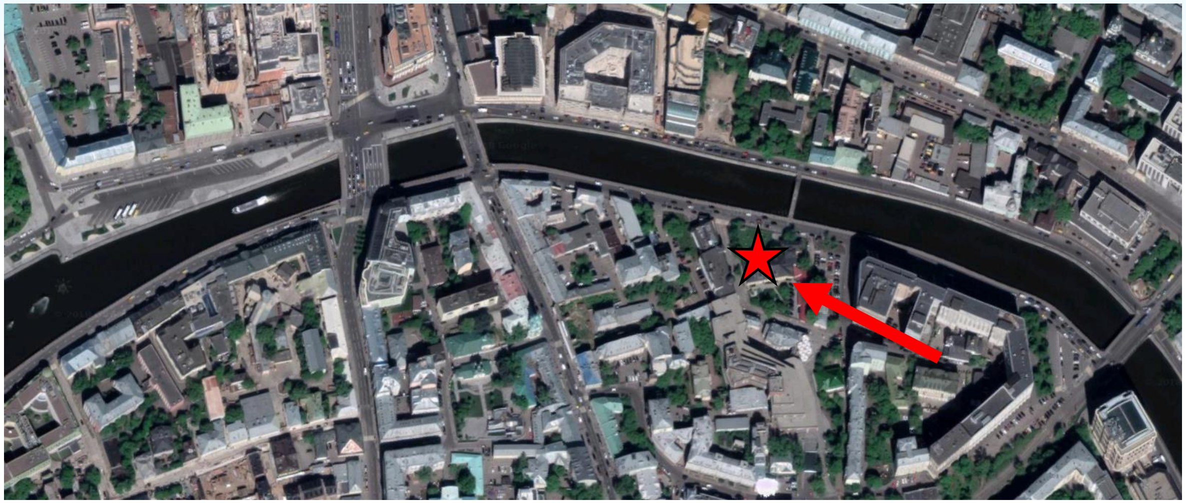
July 2014
(warm and dry)

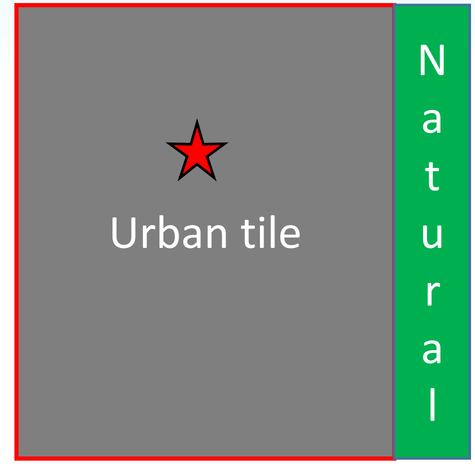
Default model settings
(tkhmin = tkmmin = 0.4; pat_len = 500; itype_canopy = 1)

Tunned settings
(tkhmin = tkmmin = 0.05; pat_len = 50; itype_canopy = 2; calamrur = 30; etc.)

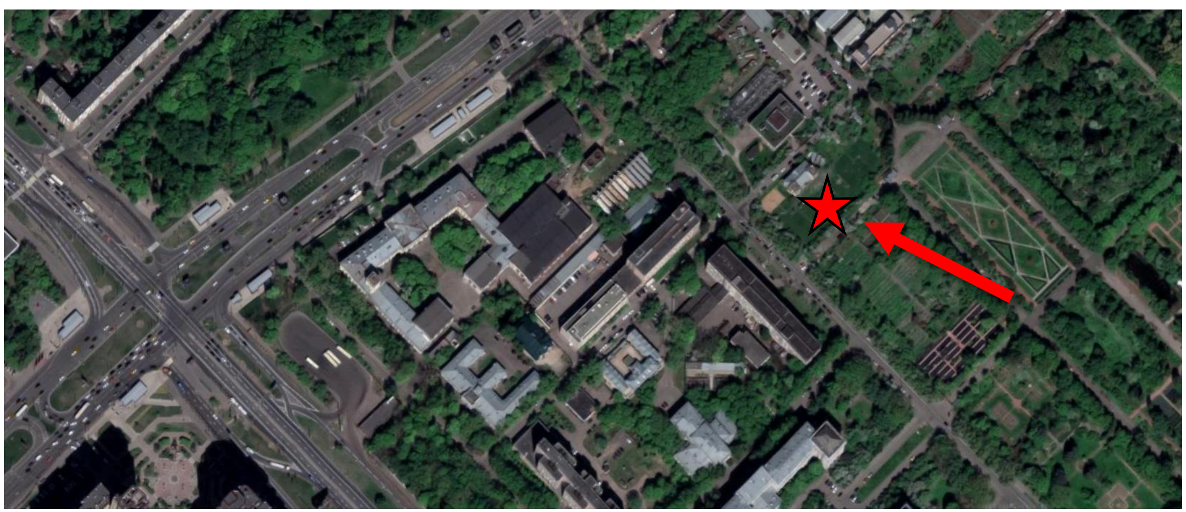
Model-to-observation comparison in the city

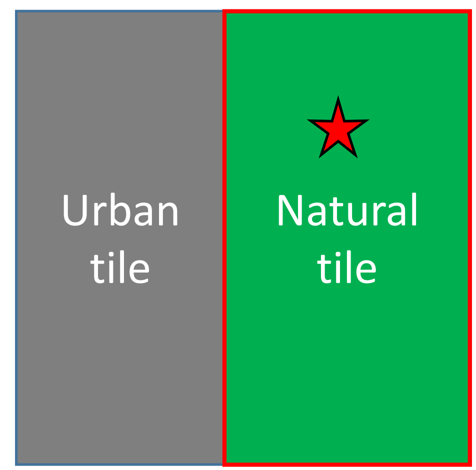
Station in a densely build environment





Station in an urban park (LSMU campus)





Why TERRA_URB?

The urban land use in the COSMO-CLM model: a comparison of three parameterizations for Berlin

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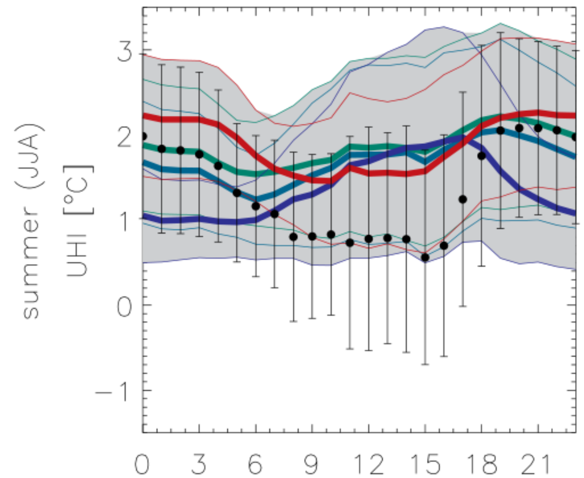
(Manuscript received February 25, 2014; in revised form August 6, 2014; accepted February 25, 2015)

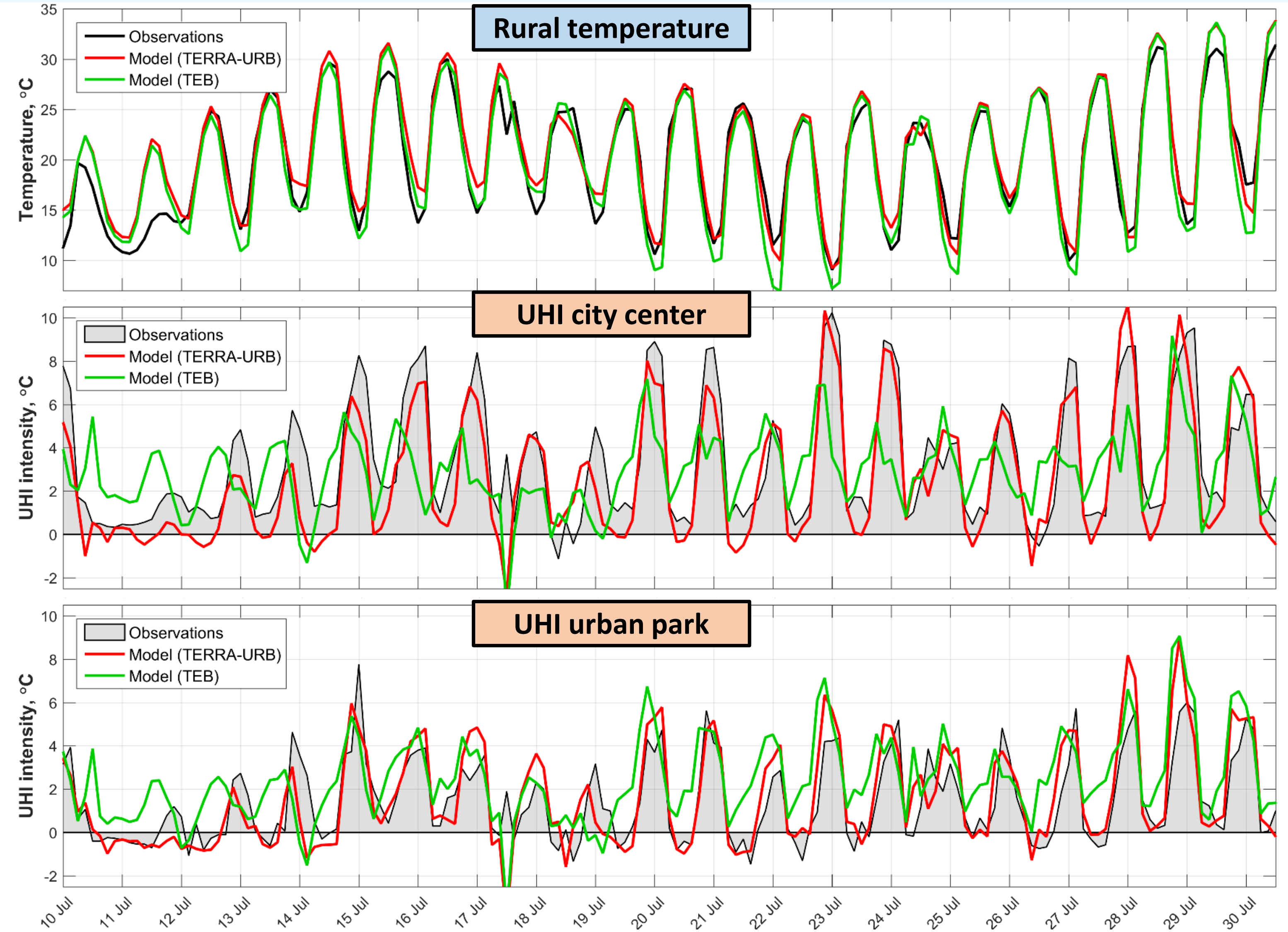
Abstract

The regional non-hydrostatic climate model COSMO-CLM is increasingly being used on fine spatial scales of 1–5 km. Such applications require a detailed differentiation between the parameterization for natural and urban land uses. Since 2010, three parameterizations for urban land use have been incorporated into COSMO-CLM. These parameterizations vary in their complexity, required city parameters and their computational cost. We perform model simulations with the COSMO-CLM coupled to these three parameterizations for urban land in the same model domain of Berlin on a 1-km grid and compare results with available temperature observations. While all models capture the urban heat island, they differ in spatial detail, magnitude and the diurnal variation.



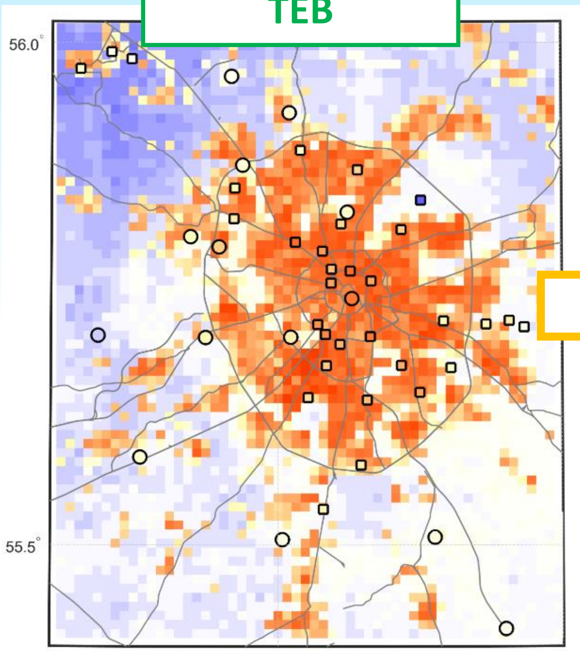
While all models capture the urban heat island, they differ in spatial detail, magnitude and the diurnal variation.

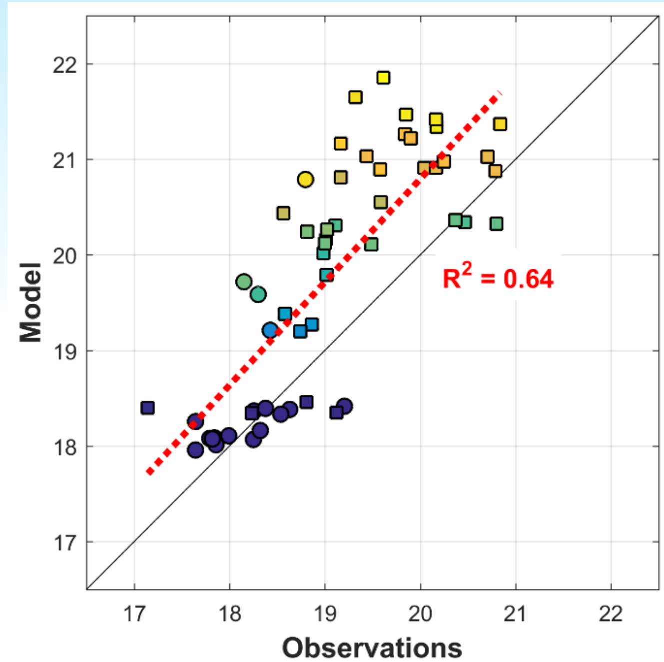
What urban canopy scheme is better?



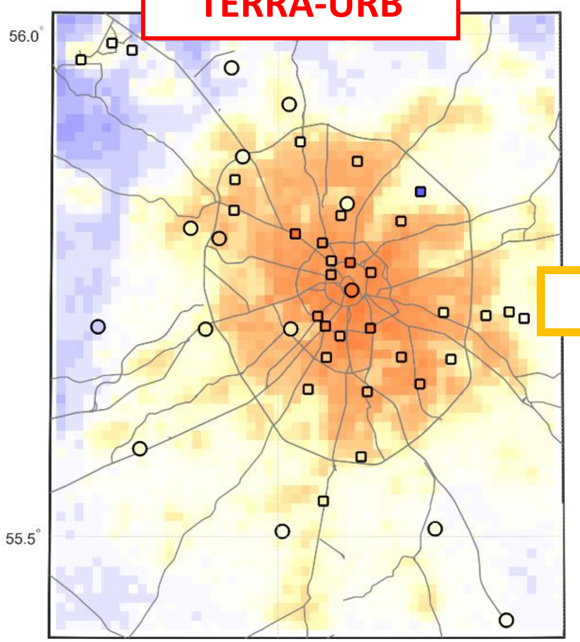
Comparison for model experiments with reduced turbulent mixing for stable conditions

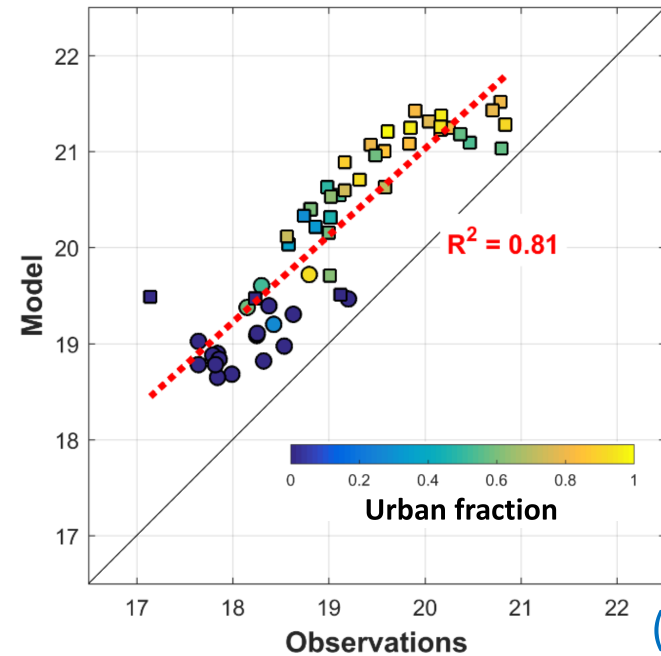
TEB

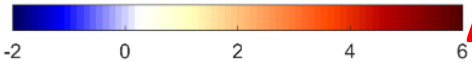




TERRA-URB







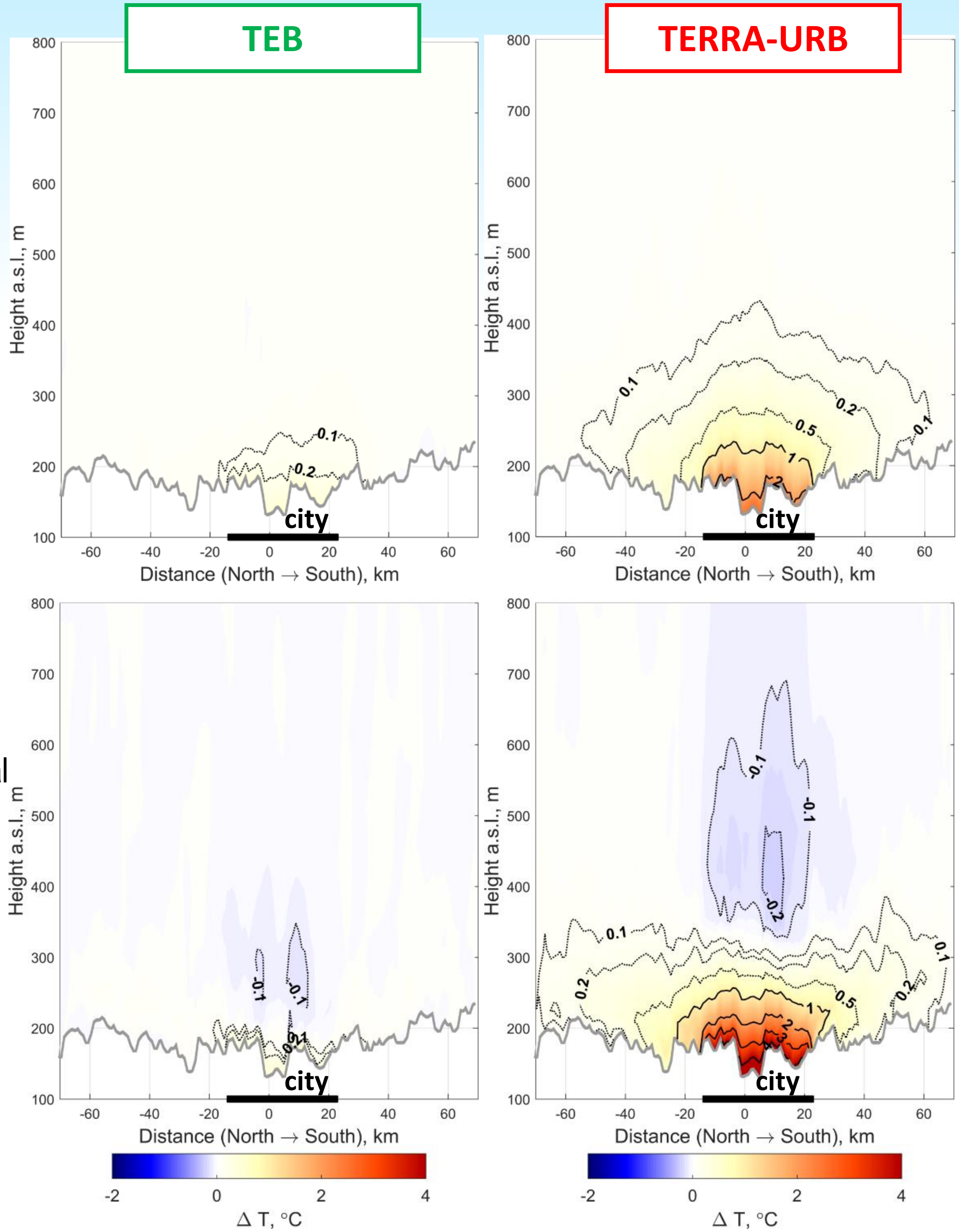
$\Delta T = T - T_{ref.\ rural\ mean}$

Maps of the UHI intensity and correlation plots for mean temperature over summer 2014 according to observations and modelling results

(Varentsov et al., 2017)

Day mean temperature response

Mean nocturnal (0 UTC) temperature response

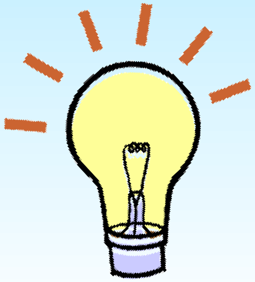


Vertical cross-sections, built for temperature response to switching on the urban scheme (for mean summer T)

$\Delta T = T_{URB} - T_{noURB}$

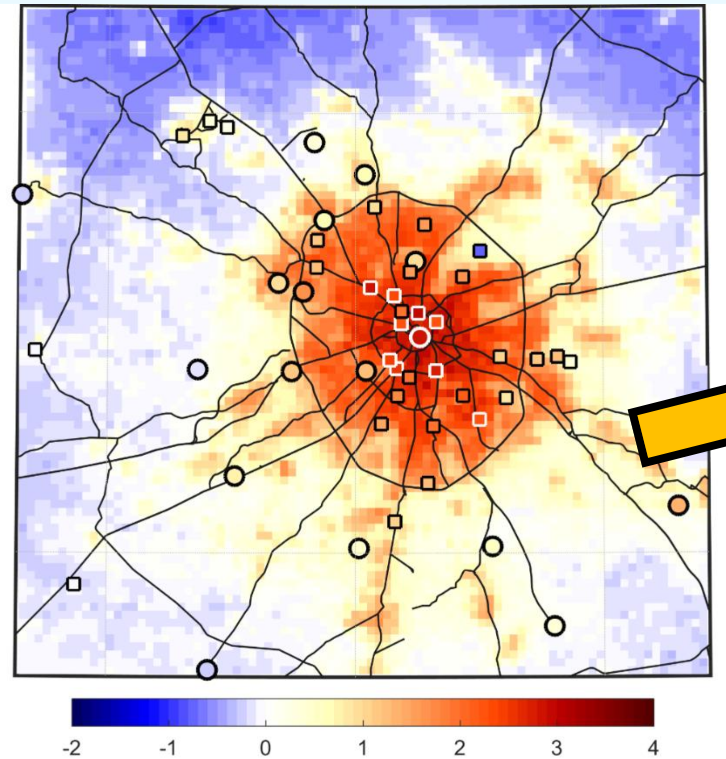
(Varentsov et al., 2017)

Highlights:

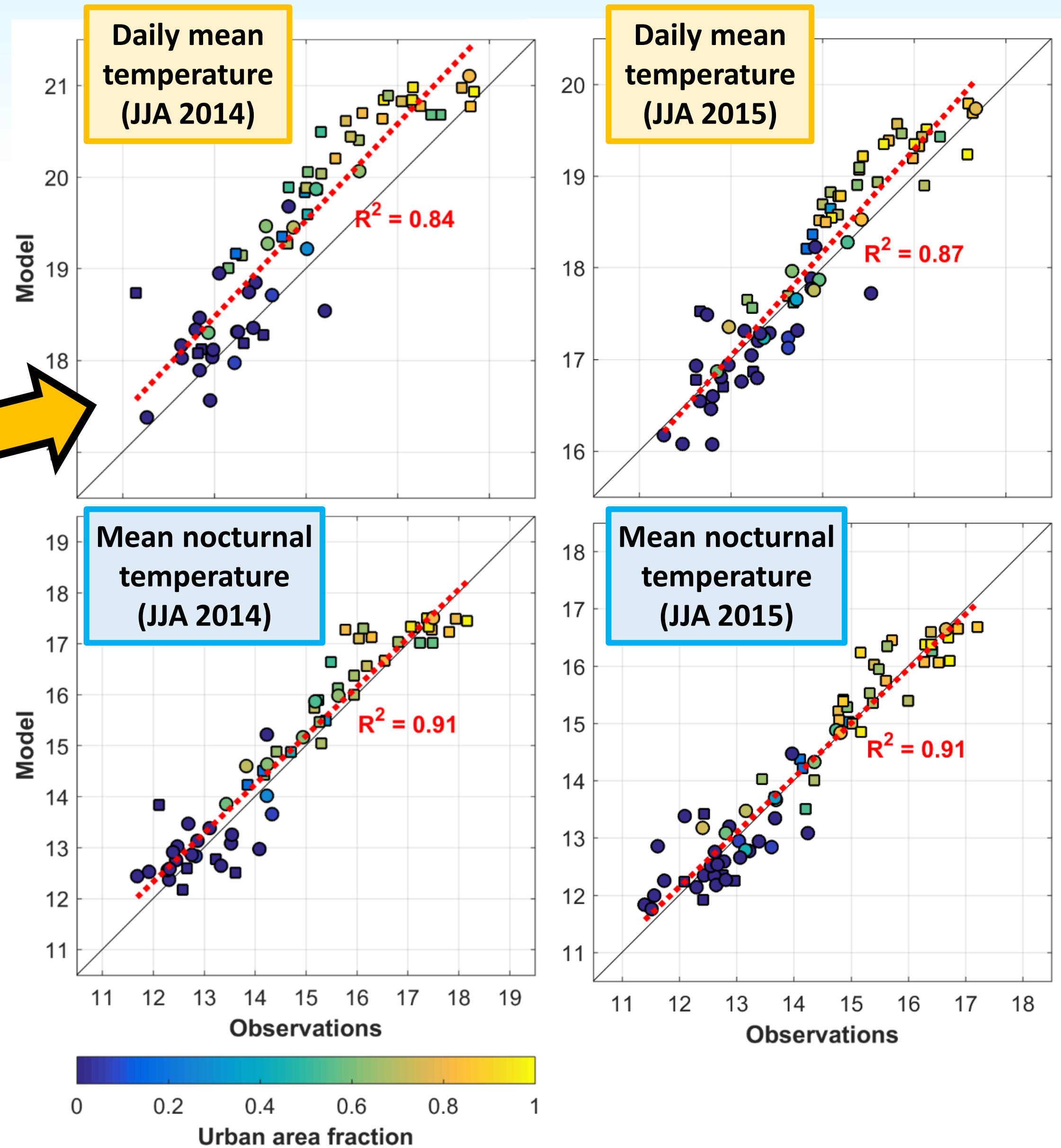


- Tuning of the *general model setting* (not related directly to the urban physics) could be important for reproducing the urban-rural contrasts (e.g. UHI intensity).
- Detailed model-to-observation comparison is essential for good tuning
- In case of existence of large and systematic biases, taking urban physics into account may not improve the formal verification scores for urban areas
- Simple comparisons between the time series and error statistics could be insufficient for detecting inadequate model behavior

Verification for the final configuration



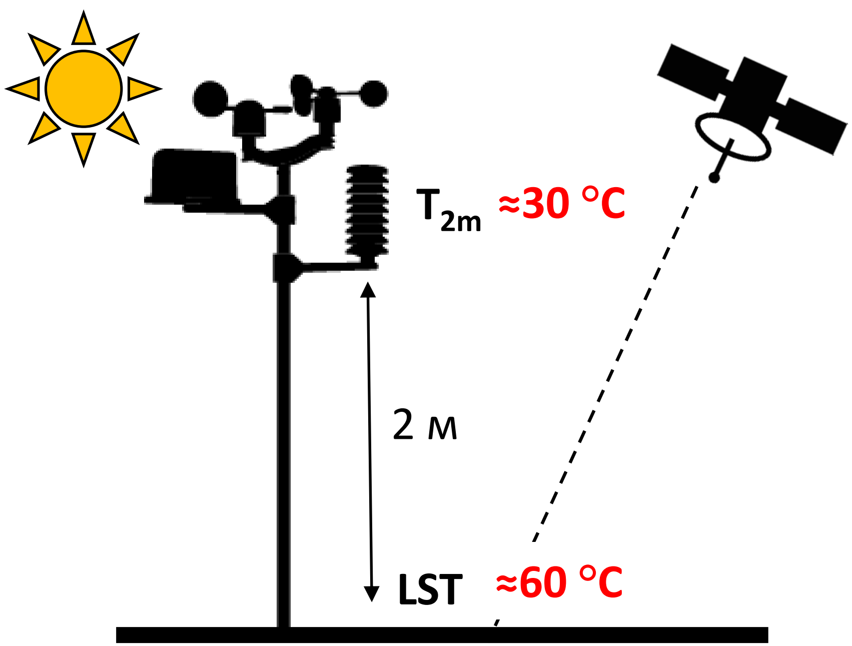
Mean temperature anomaly for summer 2014 (deviation from mean rural value) modelling (shading) and observations (colored circles)



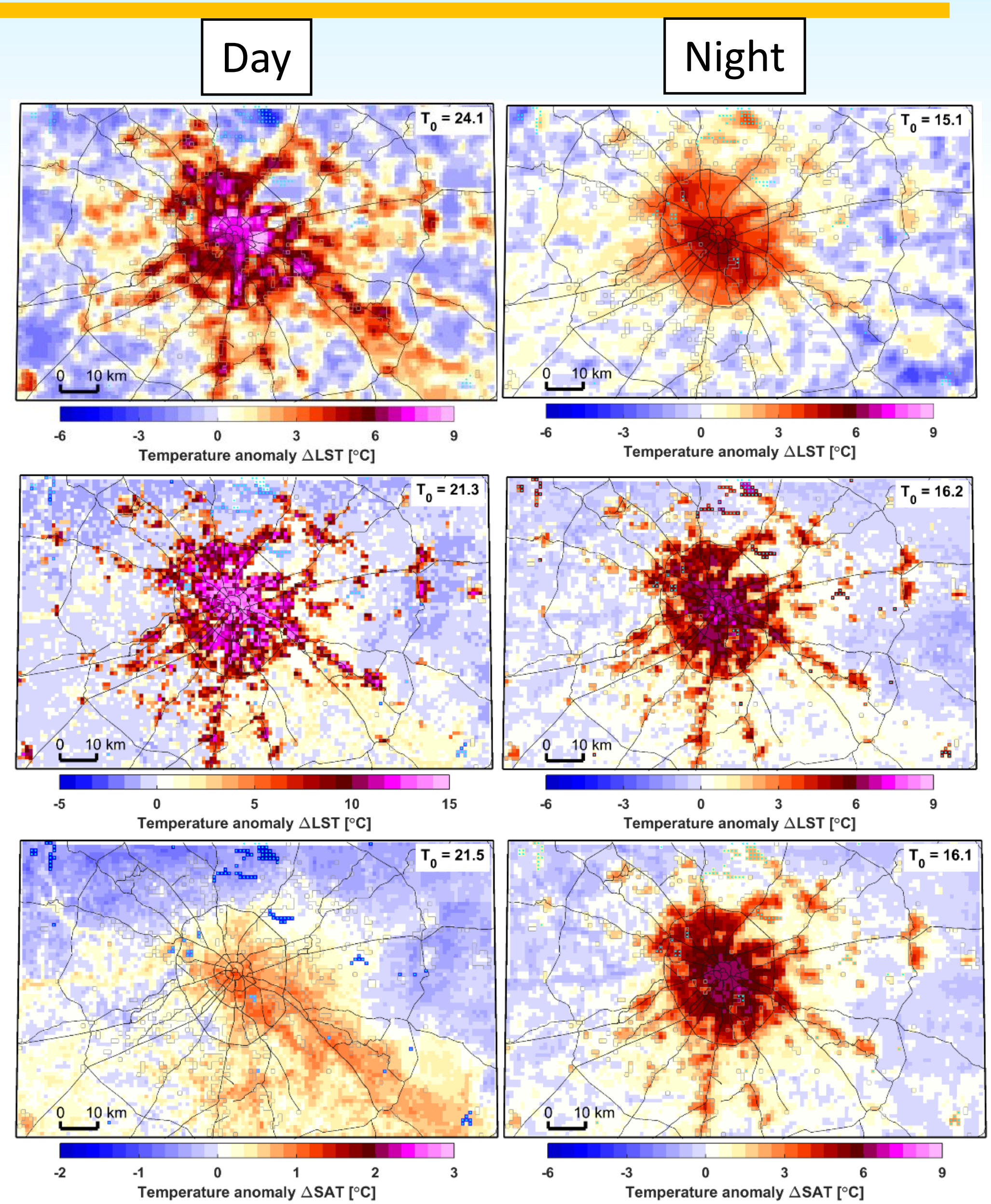
Alternative data for model verification

Remote sensing data (MODIS)

- MODIS provides high-resolution (1km) LST data 4 times per day
- **Warning:** LST is not equal to modelled/observed air temperature (T_{2m}), and surface UHI is not equal to canopy-layer UHI
- Model could be good in simulating canopy-layer UHI and not so good in simulation surface UHI (like in our case)



(Varentsov et al., 2019)

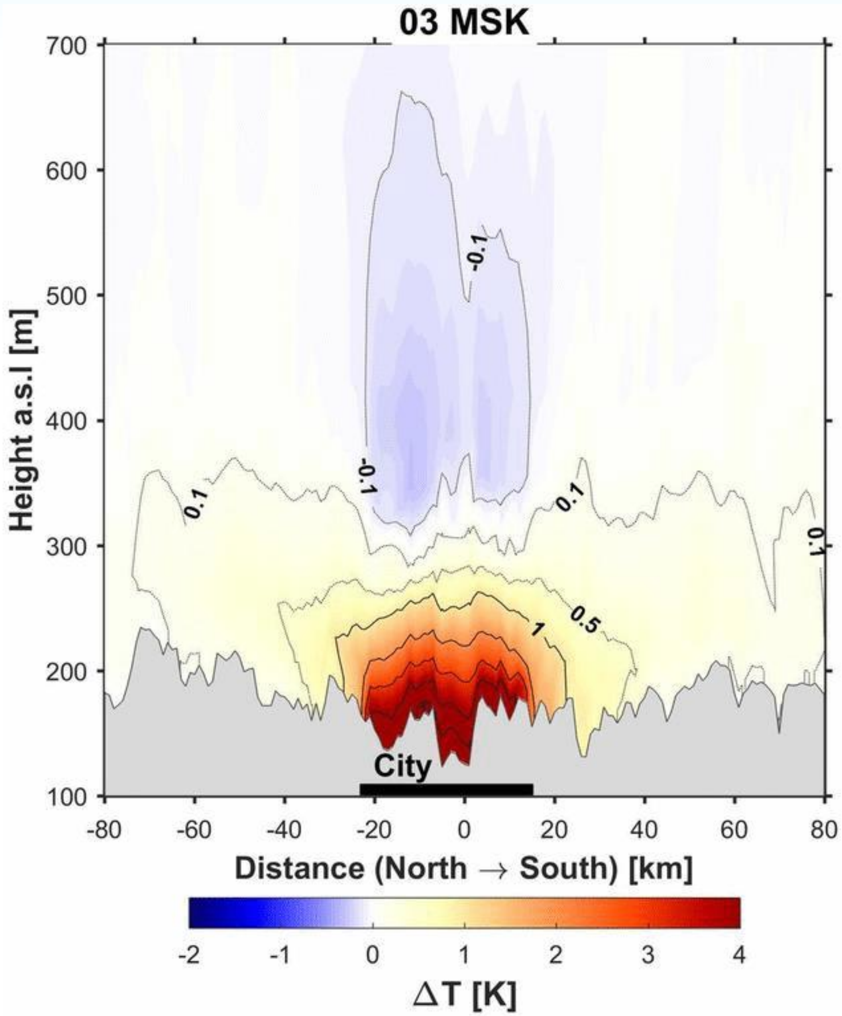


Model application #1:

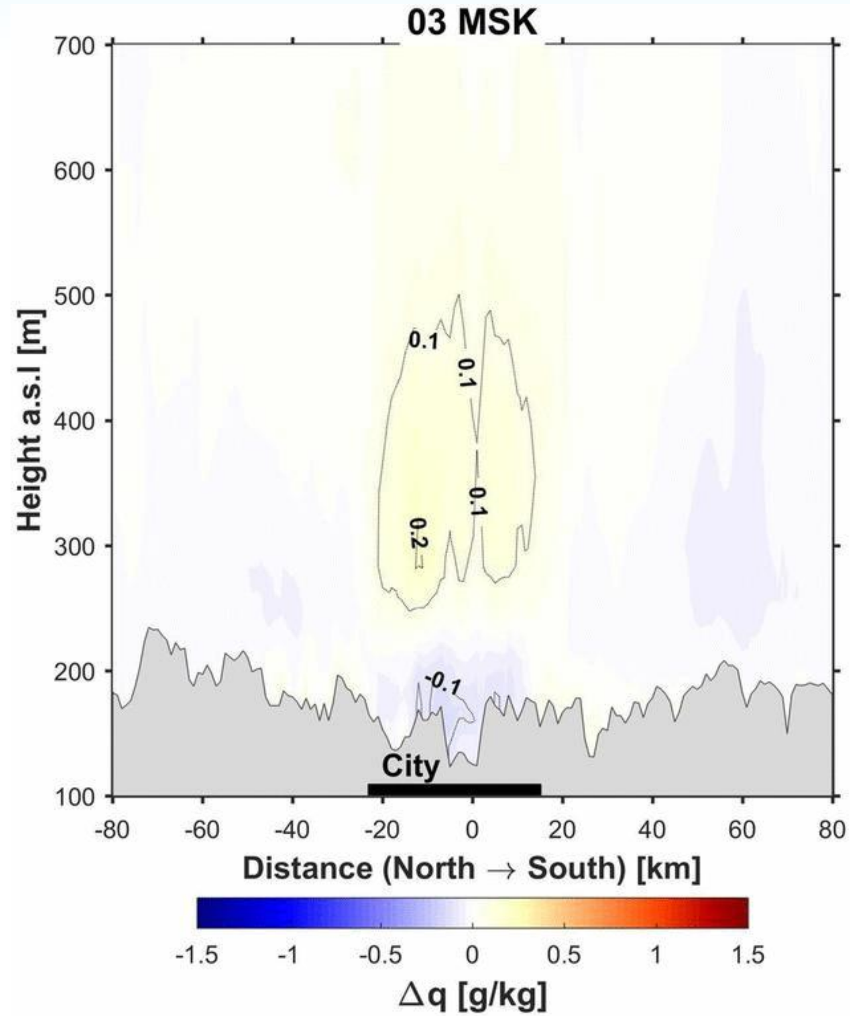
Investigation of the urban-induced mesoclimatic features

Vertical structure of the UHI and UDI

Temperature anomaly ($\Delta T = T_{urb} - T_{nourb}$)

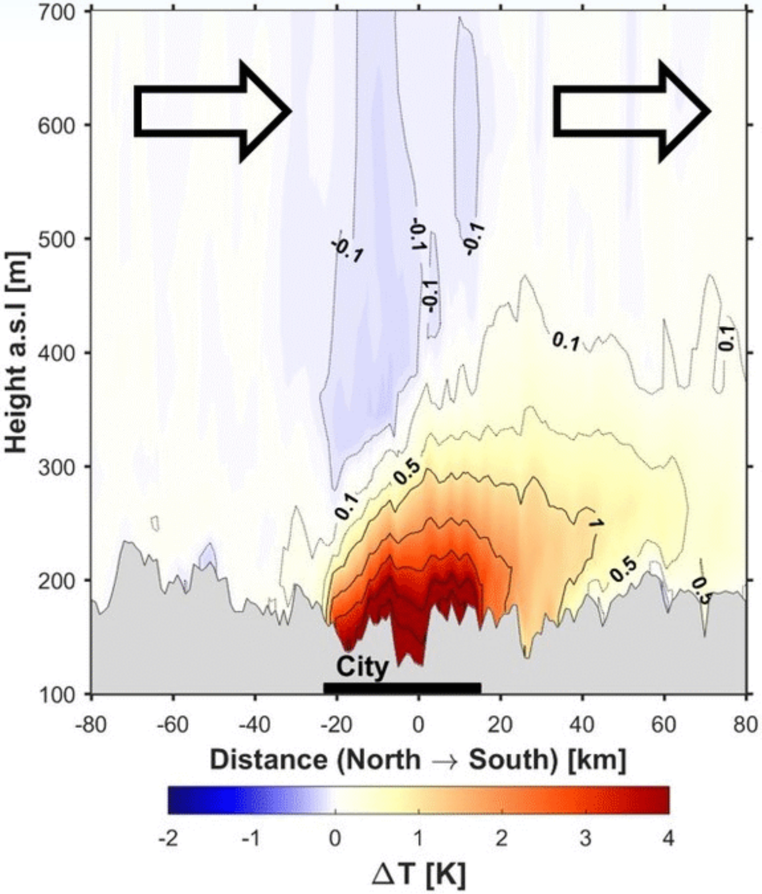


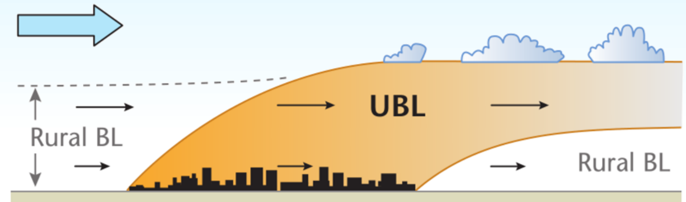
Specific humidity anomaly



(Varentsov et al., 2018)

Urban heat plumes

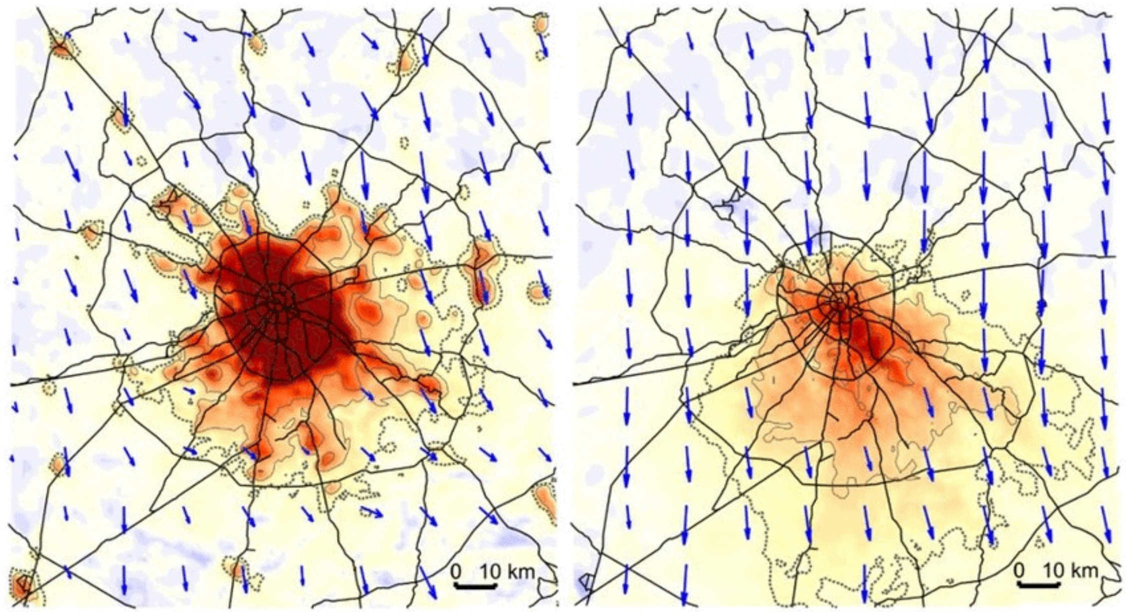




(Oke et al., 2017)

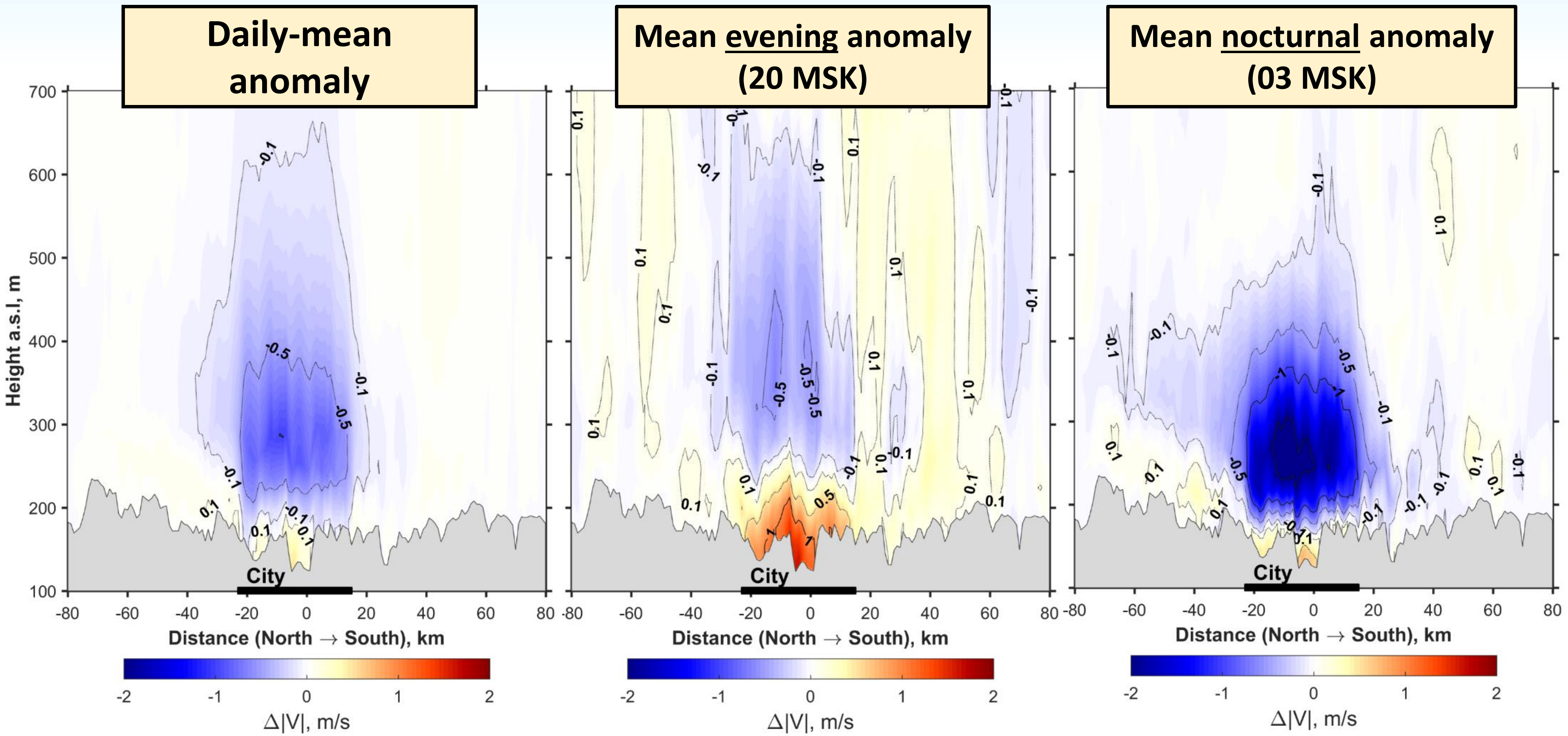
I model level (10 m)

III model level (71 m)



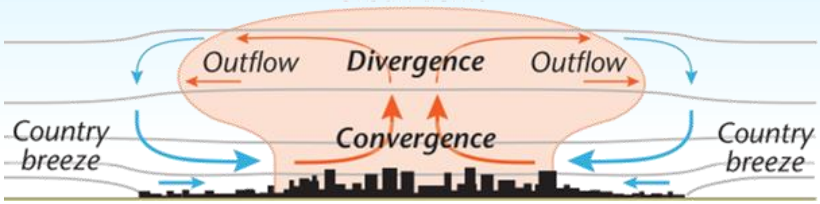
Vertical cross-section and maps for urban-induced temperature anomaly ($\Delta T = T_{URB} - T_{noURB}$) averaged over summer 2014, **for nocturnal hours** (3-4 MSK) with prevailing **northern/southern wind**

Urban effect on the wind speed

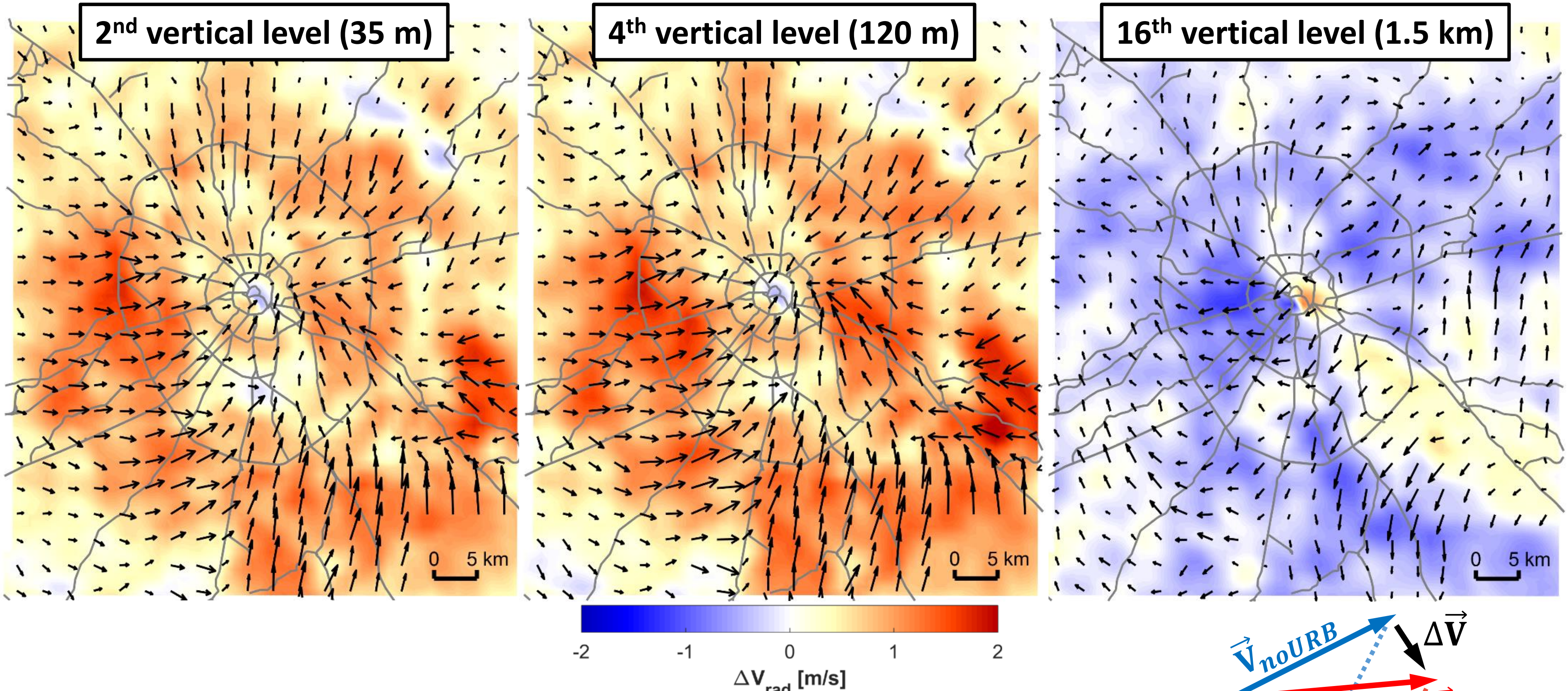


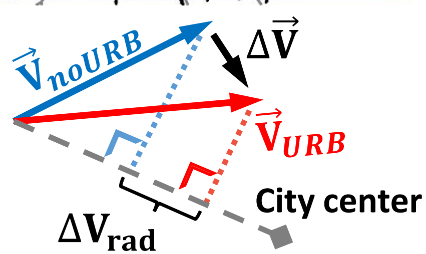
Vertical cross-sections of the urban-induced wind speed anomaly ($\boldsymbol{\Delta|V| = |V|_{URB} - |V|_{noURB}}$) averaged over summer 2014 (for selection of days with UHI_{max} > 4 °C, aprox. 78% of whole period)

Urban breeze effect (evening)



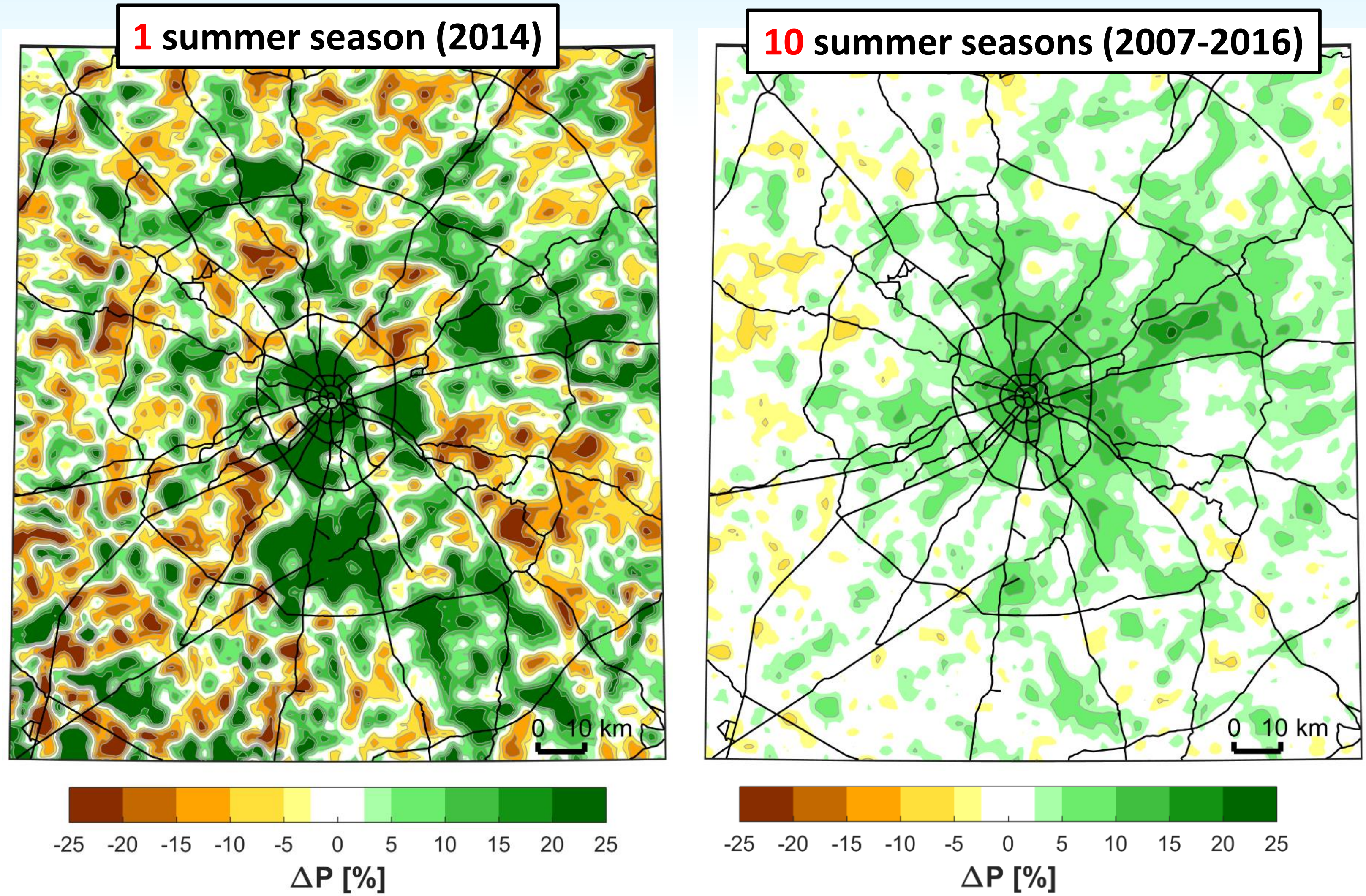
(Oke et al., 2017)





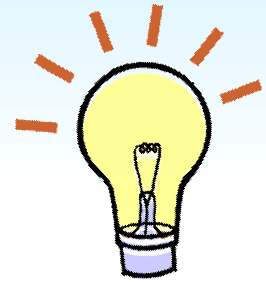
Urban-induced anomalies of the wind ($\Delta\vec{\mathbf{V}}$, arrows) and its radial component ($\Delta\mathbf{V}_{\mathbf{rad}}$) averaged over summer 2014, **for evening hours** (18-19 MSK) **with low wind speed**

Urban effects on precipitation



Urban-induced anomaly of summer precipitation amount

$$\Delta P = 100 \cdot (P_{URB} - P_{noURB}) / P_{noURB}$$



Highlights:

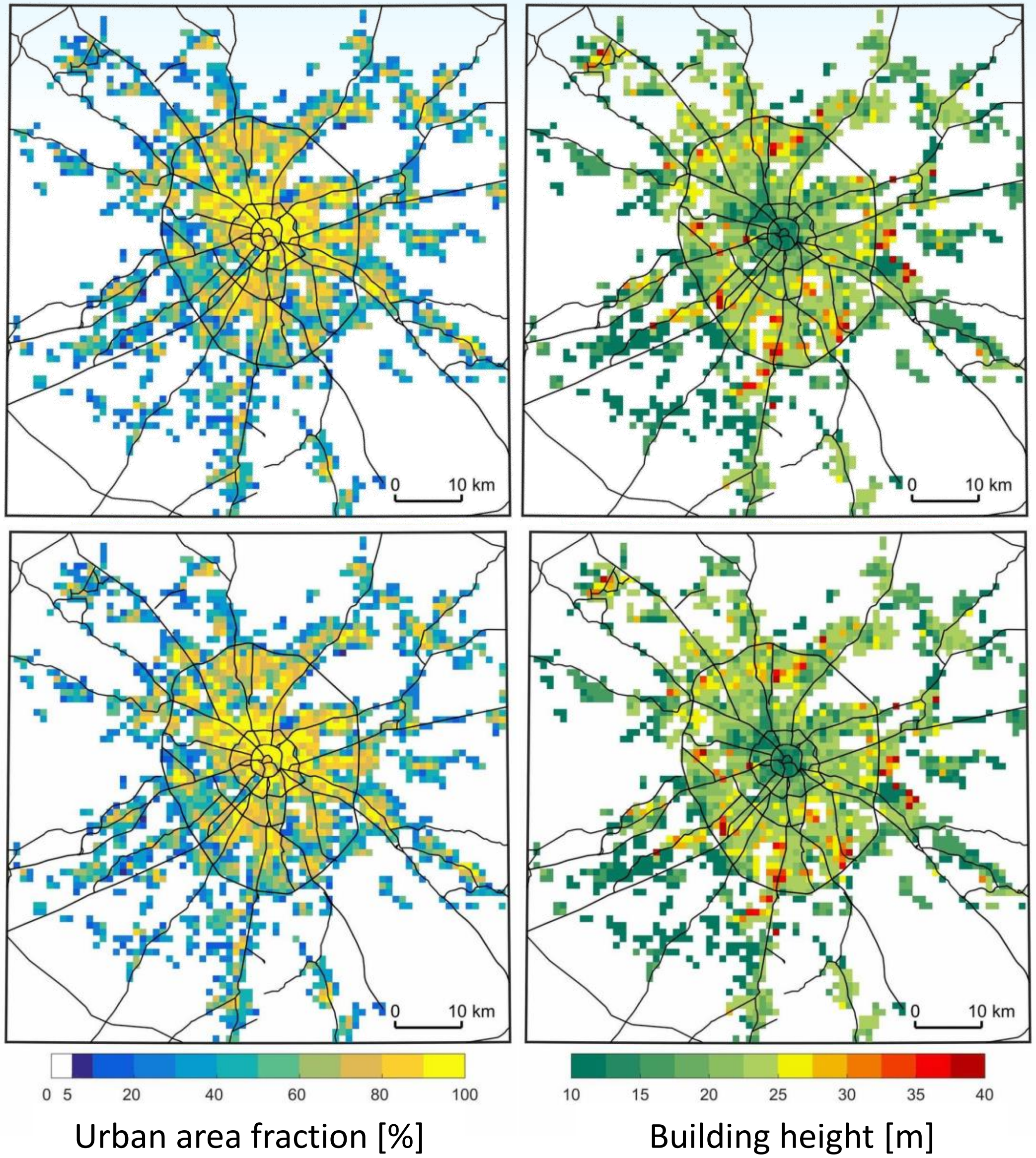
- Separation between day-time and night-time is essential in the urban climate research
- Stochastic and synoptic effects could distort the modelling results (long-term runs could solve this issue).

Model application #2: urbanization scenarios

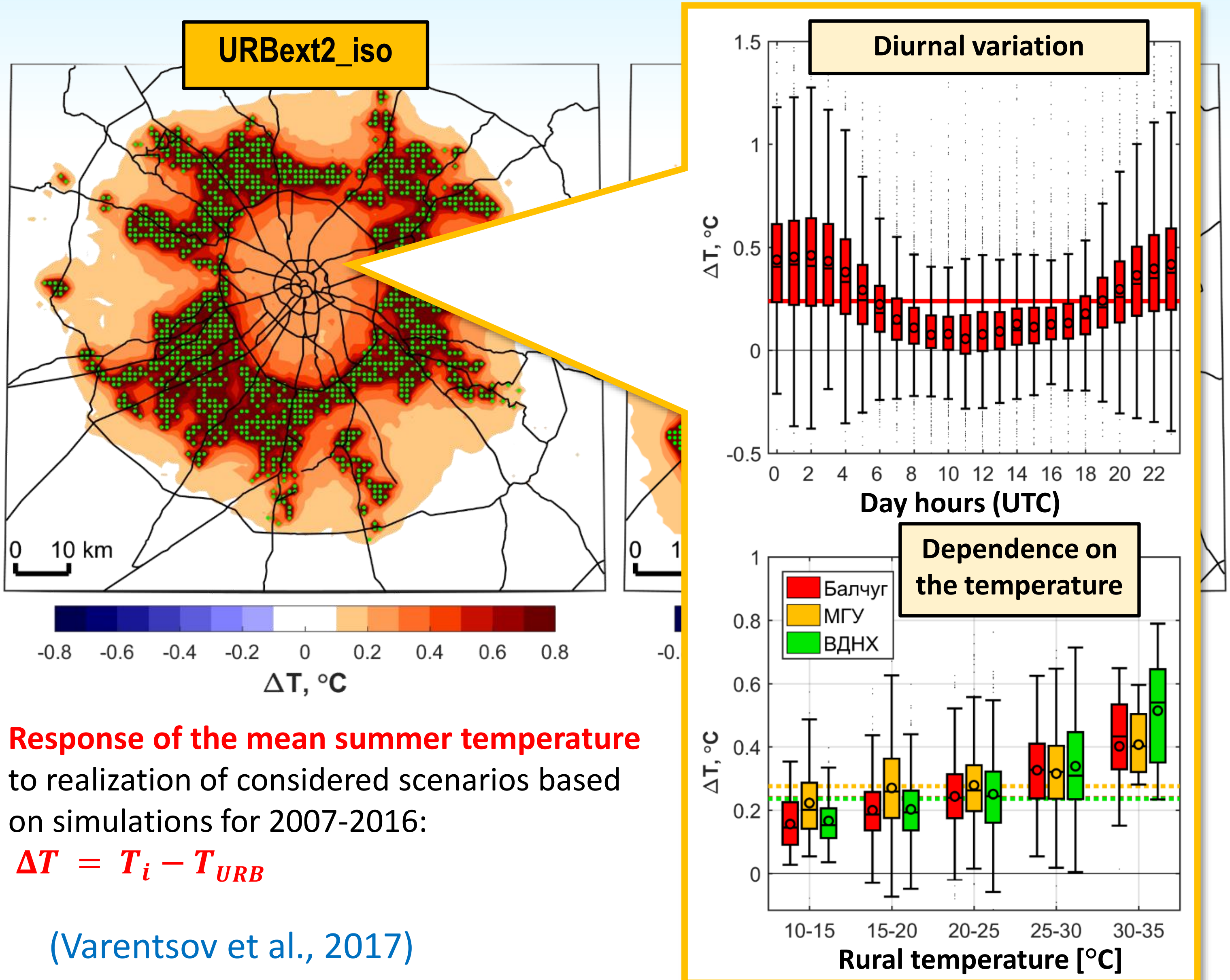
Scenarios of extensive development

Quasi-isotropic twofold urban expansion (URBext2_iso)

Twofold urban expansion in “New Moscow” (URBext2_NM)



Summer temperature response

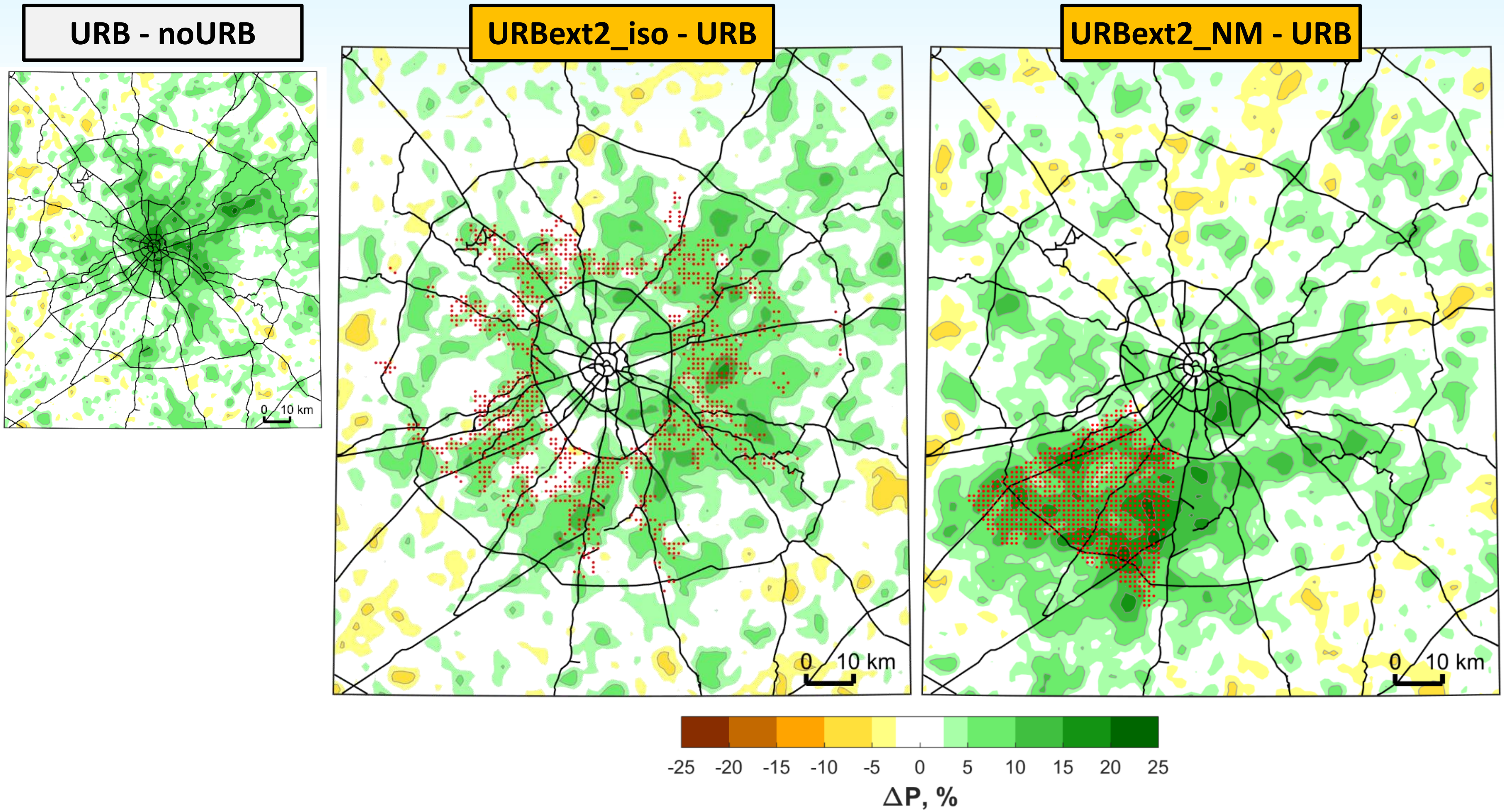


Response of the mean summer temperature to realization of considered scenarios based on simulations for 2007-2016:

$$\Delta T = T_i - T_{URB}$$

(Varentsov et al., 2017)

Summer precipitation response



Response of the summer precipitation amount to realization of considered scenarios based on simulations for 2007-2016 relative to modern city conditions (URB run):

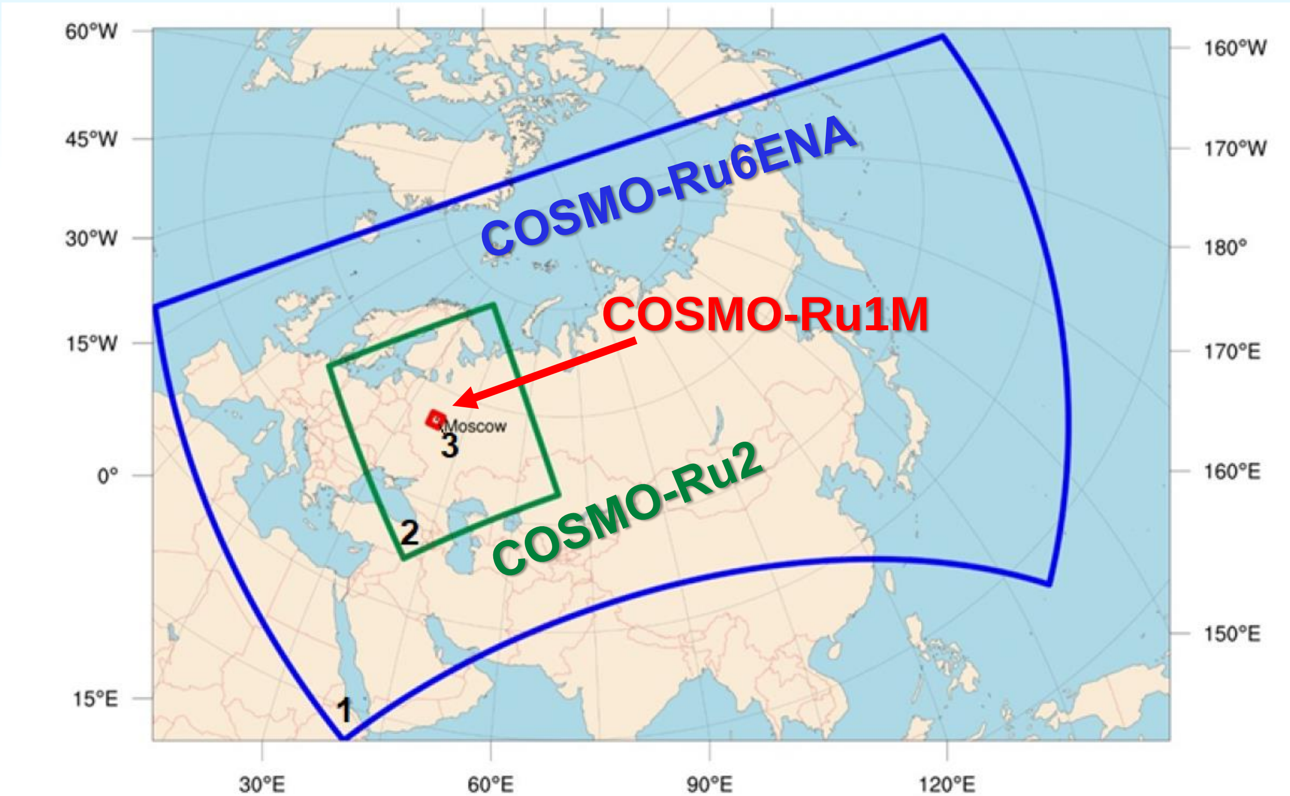
$$\Delta P \; = \; (P_i - P_{URB})/P_{URB}) \cdot 100\%$$

Application #3: NWP for urban areas

Motivation: Moscow storm at May 29th 2017

- Strong wind (15 - 30 m/s)
- 18 persons were killed, about 170 people were injured
- 27 000 trees were broken, some of them have damaged cars
- Some small buildings were destroyed
- Triggered “Safe City” Moscow government Program (started at 23 Oct 2018)

Application #3: NWP for urban areas



ICON IC&BC

↓

COSMO-Ru6ENA

↓

COSMO-Ru2

↓

COSMO-Ru1M

The operational domains of COSMO-Ru NWP system forecasts on Cray XC40-LC supercomputer at the Hydrometcenter of Russia

NWP for COSMO-RU1M domain, based on 5.0_clm9 model version with TERRA_URB included, is running operationally since Dec 2018 (Rivin et al., 2019)

Plan for 2020: **operational NWP runs with 500-m grid step and the recent 5.05urb model version**

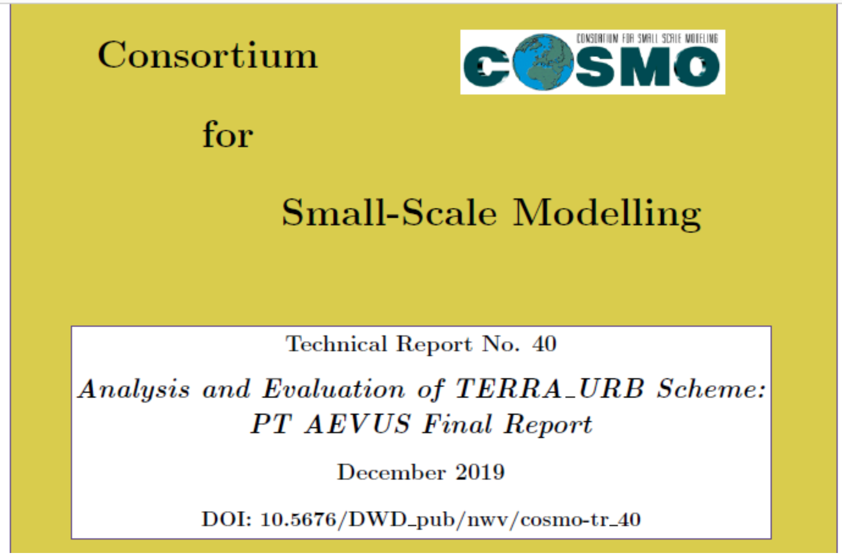
Recent developments

Status of TERRA_URB development

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 versions (5.04, 5.05).


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

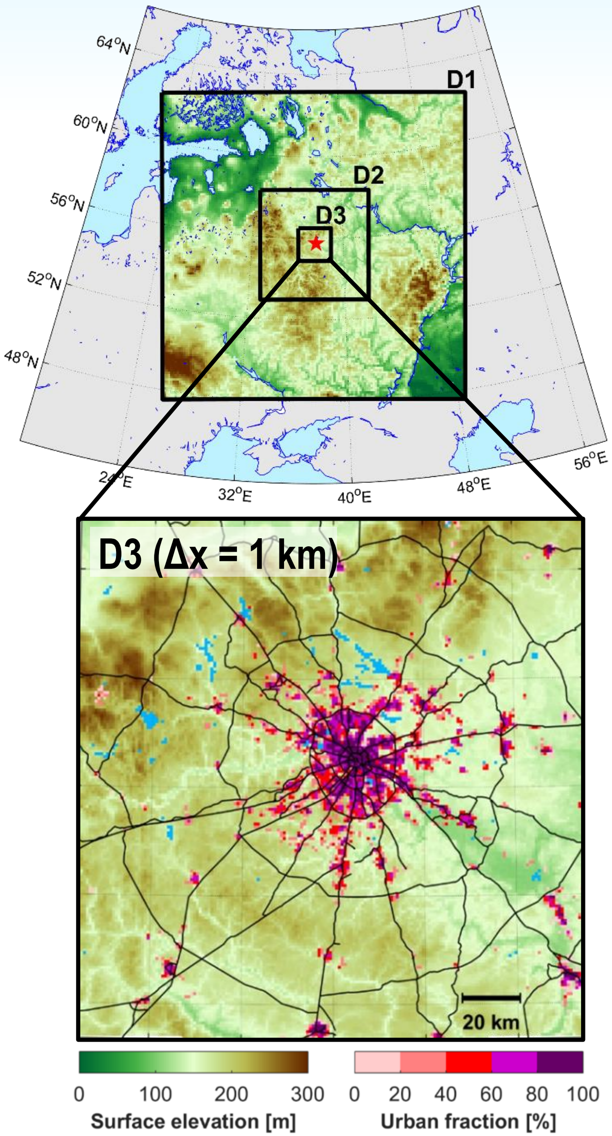
2019: start of AEVUS 2 with following aims:

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

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

Recent modelling experience

- ❑ Comparison between two model versions:
  - COSMO 5.0_clm9 TERRA_URB2.2: the original model version, developed by Wouters et al., that was used in previous modelling studies for Moscow
  - COSMO_5.05urb: implementation of the TERRA_URB scheme to the recent model version, developed within the framework of AEVUS PT. **The key feature - new ICON physics.**
- ❑ Same forcing data, domains and model setup as before, but shorter case-focused simulations for 10-15 days.
- ❑ Main focus on the air temperature and UHI intensity for now



Namelist settings

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
DYNCTL			
hd_corr_(t, u, p…)	defaults	0.25 for all	defaults

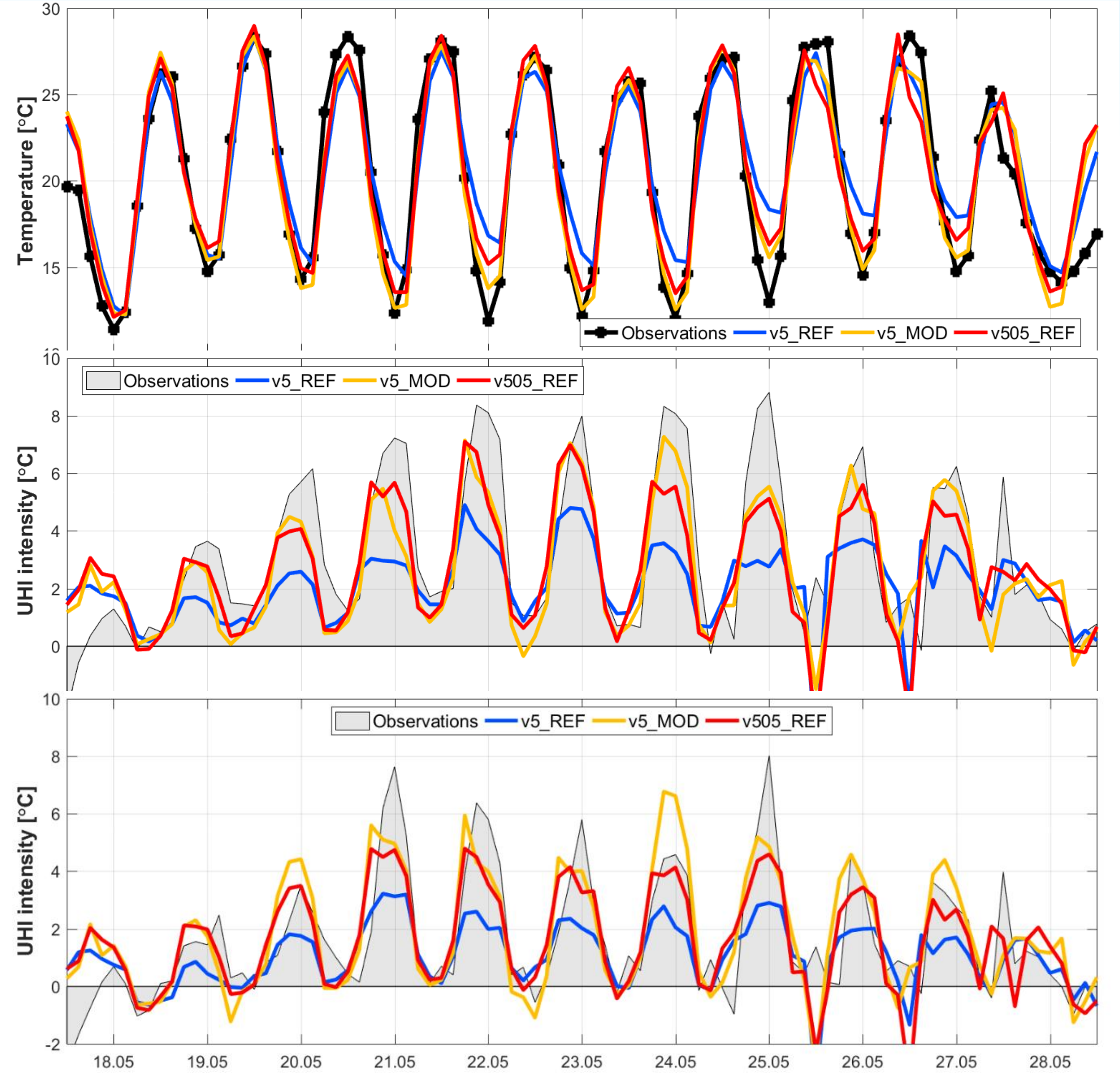
/PHYCTL/	OLD	NEW
itype_evsl	2	4
itpye_heatcond	1	3
itype_root	1	2

***Defaults for "new" physics**

(Different Configurations for the COSMO-ICON Physics, 2018)

Skin-layer temperature scheme for 5.05_urb was not completely debugged when simulations were performed

Model verification (case 1: May 2014)



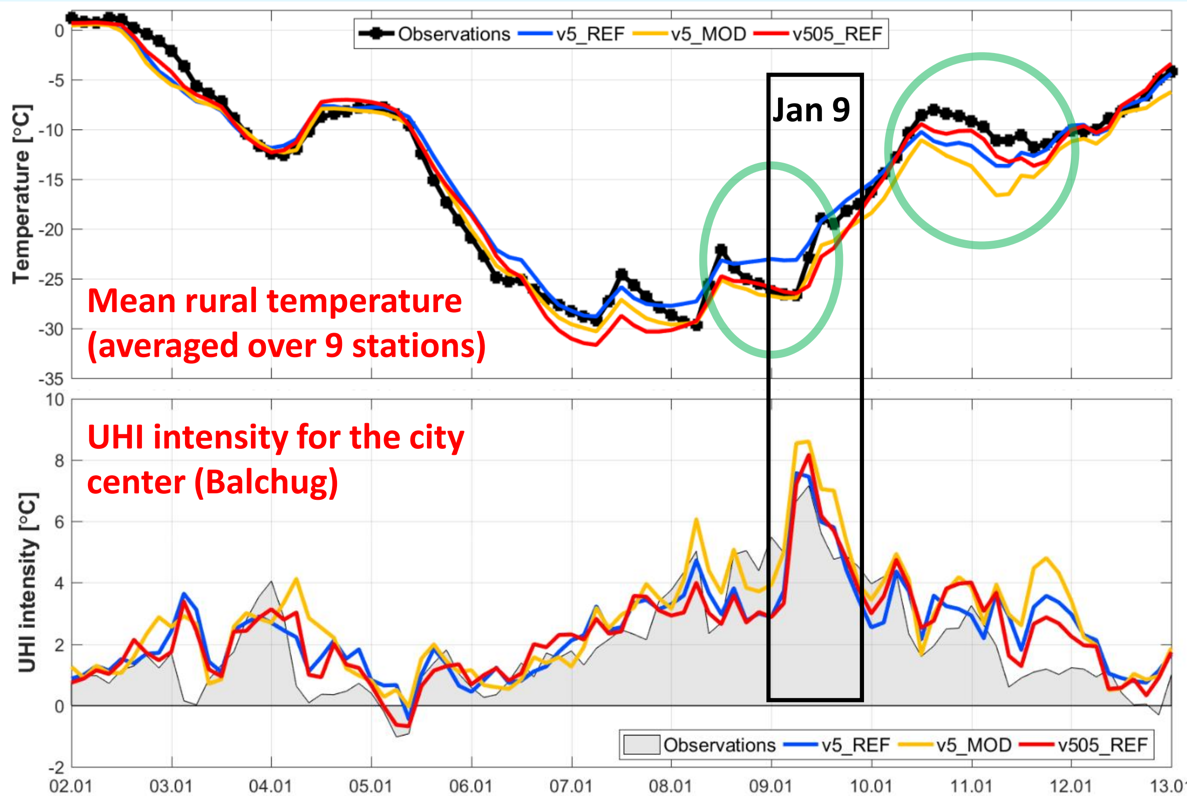
Mean rural temperature (averaged over 9 stations)

UHI intensity for the city center (Balchug)

UHI intensity for the urban park (MSU)

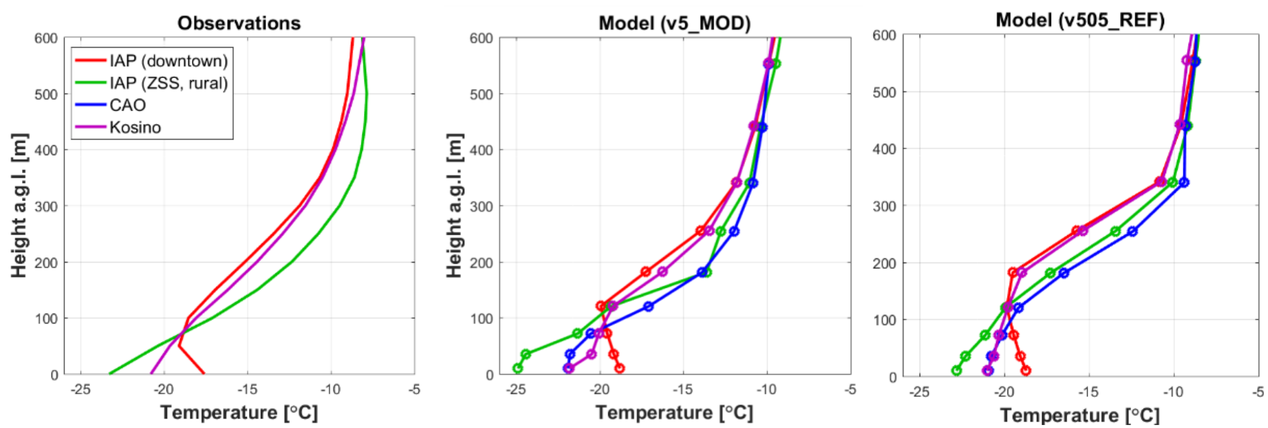
(PT AEVUS report, 2019)

Model verification (case 2: Jan 2017)



7-9 Jan 2017 – one of the coldest periods in Moscow region in XXI century

(T_{min} = -35 °C in the north of the region at 9th of January)



Mean vertical temperature profiles for 9th of January, modelled and observed by MTP-5. The model captured the vertical UIHI extent and a so-called cross-over effect.

(PT AEVUS report, 2019)

Ongoing AEVUS2 PT

AEVUS2 tasks:

- Implementation of 2D external parameters for urban morphology and thermal properties to the recent model version, exploring the added-value of these parameters
- Exploring the new data sets for external parameters
- Further tests with different model set ups
- Supporting implementation of TERRA_URB to the final unified COSMO version 6.0
- Preparations towards TERRA_URB implement in ICON

Motivation for new parameters

Table 1 from (Wouters et al., 2016)

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
Bulk parameters (output of SURY)		
Parameter name	Symbol	Surface values corresponding to the defaults
Albedo	α_{bulk}	0.081 (snow-free)
Emissivity	ϵ_{bulk}	0.89 (snow-free)
Heat conductivity	λ_{bulk}	$1.55\,\mathrm{W\,m^{-1}\,K^{-1}}$
Heat capacity	$C_{v,\mathrm{bulk}}$	$2.50 \times 10^6\,\mathrm{J\,m^{-3}\,K^{-1}}$
Thermal admittance	$\mu_{\mathrm{bulk}}\ (= \sqrt{C_{v,\mathrm{bulk}}\lambda_{\mathrm{bulk}}})$	$1.97 \times 10^3\,\mathrm{J\,m^{-2}\,K^{-1}\,s^{-1/2}}$
Aerodynamic roughness length	z_0	1.125 m
Inverse Stanton number	kB^{-1}	13.2 (in case that $u_* = 0.25\,\mathrm{m\,s^{-1}}$)

Thermal parameters (surface albedo, surface emissivity, surface heat conductivity, surface heat capacity)

Urban canopy parameters (building height, canyon height-to-width ratio, roof fraction)

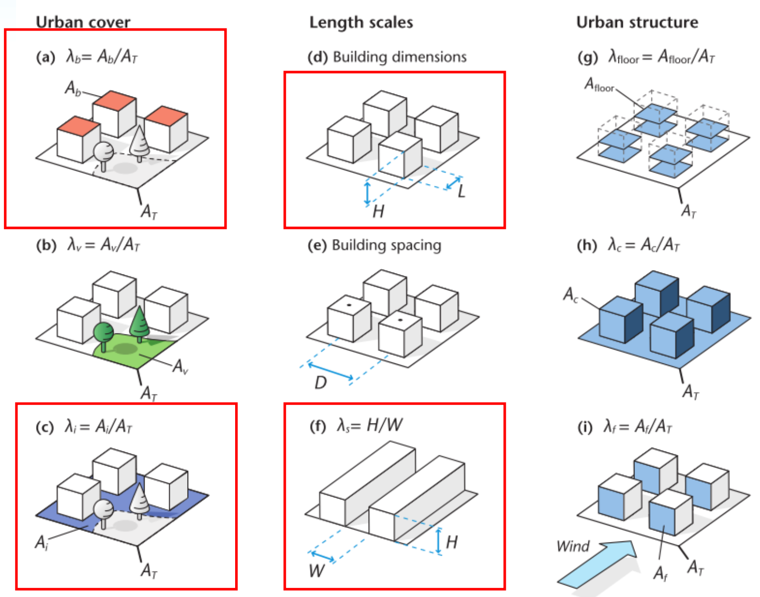


Figure 2.4 Parameters used to describe urban cover, length scales and urban structure.

Limitations : urban canopy parameters and thermal parameters are defined as hard-coded constants

Motivation for new parameters

Cities and their parts are very different!

Implementation of new parameters

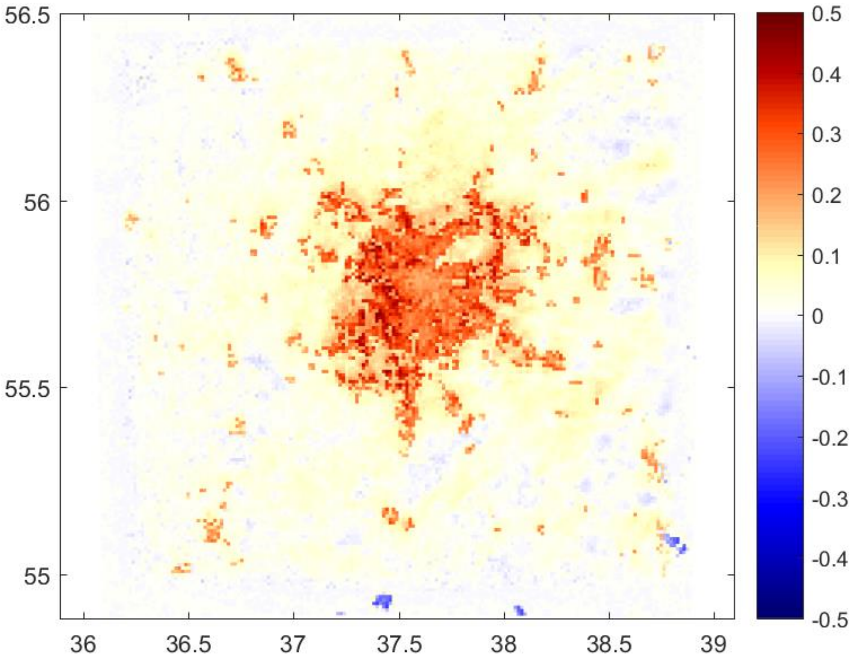
- **New 2D external parameters:** URB_BLDH, URB_BLDFR, URB_H2W, URB_HCAP, URB_HCON, URB_SALB, URB_TABL
- **New COSMO namelist parameters: curb_bldh, curb_bldfr, curb_h2w, curb_hcap, curb_hcon, curb_salb, curb_talb**
- **General principle;**
  - If **curb_*** is not specified in the namelist, a default values is used
  - If **curb_*** is positive, it is used as a constant.
  - If **curb_*** is -1, external parameter URB_* is used
  - If **curb_*** < 0, it is used as a scaling factor for corresponding external parameters
  - **lurb_*** switch controls the processing of URB_* in INT2LM.
- **Affected source files:**

COSMO: data_fields.f90, data_block_fields.f90, src_allocation.f90, src_block_fields_org.f90, sfc_interface.f90, sfc_tile_approach.f90, src_input.f90, radiation_utilities.f90, sfc_terra.f90, src_setup_vartab.f90, organize_data.f90, sfc_terra_data.f90, organize_physics.f90, radiation_interface.f90

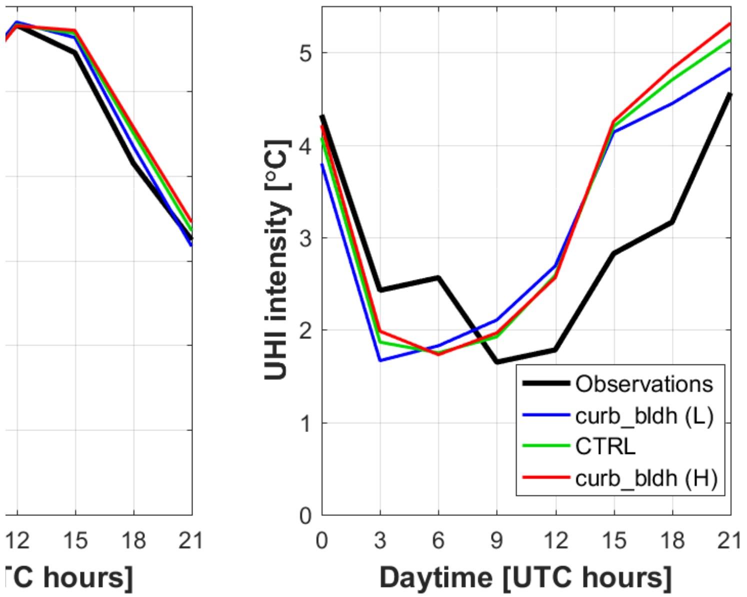
INT2LM: src_read_ext.f90, src_namelists.f90, src_memory.f90, src_gribtabs.f90, src_cleanup.f90, data_fields_lm.f90, external_data.f90, data_int2lm_control.f90

First results of sensitivity tests

Model sensitivity to building height (curb_bldh)



ΔT_{H-L}



EXP-ID	Urban canopy parameter	Symbol	L	H
A	surface albedo	α	0.10	0.25
B	surface heat conductivity	λ_s [$W m^{-1} K^{-1}$]	0.200	0.968
C	surface heat capacity	$C_{v,s}$ [10^6 $J m^{-3} K^{-1}$]	0.321	1.56
D	canyon height-to-width ratio	$\frac{h}{w_c}$	0.75	2.0
E	building height	h [m]	3	30
F	roof fraction	R	0.40	0.70
G	anthropogenic heat emission	AHE	0	2 × FL09

	all / night
ΔT_{H-L} (mean over city):	0.21 K / 0.45 K
ΔT_{H-L} (city center):	0.23 K / 0.48 K
ΔT_{H-L} (Wouters et al., 2016):	0.16 K / 0.24 K

Towards the higher-resolution simulations

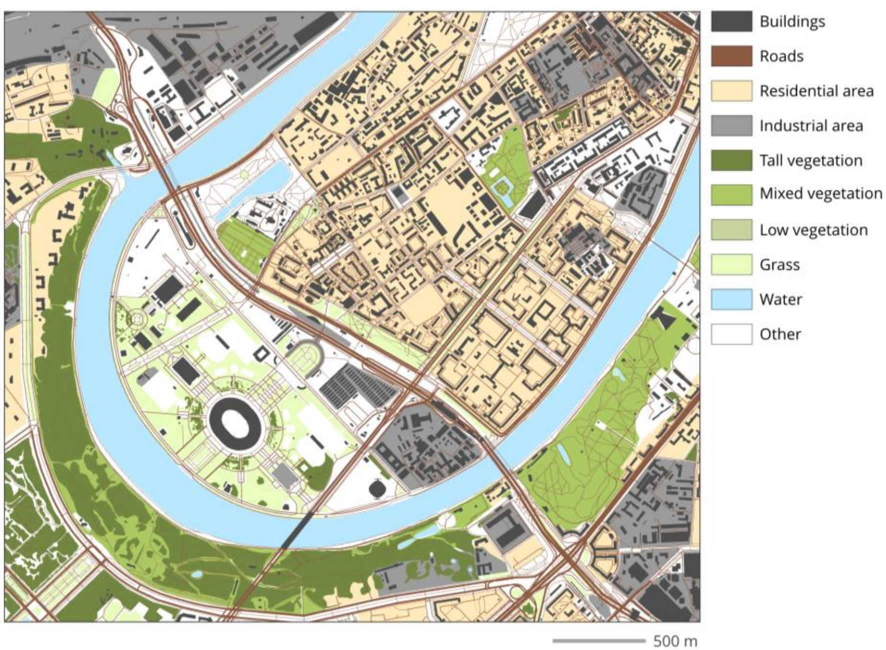
External parameters for TERRA_URB

Old approach (for Δx = 1 km):

1) OpenStreetMap data
2) Empiric estimates

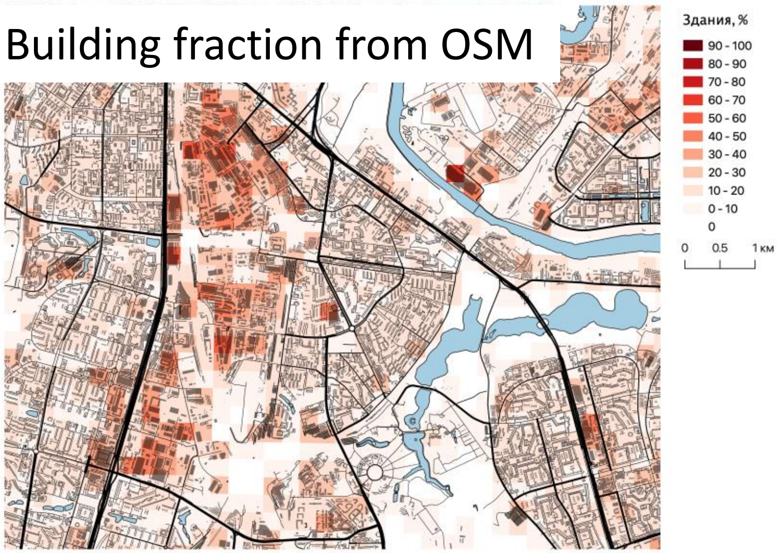
New approach (for Δx = 500 m):

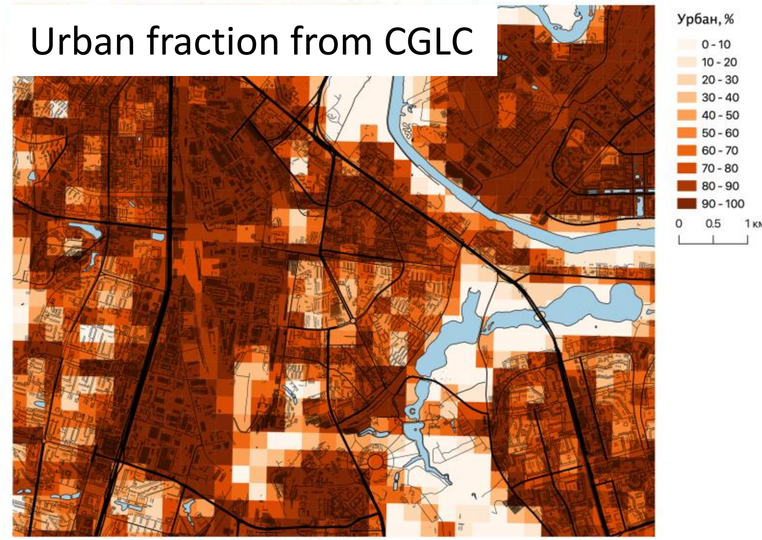
1) New Copernicus Global Land Cover data
2) OpenStreetMap data
3) High-resolution (10 m) vegetation data from Sentinel images

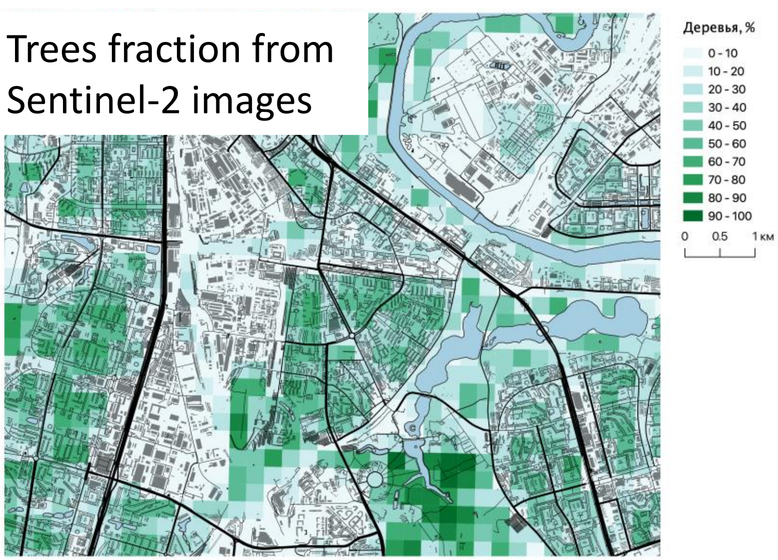


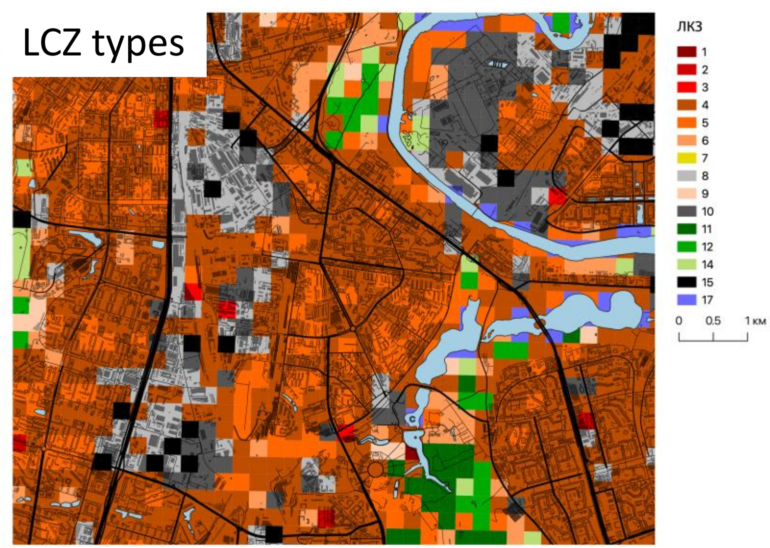
Towards the higher-resolution simulations

Detailed data for Moscow (250 m grid)



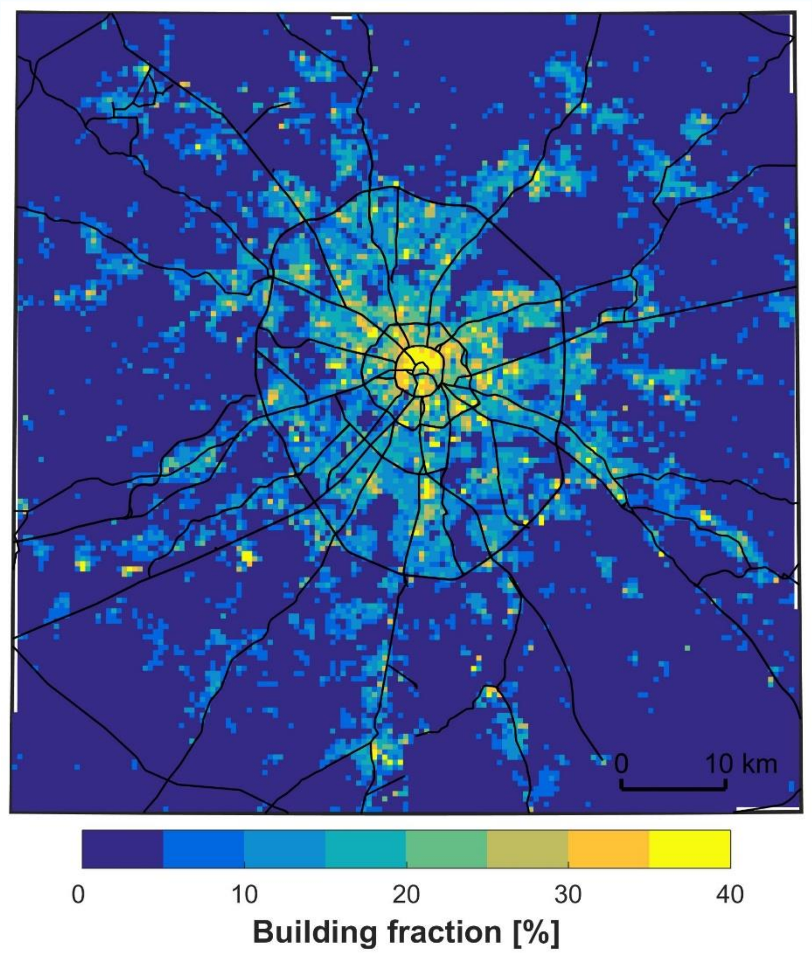


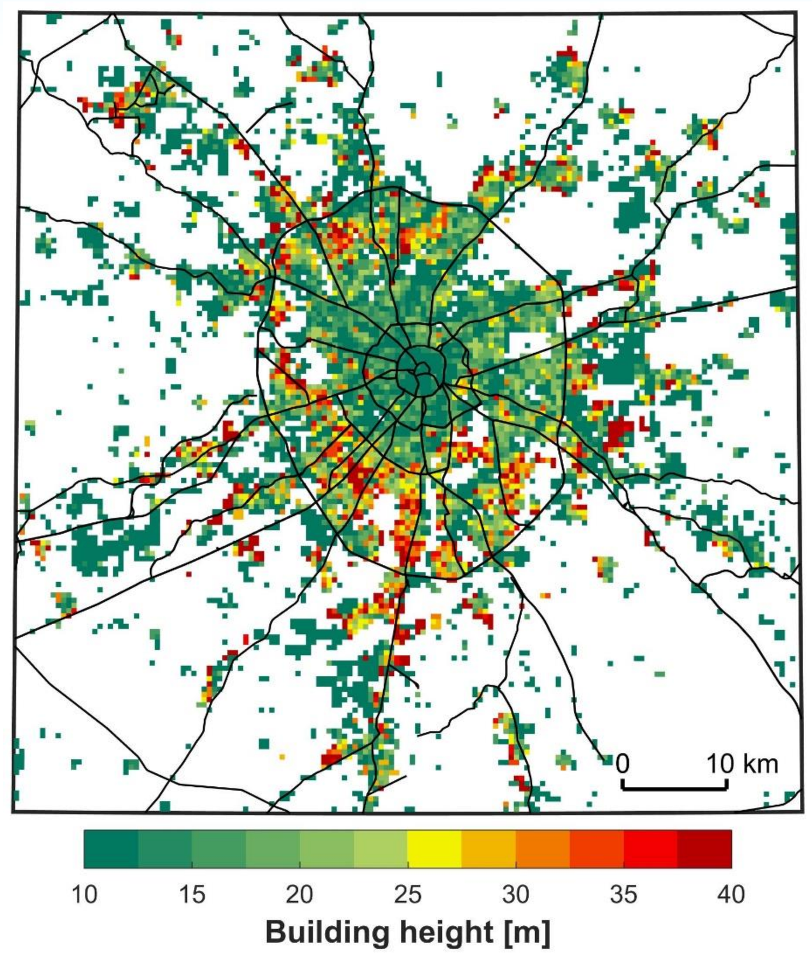




Building morphology parameters from OSM data

New 2D external parameters **(Δx = 0.5 km)**

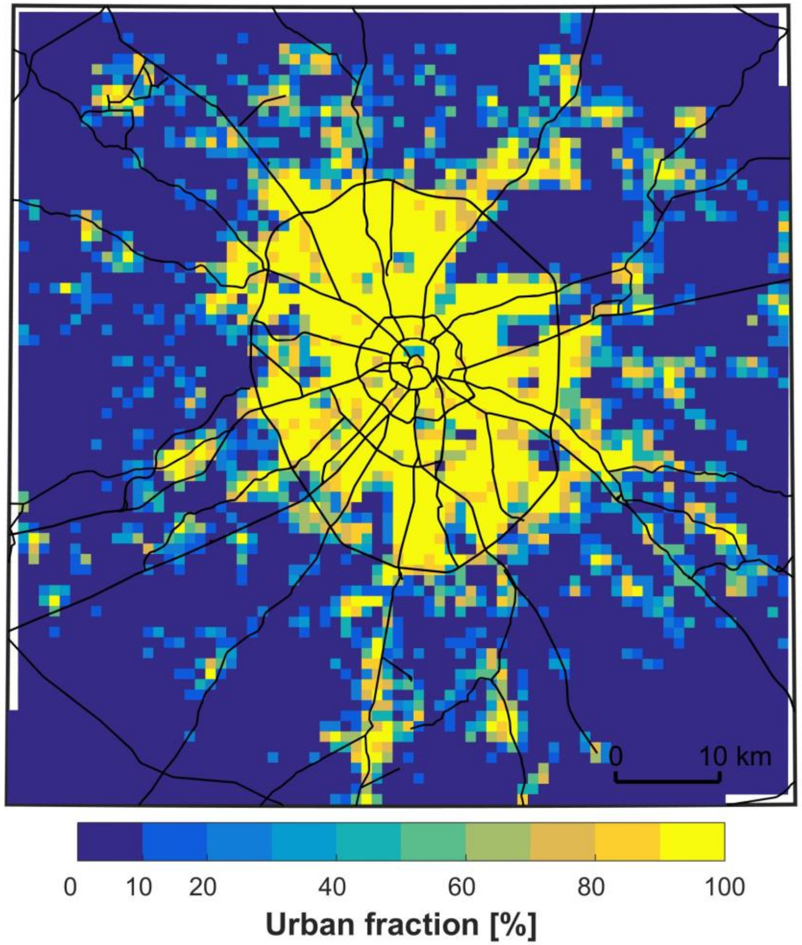




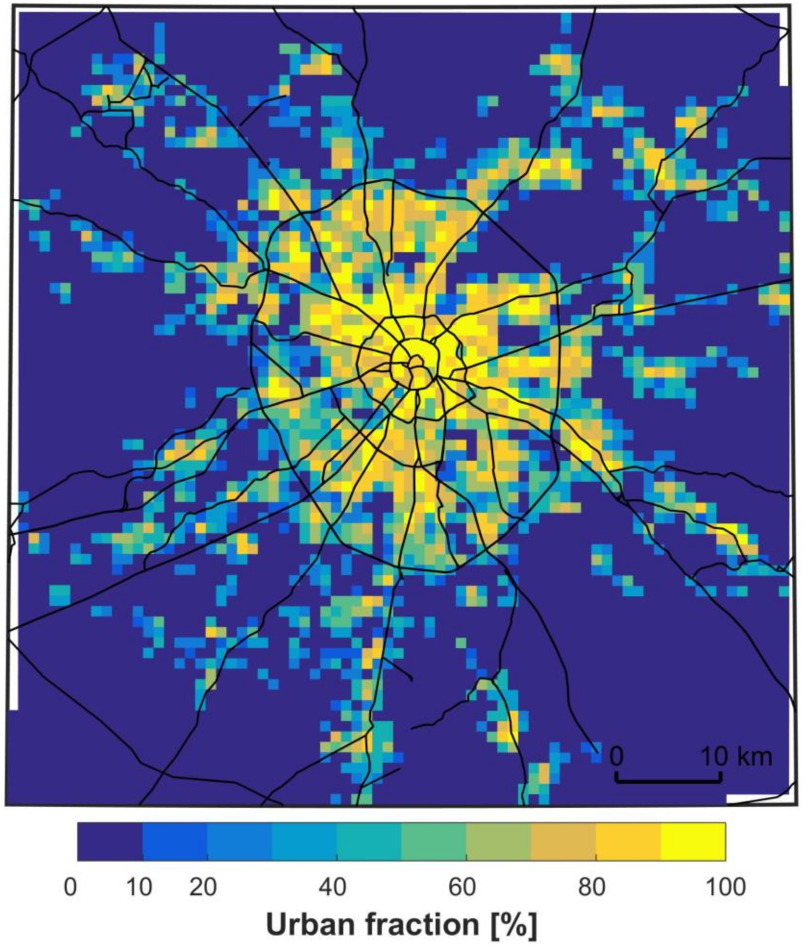
Towards higher-resolution simulations

External parameters for TERRA_URB: urban fraction **(Δx = 1 km)**

EXTPAR/WebPEP output
(Globcover data, URBAN field)



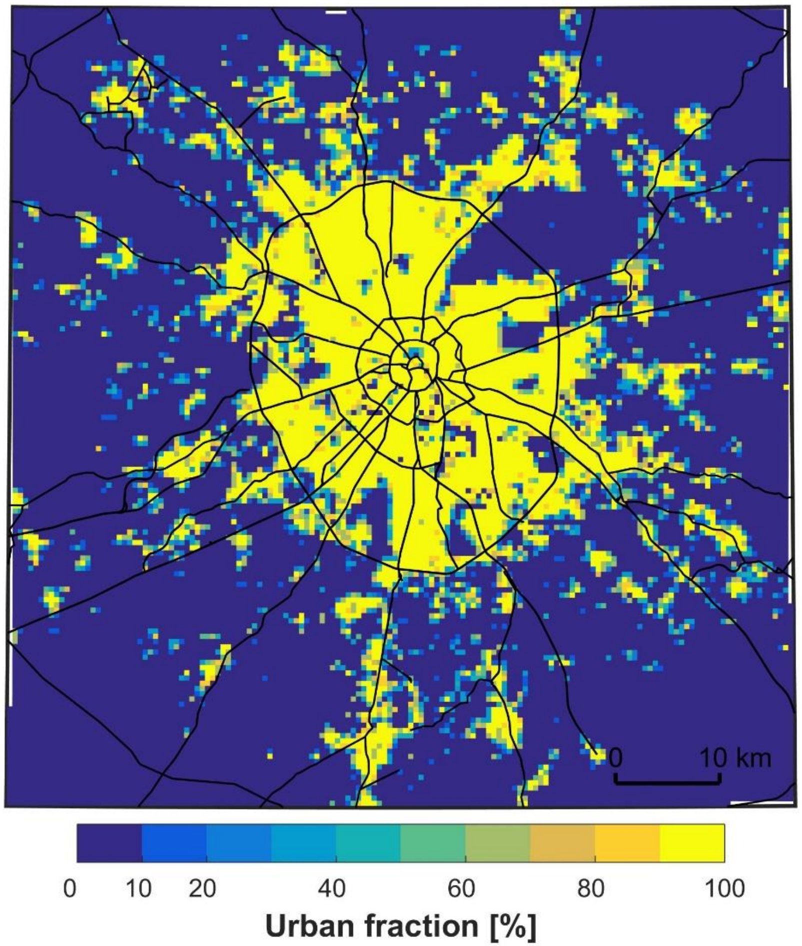
What we used before
(based on OpenStreetMaps data and empiric estimates)



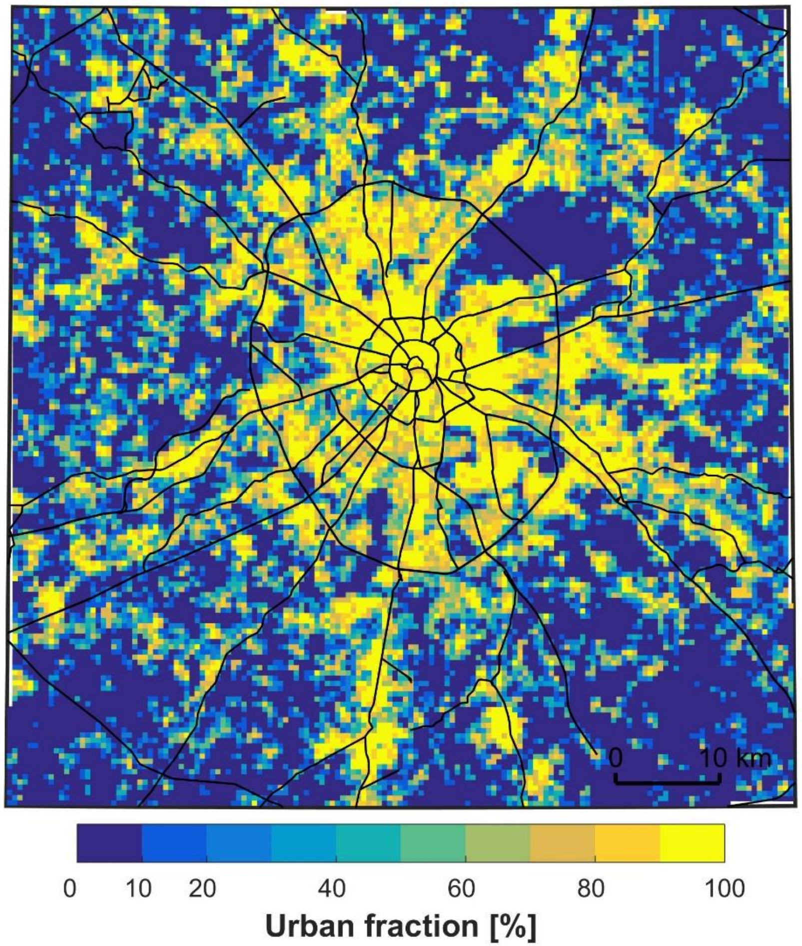
Towards higher-resolution simulations

External parameters for TERRA_URB: urban fraction **(Δx = 0.5 km)**

EXTPAR/WebPEP output (Globcover data, URBAN field)



New CGLC data (after averaging of the original data on 100-m grid)

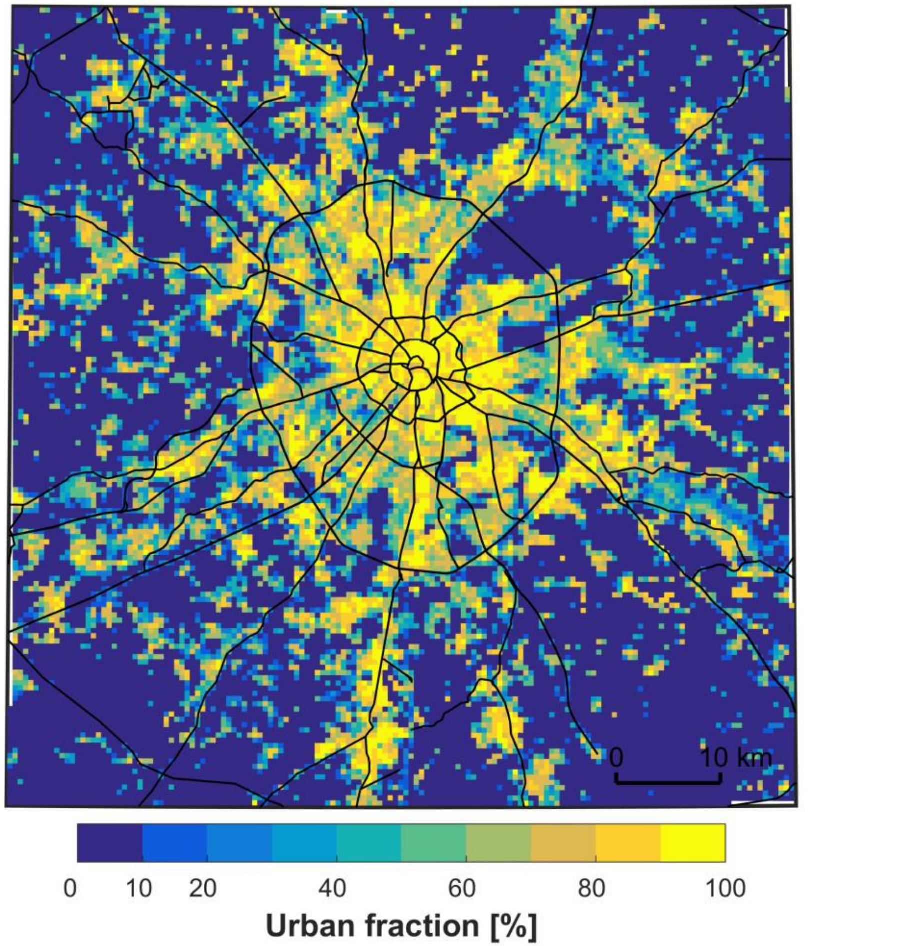


Towards higher-resolution simulations

Attempt to correct CGLC data

URBAN_FR = **max (min (URBAN_FRC$_{GLC}$, 1 – GREEN_FR), URBAN_FR$_{OSM}$)**
GREEN_FR = **max (GREEN_FR$_{OSM}$, FREEN_FR$_{SENTINEL}$)**
URBAN_FR$_{OSM}$ = BLDF_FR$_{OSM}$ + ROAD_FR$_{OSM}$

Corrected CGLC data --->



Thank you for your attention!

Any questions?

For more details and references see our recent publications:

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- **COSMO Tech. Rep. No. 40. PT AEVUS Final Report.** https://doi.org/10.5676/DWD pub/nwv/cosmo-tr_40

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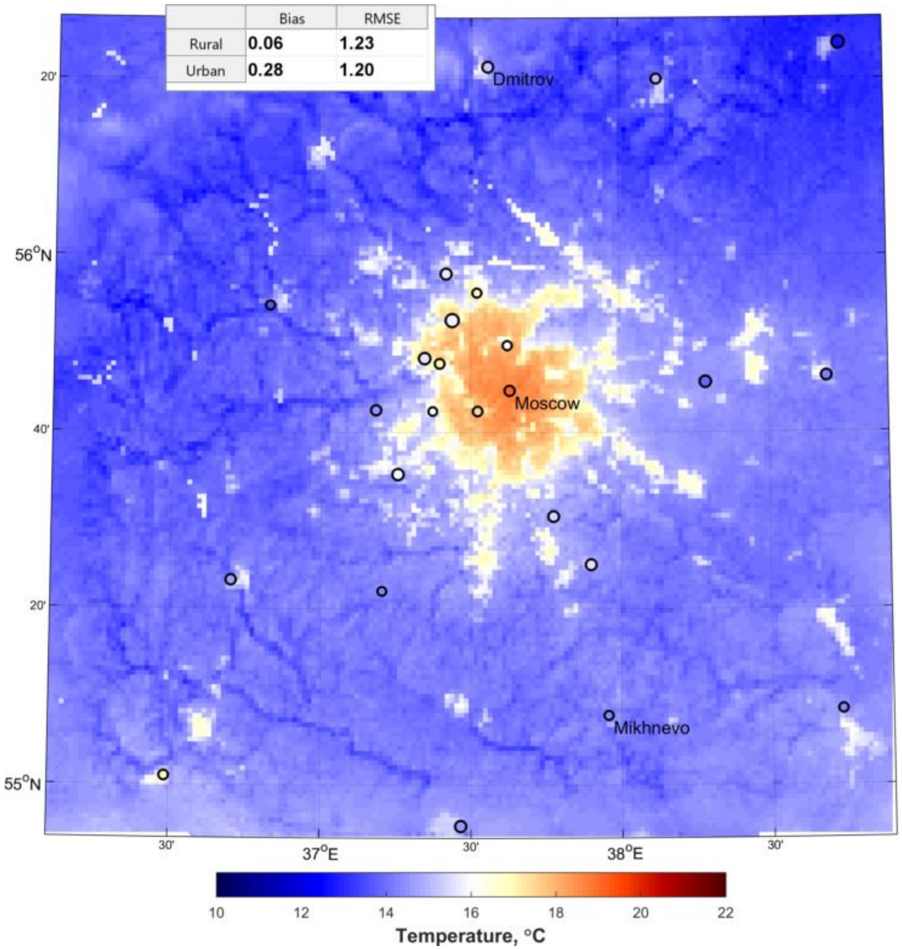
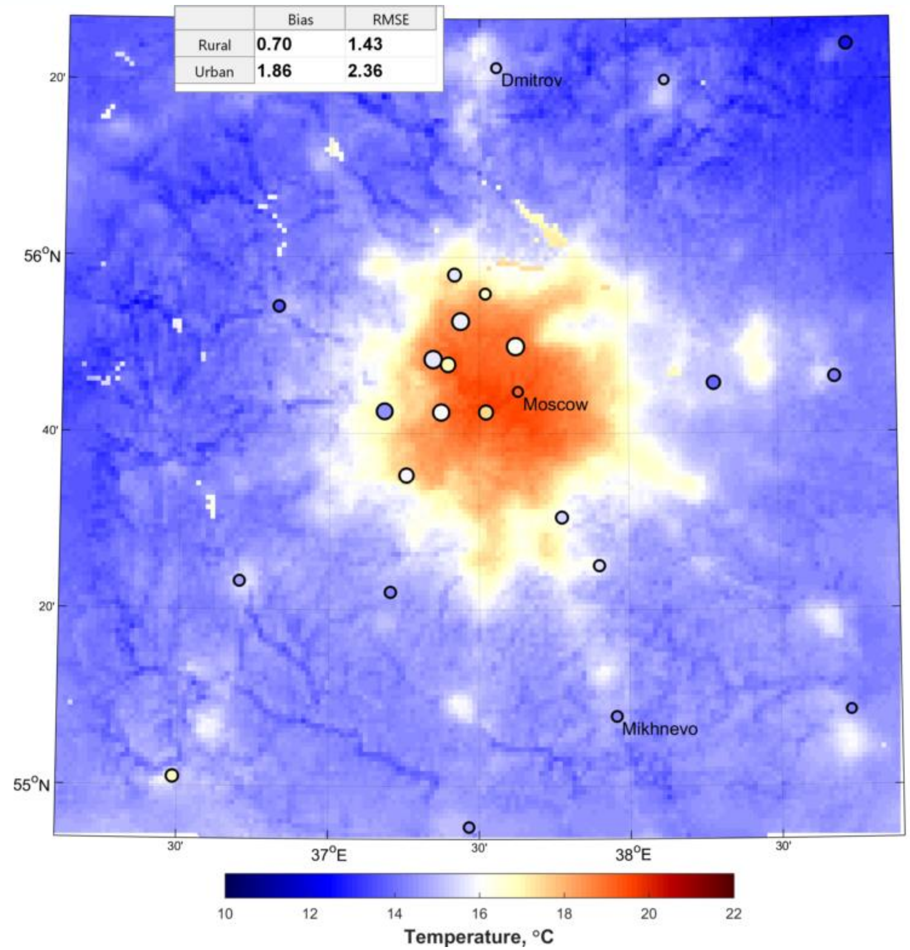
Tests with default ISA data for Moscow

Run with our clarified data for Moscow from previous studies



Run with default ISA from EXTPAR



Mean nocturnal temperature over 5-20th of August 2017