Simulations of Moscow megacity heat island with COSMO-CLM model and the TERRA_URB urban scheme: developments, verification and applications

Mikhail Varentsov[1]* , Hendrik Wouters[2],
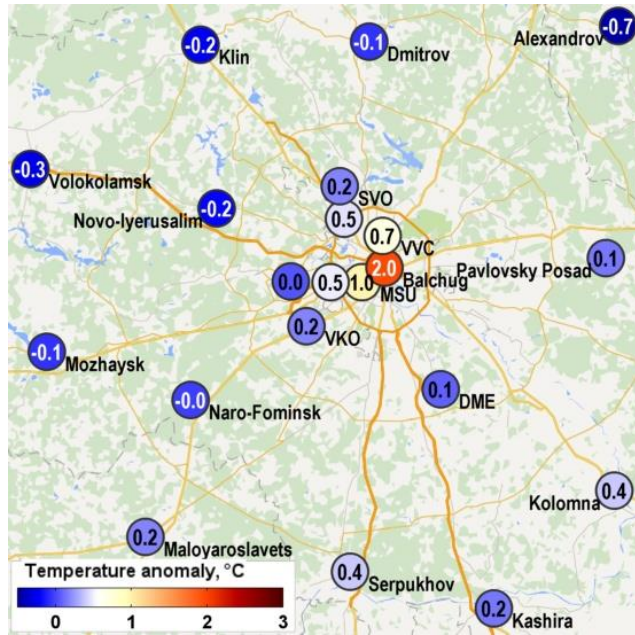Pavel Konstantinov[1], Timofey Samsonov[1]

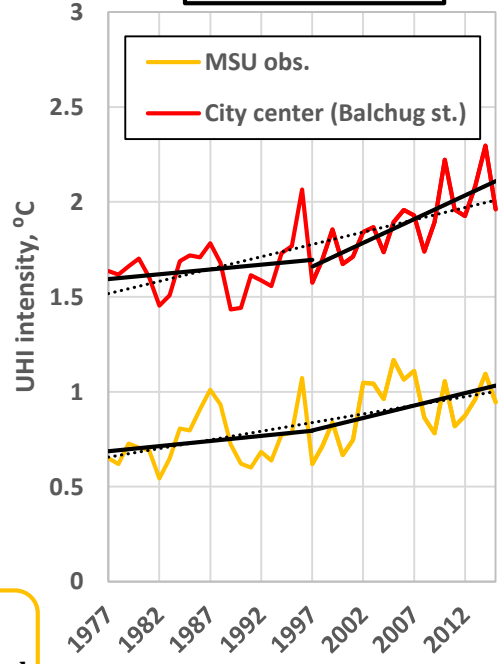[1] Lomonosov Moscow State University, Faculty of Geography

[2] KU Leuven, Belgium

* *mvar91@gmail.com*

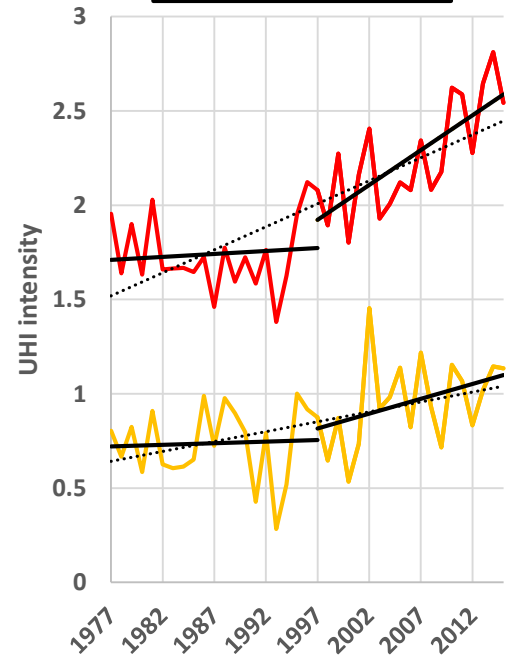# Moscow city as a prospective test-bed for urban climate modelling

Year-mean

Summer

- MSU obs.
- City center (Balchug st.)

UHI intensity, °C

UHI intensity
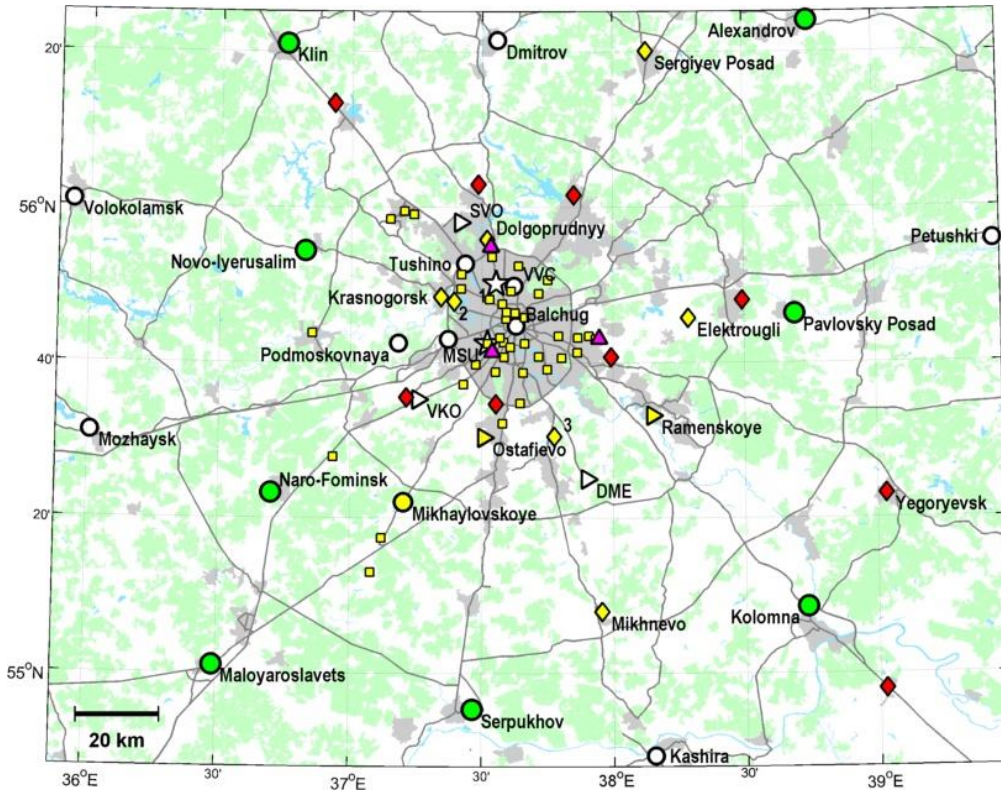
$$\text{UHI intensity} = \Delta T = T_{urban} - 1/n \sum_{i=1}^{n} T_{rural}^{i}$$

Moscow city as a prospective test-bed for urban climate modelling

Map of Moscow region weather and monitoring stations

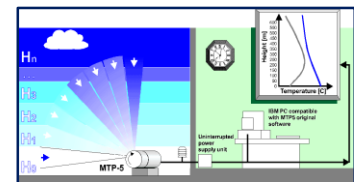*Meteorological observatory of Moscow University (MSU)*

Balchug weather station in city center

One of the new AWS

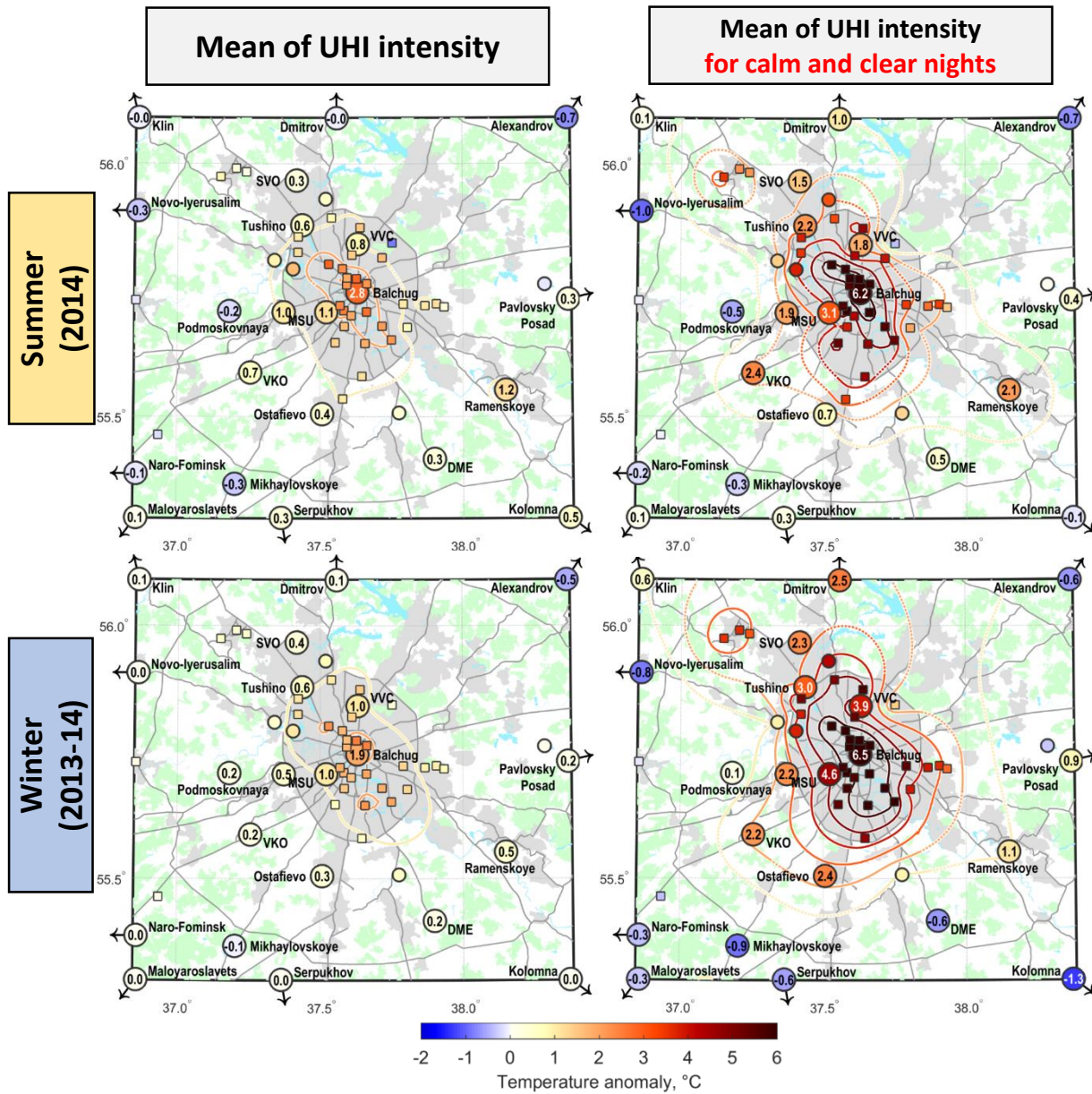*One of air-quality monitoring stations*

MTP-5 temperature profiler and its principle of operation

Legend:

- ○ State weather station
- ☆ Meteorological observatory
- ▷ Airport weather station
- ◇ Automatic weather station
- ▫ Air-quality monitoring station
- △ MTP-5 Temperature profiler

# Moscow city as a prospective test-bed for urban climate modelling

Modelling technology

Configuration of numerical experiments

- Model version cclm 5.0_clm8
  with TERRA_URB v 2.1 with some fixed bugs,
  and some additional runs with cclm + TEB

- **Configuration of nested domains:**
  ERA-Interim reanalysis → 12 km (140x140)
  → 4 km (180x180) → 1 km with TERRA_URB
  (160x160)

- Spectral nudging for U, V and T for basic domain

- Surface parameters from Globcover database

- Usage of **tuned model configuration**, adopted for
  the best simulations of thermal regime of rural
  areas around Moscow

- Calculations at supercomputer "Lomonosov-2"
  of Moscow State University

- Numerical experiments for certain seasons
  (winter 2013-2014, summer 2014) with model
  one year spin up

ERA-Interim reanalysis

ETR (12 km)

MSK (4 km)

MSK (1 km)
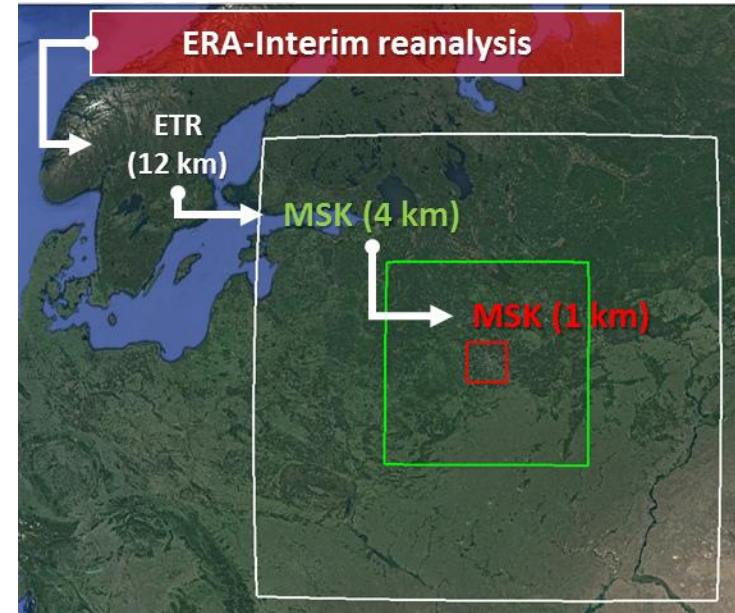
Semi-empirical Urban canopY parametrization SURY

(Wouters et al., in submission)

SURY
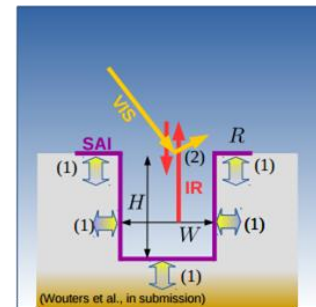
"Translation of urban canopy parameters into bulk parameters"

Tuning of the model configuration

Namelist	Option name	Default setup	Tuned setup
CONTROL (int2lm)	**itype_rootdp** treatment of the external parameter for root depth	**0** input is modified with an annual cycle	**3** Same without maximum cut off.
PHYCTL (cclm)	**itype_albedo**	**1** albedo is a function of soil type	**4** vegetation albedo is modified by forest fraction
	itype_root type of root distribution	**1** Uniform	**2** Exponential
	itype_evsl parameterization for evaporation of bare soil	**2** Bucket version	**1** BATS version
	itype_heatcond type of soil heat conductivity	**1** Use average soil moisture	**2** Take into account soil moisture/ice
	lstomata switch to use a minimum stomata resistance map	**FALSE**	**TRUE**
	ltype_aerosol	**1**	**2**
TUNNING (cclm)	**tkmmin, tkhmin** Minimal diffusion coefficients in stable BL conditions	**0.4**	**0.02**
	pat_len Length scale (m) of sub-scale surface patterns	**500**	**10**
	entr_sc Mean entrainment rate for shallow convection	**0.0003**	**0.001**
	thick_sc limit for convective clouds to be "shallow" (in Pa)	**25000**	**10000**

Model verification for intermediate domain

Default configuration
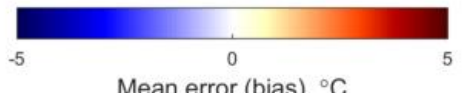

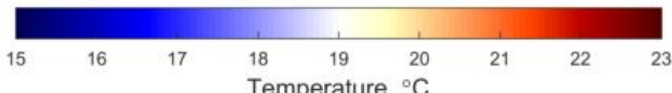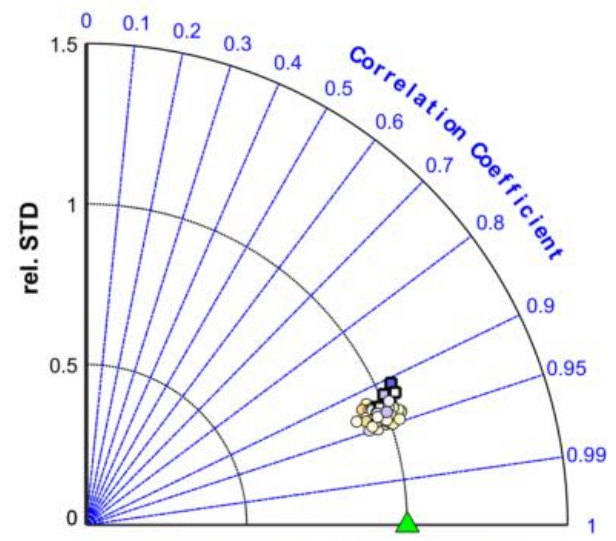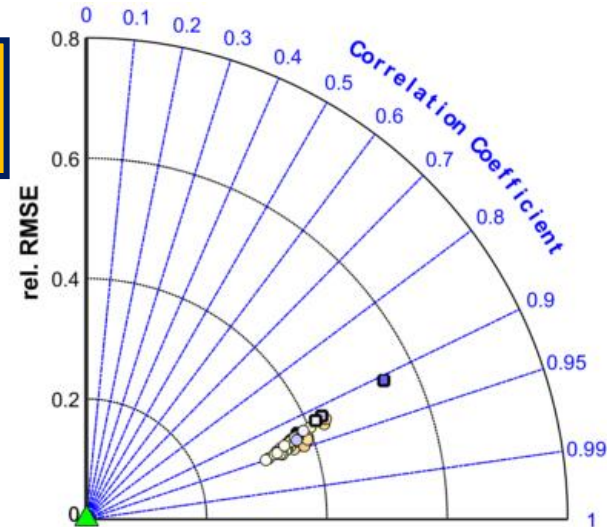|	Bias	RMSE
Rural	1.93	3.04
Urban	0.92	2.31

Mean temperature for summer 2014
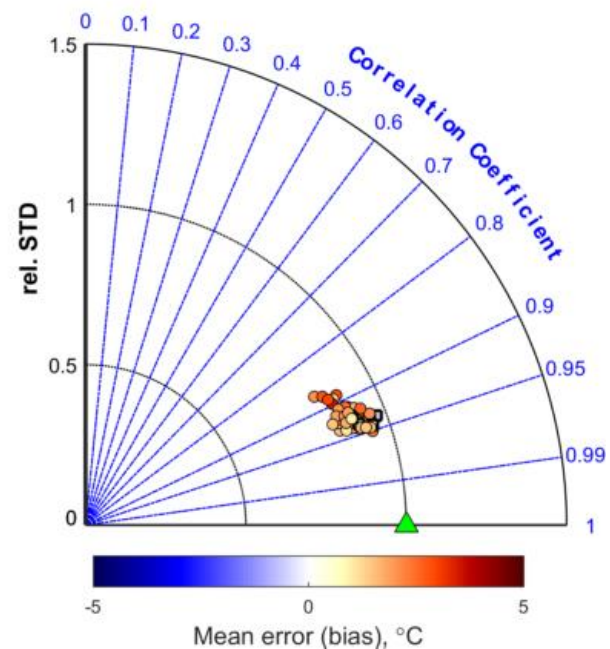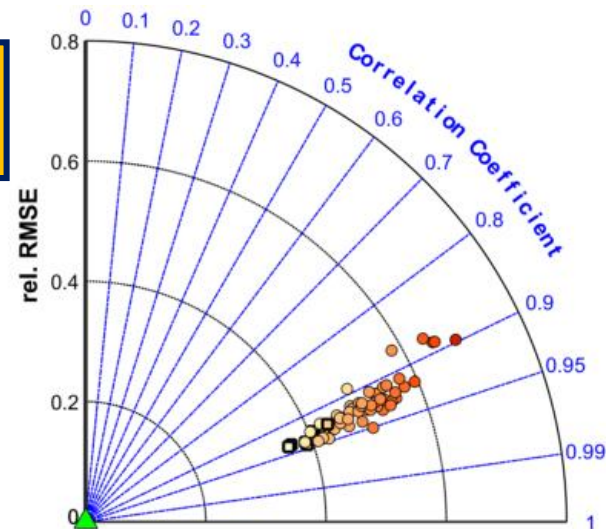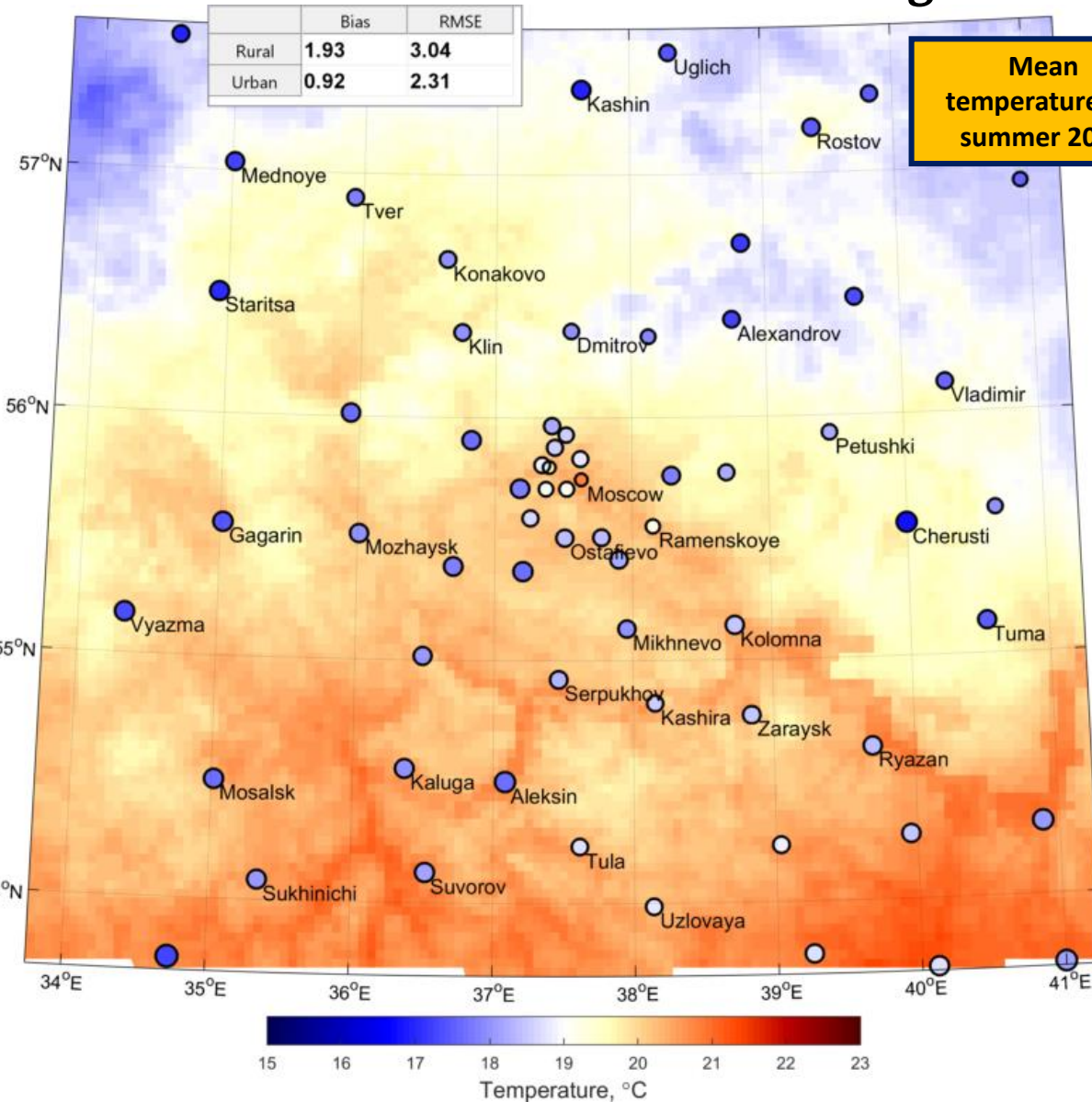
Model verification for intermediate domain

Tuned configuration

	Bias	RMSE
Rural	0.44	2.21
Urban	-0.33	2.36

Mean temperature for summer 2014
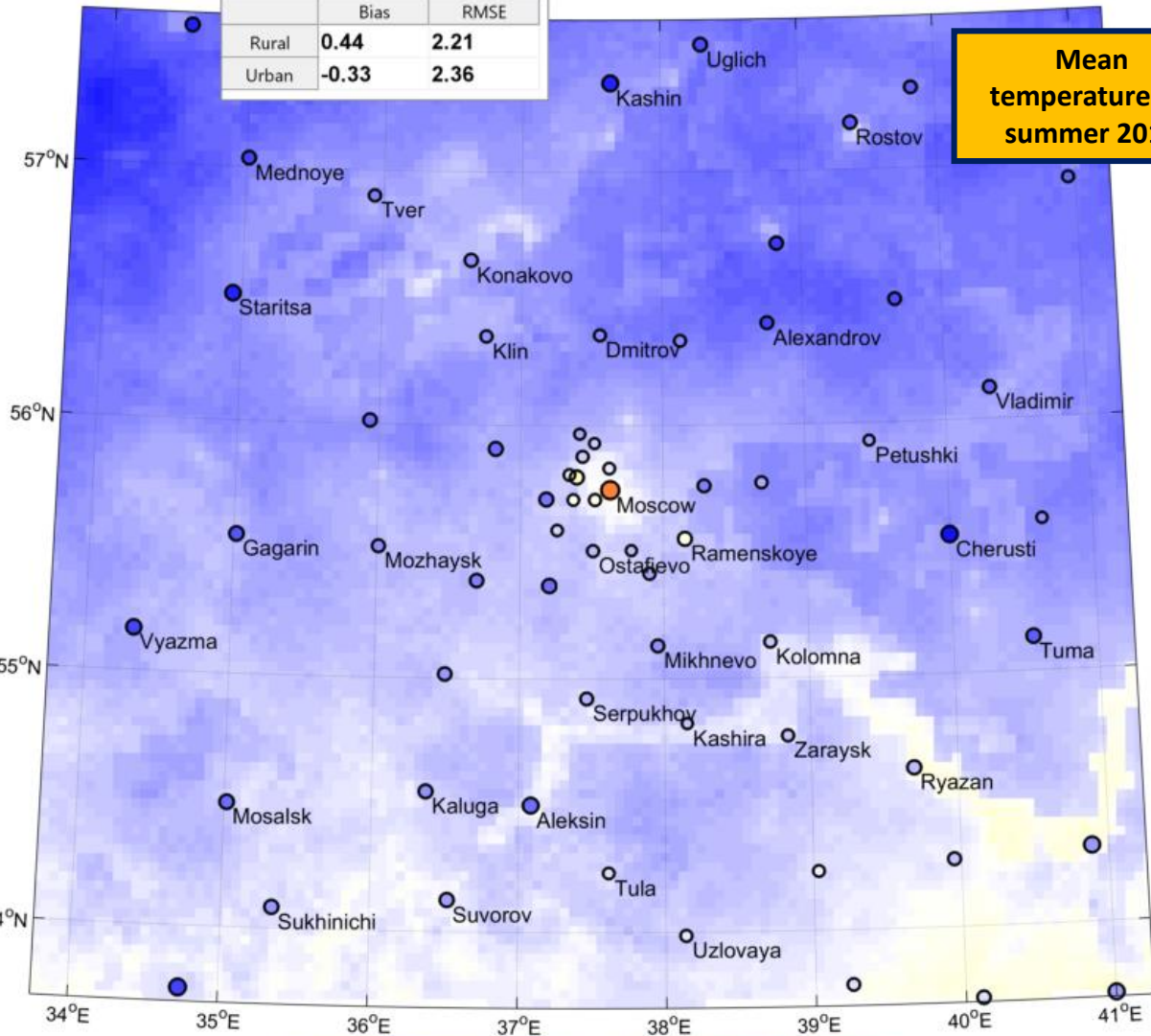
Input data for urban canopy scheme

1) Building properties

- Urban fraction
- Building height
- H/W ration for street canyons
- Roof fraction

Code of TERRA_URB (cclm and int2lm) was modified to allow separate definition of this parameters for each grid cell (as it is made for CCLM + TEB)

2) Physical parameters:

Albedo, heat capacity, etc

3) Anthropogenic heat flux

- Mean annual value for TERRA-URB

Building height

Canyon H/W ration
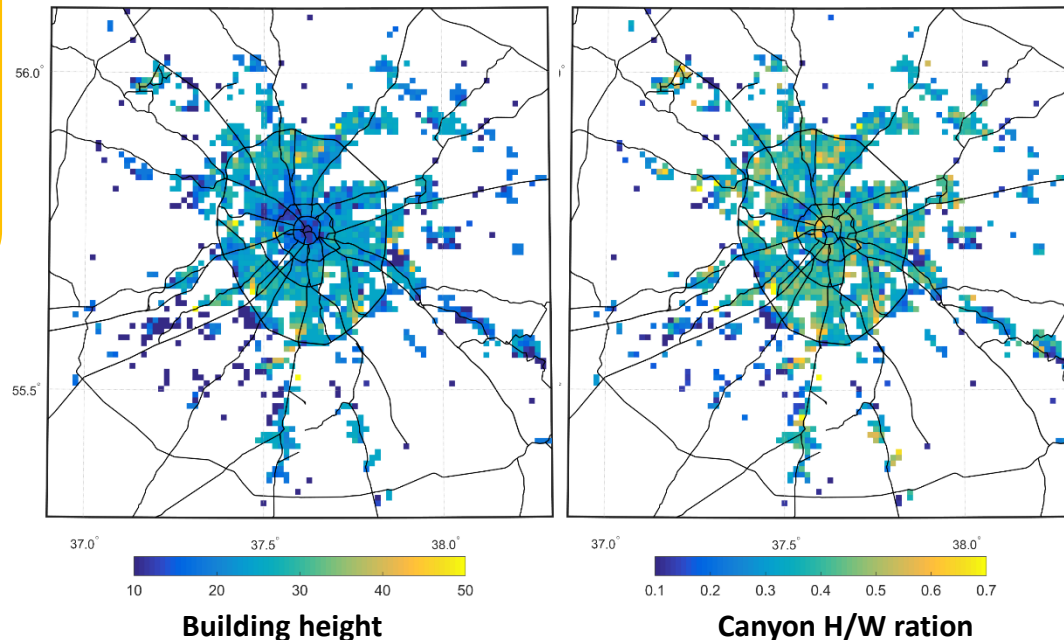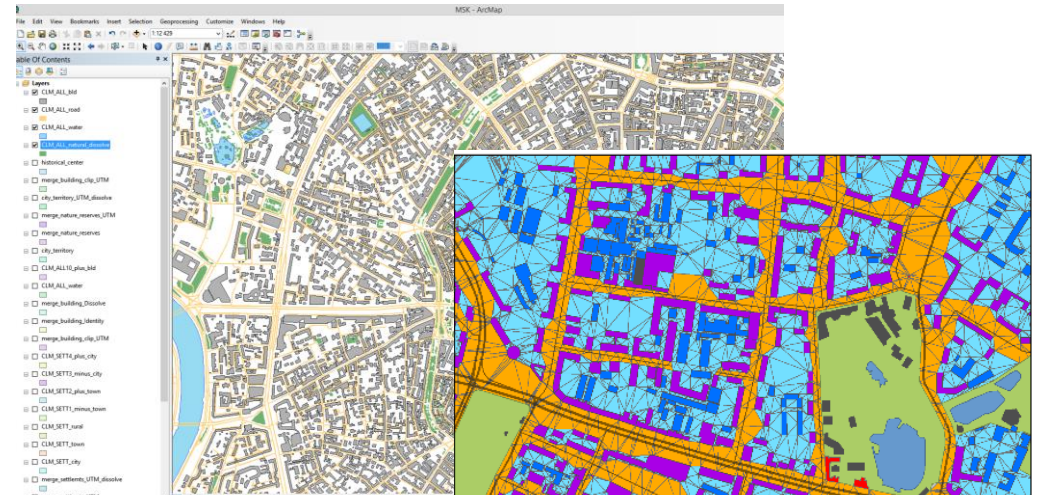
Input data for urban canopy scheme

Urban fraction

Urban fraction from EXTPAR (Globcover)
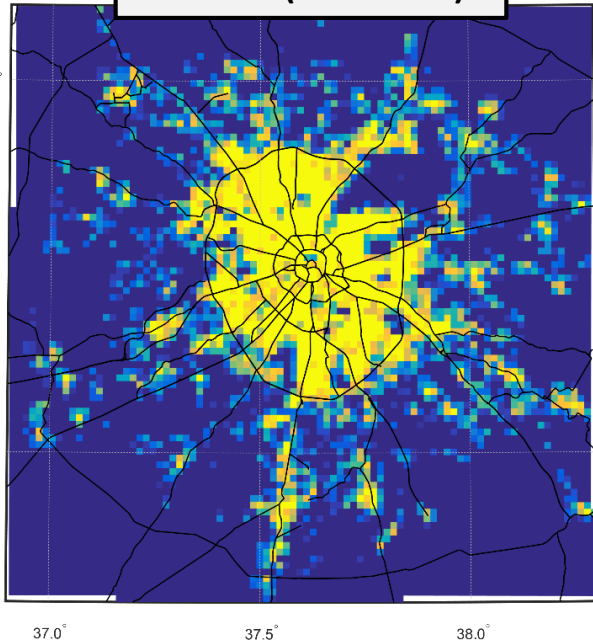
ISA from EXTPAR (fine resolution)
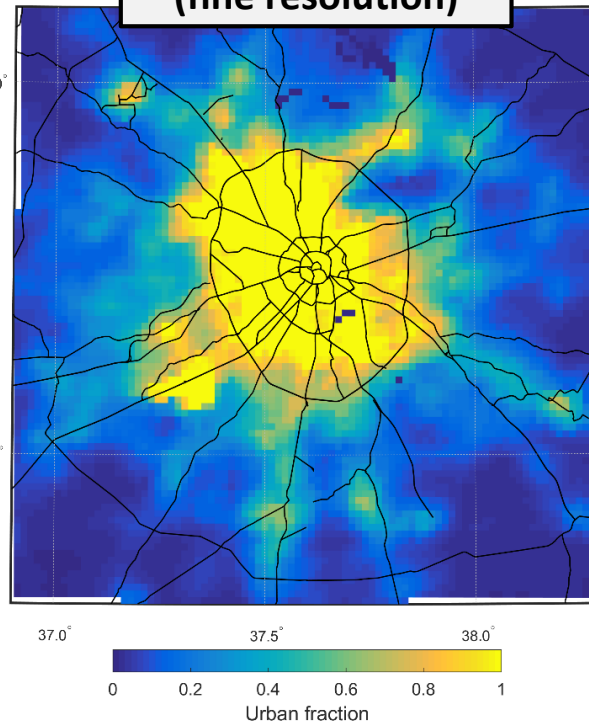
Urban fraction derived from OSM data

Urban fraction
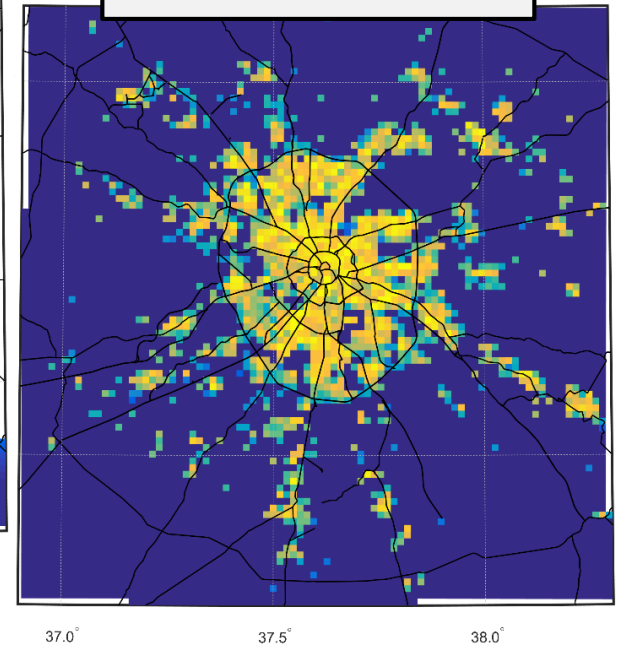
U1= building area + road area + "yard" area + industrial area
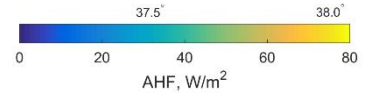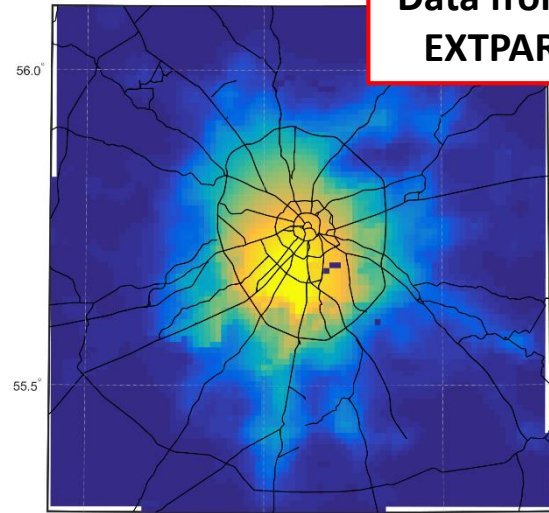
Urb2= building area + street canyon area

Urban area = min [max (Urb1, Urb2), 1 – "green" area
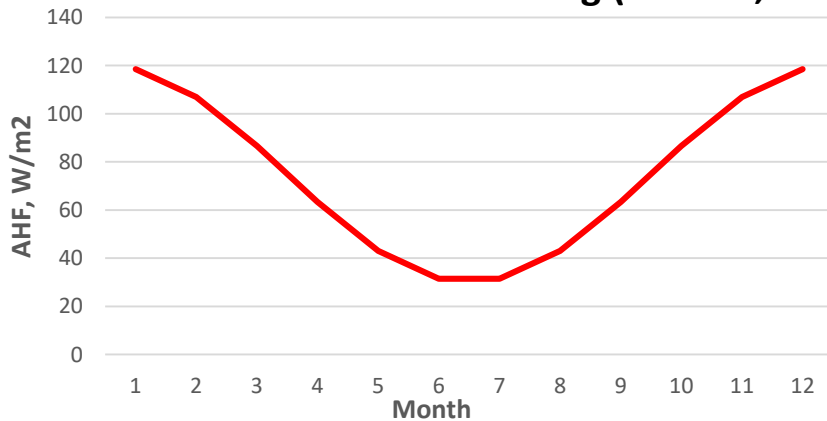
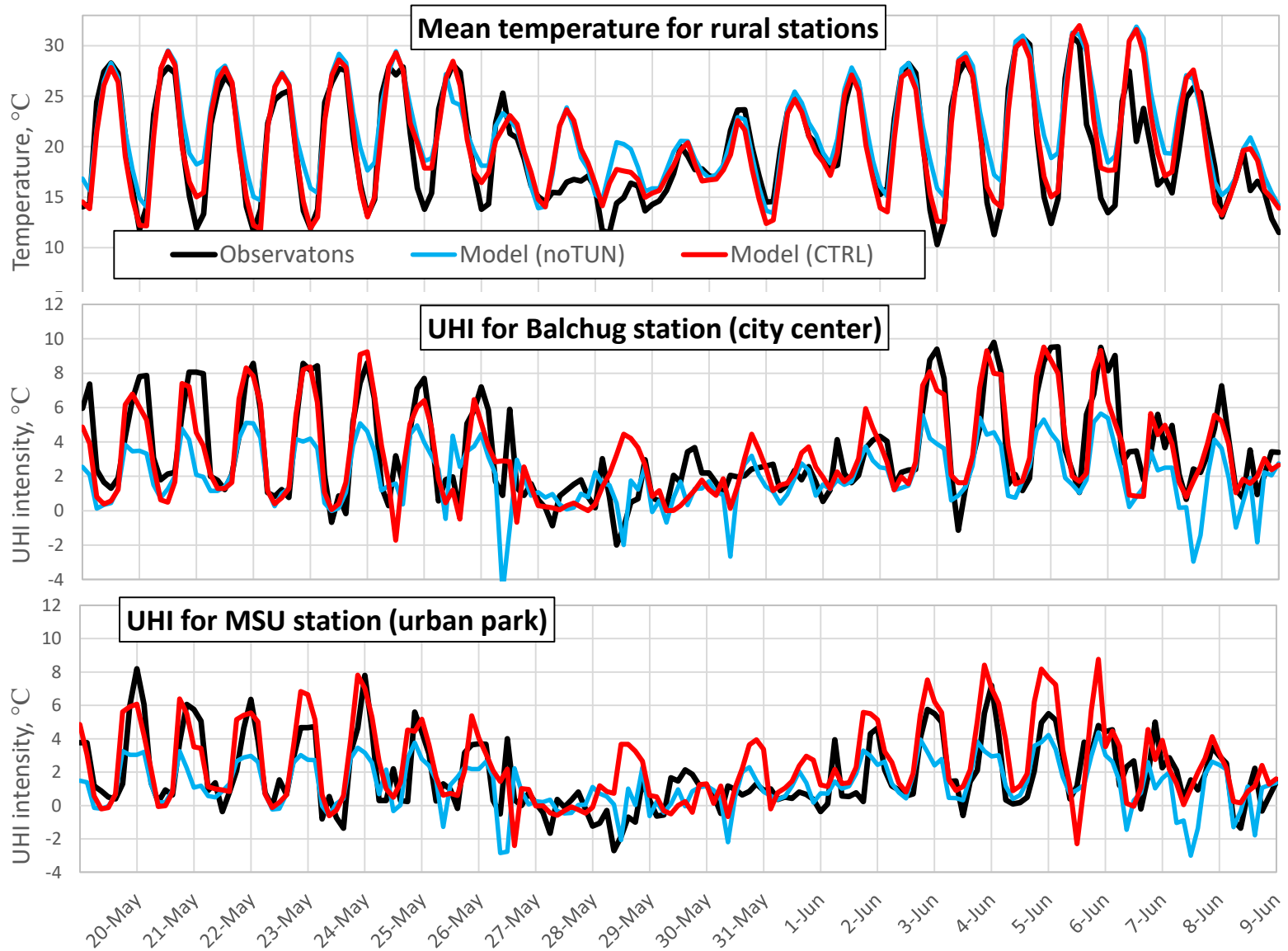# Input data for urban canopy scheme

Anthropogenic heat flux

Mean annual value for Moscow

(Stewart, Kennedy, 2015)

- ■ Domestic & industrial fuel use
- ■ Electricity consumption
- ▨ Transportation fuel use
- ☐ Human & animal metabolism
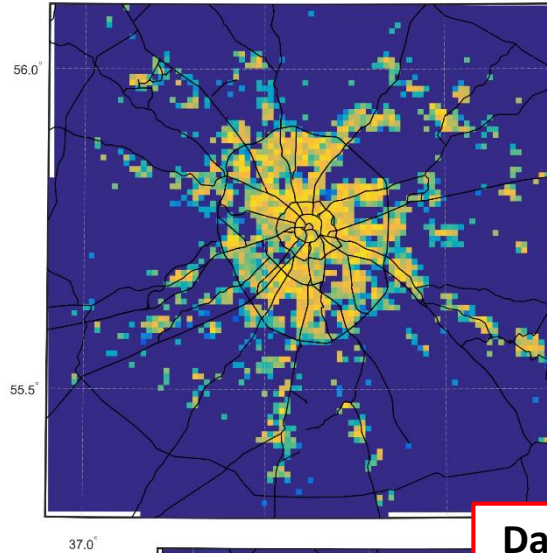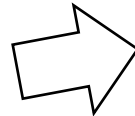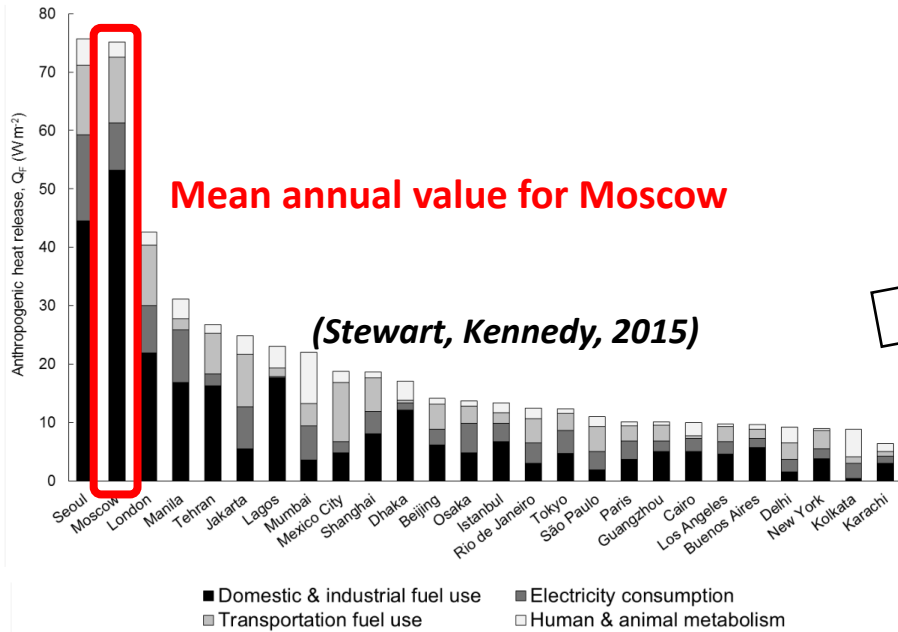
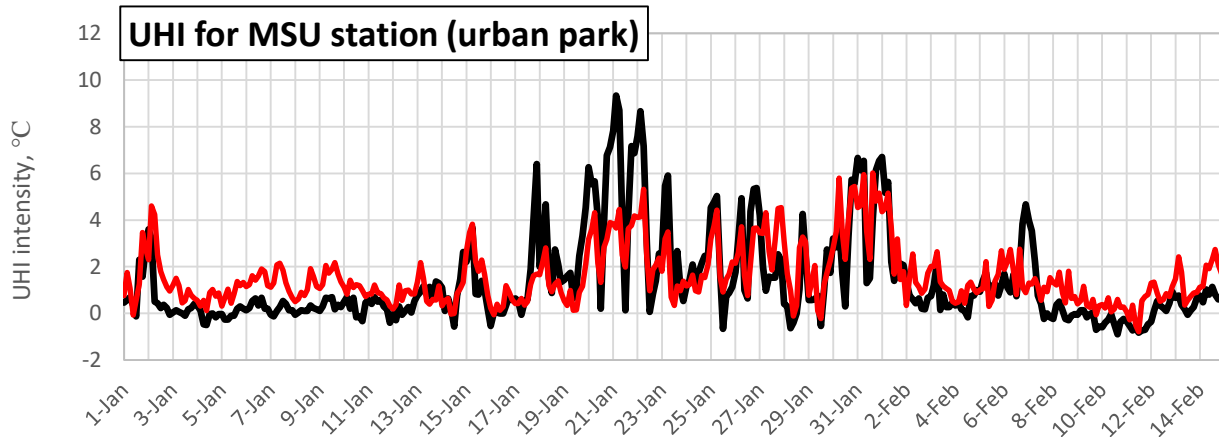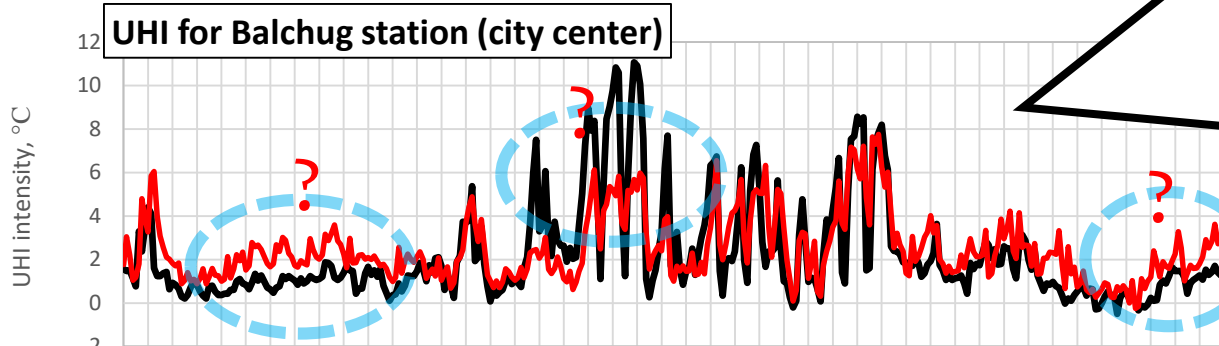### Seasonal variation according (Flanner, 2009)

Data from EXTPAR
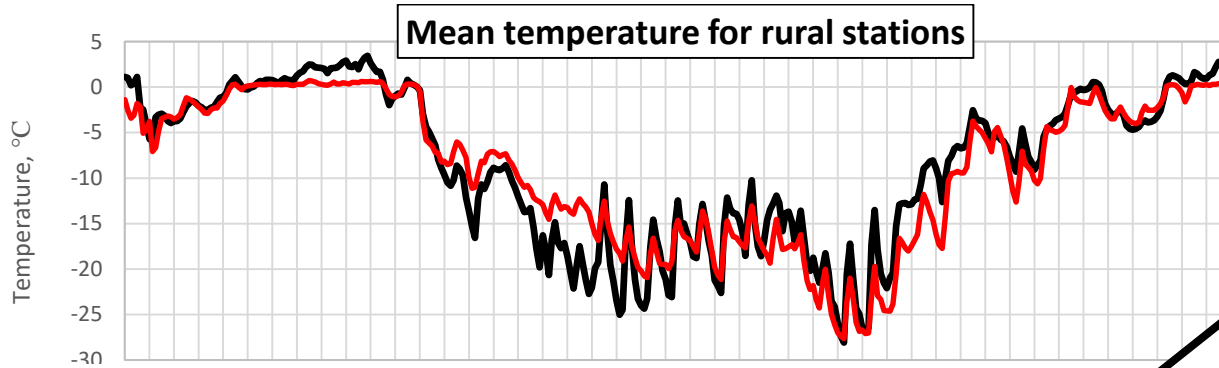
Model verification for urban domain

Summer season

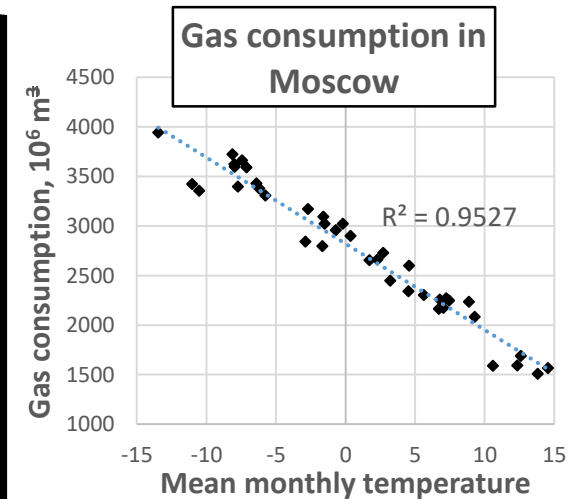# Model verification for urban domain

Mean temperature for rural stations

UHI for Balchug station (city center)
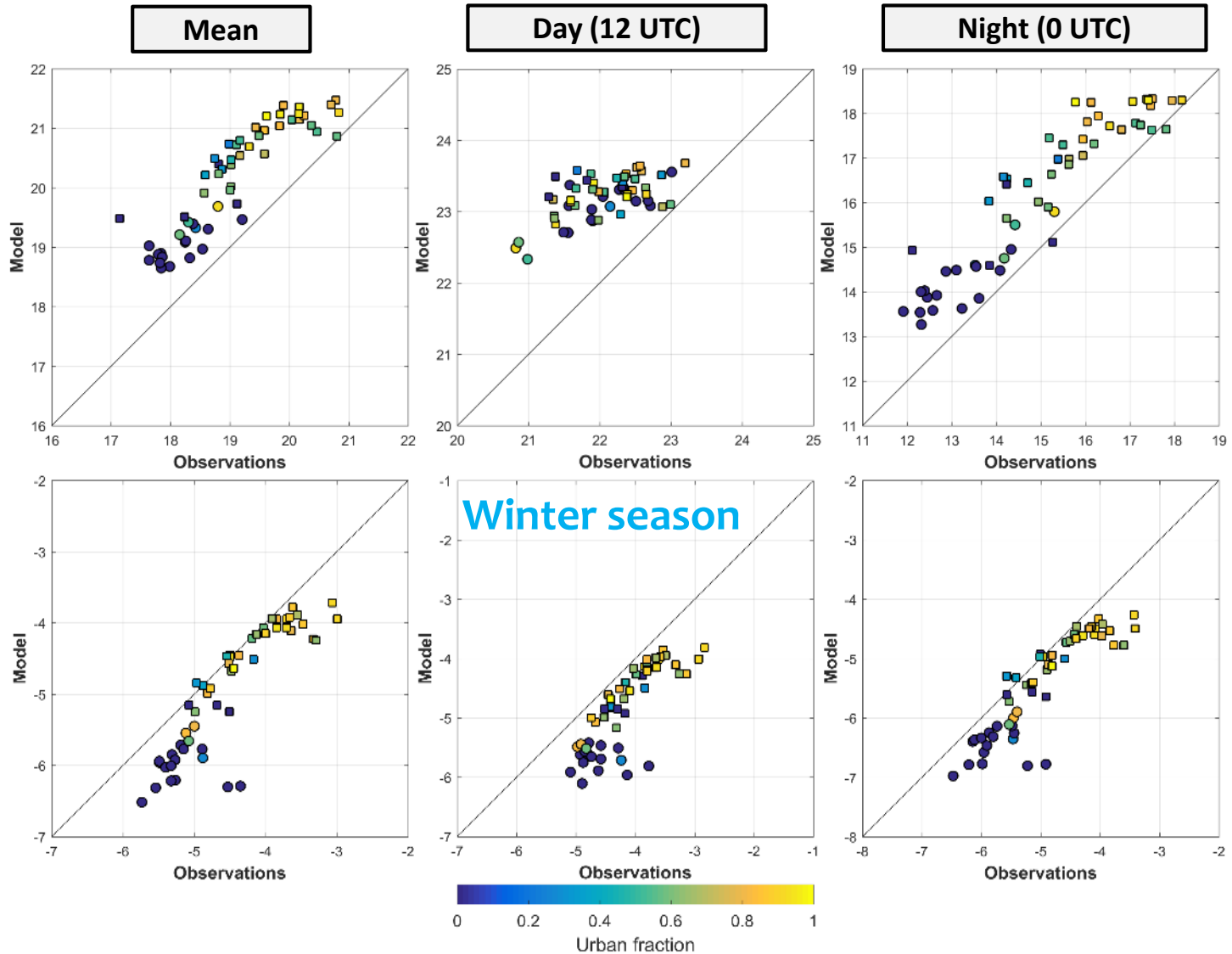
UHI for MSU station (urban park)

Why does this happen?

One of possible reasons: typical annual variation of anthropogenic heat flux is taken into account (Flanner, 2009), **but not its dependence on real temperature**
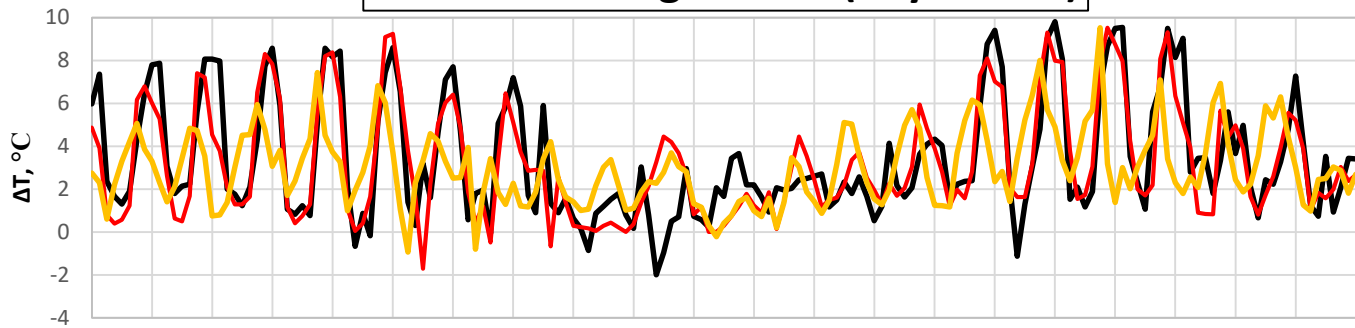
Gas consumption in Moscow

$R^2 = 0.9527$

Model verification for urban domain

Summer season · Winter season. Scatter plots comparing Model vs Observations for Mean, Day (12 UTC), and Night (0 UTC), colored by Urban fraction (0 to 1).
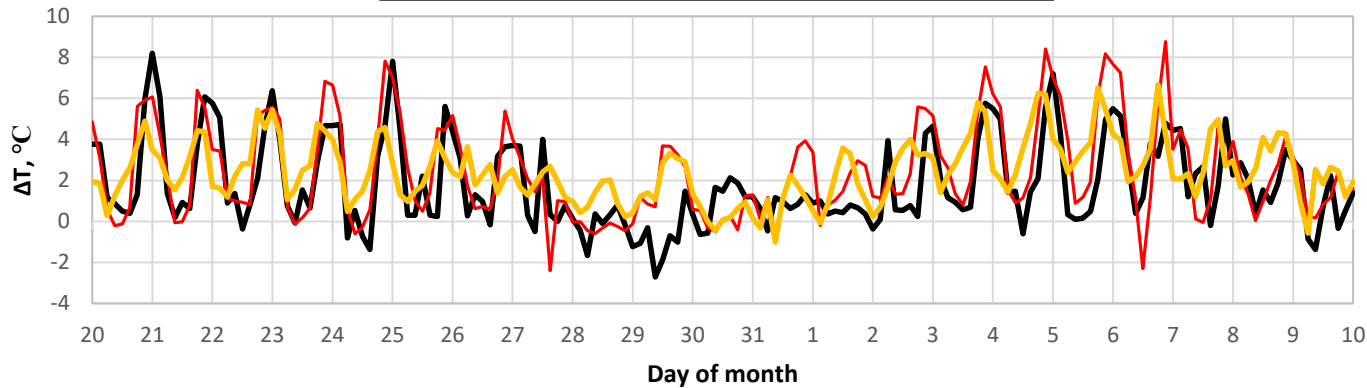
TERRA-URB vs TEB

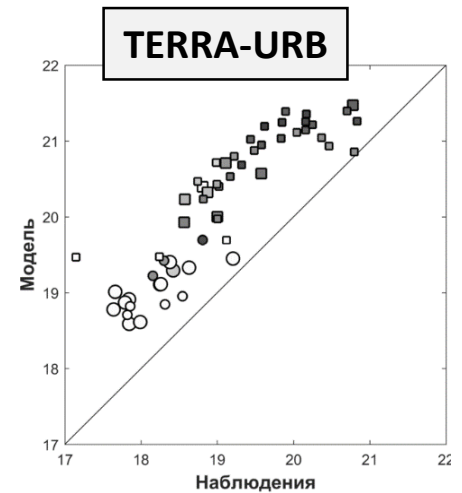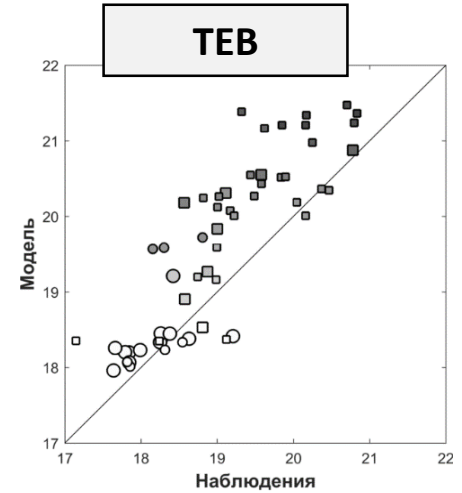UHI for Balchug station (city center)

UHI for MSU station (urban park)

Наблюдения   Модель (TERRA-URB)   Модель (TEB)

TEB

TERRA-URB

TERRA-URB vs TEB

TEB

TERRA-URB

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

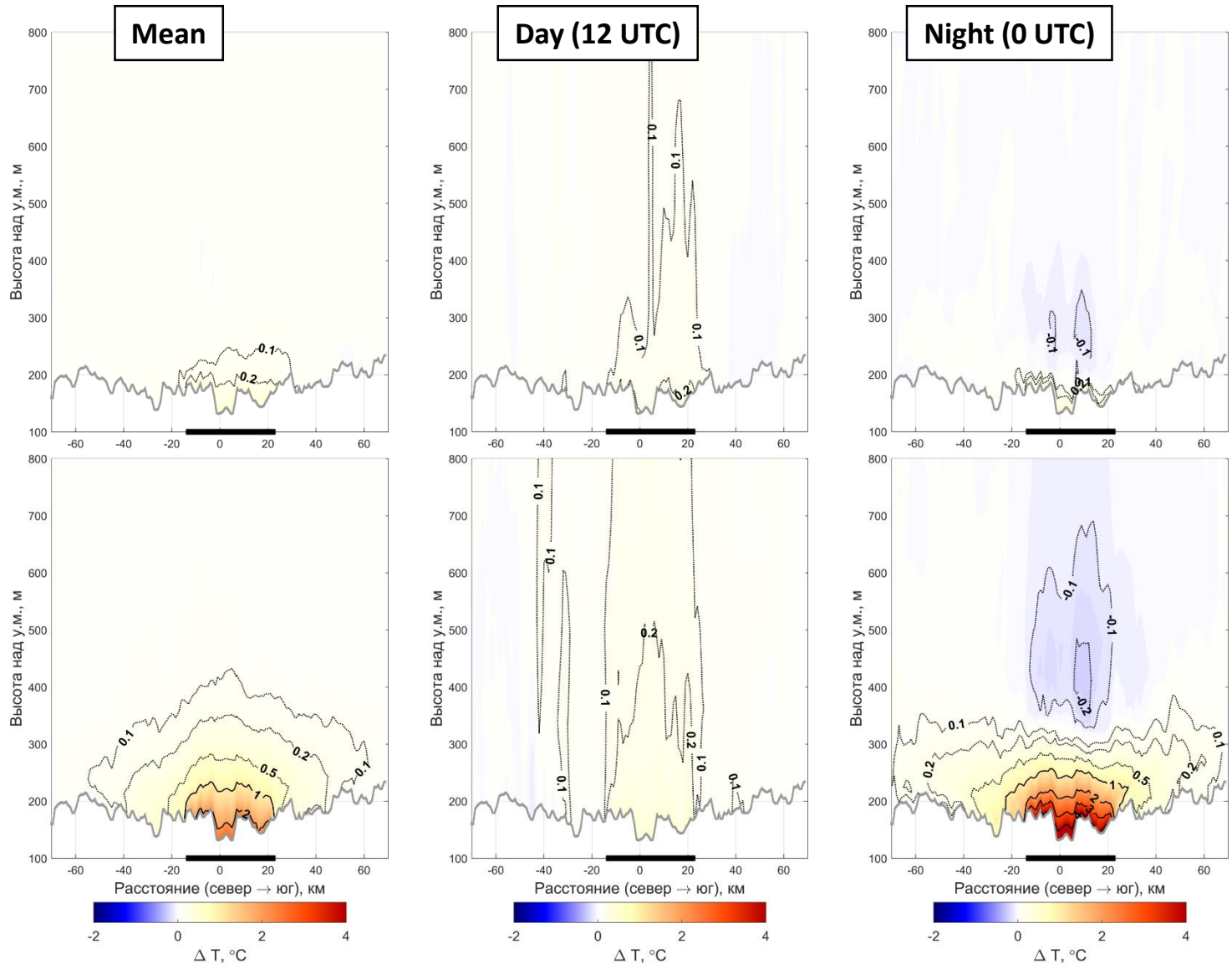$\Delta T = T - T_{ref.\ rural\ mean}$
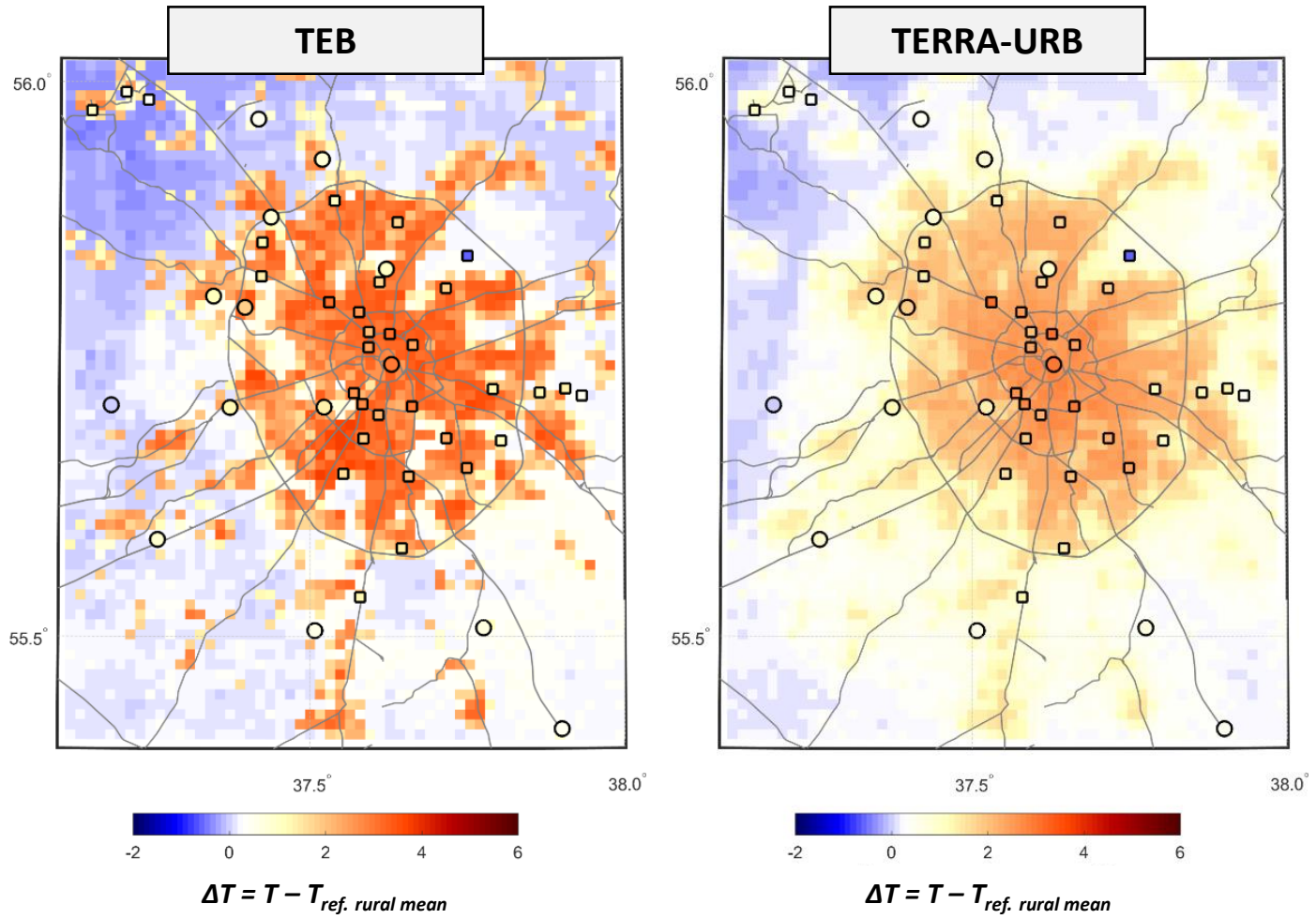
Mean values for summer 2014

TERRA-URB vs TEB

TEB

TERRA-URB

Mean values for summer 2014

Does usage of OSM data provides any improvements?

List of numerical experiments for urban domain (1 km)			
Name	**Turb. diffusion options**	**Urban fraction data**	**Urban morphology parameters data**
noURB	Tuned	no urban fraction	
CTRL		OSM	building parameters from OSM
noTUN	Default		
noOSM	Tuned	Globcover	**Default values** are used for **all model cells** (H/W = 1.5, roof fr. = 0.67, building height = 15)
noOSM_MSK			**Means** of OSM-derived values are used **for all model cells** (H/W = 0.35, roof fr. = 0.18, height = 22)

| RMSE for nocturnal temperatures, °C				
Experiment name	**R**ural stations* (out of 25 km from center)	**Urban** stations* (within 25 km from center)	Balchug st. (city center)	MSU st. (urban park)
noOSM	**1.63**	**1.97**	**1.57**	**2.14**
noOSM_MSK	**1.64**	**1.91**	**1.59**	**1.99**
CTRL	**1.57**	**1.61**	**1.64**	**1.68**
noURB	1.71	3.11	5.87	2.45
noTUN	1.58	1.80	2.94	1.59

Applications

CCLM + TERRA_URB as tool for analysis of different scenarios of urban change

noURB, CTRL, URBx2 and AHFx2 experiments are considered
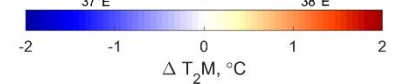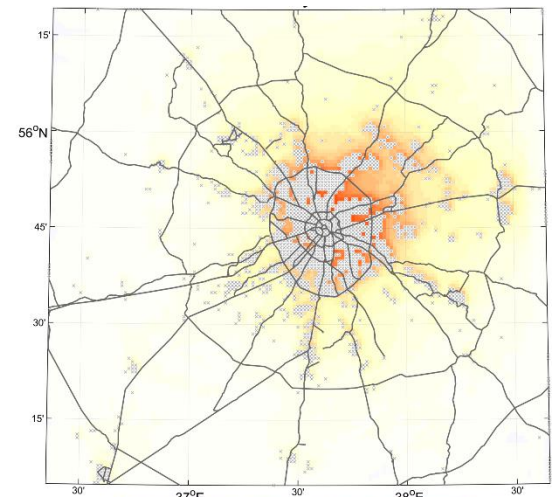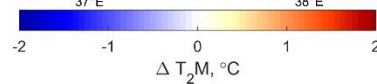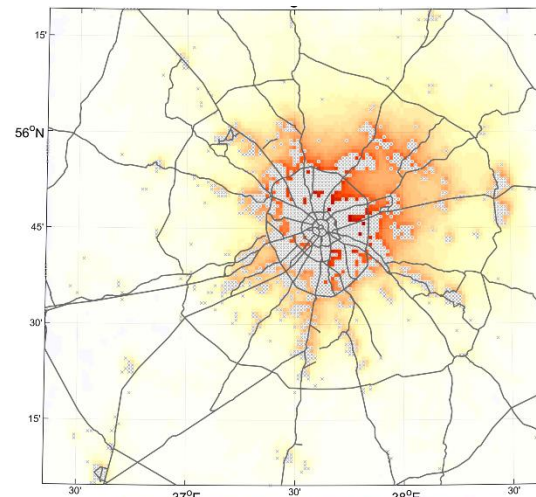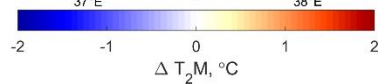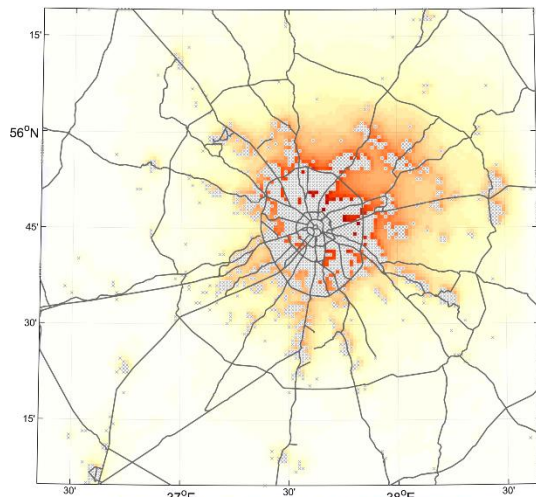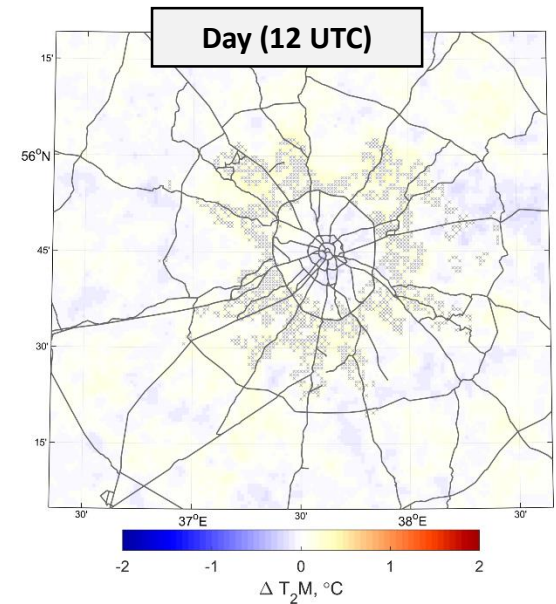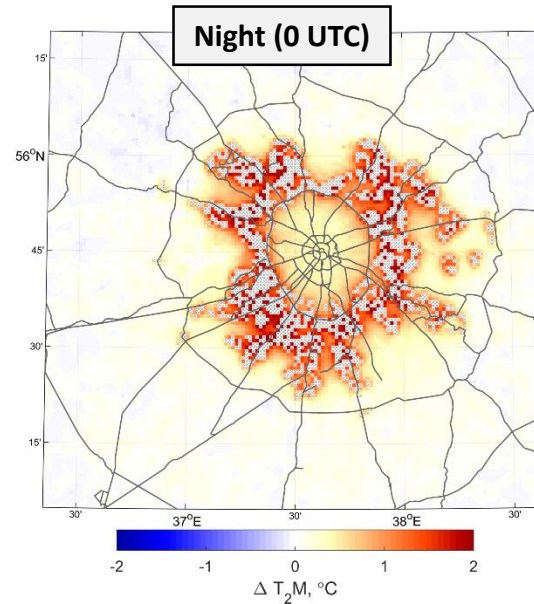
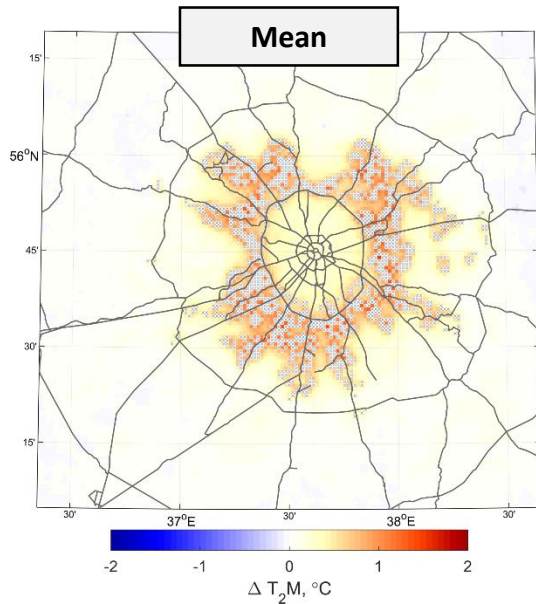# Temperature difference [CTRL – noURB]
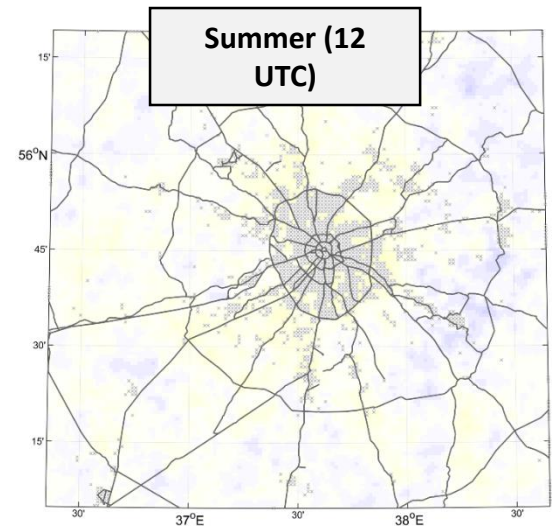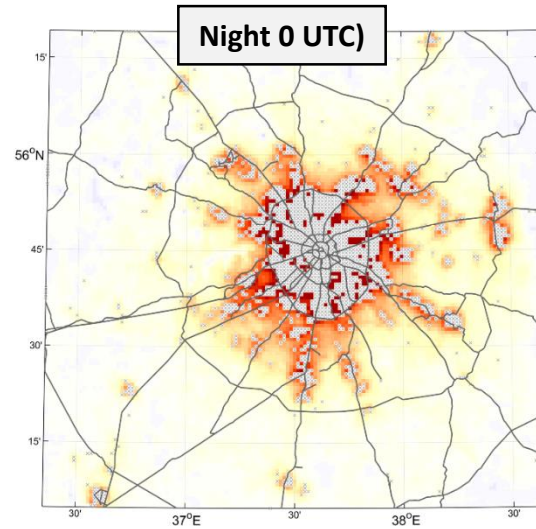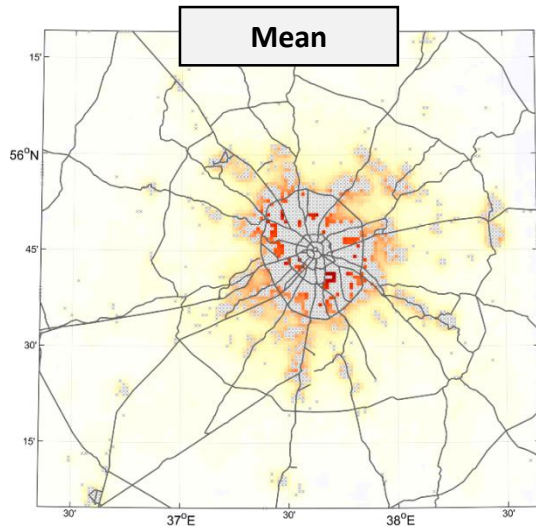
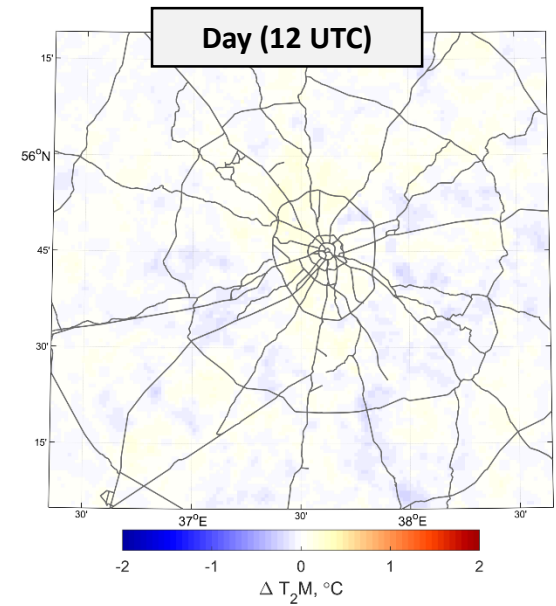**Summer season (2014)**

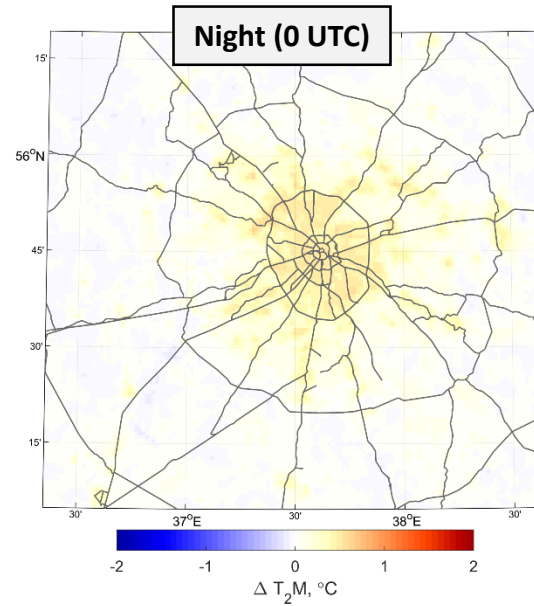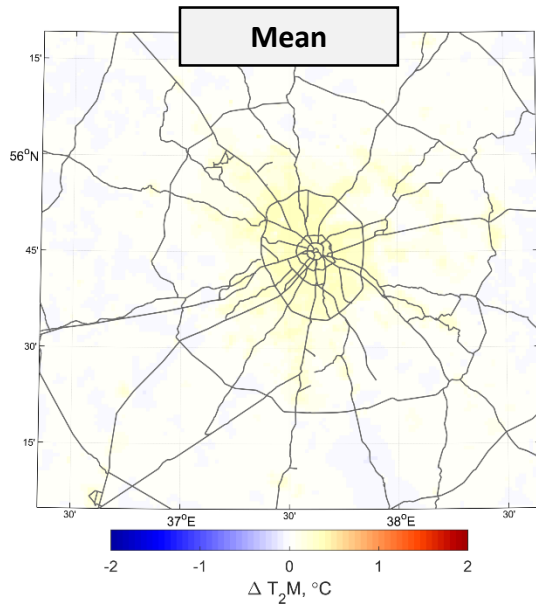**Winter season (2013-2014)**
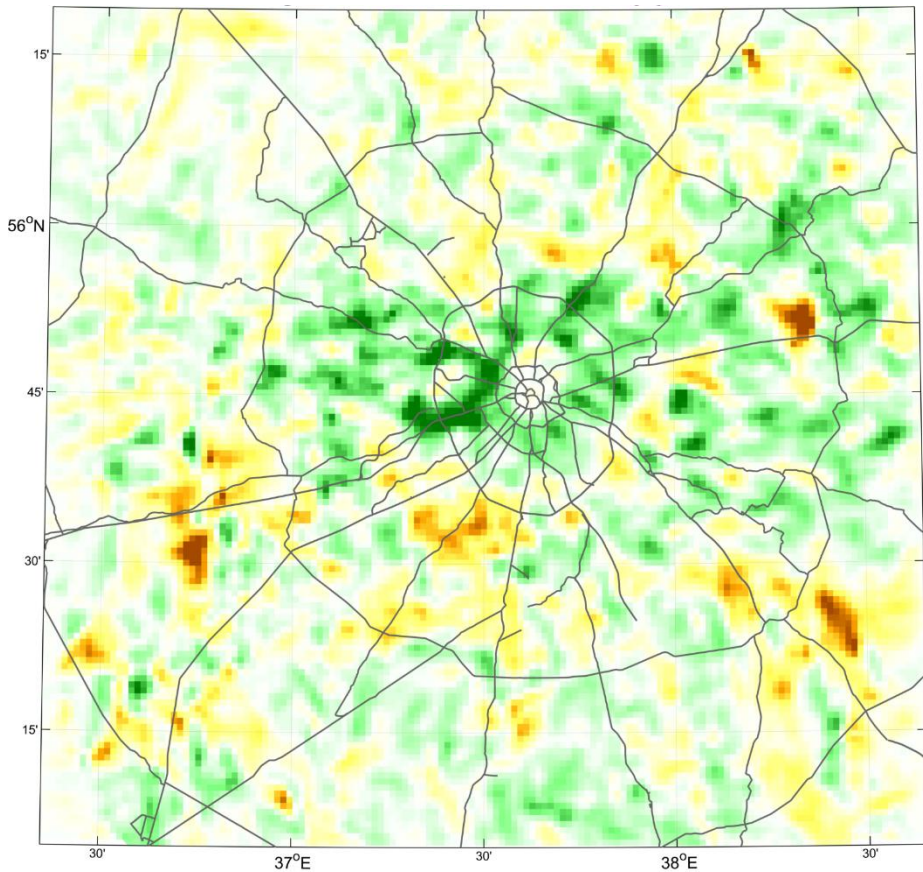
Temperature difference [URBx2 – CTRL]

Summer season (2014)

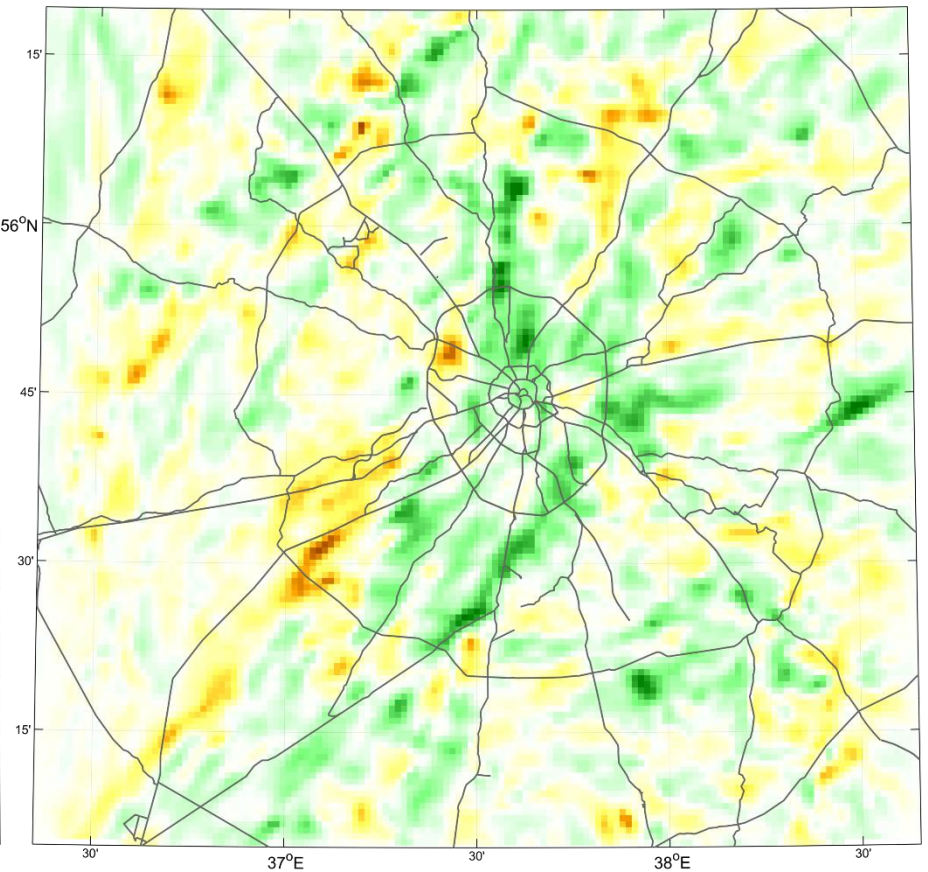# Temperature difference [AHFx2 – CTRL]

Summer season (2014)

Precipitation difference [CTRL – noURB]

Summer season

Δ of summer precipitation (2014)
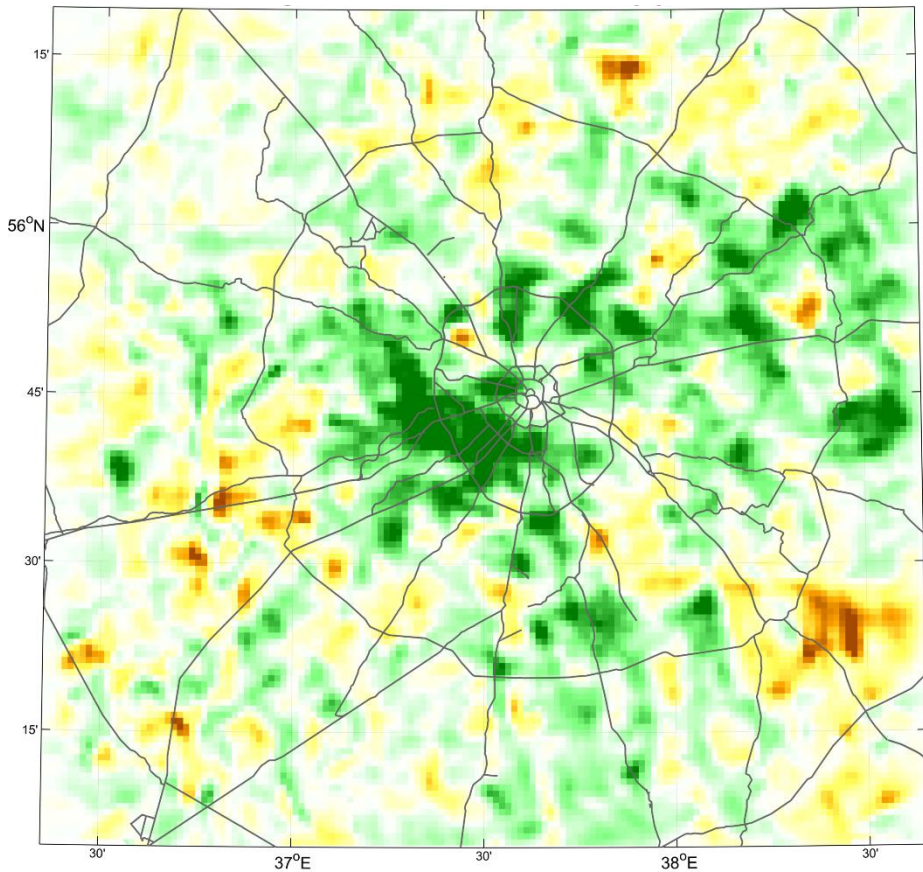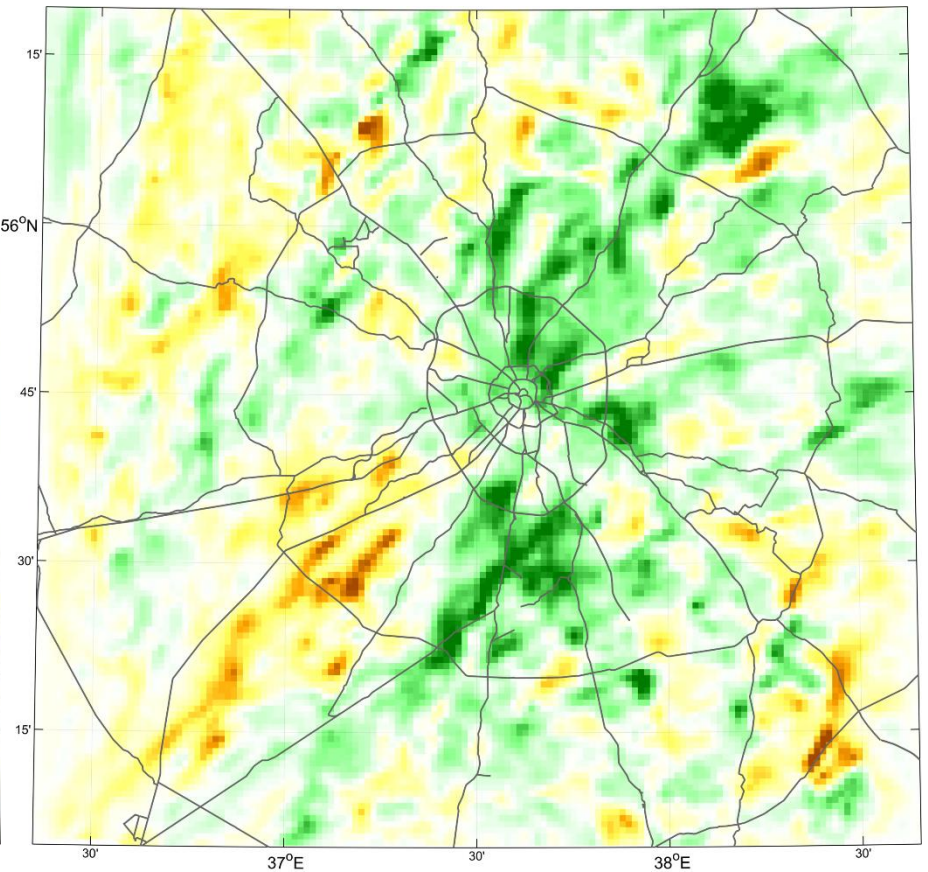
Δ of summer precipitation (2015)

Precipitation difference [URBx2 – noURB]

Summer season (2014)

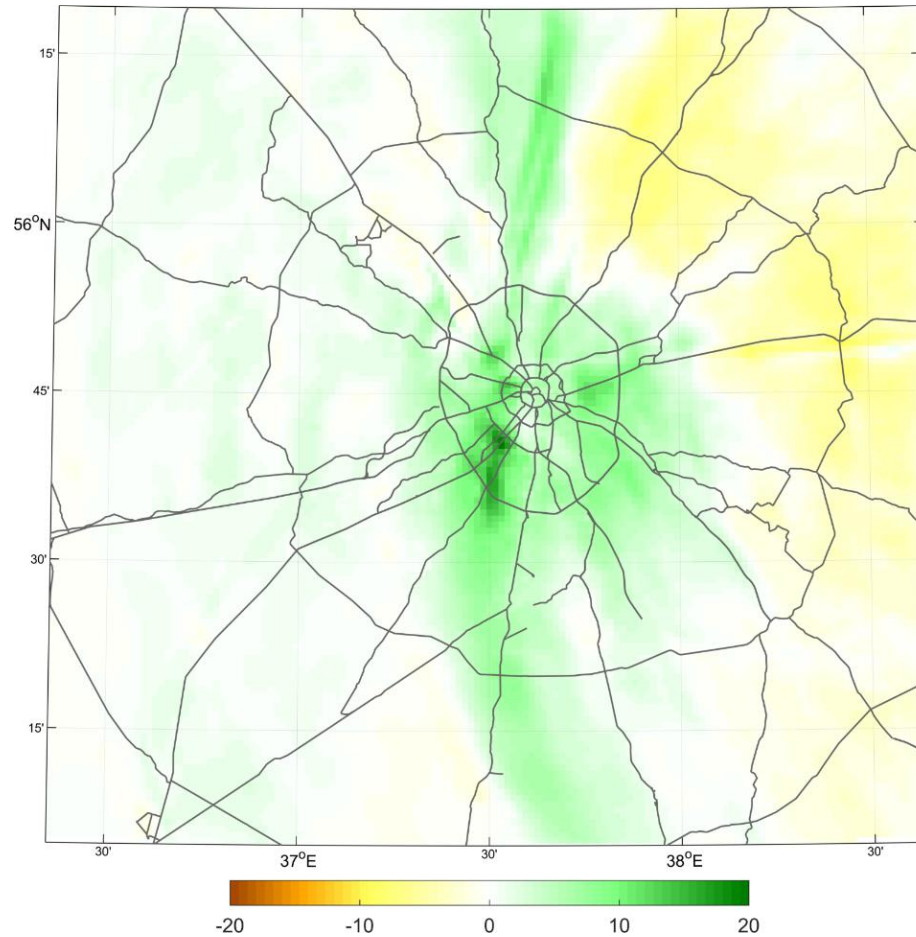Δ of summer precipitation (2014)

Δ of summer precipitation (2015)

Precipitation difference [CTRL – noURB]

Winter season

Δ of winter precipitation (2013-2014)

Additional slides

Vertical extent of urban heat island

Observation data

"Triada-II" experiment

- Measurements by microwave temperature profilers at one urban point (MSU) and two suburb points

- Vertical range of measurements:
  0 – 1000 m

- Period of observations:
  17 April – 3 July 2015 года

Day (12 UTC)

Night (0 UTC)

Mean

All cases with UHI > 4 °C