ICCARUS 2019, Offenbach, Germany, 18-20 March 2019

Lomonosov Moscow State University

Moscow megacity as a test-bed for high-resolution modelling systems:

an overview and application for evaluation of the two versions of COSMO model

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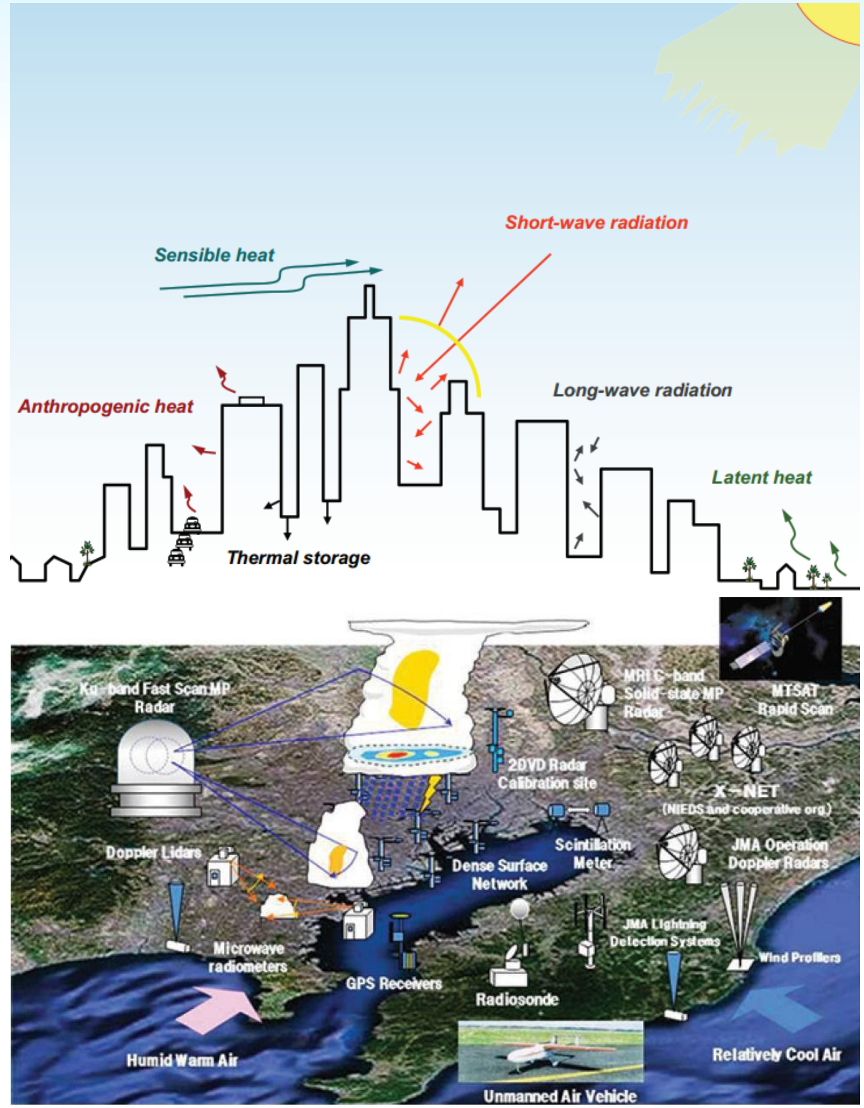
Motivation

- ❑ Models are good, but still not perfect :(
- ❑ The **verification and calibration** is an essential part of the model development
- ❑ There is a public and scientific interest for high resolution weather forecasts and climate simulations for urban areas, but:
  - o Urban climate features are very complex. They are shaped by different processes and scales.
  - o Regular meteorological observations in urban areas are very rare, especially above the roof level
- ❑ Need for **"urban climate laboratories",** which could provide detailed canopy-layer and ABL observational for the verification of the high-resolution urban weather & climate models.



Dense urban observations in Tokyo
(Nakatani et al., 2014, BAMS)

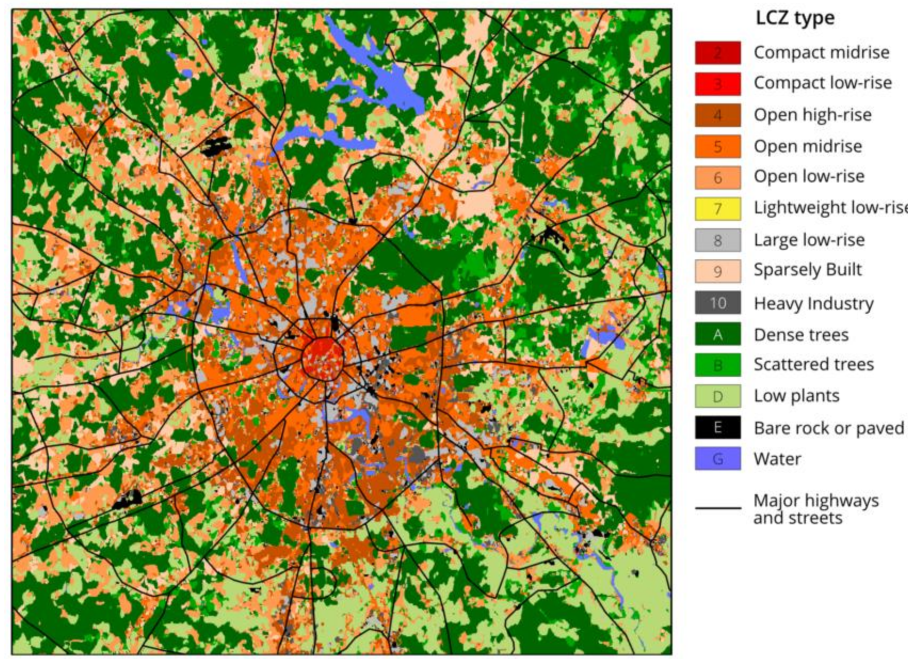
Outline

1. Overview of the regular weather and ABL observations in Moscow megacity and Moscow region.
2. Verification and intercomparison of the two model versions (5.0_clm9 and recent 5.05_urb1) for Moscow
3. Plans and prospects for further research

Why Moscow megacity?

Key features of Moscow megacity as place of urban climate research & urban model development:

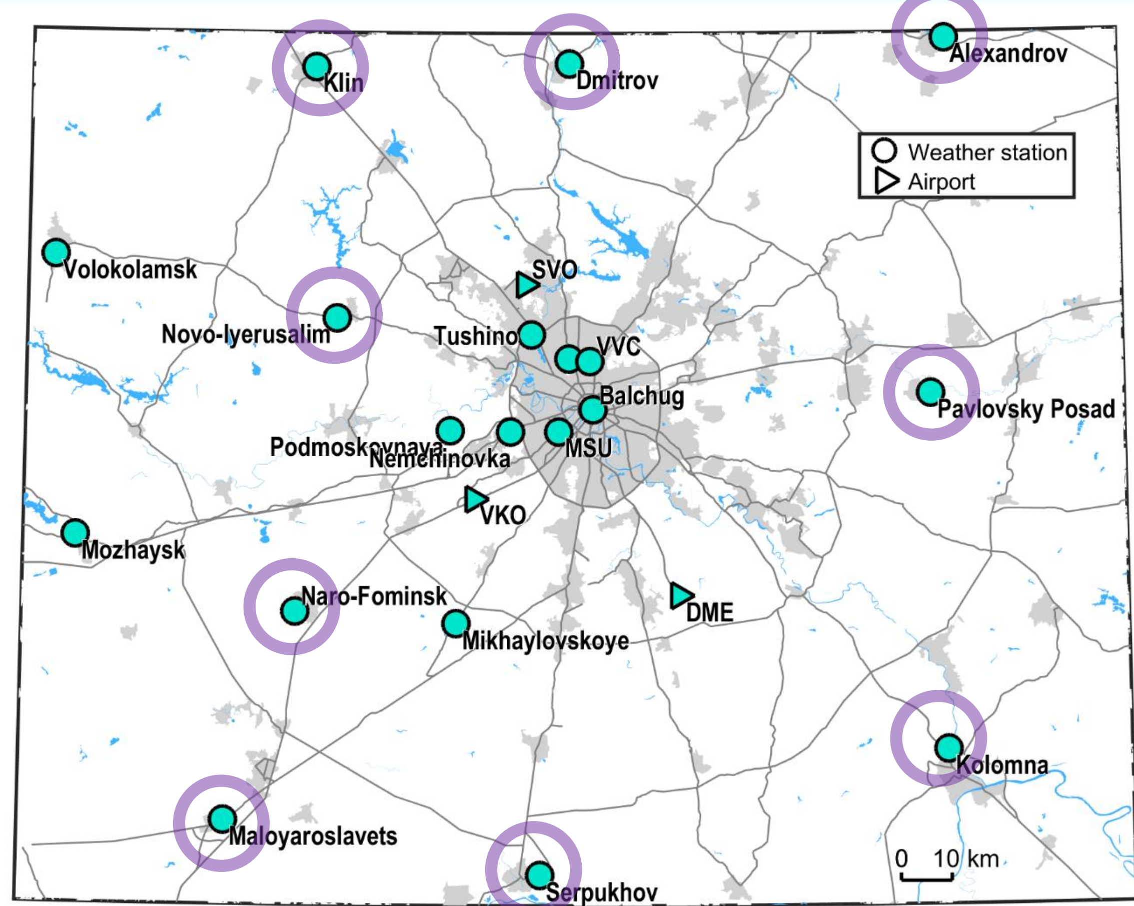
- ✓ Biggest agglomeration in Europe (≈ $17 \cdot 10^6$ people)
- ✓ Flat and homogenous landscape around the city
- ✓ Continental climate with warm summer and cold winter
- ✓ Strong UHI with mean annual intensity of 2 °C and maximum intensity up to 13 °C (Lokoschenko, 2014)
- ✓ Specific building features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



Local climate zones (Samsonov & Tribub, 2017)

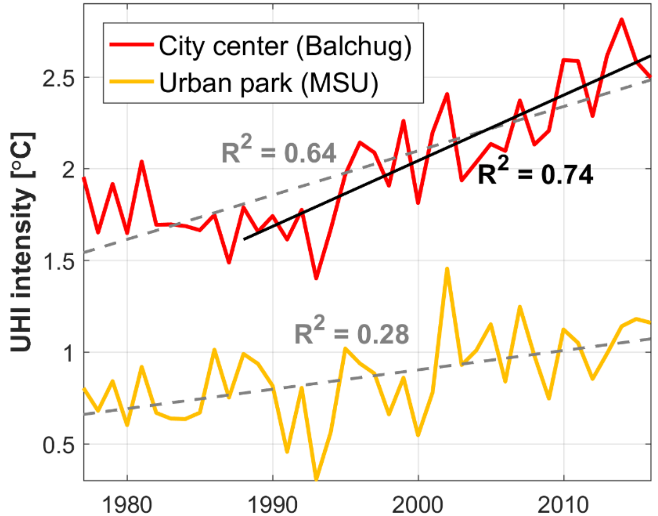
Weather observations in Moscow region

Long-term (historical) weather observations



Balchug station
(downtown, 500 m from Kremlin)

Meteorological observatory of Moscow State University (MSU)

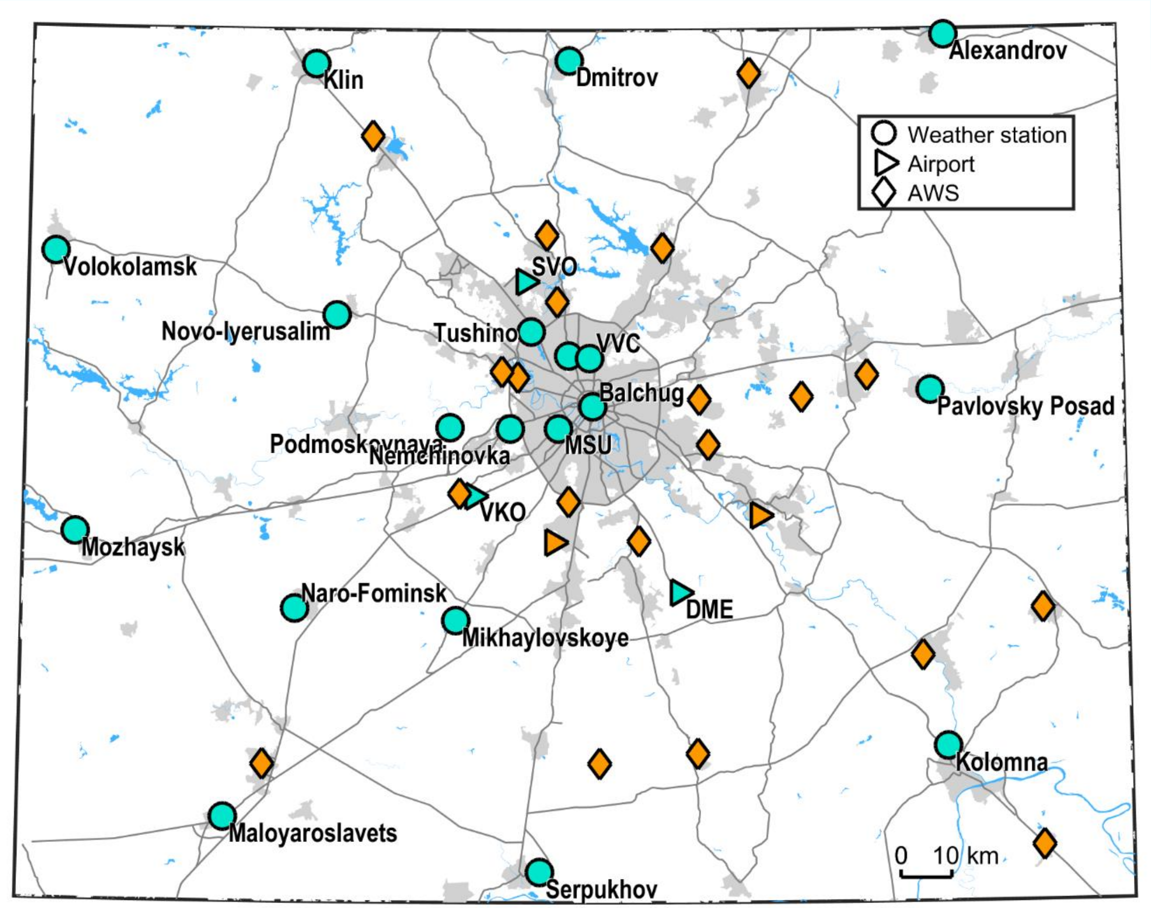


Trends of the summer UHI intensity (1977-2016)

UHI intensity – temperature deviation from mean rural value, averaged over 9 stations around Moscow

Weather observations in Moscow region

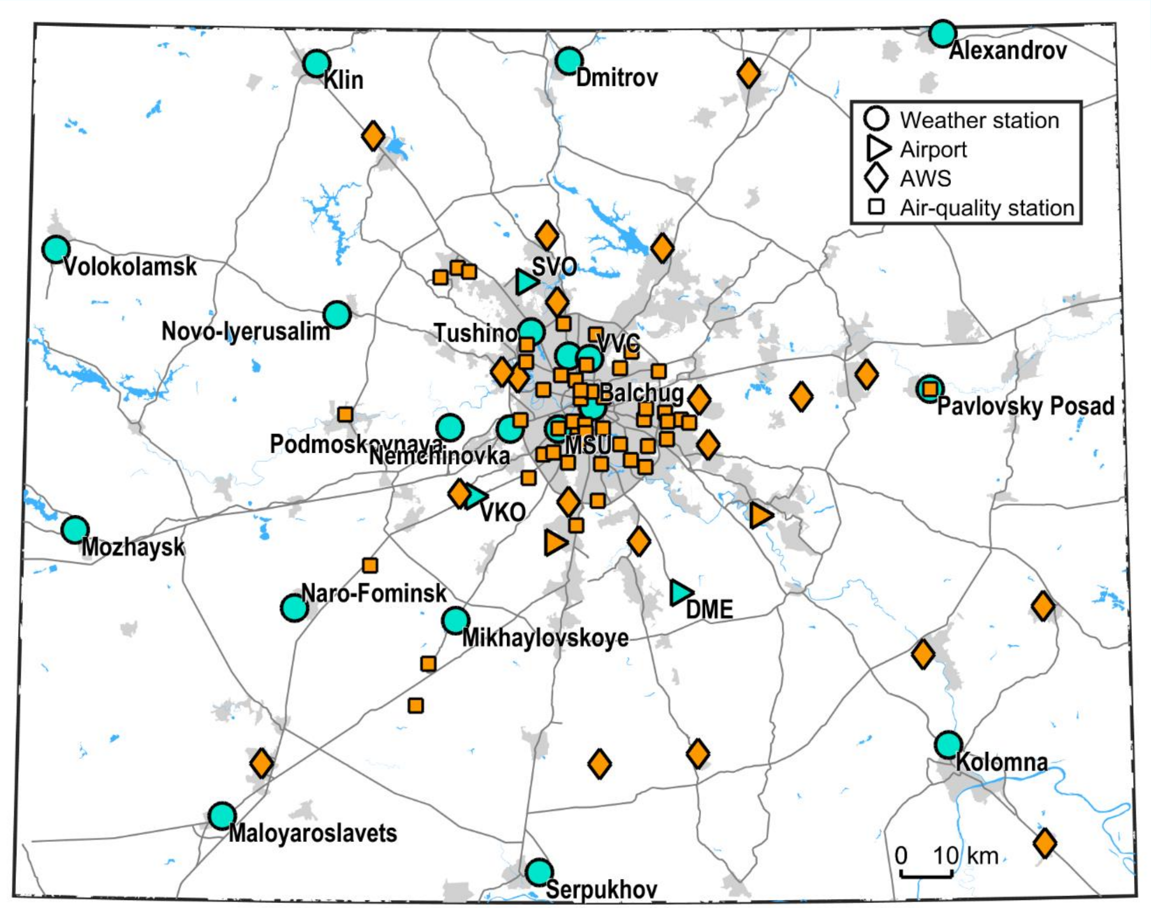
New dense meteorological networks



New automatic weather stations (AWSs) of Roshydromet
(since 2013)

Weather observations in Moscow region

New dense meteorological networks



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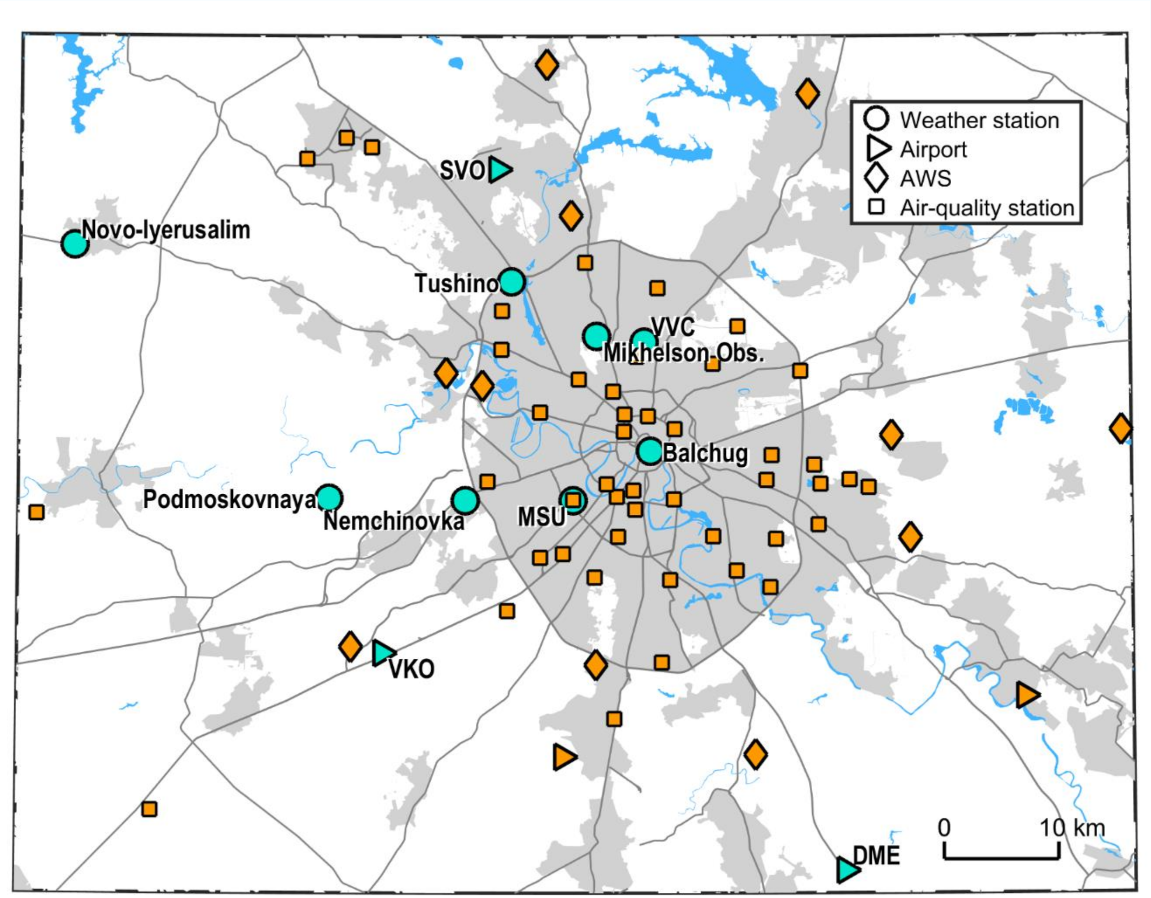
Air-quality monitoring stations of Mosecomonitring
(since 1990th)

Weather observations in Moscow region

New dense meteorological networks



New automatic weather stations (AWSs) of Roshydromet
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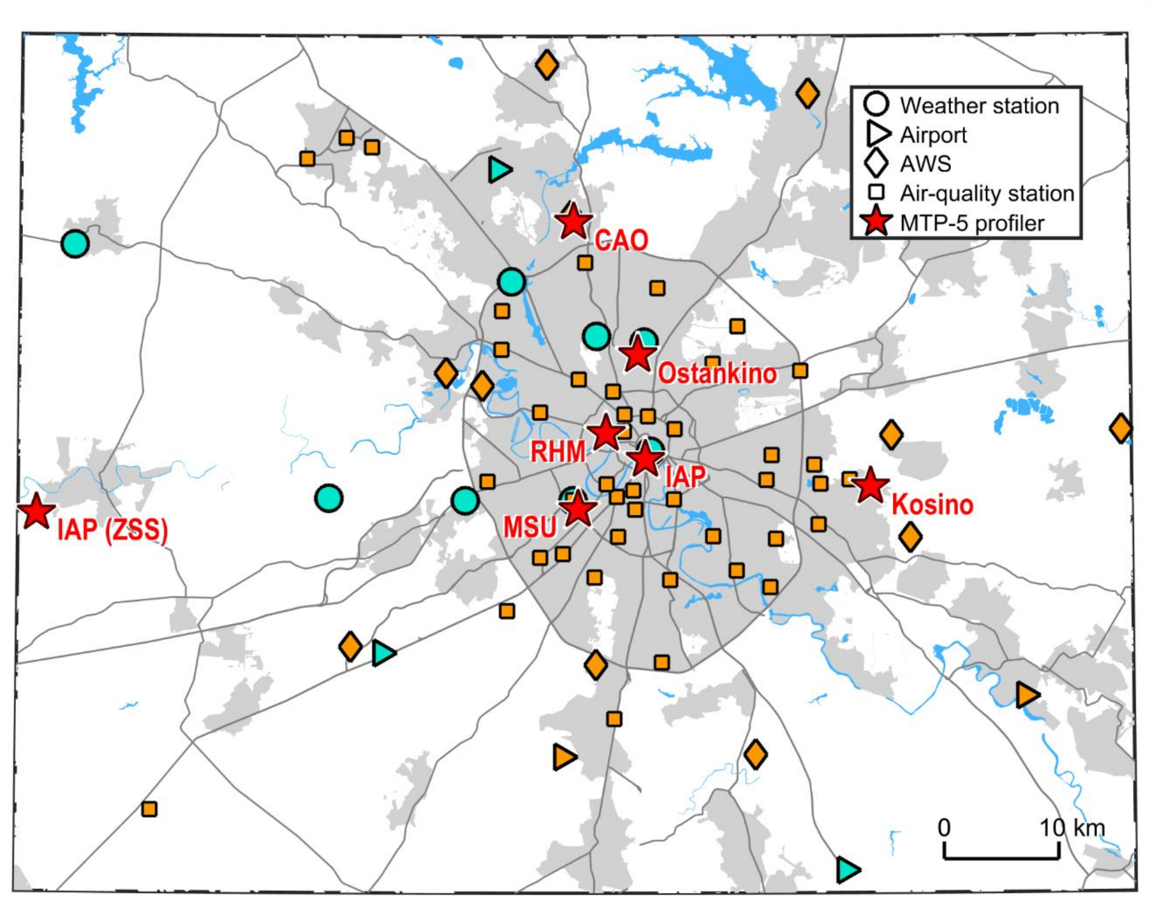
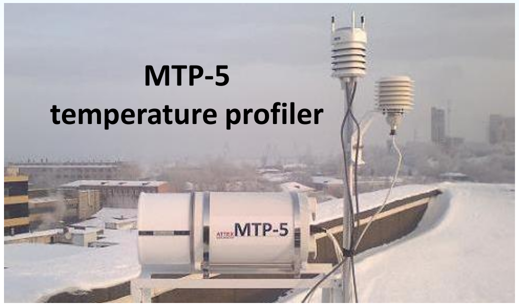
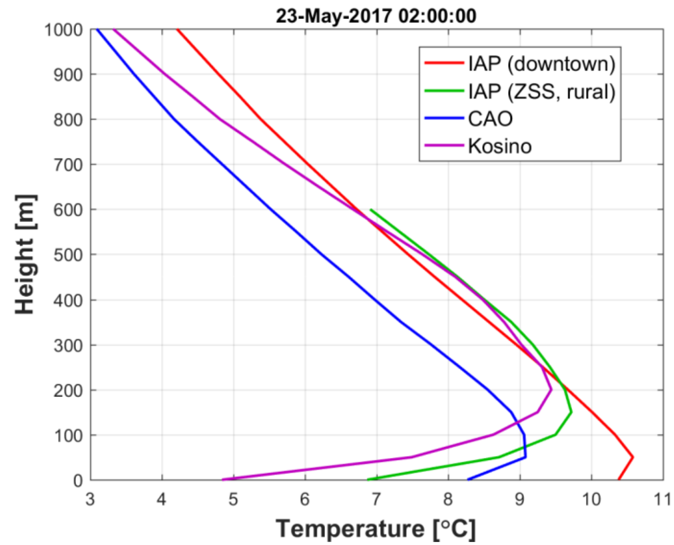
Air-quality monitoring stations of Mosecomonitring
(since 1990th)

Weather observations in Moscow region

ABL observations: microwave temperature profilers



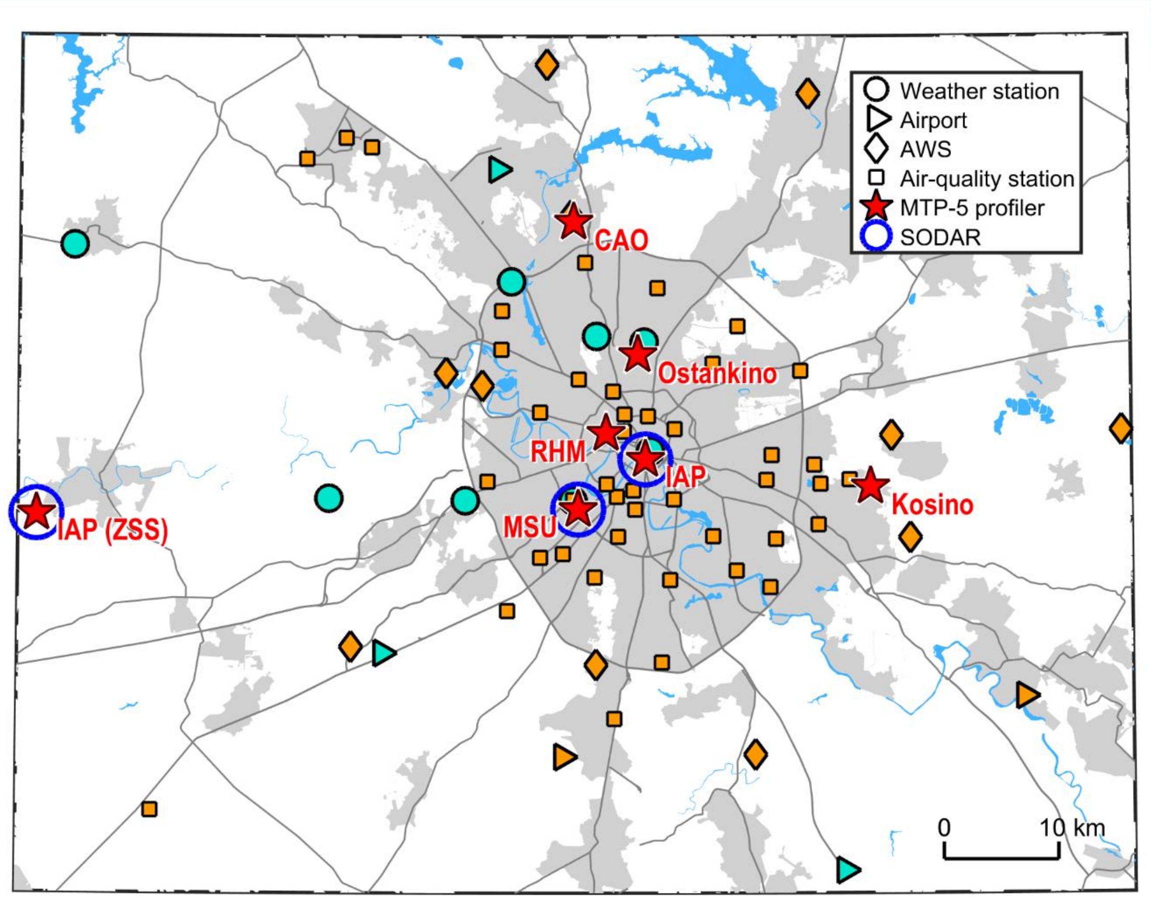


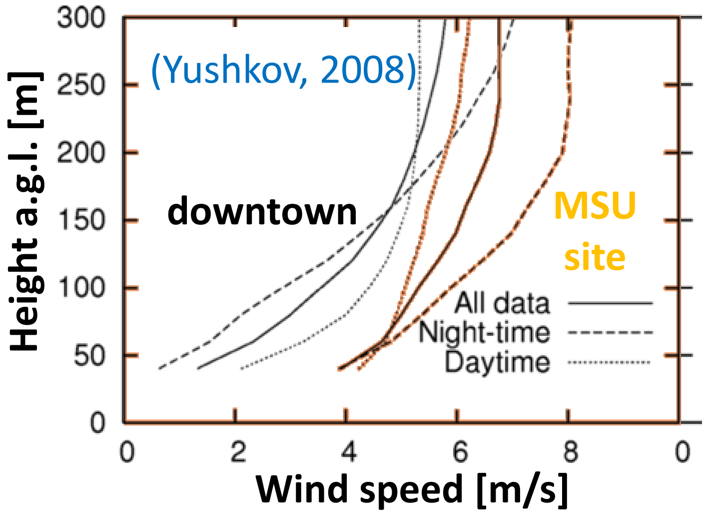


Thanks to Dr. I.A. Repina (IAP), A.Yu. Artamonov (IAP), E.A. Miller (CAO) and to Mosecomonitoring agency

Weather observations in Moscow region

ABL observations: acoustic wind profilers (SODARs)





Weather observations in Moscow region

Other observations (too many of them to describe in detail)

1. Detailed radiation and aerosol observations in the city at the MSU meteorological observatory and in rural area at the IAP ZSS site (mode details by Chubarova et al.)
2. Air quality data from Mosecomonitoring
3. Regular radio sounding in Dolgoprudny (CAO)
4. Meteorological radars
5. Eddy-covariance flux measurements (LAMP project, http://lamp-lab.ru/)

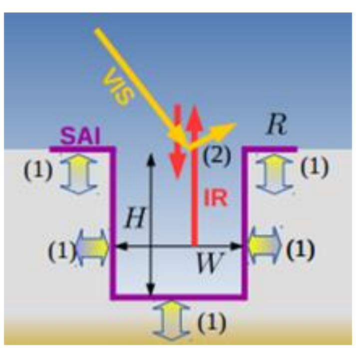
General problem: the data belongs to different organizations, so its collection and usage is not so easy

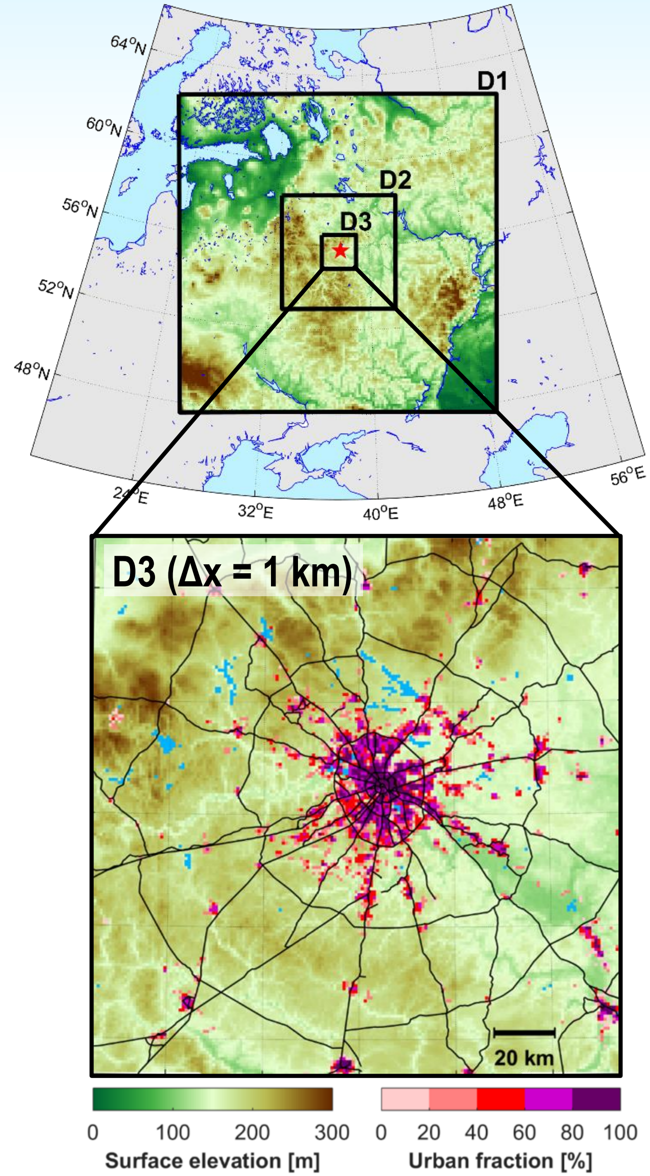
Let's switch to modelling!

Previous modelling experience

- ❑ **COSMO-CLM regional climate model** (COSMO 5.0_clm9 + TERRA_URB2.2)
- ❑ **Continuous simulations for 10 summer seasons (1 month of spin up) and a few winter seasons**
- ❑ 3 steps of dynamical downscaling

  (12 km ⟶ 3 km ⟶ **1 km**)
- ❑ Boundary conditions for the fist domain from ERA-Interim reanalysis + spectral nudging for U, V and T
- ❑ Tuned model configuration including reduced turbulent mixing in stable condition according (Cerenzia et al., 2014), new evaporation & canopy schemes (Schulz, 2016; Schulz, Vogel, 2017)
- ❑ **TERRA_URB urban scheme** (Wouters et al., 2015; 2016)



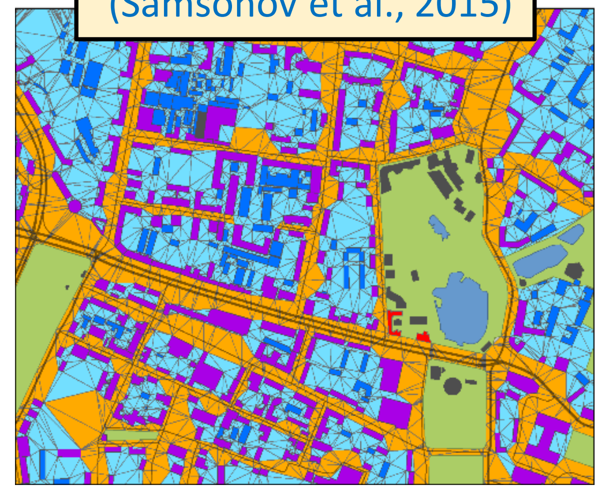


Urban canopy parameters

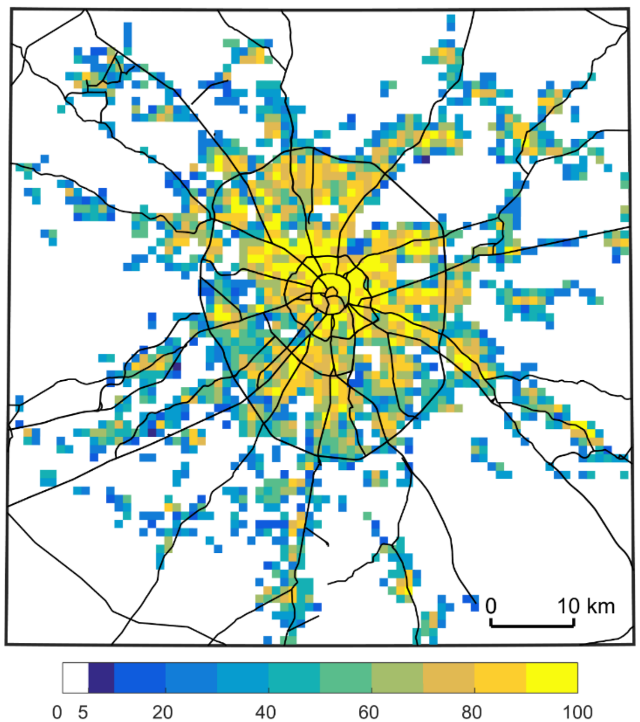
Required urban canopy parameters for TERRA_URB:

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

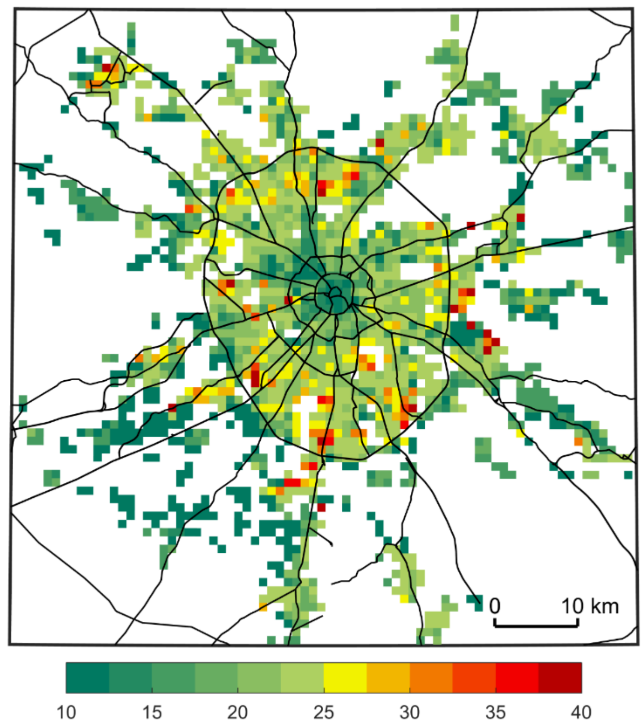
1) GIS-processing of OpenStreetMaps data (Samsonov et al., 2015)



2) Averaging over given model grid cells



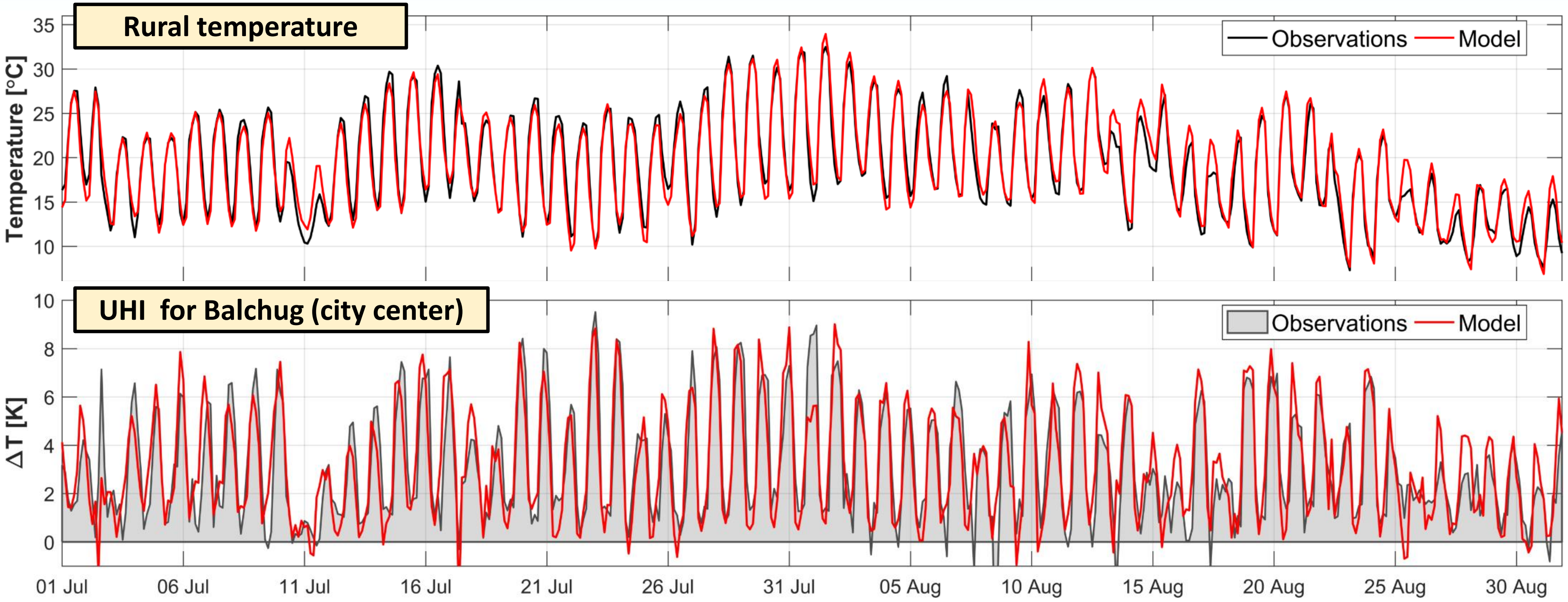
Urban area fraction [%]



Building height [m]

3) Calculation of the required parameters

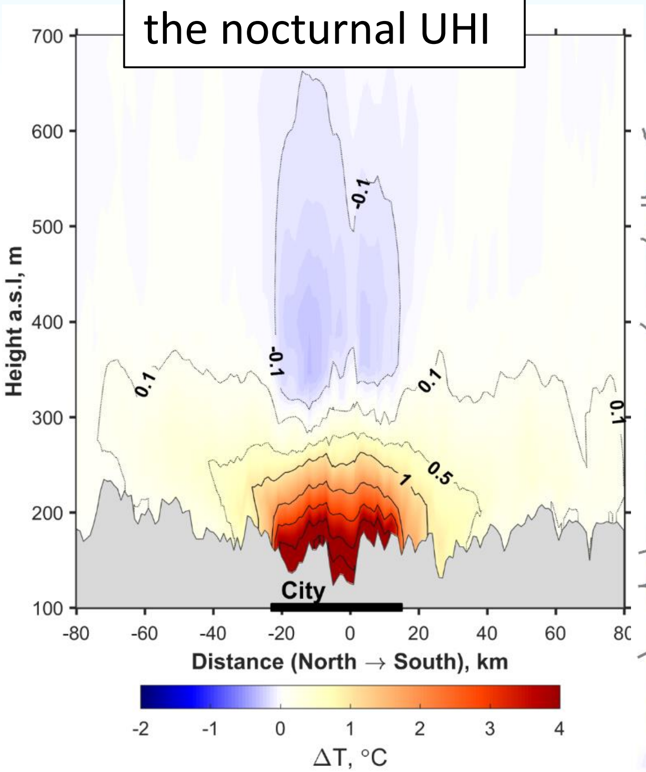
Previous modelling experience



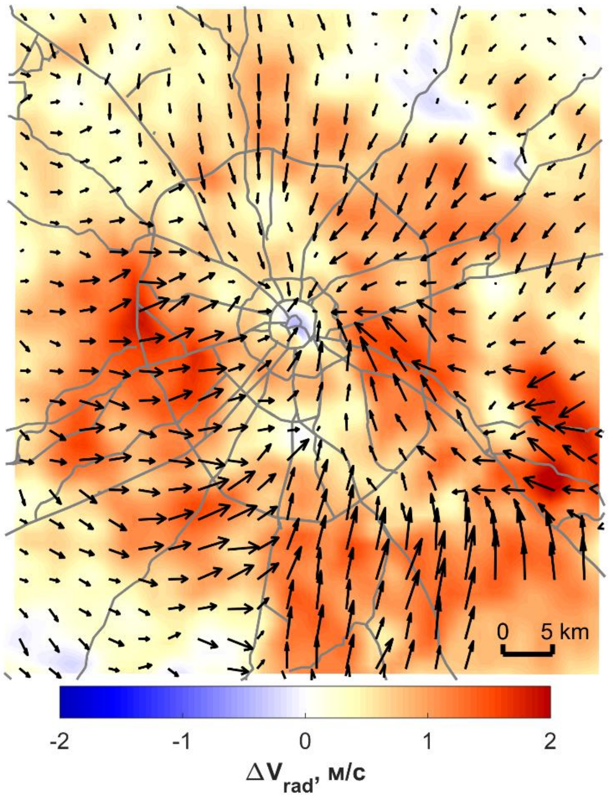
Some verification for summer 2014

Previous modelling experience

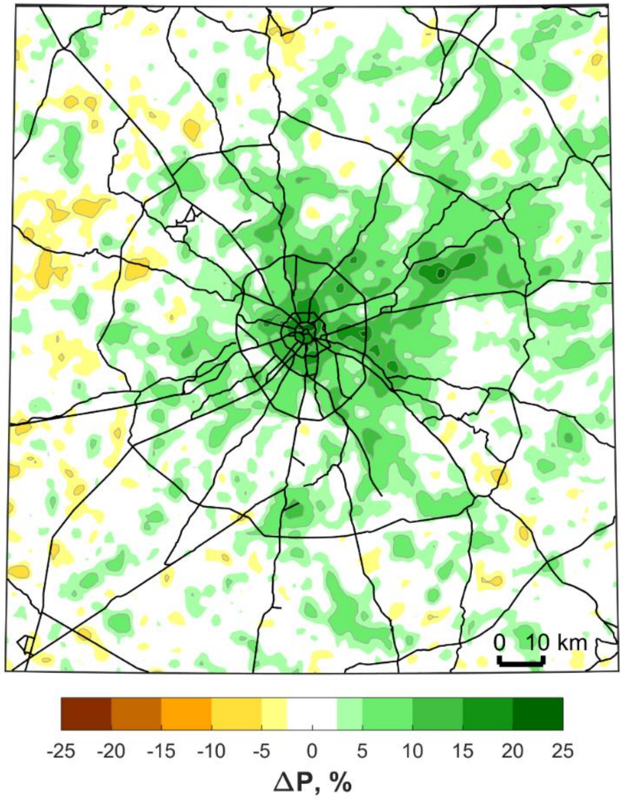
Vertical extent of the nocturnal UHI



Urban-induced mesoscale circulation ("urban breeze")



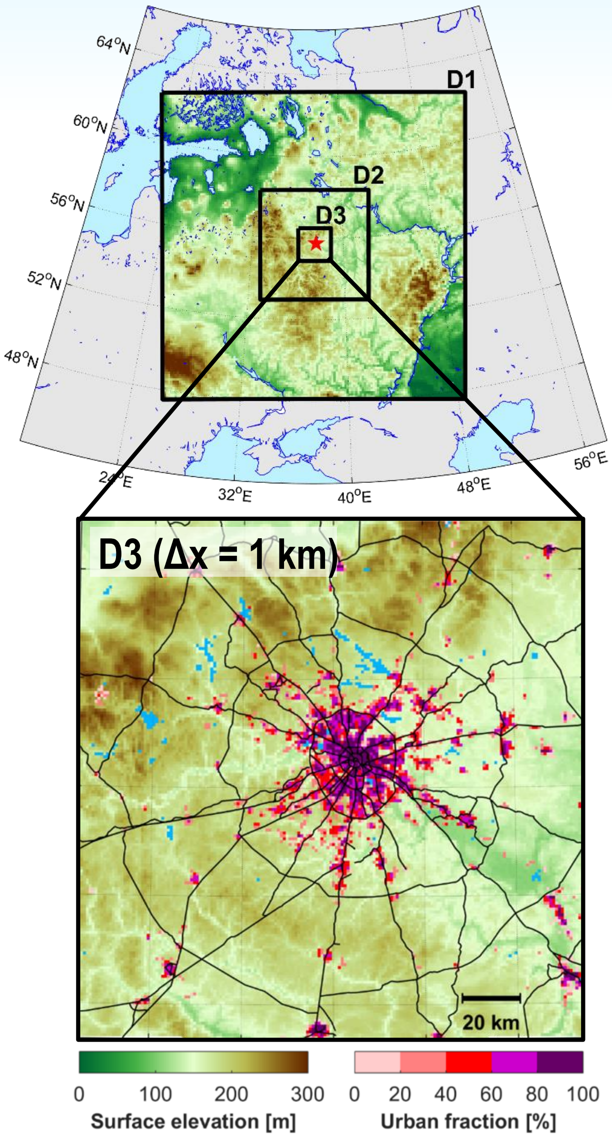
Urban-induced amplification of summer precipitation



Details in (Varentsov et al., 2018, Atmosphere)

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_5.05_urb1: implementation of the TERRA_URB scheme to the recent model version, developed within the framework of AEVUS PT. The key feature - new ICON physics. But some bugs are still under debugging :(
- 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**	**-****
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

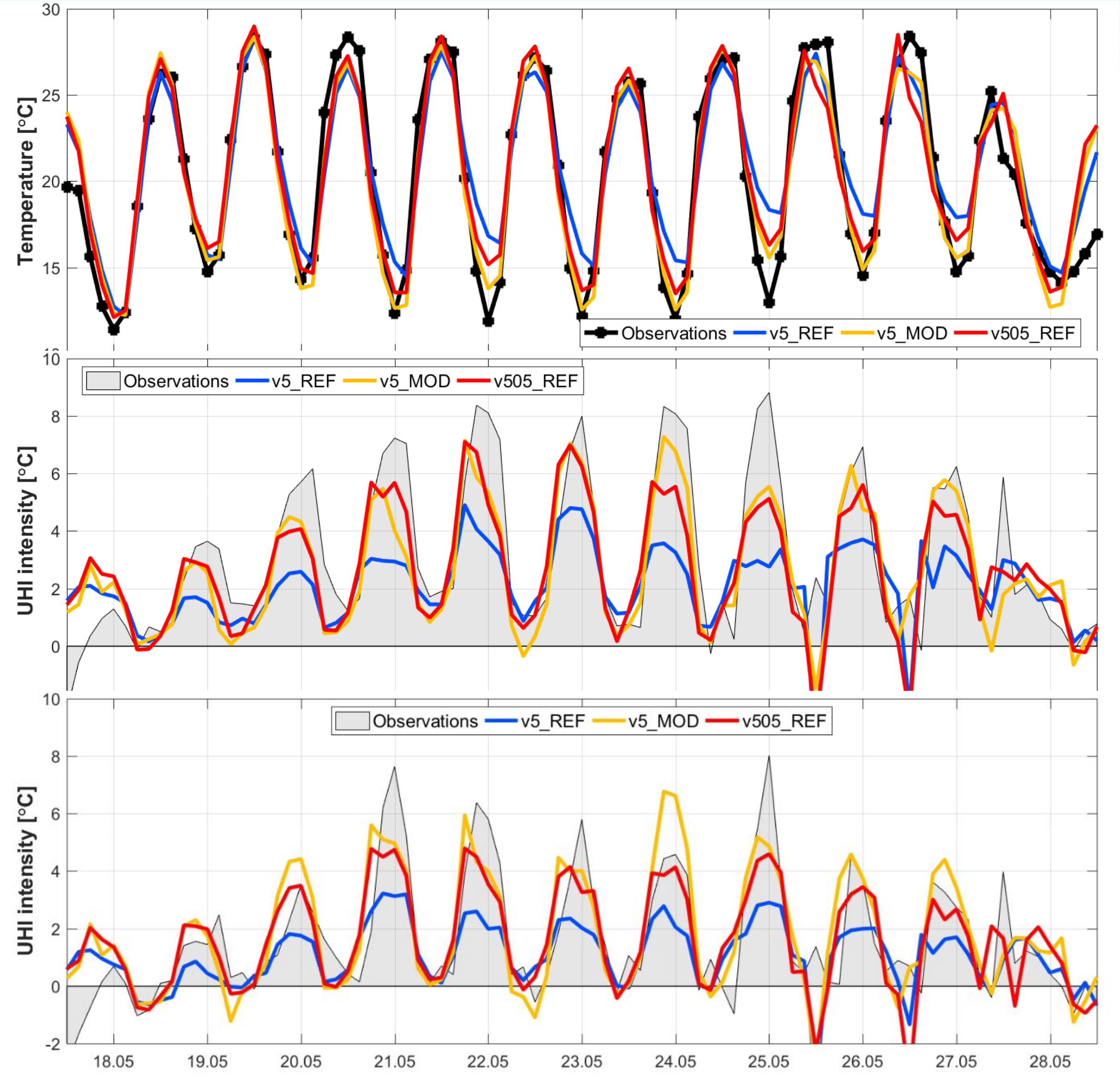
***Defaults for "new" physics**

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

**JP's skin-layer temperature scheme for 5.05_urb is still under debugging

Model verification (case 1: May 2014)

Temperature & UHI intensity dynamics



Mean rural temperature (averaged over 9 stations)

UHI intensity for the city center (Balchug)

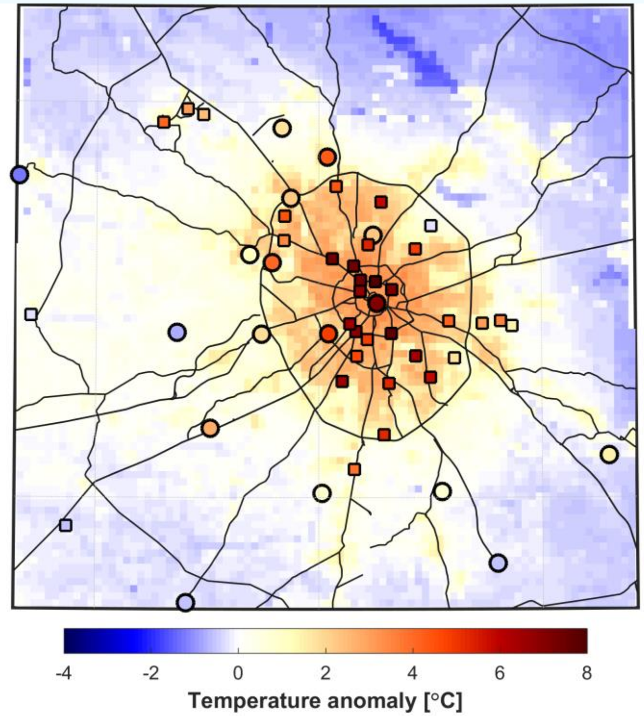
UHI intensity for the urban park (MSU)

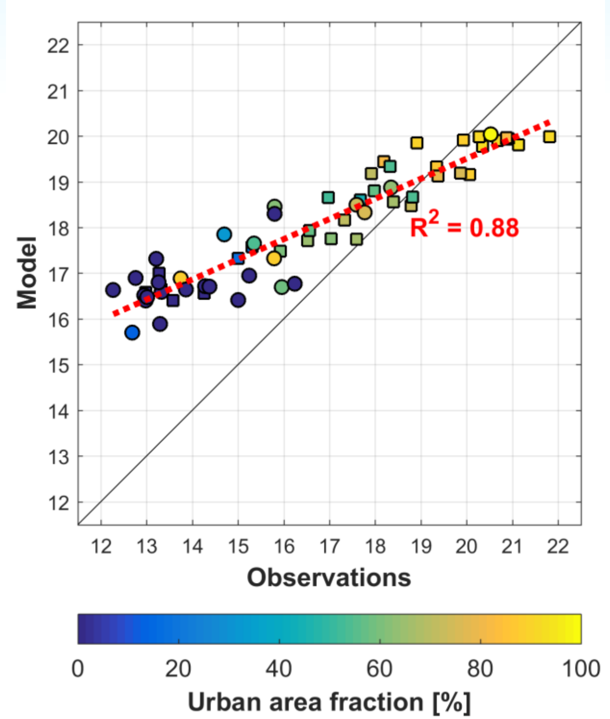
Model verification (case 1: May 2014)

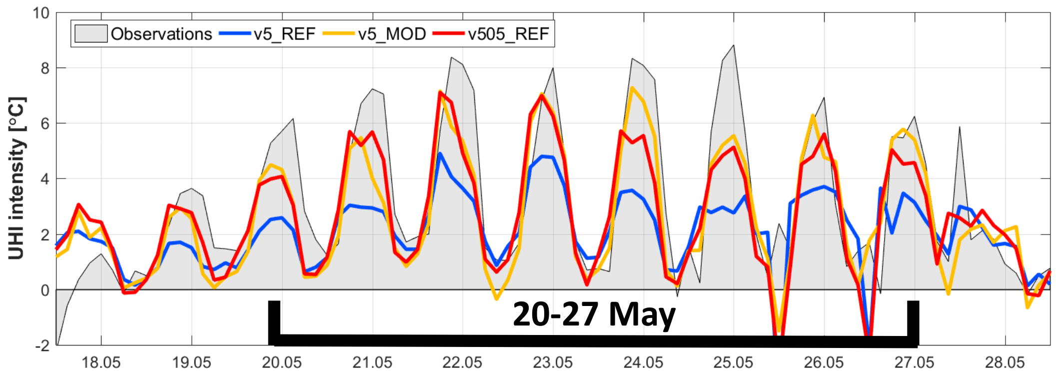
UHI spatial structure

Mean nighttime (0 UTC) temperatures over 20-27 May

v5_REF





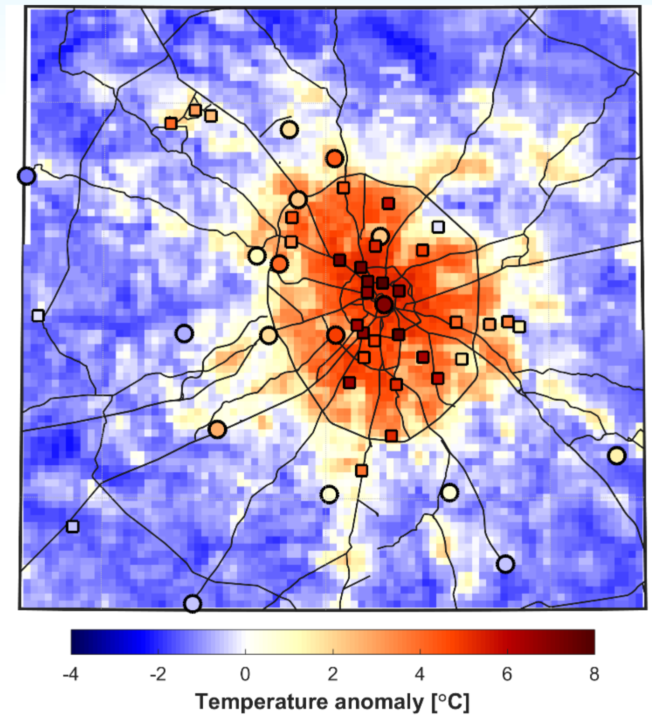


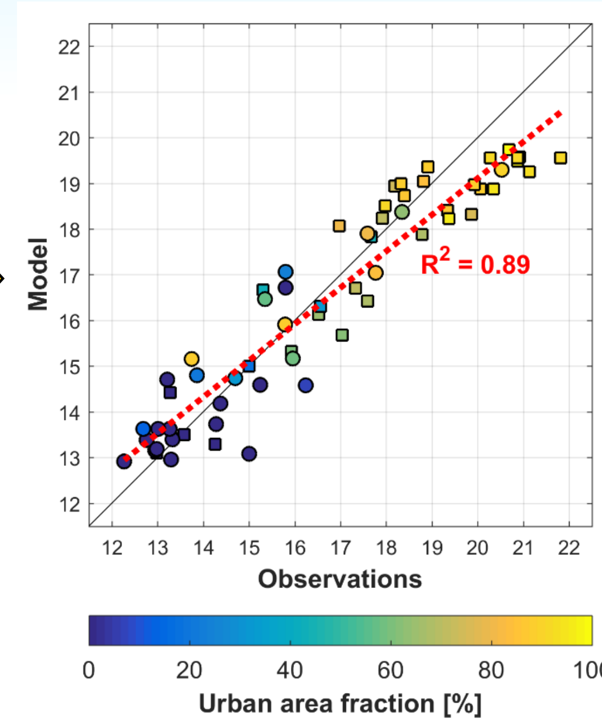
Model verification (case 1: May 2014)

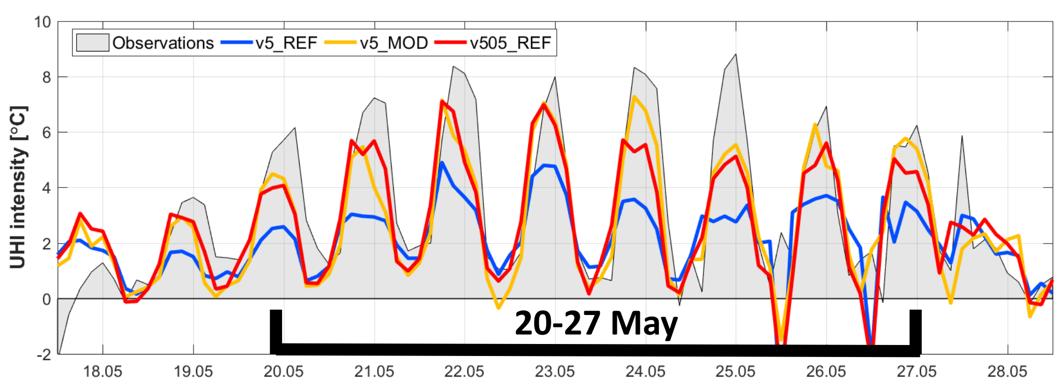
UHI spatial structure

Mean nighttime (0 UTC) temperatures over 20-27 May

v5_MOD





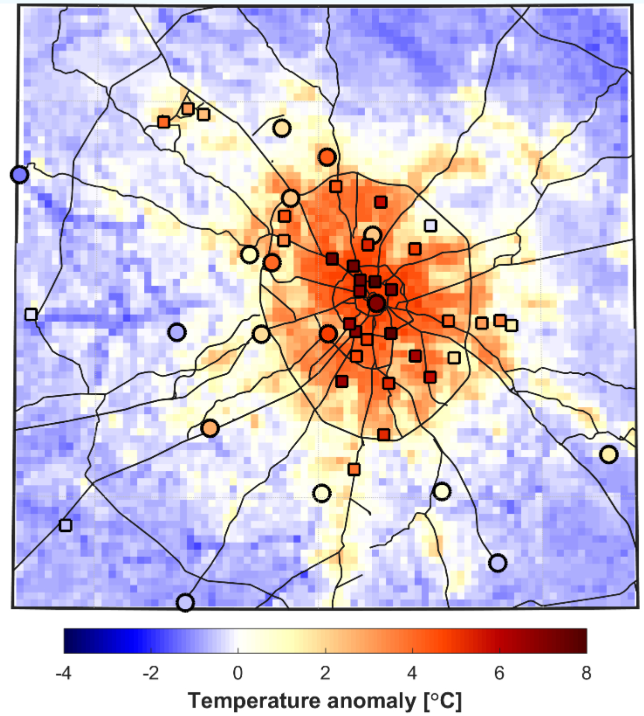


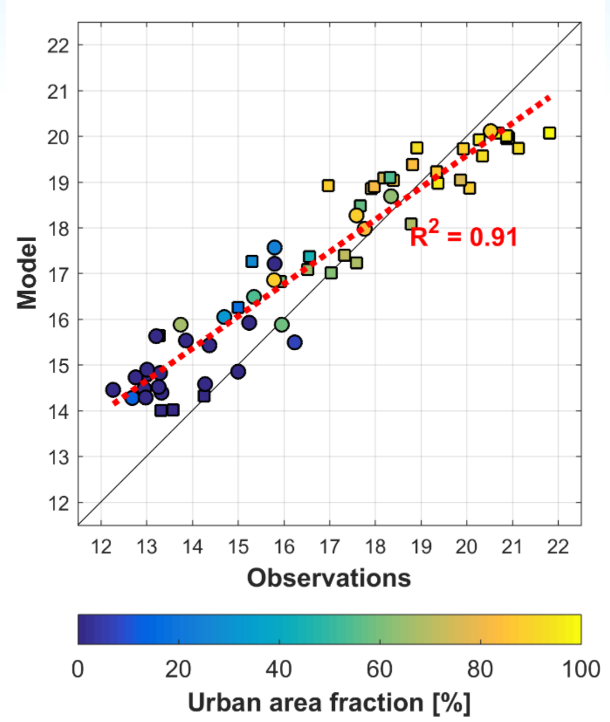
Model verification (case 1: May 2014)

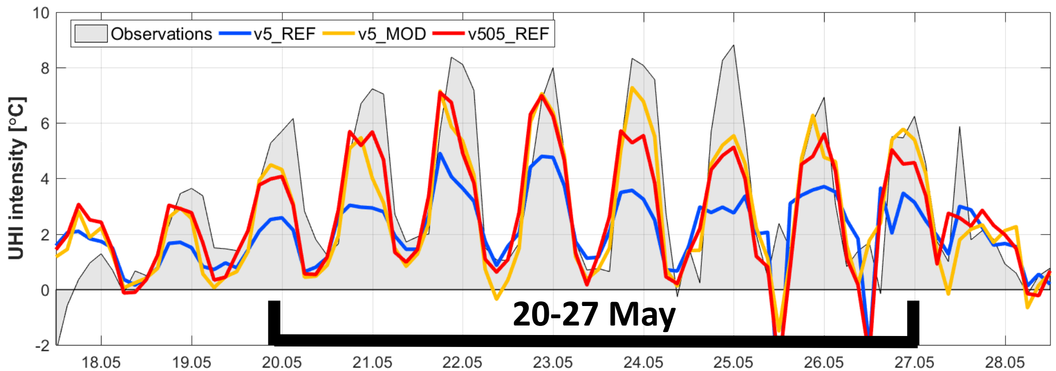
UHI spatial structure

Mean nighttime (0 UTC) temperatures over 20-27 May

v505_REF



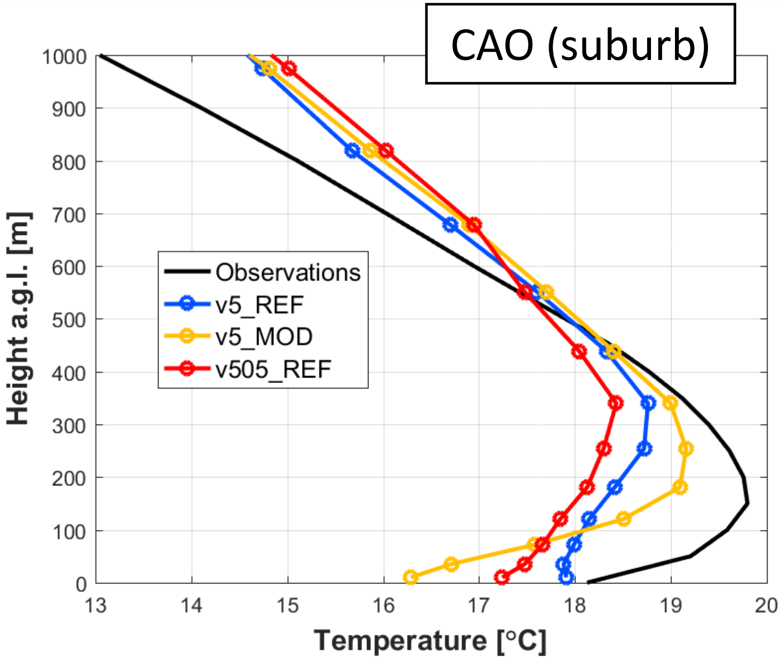


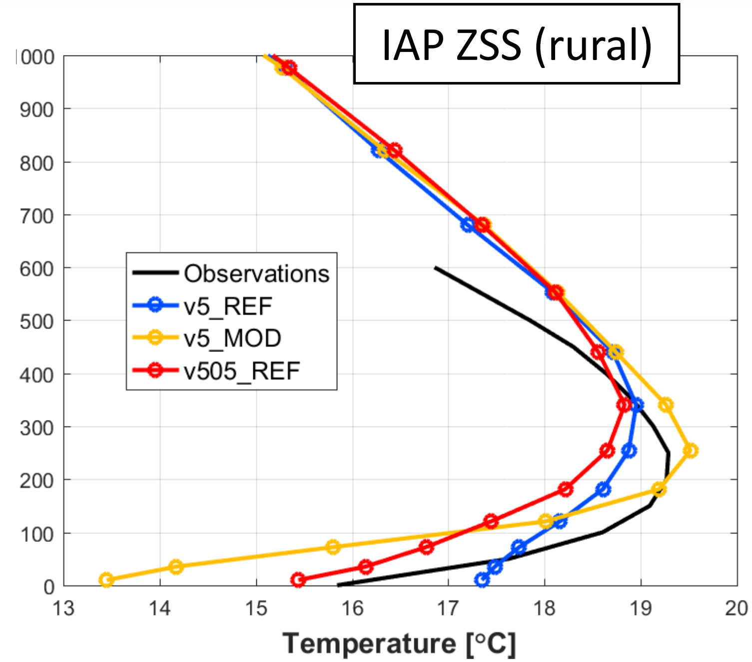


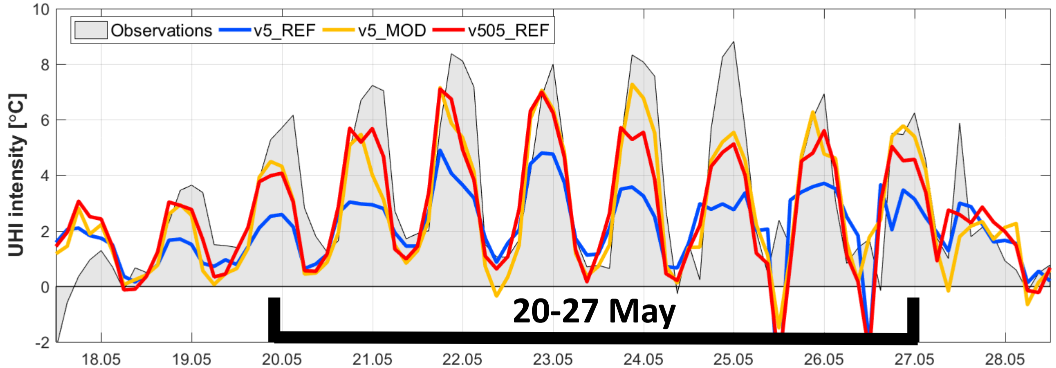
Model verification (case 1: May 2014)

ABL temperature stratification

Mean nighttime (0 UTC) temperature profiles over 20-27 May



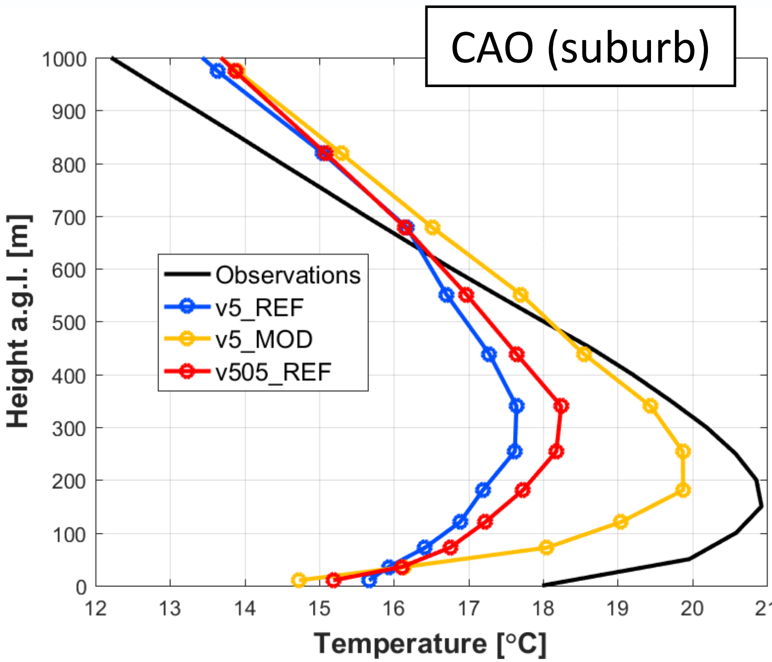


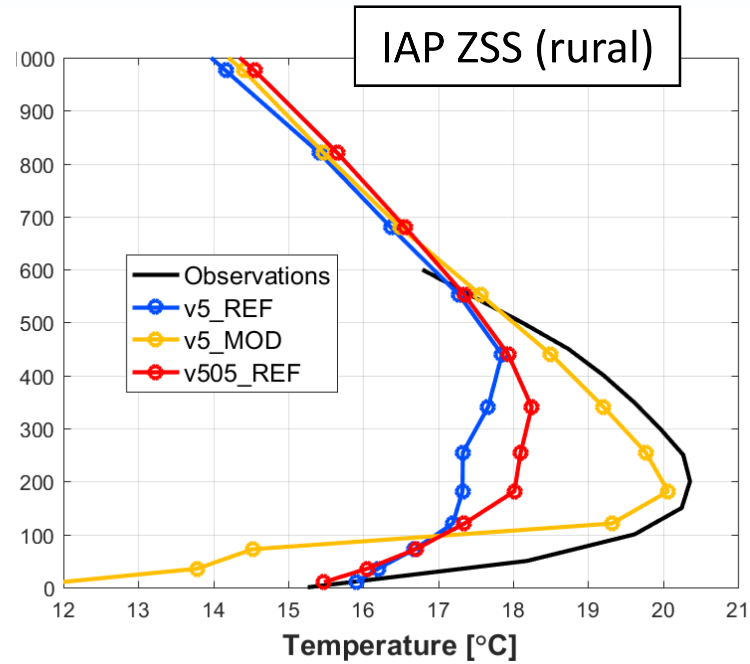


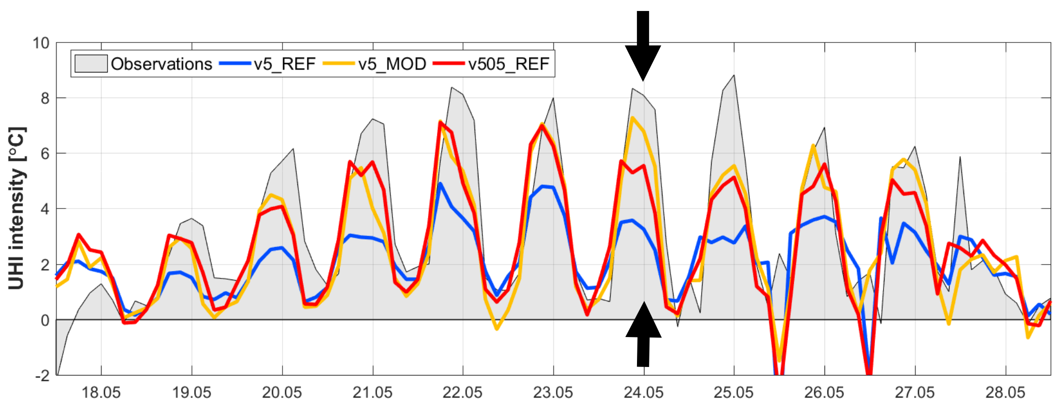
Model verification (case 1: May 2014)

ABL temperature stratification

Temperature profiles at 00 UTC 24.05.2014

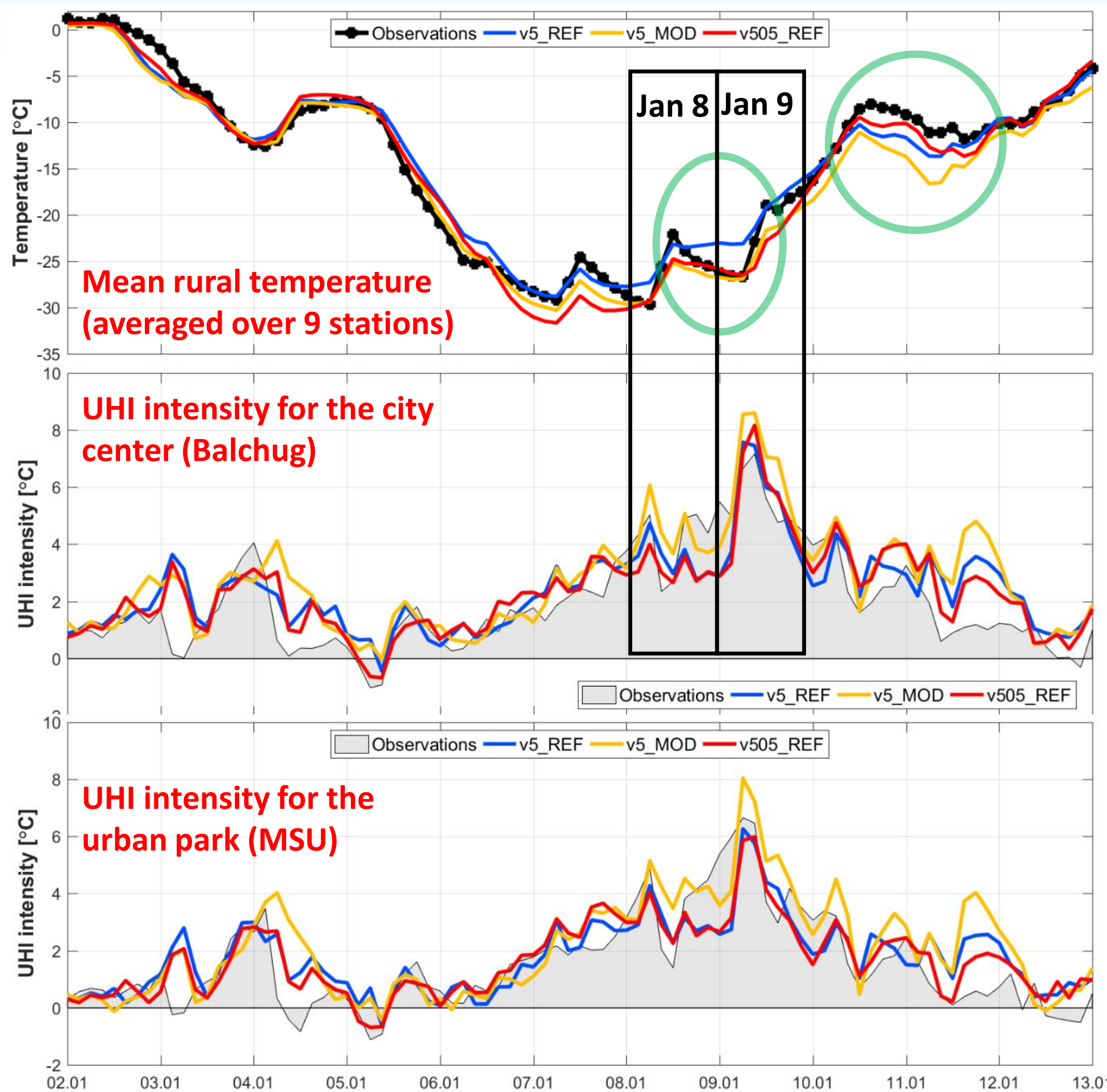






Model verification (case 2: Jan 2017)

Temperature & UHI intensity dynamics



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

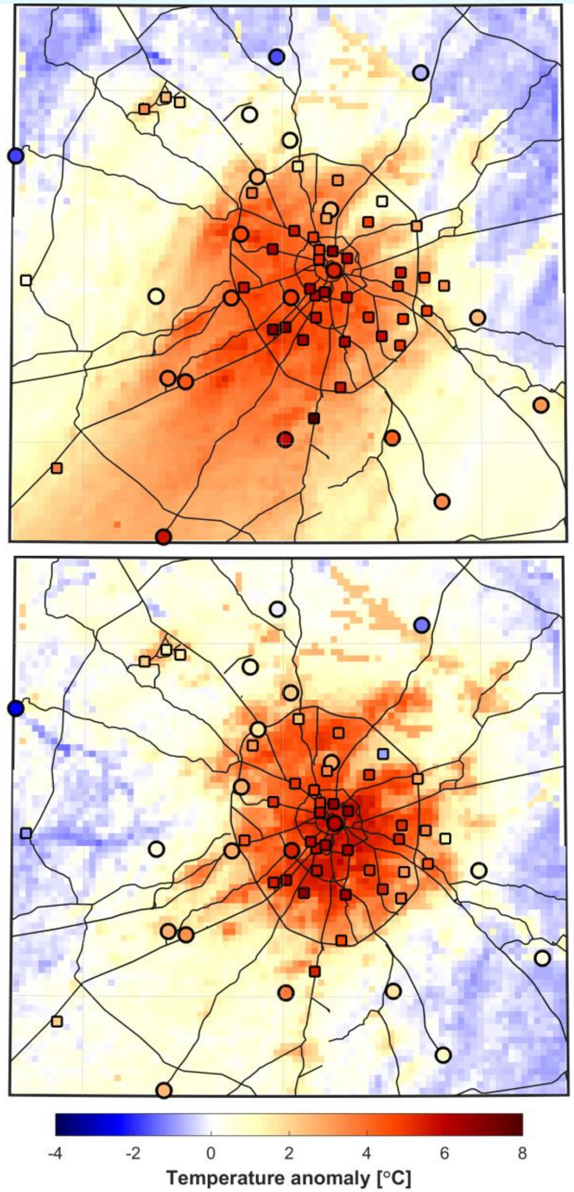
(T_{min} = -35 °C in the north of the region at 9th of January)

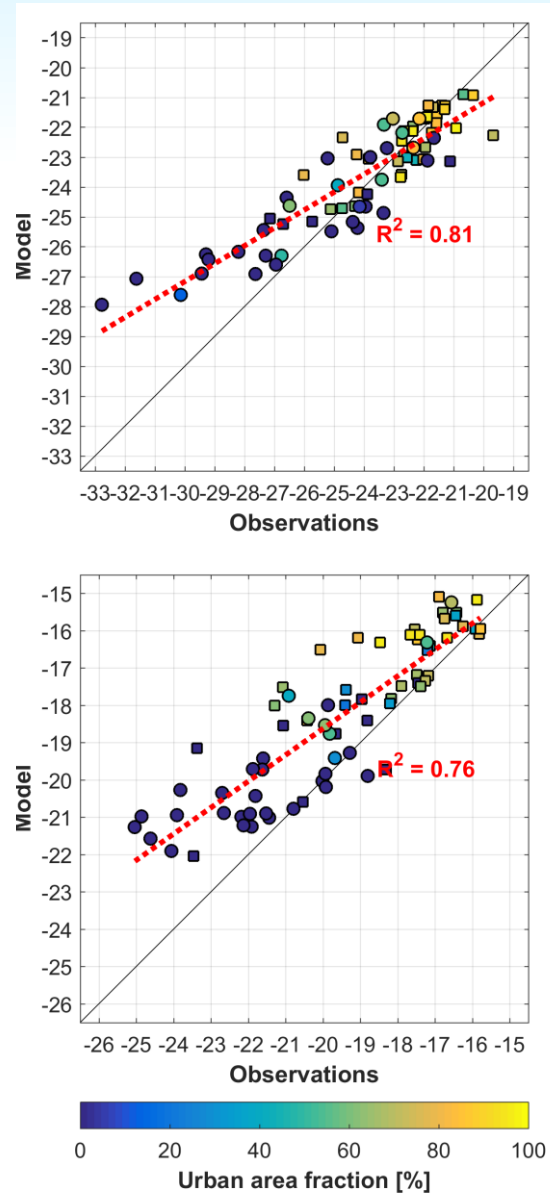
Model verification (case 2: Jan 2017)

V5_REF

8th Jan:
UHI advection to SW

9th Jan:
Localized UHI



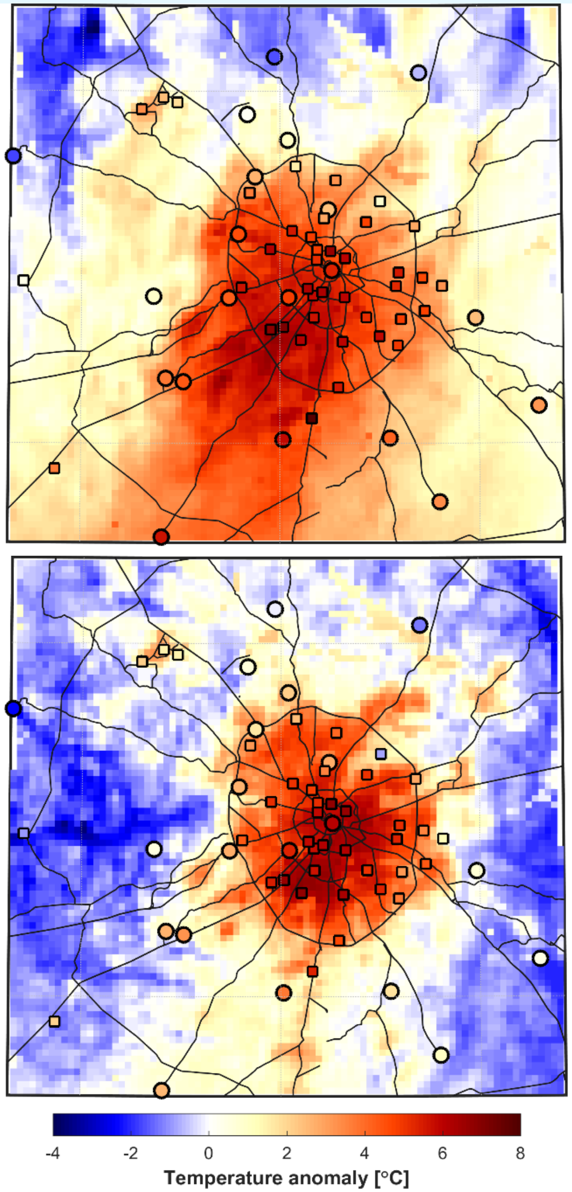


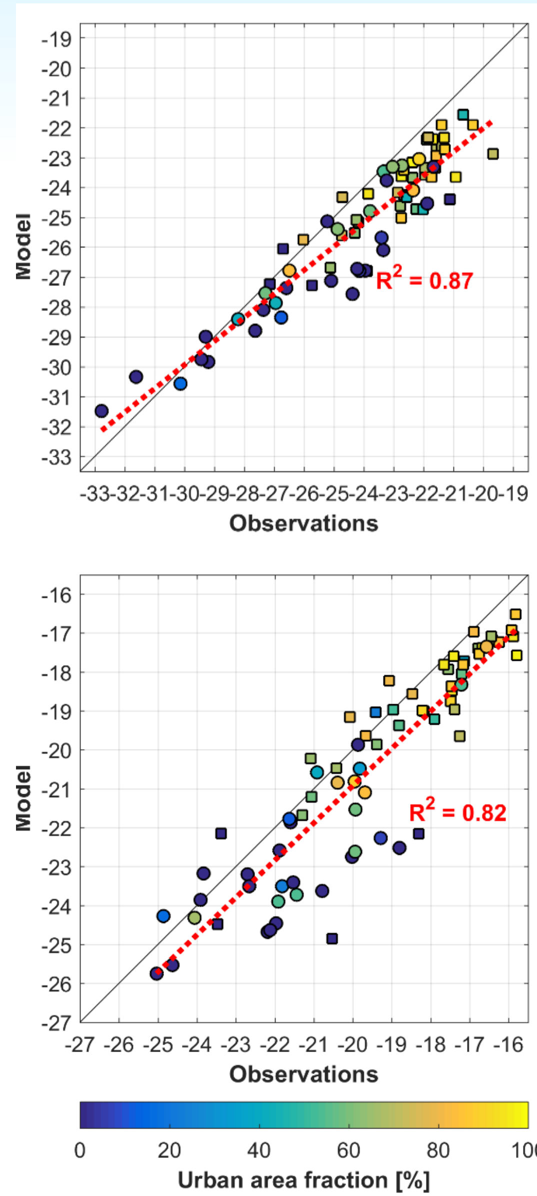
Model verification (case 2: Jan 2017)

V5_MOD

8th Jan:
UHI advection to SW

9th Jan:
Localized UHI



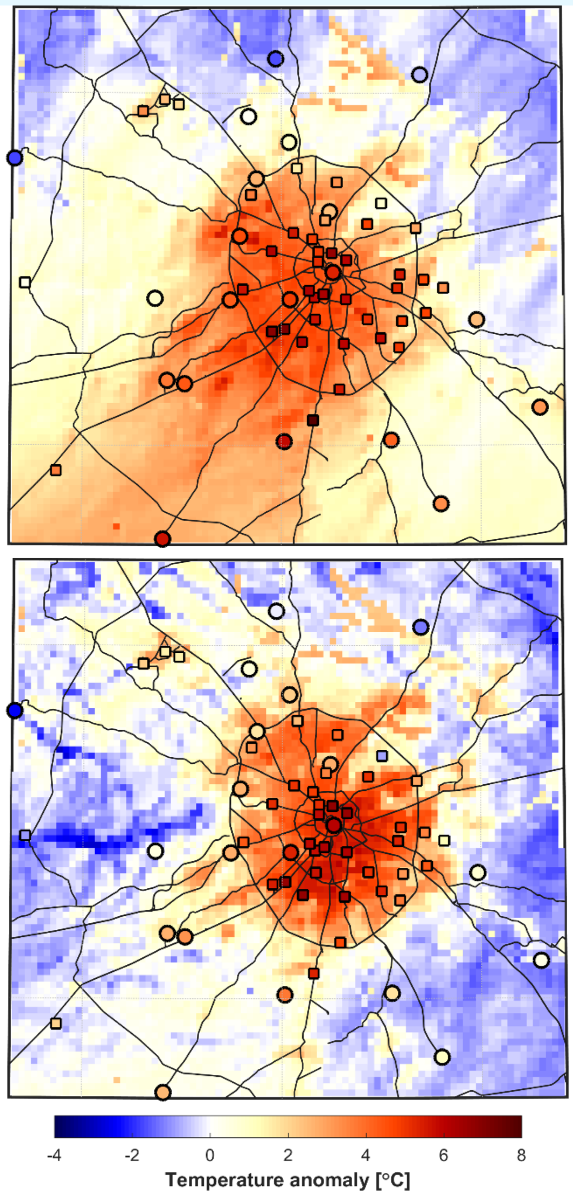


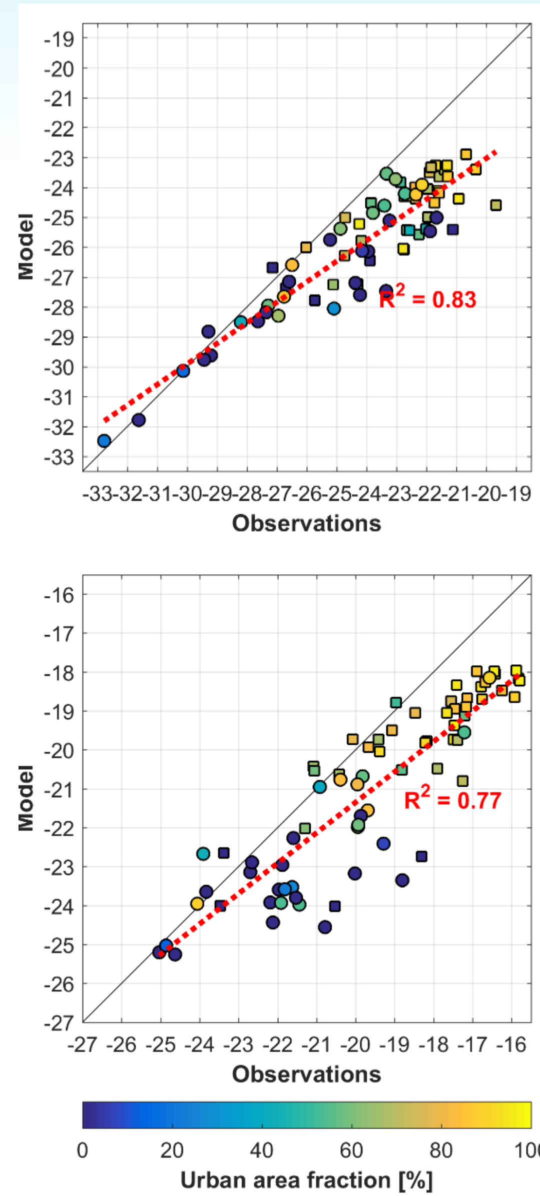
Model verification (case 2: Jan 2017)

V505_REF

8th Jan: UHI advection to SW

9th Jan: Localized UHI

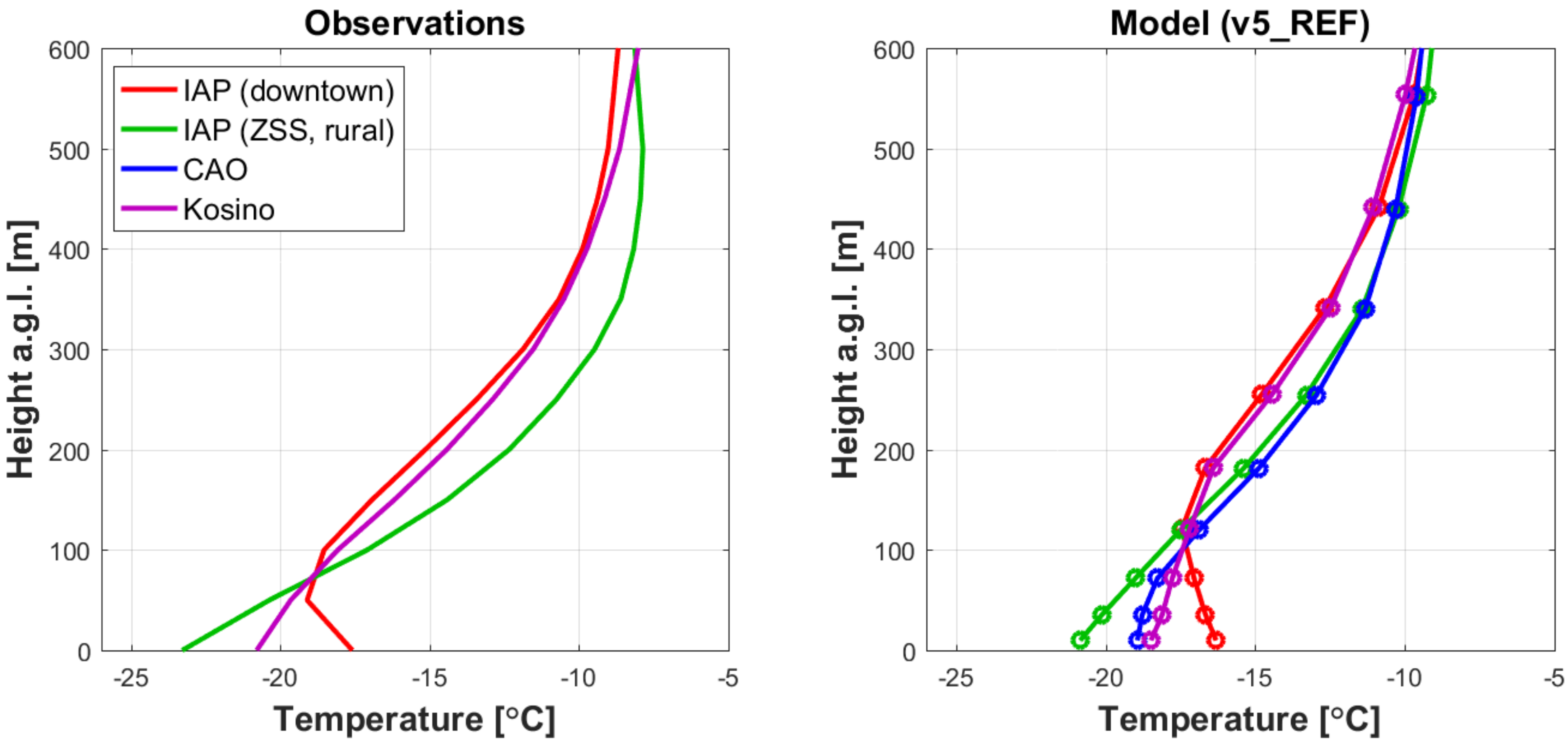




Model verification (case 2: Jan 2017)

ABL temperature stratification

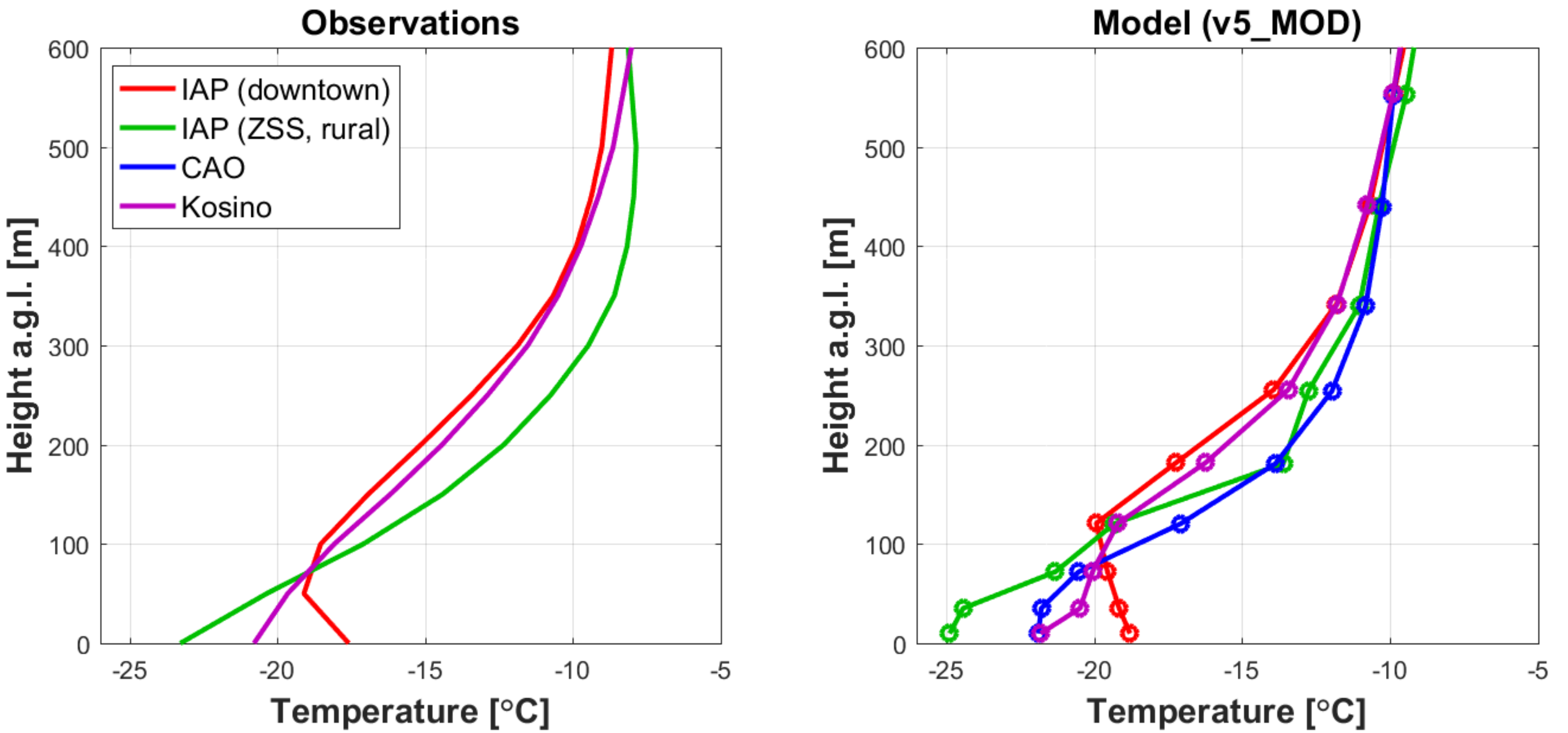
Mean profiles over 9th of January



Model verification (case 2: Jan 2017)

ABL temperature stratification

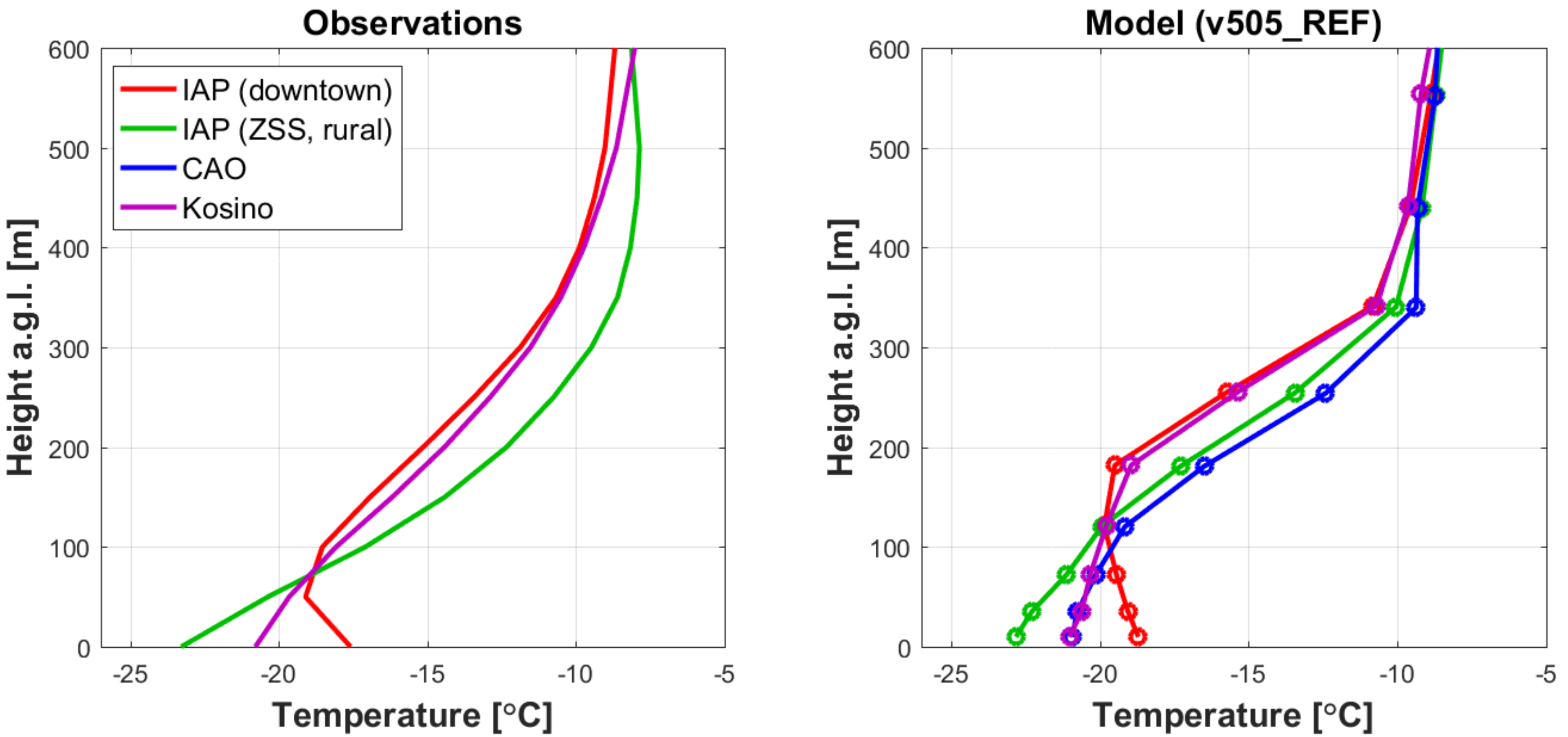
Mean profiles over 9th of January



Model verification (case 2: Jan 2017)

ABL temperature stratification

Mean profiles over 9th of January



Conclusion on the model runs

- COSMO 5.0_and COSMO 5.05 model versions, coupled with TERRA_URB scheme, successfully simulate the general features of the Moscow UHI for summer and winter conditions
- Model success on the UHI intensity is densely linked with model success on T_{min} and on the ABL temperature stratification.
  - Modelling results on UHI intensity are highly sensitive to model tuning, related to surface and ABL processes (horizontal and vertical diffusion, skin-layer temperature scheme, etc.)
- COSMO 5.0 with reference settings (v5_REF) strongly underestimate the UHI intensity, but this could be fixed by tuning (v5_MOD)
- COSMO 5.05 with reference settings and new ICON-physics (v505_REF) simulates the T_{min} and UHI better than reference COSMO 5.0 run (v5_REF), but still not perfectly.
- A lot of further research is still needed…

Outlook

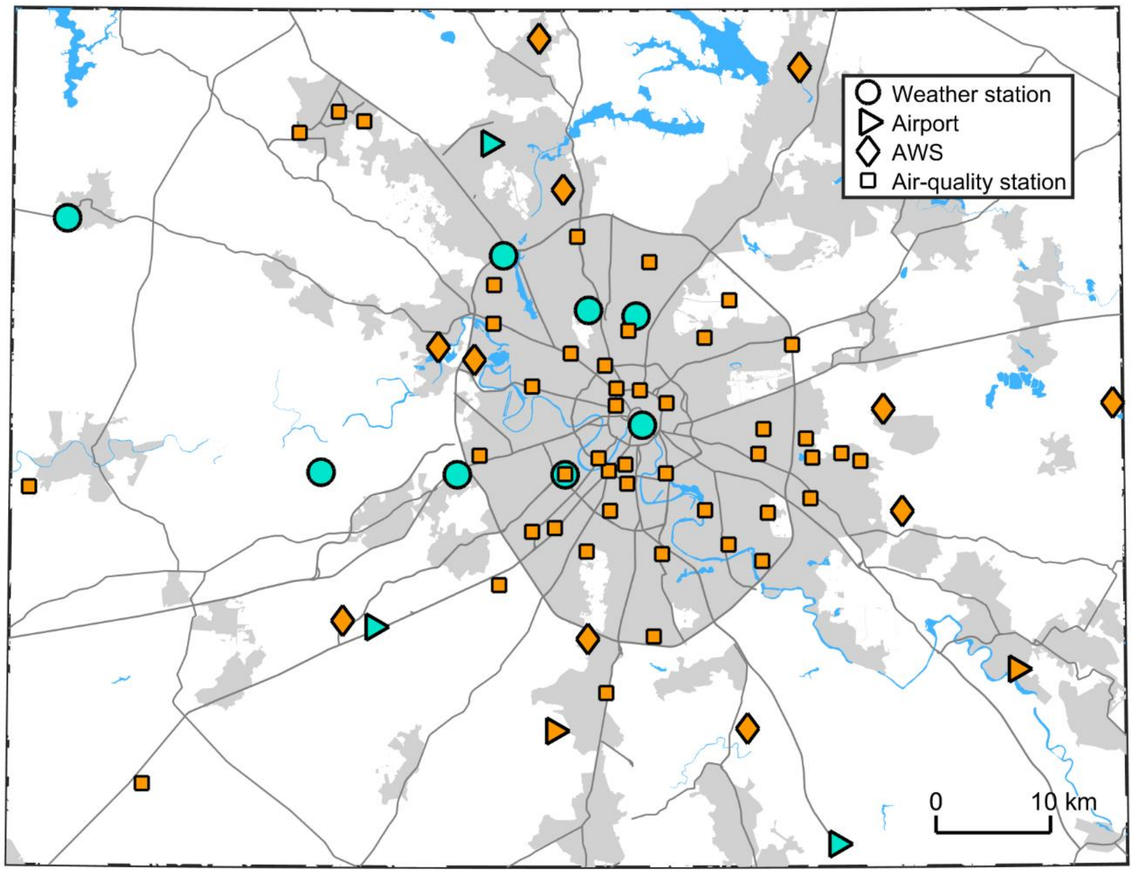
Towards high resolution urban weather forecast for Moscow

- New big research project of Roshydromet **"development of a monitoring, forecasting and warning system for hazardous and adverse weather events for the city of Moscow"**, funded by Moscow city government (since 2018)
  - Aim: creation of the high-resolution NWP system for Moscow
  - Urban canopy model is needed according to a contract
  - **COSMO-RuM NWP** system is already running in a test mode (based on COSMO 5.0 + TERRA_URB, 1 km grid step)

- Further research and development
  - Developing of the COSMO-RuM: incising the resolution **(1 km → 500 m)**, migration to the recent model version **(v5.0 → v5.05)** and further to ICON-Lam
  - Acquisition and usage of the detailed **official** data on the land-use and building morphology
  - Further verification and calibration using existing and new observational systems

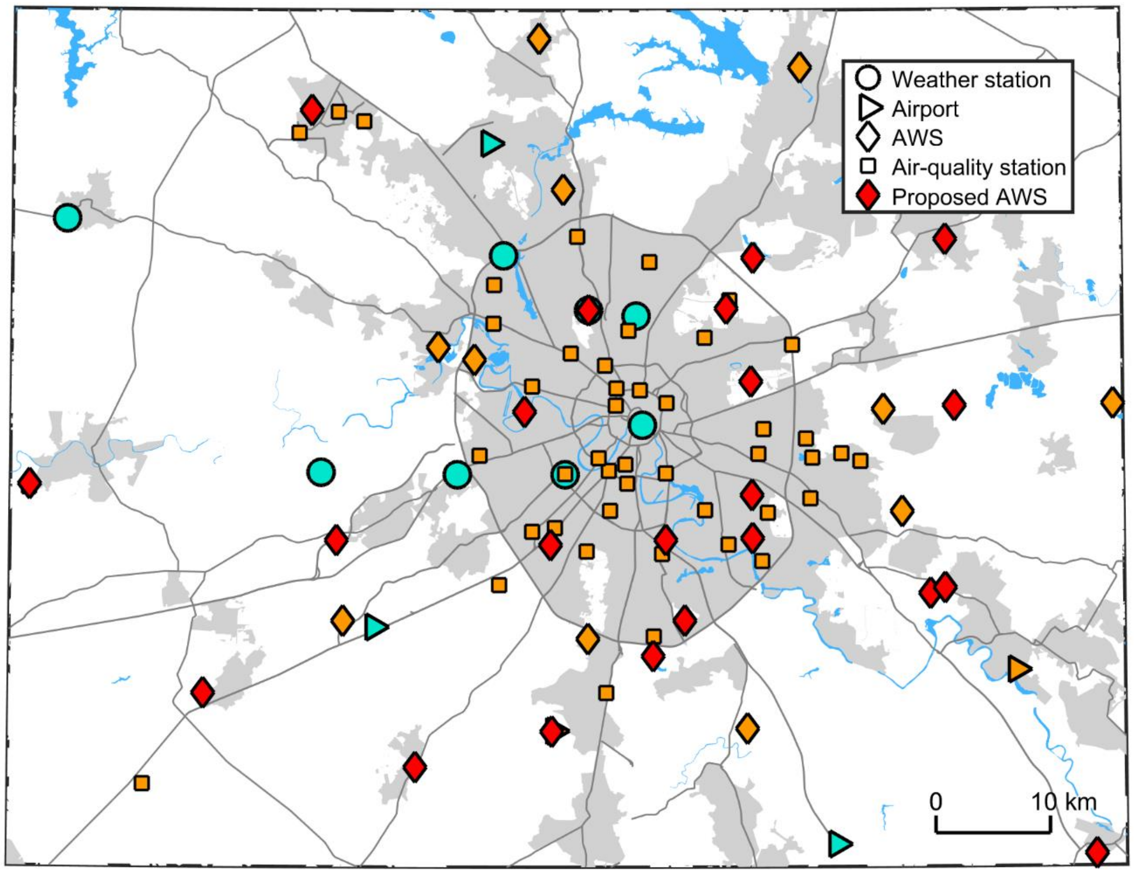
Outlook

Proposed extension of the weather monitoring system



Outlook

Proposed extension of the weather monitoring system

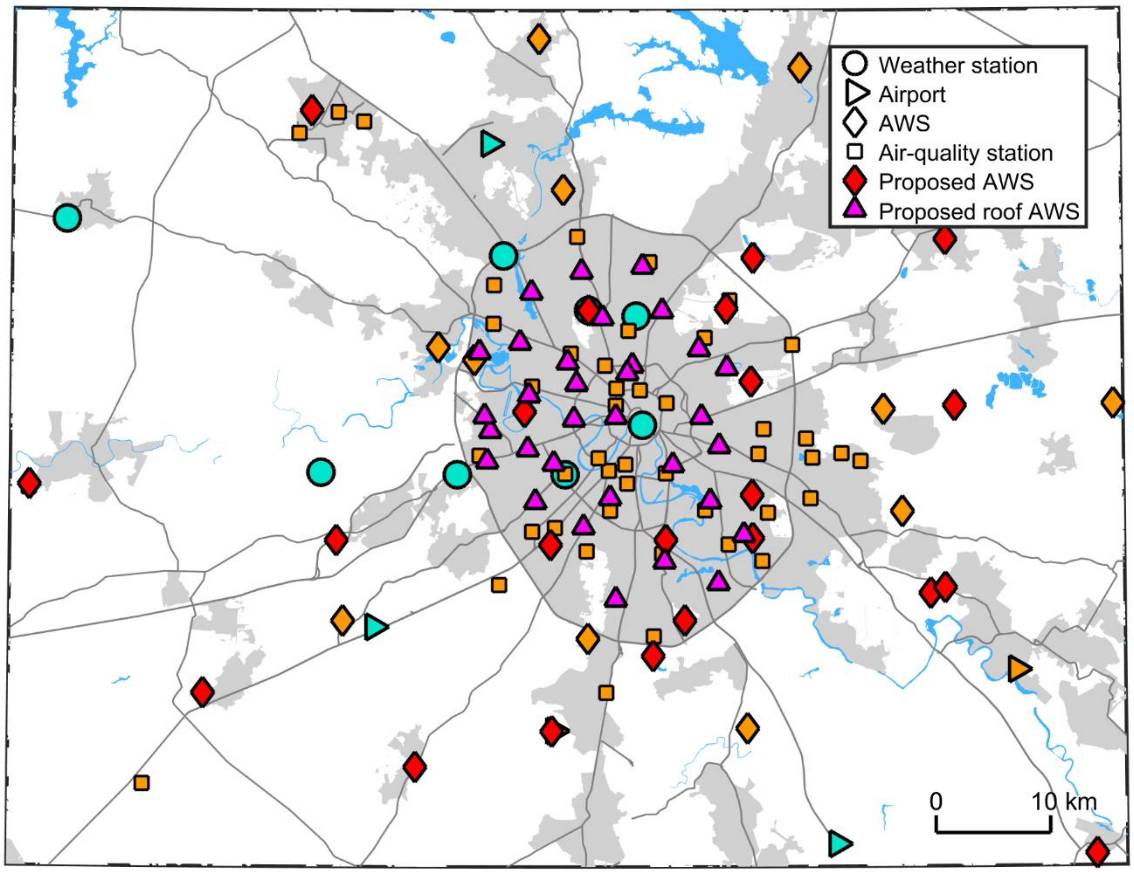


It is planned to install:

- 44 new AWS

Outlook

Proposed extension of the weather monitoring system

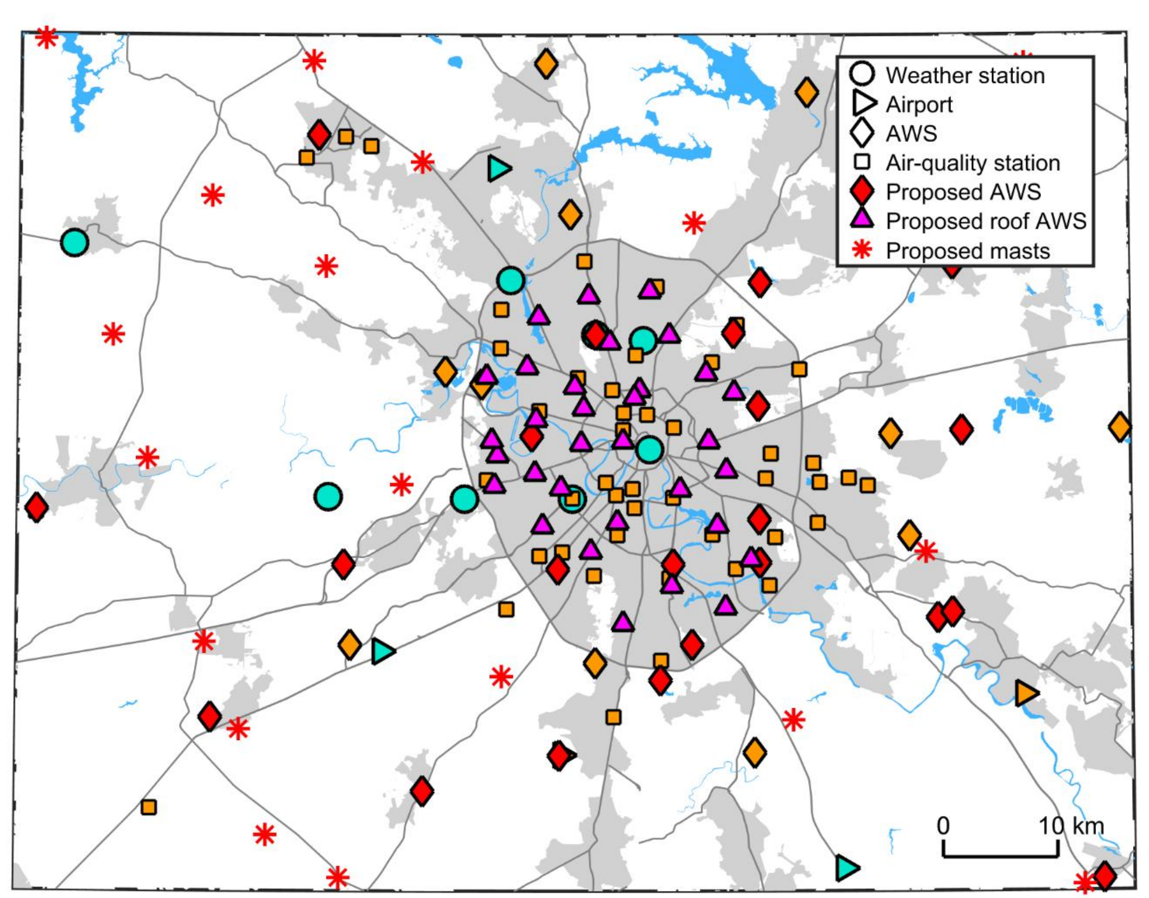


It is planned to install:

- 44 new AWSs
- 32 roof AWSs

Outlook

Proposed extension of the weather monitoring system

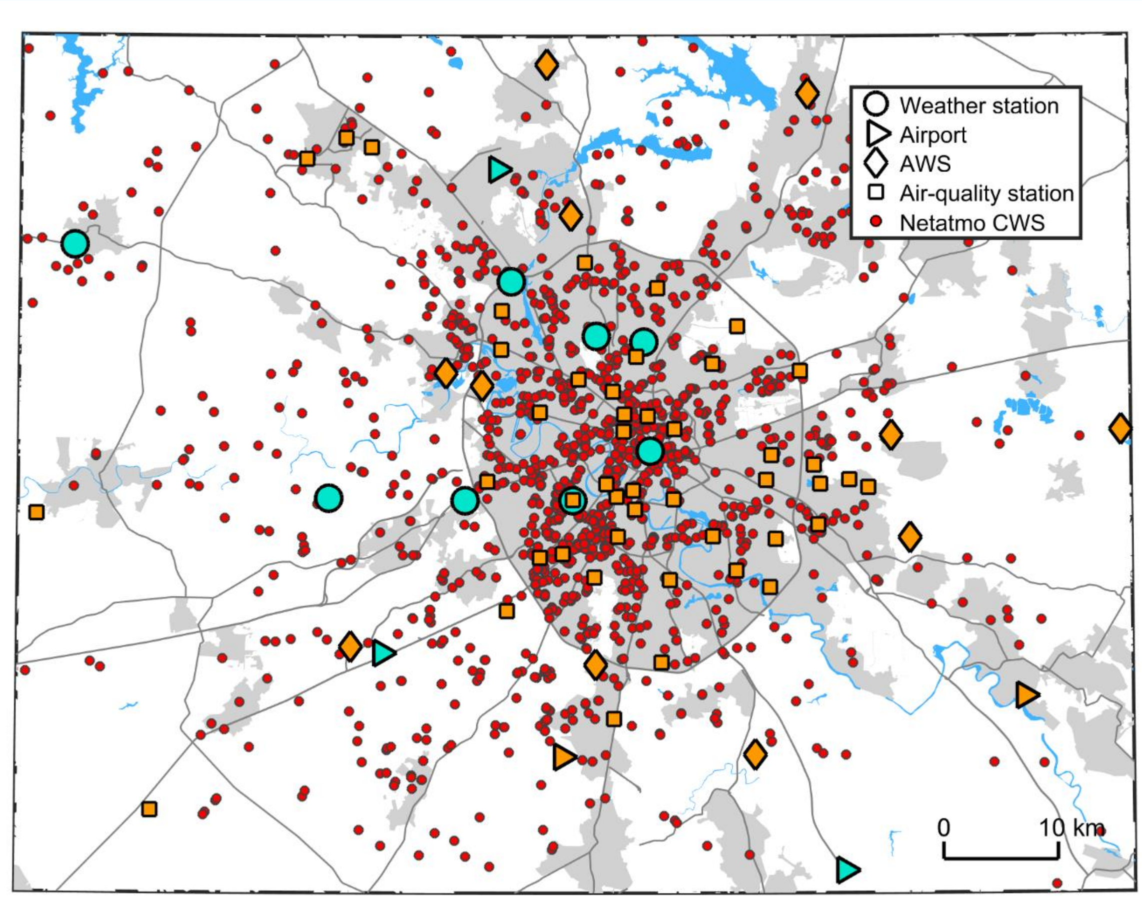


It is planned to install:

- 44 new AWSs
- 32 roof AWSs
- 90 gradient masts (using existing cell towers)

Outlook

What about even denser urban network?



With contribution of Dr. Fred Meier and Daniel Fenner (TU Berlin)

Citizen weather stations (CWS):
Netatmo network

≈7000 CWSs in Paris
≈ 800 CWSs in Moscow region

After filtering, CWS data becomes useful for urban climate research (Meier et al., 2017, Urb. Clim)

What about model verification?

Moscow testbed is opened for you!

Let’s verify the models together!

Thank you for your attention!

Questions, please?

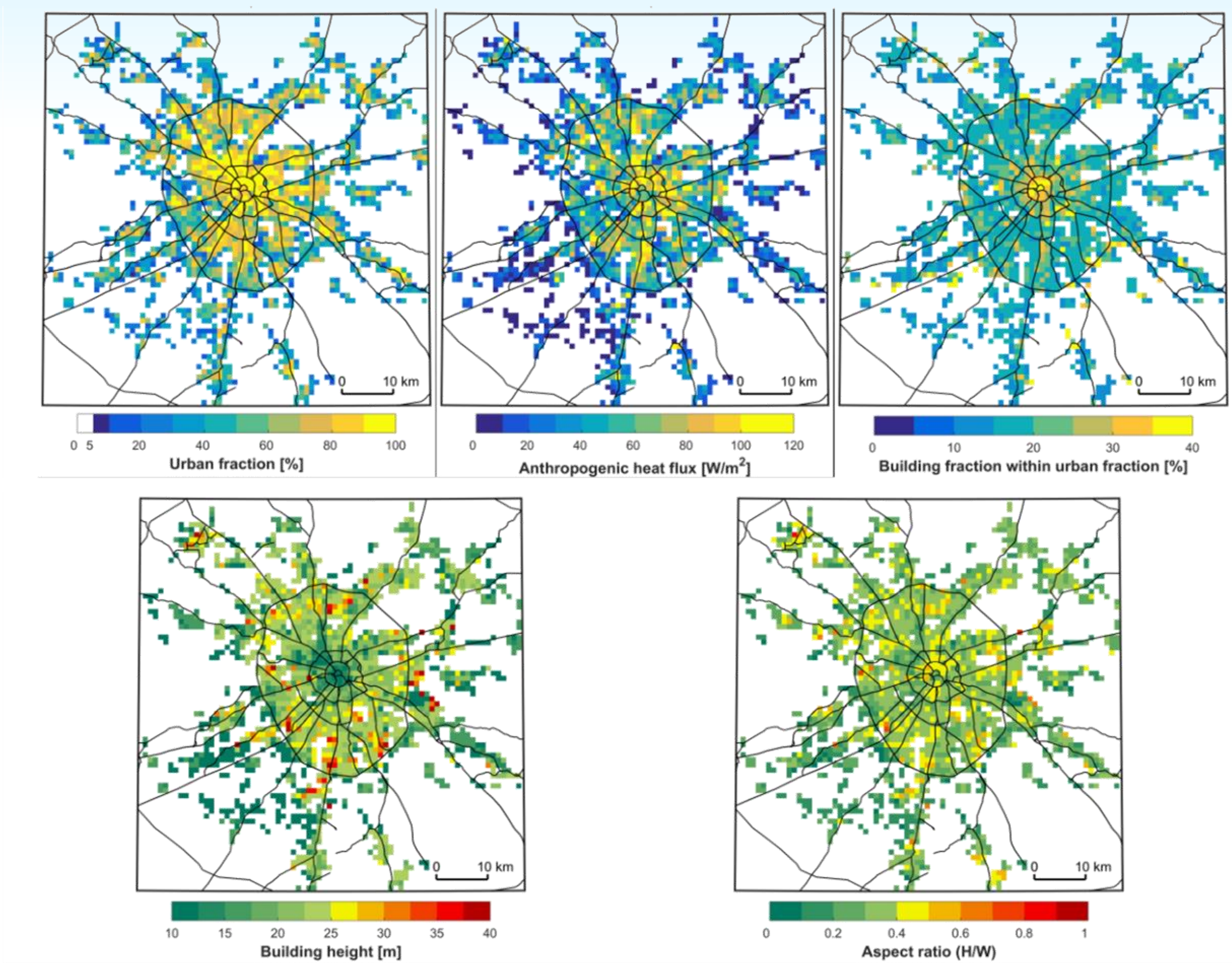
Extra slides

References

Key references from the slides:

- Cerenzia et al., 2014. Diagnosis of Turbulence Schema in Stable Atmospheric Conditions and Sensitivity Tests. COSMO Newsletter, 14, pp.28–36.
- Flanner, 2009. Integrating anthropogenic heat flux with global climate models. GRL, 36(2), p.L02801.
- Lokoshchenko, 2014. Urban “heat island” in Moscow. Urb. Clim., 10, P. 3, pp.550–562.
- Meier et al., 2017. Crowdsourcing air temperature from citizen weather stations for urban climate research. Urban Clim., 19, pp 170–191.
- Nakatani et al., 2015. Tokyo metropolitan area convection study for extreme weather resilient cities. Bull. Am. Meteorol. Soc., 8, p. 123–126.
- Oke et al., 2017. Urban climates, Cambridge University Press.
- Samsonov et al., 2015. Object-oriented approach to urban canyon analysis and its applications in meteorological modeling. Urb. Clim., 13, pp.122–139.
- Samsonov & Trigub, 2017. Towards computation of urban local climate zones (LCZ) from openstreetmap data.roceedings of the 14th International Conference on GeoComputation, 4th-7th September 2017. Leeds.
- Varentsov et al., 2018. Megacity-Induced Mesoclimatic Effects in the Lower Atmosphere: A Modeling Study for Multiple Summers over Moscow, Russia. Atmosphere, 9, p. 50.
- Wouters et al., 2016. Efficient urban canopy parametrization for atmospheric modelling: description and application with the COSMO-CLM model for a Belgian Summer. GMD, 9, pp.3027–3054.

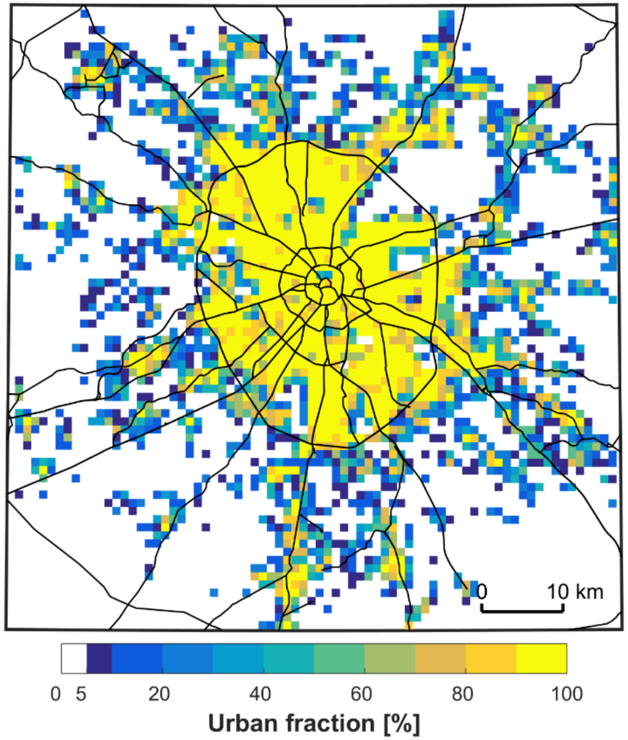
Input parameters of urban canopy



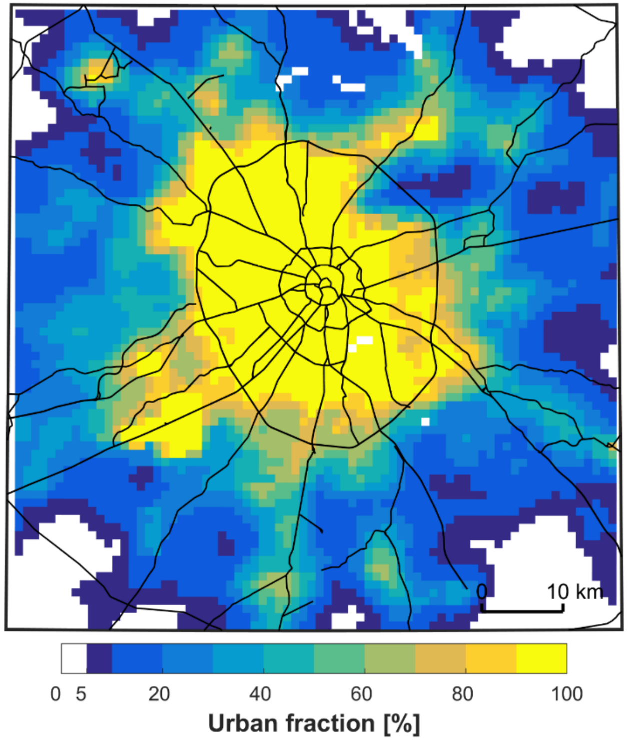
Urban canopy parameters

Urban fraction

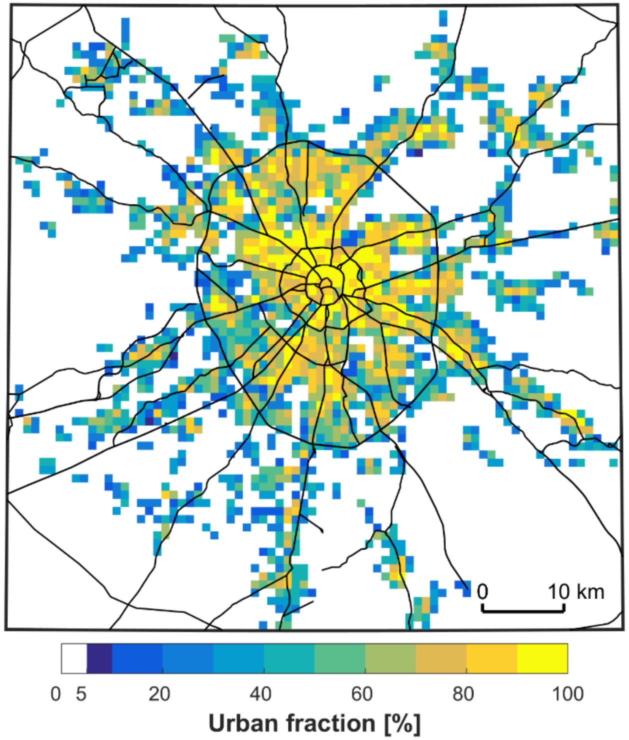
Urban fraction from EXTPAR (Globcover)



ISA from EXTPAR (fine resolution)

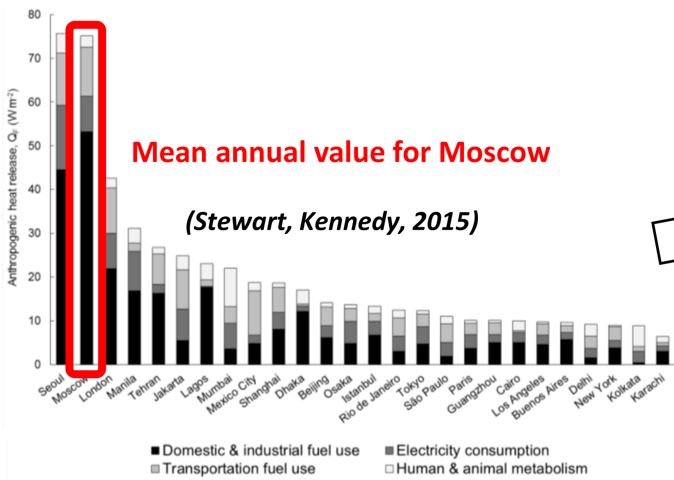


Urban fraction derived from OSM data



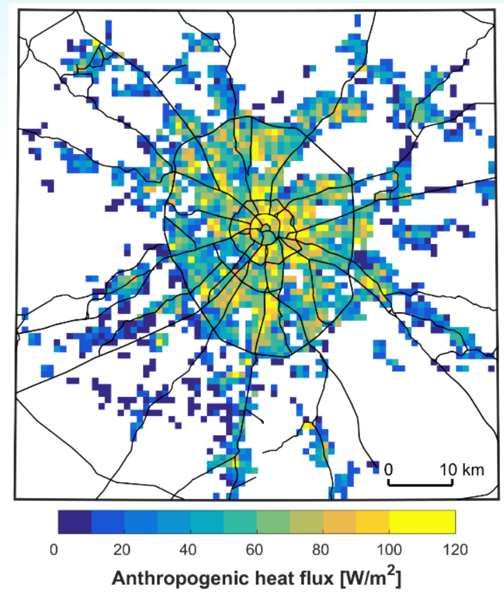
Urban canopy parameters

AHF

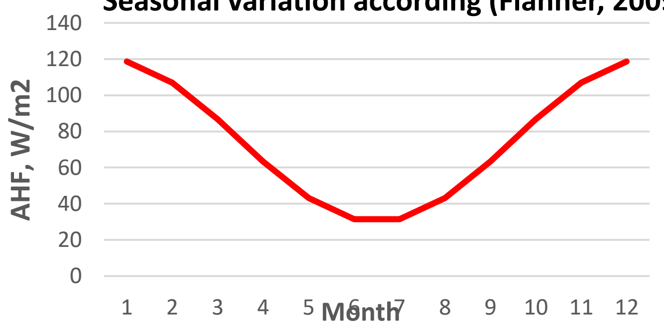


Mean annual value for Moscow

(Stewart, Kennedy, 2015)



Seasonal variation according (Flanner, 2009)



Data from EXTPAR