Investigation of detailed spatial structure of the Moscow megacity climate features according to the newest meteorological observations and regional climate modelling with connection to human comfort

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Aim of the research:

To analyze weather observation data in Moscow region, including the data of newest AWS and air-quality monitoring network, to investigate spatial patterns of temperature distribution (first of all, UHI shape, size and intensity), its climatic trends and parameters, related to human comfort, and compare it with the results of numerical experiments with mesoscale regional climate modelling.

Meteorological observations in Moscow region

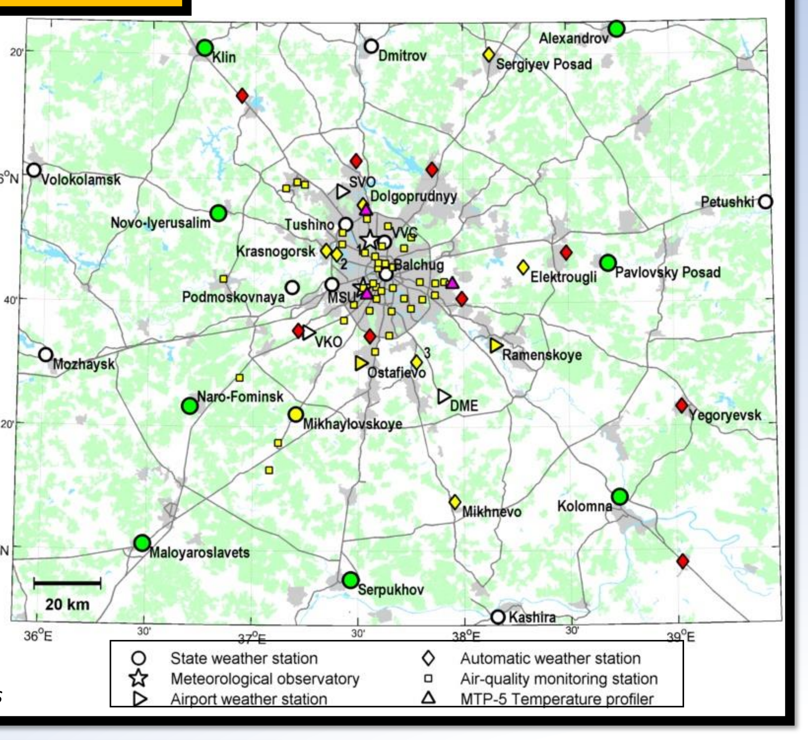
23 points (weather stations, airports, spatialized observatories) with **long-term observation datasets**.
8 among them marked as **reference rural stations (green)**

Network of **air-quality monitoring stations** MosEcoMonitoring developing since 1990th, **with more then 30 stations now**

10 points (including 7 AWS, 2 airports) appears in 2008-2013

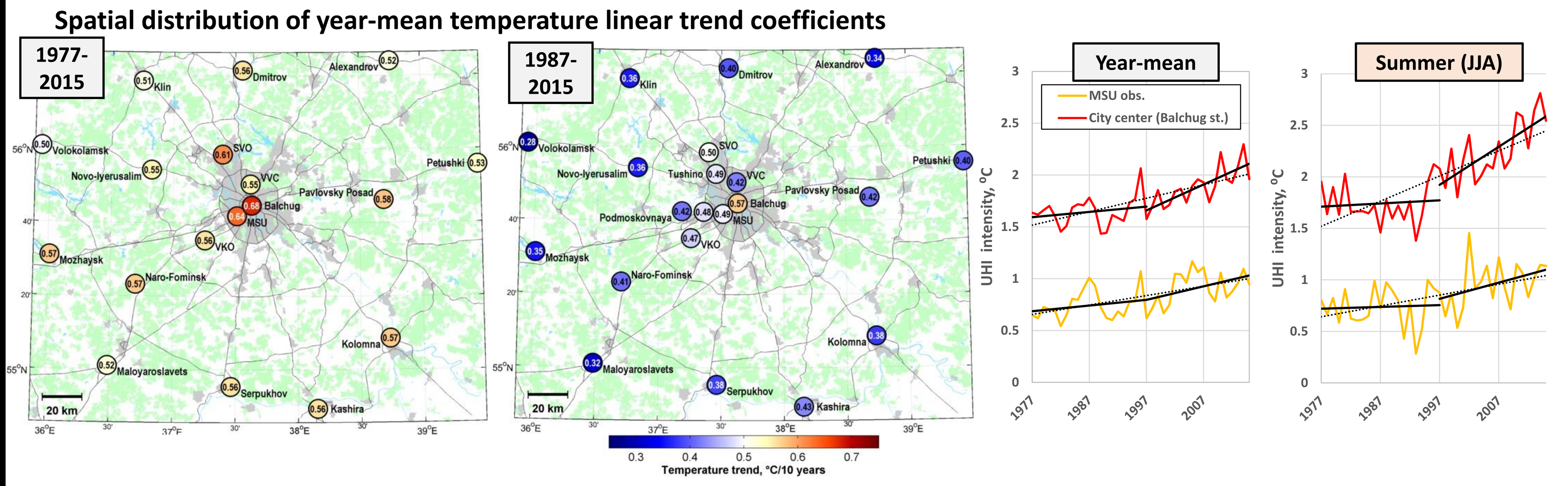
Several new AWS appears in 2014-2015 (data under processing)

MSU meteorological observatory | *Balchug weather station in city center* | *New AWS* | *One of air-quality monitoring stations*



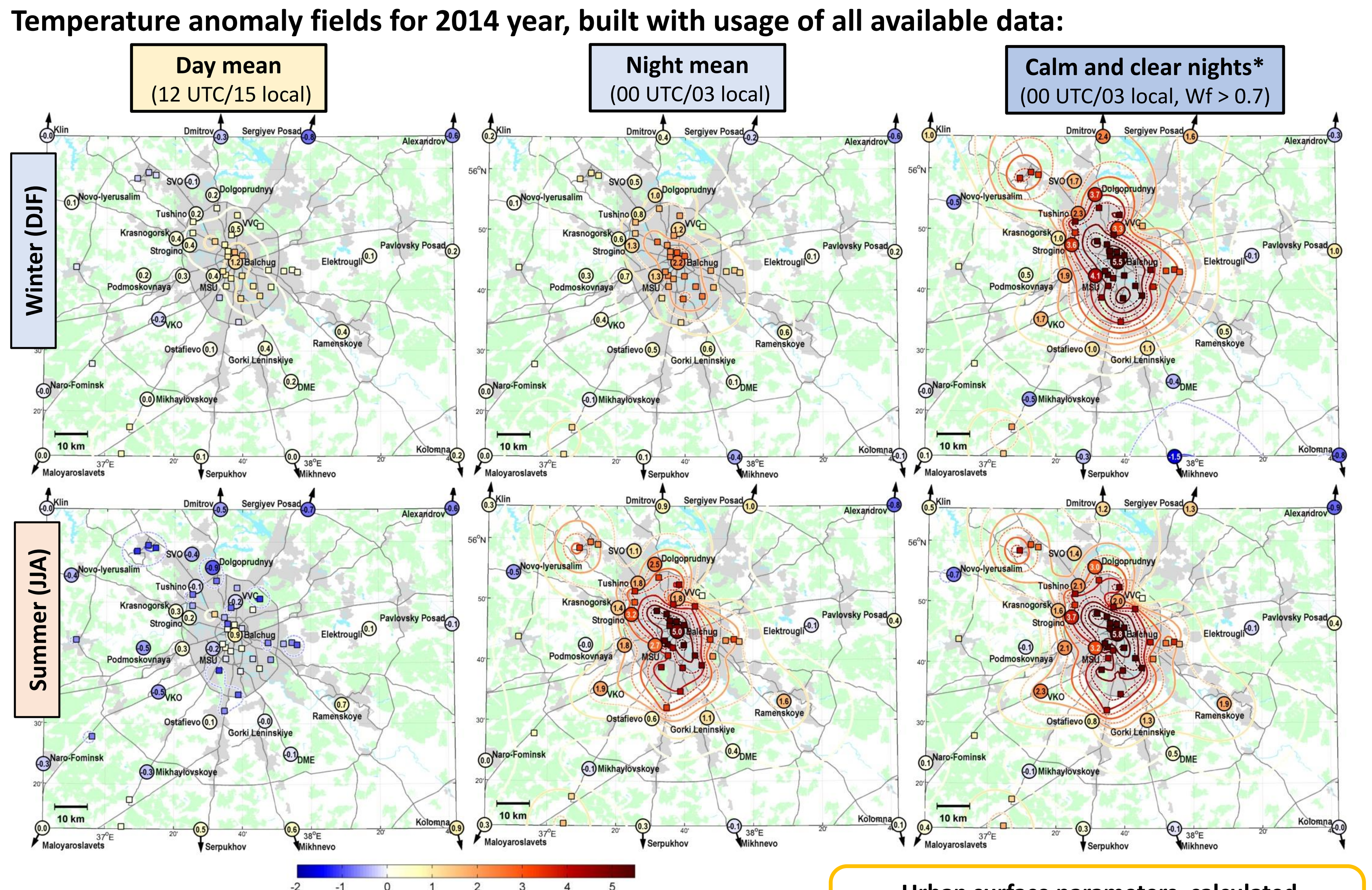
Urban amplification of global warming in Moscow

Spatial distribution of year-mean temperature linear trend coefficients



UHI spatial structure according to the newest observations

Temperature anomaly fields for 2014 year, built with usage of all available data:

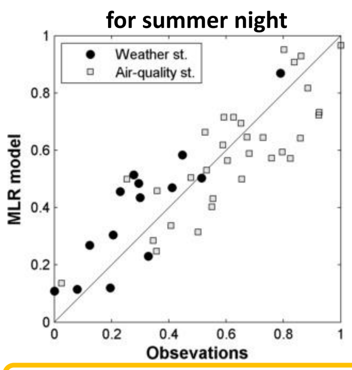


Relationships with building and city planning parameters, estimated using multiple linear regression model (MLR):

$$y = a + \sum k_i \cdot x_i,$$

where y – normalized UHI intensity, x_i - predictors from the table below (also normalized for more clear comparison), k_i - regression coefficients.

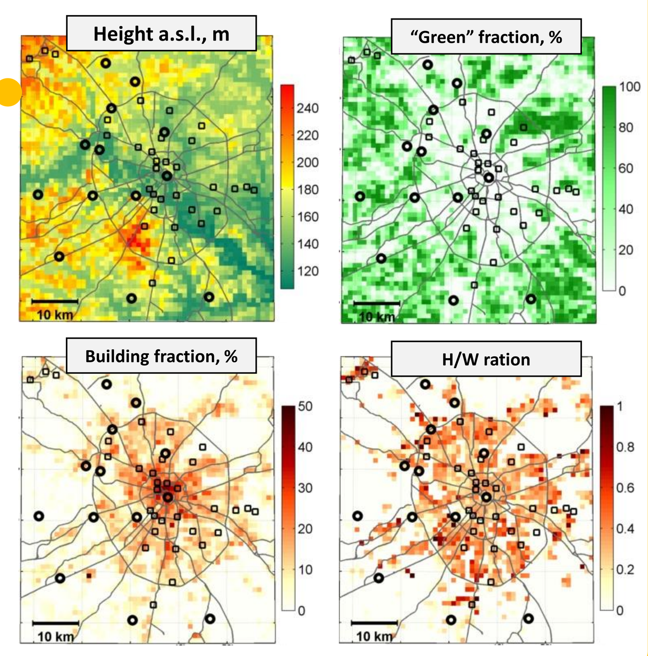
MLR model vs observations for summer night



MLR coefficients for different seasons and times of the day (calculated only for calm and clear* cases)

Predictor	Summer night	Summer day	Winter night	Winter day
Distance from city center	-0.30	-0.01	-0.39	-0.33
Building fraction	0.41	-0.02	0.33	0.33
H/W street canyon ratio	0.26	-0.52	0.37	-0.06
"Green" fraction	-0.23	-0.49	-0.04	0.00
Surface elevation a.s.l.	0.05	-0.36	0.03	-0.38

Urban surface parameters, calculated from OpenStreetMap (Samsonov et. al, 2015)



*** Weather factor for selecting "calm and clear" days and nights:**

$$W_f = max\,(1, u^{-1/2}) \cdot (1 - kn)$$

where u – mean wind speed at rural reference stations, n – low cloudiness fraction, k ≈ 0.8

Wind effect on UHI shape and position

Selection of the cases for analysis:

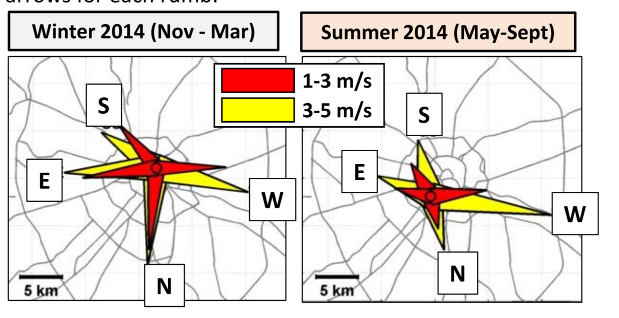
1) Classification by wind direction within +/- 45° lags for each of 4 **main wind directions (N, S, W, E)**. Only cases with agreement between mean wind direction at reference rural stations and direction according ERA-Interim reanalysis are selected.
2) Classification **by wind speed** according ERA-Interim reanalysis**: 1-3 m/s, 3-5 m/s** (agreement with observations is also required)
3) Additional filters:
   - Nocturnal time for avoiding solar heating effect
   - Significant UHI: $\Delta T_{max} > 2$°C

UHI "mass center" - parameter for evaluation of wind-caused UHI shift:

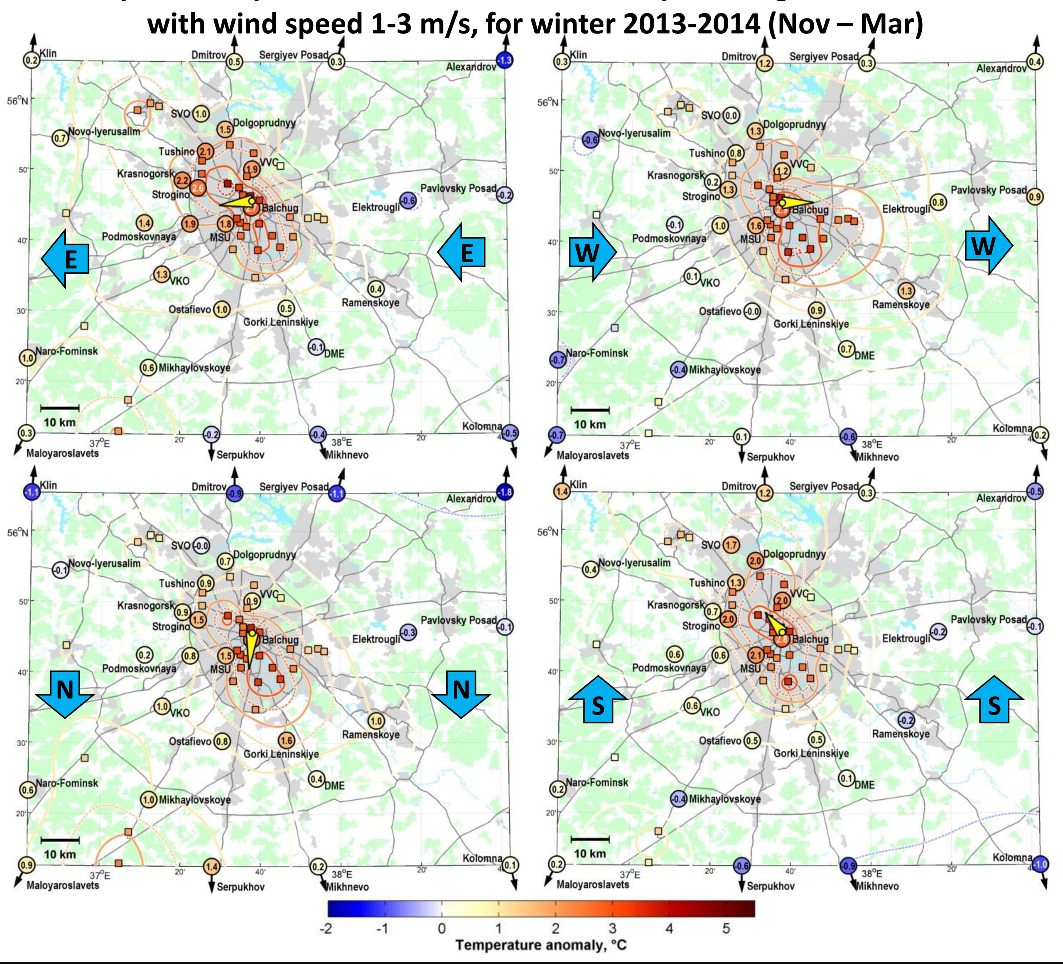
$$\overline{x_m} = \frac{1}{M}\int_S \bar{x} \cdot \Delta T \cdot ds\text{, where}$$

$$M = \int_S \Delta T \cdot ds,\ and\ S - area\ where\ \Delta T > \Delta T_{min}$$

"Mass center" shift from its reference position is shown by arrows for each rumb.



Temperature spatial distribution for different prevailing wind directions with wind speed 1-3 m/s, for winter 2013-2014 (Nov – Mar)



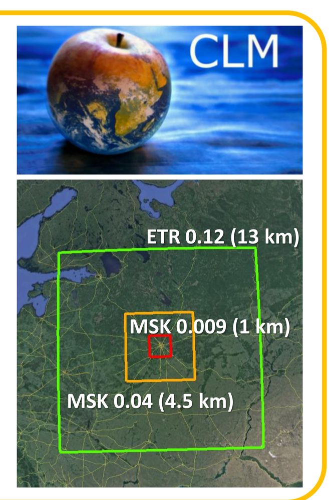
Simulations with regional climate model COSMO-CLM

Experiments setup:

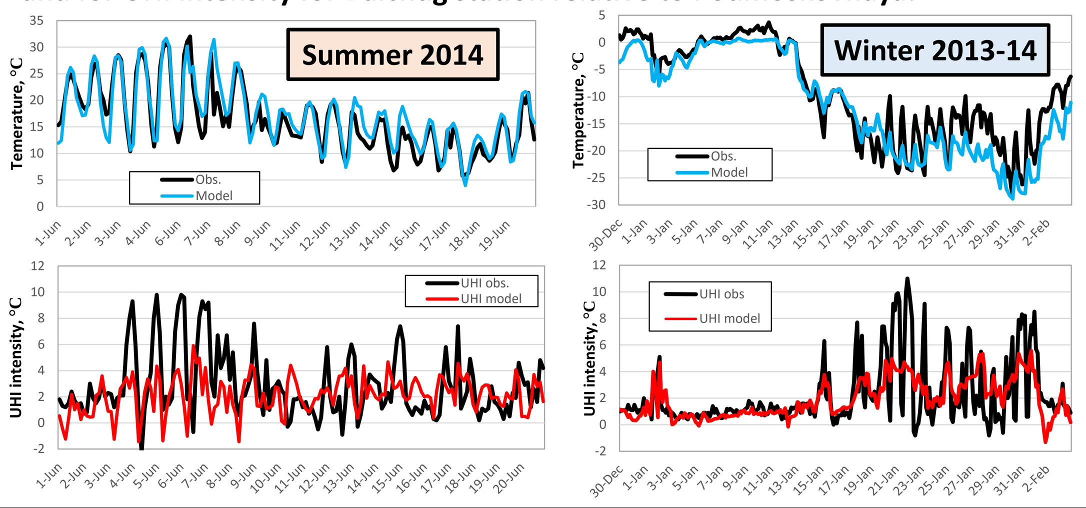
- Runs for four months (first one for spin up)
- 2 steps of nesting: 12 km -> 4 km -> 1 km
- Boundary conditions for 12km domain from ERA-Interim
- Surface parameters from Ecoclimap database
- Spectral nudging
- **Turbulence scheme tuning for reduction of the overmixing**
- **Coupled with TEB urban scheme (Trusiliva at. al., 2013)**

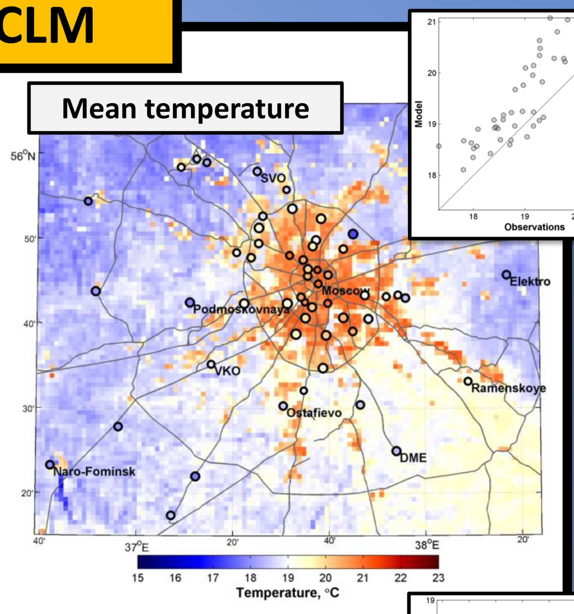
TEB configuration:

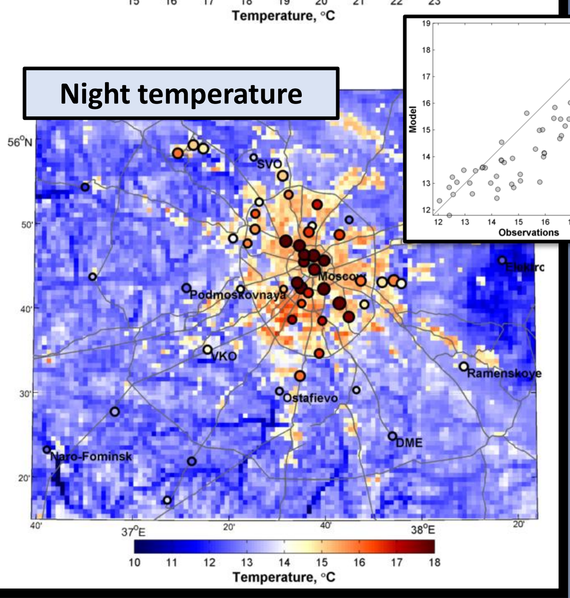
- Building parameters, calculated from OpenStreetMap
- Constant anthropogenic heat flux 30 W/m2
- Kanda scheme for street canyon exchange coefficients



Model verification for rural temperature (for Podmoskovnaya station) and for UHI intensity for Balchug station relative to Podmoskovnaya:





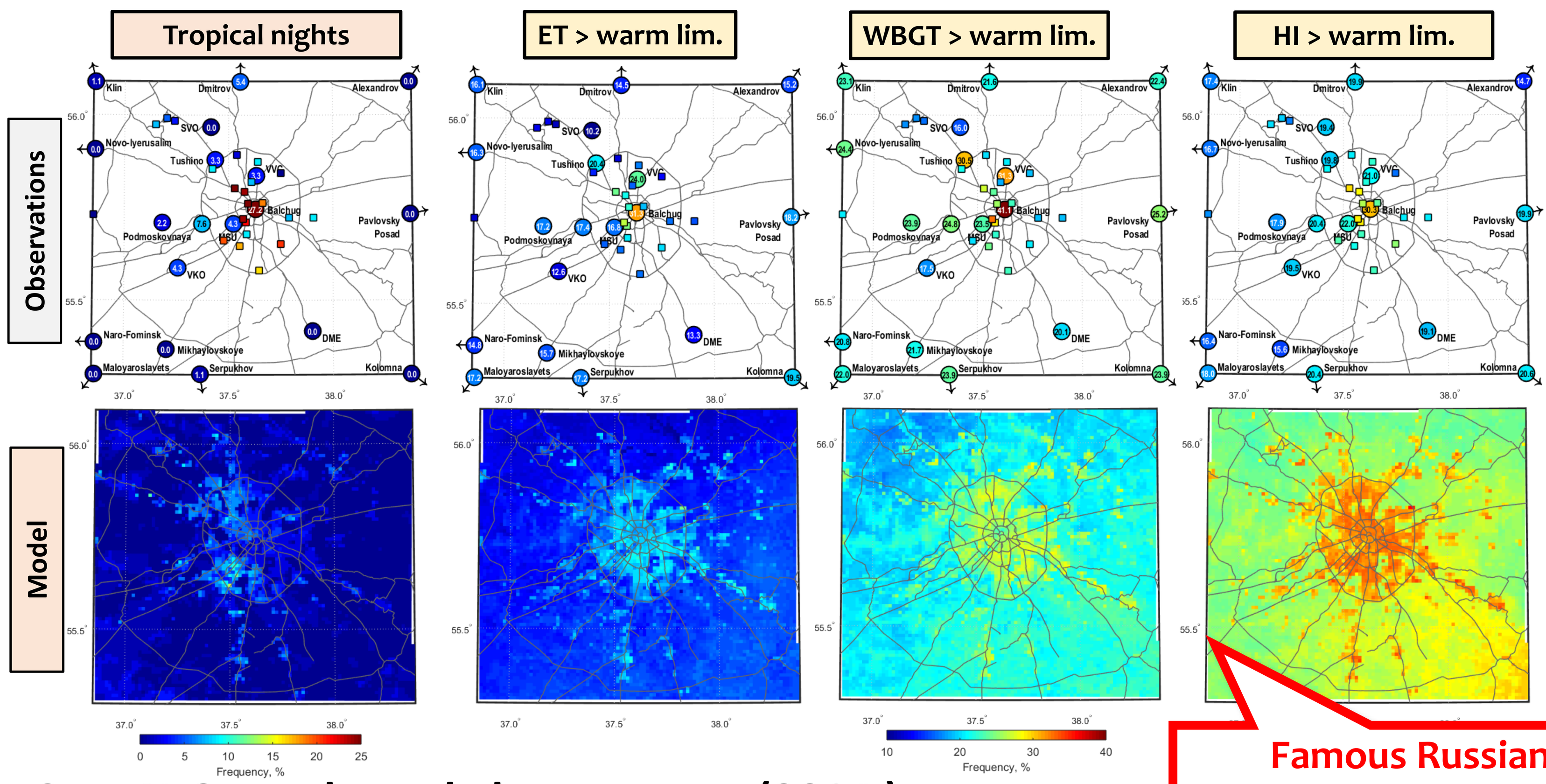


Connections with human comfort for observations and modelling results

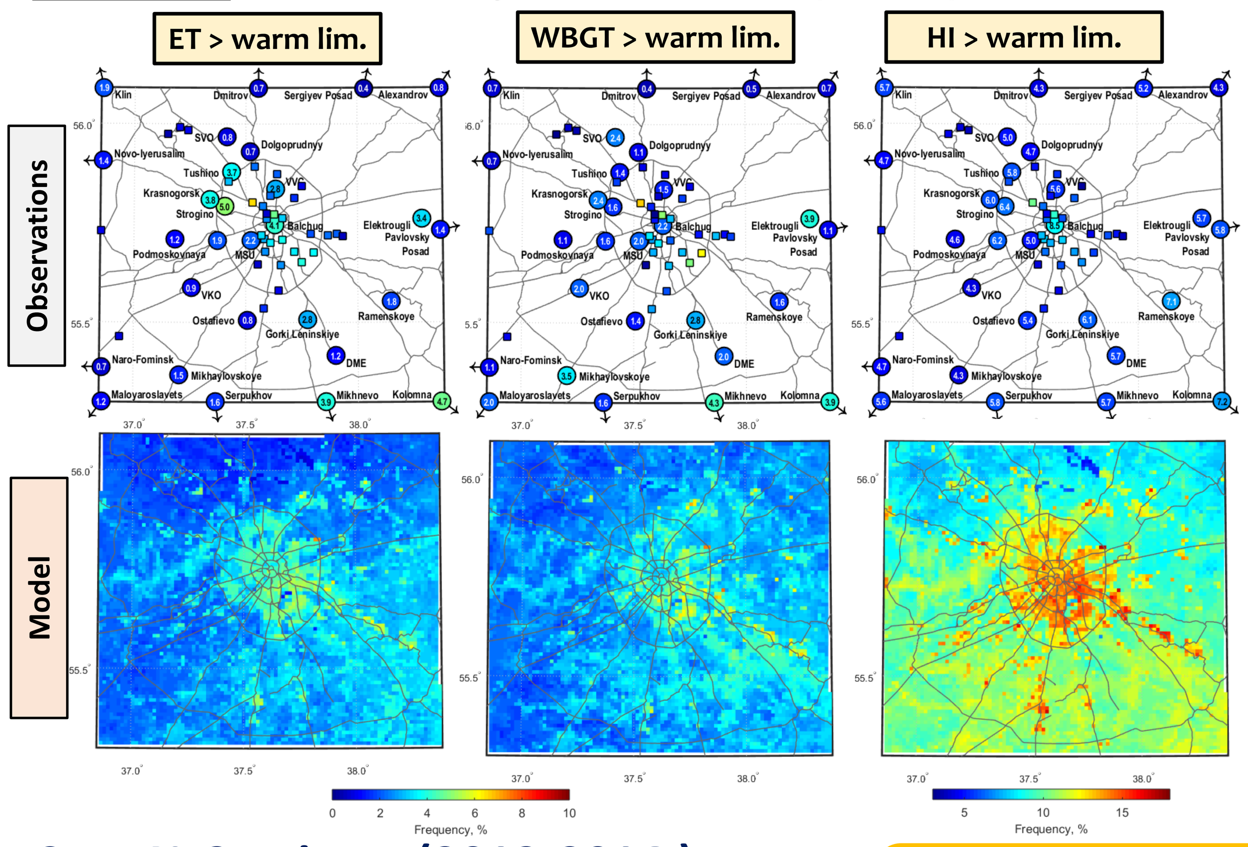
We analyzed spatial distribution of frequency of uncomfortable conditions during the season according several thermal indices, calculated from observation data and modelled fields:

Index of thermal comfort	Formula (for shadow conditions)	"Warm" threshold	"Very cold" threshold
Effective temperature (ET)	$ET = 37 - \frac{37-T}{0.68-0.0014*RH+\frac{1}{1.76+1.4*v^{0.75}}} - 0.29*T*(1-0.01*RH);$	> 24	< -21
Wet-Bulb Globe Temperature (WBGT)*	$WBGT = 0.567*T + 0.393*e + 3.94$	> 26.5	-
Heat Index (HI)	$HI = -8.78 + 1.61*T + 2.34*RH - 0.146*T*RH - 1.23*10^{-2}*T^2 - 1.64*10^{-2}*RH^2 + 2.21*10^{-3}*T^2*RH + 7.25*10^{-4}*T*RH^2 - 3.58*10^{-6}*T^2*RH^2;$	> 31	-
Wind Chill (WCI), US version	$WCI=13.12+0.6215*T-11.37*V^{0.16}+0.3965*T*V^{0.16}$	-	< -15
Tropical nights	-	T^{min} > 24	-

Case №1: extremely hot summer (Russian heat wave 2010)

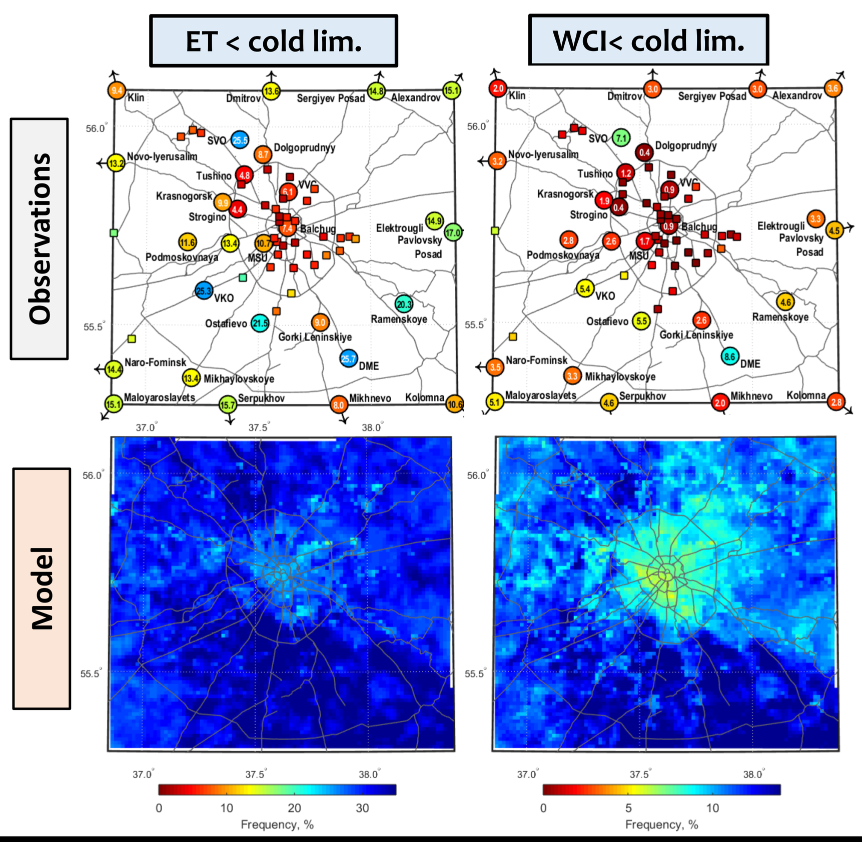


Case №2: moderately hot summer (2014)



Famous Russian heat wave 2010

Case №3: winter (2013-2014)



Summary

- ✓ Urban amplification of global warming in Moscow become more intensive during last to decades, especially during summer
- ✓ Temperature distribution within the city is complicated and driven by local and mesoscale factors (size and shape of the city, wind speed & direction)
- ✓ In winter temperature field is smoother and more affected by advection
- ✓ Experiments with COSMO-CLM + TEB model shows relatively good agreement with observations for the temperature spatial distribution and UHI intensity diurnal variation; however, model underestimate maximum values of UHI intensity, so further tuning is required
- ✓ Strong effect of the city on the frequency if uncomfortable conditions is show. Model here shows poor agreement with observations, underestimating urban-related contrasts and underestimating or overestimating background values

References & acknowledgements

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- Trusilova K., Früh B., Brienen S., Walter A., Masson V., Pigeon G., Becker P. Implementation of an Urban Parameterization Scheme into the Regional Climate Model COSMO-CLM. J. Appl. Meteor. Climatol. V. 52. P. 2296–2311

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