Investigation of 3D structure of urban heat island of Moscow city with application of microwave temperature sounding and high resolution regional modelling with data assimilation

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Abstract

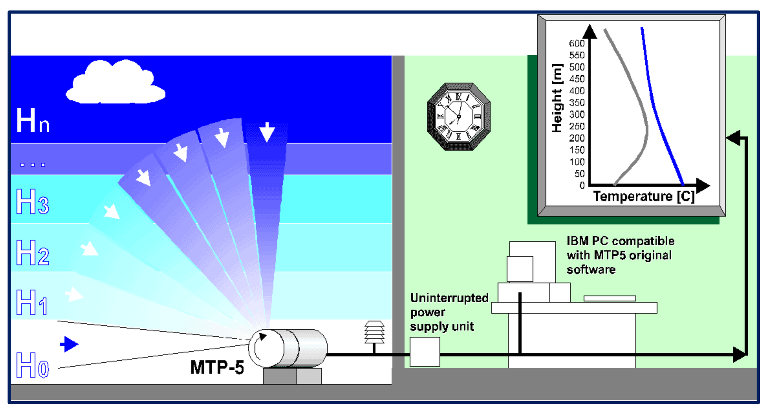
Development and validation of urban-scale numerical weather and climate models requires better understanding of three-dimensional structure of urban heat island, including its shape and vertical thickness. An attempt to investigate 3D structure of the urban heat island of Moscow city, which forms the biggest urban agglomeration in Europe, was made during September-October 2014. Three similar MTP-5 microwave temperature profilers, which are available to measure temperature at the heights from 0 to 1000 meters with 50-m resolution, were install at three points in the city and its suburbs. These measurements were joined in single database with weather observations at more than 15 meteorological stations, located in the city and neighborhood.

Observations with MTP-5 profilers were taken one month. During this period, different weather conditions were observed, including periods of calm and clear anticyclonic weather, when urban heat island intensity at ground level reached values up to 8 ^oC, with mean value about 1.8 ^oC. Temperature difference between urban territory and suburbs over the surface, according MTP-5 measurements, was also significant (up to 2 ^oC at several moments) until the height of 1000 m.

Measurements of temperature profilers were used for data assimilation in numerical experiments with WRF (Weather Research & Forecasting) model, launched with resolution about 1 km for Moscow region. The effect of data assimilation on forecast quality for rural and urban territories was examined and evaluated. Observations of the MTP-5 temperature profilers and meteorological stations and modelling results were used for investigation of the 3-dimentional structure of urban heat island and It's dependence on synoptic conditions and wind direction.

MTP5 microwave temperature profiler

Microwave temperature profiler MTP-5 is produced by Russian company Attex (http://attex.net/). It makes measurements up to 1000 m above the instrument and gives the same performance in all weather conditions. Declared temperature accuracy is 0.2 – 1.2 ^{o}.



Observations description & analysis

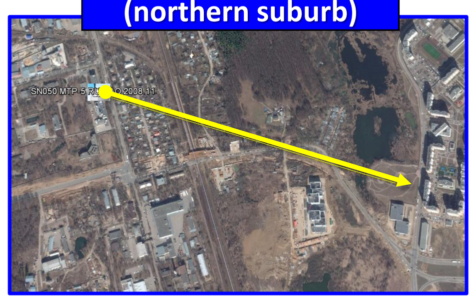
Measurements period:
20.09.2014 – 22.10.2014

Data sources:

- MTP-5 profilers at 3 points
- Meteorological observatory of Moscow University (MSU)
- Local weather stations & MosEcoMonitoring stations

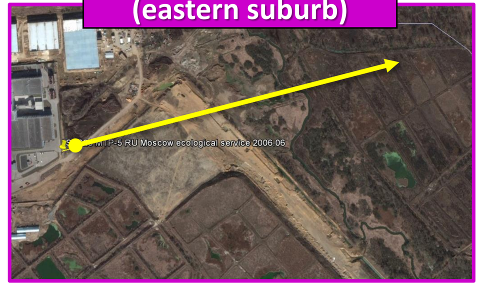
Location of MTP devised and sounding directions:

Dolgoprudyy site (northern suburb)

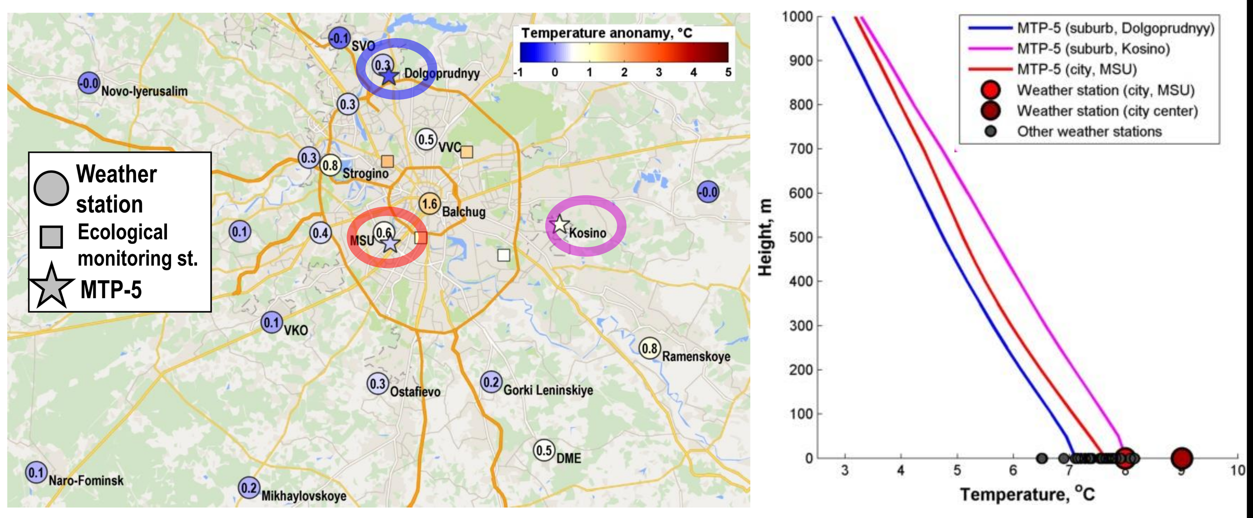


MSU site (city park)

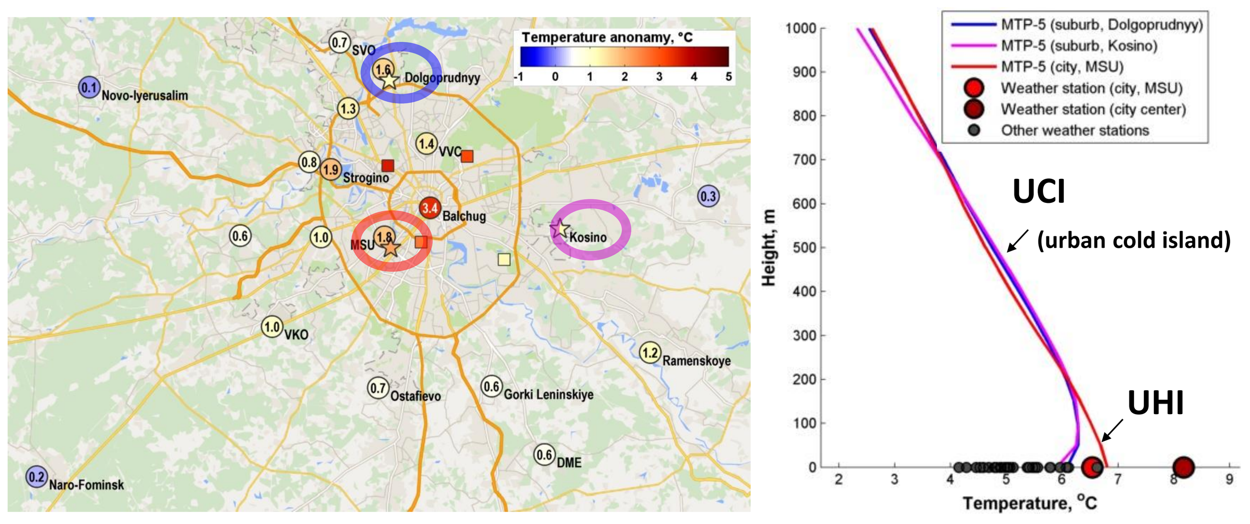
Kosino site (eastern suburb)



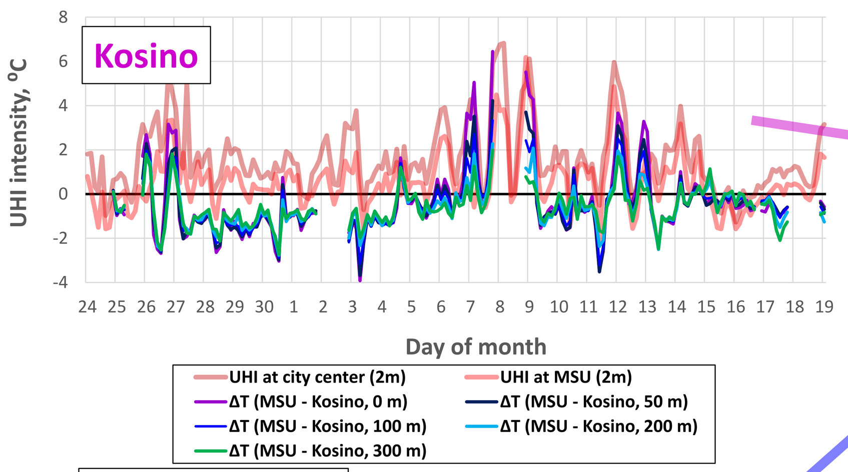
Mean temperature distribution (all cases with data available):

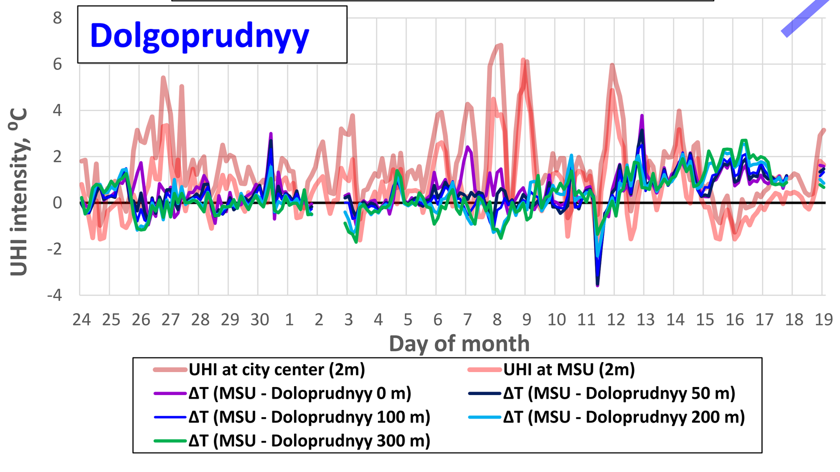


Mean temperature distribution (cases with UHI at city center > 2 ^oC) :

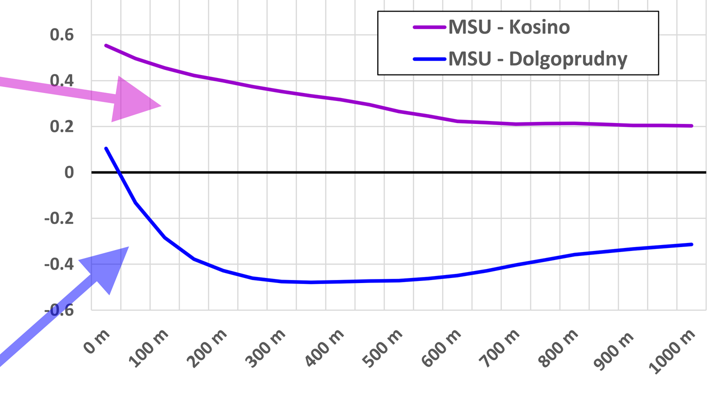


UHI intensity dynamics at different heights:

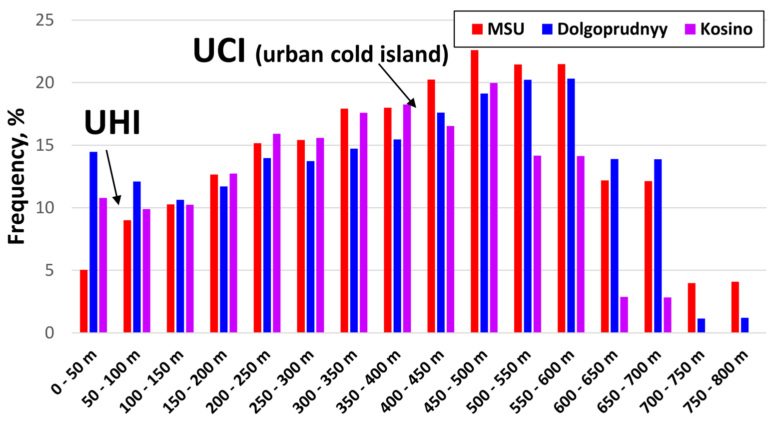




Correlation between UHI at city center and temperature difference between urban and city MTP measurements at different heights



Inversion frequency (dt/dz > 0.1°C/100 m)



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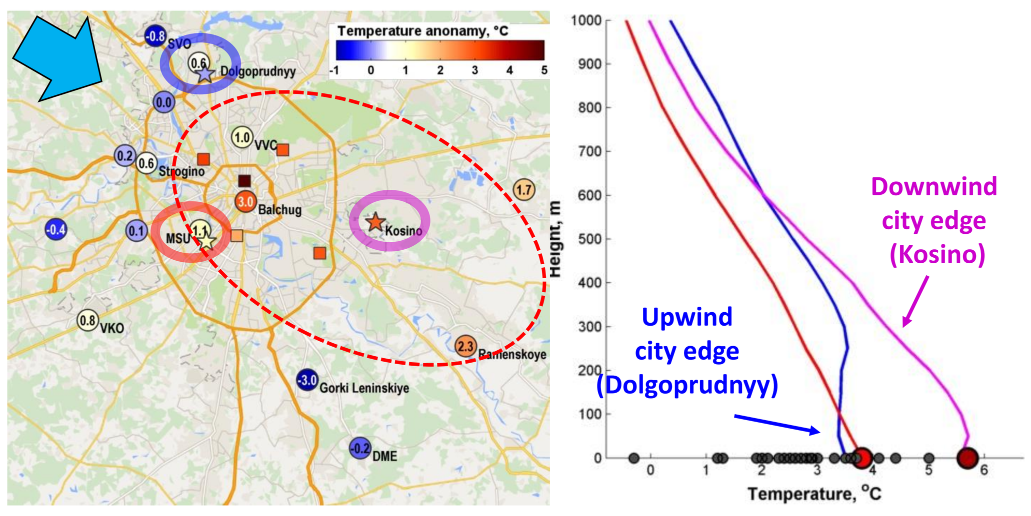
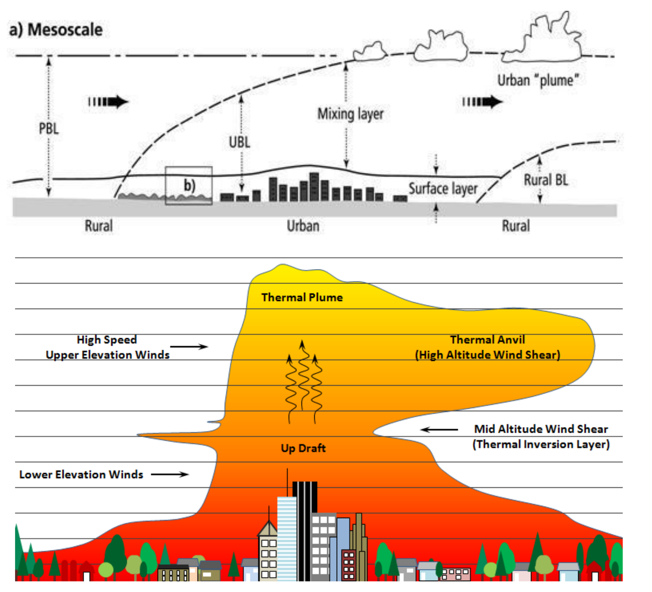
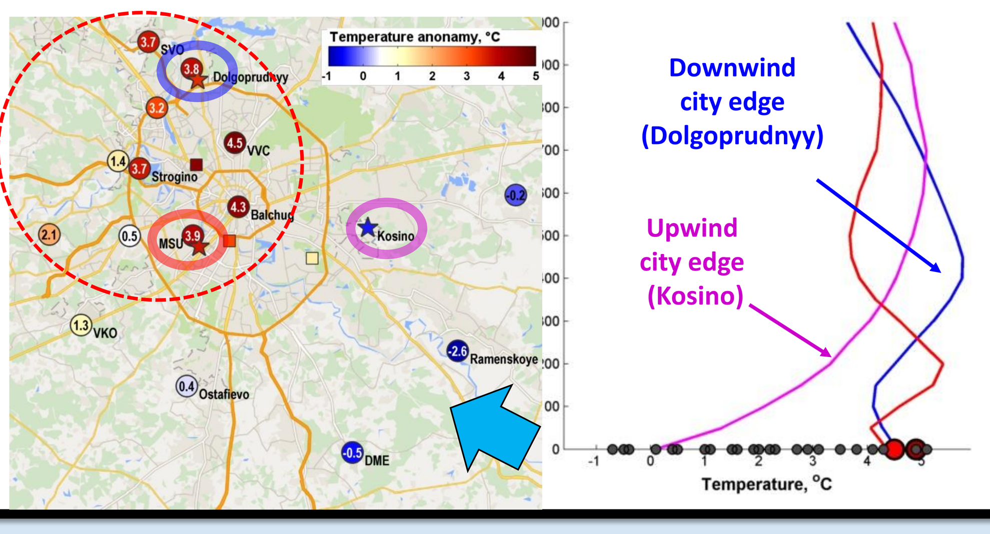
3D-structure of the urban plumes

Case with north-west wind (02-Oct-2014 00 MSK)





Case with south-east wind (09-Oct-2014 06 MSK)



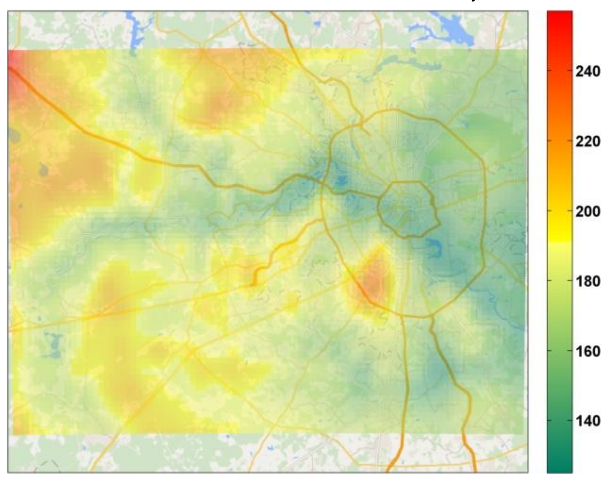
Data shows that described in theory so-called "urban plumes" were observed in cases with significant UHI intensity and weak wind. They were accompanied by the shift of heat island core to downwind side of the city.

WRF simulations with temperature profiles assimilation

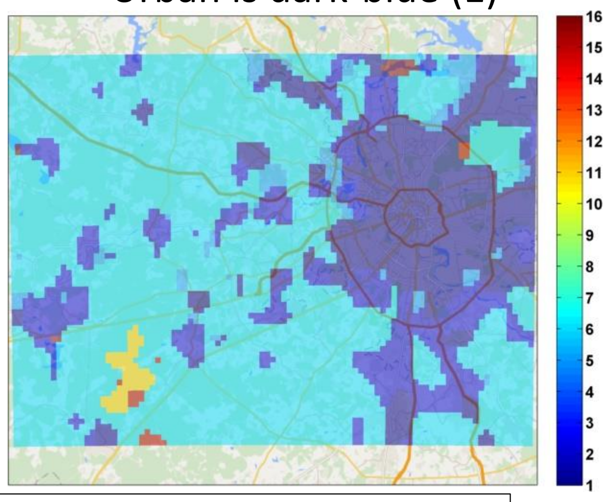
Model configuration (smaller nested domain):

```
97 (w-e) x 73 (s-n) x 35 (vert) cells,
time_step = 60 sec,
dx = dy = 1000 m,
sf_urban_physics = 0 (None),
sf_surface_physics = 2 (Noah Land Surf.)
bl_pbl_physics = 2 (Mellor-Yamada-Janjic)
```

Surface elevation a.s.l, m



Landuse classed for WRF. Urban is dark-blue (1)



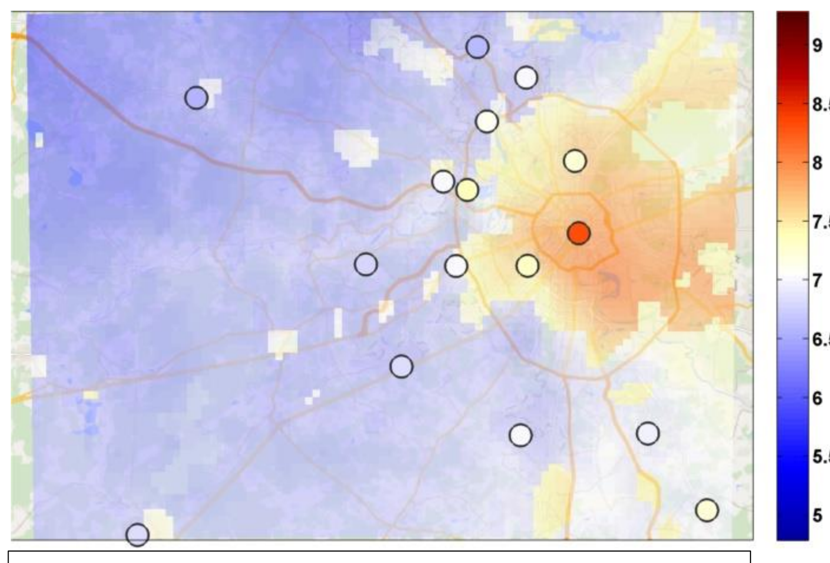
Scheme of the model runs:

Forecast starts from original initial conditions from basic domain and from corrected initial conditions (with assimilated temperature profiles for initial moment) every 6 hours, for 24 hours – producing forecasts for 6 (h6), 12 (h12), 18 (h18) and 24 (h24).
Model runs for 26 Sept – 18 Oct 2014.

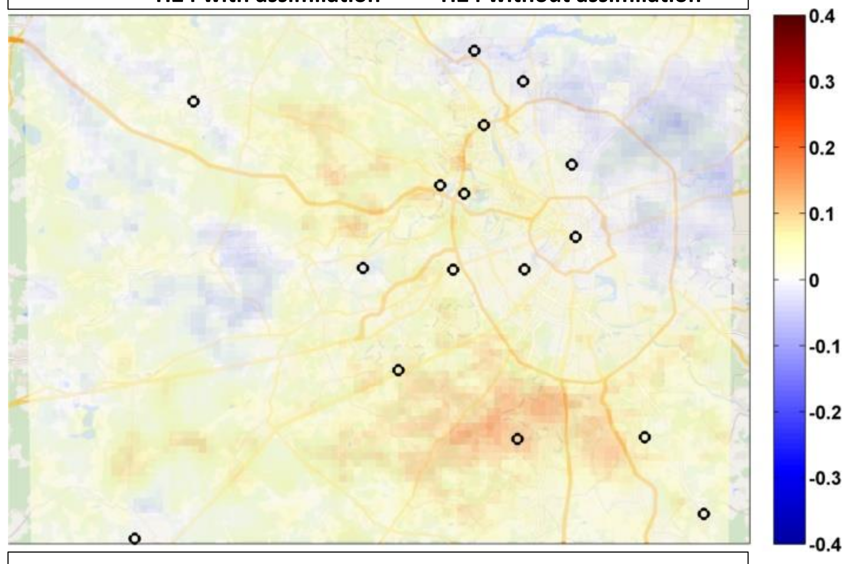
Comparison with observation at weather stations:

	H6	H6_as	H12	H12_as	h18	h18_as	h24	h24_as
Mean RMSE	1.80	1.80	1.97	1.92	1.96	1.95	2.08	2.06
City center RMSE	1.63	1.59	1.77	1.71	1.71	1.68	1.79	1.75
Mean bias	-0.13	-0.10	-0.07	-0.14	0.03	0.02	0.04	0.06
City center bias	-0.56	-0.54	-0.49	-0.55	-0.34	-0.37	-0.31	-0.31

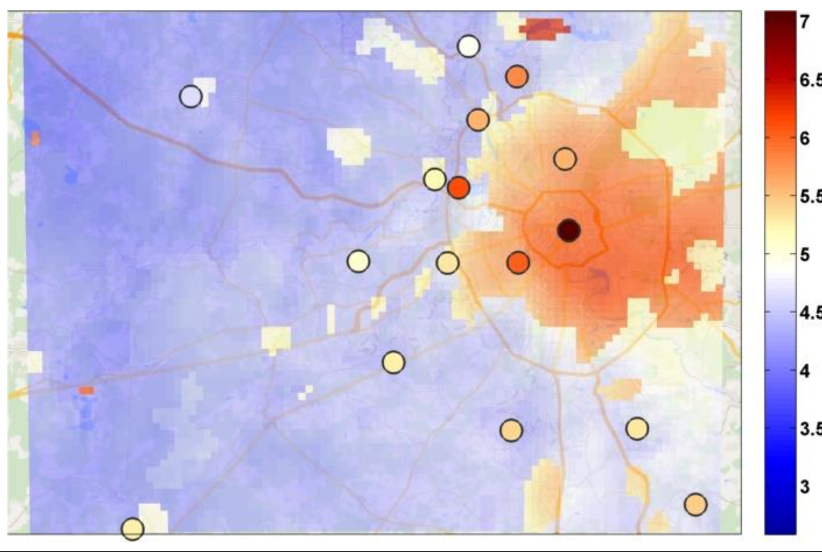
Mean temperature (H24 forecast without assimilation & observations)



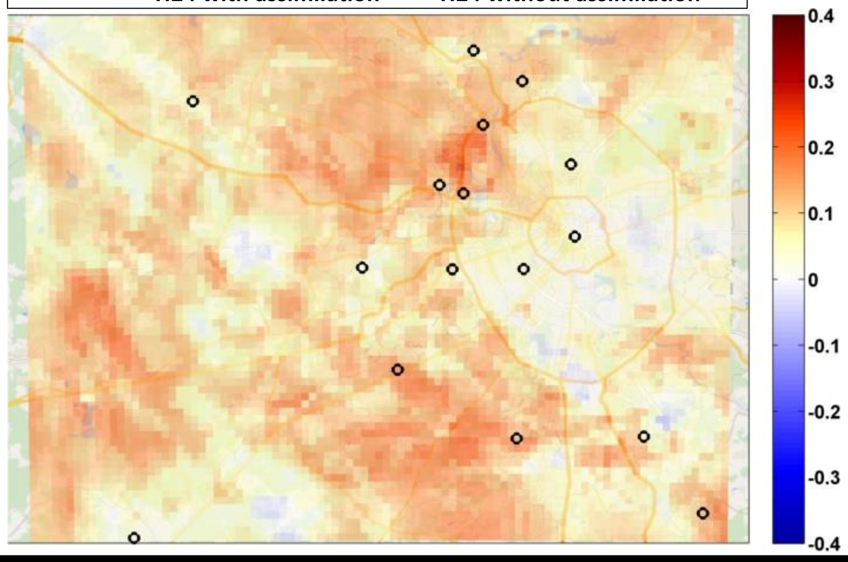
Mean difference $\Delta T = T_{H24\ with\ assimilation} - T_{H24\ without\ assimilation}$



Mean night (0 UTC) temperature (H24 forecast without assimilation & observations)



Mean night (0 UTC) difference $\Delta T = T_{H24\ with\ assimilation} - T_{H24\ without\ assimilation}$



Summary

1. Temperature profiles, averaged for whole observation period, hadn't shown significant urban-caused anomalies , probably because of unfavorable synoptic conditions and gaps in the data. **But averaging for the cases with significant UHI (higher than 2 ^oC) had shown that vertical extent of UHI in average was about 200 m and extent of overlaying urban cool island (UCI) from 200 to 600 m;**
2. Lower ratio of inversions was observed over the city then over suburbs in lower 100 m (UHI) and higher ration – from 100 to 600 m (UCI);
3. At Kosino suburb site positive correlation between UHI intensity over ground (2m) and in UHI intensity in different heights was observed. At Dolgoprudnyy suburb site negative correlation was observed.
4. Cases with shifted by wind UHI warm core and urban plumes over the city were observed;
5. Comparison between WRF model simulations and observations shows that model relatively good simulates temperature regime of Moscow city (including UHI intensity variation), but temperature profiles assimilation hadn't provided any significant effect on forecast quality.