Work package 4

”Creation of concept and methods for simulation of the mega-urban planetary boundary layer”
(in collaboration with WP2 & WP5)

Victor Stepanenko

Moscow State University

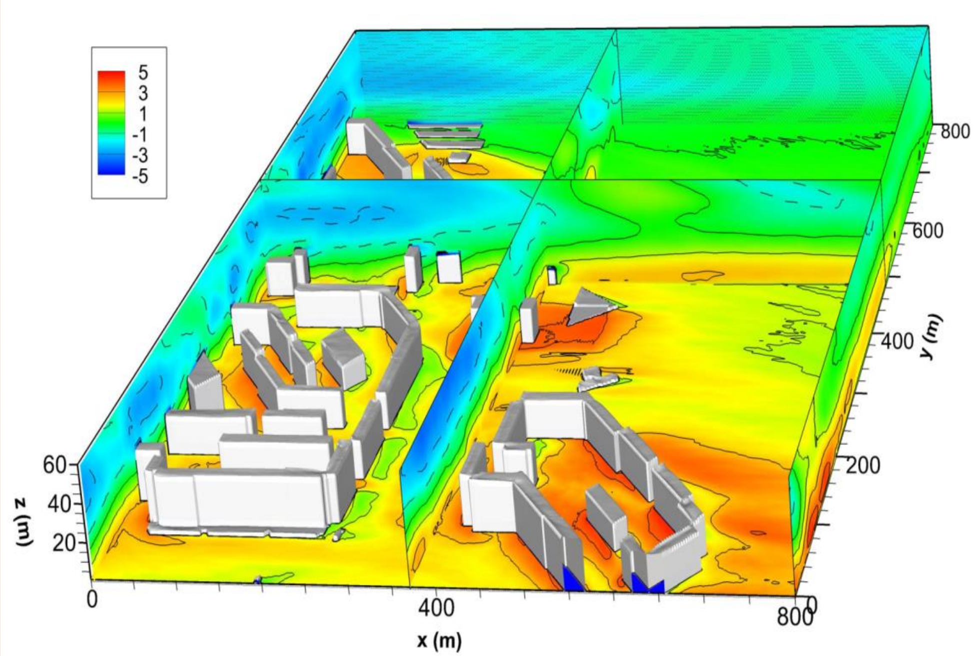
Expected results of the WP in 2021

- Observational data on the **structure and dynamics of the surface layer** of the atmosphere within urban areas
- Methodology for determination of **aerosol vertical mixing index**
- Turbulence characteristics and **spatial distribution of aerosols in urban environment** based on model calculations
- **Database of turbulence and profile measurements** performed in urban environment. Classification of hazardous atmospheric phenomena developing in the Moscow agglomeration in different seasons.
- Data on statistical moments and spectral characteristics of turbulence. Estimates of the influence of **large-scale organized structures in the PBLs** on the frequency spectra of surface turbulence.
- **Parameterizations of the transformation of aerosols** in the boundary layer
- Database of observational data and model calculations for further analysis of typical features of **long-lived circulation systems** over the Moscow agglomeration

Urban boundary layer dynamics and street-scale aerosol transport

Numerical simulation of hydrodynamics and aerosol transport in urban canopy (LES by INM RAS/MSU)

Temperature anomalies in the urban canopy

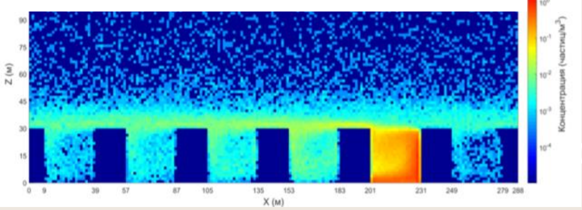


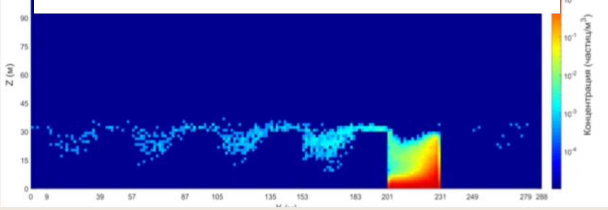
Large-Eddy simulation model of INM RAS/MSU

↓ One-way coupling

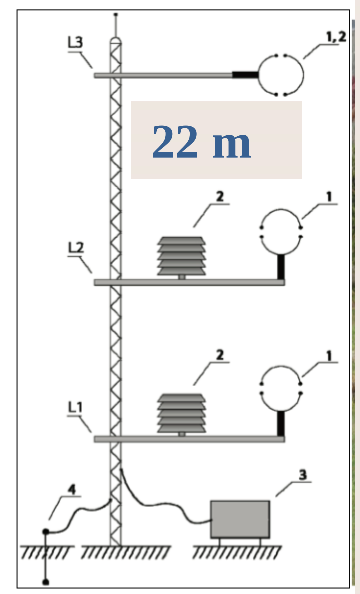
SILAM model (System for Integrated modeLling of Atmospheric composition)

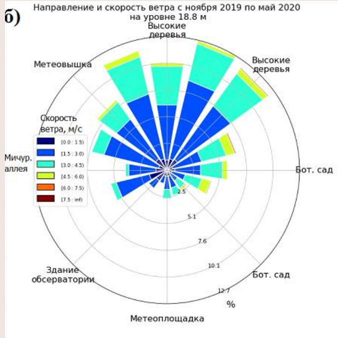
Simulations of aerosol in a series of urban canyons


Stable stratification


Unstable stratification

Measurements of atmospheric turbulence quantities at the micrometeorological mast in the MSU meteorological observatory





The test for organized turbulent eddies in the urban boundary layer (I.Repina, I.Drozd)

Sergej Zilitinkevich (1936 - 2021)

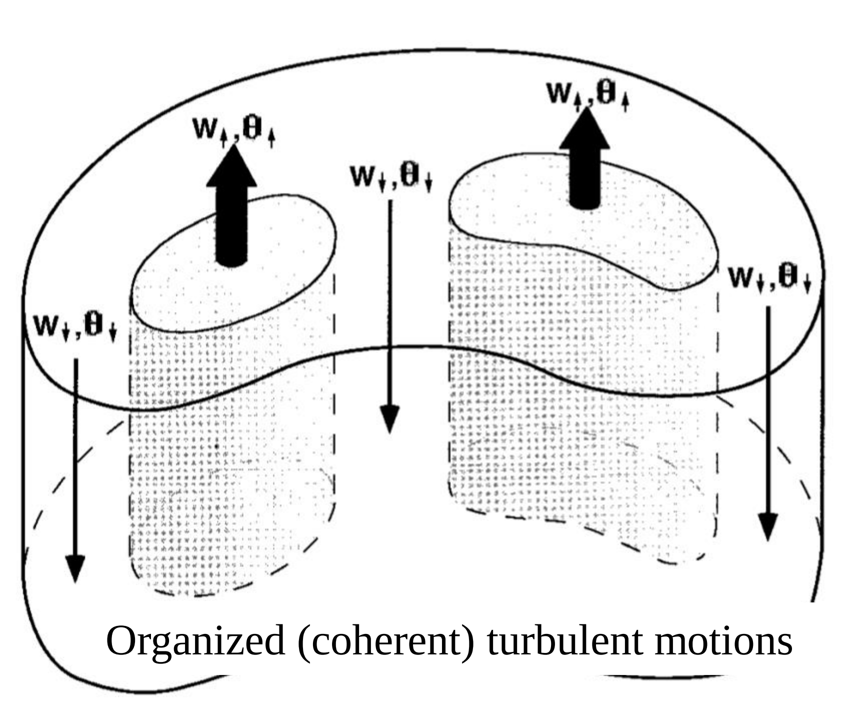
Vasiliy Lykosov (1945 - 2021)

Zi et al. theory for convective boundary layers predicts a relationship of ”flux of heat flux” and heat flux:

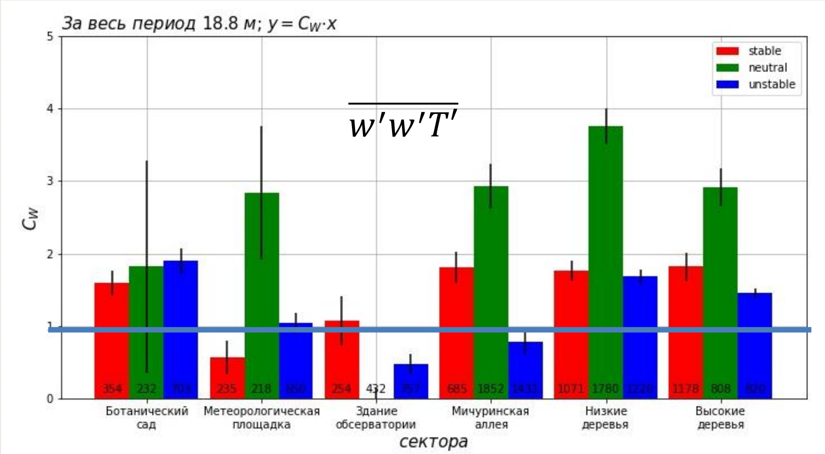
$$\overline{w'w'T'} = C_w S_w \left(\overline{w'^2}\right)^{\frac{1}{2}} \overline{w'T'} \quad \overline{w'T'T'} = C_T S_T \left(\overline{T'^2}\right)^{\frac{1}{2}} \overline{w'T'}$$

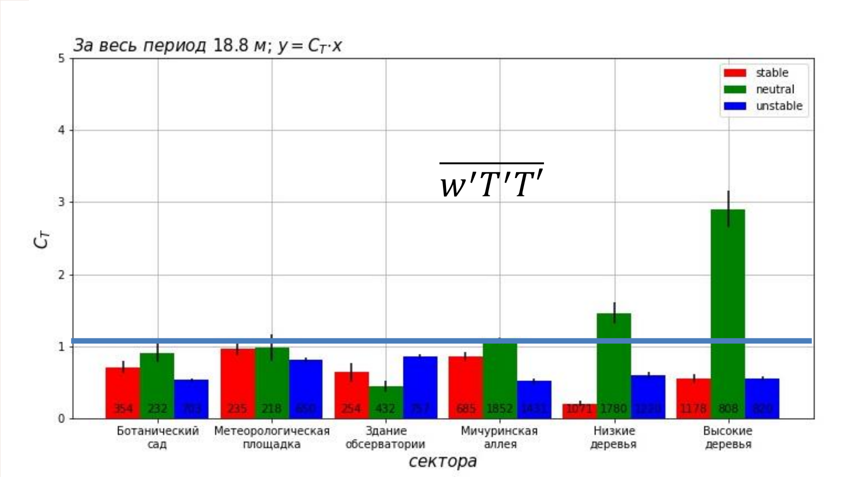
We demonstrate by our measurements that this hypothesis is applicable in more general conditions in the urban canopy

(Zilitinkevich, Gryanik, Lykossov, Mironov, 1999)



Organized (coherent) turbulent motions





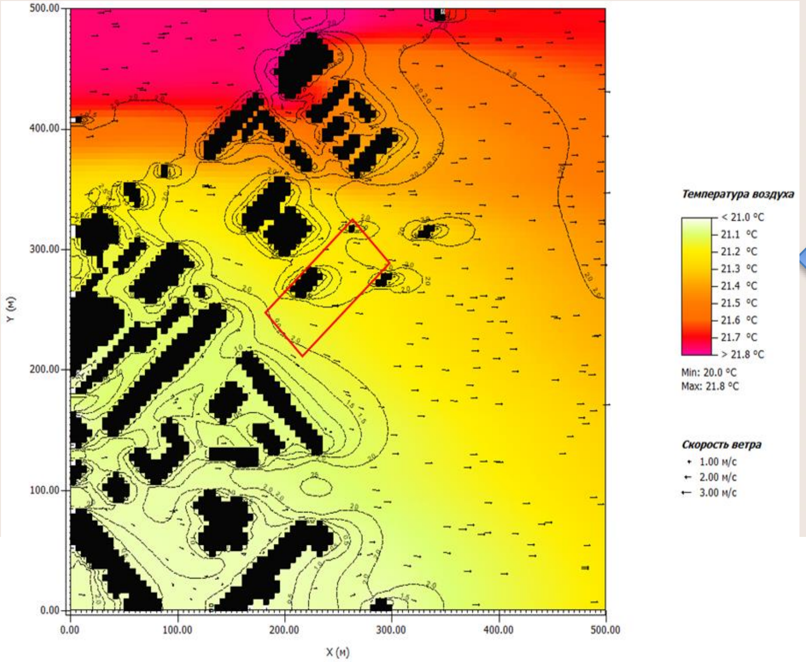
<u>Hypothesis:</u>

$C_T \sim 1$

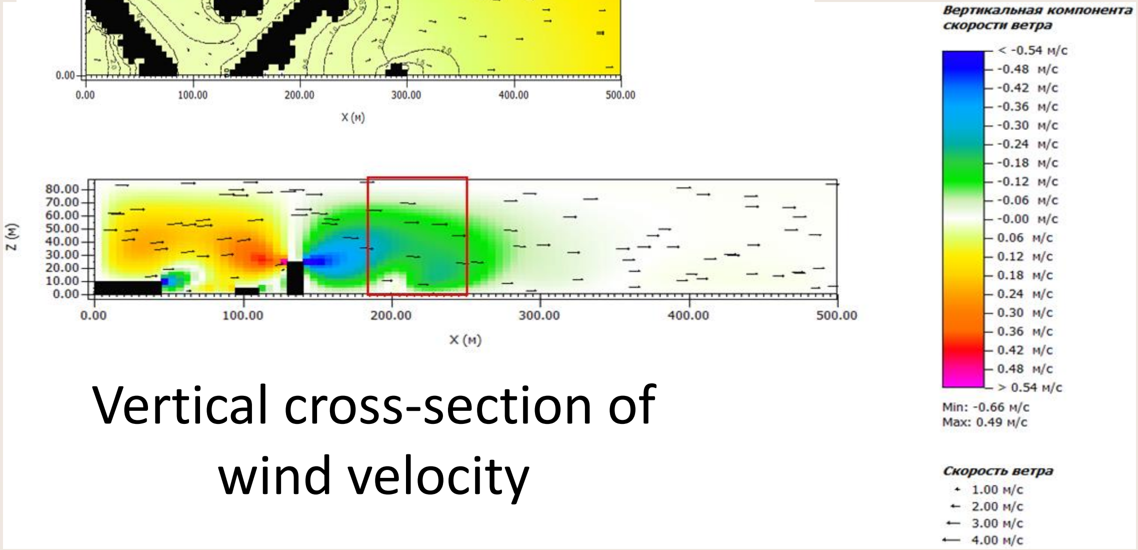
$C_W \sim 1$

Numerical hydrodynamic modelling of the wind in the MSU campus development for simulation of aerosol transport and deposition (A.I. Varentsov)

Geometry of the development in the area of the MSU Meteorological Observatory presented on a computational grid of the ENVI-met model of 500 by 500 by 120 cells with one cell size of 5 m x 5 m x 2.5 m. The location of the MO MSU is indicated by a red circle.



Air temperature, 2 m

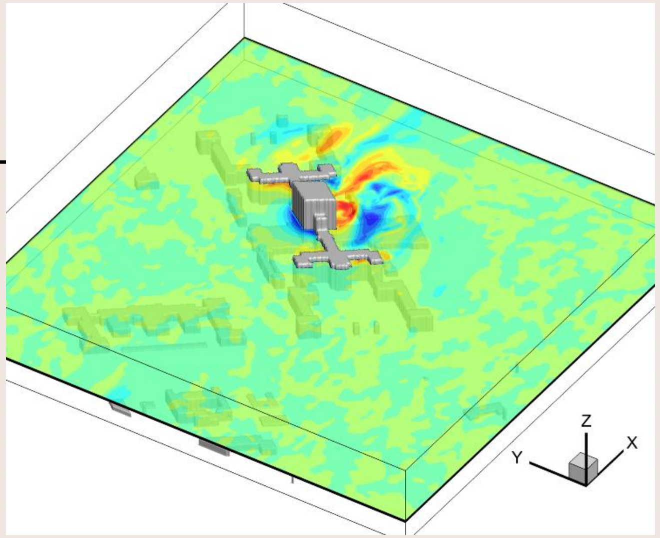


Vertical cross-section of wind velocity

Urban boundary layer Large Eddy Simulations (LES)

Numerical simulation of Eulerian tracer & Lagrangian particle transport in turbulent ABL (SBL & CBL)

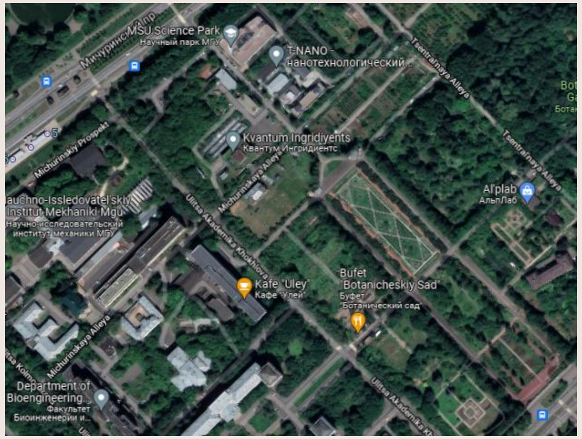
– Using LES model developed at MSU/INM RAS



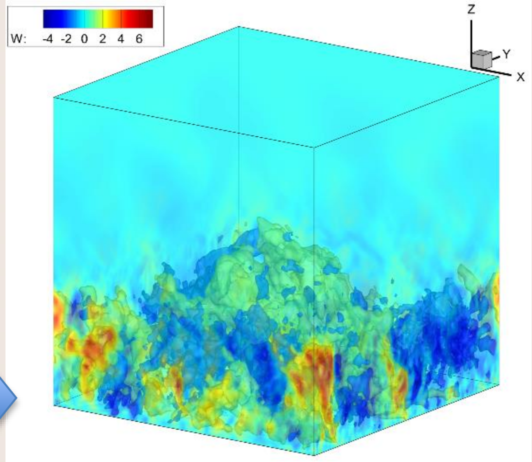
Convective boundary layer simulations

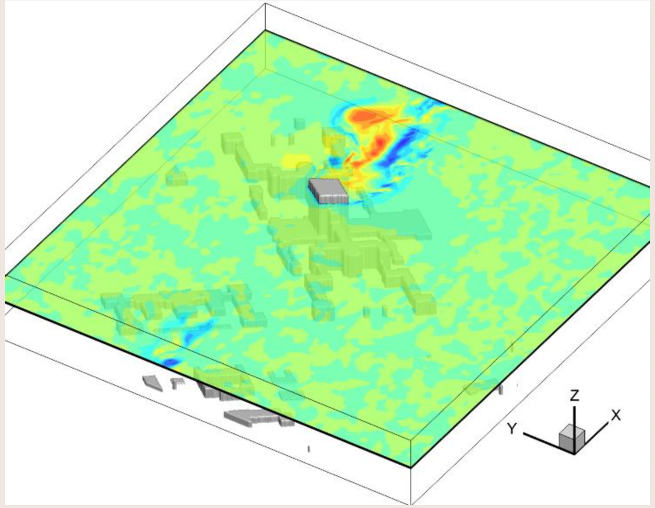
- 2-4 km^3 domain with up to ~4 meter resolution
- Verification of Lagrangian particle transport vs. Eulerian scalar transport
- Different “lifetime” for particles/concentrations, using simple model of decay. Correlations between different substances transport in CBL conditions depend on the ratio of decay time scale and the CBL time scale, e.g. h_CBL/w*
- Flat surface and urban-like terrain simulations

3D Map of MSU camp & neighborhood



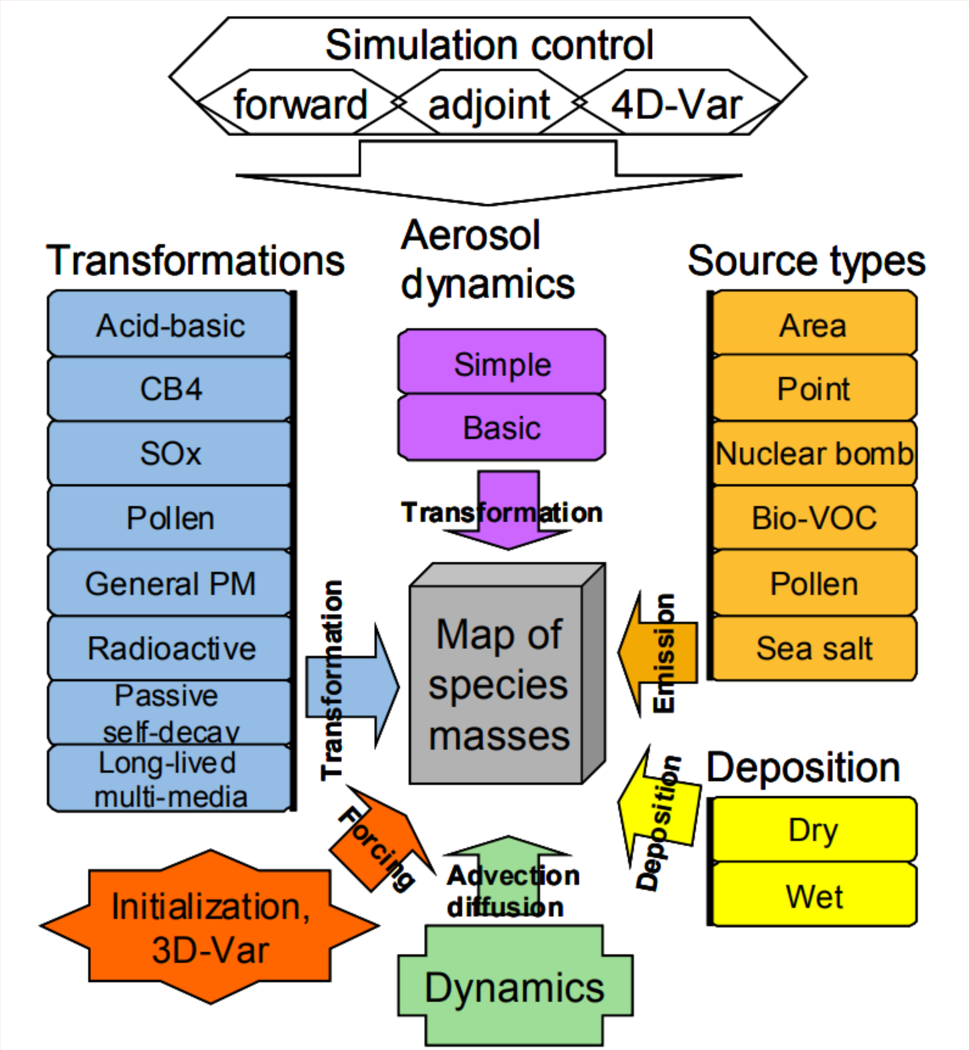
CBL turbulence in LES, evident large-scale transport





In progress: adding the “spire” to MSU main building

Coupling of SILAM model to the MSU/INM RAS LES model



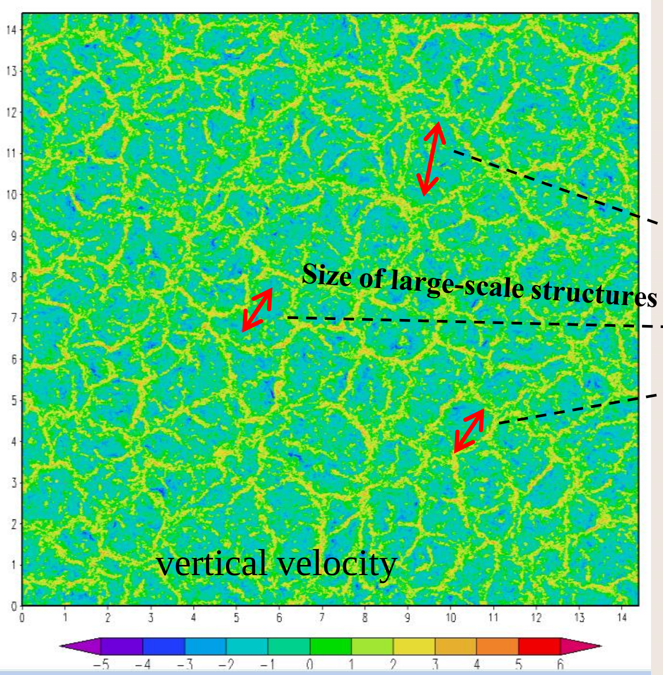
- Modelling atmospheric composition and air quality at global and mesoscale
- More than 100 substances and particle species, their reactions and interactions
- Need for input data on airflow properties

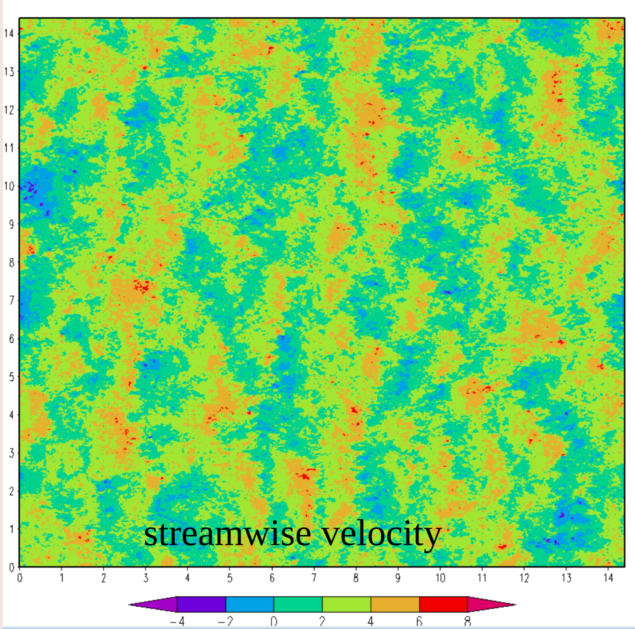
Application to street-level transport and chemistry?

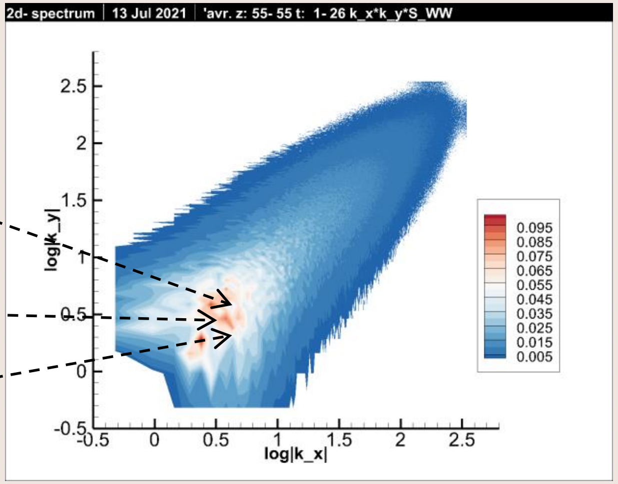
High resolution input data:
one-way coupling with the LES model

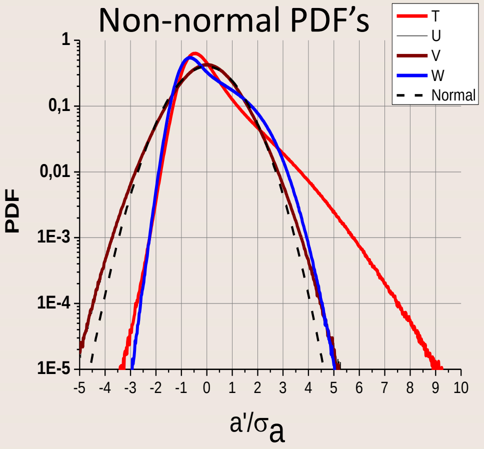
Problem: huge amount of LES data
Solution: spatio-temporal coarsening?

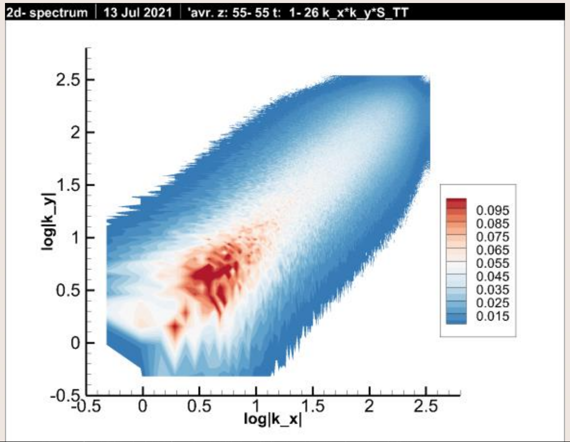
Large Eddy Simulation of the convective atmospheric boundary Layer

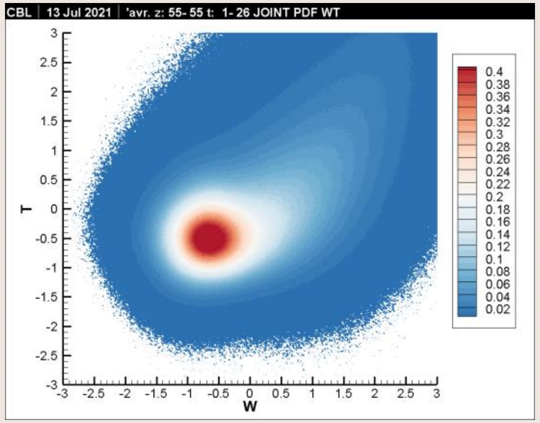


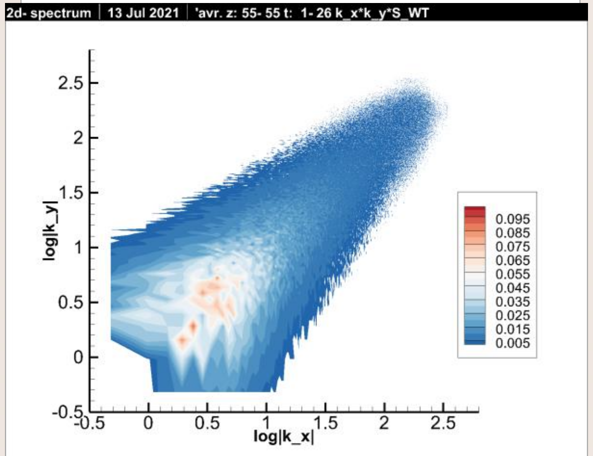


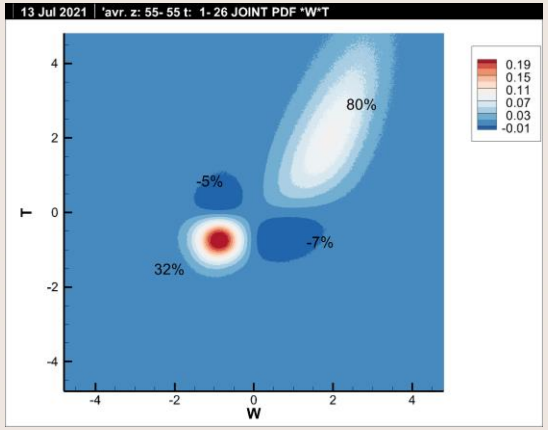








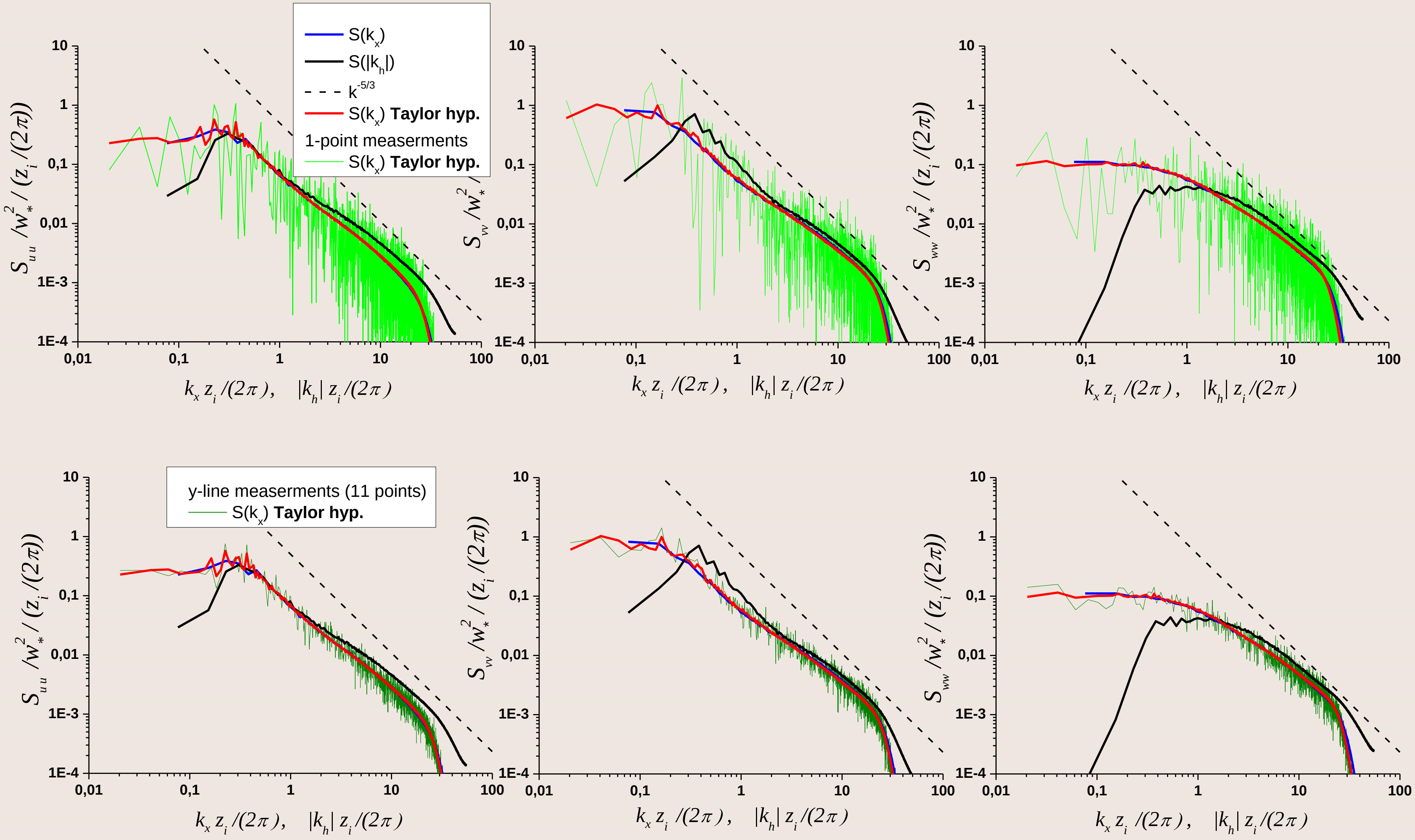




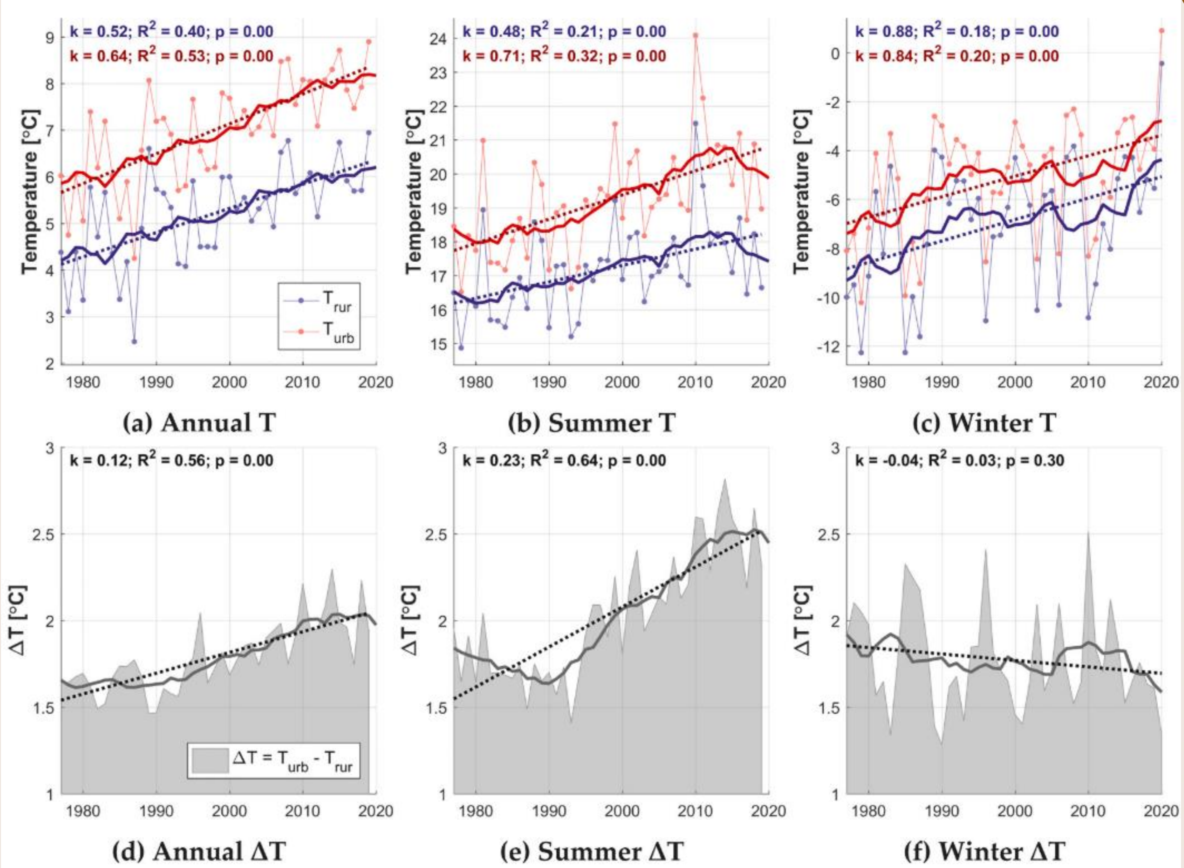
Imitation of field measurements of spectra using LES data

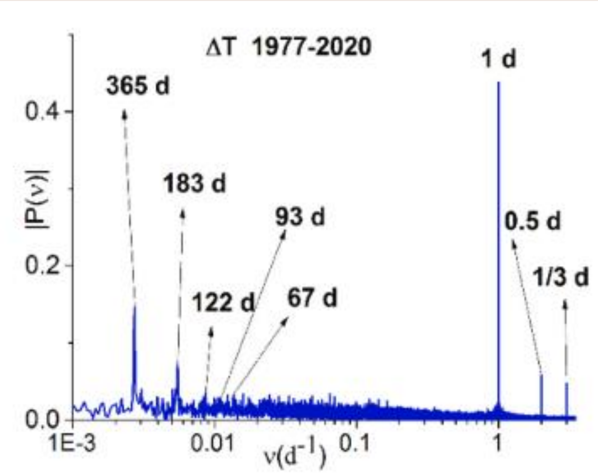
$U_g/w^* = 3.4$ $|U|/w^* = 2.72$ $U_g = 9$ m/s, $z = 0.1z_i$

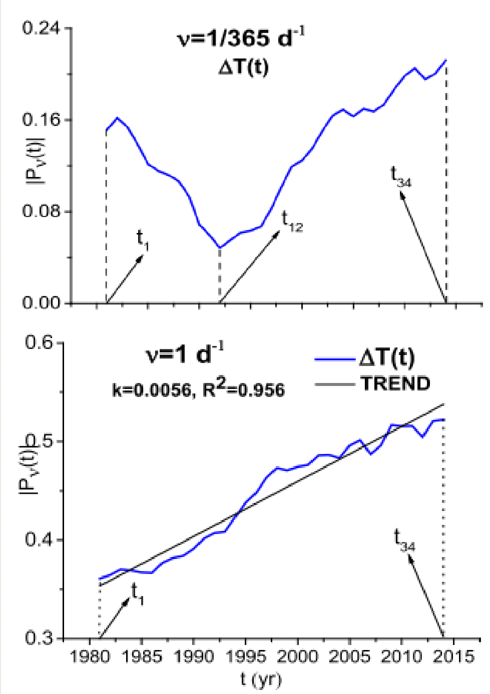
$|U|/u' = 4.7$
$|U|/v' = 4.2$
$|U|/w' = 5.4$



Long-term dynamics of Moscow UHI and its spectra







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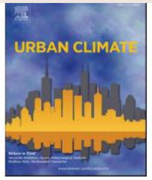
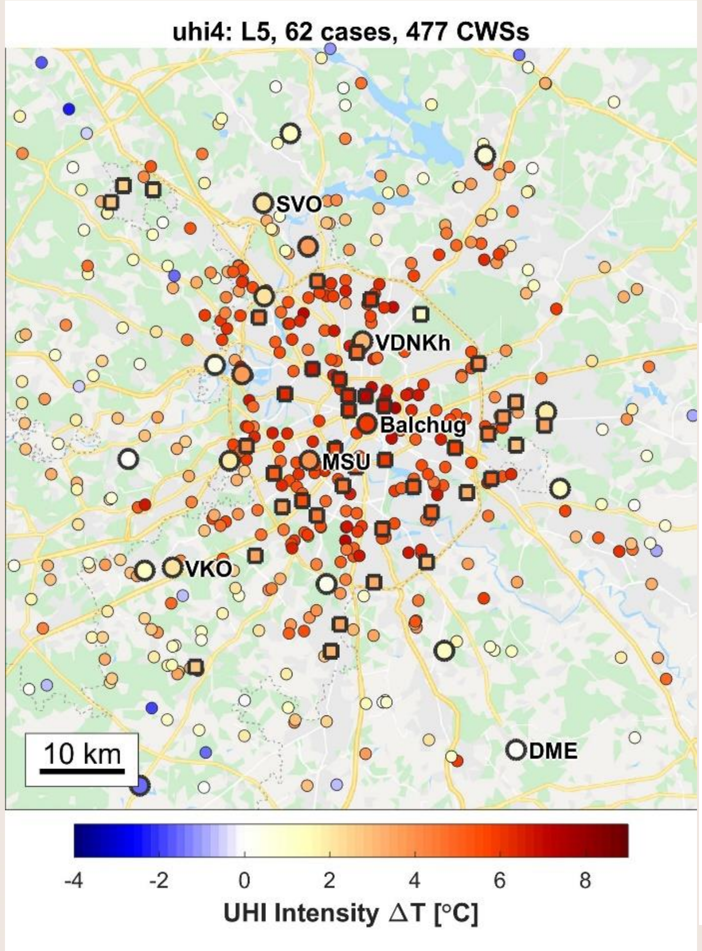
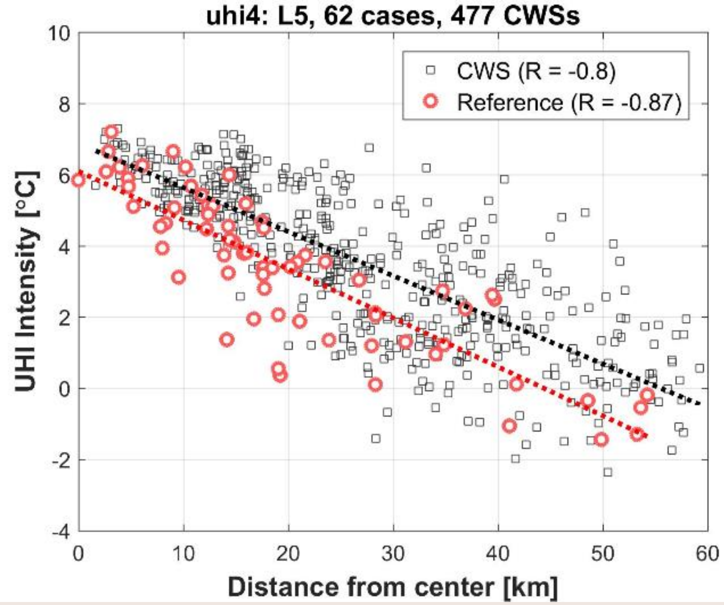


A new approach to study the long-term urban heat island evolution using time-dependent spectroscopy

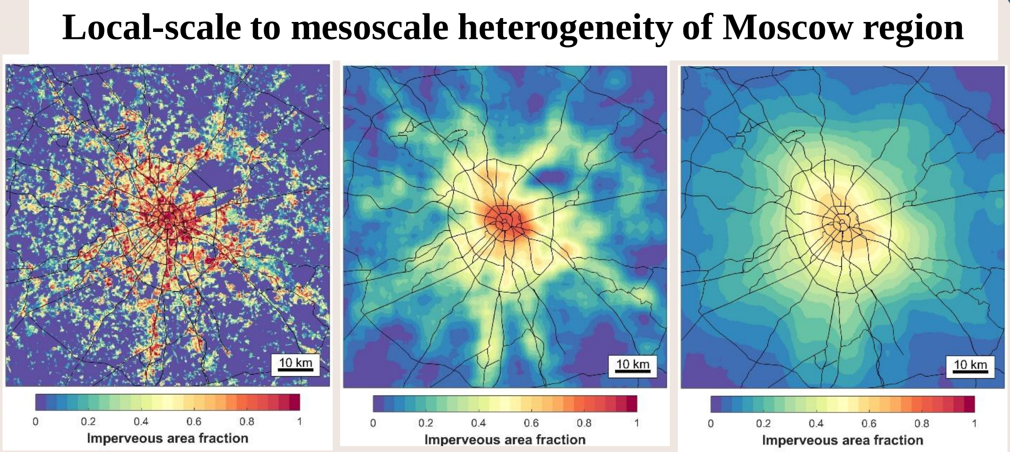
Svetlana A. Varentsova [a], Mikhail I. Varentsov [b,c,d,*]

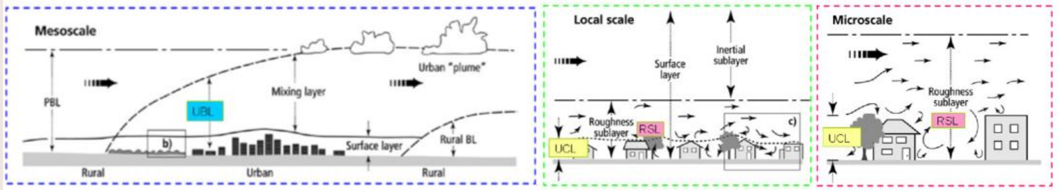
Local-scale and mesoscale drivers shaping UHI





Decreasing UHI intensity with a distance from city center indicates contribution of the mesoscale processes






frontiers in Environmental Science

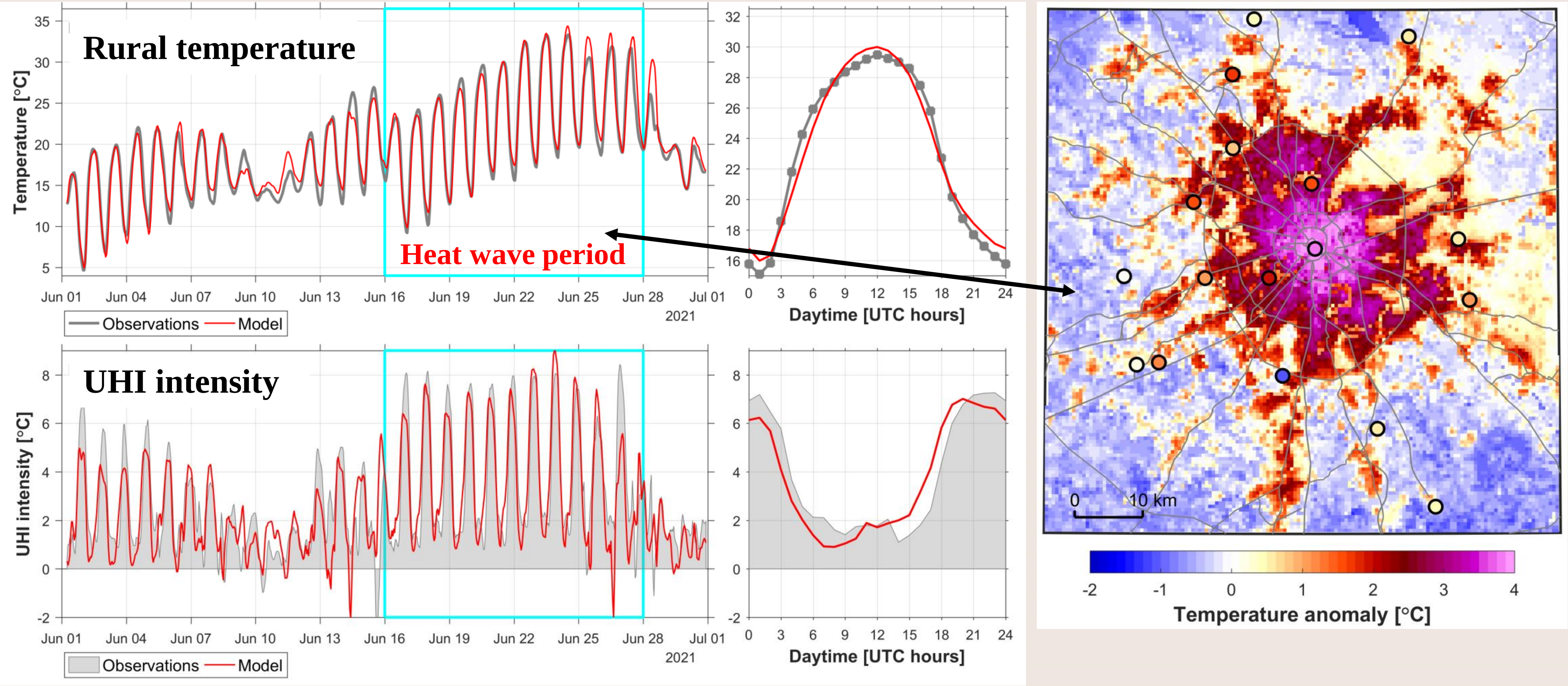
ORIGINAL RESEARCH
published: 25 November 2021
doi: 10.3389/fenvs.2021.716968

Quantifying Local and Mesoscale Drivers of the Urban Heat Island of Moscow with Reference and Crowdsourced Observations

Mikhail Varentsov[1,2,3], Daniel Fenner[4,5], Fred Meier[6]*, Timofey Samsonov[1,2] and Matthias Demuzere[4]*

New high-resolution COSMO simulations

Mesoscale simulations of Moscow's heat island during June-2021 heatwave with 500-m horizontal grid step

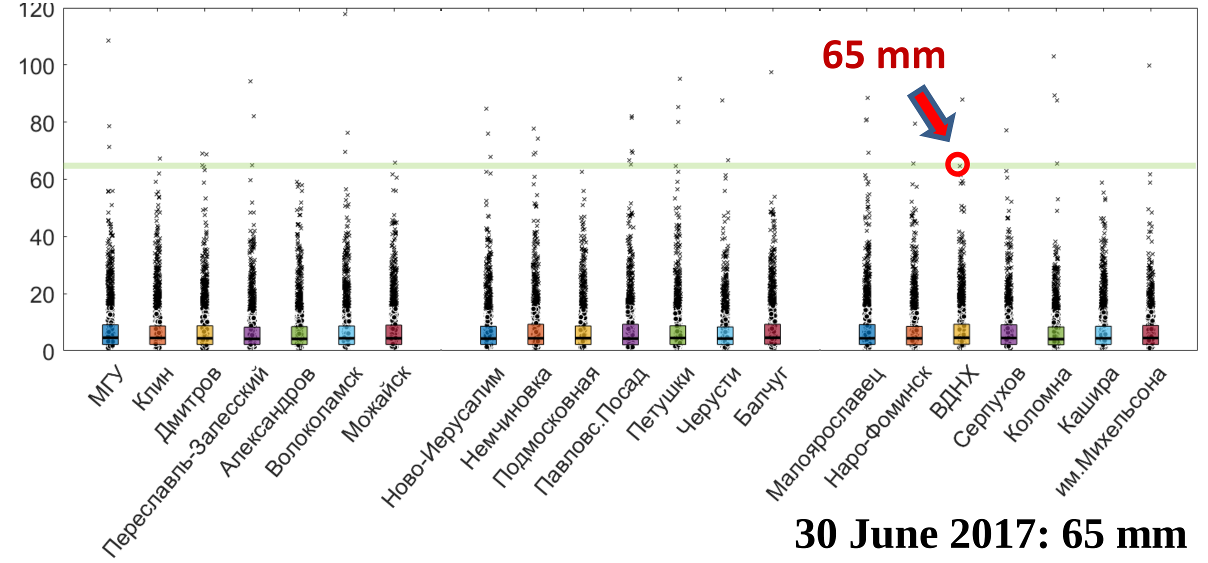


Modelling results obtained with and without urban scheme (URB/noURB runs)
will be further used to investigate urban-induced ABL anomalies under heat wave conditions

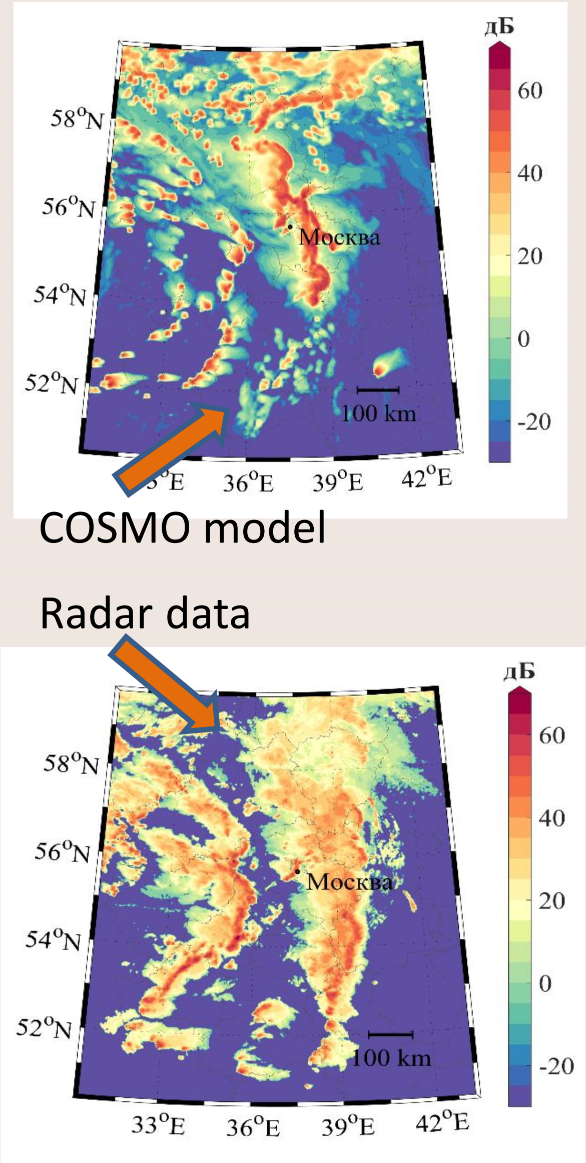
Summertime precipitation events:
statistics and hydrodynamic simulation of extreme cases (Yu.Yarinich, M.Varentsov)

May-Sept daily precipitation statistics over **1978 – 2018**

Quantile level 0.999: **68.16 mm**
Max daily precipitation: **117.8 mm**

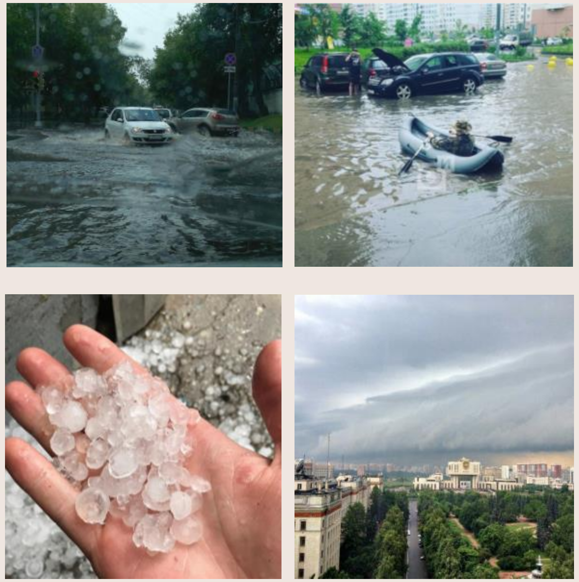


Radio reflectivity, dB

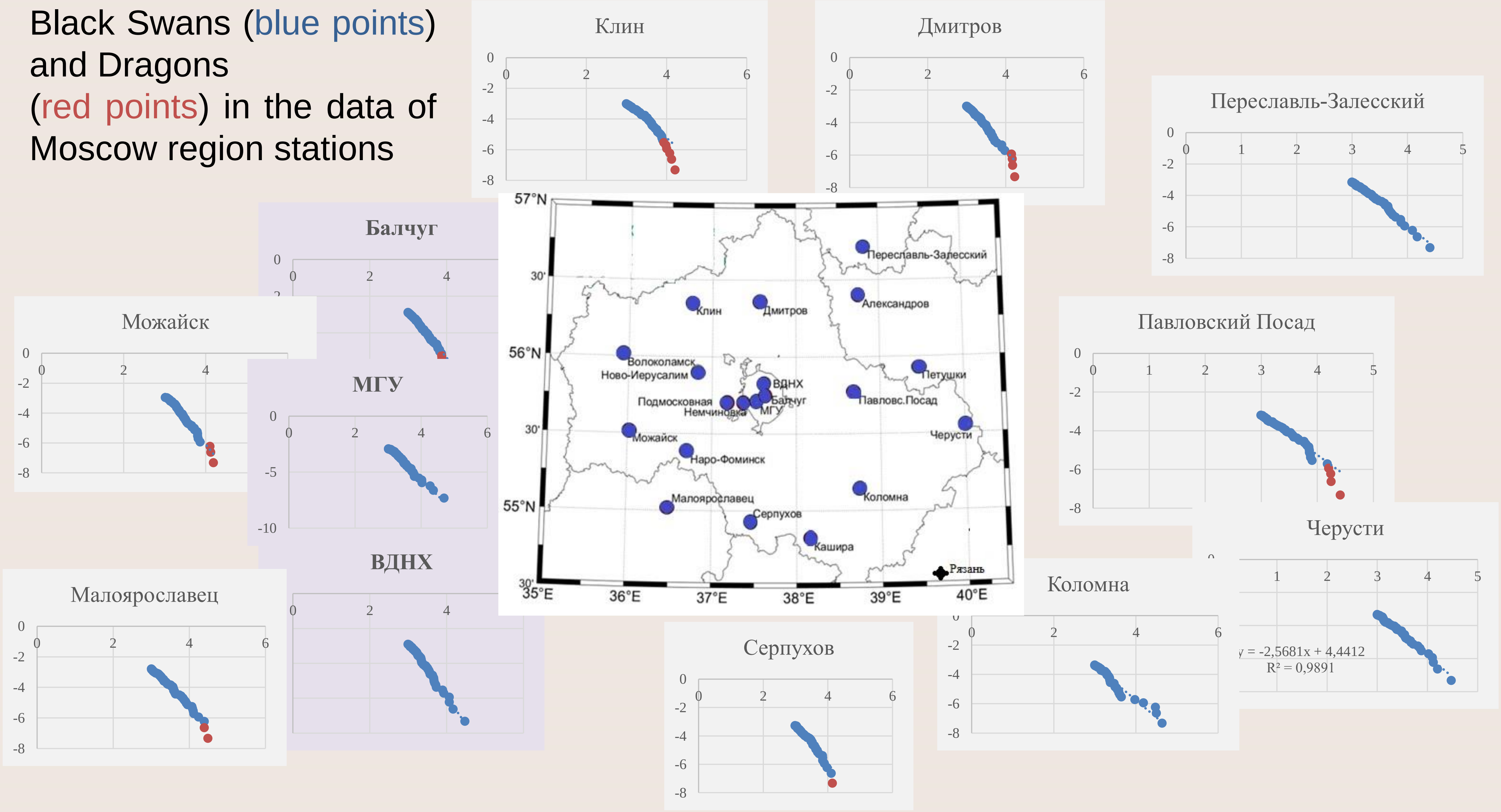


What is the megacity effect on precipitation extremes?

- Extreme precipitation events are identified from statistical distributions
- Synoptic analysis and hydrodynamic simulations are performed for extreme cases to study physical mechanisms and the megacity effects on extremes

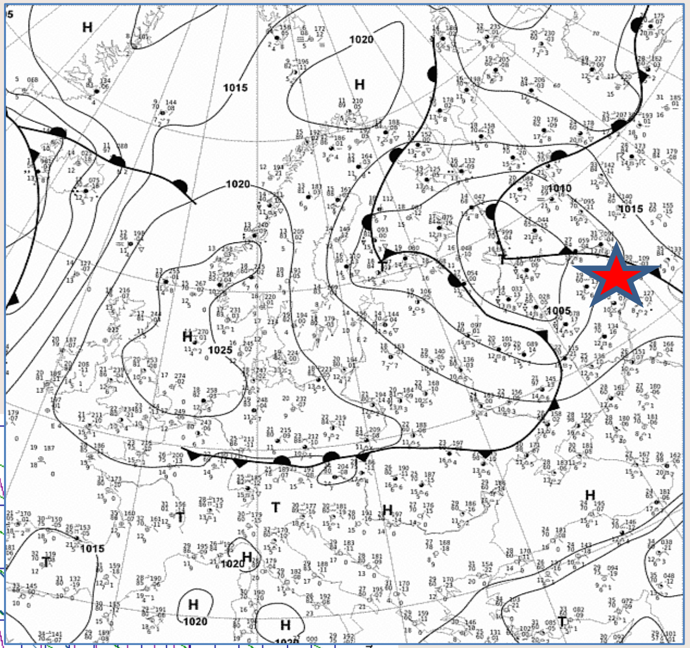


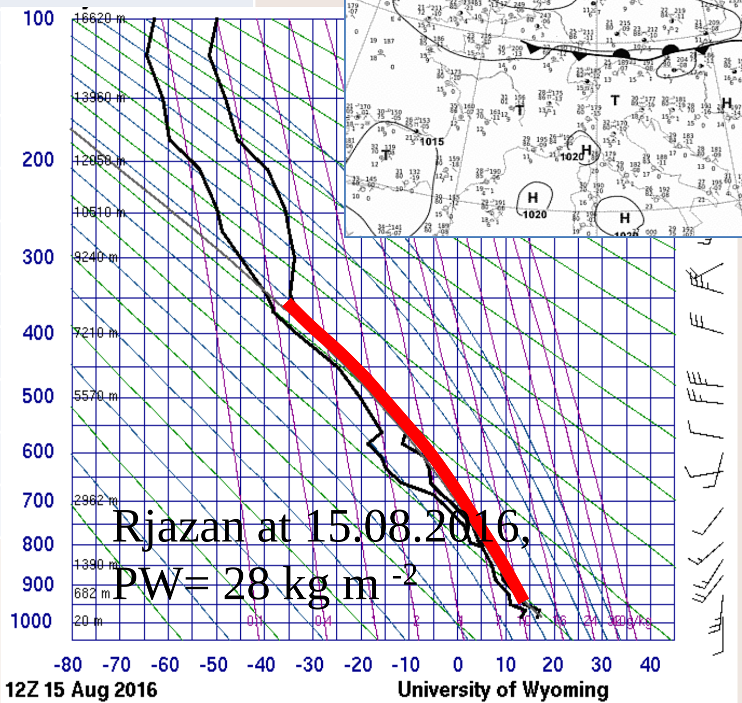
Black Swans (blue points) and Dragons (red points) in the data of Moscow region stations



Circulation systems that determine the appearance of D-anomalies (Yu.Yarinich, A.Kislov)

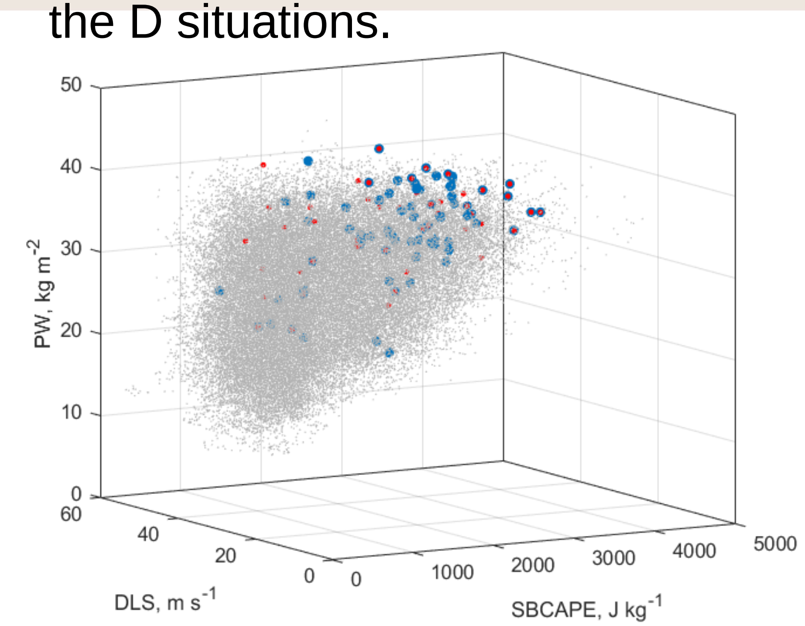
Station	Type of anomaly
Moscow university observatory	BS
Bulchug	D
VDNH station	BS
Dmitrov	D
Alexandrov	D
Pavlov Posad	D
Pereslavl-Zalessky	BS
Petushki	BS
Volokolamsk	BS
Naro-Fominsk	BS
Klin	BS
MoJaisk	BS
New Jerusalem	BS
Nemchinivka	D
Podmoskovnaya	D
Cherusty	BS
Maloyaroslavets	BS
Serpuchov	D
Kolomna	BS
Kashira	BS





Weather map at 15.08.2016 and atmospheric sounding

Observed water content, the CAPE and vertical wind shear of the environments, as determined by soundings for the D situations.




Thank you!
Общее собрание ОНЗ РАН, 23 марта 2015 г.

Data and research directions

Source data

Long-term meteorological observations (Roshydroment)

Surface-layer observations on denser networks for specific seasons (Moseconitoring, crowdsourcing

Profile & turbulence observations (ABL profiles, masts, etc.)

High-resolution simulations with COSMO mesoscale model + TERRA_URB scheme

Research directions

Long-term evolution of urban-induced atmospheric effects under climate change and urban development

Urban-induced effects in the lower atmosphere (ABL heat/dry islands, urban circulation…)

Feedbacks between urban-induced ABL effects, radiation and aerosols

Extreme precipitation and wind events in urban atmosphere

To be continued…

Specific results

Moscow UHI evolution during 1977-2020 (paper published)

Interaction between local-scale and mesoscale factors shaping Moscow UHI (paper published)

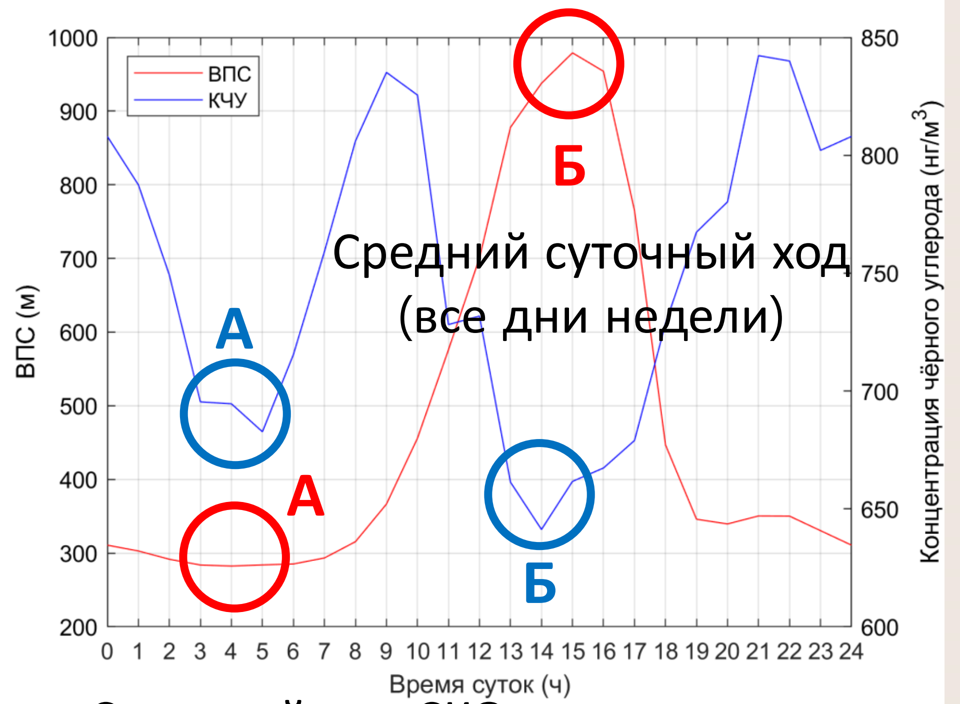
To be continued…

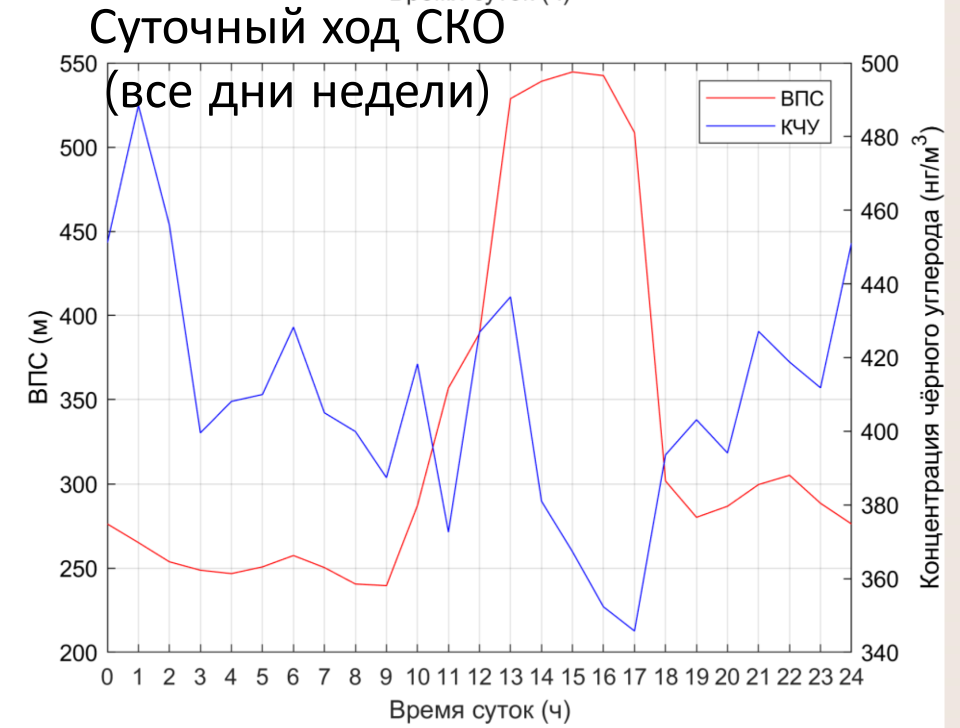
Зависимость суточного хода концентрации чёрного углерода от вертикального перемешивания в пограничном слое атмосферы (А.И.Варенцов)

<u>Гипотеза</u>: существует зависимость **А–Б** от **Б–А.**

А–Б – разница между КЦУ в ночной и дневной минимумы

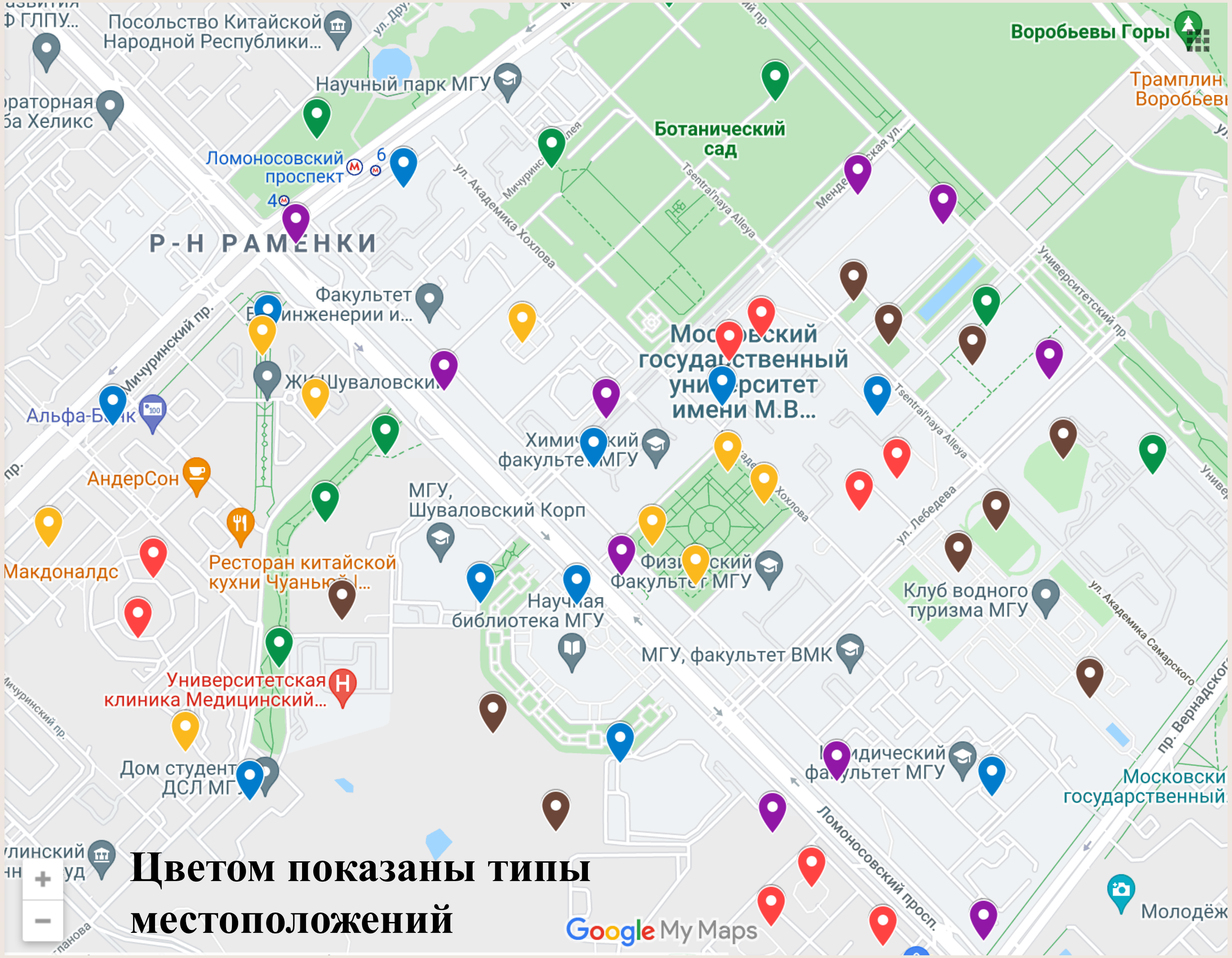
Б–А – разница между максимумом и минимумом ВПС





Точки опробования содержания частиц в снежном покрове (Н.Е.Кошелева, Д.В.Власов)

- Срок отбора – январь 2022 г.
- Валовое содержание элементов
- Гранулометрический состав взвеси

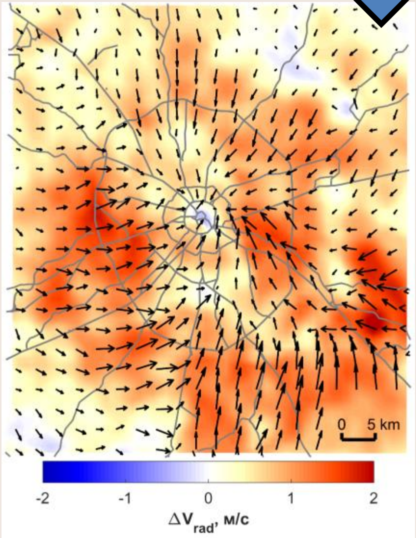


Цветом показаны типы местоположений

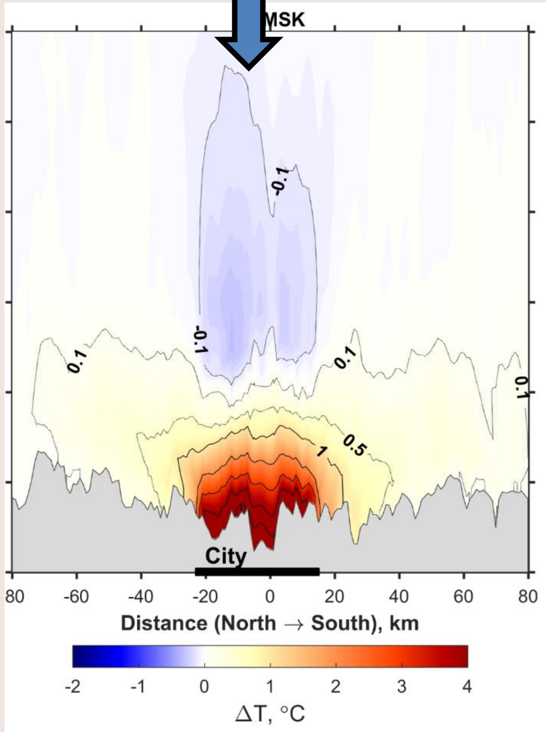
Impacts of Moscow megacity on mesoclimate (M.I.Varentsov)

Supercomputer simulations with COSMO model

Supercomputer «Lomonosov-2»



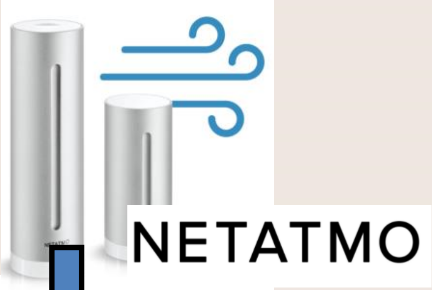
Surface wind

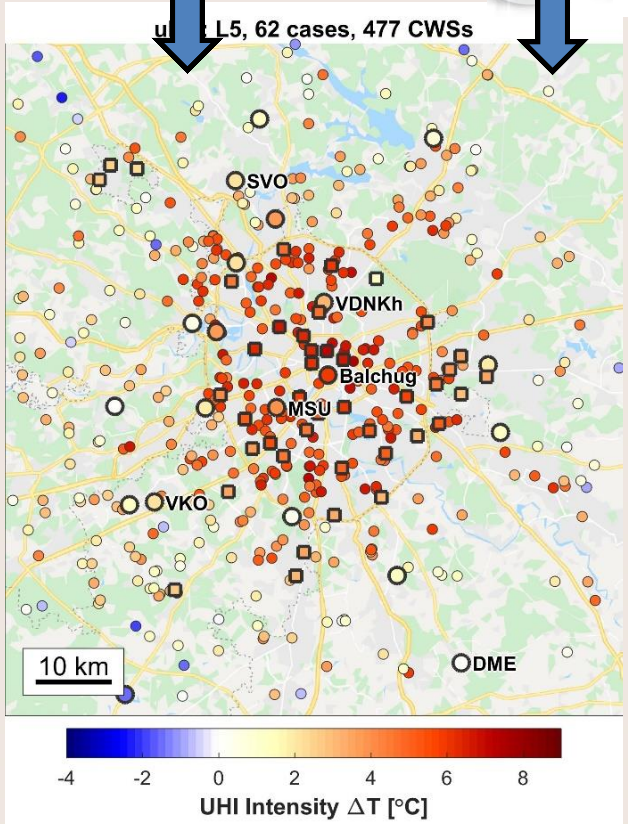


Temperature

(Varentsov et al., 2018; Kislov et al., 2020)

The data of conventional meteostations and crowdsourcing networks





(Varentsov et al., 2020)

The surface temperature anomaly in Moscow

Testing the validity of Taylor's "frozen turbulence" hypothesis