UNIVERSITY OF HELSINKI

LOMONOSOV MOSCOW STATE UNIVERSITY

Russian MegaGrant “Megapolis – heat and pollution island”

WP3 REPORT

The interaction of atmospheric aerosol with solar radiation and heat island in the urban environment and the synergy of the influence of heat waves and air pollution on population mortality.

Natalia Chubarova on behalf of WP3 group participants

January 14, 2022

Working Plan of the WP3 for 2021:

Task 3.1 The analysis of long-term variability of atmospheric aerosol and its dynamics during the COVID-19 pandemic and their relationship with heat island:

1. Quantitative estimates of long-term variations of AOT and solar radiation for the period up to 2020 in Moscow, features of atmospheric pollution and aerosol properties in the spring of the COVID-19 pandemic. *(Results - Archives, results of primary data analysis, results of aerosol pollution assessment during the COVID period. Radiation measurements, calibration of instruments based on the Moscow State University MO.)*
2. Preparation of data for the estimates of spatial features of aerosol pollution from satellite data, long-term estimates of aerosol pollution from ground measurements in the atmospheric column *(Results - Archives of aerosol optical thickness according to MODIS MISR satellite instruments, results of preliminary assessments of aerosol properties of the atmosphere based on satellite data.);*
3. Determination of parameters for testing model results in the Moscow region to assess the cloud-aerosol interaction *(Results - The results of the preparation of satellite data for the assessment of cloud characteristics with different aerosol in the atmosphere for testing model calculations. The results of preliminary numerical experiments to evaluate the radiation effects of the cloud-aerosol interaction).*

WP3. The interaction of atmospheric aerosol with solar radiation and heat island in the urban environment and the synergy of the influence of heat waves and air pollution on population mortality

Task 3.2. Atmospheric urban aerosols in the city environment with account of its morphology, and their relationship with solar radiation and the urban heat island.

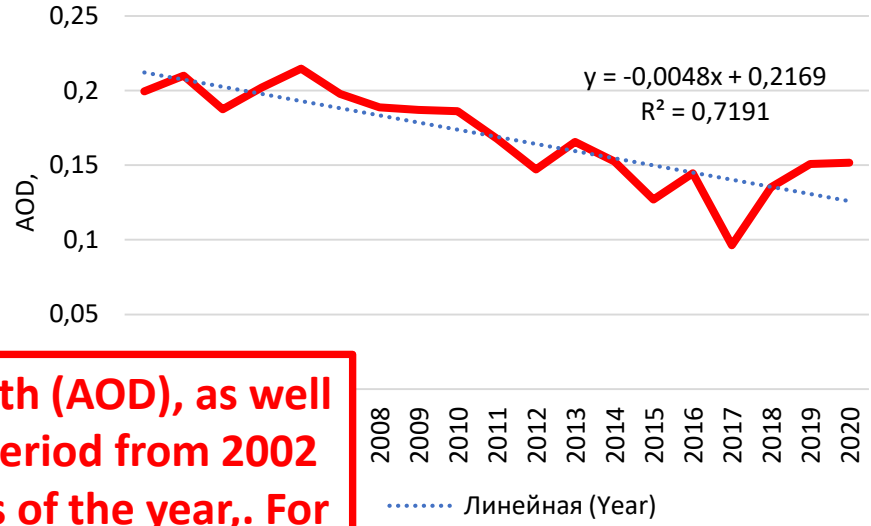
1.Development of the COSMO-ART model complex taking into account the urban component and preparation of emission data for the assessment of aerosol-radiation and temperature effects. *(Results - The results of the preparation of input parameters for modeling the features of the heat island and its relationship with radiation-aerosol characteristics in the spring of 2020 compared to the typical spring period of 2019 in Moscow, the results of preliminary experiments, testing of techniques, data analysis)*

2. Formation of input databases of parameters of the underlying surface for subsequent regional (WRF-ARW) and microclimatic RANS modeling within the framework of the Project for the Moscow region and conducting test model experiments for wind speeds and biometeorological parameters.*(Results - The results of initial assessments and a prototype database of the influence of trees and buildings within the experimental site (MSU) on the formation of both stagnation zones and squally gusts of wind.)*

Task 3.3. Synergistic effects of heat waves and air pollution on urban mortality. Carrying out work on the formation of databases (statistical meteorological, pollution, etc.), preparation of cartographic bases, selection of statistical models and their approbation *(Results - Statistical model of the impact of urban heat island and pollution on public health)*

3.1.1. Quantitative estimates of long-term variations of AOD and solar radiation for the period up to 2020 in Moscow, features of atmospheric pollution and aerosol properties in the spring of the COVID-19 pandemic.

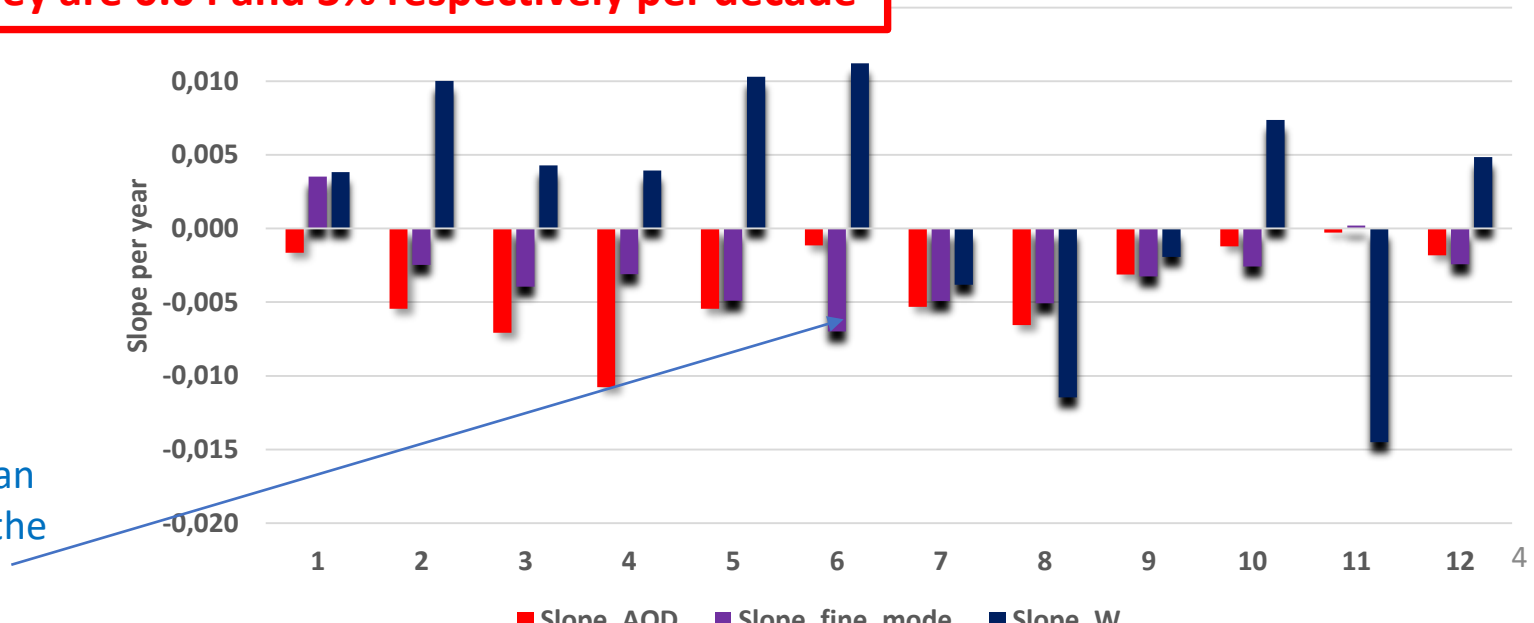
AERONET aerosol robotic network since 2001 at the MSU MO



Negative linear trends of aerosol optical depth (AOD), as well as the AOD fraction of fine aerosol for the period from 2002 to 2020 were obtained for almost all months of the year,. For annual values, they are 0.04 and 3% respectively per decade

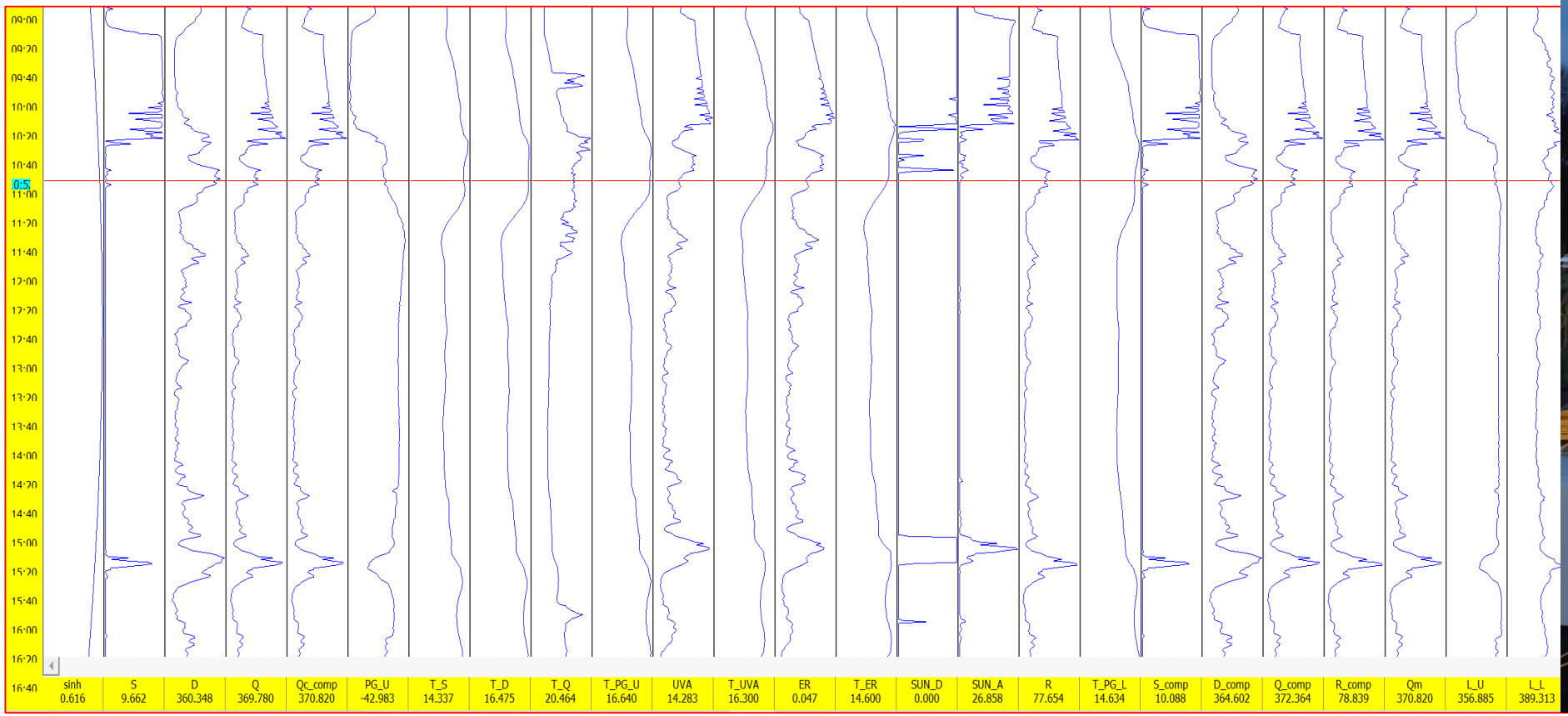
The monthly change in AOD, Fine-mode AOD fraction and water vapor content W per year according to linear regression model

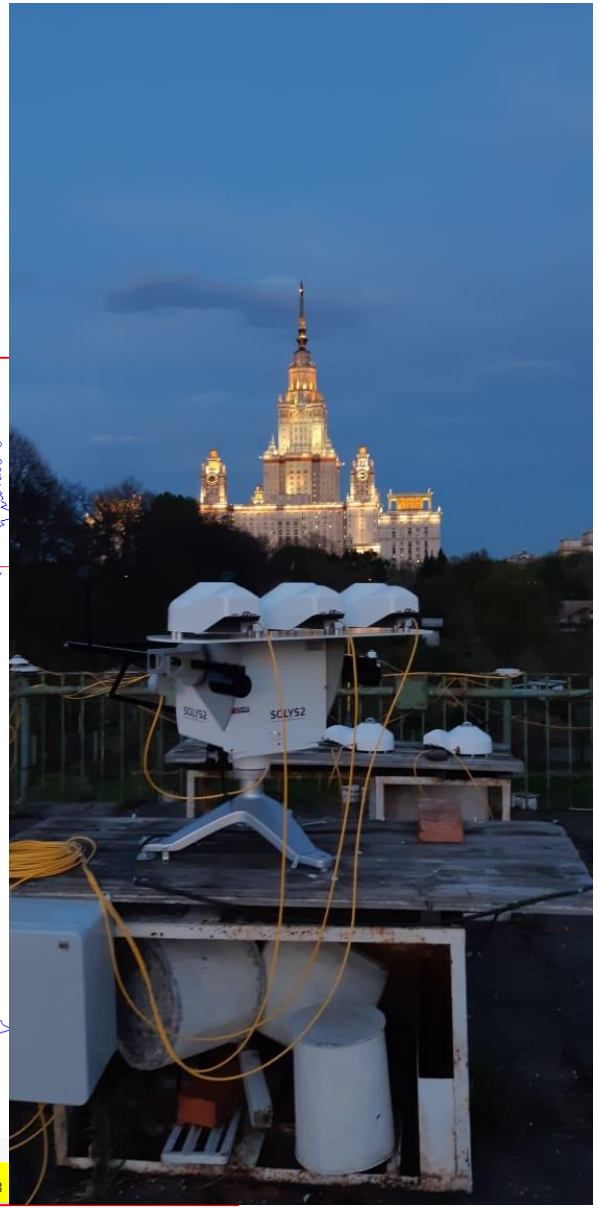
Fine mode fraction is important since this is an indicator of secondary aerosol generation in the atmosphere.



3.1.1. Quantitative estimates of long-term variations of AOD and solar radiation for the period up to 2020 in Moscow, features of atmospheric pollution and aerosol properties in the spring of the COVID-19 pandemic.

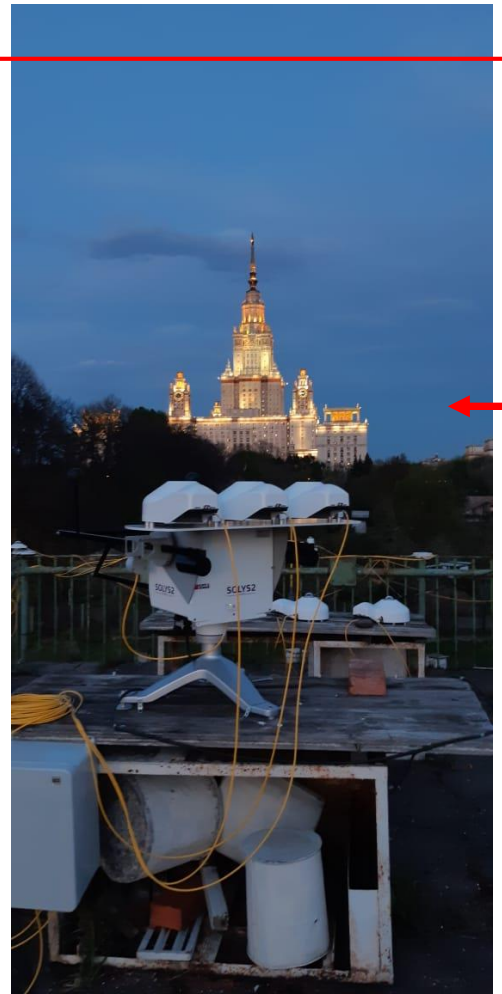
A new radiation complex equipped with the most accurate instruments has been installed. Special software has been developed following the highest BSRN standards for vizualization and processing the radiative data.

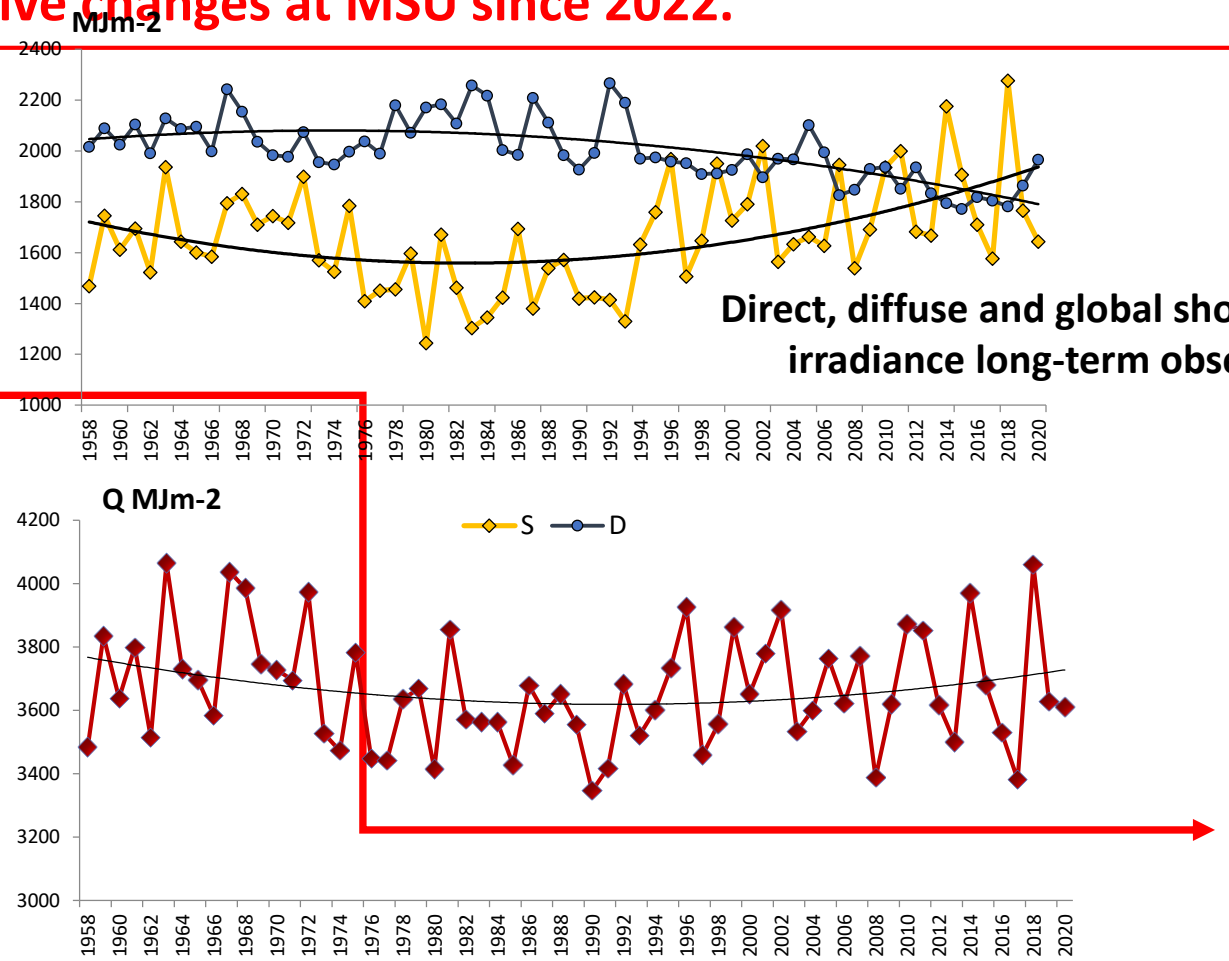




3.1.1. Quantitative estimates of long-term variations of AOD and solar radiation for the period up to 2020 in Moscow, features of atmospheric pollution and aerosol properties in the spring of the COVID-19 pandemic.

The analysis of the long-term variability of global solar radiation from 1958 to 2020 was made. In the temporal variability there is a tendency of decrease until 1980s, which was later replaced by its growth. The measurement data of the new radiative complex will be added in studies of long-term radiative changes at MSU since 2022.

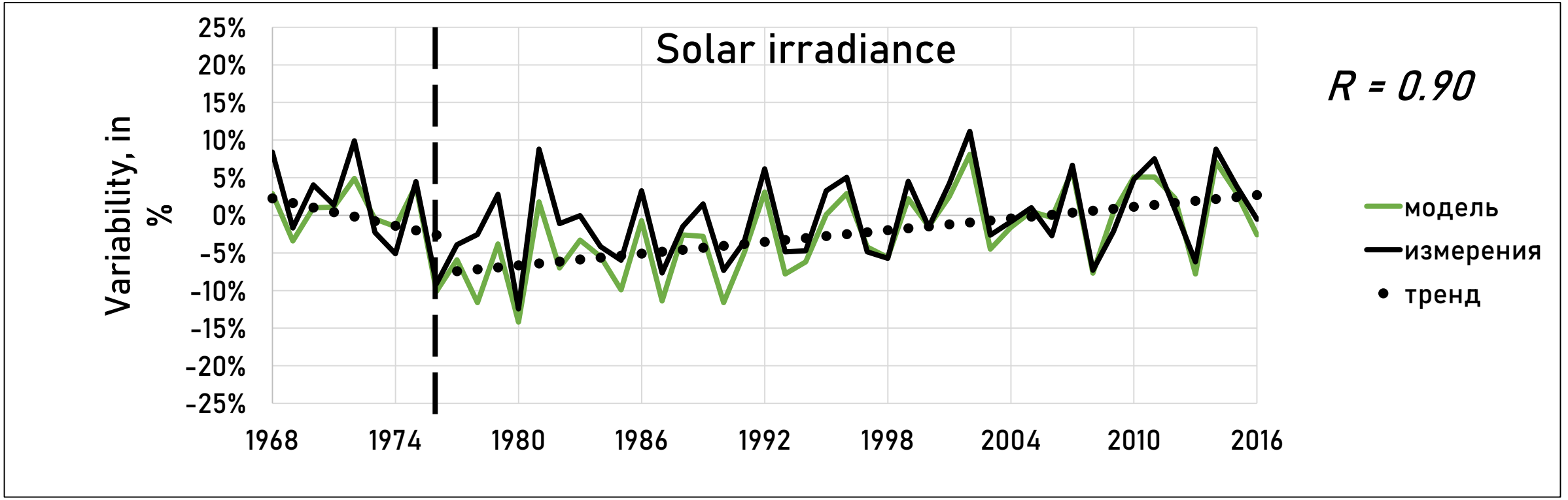




Direct, diffuse and global shortwave solar irradiance long-term observations

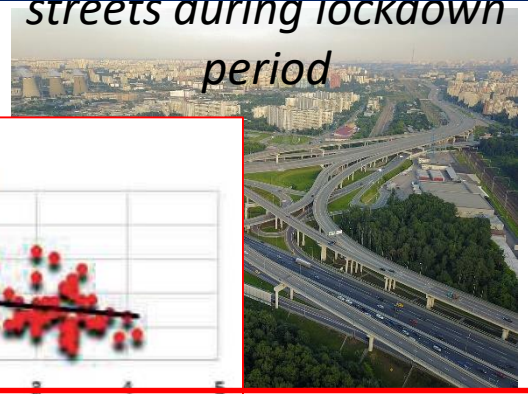
3.1.1. Quantitative estimates of long-term variations of AOD and solar radiation for the period up to 2020 in Moscow, features of atmospheric pollution and aerosol properties in the spring of the COVID-19 pandemic.

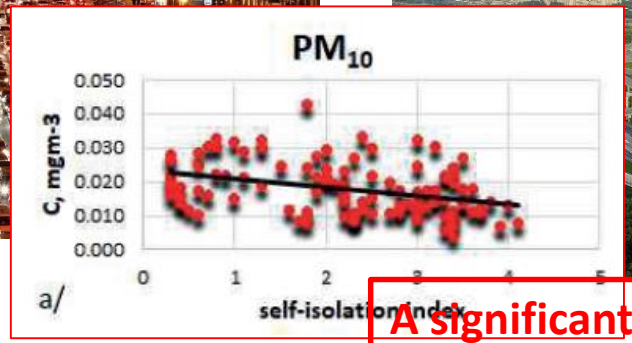
Synergy use of aerosol and solar irradiance dataset with the application of reconstruction model. (Volpert, Chubarova 2021)



Shortwave irradiance trend due to AOD negative changes according to reconstruction model is about +0.4% per decade since 1979.

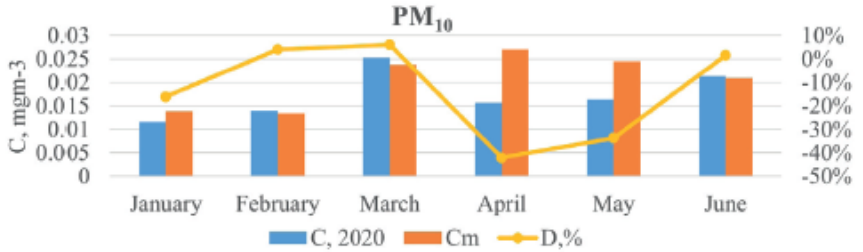
3.1.1. Quantitative estimates of long-term variations of AOD and solar radiation for the period up to 2020 in Moscow, features of atmospheric pollution and aerosol properties in the spring of the COVID-19 pandemic.





The correlation between daily mean mass concentration (C, mgm$_{-3}$) of PM10 with self-isolation index *SII*

PM10 – Particulate matter of particles with the diameter smaller 10 micron

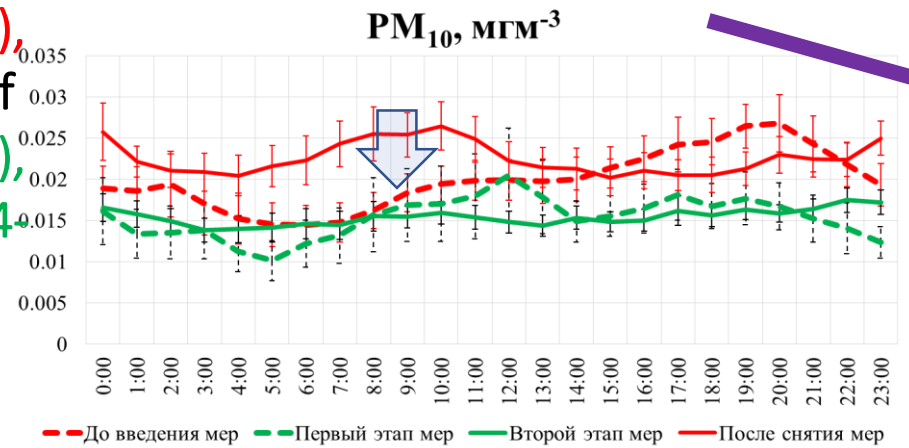


Monthly mean values of the PM10 mass concentration (C, mgm$_{-3}$) observed in 2020, and in the 2015–2019 period (Cm, mgm$_{-3}$) and relative differences D (in %).

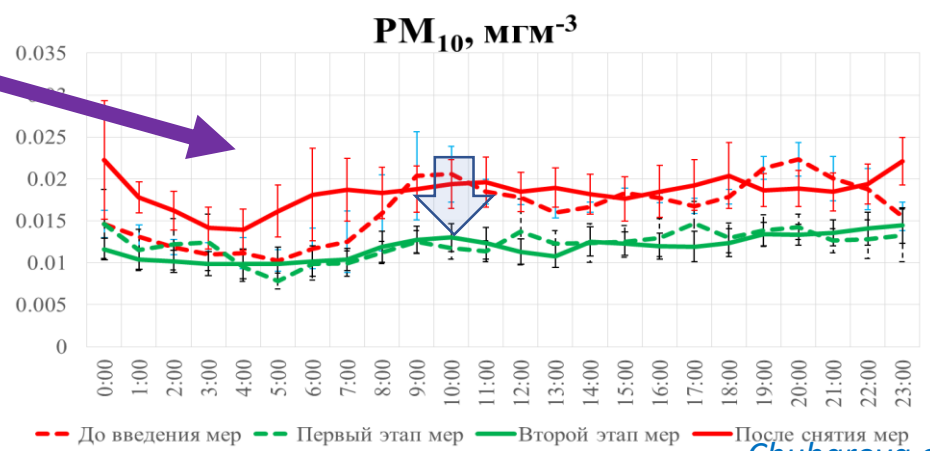
A significant decrease in PM10 of 30-40% during the period of lockdown against PM10 over the 2015-2019 period was observed due to the reduction in emissions and the influence of atmospheric circulation features. However, in similar meteorological conditions we also see a decrease in PM10 due to lockdown emission reduction compared with PM10 before and after lockdown. A statistically significant negative relationship was obtained between self-isolation indices (according to the Yandex server) and average daily PM10.

Diurnal cycle of PM10 (mgm-3) before lockdown (01.03-29.03), during the first stage of lockdown (30.03-12.04), the second stage (13.04-08.06), and after lockdown (09-30.06)

All cases



Only northern advection



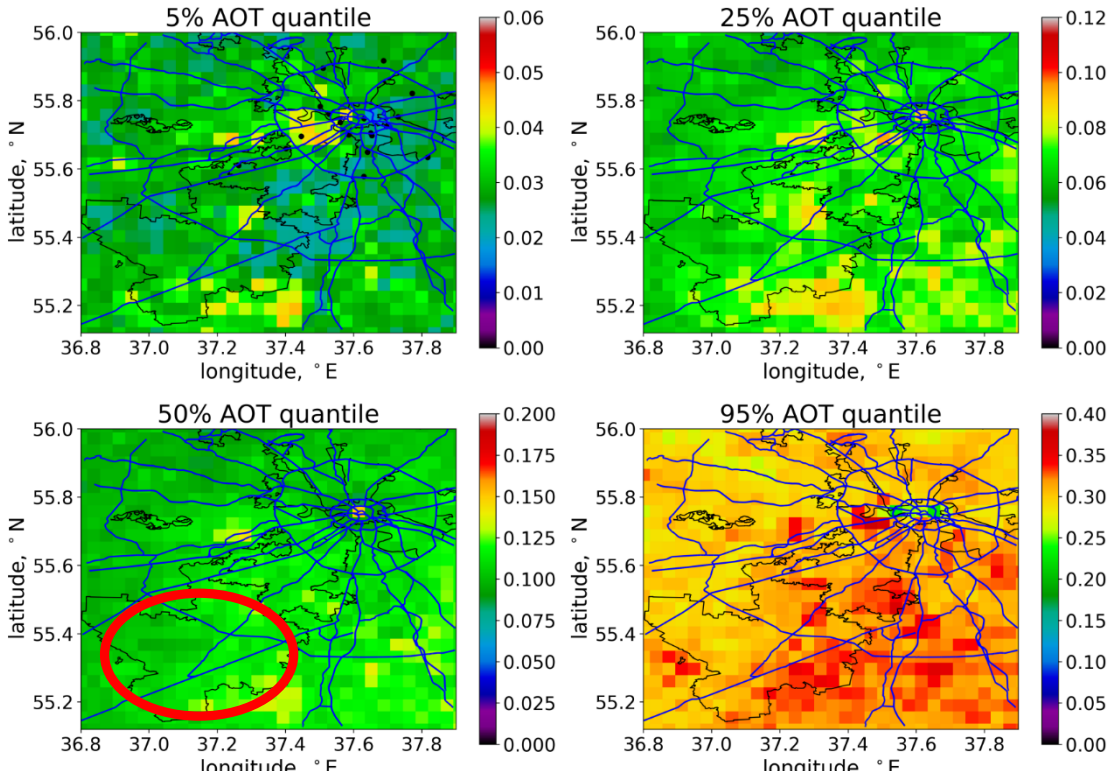
Chubarova et al., 2021

3.1.2. Preparation of data for the estimates of spatial features of aerosol pollution from satellite data, long-term estimates of aerosol pollution from ground measurements in the atmospheric column;

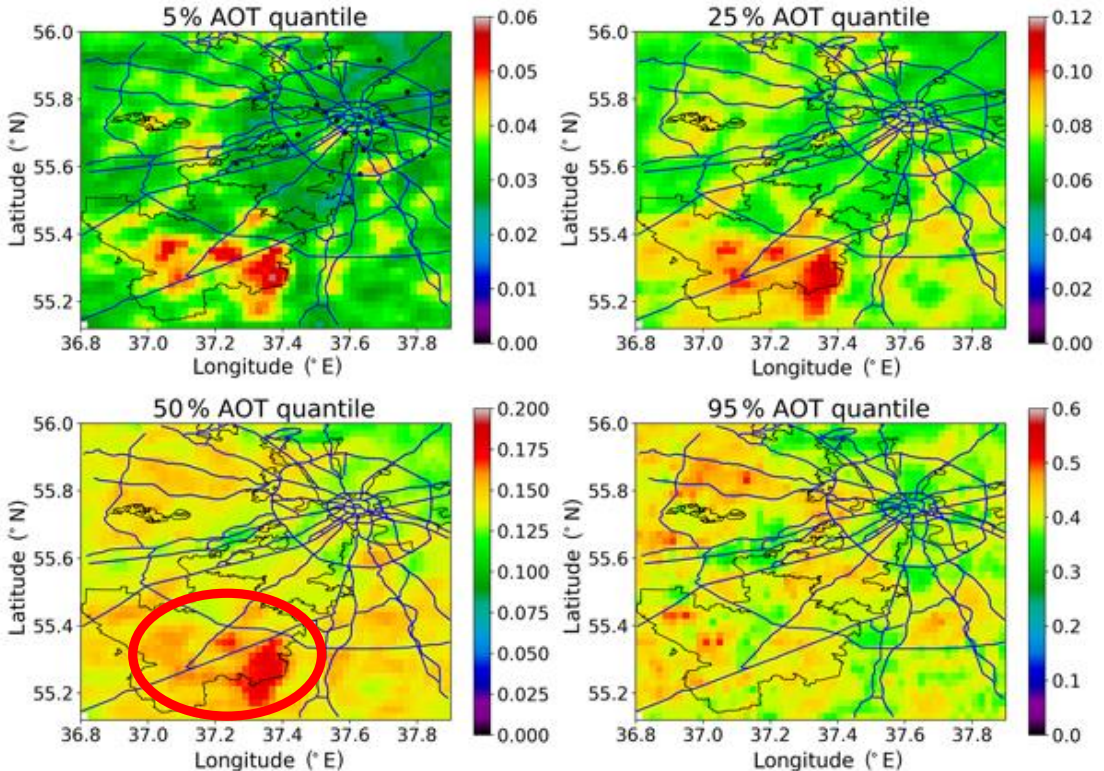
Preliminary results:

According to MODIS/MAIAC data with a grid step of 1 km and according to MISR data with a grid step of 4.4 km, aerosol data archives have been prepared for the period from 2001 to 2021 , which include quantile estimates of AOD and some other aerosol parameters for the territory of the Moscow region and two AERONET stations (Moscow MO and Zvenigorod). The preliminary analysis of the temporal dynamics in spatial AOD distribution from satellite data revealed pronounced AOD changes in the Moscow region and a significant decrease in AOD in recent years, especially at South-West due to the termination of the active phase of construction in the New Moscow area.

AOD 470 nm, MODIS/MAIAC, 2017-2021



AOD 470 nm, MODIS/MAIAC, 2001-2017



3.1.3. The results of the preparation of satellite data for the assessment of cloud characteristics in the Moscow region to assess the effects of cloud- aerosol interaction

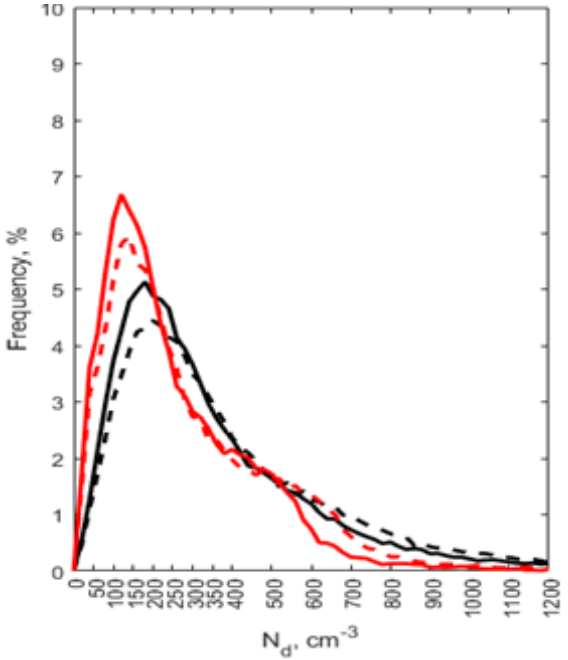
We obtained a significant decrease in concentration of cloud condencation nuclear N_{CCN} during the lockdown period in similar synoptic conditions of about 80-100 cm-3. Preliminary numerical experiments have shown that a decrease in the concentration of condensation nuclei by 100 cm-3 (from 250 to 150 cm-3) leads to an increase in global radiation by an average of 18 W/m2 (16%).

Distributions of $N_d = N_{CCN}$ (cm^{-3}) for April-May of 2018-2019 and 2020 by the method 1 (Quaas et al., 2006 - solid line) and method 2 (McComiskey et al., 2009 - dashed line)

Median CNN: method 1 (2)

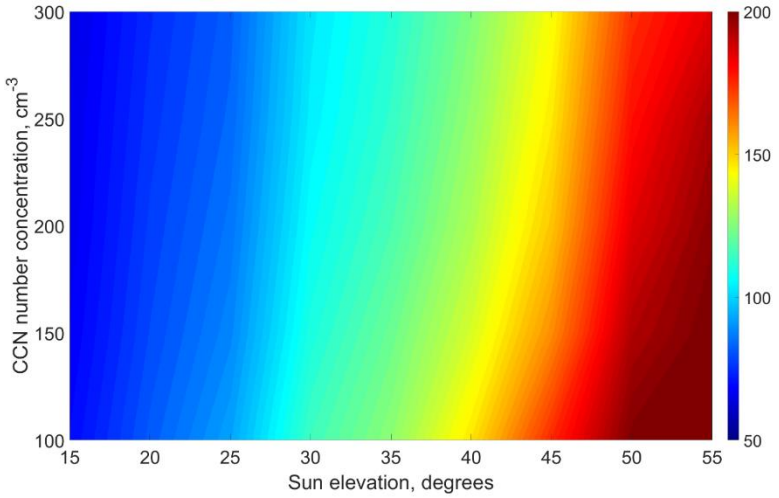
2018-2019: 269 (306) cm^{-3}

2020: 196 (221) cm^{-3}



Period: April and May of 2018-2020, **Only northern advection cases**

The distribution of average COSMO simulated solar irradiance (W/m^2) as a function of Sun elevation and CCN number concentration. Overcast conditions



The simulated solar irradiance increases 18 W/m^2 (16%) on average for CCN reduction from 250 cm^{-3} to 150 cm^{-3} (overcast cases with Sun elevation above 35°)

LAADS DAAC

https://ladsweb.modaps.eosdis.nasa.gov/

EARTHDATA SEARCH

https://search.earthdata.nasa.gov/

Satellites: Terra and Aqua

- **Spectroradiometer MODIS:** 1 km, Collection 6 Level 2 for evaluation of N_{CCN}, LWP, R_{eff} and COT

Number concentration of cloud condensation nuclei (N_{CCN})

Liquid water path (LWP)

Cloud optical thickness (COT)

Effective radius of cloud droplets (R_{eff})

- **CERES system:** 20 km, SSF FM2-FM3, (Kratz et al., 2020)

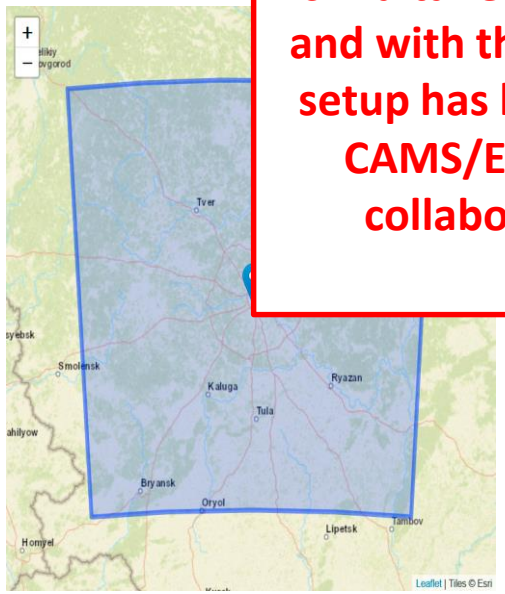
for solar irradiance evaluation

Solar irradiance at ground (Gupta S.K., 2001)

3.2.1. Atmospheric urban aerosols in the city environment with account of its morphology, and their relationship with solar radiation and the urban heat island.

Development of the COSMO-ART model complex taking into account the urban component and preparation of emission data for the assessment of aerosol-radiation and temperature effects.

The new updated version of the COSMO-ART model complex allows simultaneous calculations with the atmospheric chemistry ART model and with the urban TERRA_URB parameterization. The optimal COSMO setup has been chosen. City descriptive parameters as well as the new CAMS/ECLIPSE emission dataset were prepared. Ongoing work in collaboration with Finnish group (Enviro-HIRLAM, Dr. Alexander Mahura).

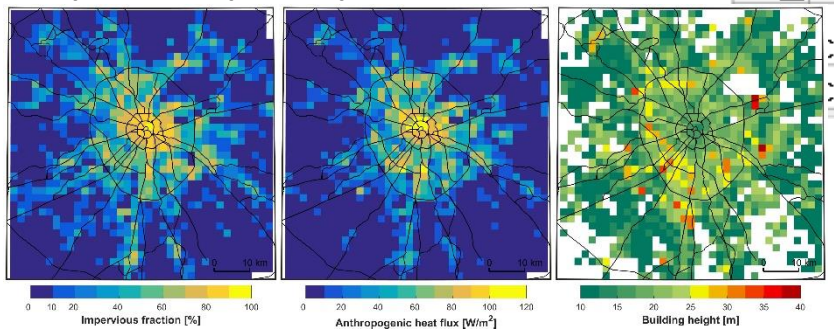


	COSMO Version 6.0
URB compiled	✓
ART compiled	✓
URB or ART	✓
URB and ART	✓

The choice of optimal COSMO setup against 75 meteorological station in Moscow region for May 2019 and other periods

№	Initial conditions	Boundary conditions	Extra options for model's soil hydrology	T2M ME [°C]	T2M RMSE [°C]	
1	ERA5	ERA5	-	-1.03	2.14	
2	ICON	ICON	-	0.53	2.14	
3	ICON	ICON	new hydrology scheme	0.13	2.01	
4	ICON	ERA5	-	0.31	2.02	
5	ICON	ERA5	new hydrology scheme	-0.05	1.92	the best
6	ICON	ERA5	rooting depth tuning	-0.16	1.86	

City-descriptive parameters for TERRA_URB

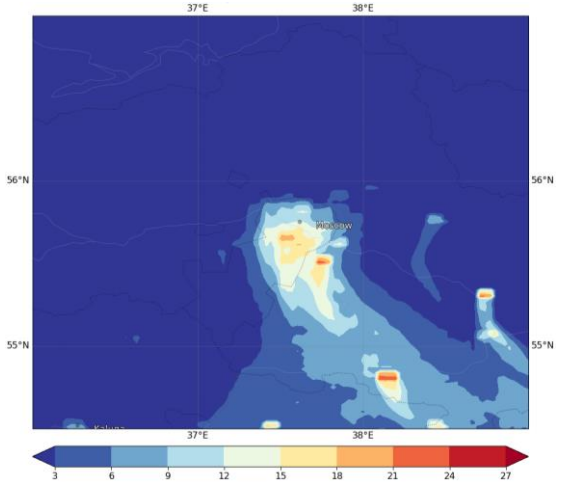


- Modifications have been made to the ART module to output AOD, SSA output. Other changes to make ART calculations work as intended.
- The new emission data based on CAMS and ECLIPSE were added in the system.

3.2.1. Atmospheric urban aerosols in the city environment with account of its morphology, and their relationship with solar radiation and the urban heat island.

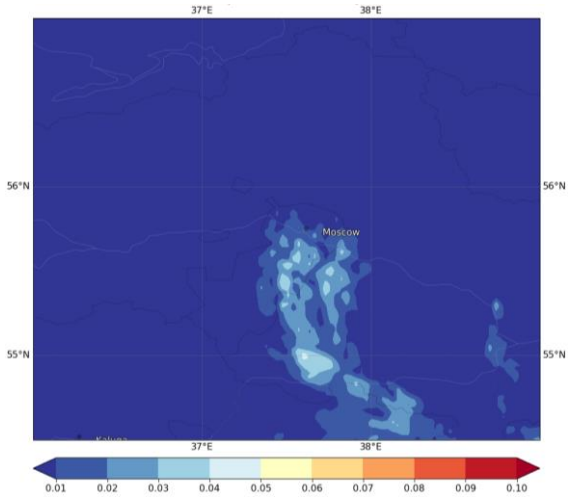
Development of the COSMO-ART model complex taking into account the urban component and preparation of emission data for the assessment of aerosol-radiation and temperature effects.

Case studies. 18.05.2019 9:00 (MSK), PM_{10} (μg/m³) (upper fig) and urban AOD (bottom Fig.) spatial distribution



Map for the bottom model layer (0-10 m height)

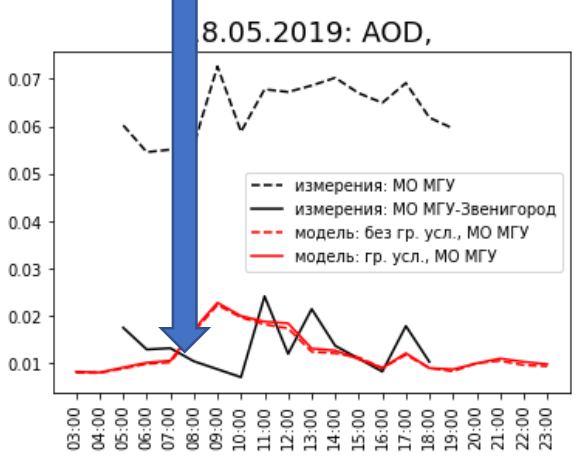
- Moscow megacity plume is affecting other regions
- Exceeding the maximum permissible concentrations was not observed

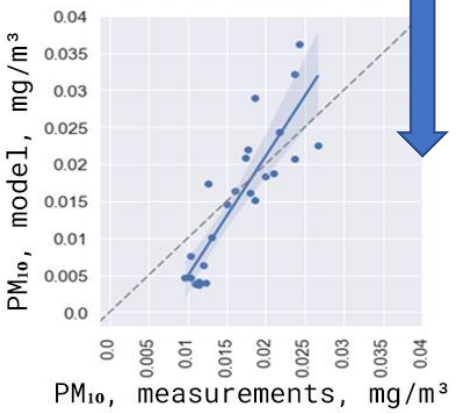


Aerosol Optical Depth of the anthropogenic aerosol

- Moscow megacity plume is affecting other regions
- Direct aerosol effect is the most significant to the south of Moscow (where anthropogenic aerosol is transferred in this experiment)

Reasonable agreement of the calculated PM_{10} values with the measurements at the Meteorological Observatory of Moscow State University is shown. There is also an agreement in the urban component evaluation against the difference in AOD between Moscow and Zvenigorod.





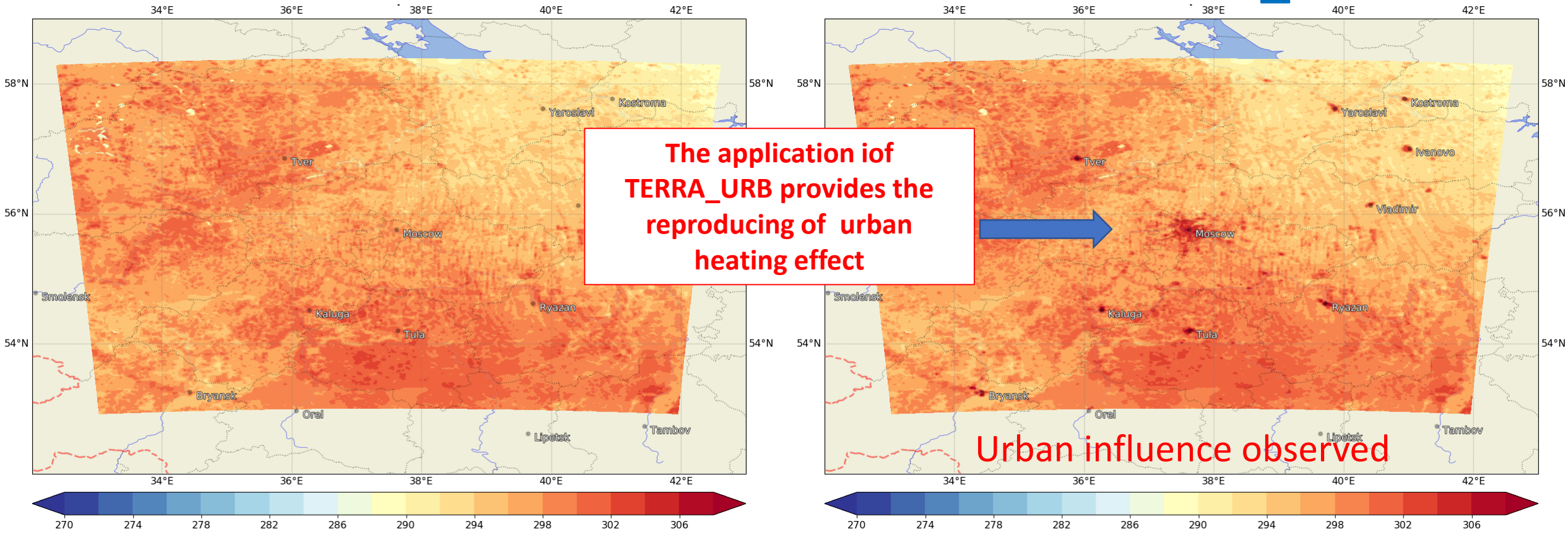
3.2.1. Atmospheric urban aerosols in the city environment with account of its morphology, and their relationship with solar radiation and the urban heat island.

Development of the COSMO-ART model complex taking into account the urban component and preparation of emission data for the assessment of aerosol-radiation and temperature effects.

Preliminary results

No TERRA_URB

With TERRA_URB



The application iof TERRA_URB provides the reproducing of urban heating effect

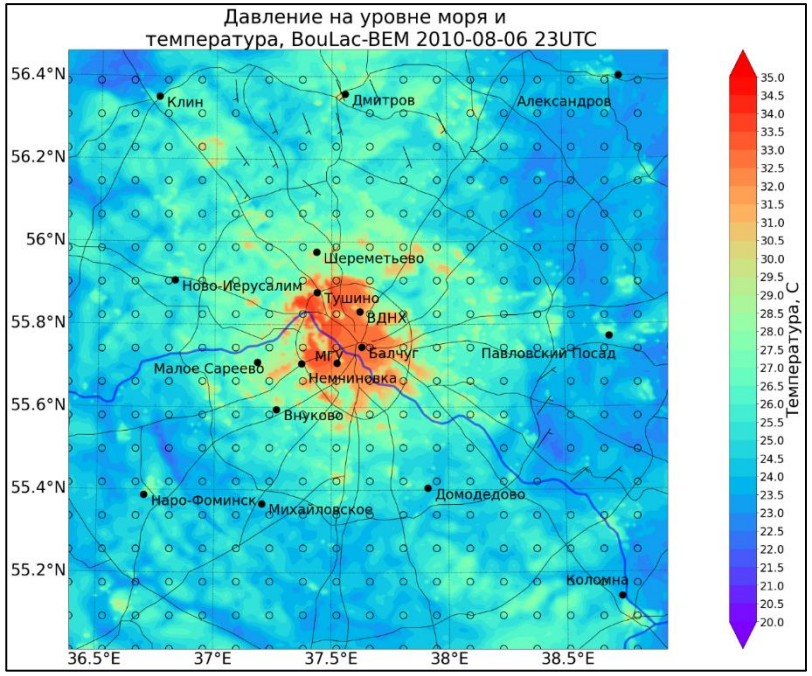
Urban influence observed

With the new COSMO-ART version it is possible to enable both ART module and TERRA_URB parameterization at the same time.

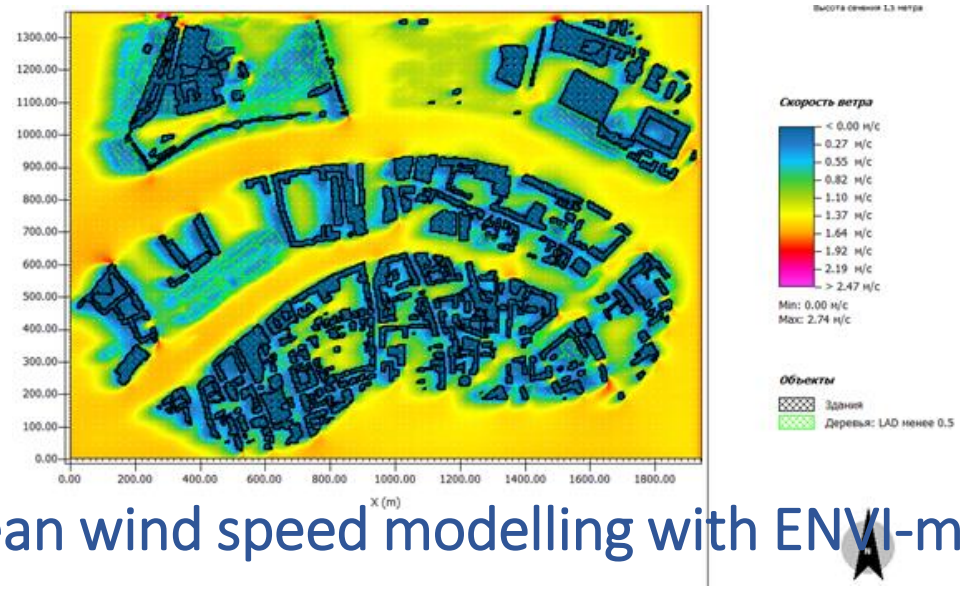
3.2.2. Atmospheric urban aerosols in the city environment with account of its morphology, and their relationship with solar radiation and the urban heat island.

Formation of input databases of parameters of the underlying surface for subsequent regional (WRF-ARW) and microclimatic RANS modeling within the framework of the Project for the Moscow region

The input databases of the underlying surface parameters for subsequent regional (WRF-ARW) and microclimatic RANS modeling have been prepared. The results of hierarchical modeling of the coupled microclimatic ENVI-met model on July 14, 2010 (the size of the modeling area is 1960*1380 meters with a horizontal resolution of 5*5 meters and 3 meters vertically) showed a physically justified reproduction of the wind velocity field in an urban environment: an increase in wind speed at the corners of buildings (by 20-30%) and the appearance of so-called plumes behind buildings, where the wind speed is significantly lower than in the incoming flow.



Urban Heat Island 06/08/2010 – WRF (BouLac + Building Energy Model)



Mean wind speed modelling with ENVI-met

Task 3.3. Synergistic effects of heat waves and air pollution on urban mortality. Carrying out work on the formation of databases (statistical meteorological, pollution, etc.), preparation of cartographic bases, selection of statistical models and their approbation

A statistical model of the impact of urban heat island and pollution on the population health in Moscow has been determined for further use on the basis of a generalized additive model of Poisson regression with excess variance. As dependent variables for the model, a long-term daily series of population mortality has been prepared for three selected sections of the city – Center, South-West and South-East for 2005-2019 period. Long-term daily series have been prepared for the same time period, characterizing the state of air pollution and temperature conditions.

The influence of heat waves and air pollution on population mortality

Step 1 - Statistical models

Period: *January 2005 – December 2019*

Territory: 3 areas of Moscow:
Center - 13 administrative districts with 950,000 population
Southwest - 13 districts with a total population of 1.3 million
Southeast - 9 districts with a total population of 1.3 million

Generalized additive model with Poisson regression

Confounders

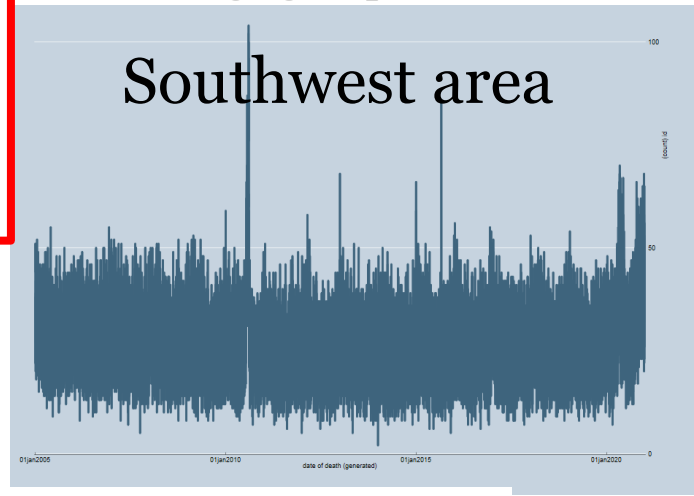
1 - natural cubic spline with eight degrees of freedom (df) per year to control for long-term and seasonal trend;
2 - indicator variables for day of the week;
3 - an indicator variable for population dynamics due to summer vacation and holidays;
4 - a penalized distributed lag nonlinear temperature

Prepared data

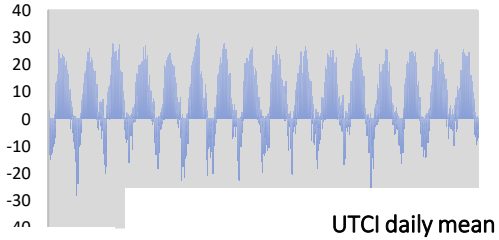
- Daily mortality *stratified by sex and age (0–64 years and 65 and above years)*
- Daily temperature *max, min, mean*
- Daily bioclimatic indices
  - Physiologically Equivalent Temperature *max, min, mean*

Data source: Weather and pollution data – "Mosecomonitoring",

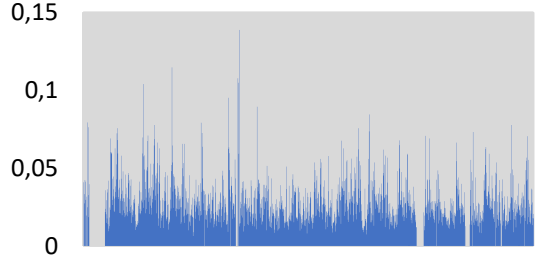
Daily mortality, both sex and age groups



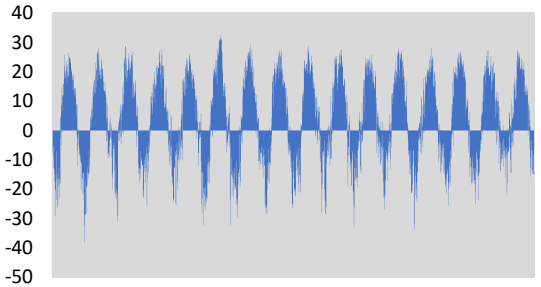
Daily temperature mean



PM10 daily



UTCI daily mean



Thank you for your attention!

Questions?