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.

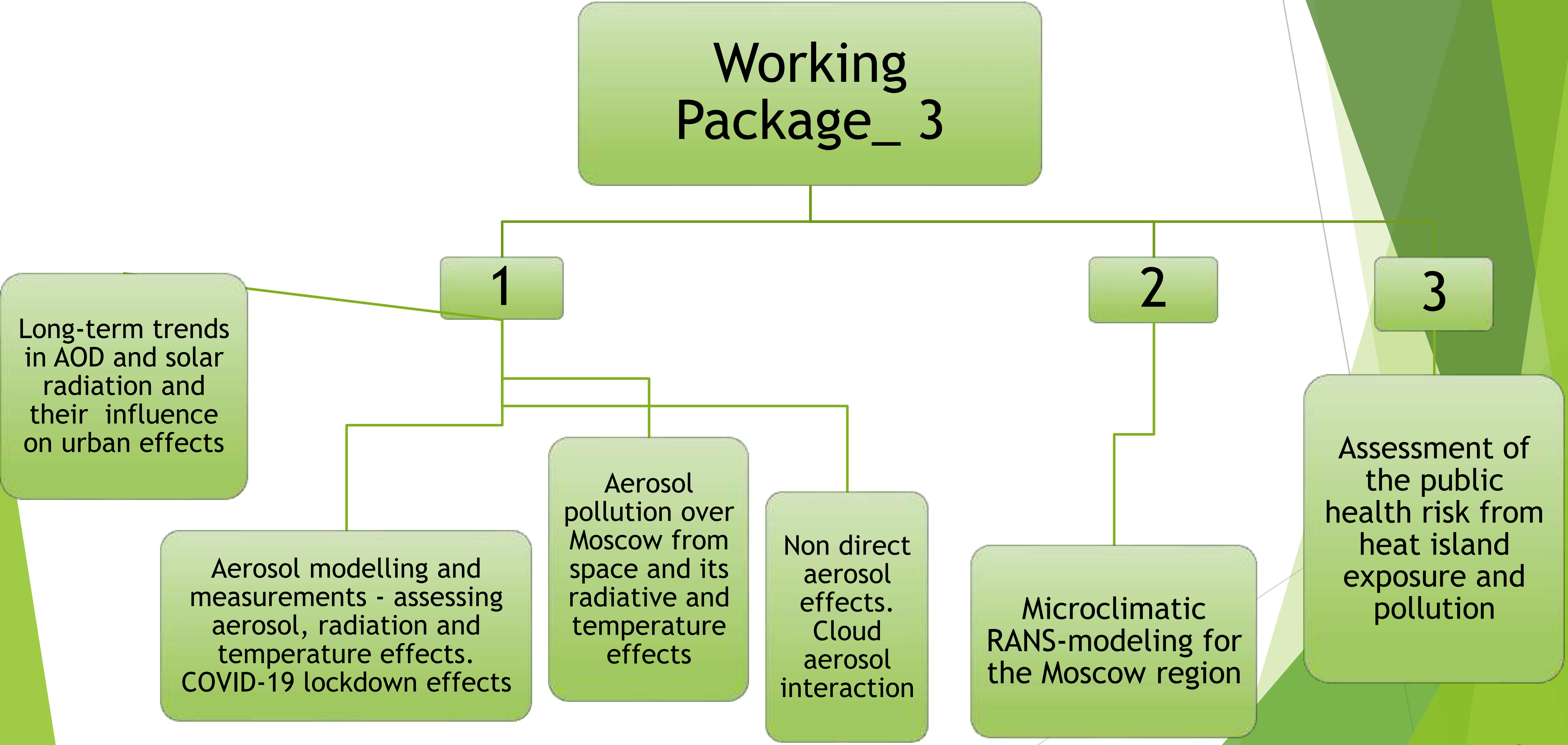
Natalia Chubarova on behalf of the WP3 team

23/03/2021

Main goals:

1. The assessment of the relationships between urban aerosol and solar radiation and their connection with heat island in the Moscow megacity.
2. The features of the formation and transport of urban aerosol, taking into account the emissions of pollutants with spatial detail to the scale of individual streets and buildings.
3. The analysis of the response in the mortality rate of the population under the influence of critical factors of temperature and air pollution in Moscow .

Structure of WP3



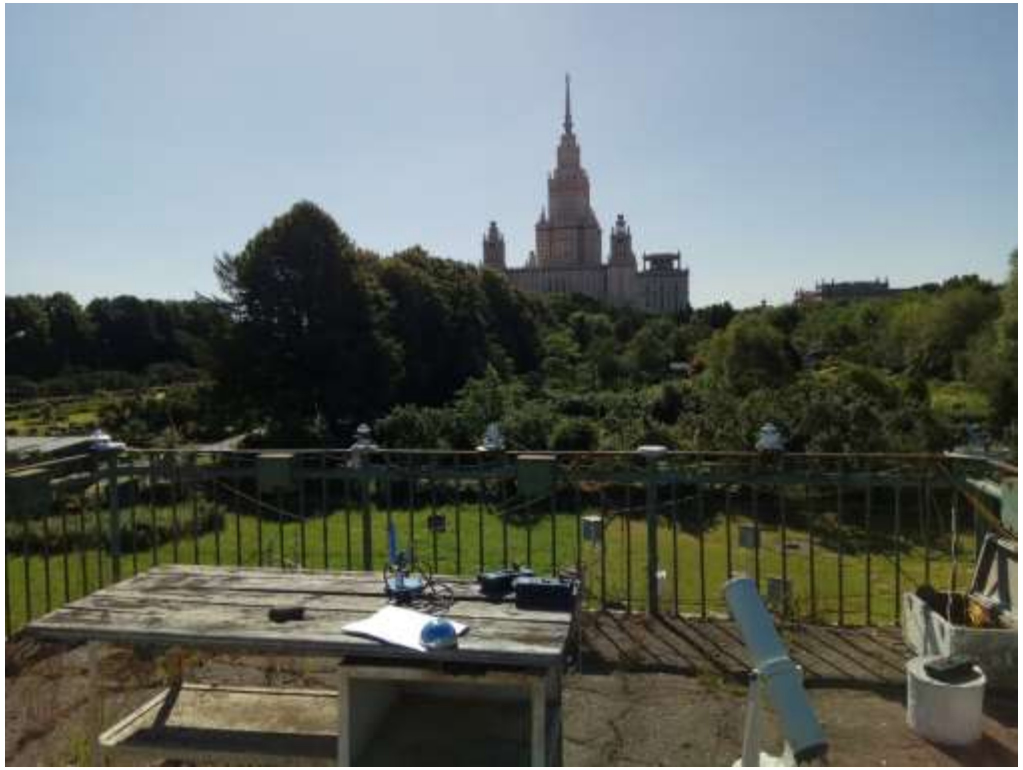
Task 3.1.1

Long-term variations of aerosol properties of the atmosphere, solar radiation and their possible influence on the heat island.

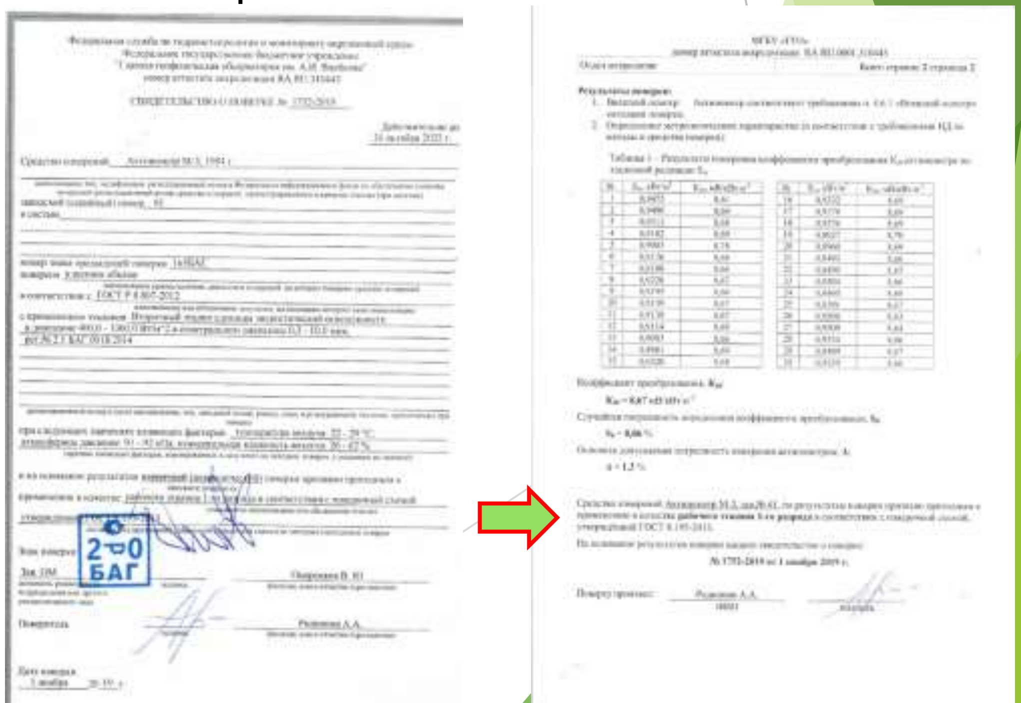
The radiative and aerosol measurements are in operation at the Meteorological Observatory of Lomonosov Moscow State University (MSU MO) for more than 60 years since 1954.

The radiometric instruments are calibrated regularly against the control instruments, which are annually calibrated against the reference instruments, which in turn are calibrated against the World Standard Reference.

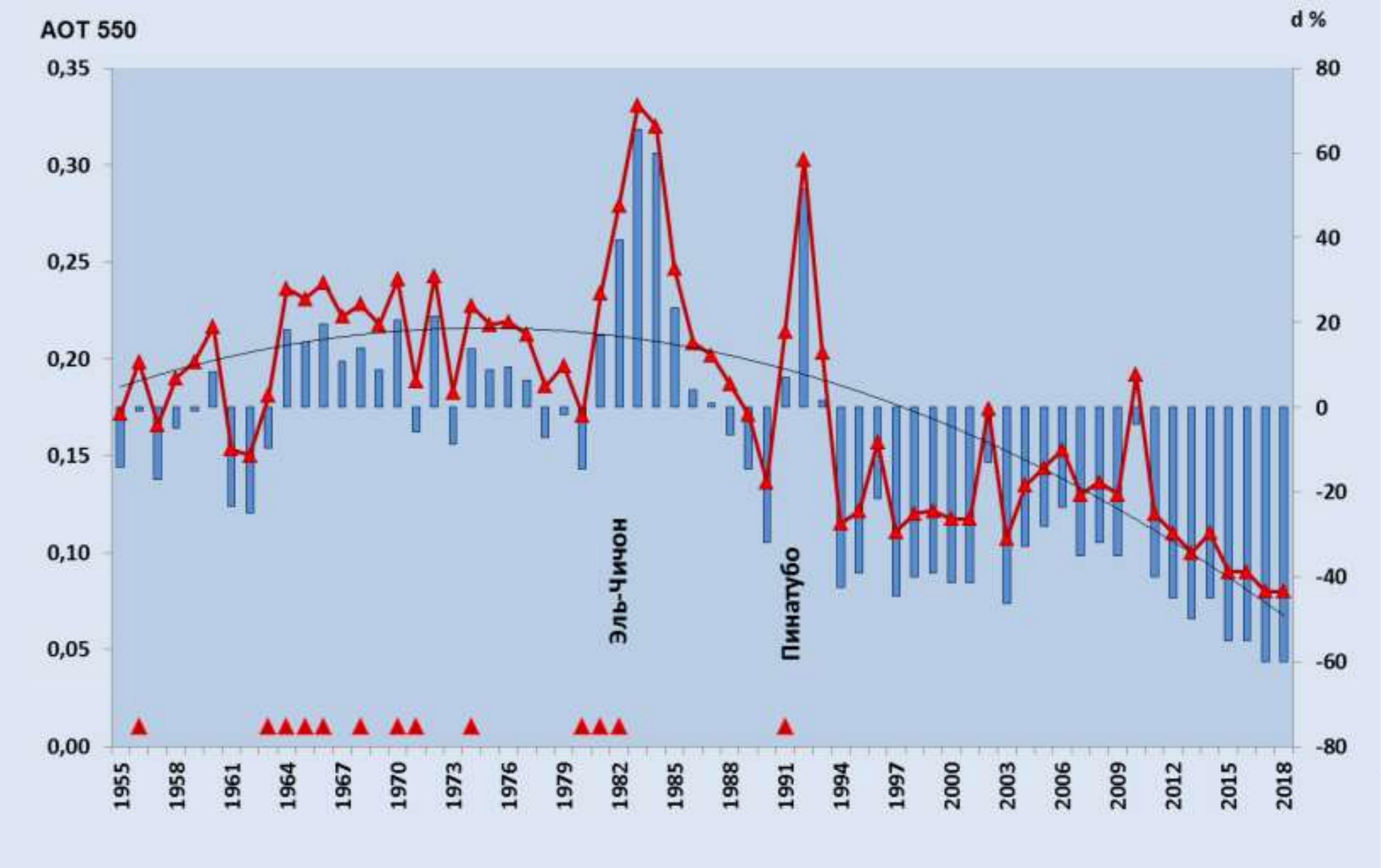
The MSU MO data are worldwide known and published in the quarterly bulletin “Solar Radiation and Radiation Budget (Global Network).”



Example of an instrument certificate



The long-term variability of AOT550 from direct solar irradiance and water vapor content

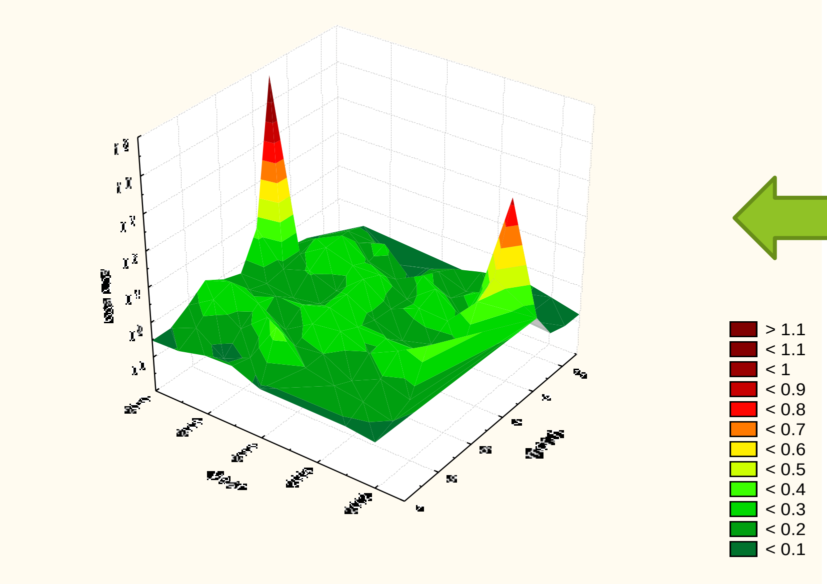


Gorbarenko, 2018

Twenty years of AERONET continuous records at the MSU MO 2001-2021

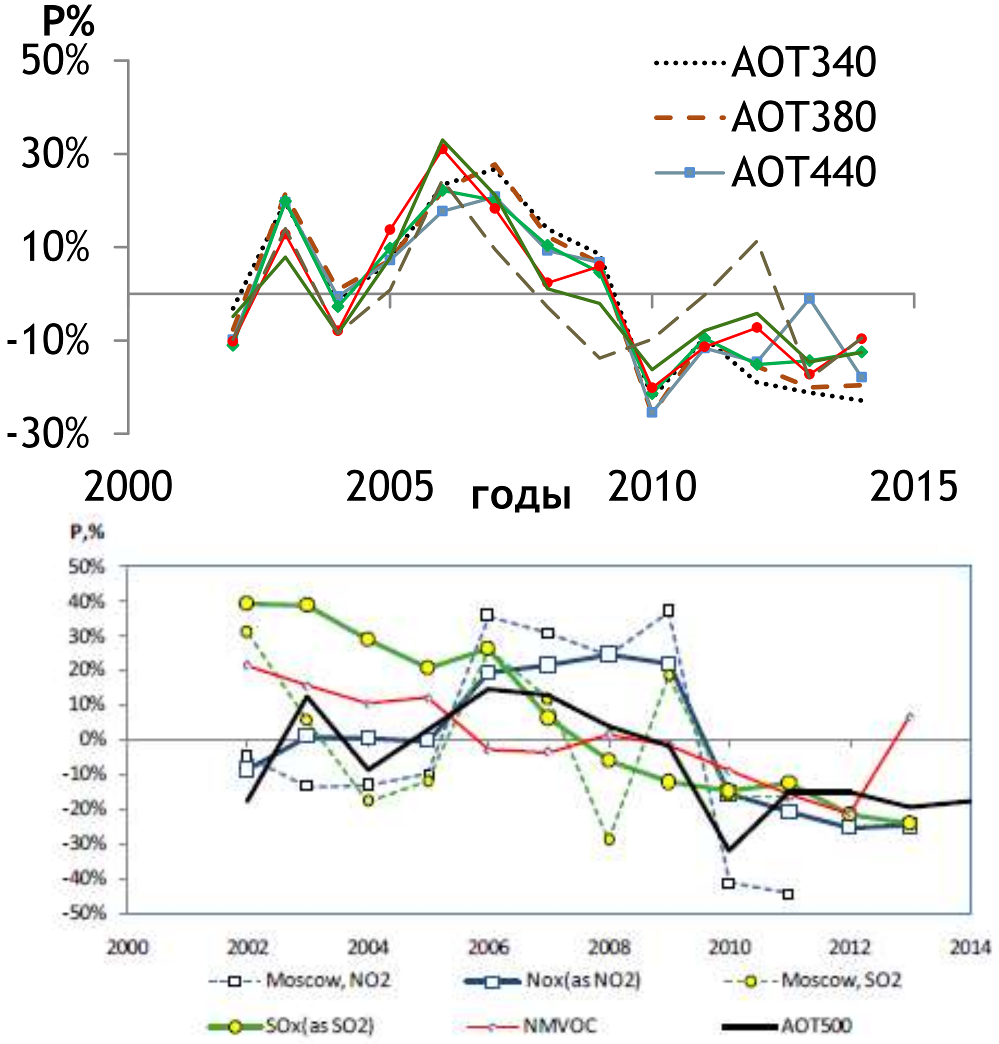
AERONET aerosol robotic network since 2001 at the MSU MO

AOT500	SSA – single scattering albedo	Factor of asymmetry
0.184 (AOT550)=0.161	0.9	0.65



Monthly variations of optical thickness in Moscow according to AERONET

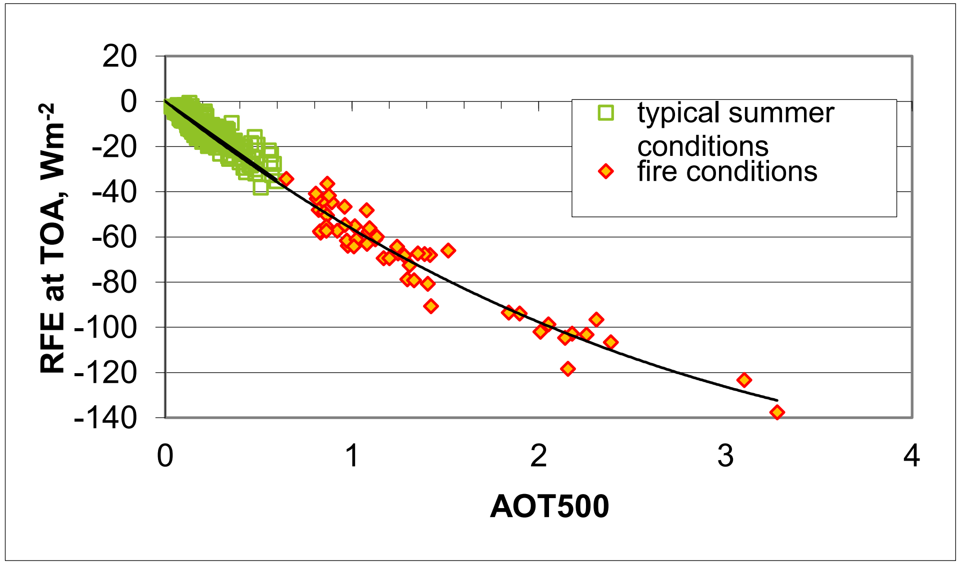
Year-to-year variability of aerosol optical thickness (upper panel) and aerosol-precursor (low panel) in Moscow according to AERONET data



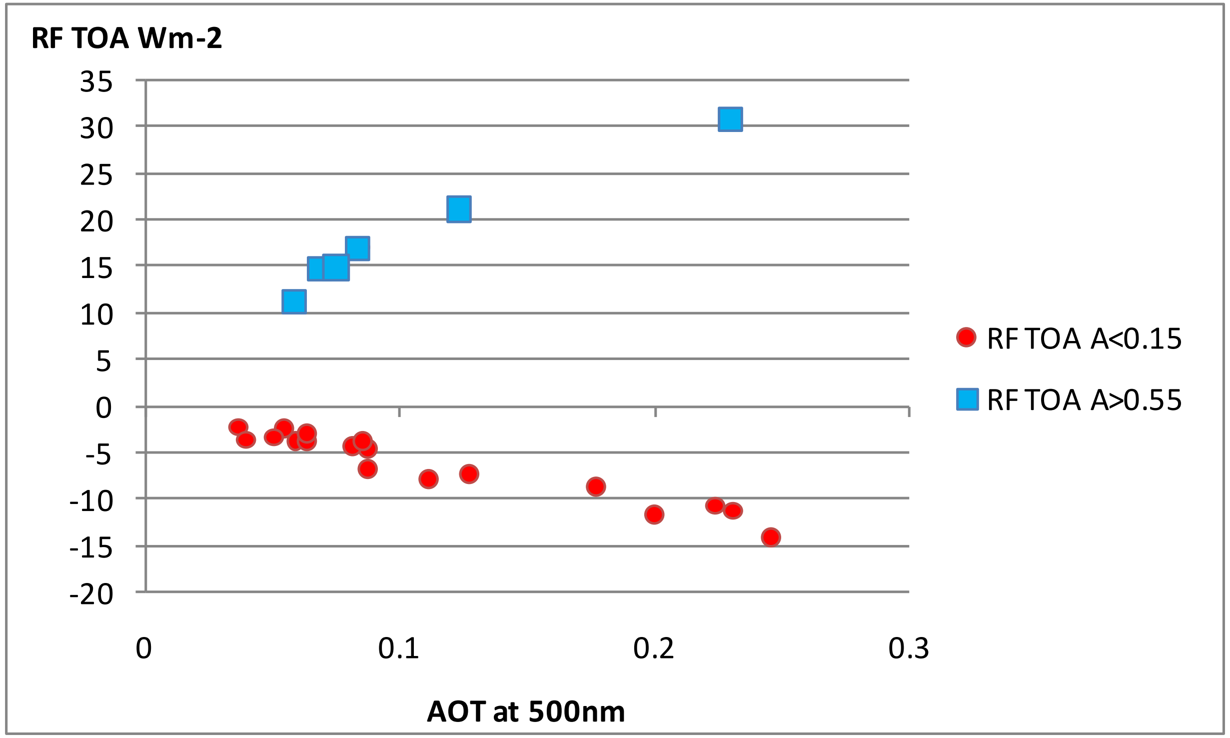
Chubarova et al., 2016, AMT

Radiative effects of aerosol at TOA in typical and fire conditions. Moscow

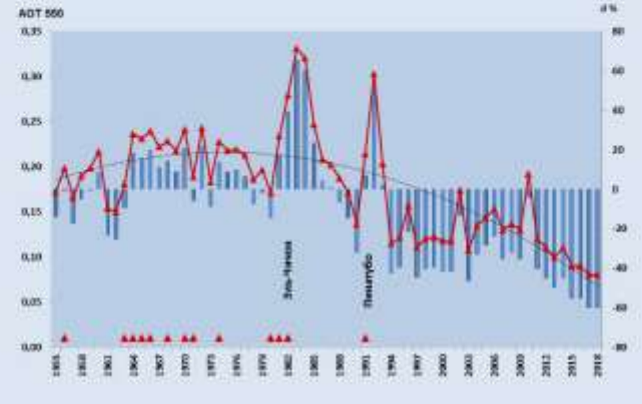
$$RFE(TOA)=F_{net,aerosol}-F_{net,no\ aerosol}$$



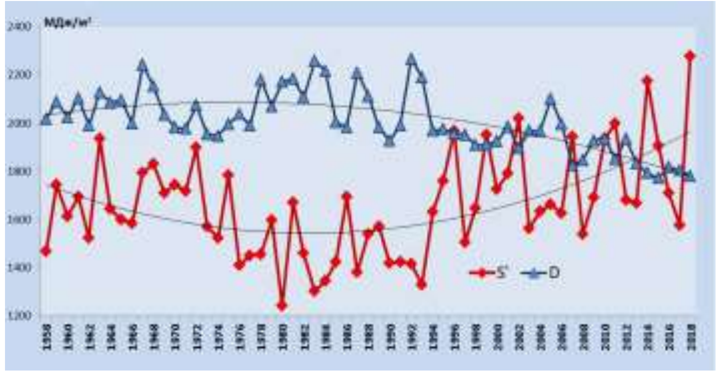
However, it can be of different sign!



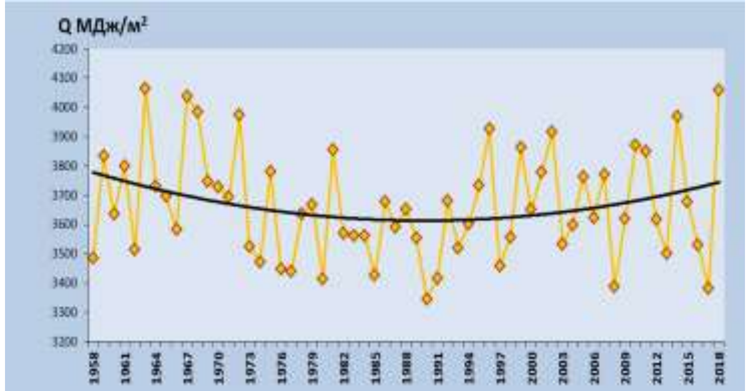
Long-term variations of solar radiation in Moscow



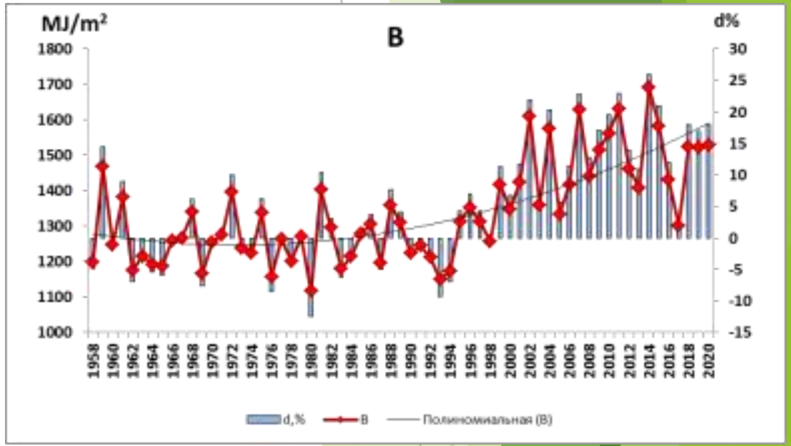
- Based on long-term measurements at MSU MO up to 2020 with additional radiative transfer model simulations and COSMO model runs



Direct irradiance (red) and diffuse irradiance (blue)



Global irradiance



Task 3.1.2

Aerosol and radiative urban effects in Moscow according to model and measurements.

- The analysis of COVID-19 lockdown for evaluation of the intensity of urban effects on the changes in gas-aerosol properties in Moscow in 2020.
- COSMO-Art / Enviro-HIRLAM - model intercomparisons for Moscow in typical and COVID-19 lockdown conditions with additional account for +Terra_URB (together with Alexander Mahura group)

Moscow air pollution

Moscow megacity:
Area – 2561.5 sq.km
Population - 12.5 million (live in the city permanently)
Personal car fleet - 4.7 million vehicles (7.7 million with Moscow region)

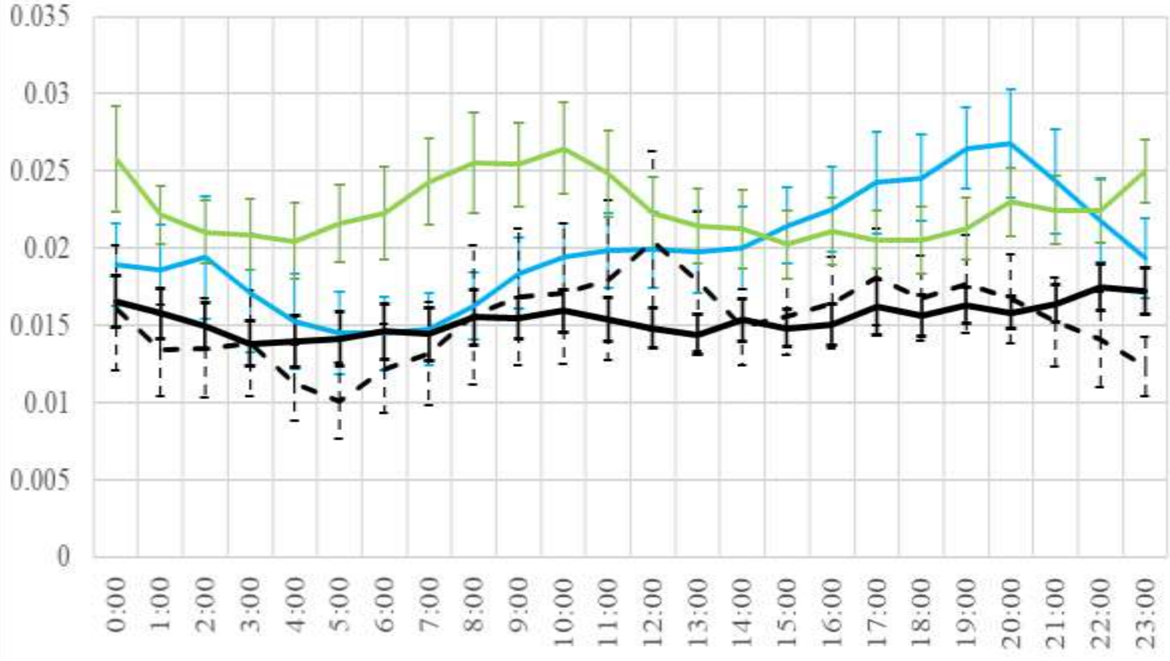
3.6 million cars are moving around Moscow every day

typical situation on the streets during rush hour

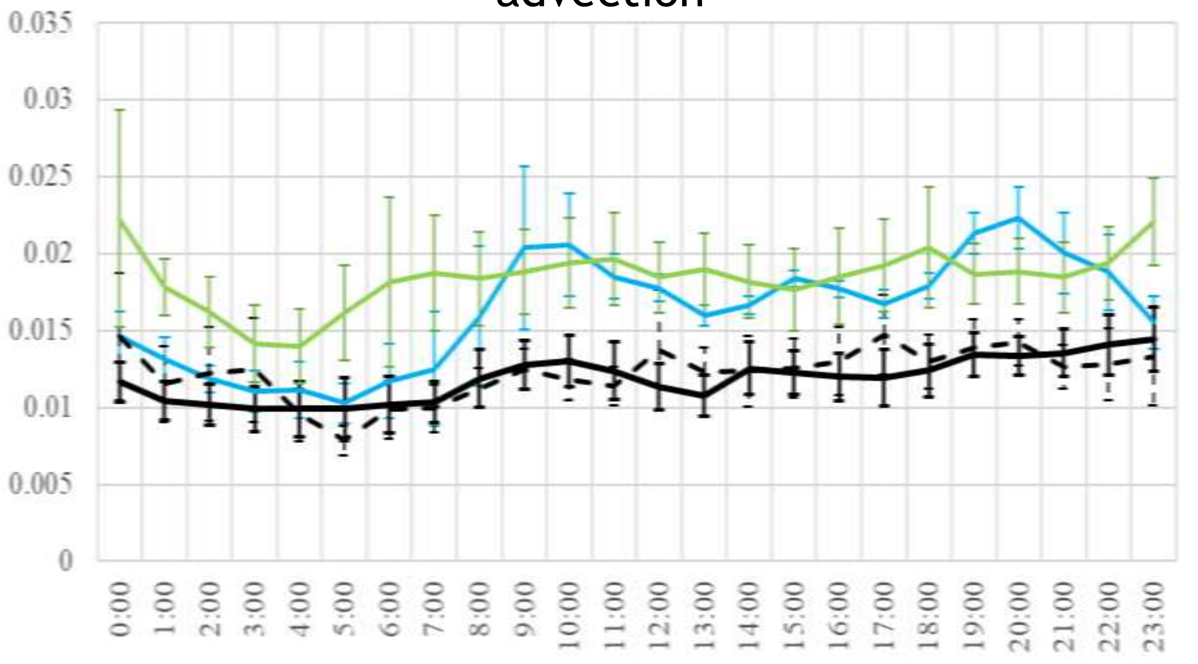
streets during lockdown period

Diurnal cycle of PM10 (mgm-3) before lockdown (01.01-29.03), 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 the cases with northern air advection

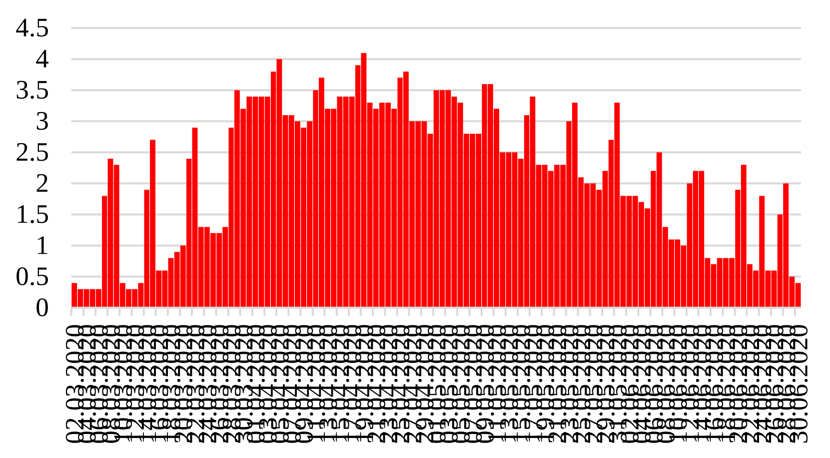


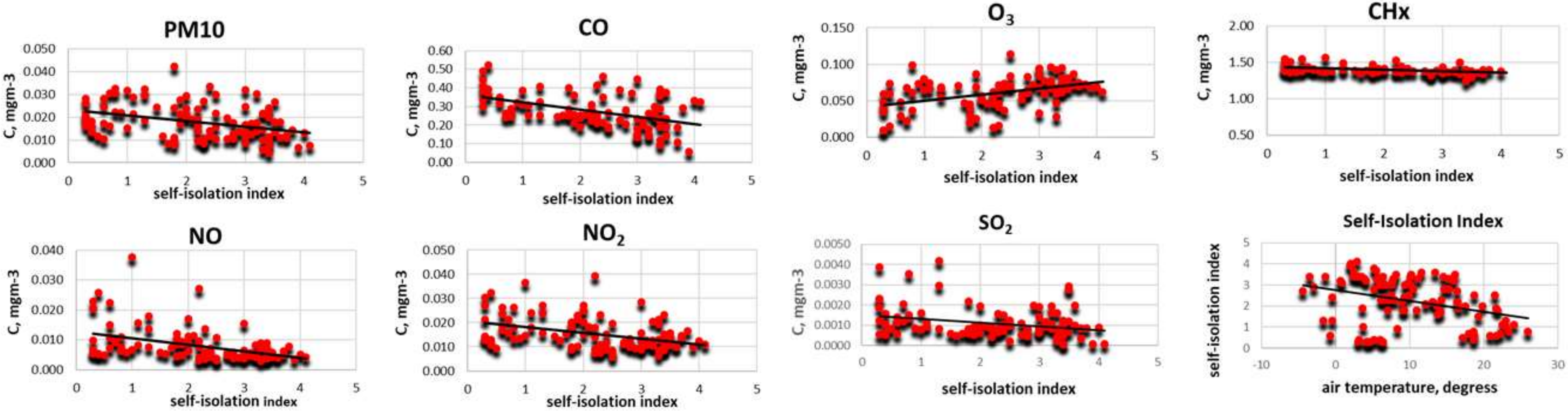
Chubarova et al, submitted, 2021

Moscow COVID-19 lockdown conditions.

The correlation between daily-mean mass concentrations C (mgm-3) and self-isolation index (https://yandex.ru/company/researches/2020/podomam).

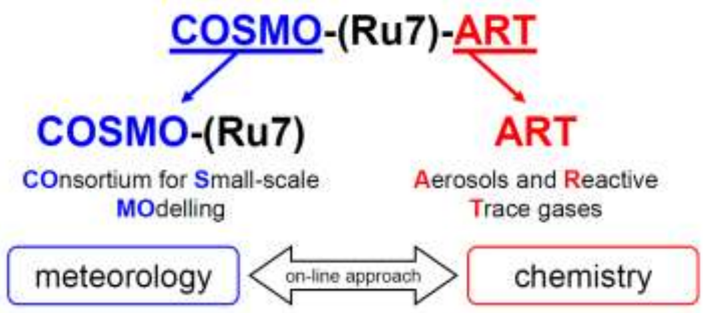
No smoke advection cases.

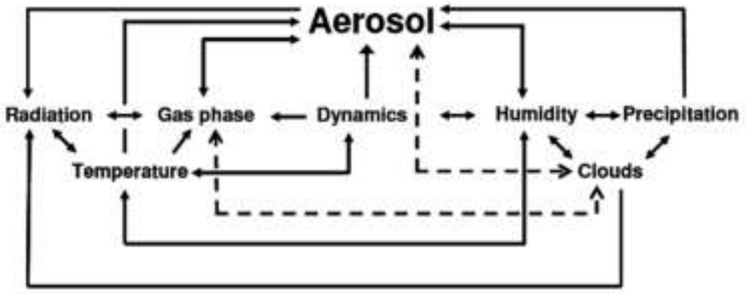




Chubarova et al., submitted, 2021

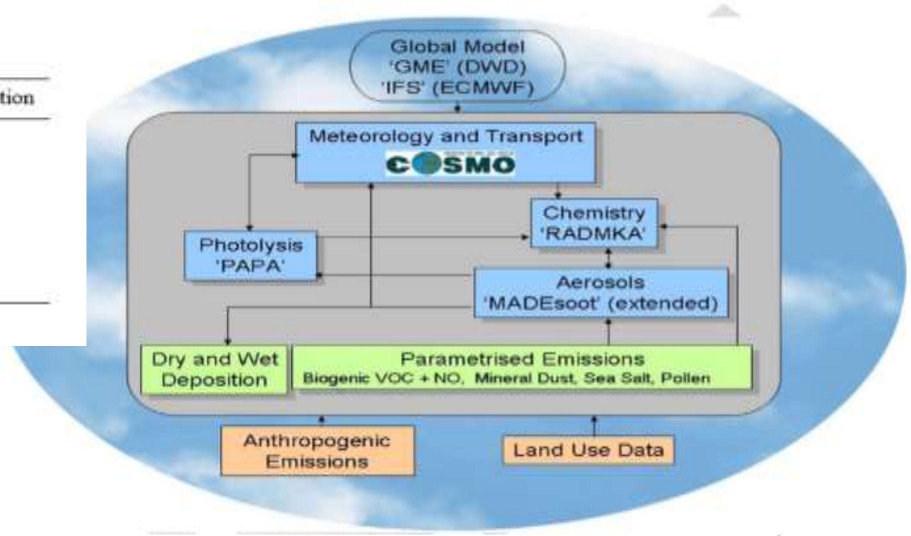
COSMO-ART model and experimental data



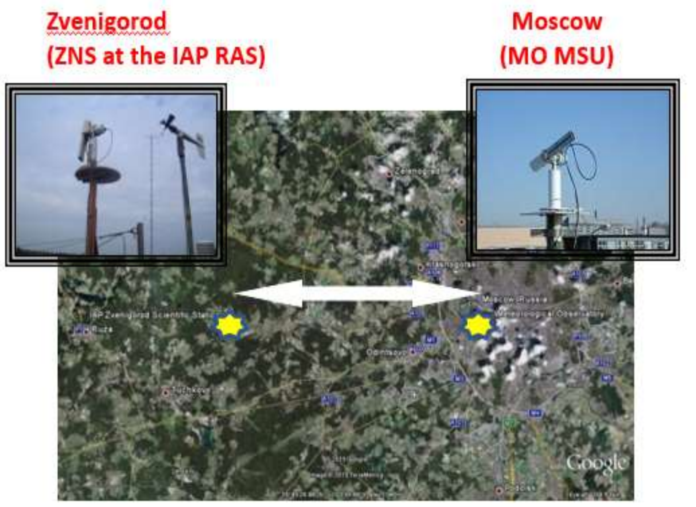


Mode	Chemical composition and mixing state	Standard deviation
if	SO_4^{2-}, NO_3^-, NH_4^+, H_2O, SOA (internally mixed)	1.7
ic	SO_4^{2-}, NO_3^-, NH_4^+, H_2O, SOA, soot (internally mixed)	1.7
jf	SO_4^{2-}, NO_3^-, NH_4^+, H_2O, SOA (internally mixed)	2.0
jc	SO_4^{2-}, NO_3^-, NH_4^+, H_2O, SOA, soot (internally mixed)	2.0
s	soot	1.4
c	direct PM_{10} emissions	2.5

Satellite Modis/MAIAC and MISR dataset with 1 km retrievals



AOD (total) =AOD (regional) +AOD(urb from the two AERONET sites



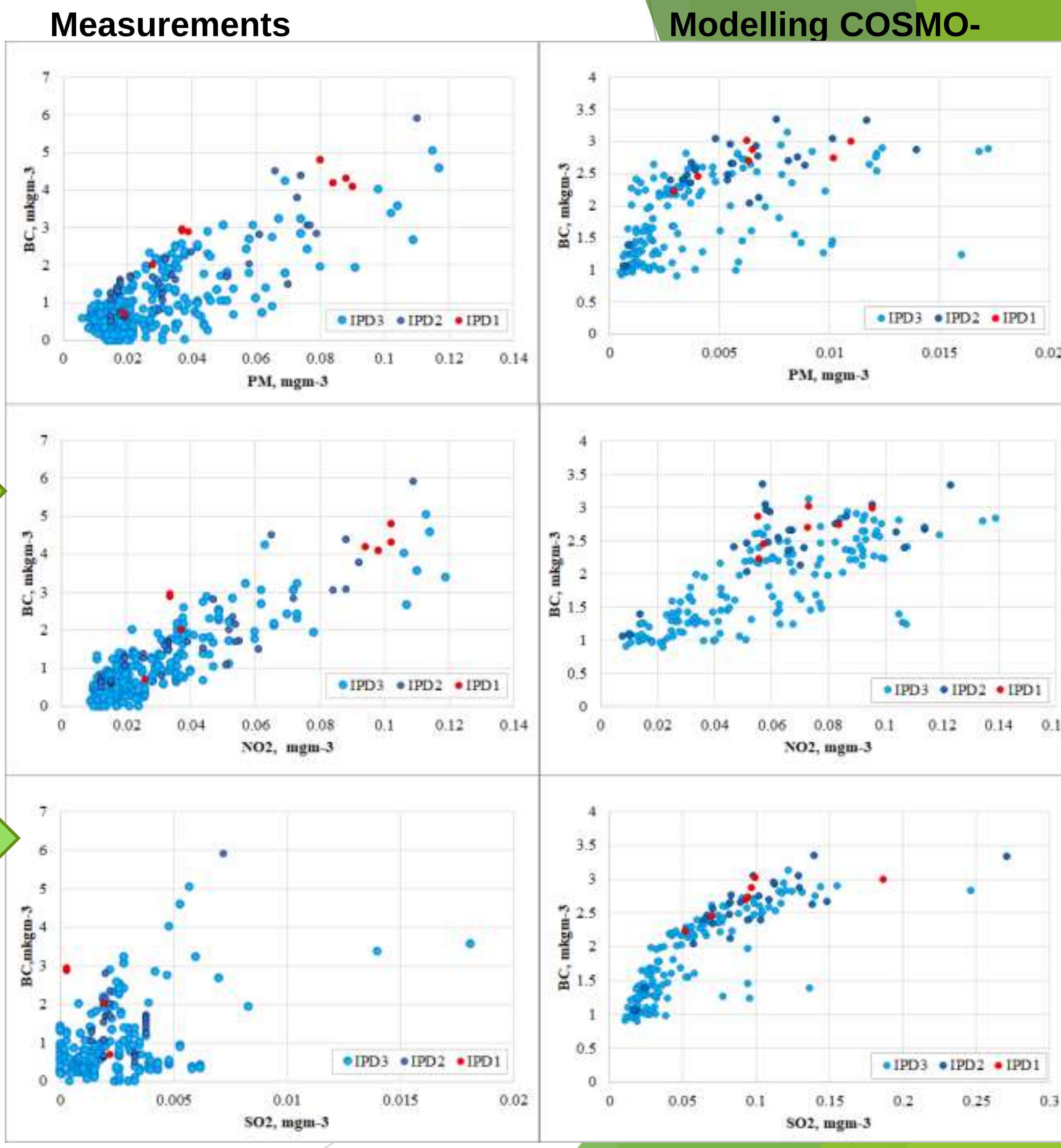
B. Vogel, et al. ACP, 2009
Vil'fand et al., 2017

Measured and modelled (COSMO-ART) mass concentrations of Black Carbon (BC) versus PM, NO_2 and SO_2 at different Intensity of Particle Dispersion (IPD) levels

An existing correlation between BC and NO_2 concentrations due to same source of traffic emissions.

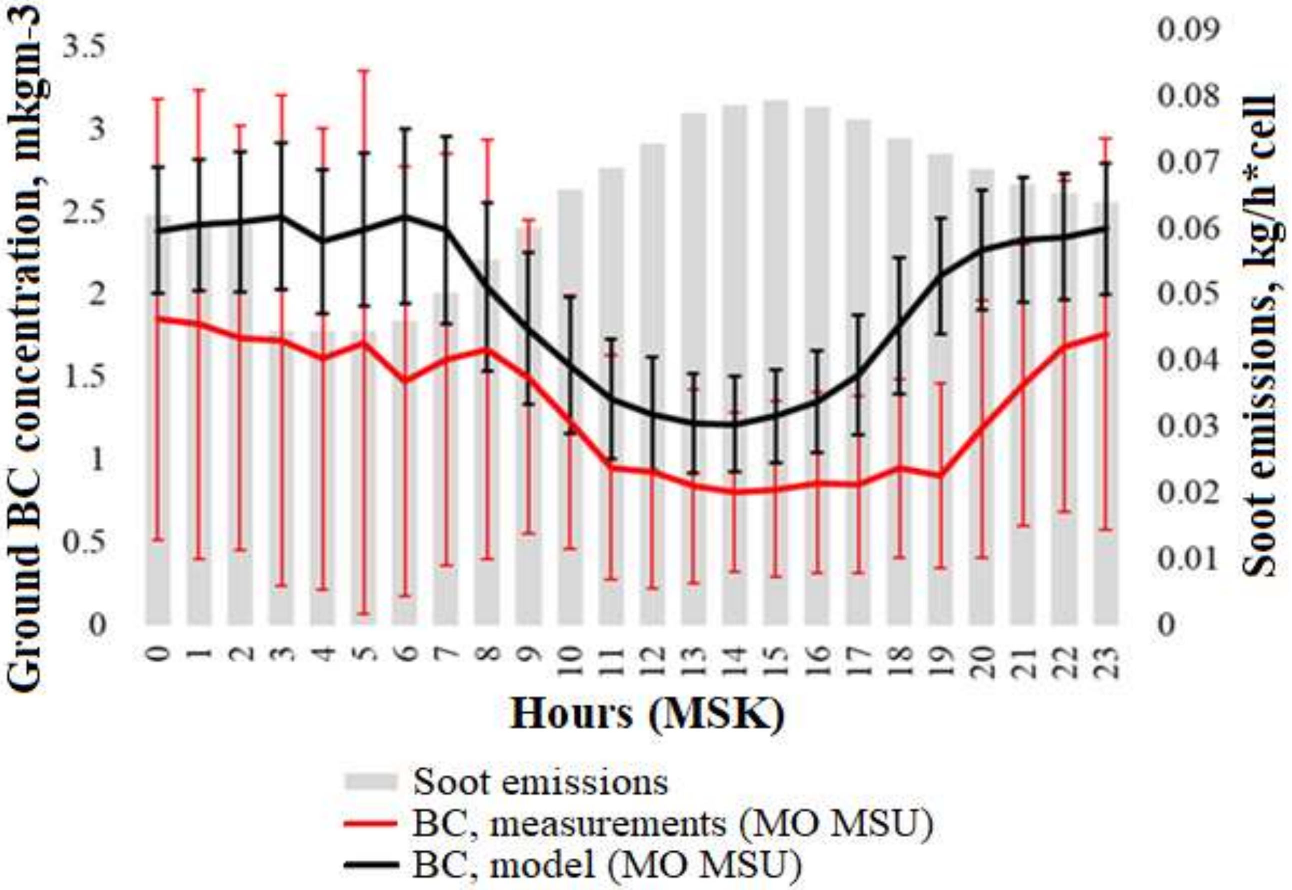
No correlation between measured BC and SO_2 due to extremely low SO_2 concentrations in Moscow in contrast with modelled data.

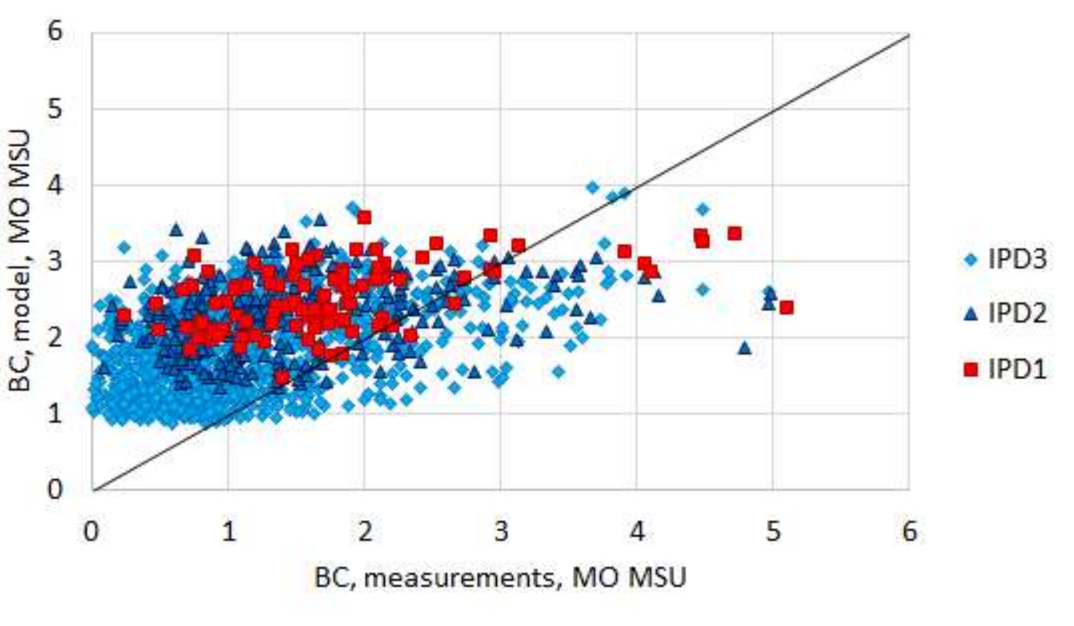
IPD1 - very stable atmosphere
IPD2 - intermediate
IPD3 - unstable atmosphere



From Chubarova et al. Monograph, 2020

Black carbon aerosol: comparisons between model (COSMO-ART) and measurements. *2018-2019 AeroRadCity experiment*.



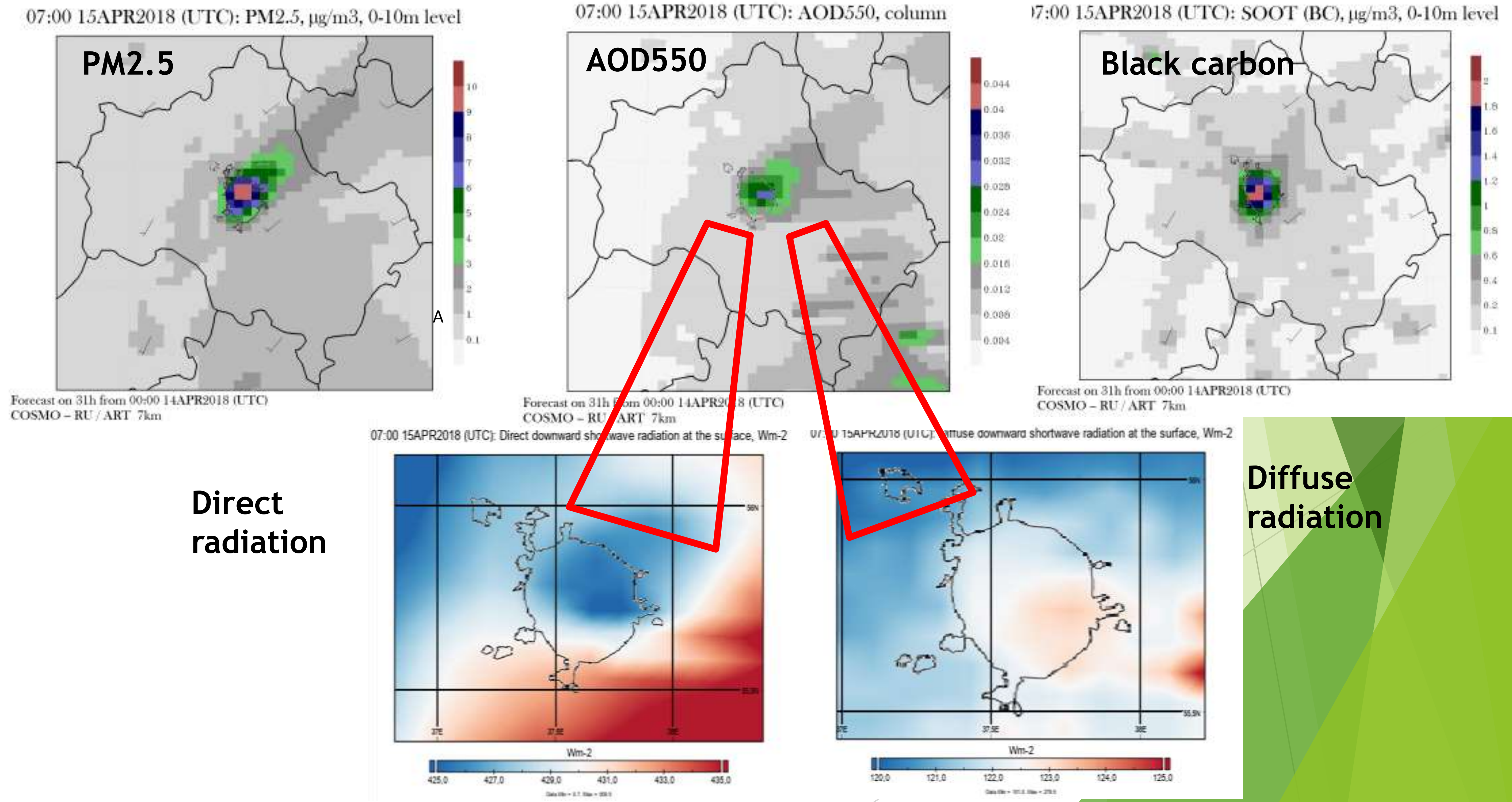


IPD1 – very stable atmosphere
IPD2 - intermediate
IPD3 – unstable atmosphere

BC measurements at the MSU MO were carried out by Dr. O.B. Popovicheva (2020)

Chubarova et al. Regional aerosol pollution….Monograph 2020

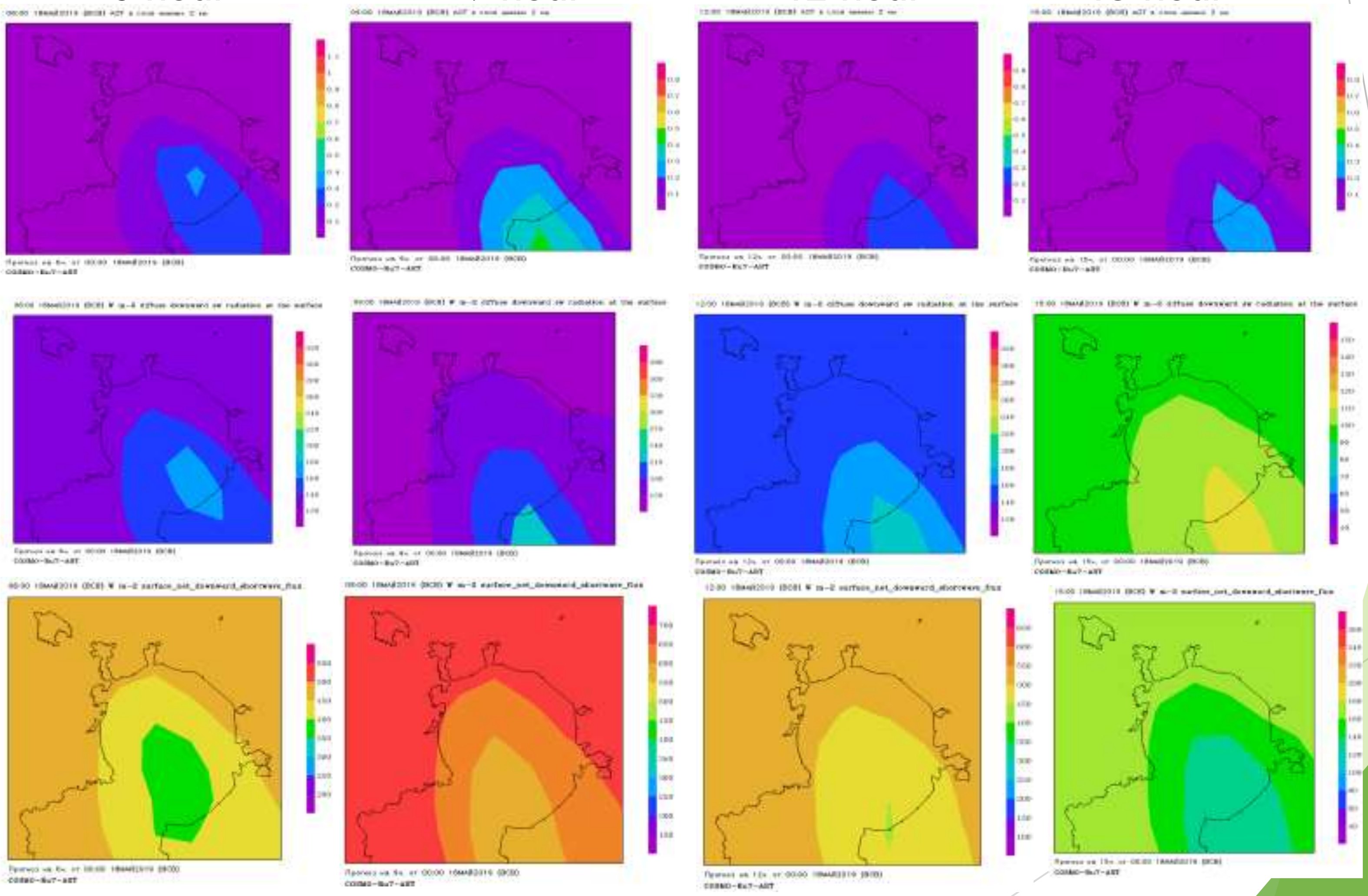
Radiative effect of aerosol urban pollution in Moscow according to COSMO-ART evaluation. 15/04/2018



The dynamic of urban aerosol development in Moscow region and its influence on radiative characteristics of the atmosphere according to COSMO-Ru-ART. 18.05.2019.

wind direction

6 hour | 9 hour | 12 hour | 15 hour

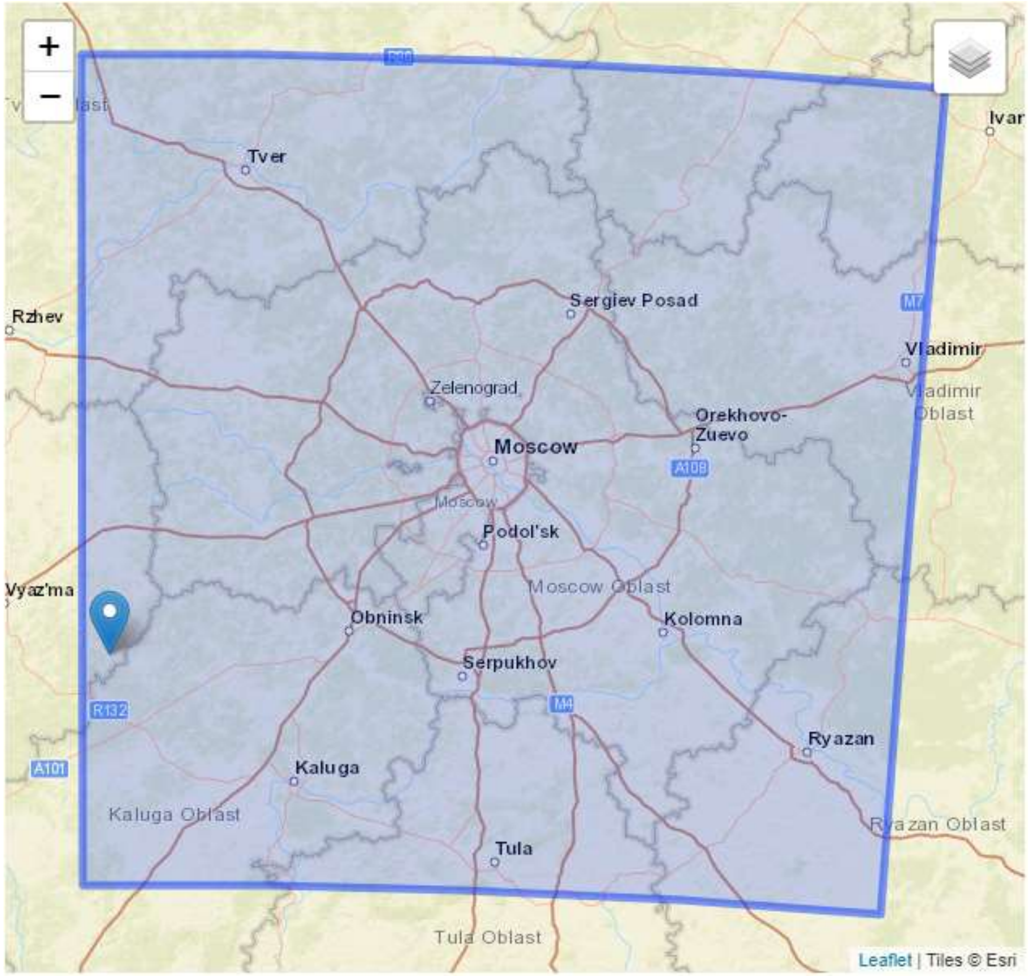


aerosol optical depth

diffuse radiation

net radiation at ground

New experiments with COSMO-ART + TERRA_URB



Currently selected model domain for COSMO-ART + TERRA_URB experiments

COSMO-Art / Enviro-HIRLAM - model intercomparison for Moscow typical and lockdown conditions

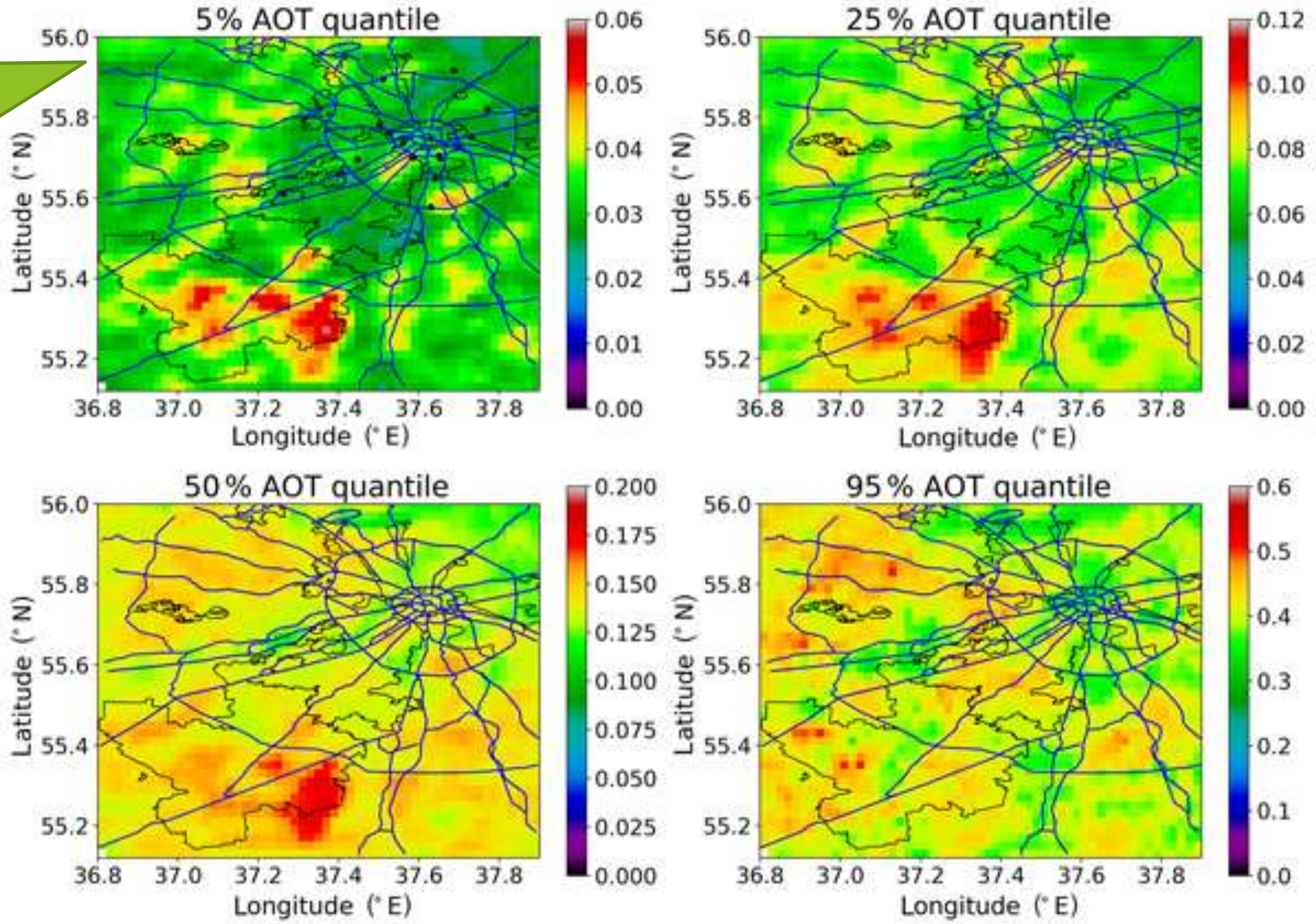
- (I). Selected periods of interest/ study: 2018-2020
- (II) Planned experiments (aerosols / urban areas, UHI):
- (III) Models Setup:
- (IV) Model Urbanization:
- (V) Emission Inventories (EI):
- (VI) ICs/ BCs - Boundary conditions:
- (VII) Observations (& for models verification):

Task 3.1.3
Evaluation of aerosol pollution in Moscow region and its direct and semi-direct radiative and temperature effects using satellite data.

- Spatial features of aerosol pollution according to MODIS and MISR data and estimates of radiation and temperature effects due to aerosol according to the COSMO model

Quantiles (5 %, 25 %, 50 %, 95 %) AOT at 0.47 μm over the Moscow megacity, 2001–2017, Aqua and Terra datasets

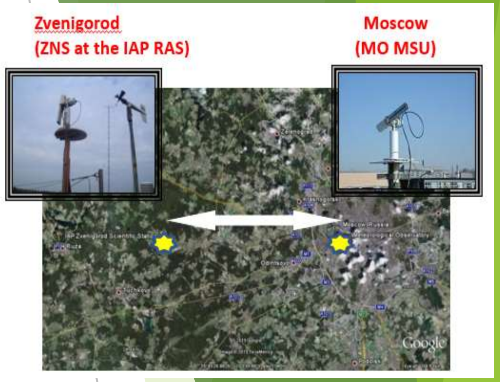
the most pronounced conditions for urban aerosol evaluation



Zhdanova et al., 2020

Method for evaluating the direct aerosol effect of urban aerosol

Clear sky conditions



MODIS MAIAC AOD (MCD19A2), Moscow region

2000-2019

2020

AERONET, (MO MSU, Zvenigorod)

2000-2019

2020

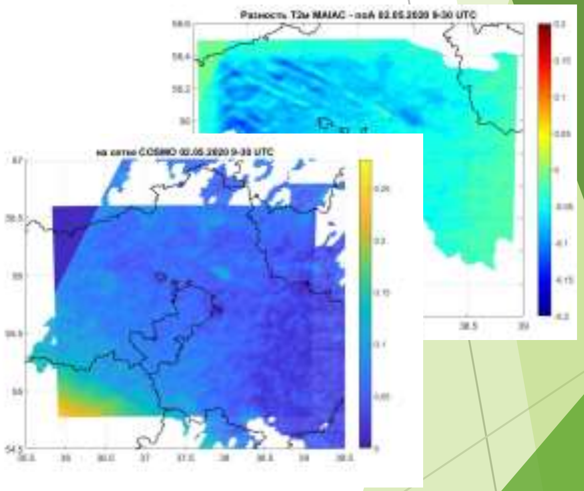
for correction of satellite data

Pre-processing: reprojection, scaling, sampling

Clear sky sampling

Selection of synoptic analogues

AOD anomaly



Special attention to:

Advection of arctic air mass

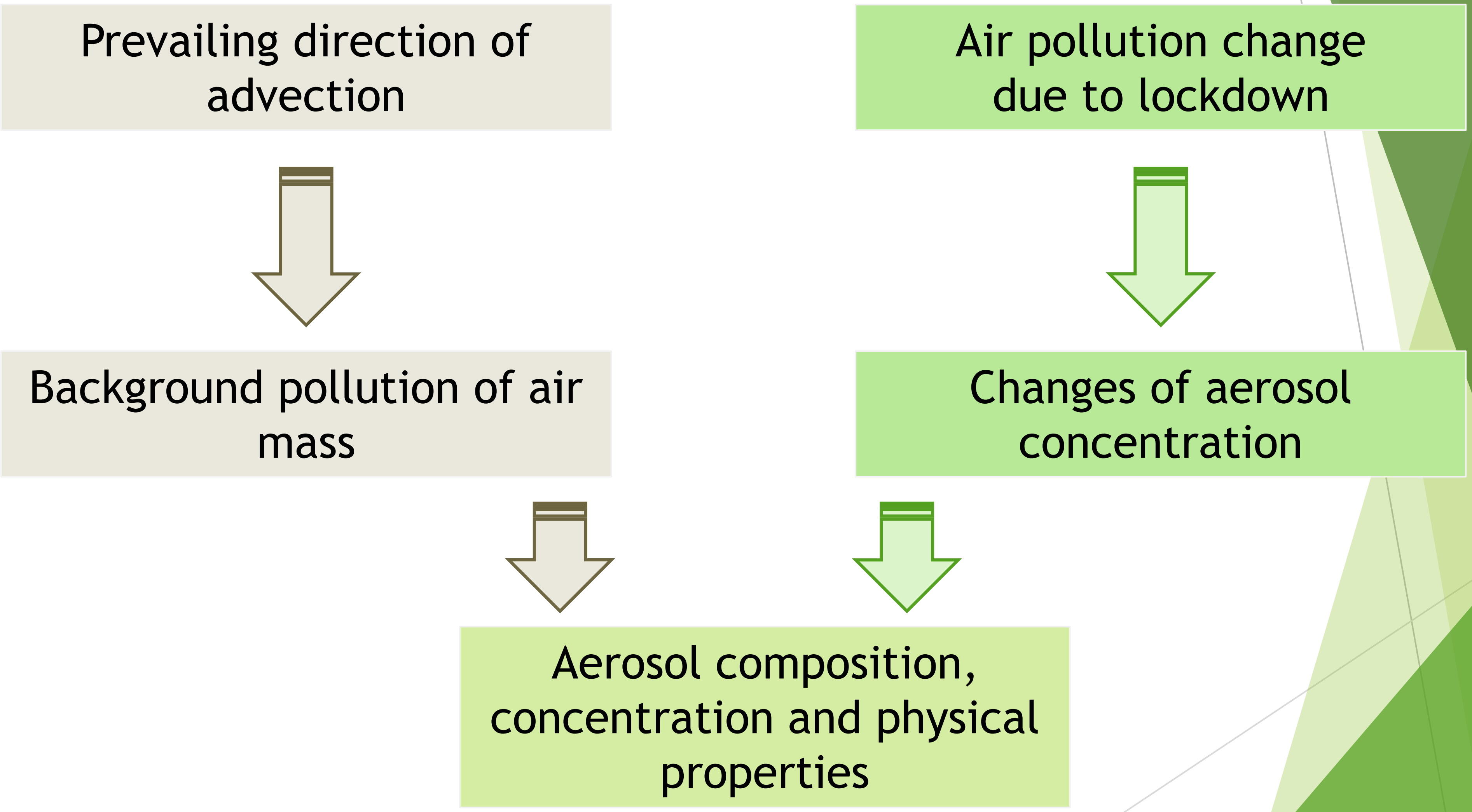
13-16, 19-24 March — before lockdown
30-31 March 1-2, 5-6, 10-12 April — 1 phase of lockdown
15-22, 24-28, 30 April 1, 13, 18, 21-25 May, 1 June — 2 phase of lockdown
14-15, 21-22, 24-26, 29-30 June — after lockdown

COSMO model – radiative and temperature effects of urban aerosol decrease due to lockdown conditions

Task 3.1.4

Indirect urban aerosol effects.
Interaction of clouds and aerosol and the assessment of radiation effects using measurements and modeling by the COSMO system

Accounting for synoptic conditions for evaluation of indirect aerosol-cloud effect in lockdown conditions



Methods for retrieval the concentration of cloud condensation nuclei (N_{CCN})

(Grandley and Stier, 2010)

$$N_d = C_1 R_{eff}^{-5/2} COT^{1/2}$$

(McComiskey et al., 2009)

$$N_d = C_2 LWP^{-5/2} COT^3$$

N_d - Number concentration of liquid cloud particles, m^{-3}
R_{eff} - Effective radius of liquid cloud particles, m
COT - Cloud optical thickness
LWP - Liquid water path, kg/m^2

By satellite data

Adiabatic approximation:

$N_{CCN} \approx N_d$ at cloud base

Methods assumptions:

- Gamma size-distribution function
- Sub adiabatic cloud
- $N_d|_z = const$
- Liquid (warm) cloud only

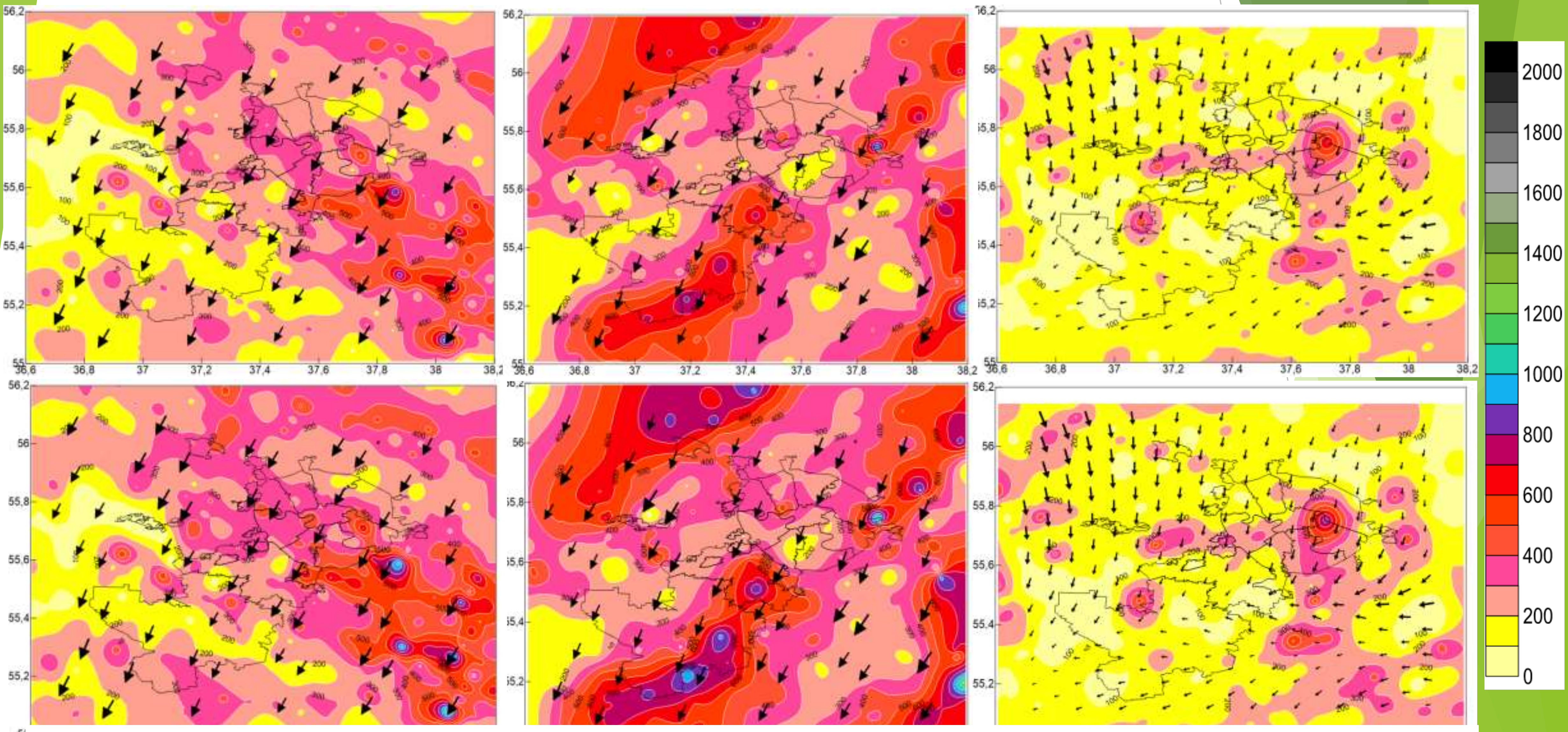
Constraints on the choice of meteorological / synoptic conditions

Preliminary results. Retrievals of N_{CCN} (cm^{-3}). Northern advection cases

22/04/**2018** 09:05 a.m. | 02/05/**2019** 10:55 a.m. | 22/05/**2020** 10:45 a.m.

GRANDLEY

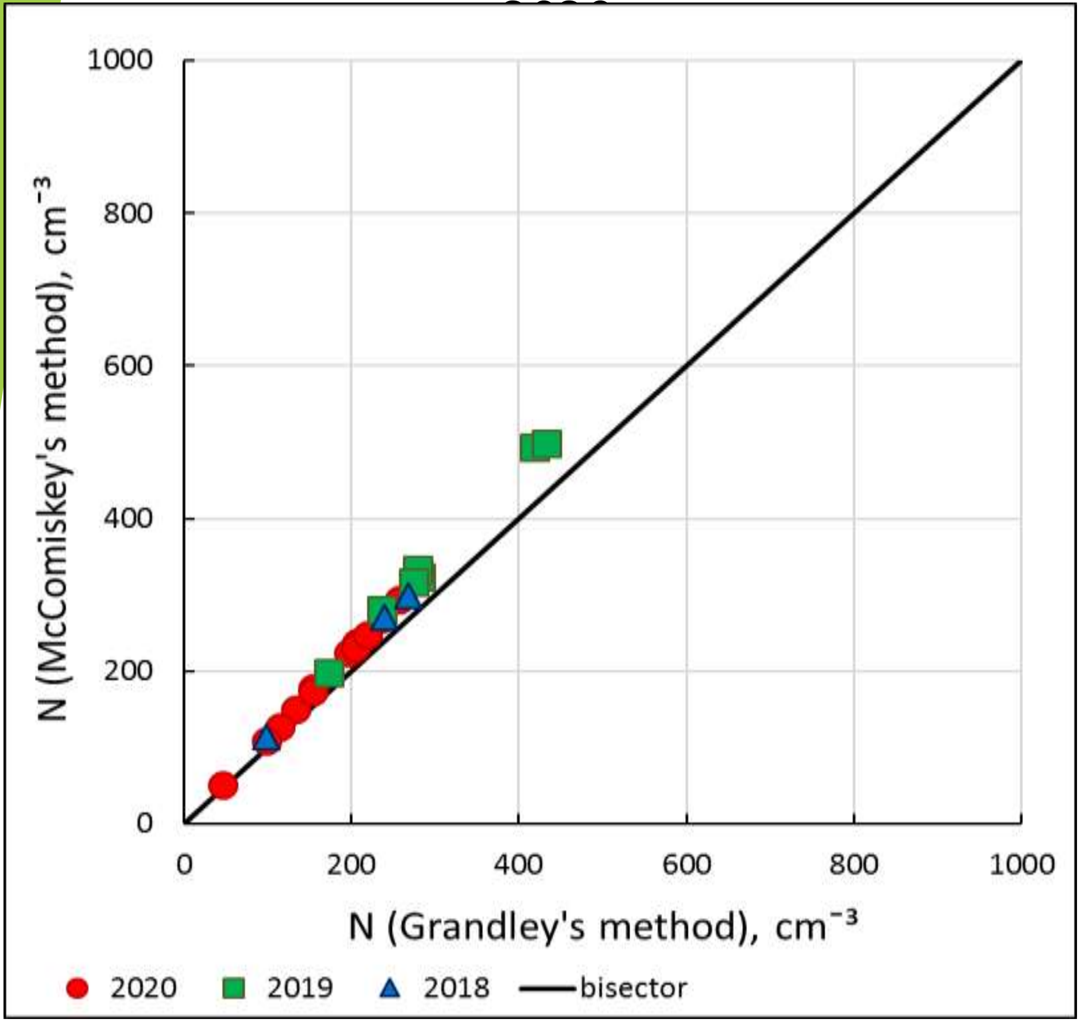
MCCOMISKEY



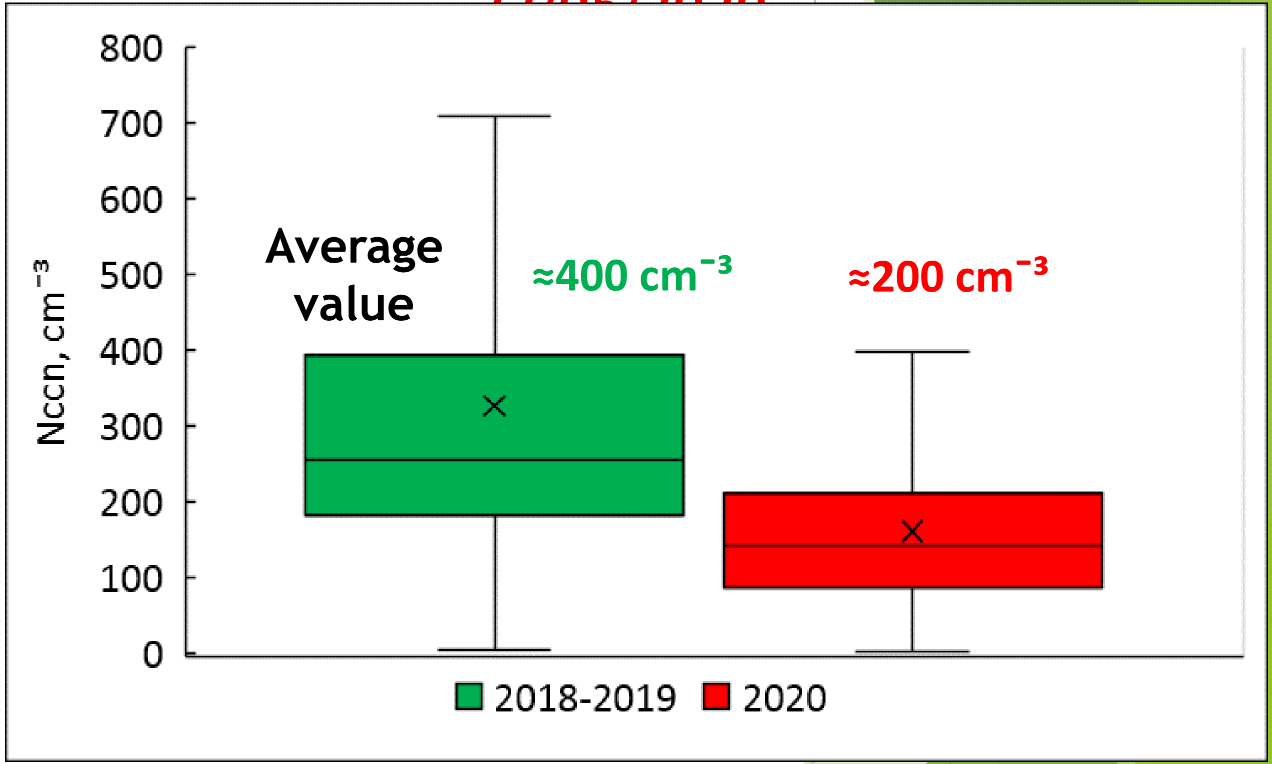
* Wind at 1500 m, COSMO-Ru forecast from 09:00 a.m.

Retrievals of N_{CCN} (cm^{-3}) by 1 km MODIS data

Northern advection. April-May of 2018-2020



Cases of northern advection, Grandley's method.
22/04/2018, 02/05/2019, 08/05/2020, 22/05/2020



The most important selection conditions:

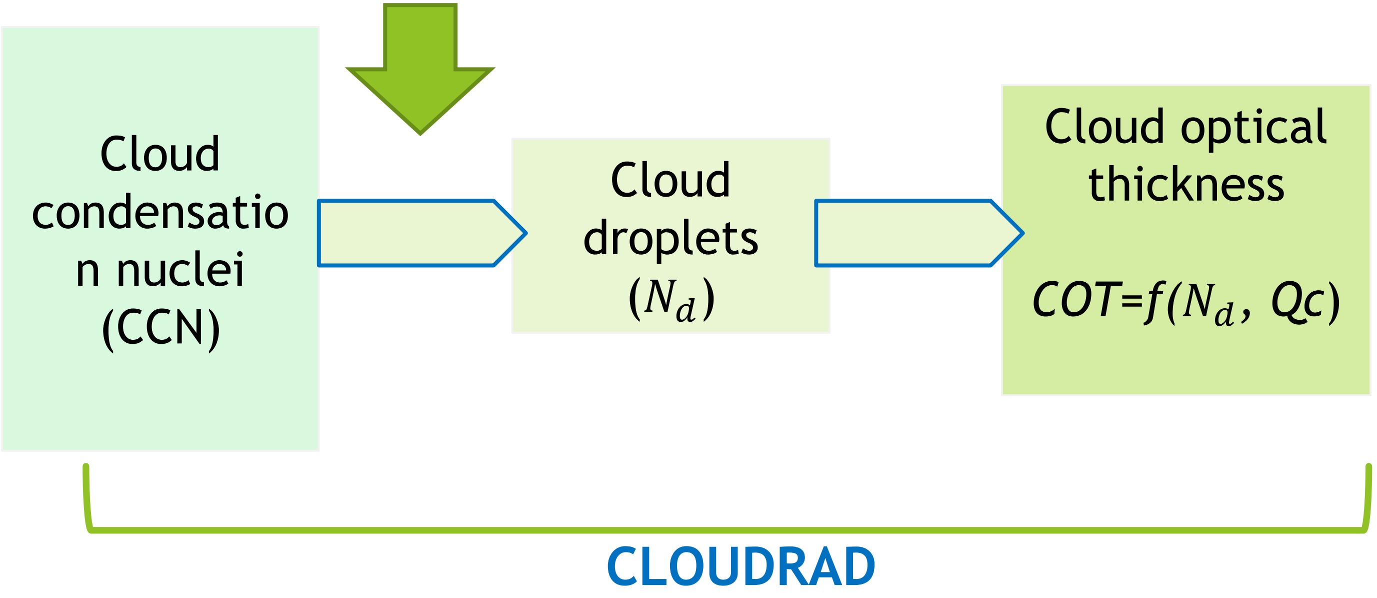
- Only liquid cloud coverage
- 1-2 layers coverage

Aerosol-cloud interaction in COSMO model

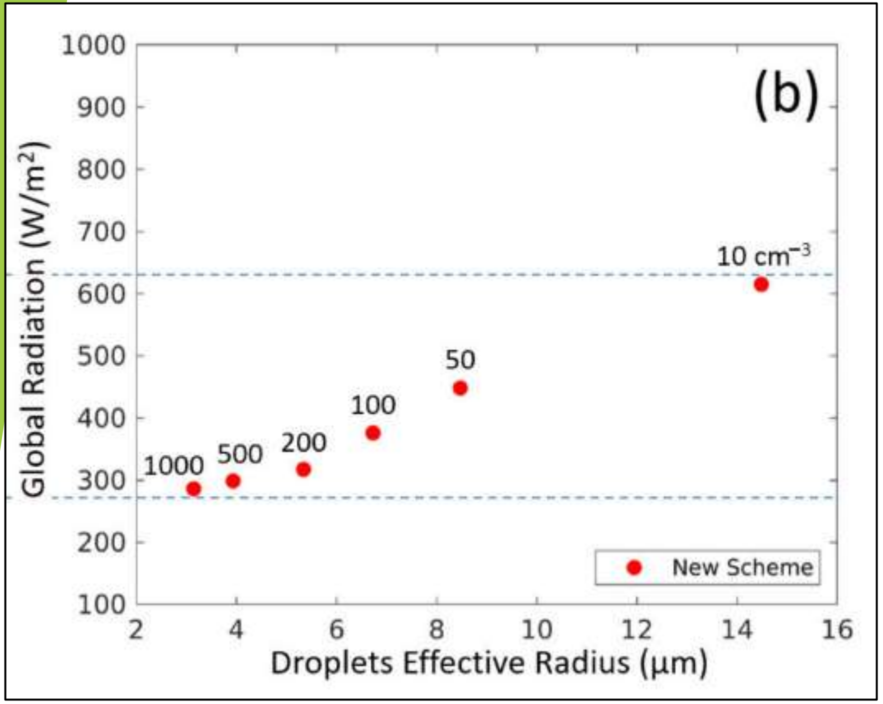
Segal-Khain scheme

N_d= f(w_{cb}, N_{CCN}),

w_{cb} – updraft speed at cloud base

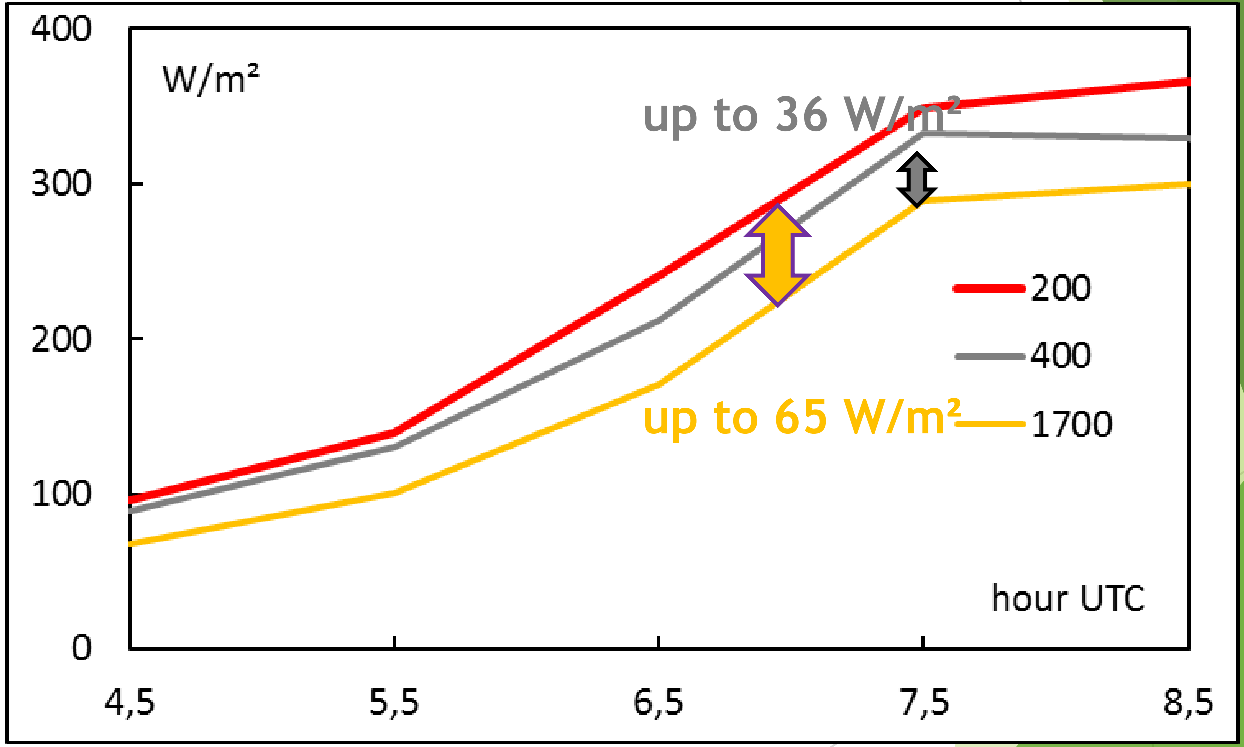


Preliminary estimates.
The global irradiance for different droplets R_{eff} (N_{CCN})



Muskatel et al., Atmosphere, 2021
https://doi.org/10.3390/atmos12010089

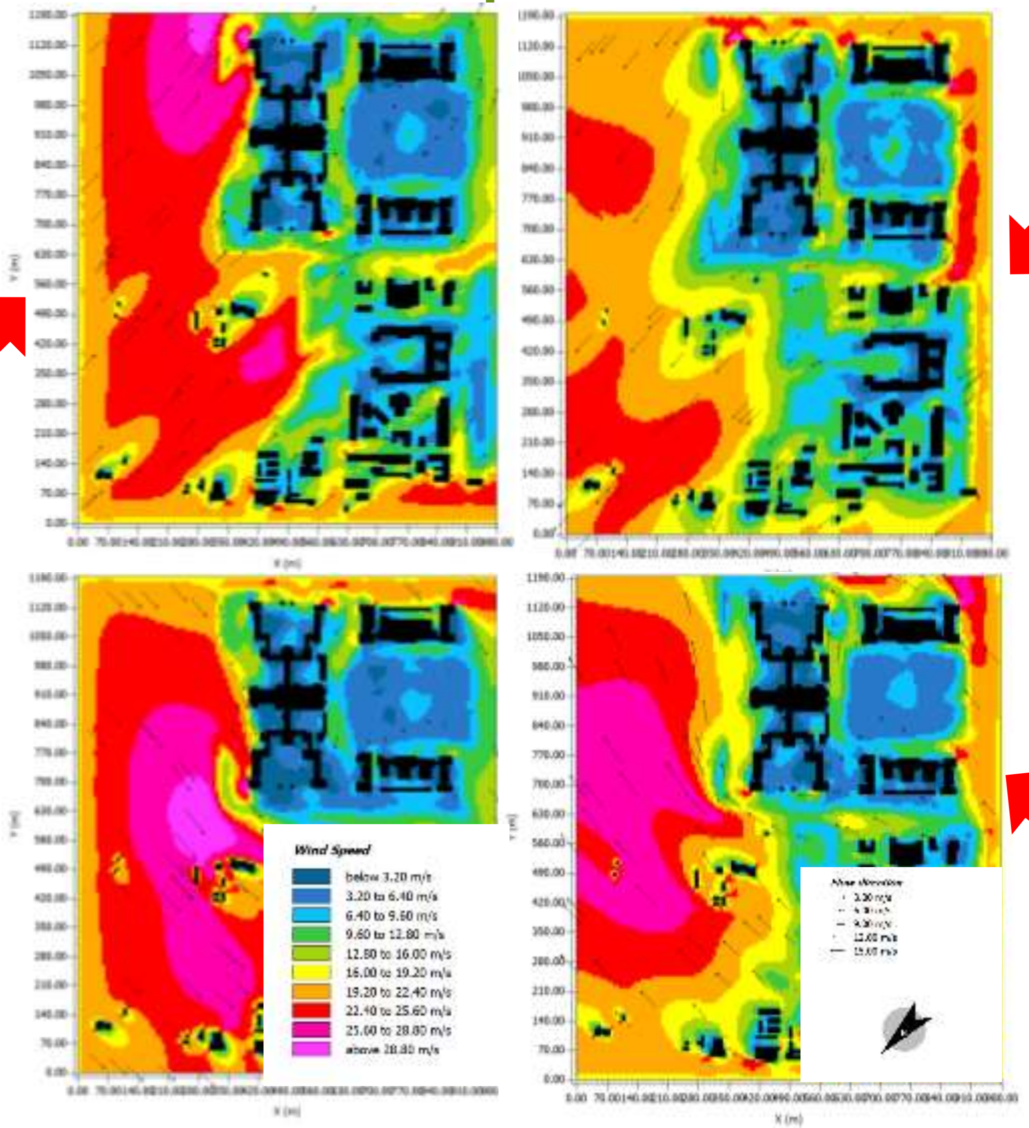
Example of global irradiance 22/05/2020.
Overcast conditions (low cloud layer)



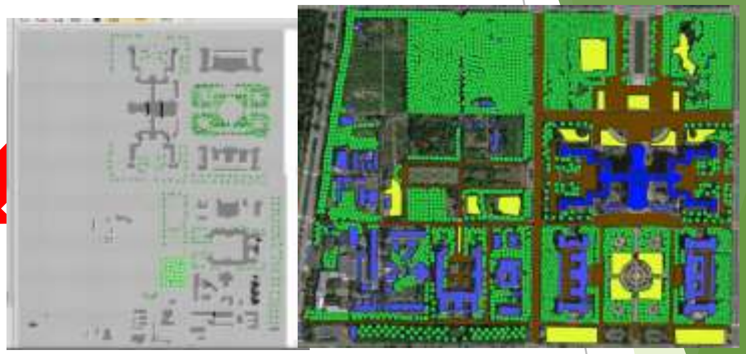
Task 3.2

Model calculations at the microclimatic level using the ENVI-met model complex for aerosol and biometeorological characteristics.
The analysis of the influence of urban environment morphology on the micro-scale dynamics of the microclimate and atmospheric aerosol concentration within the selected experimental site.

Creation of meteorological and thermal comfort parameters database for MSU-campus on microscale (5x5 m)



Digitization of MSU-domain



$$\frac{\partial u}{\partial t} + u_i \frac{\partial u}{\partial x_i} = -\frac{\partial p'}{\partial x} + K_m \left(\frac{\partial^2 u}{\partial x_i^2} \right) + f(v - v_g) - S_u$$

$$\frac{\partial v}{\partial t} + u_i \frac{\partial v}{\partial x_i} = -\frac{\partial p'}{\partial y} + K_m \left(\frac{\partial^2 v}{\partial x_i^2} \right) + f(u - u_g) - S_v$$

$$\frac{\partial w}{\partial t} + u_i \frac{\partial w}{\partial x_i} = -\frac{\partial p'}{\partial z} + K_m \left(\frac{\partial^2 w}{\partial x_i^2} \right) + g \frac{\theta(z)}{\theta_r ef(z)} - S_w$$

Task 3.3

Assessment of the public health risk from heat island exposure and air pollution

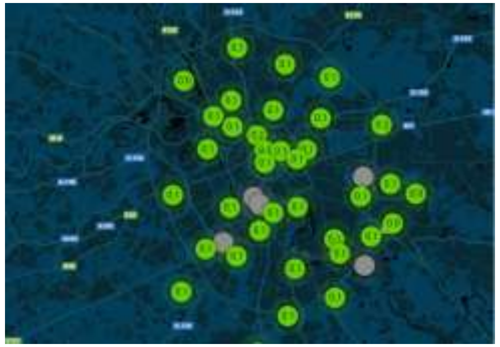
The influence of heat waves and air pollution on population mortality

Data collection

during 15 years (2005 to 2019), Moscow

Variables:

Mosecomonitoring data



Weather

Minimum and maximum daily temperature, average daily temperature, relative humidity, wind speed

Calculation of bioclimatic indices: PET , UTCI

Air Pollution

Daily concentrations of air pollutants including PM10, PM2.5, NO2, CO, SO2, NO

Rosstat data

Health Outcomes

Daily number of deaths in different age (30-65 and 65+) and sex groups (male / female)

Analysis of potential confounding variables

Travelling

Helsinki visit 2 person – 2021-2022 (M. Varentsov, A. Poliukhov) for working with Alexander Makhura group (two models intercompaprisons) aerosol urban pollution effects over Moscow.

Thank you for your attention!

Questions?