Urban aerosol and its radiative effects in Moscow Megacity according to the ground-based and satellite (MODIS/MAIAC) measurements, and COSMO-ART modelling

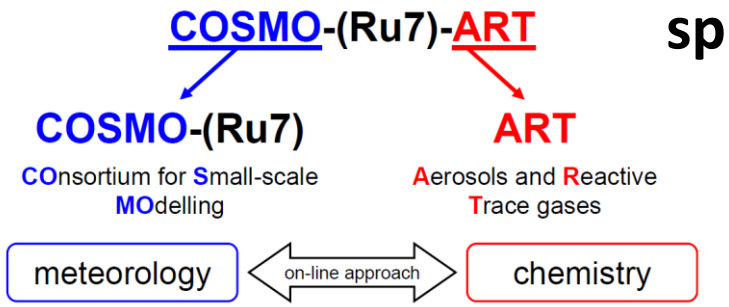
Natalia Chubarova[1], Elizaveta Androsova[1], Ekaterina Zhdanova[1], Alexander Kirsanov[2], Bernhard Vogel[3], Heike Vogel[3], Alexei I. Lyapustin[5] , Olga Popovicheva[4], and Gdaly Rivin[1,2]

1Moscow State University, Faculty of Geography, 119991, Moscow, Russian Federation
2Hydrometeorological Centre of Russia, 11-13, B. Predtechensky per., Moscow, 123242, Russia
3Karlsruhe Institute of Technology, Karlsruhe, Germany
4Moscow State University, Faculty of Physics, 119991, Moscow, Russian Federation
5 Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

The main questions:

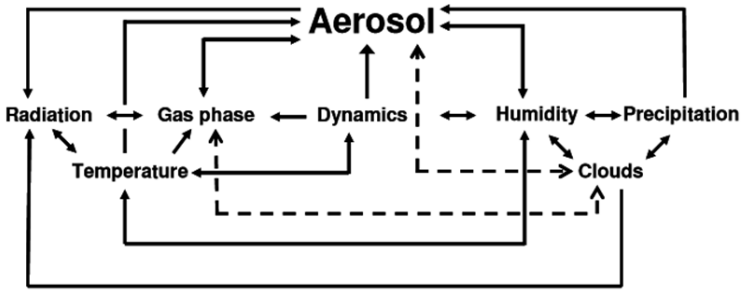
- What is the effect of Moscow megacity on aerosol properties of the atmosphere?
- What is the role of black carbon?
- What is the long-term changes in AOD in Moscow?
- Do the satellite retrievals provide an accurate estimates of urban aerosol component?
- What conditions are the best for evaluation of urban aerosol effects?

The description of the urban aerosol experiment



spring 2018-2019

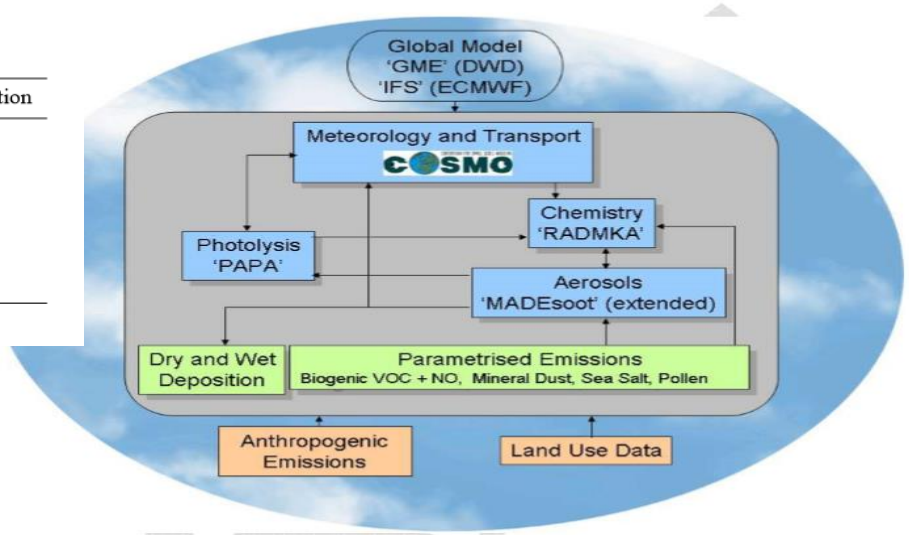
Meteorological Observatory of Moscow State University



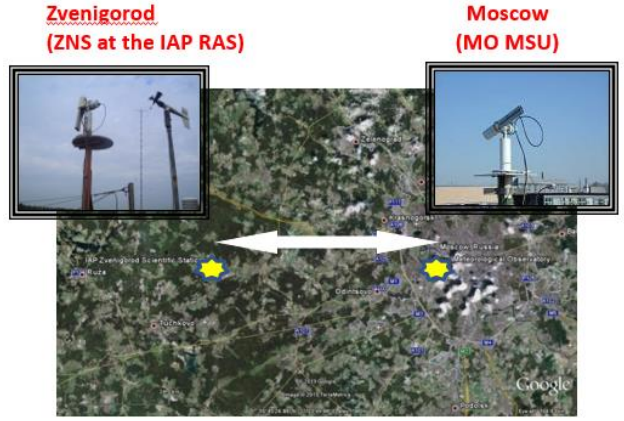
Satellite MAIAC/MODIS (Lyapustin et al., 2018) with 1 km resolution

- Data:
- AERONET microphysical and radiative aerosol properties
- Solar irradiance in UV and shortwave spectral region
- PM10
- Portable aerosol station (Black carbon, PM10 sampling)
- Chemical composition of aerosol and precipitation

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



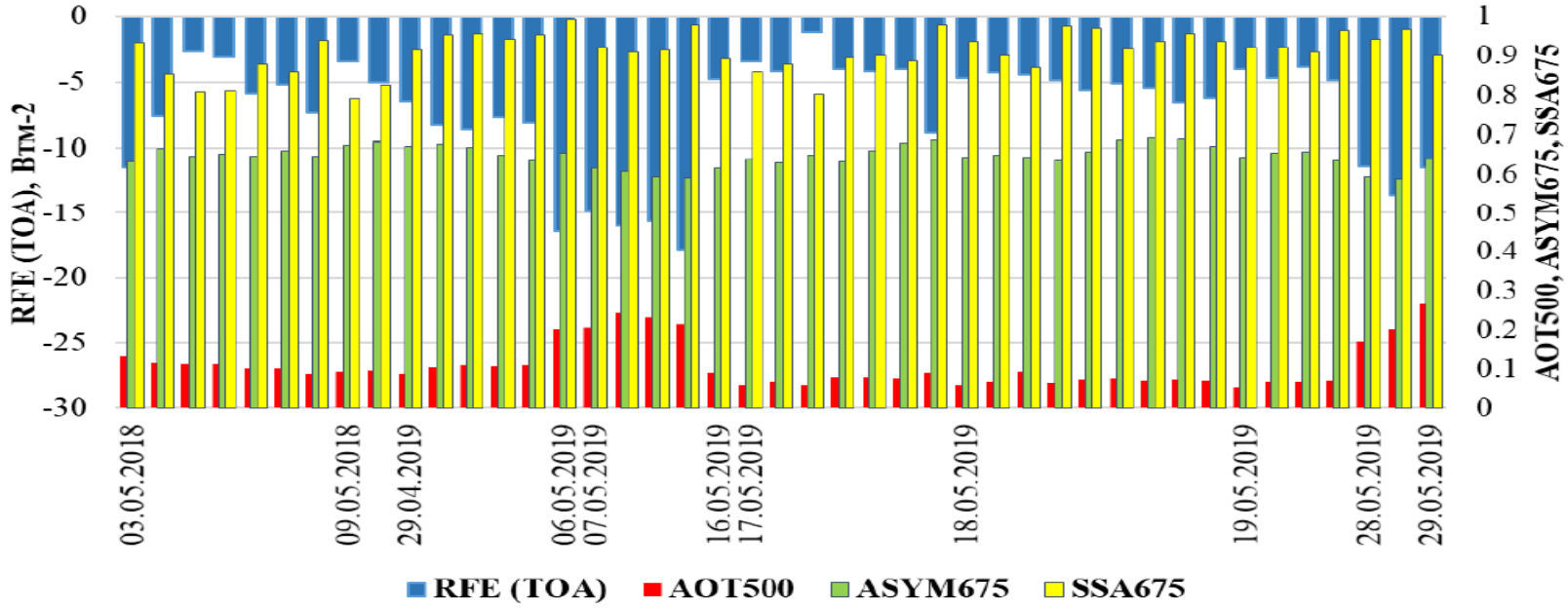
$AOD_{urban} = AOD_{Moscow} - AOD_{Zvenigorod(regional)}$ from the two AERONET sites



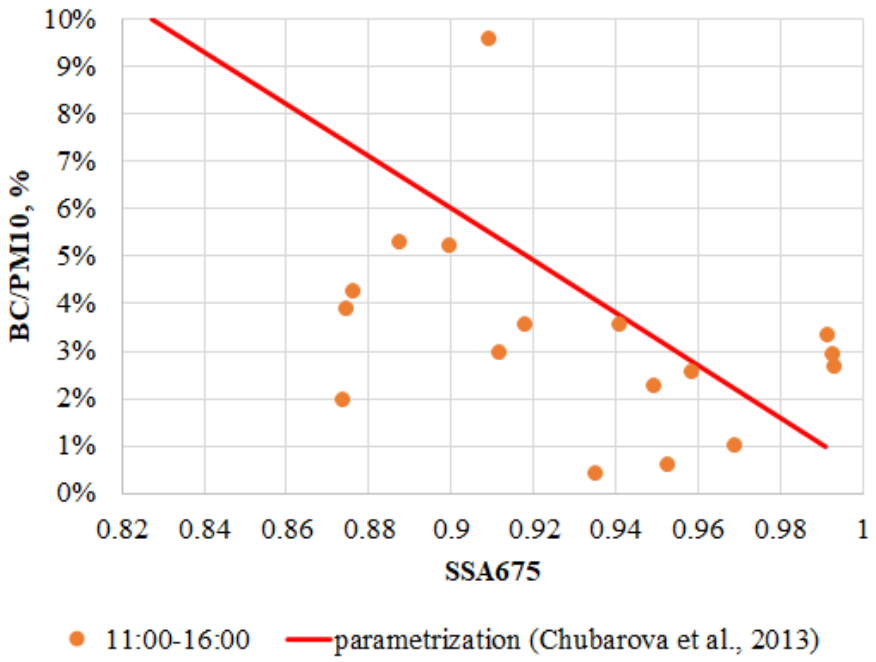
B. Vogel, et al. ACP, 2009
Vil'fand et al., 2017

Radiative effects:

Aerosol radiative forcing effect (RFE) at the top of the atmosphere and aerosol characteristics in clear sky conditions during the experiment.



Single scattering albedo as a function of BC/PM10:



The changing RFE from -18 Wm^2 to -1 Wm^2 are due to both smaller AOD and SSA.

Urban aerosol component: measurements and modelling

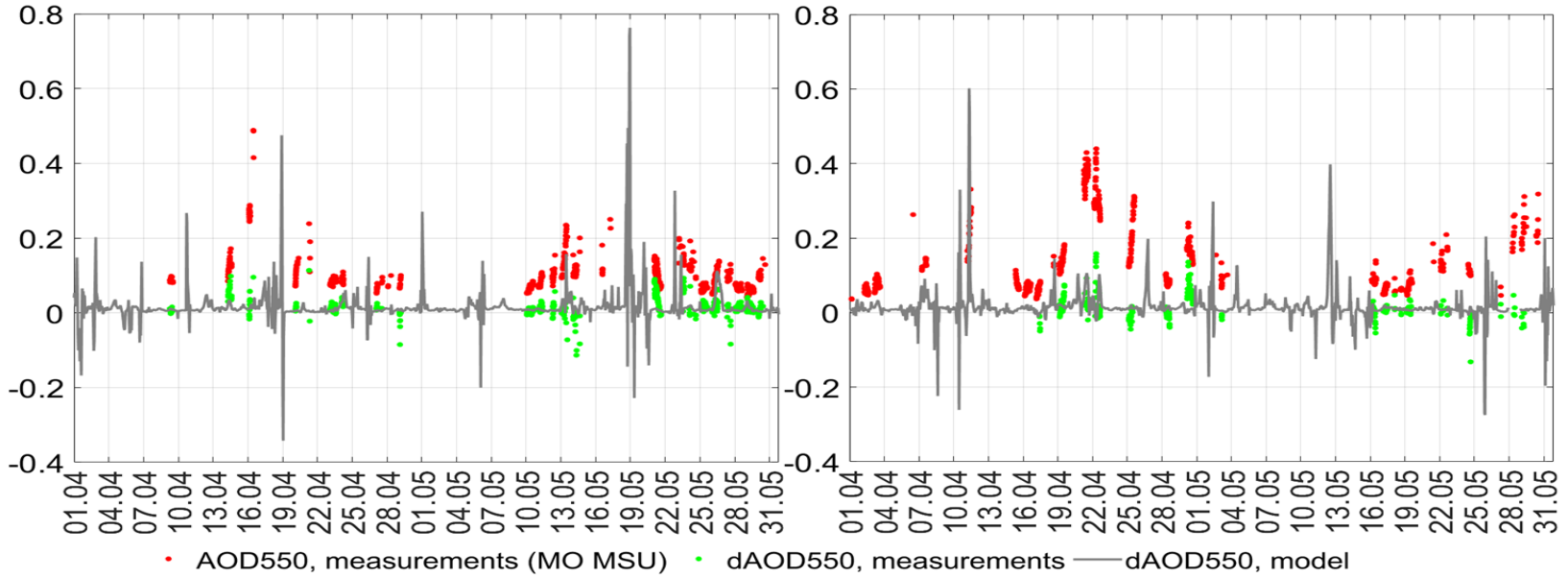
AOD_{urban}=AOD (Moscow) -AOD(Zvenigorod)

Time series of the observed and modelled AOD difference between Moscow and background conditions (measured urban AOD550 shown in Green and model urban AOD550 - in Grey or black dots) and observed total AOD in Moscow (in Red). 2018-2019.

2018 2019

all sky conditions:

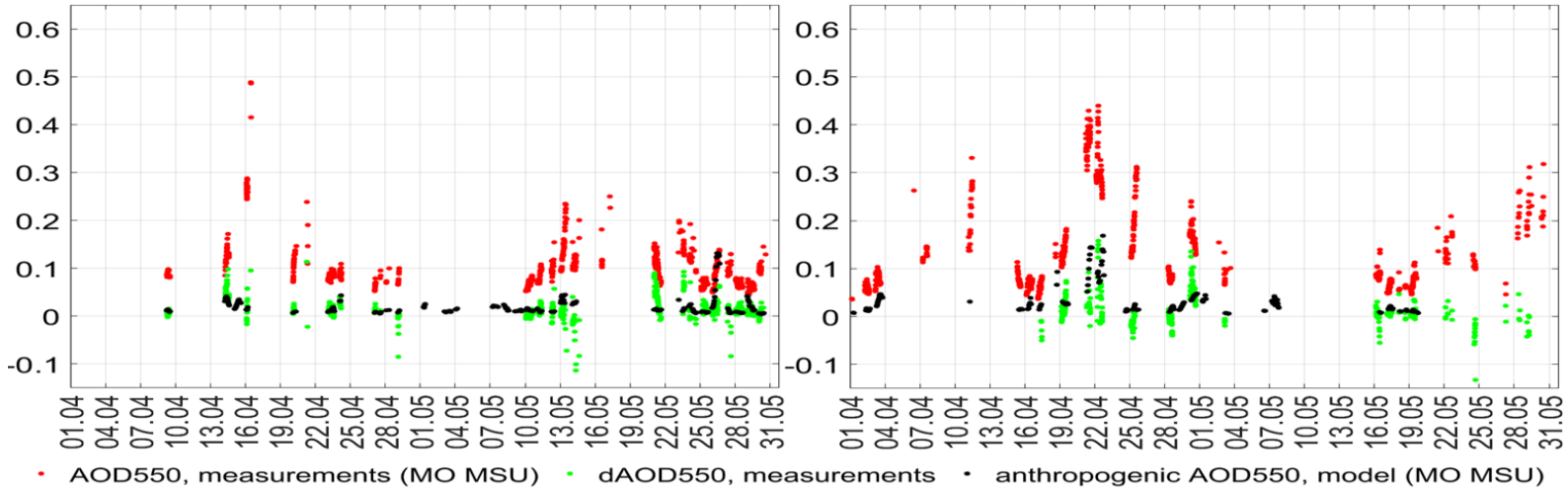
Compare GREY line with Green dots



Too effective urban aerosol generation in cloudy conditions!

quasi-clear sky conditions:

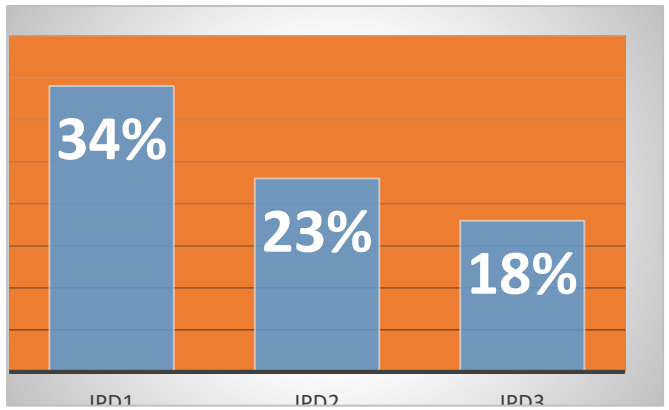
Compare Black dots with Green dots

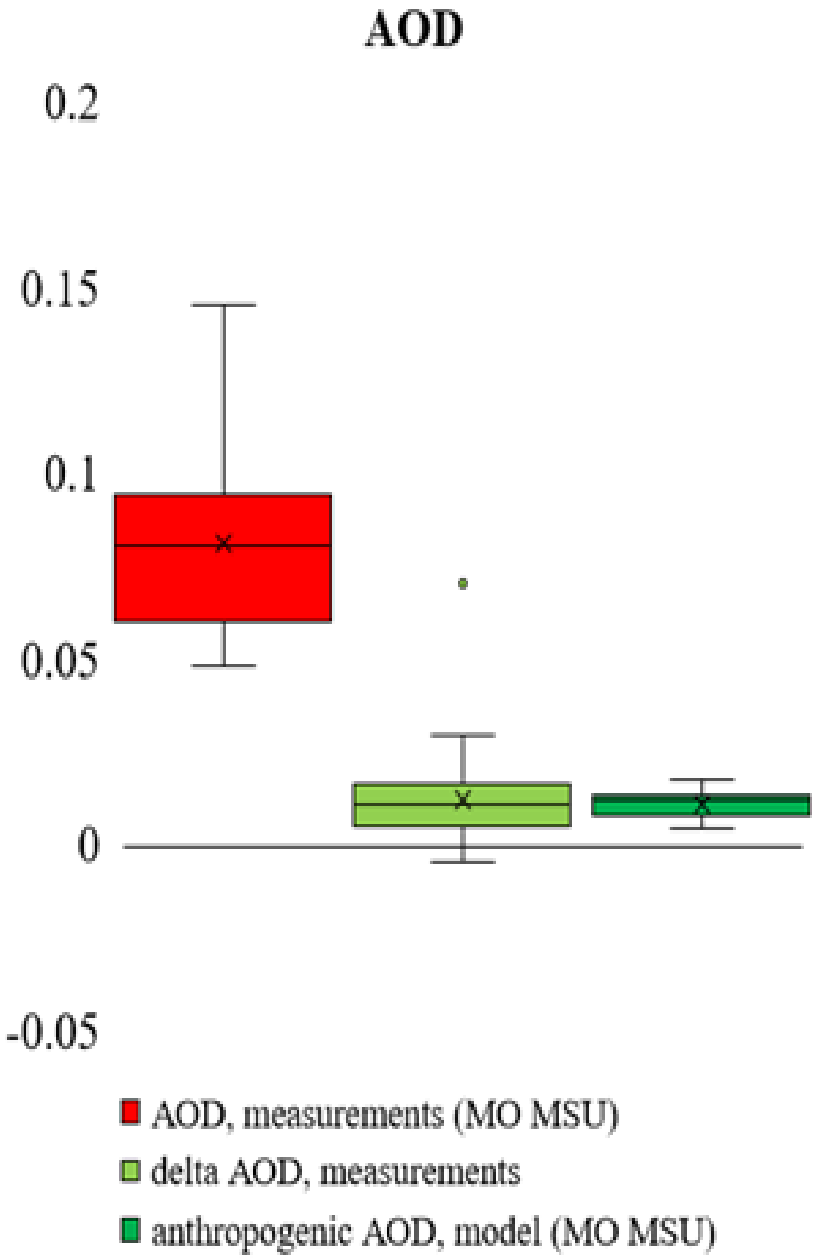


Measured and modelled urban AOD

Main statistics on AOD550 and their urban components in conditions with no advection from Moscow at background Zvenigorod site. Quasi-clear conditions.

Ratio of AOT_{urban} /AOT_{tot} is about 18-34% depending on atmospheric stability conditions

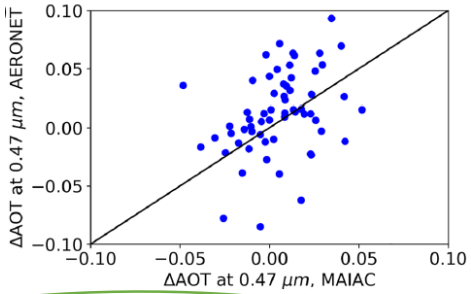




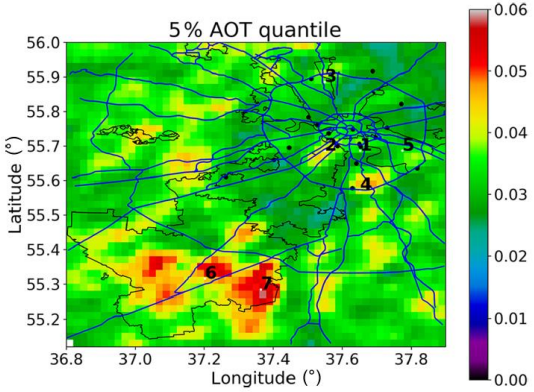
PARAMETER	Median values:
AOD, measurements (MO MSU)	0.080
urban AOD, measurements	0.010
Urban AOD, model	0.012
PM, measurements (MO MSU), mgm-3	0.026
Urban PM, model, mgm-3	0.003
BC, measurements (MO MSU), mkgm-3	1.06
Urban BC, model (MO MSU) mkgm-3	1.94

Satellite AOD_{urban} retrievals:

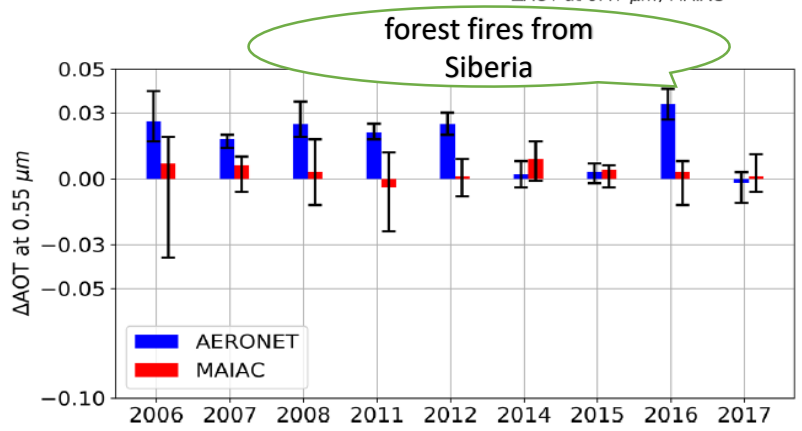
Relationship between AODurb at 0.47 µm according to AERONET (y axis) and MAIAC/MODIS (x axis)



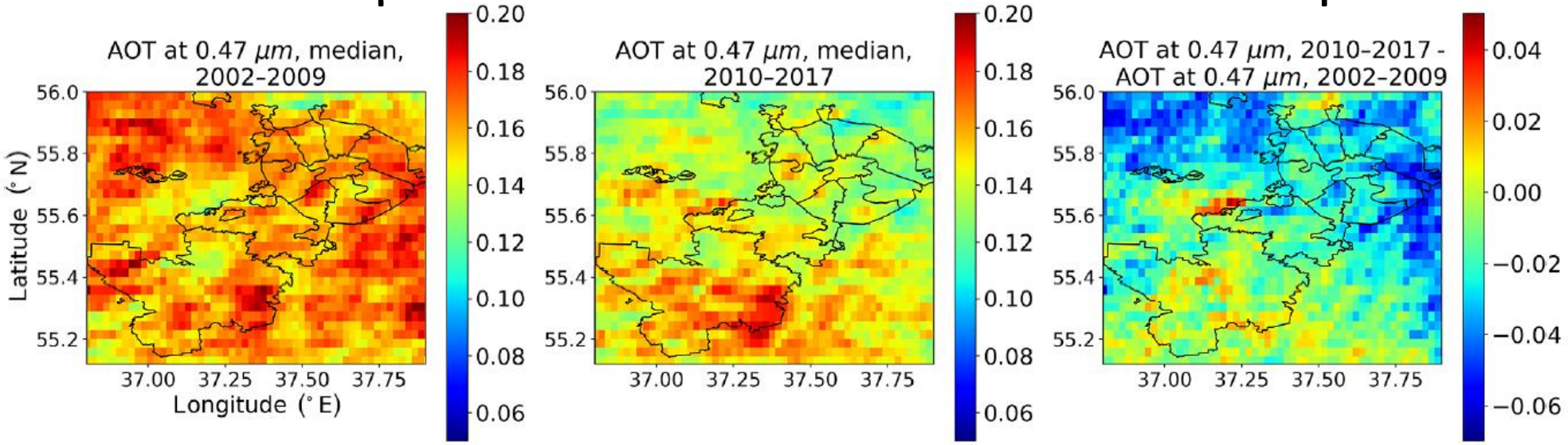
The 5% quantile of AOD at 0.47 µm, 2001–2017. Points on map are local urban pollution sources.



Year-to year variations in AOD_{urban} from AERONET and MAIAC



AOD MAIAC at 0.47 µm median values for the 2002–2009 and 2010–2017 periods and their differences



Zhdanova et al., 2020

The conclusions :

- What is the effect of Moscow megacity on aerosol properties of the atmosphere?

On average, we have AOD_{urban} of about 0.01-0.02, which is about 20% on average of total AOD.

- What is the role of black carbon?

There is a tiny effect on AOD but SSA depends on the BC/PM ratio in well-mixed atmosphere.

- What is the long-term changes in AOD in Moscow?

We have a pronounced decrease in AOD_{urban} for the center of Moscow and increase in AOD_{urban} – over the New Moscow area.

- Do the satellite retrievals provide an accurate estimates of urban aerosol component?

Yes. MAIAC algorithm provides some underestimating of AOD, but the urban effects are of the right order. Locally the urban AOD effects reach 0.05-0.06.

- What conditions are the best for evaluation of urban aerosol effects?

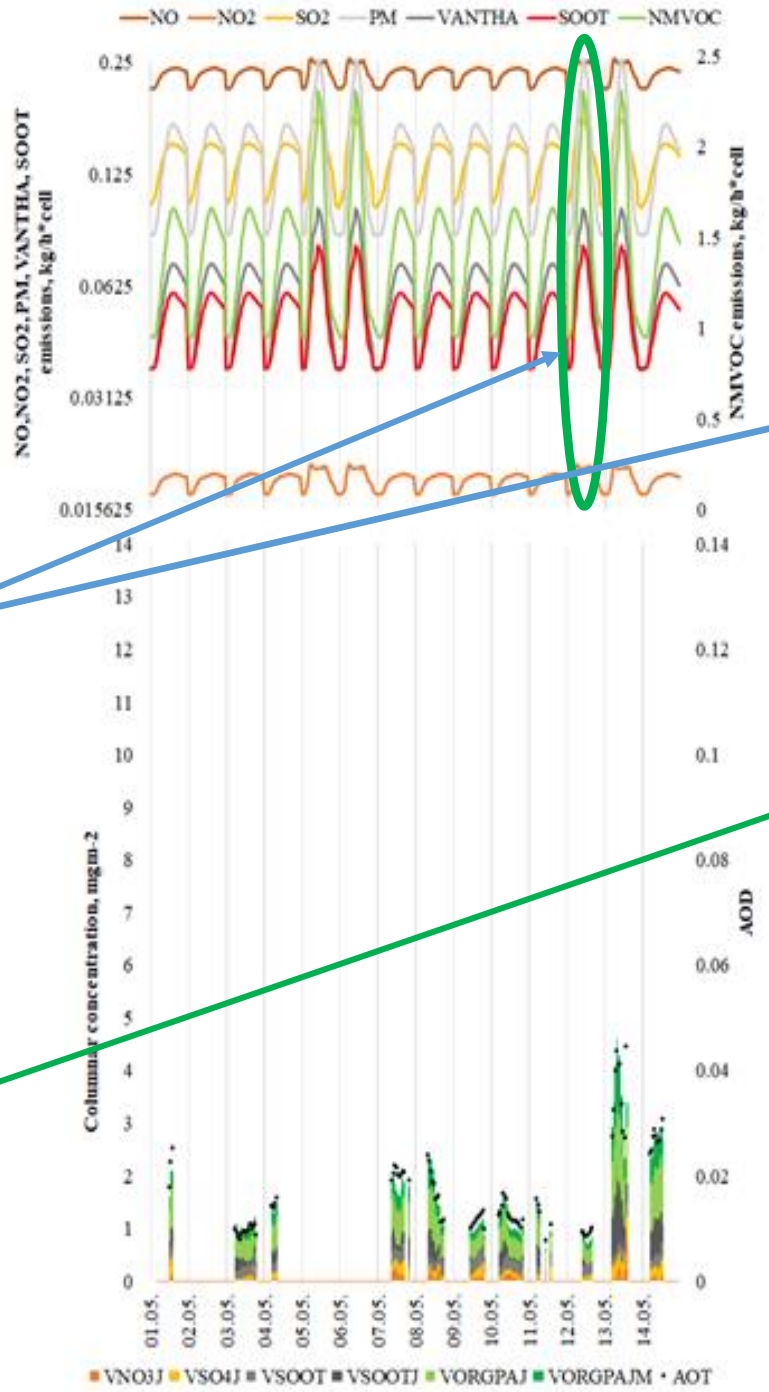
Currently the conditions with quasi-clear skies. In cloudy conditions too much aerosol is generated.

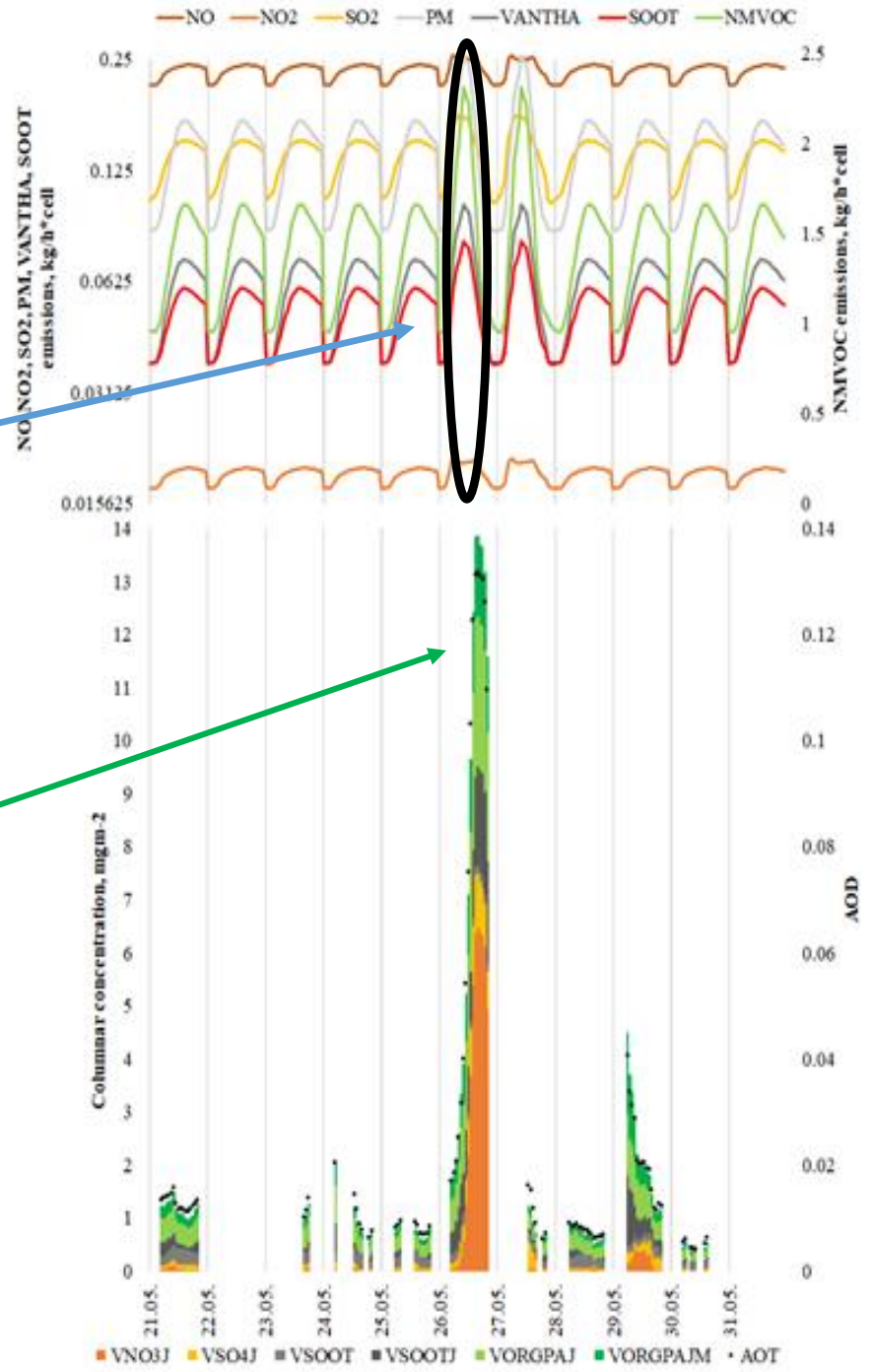
Extra slides for possible needs:

Different aerosol species modelling during the AeroRadCity experiment. Quasi clear conditions.

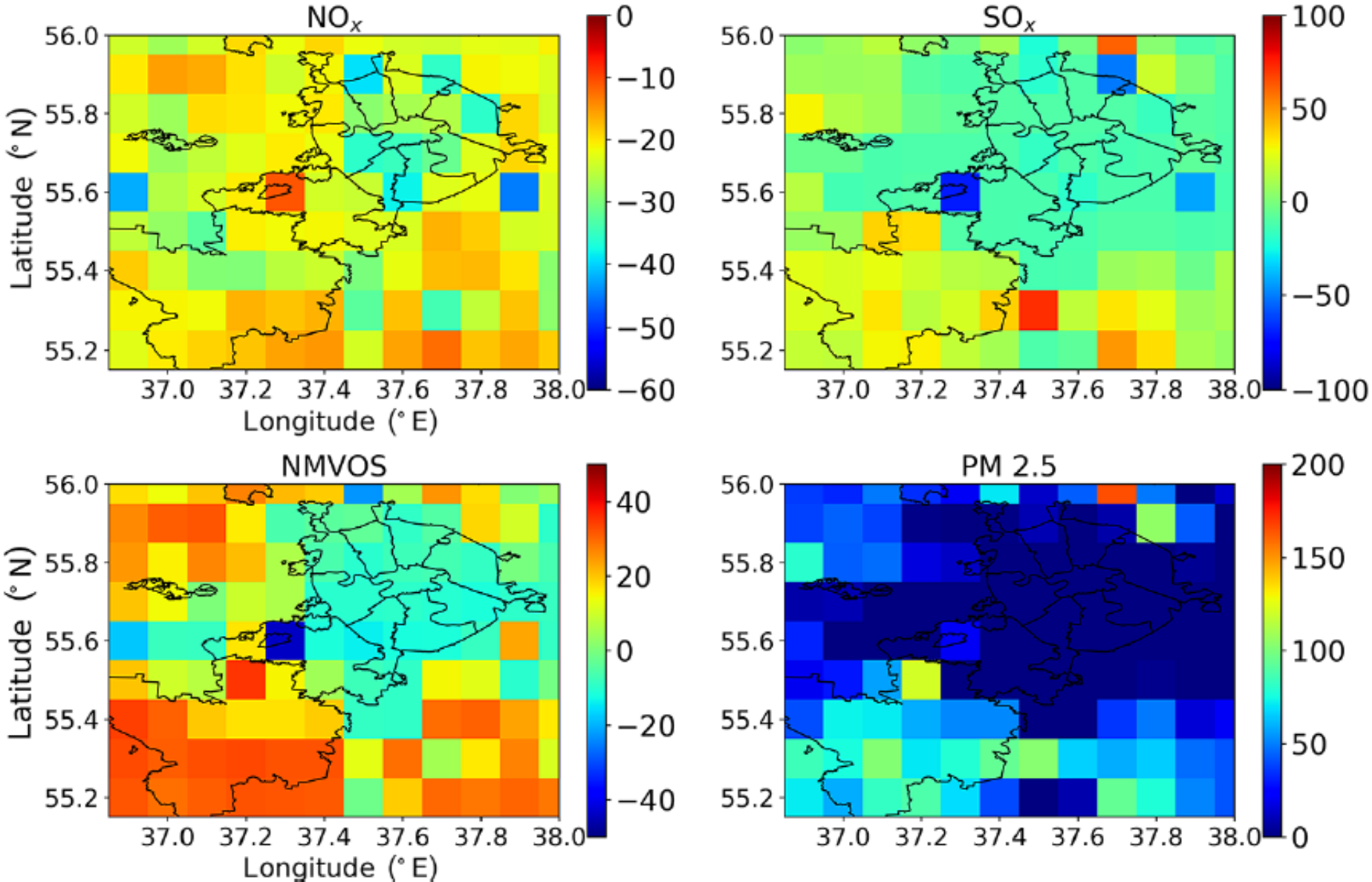
We compared two days with the same level of emissions but different urban aerosol loading

During one clear sky day 26/05/2018 we still have very large unrealistical model urban effect of about AOD urban=0.14.





Ratio of emissions of gases and particle matter averaged over the 2011–2016 period to the emissions averaged over the 2003–2009 period, in percentages. EMEP dataset (http://www.ceip.at/new_emep-grid/01_grid_data).



Diurnal cycle of cloudiness and aerosol optical thickness according to measurements and modelling. 11.04.2019.

typically AOD urban is very small