The study of urban aerosol component in the atmosphere of Moscow megacity based on measurements and COSMO-ART modelling

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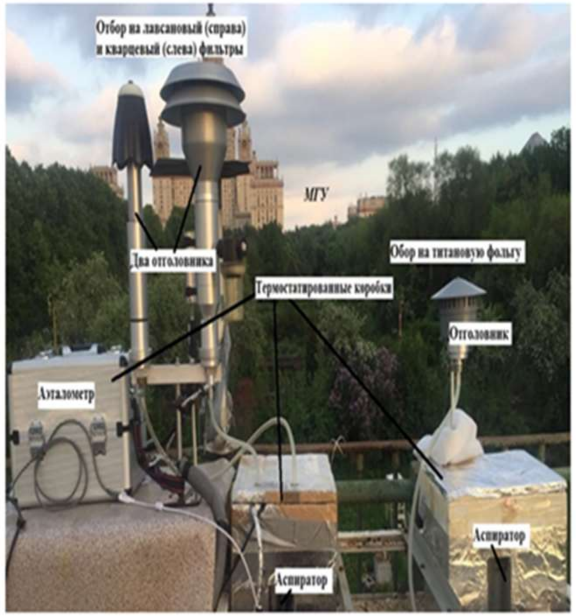
Outline:

- The description of the AeroRadCity experiment;
- Evaluation of typical Moscow aerosol component and its radiative effects;
- Urban aerosol component: measurements and modelling;
- Conclusions.

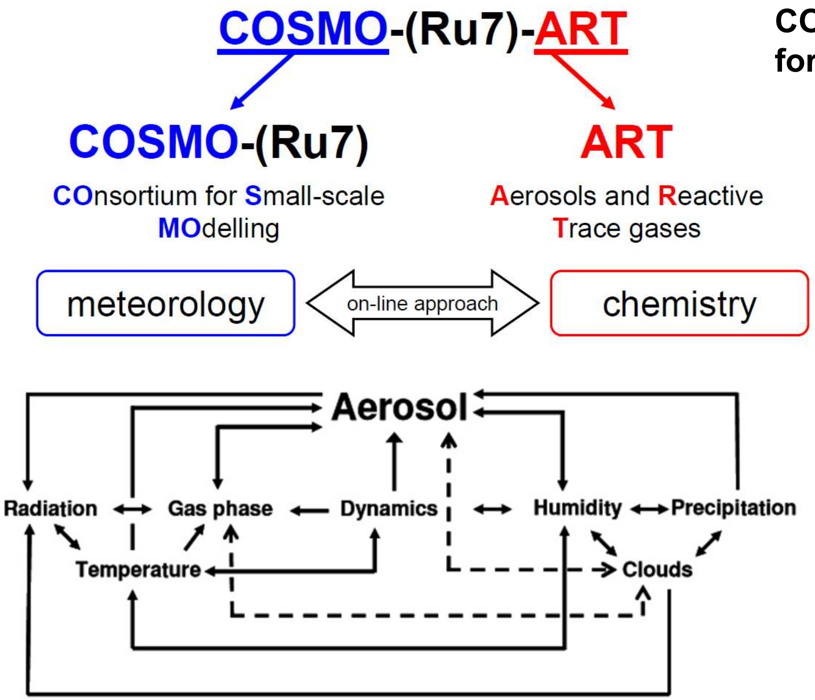
The Moscow AeroRadCity experiment, 2018-2019.

For understanding the physical processes of generating different aerosol types, their relationship with gas-precursors and their consequences for solar irradiance an intensive measurement campaign has been carried out in spring 2018, and 2019 at the Meteorological Observatory of Moscow State University (MO MSU).



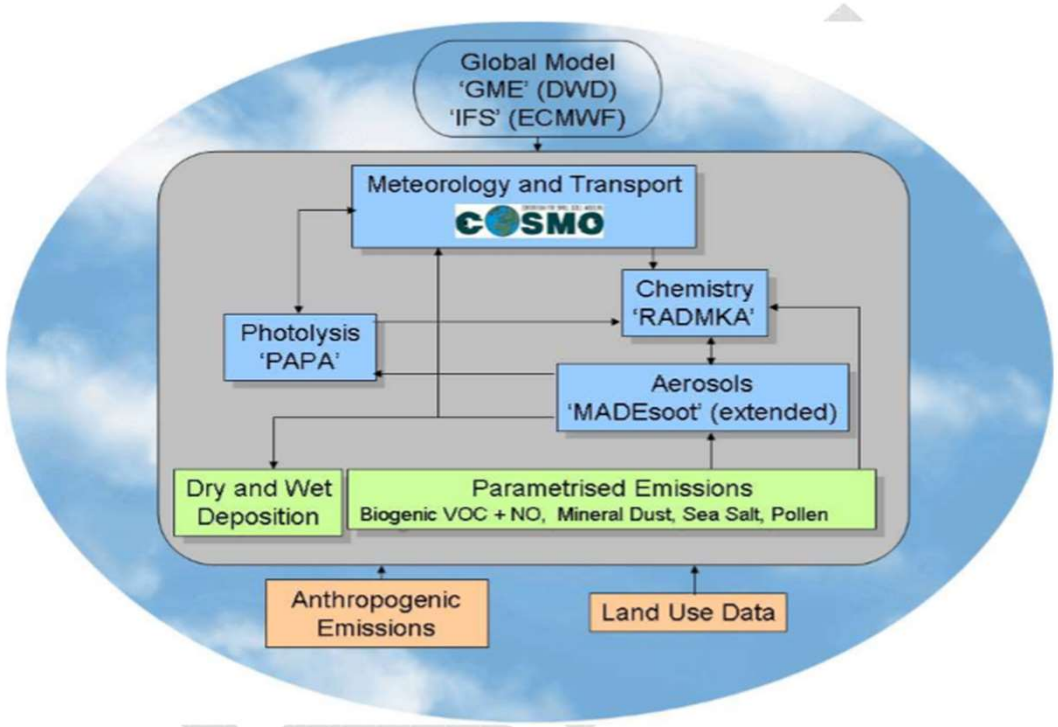
•Data:
•AERONET microphysical and radiative aerosol properties
•Solar irradiance in UV and shortwave spectral region
•PM10
•Portable aerosol station (Black carbon, PM10 sampling)
•Chemical composition of aerosol and precipitation
•Meteorological observations

COSMO-ART model:



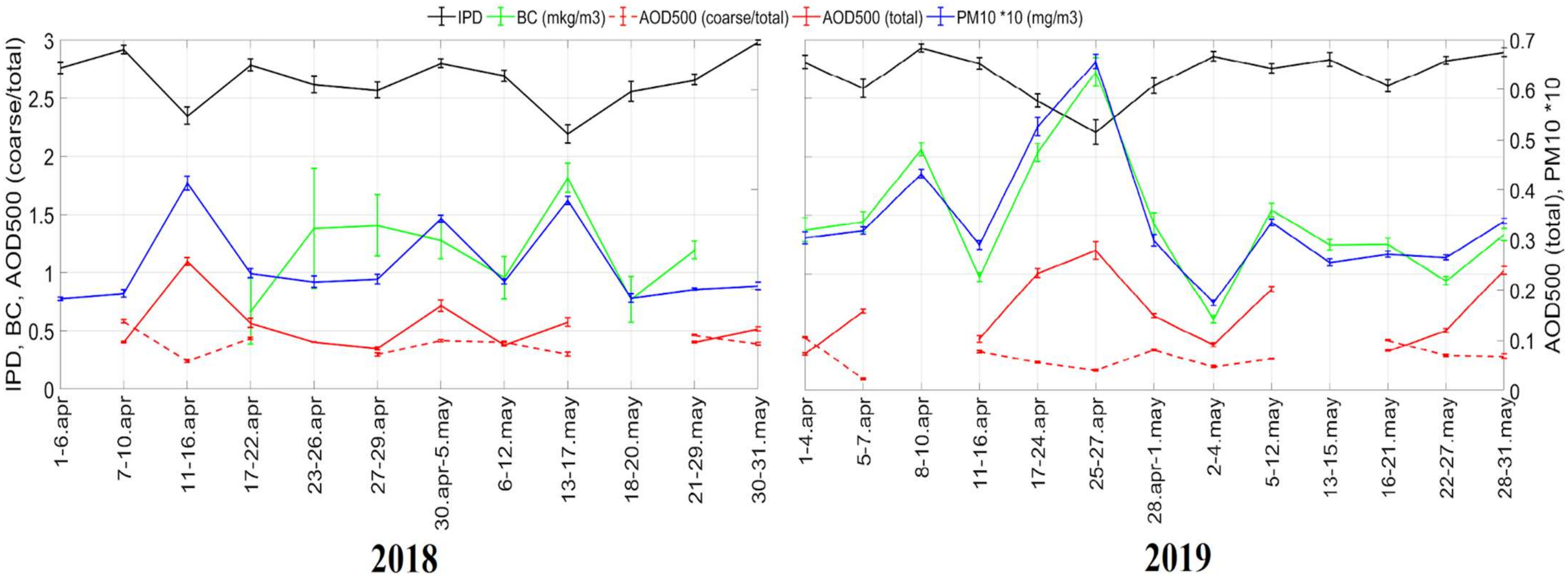
Mode	Chemical composition and mixing state	Standard deviation
if	SO_4^{2-}, NO_3^-, NH_4^+, H_2O, SOA (internally mixed)	1.7
ic	SO_4^{2-}, NO_3^-, NH_4^+, H_2O, SOA, soot (internally mixed)	1.7
jf	SO_4^{2-}, NO_3^-, NH_4^+, H_2O, SOA (internally mixed)	2.0
jc	SO_4^{2-}, NO_3^-, NH_4^+, H_2O, SOA, soot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

COSMO-Ru7-ART is the system for operational pollutant concentration forecast for the Moscow region



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

AERORADCITY experiment: variability of different aerosol characteristics AOD500, AOD coarse/total ratio, PM10(mgm^{-3}), Black Carbon (BC, $mkgm^{-3}$), and Intensity of Particle Dispersion (IPD, in black) for quasi-homogeneous synoptic periods. 2018-2019.



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IPD evaluation according to Kuznetsova et al., 2014

Moscow aerosol is a mixture of Moscow typical aerosol, and biomass burning (BB) aerosol, which significantly affect the aerosol properties.

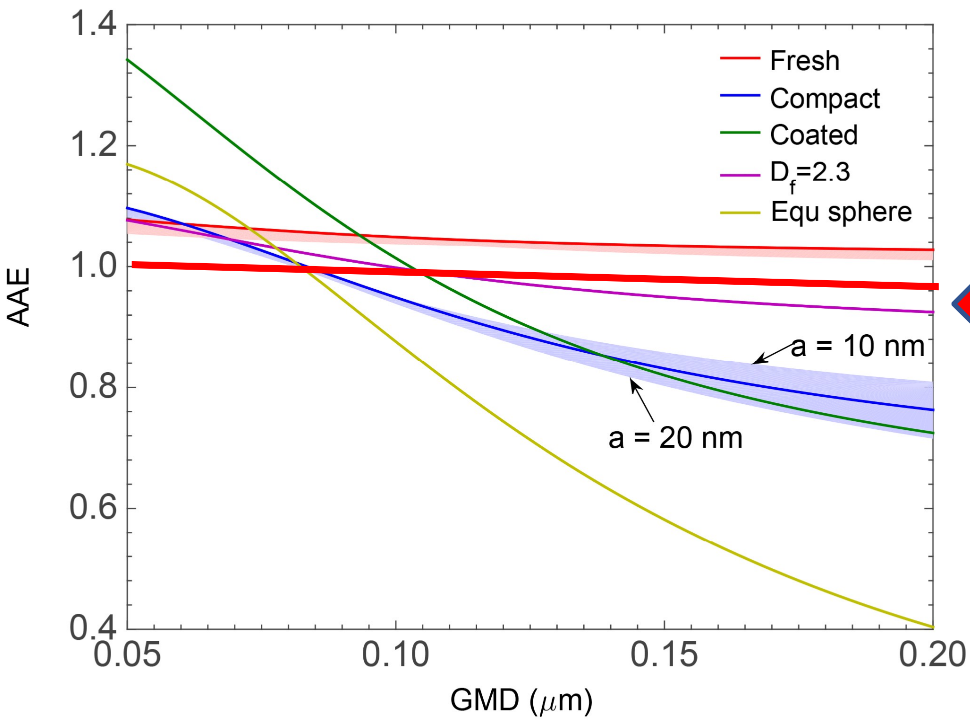
AOD =AOD (typical) +AOD(BB)

Moscow typical aerosol is a mixture of urban aerosol component and regional aerosol component

AOD(typical) =AOD (regional) +AOD(urban)

How to avoid biomass burning (BB) aerosol?

For this purpose we used Angstrom Absorption Extinction parameter (***AAE)*** 440-870nm from CIMEL sun photometer.

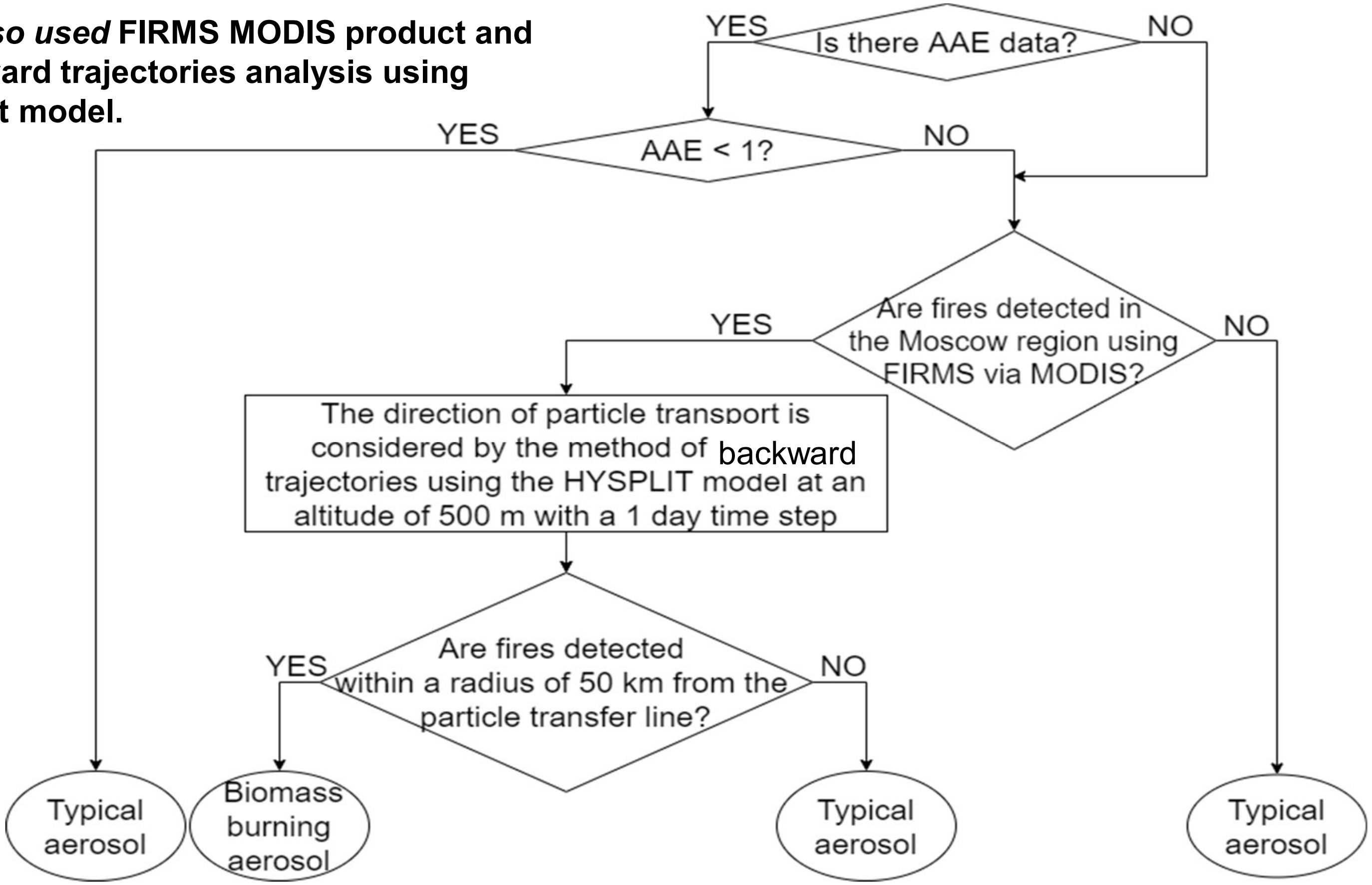


The AAE <1 for the fine mode aerosol can be used as an indicator of urban aerosol particles

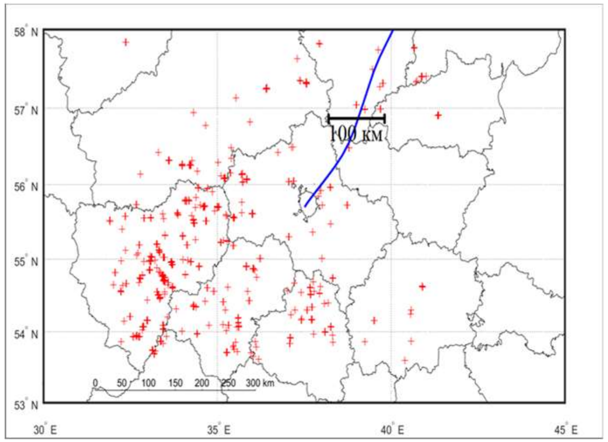
from Liu et al.2018

How to avoid biomass burning (BB) aerosol?

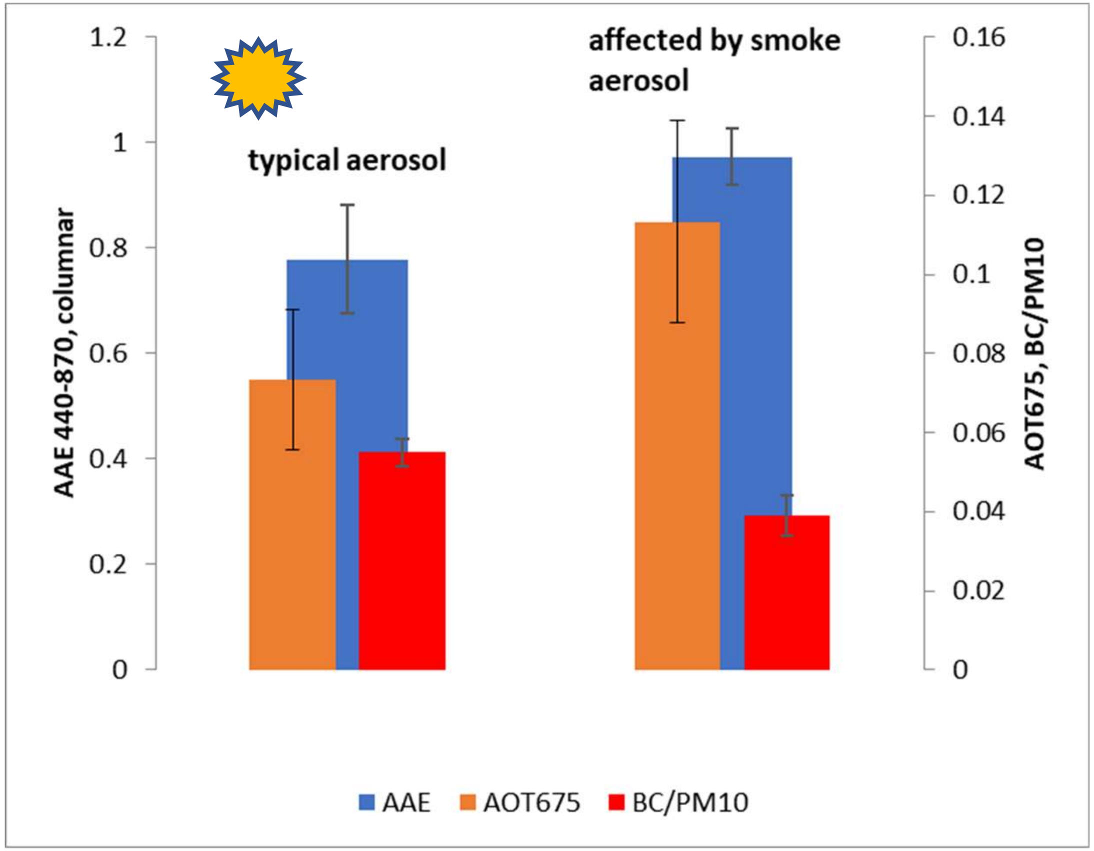
We also used **FIRMS MODIS product and backward trajectories analysis using Hysplit model.**



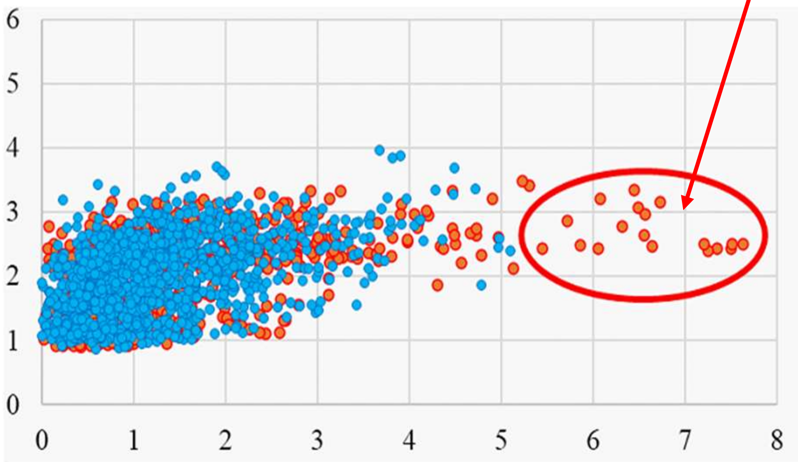
An example on advection of BB aerosol. 29.04.2019



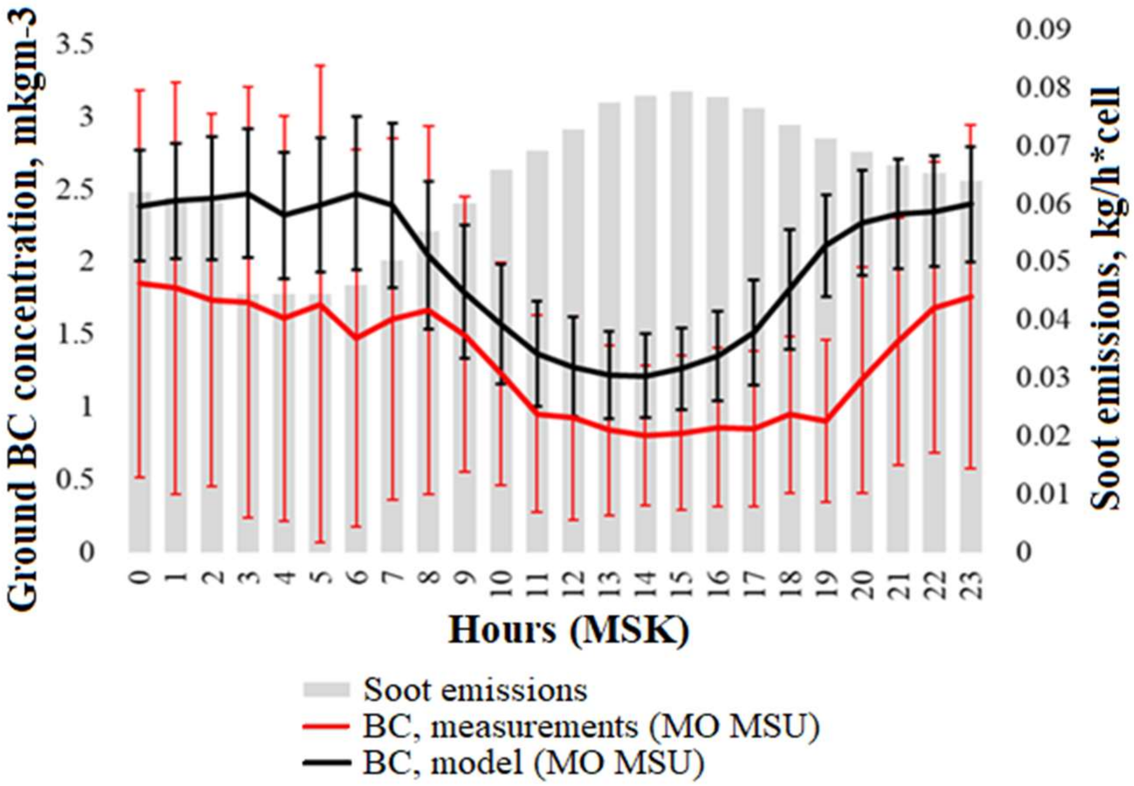
Mean AAE (Angstrom absorption exponent 440-870), AOT675, BC/PM10 ratio for conditions with typical and affected by smoke BB aerosol

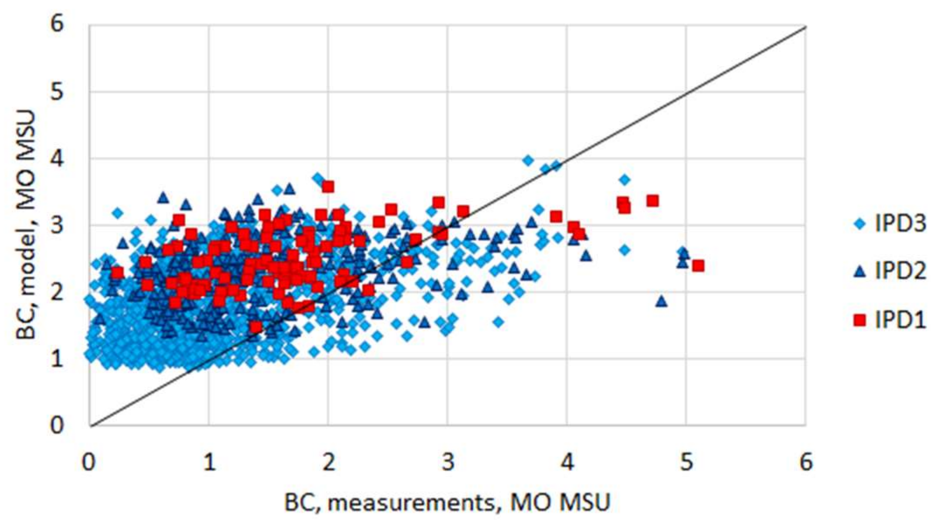


Advection of BC from the biomass burning sources



Black carbon aerosol: comparisons between model and measurements. Cases with no BB aerosol effects.



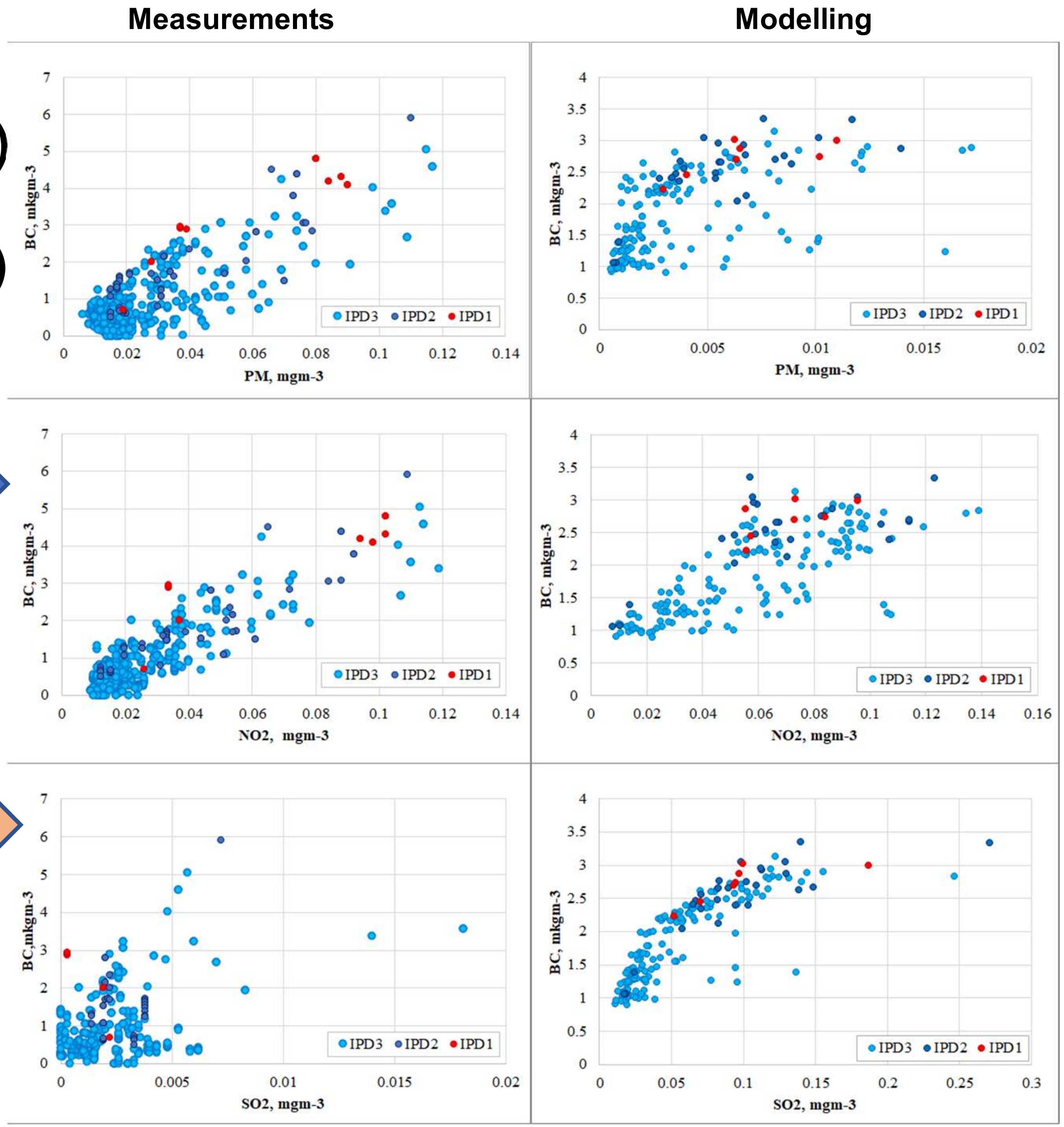


IPD1 – very stable atmosphere
IPD2 - intermediate
IPD3 – unstable atmosphere

Measured and modelled mass concentrations of Black carbon (BC) versus PM, NO_2 and SO_2 at different Intensity of Particle Dispersion (IPD) levels. No BB aerosol effects.

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.



BC = 35.986 * PM10 + 0.1114	(R = 0.63)
BC = 67.19 * NO + 0.7301	(R = 0.69)
BC = 35.495 * NO_2 + 0.1745	(R = 0.7)

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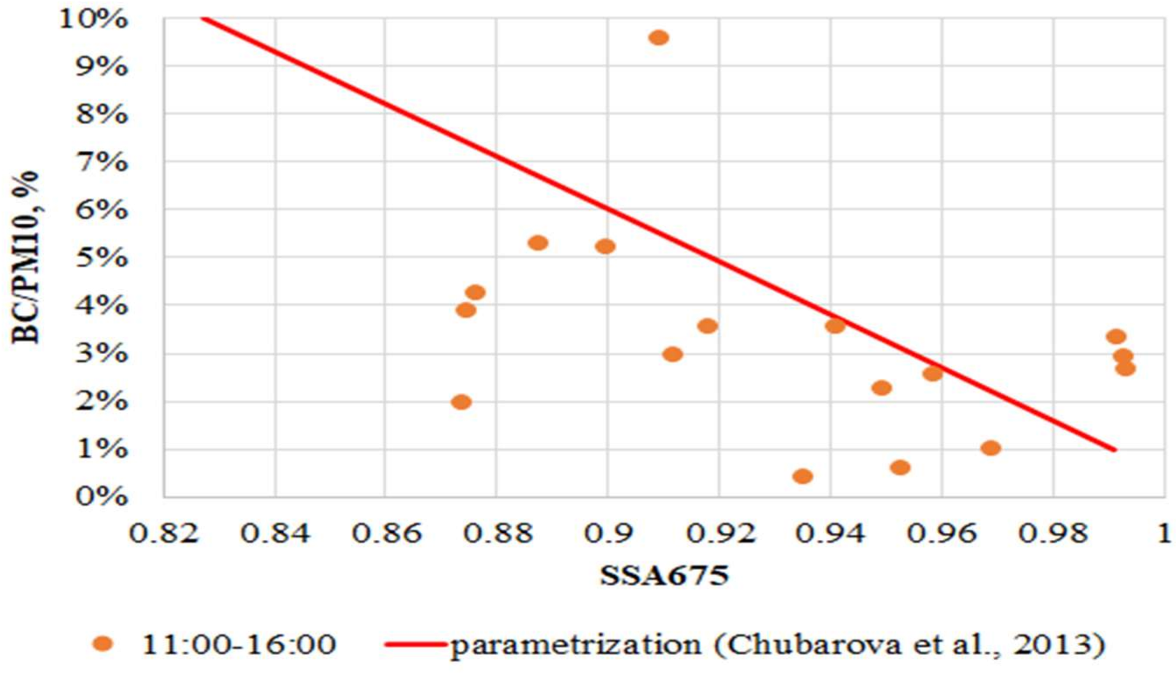
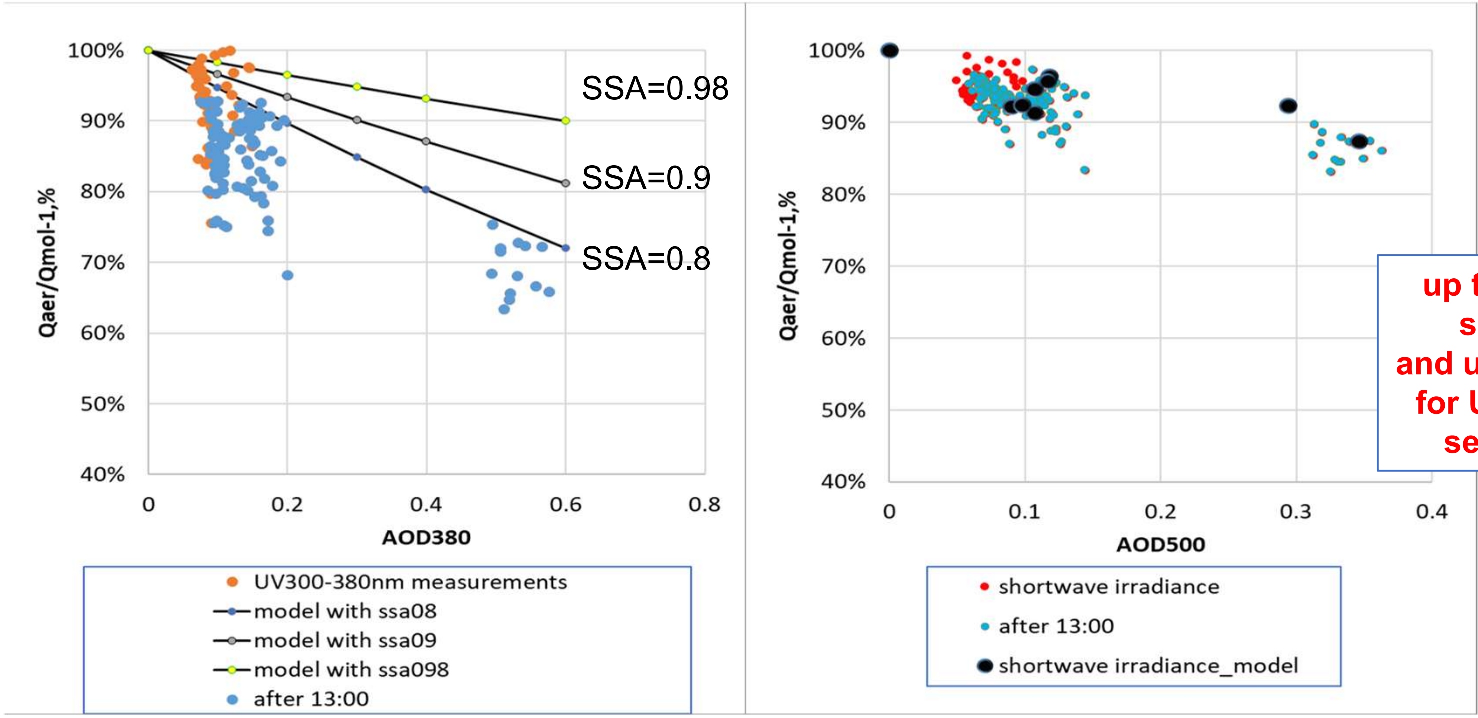
Single scattering albedo as a function of BC/PM10 can be evaluated only in well mixing conditions during daytime 11:00-16:00



Radiative effects:

The dependence of normalized on molecular atmosphere UV (left) and shortwave (right) irradiance on aerosol optical depth according to observations and radiative transfer DISORT model. Clear sky conditions.



up to 15% attenuation for shortwave irradiance and up to 30-40% attenuation for UV radiation during the second part of the day!

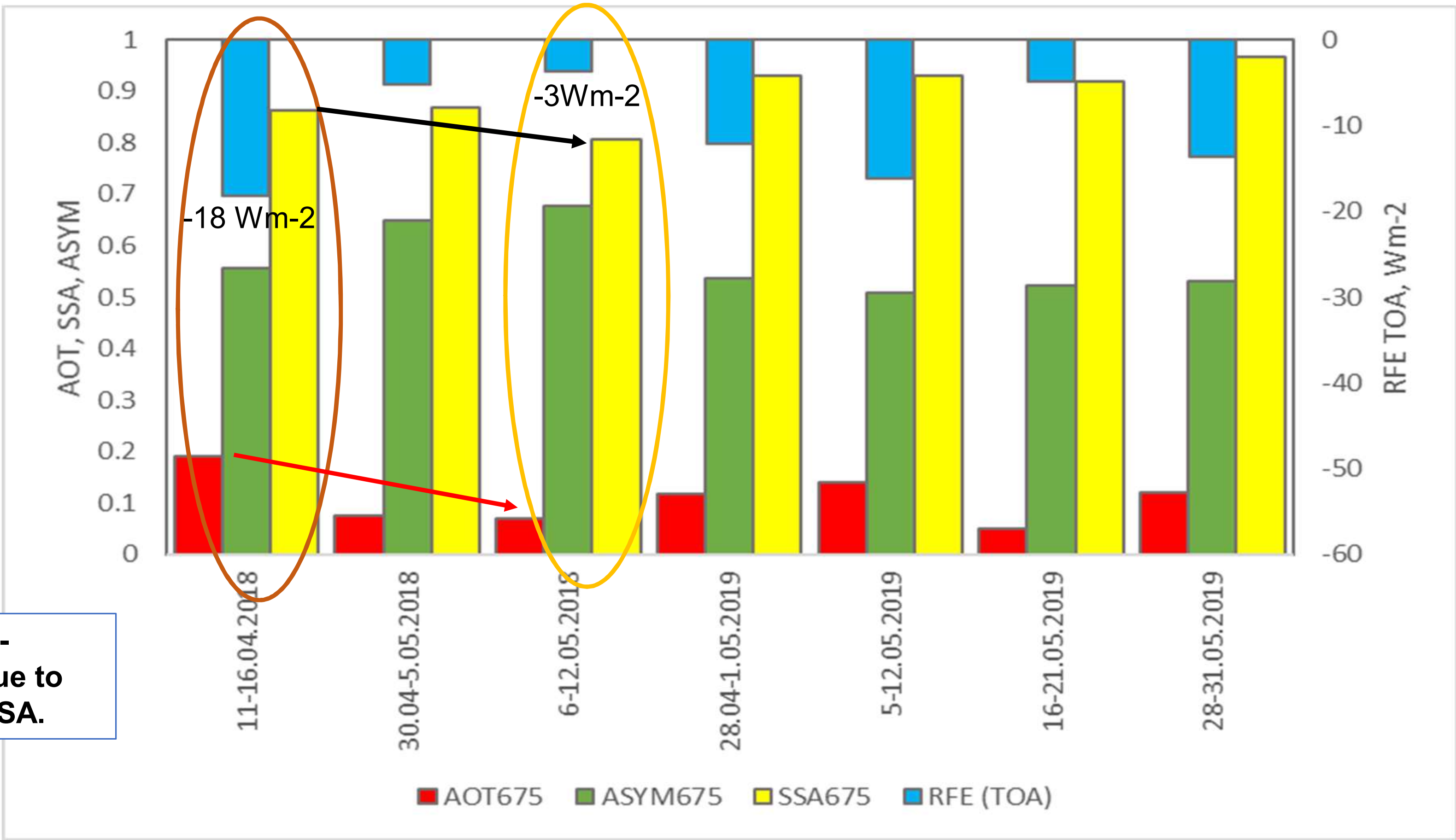
Radiative effects:

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

ASYM- aerosol asymmetry factor,

SSA – single scattering albedo,

AOD675 – aerosol optical thickness at 675nm



The changing RFE from -18Wm-2 to -3Wm2 are due to both smaller AOD and SSA.

- **Urban aerosol component: measurements and modelling**

Urban aerosol component in Moscow as seen from the difference in aerosol between Moscow MSU MO and background conditions

AOD(typical) =AOD (regional) +AOD(urban)

We attribute the difference in AOD between Moscow and Zvenigorod to the measured urban AOD.

Zvenigorod (ZNS at the IAP RAS)

Moscow (MO MSU)

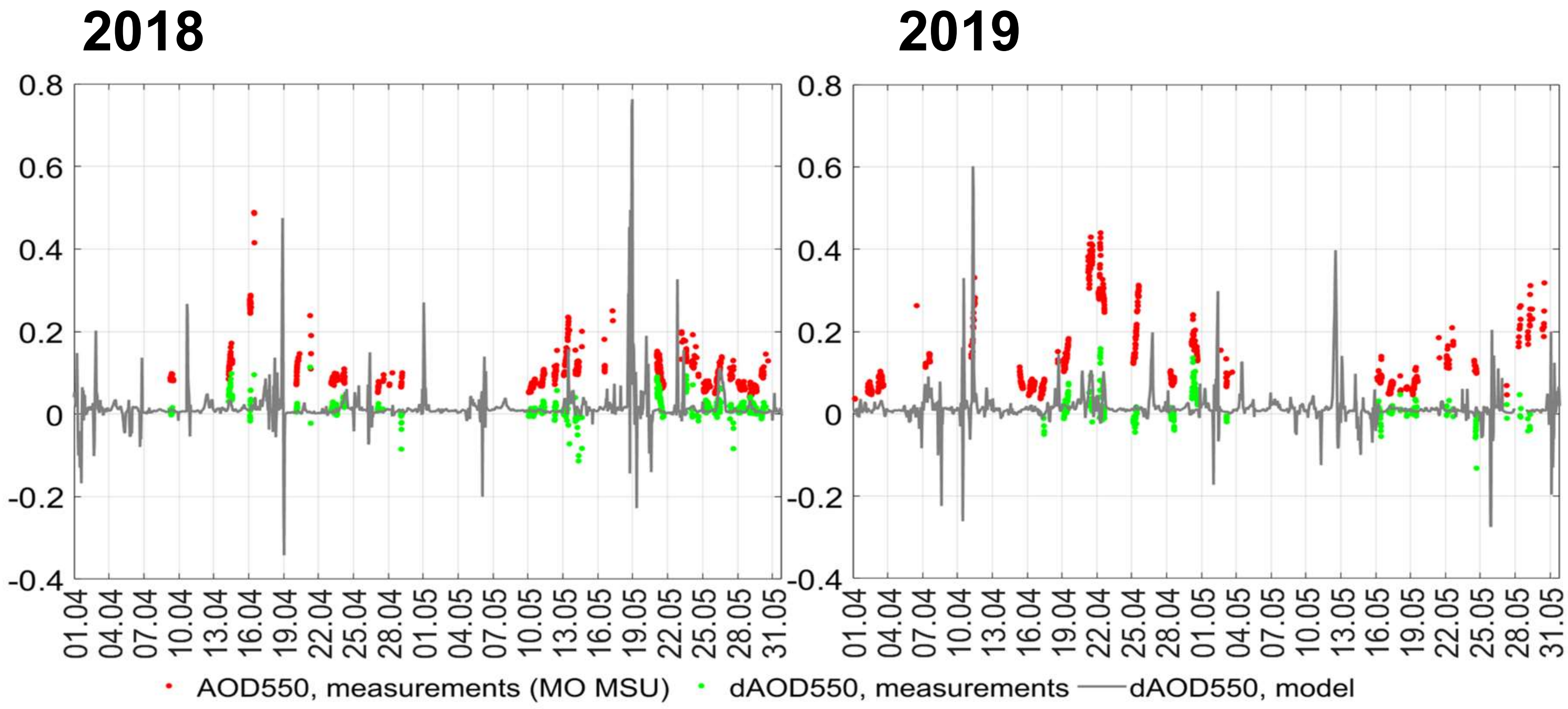
- **55 km distance;**
- **upwind location of the background site;**
- **same calibration;**
- **only 3 minute of time difference.**

- **Urban aerosol component: measurements and modelling**

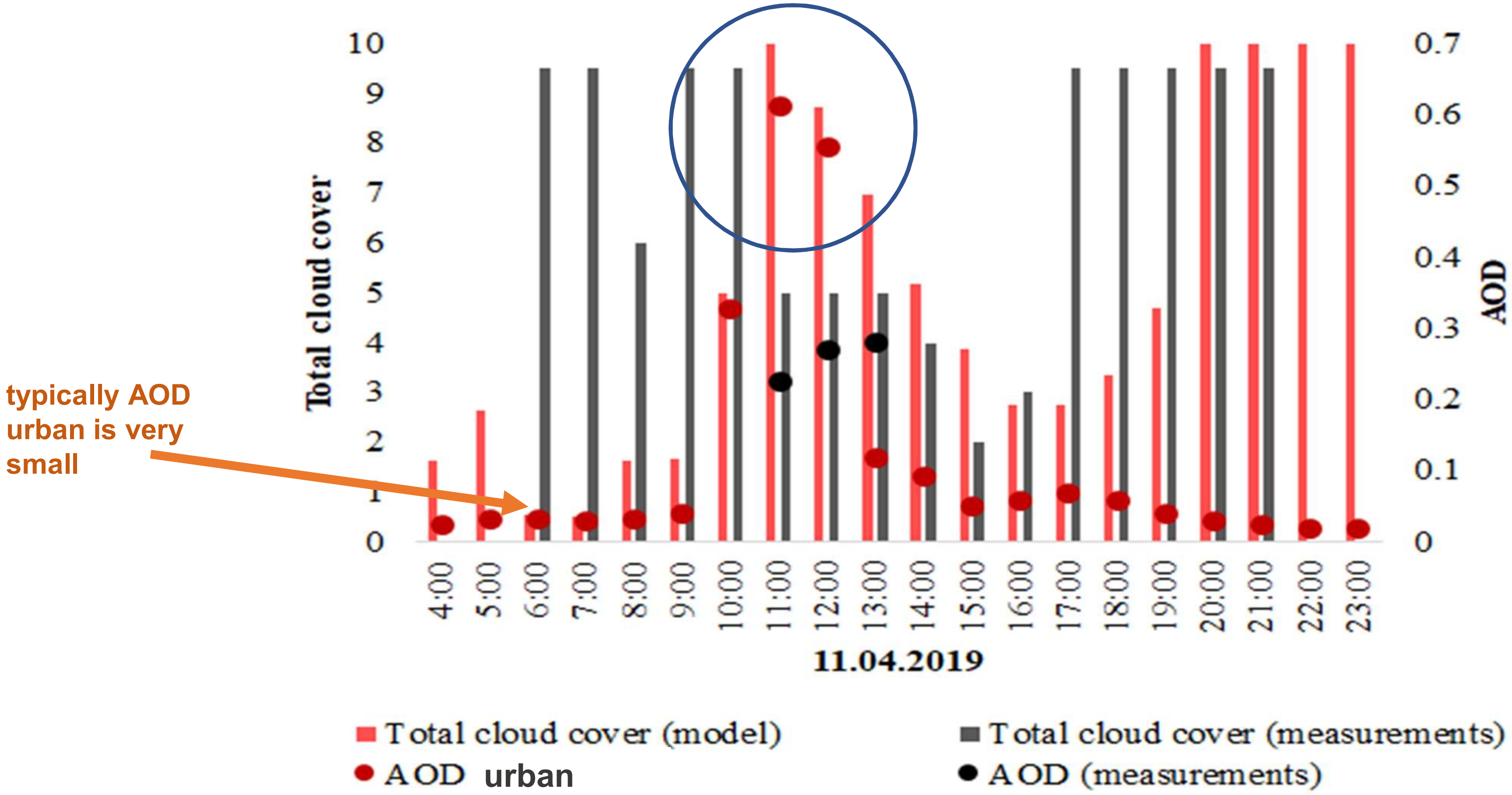
Time series of the observed and modelled AOD difference between Moscow and background conditions (measured urban AOD550 shown in Green and model urban AOD550 - in Grey) and observed total AOD in Moscow (in Red). 2018-2019. <u>All sky conditions.</u>

Too effective urban aerosol generation!

Compare GREY line with Green dots

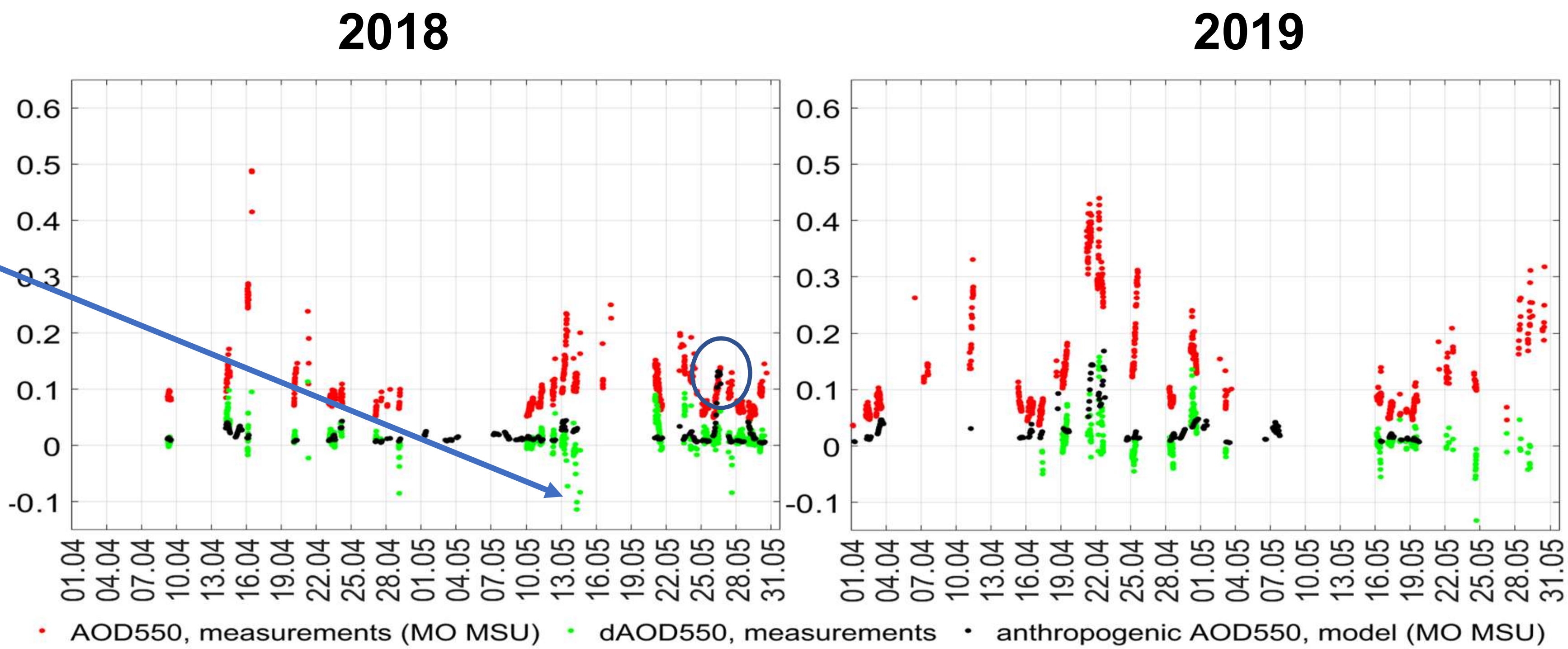


Diurnal cycle of cloudiness and aerosol optical thickness according to measurements and modelling. 11.04.2019.



Time series of modelled urban AOD (in Black), measured urban AOD (in Green) and measured total AOD500 in Moscow (in Red). 2018-2019. Quasi-clear sky conditions.

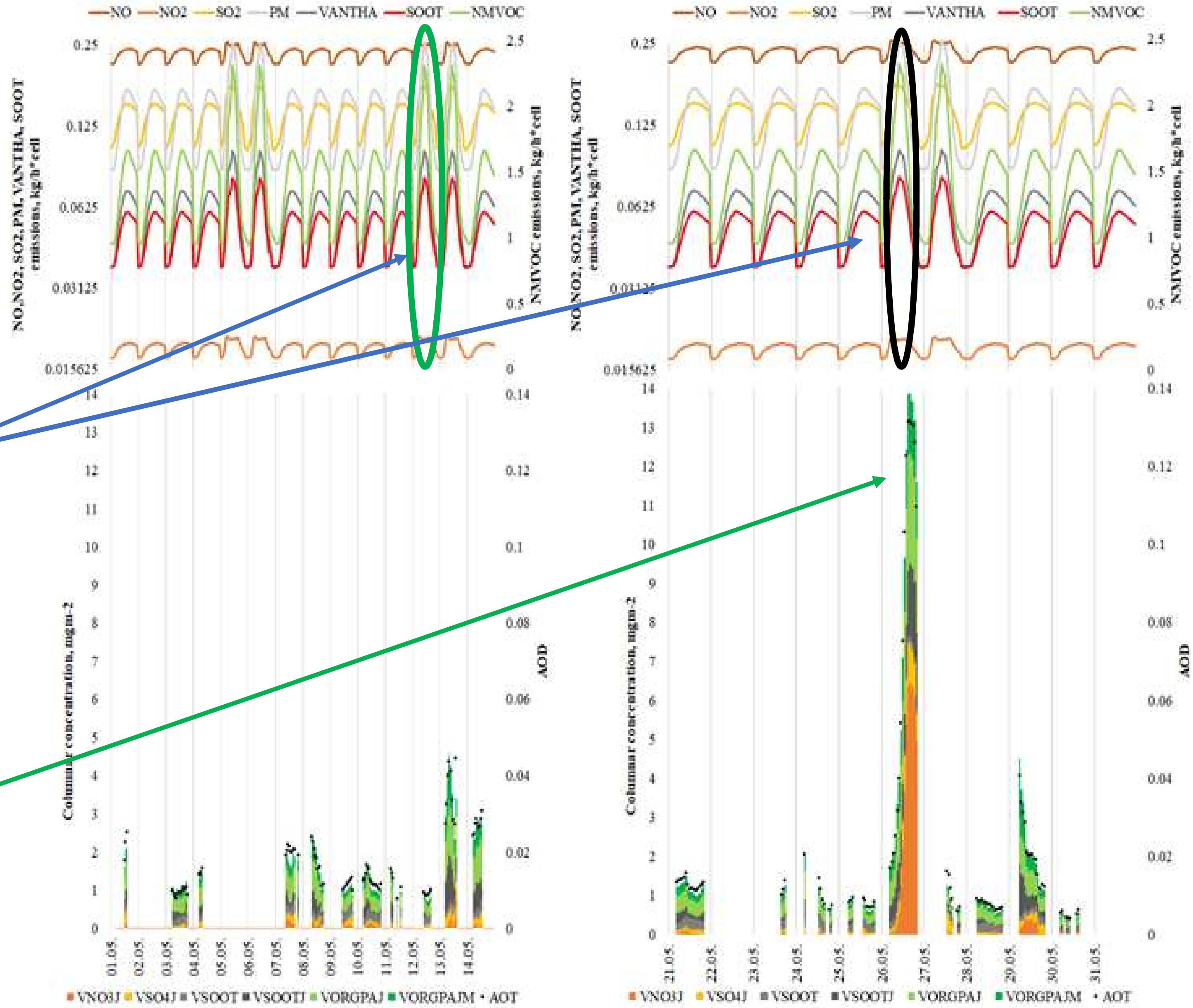
Negative observed dAOD – mainly due to advection from Moscow to Zvenigorod. Removed from the statistics.



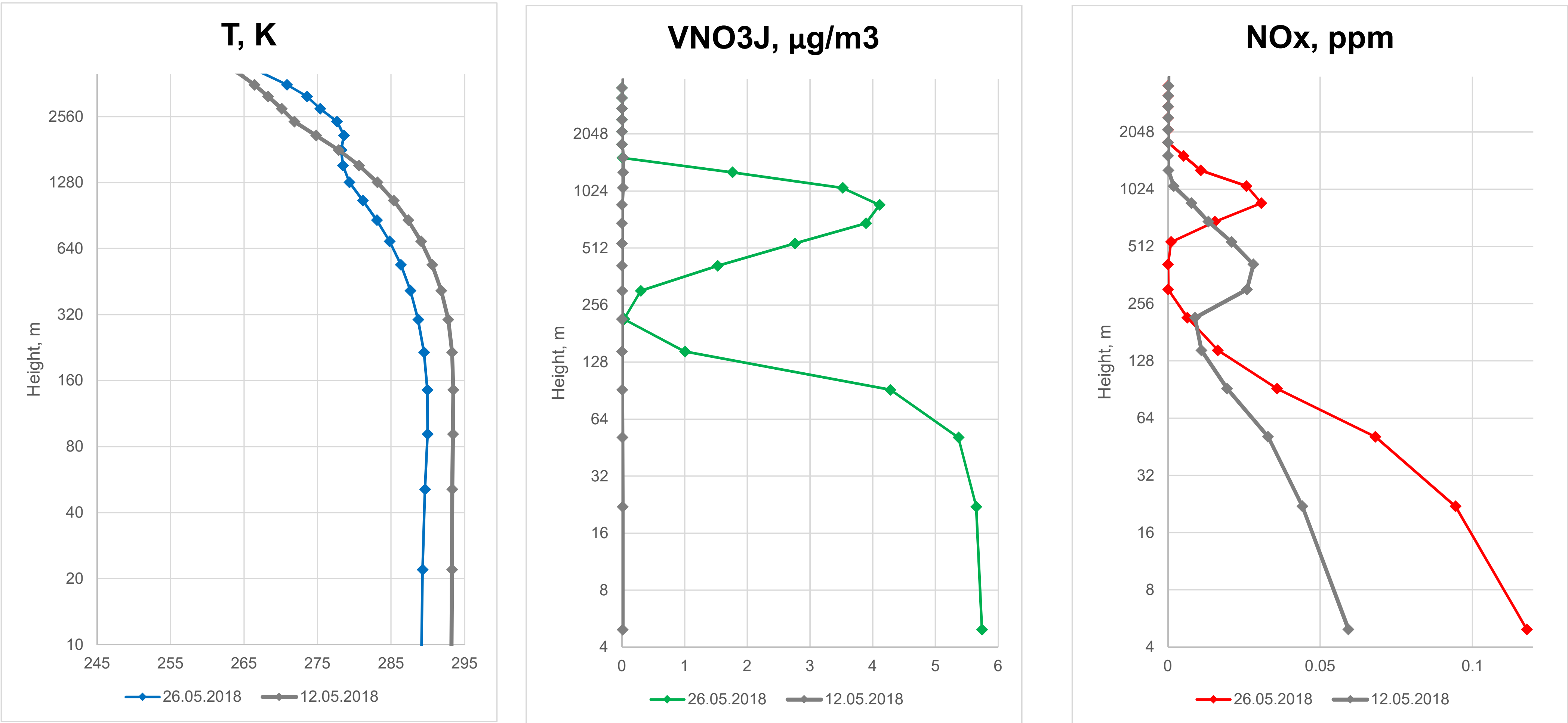
Different aerosol species modelling during the AeroRadCity experiment. Quasi clear conditions.

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

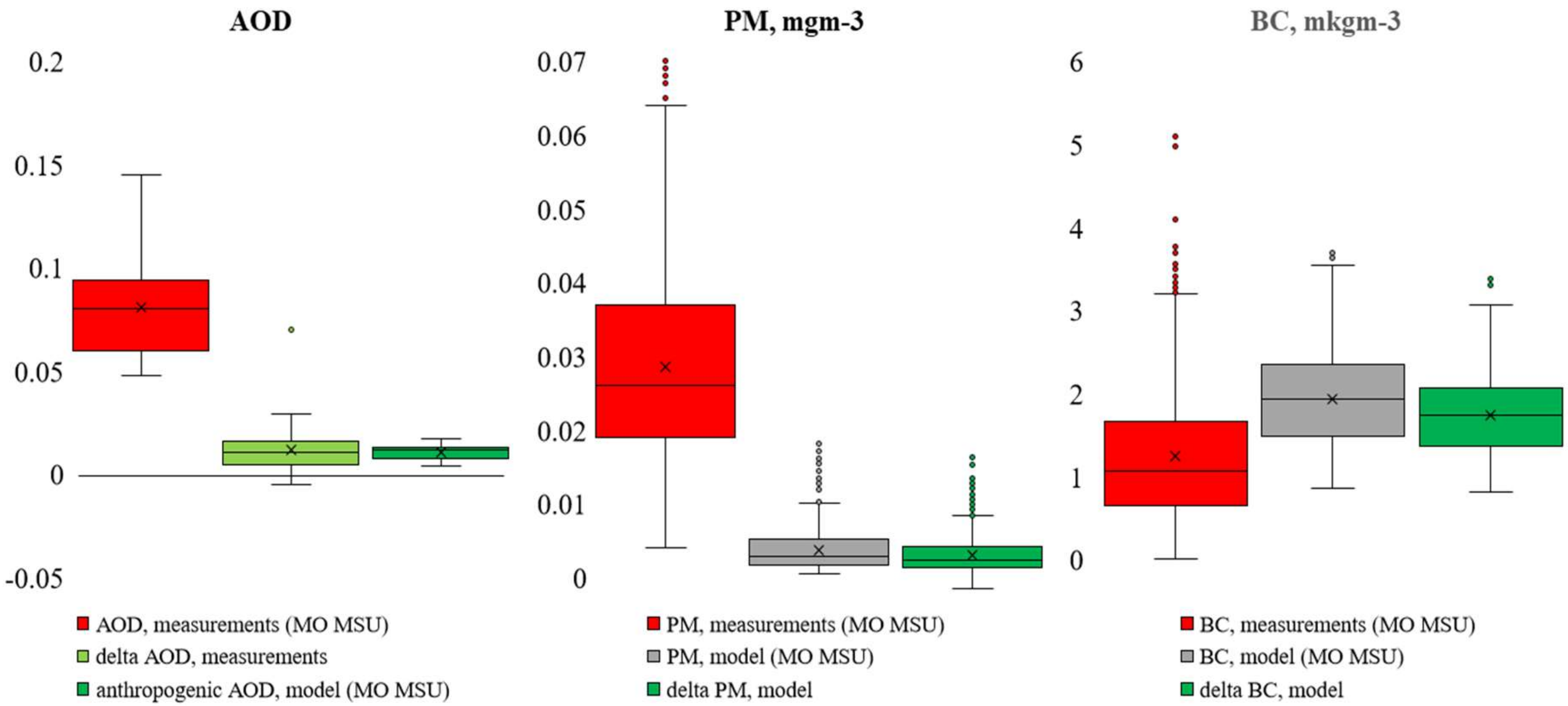
During one clear sky day 26/05/2018 we still have very large unrealistical model urban effect of about AOD urban=0.14.



Temperature and nitrate aerosol component and NOx vertical profiles.
The same emissions. 12/05/2018 and 26/05/2018

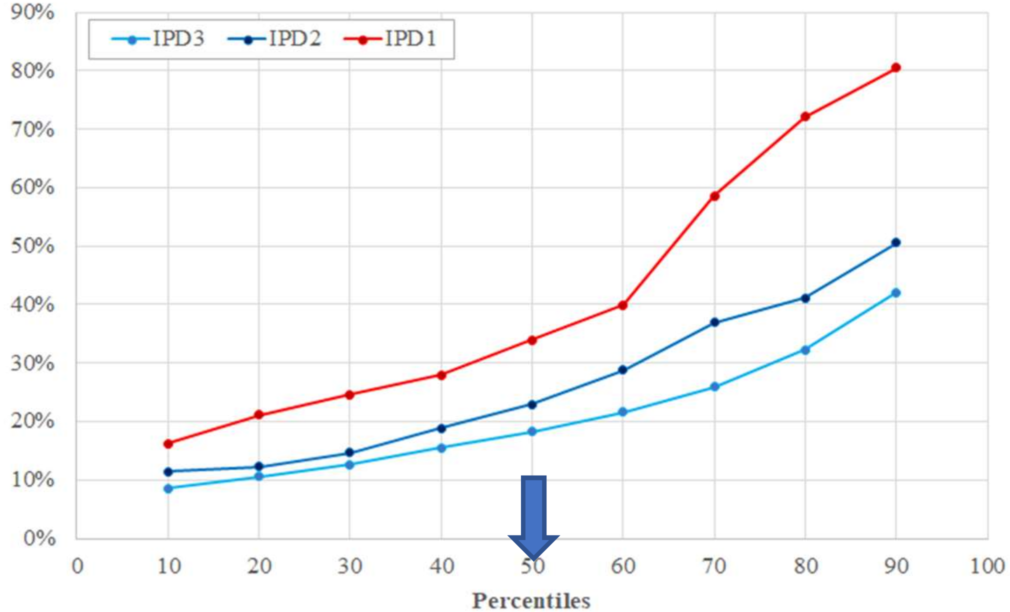


Main statistics on AOD550, PM and BC and their urban components in conditions with no advection from Moscow at background Zvenigorod site. Quasi-clear conditions.



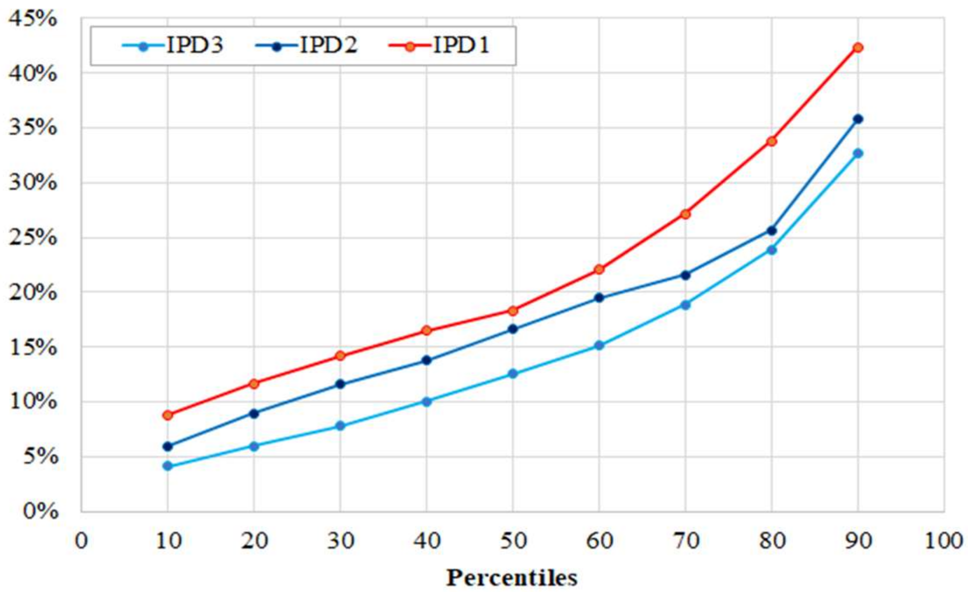
PARAMETER	Median values:
AOD, measurements (MO MSU)	0.080
urban AOD, measurements	0.010
Urban AOD, model	0.012
PM, measurements (MO MSU), mgm-3	0.026
Urban PM, model, mgm-3	0.003
BC, measurements (MO MSU), mkgm-3	1.06
Urban BC, model (MO MSU) mkgm-3	1.94

Urban AOD fraction (model estimates) in total observed AOD (different percentiles) in conditions with various Intensity of Particle Dispersion (IPD).



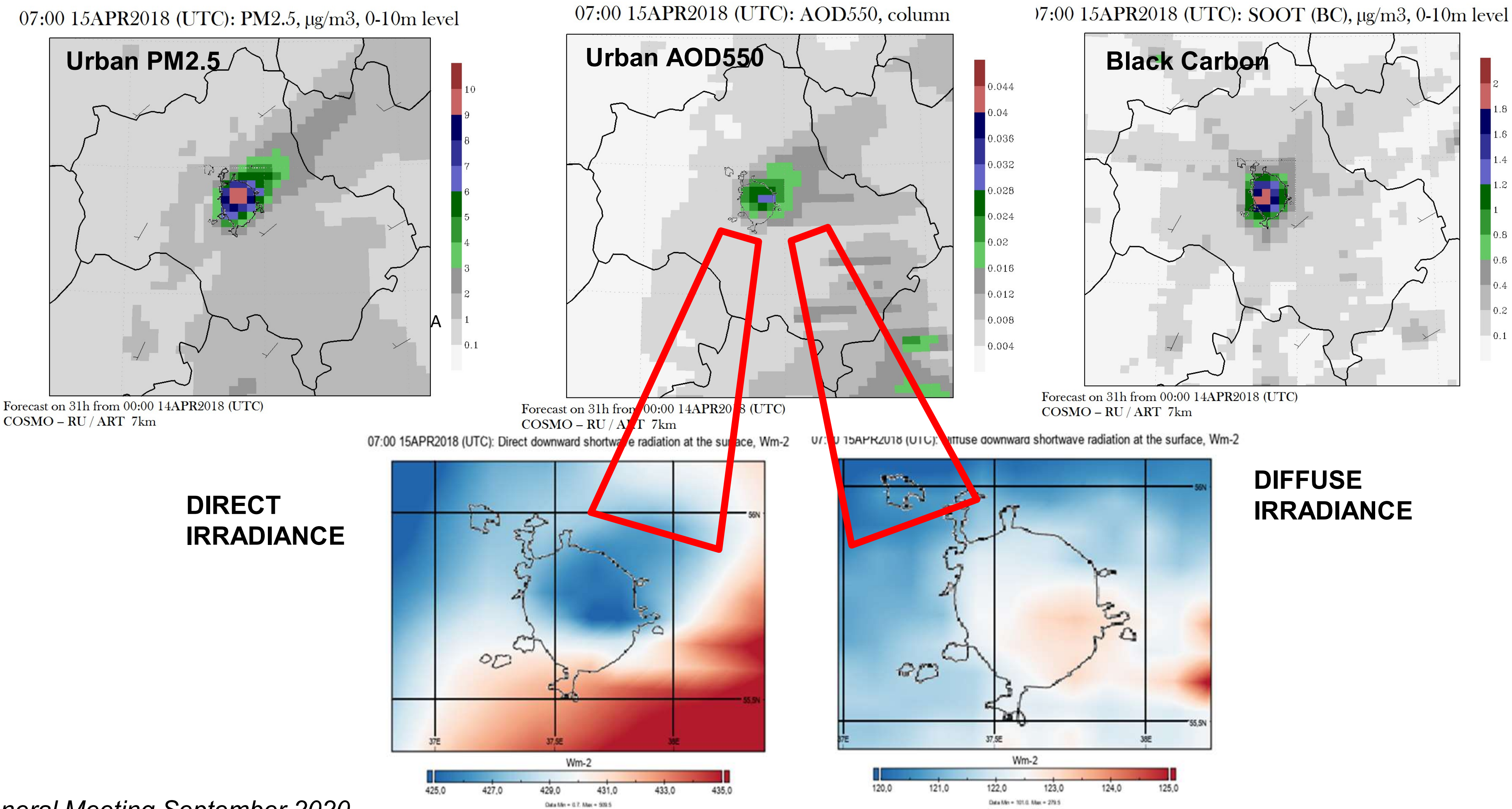
	IPD1 More stable	IPD2 Less stable	IPD3 Not stable
Median, 50% quantile	34%	23%	18%

Urban PM fraction (model estimates) in total observed PM (different percentiles) in conditions with various Intensity of Particle Dispersion (IPD).



	IPD1 More stable	IPD2 Less stable	IPD3 Not stable
Median, 50% quantile	**18%**	**17%**	**12%**

An example of radiative effect of Moscow urban aerosol for direct and diffuse irradiance. 15/04/2018



Conclusions:

- During the AeroRadCity experiment we showed that COSMO-ART model provides quite satisfactory agreement in estimates of urban aerosol in quasi-clear conditions, but overestimates them in cloudy conditions. We also showed the importance of removing cases with BB aerosol, which can significantly change aerosol properties.

- The modelled BC concentrations are of the same order with measurements and has a good agreement with PM and NOx concentrations. <u>No BC dependence on SO_2 according to the measurements!</u>

- Solar Radiation: we have much more significant loss in UV irradiance (up to 40%) compared with shortwave irradiance (up 15%) during daytime in well-mixing atmosphere. Cooling radiative forcing effect is much less (up to -3 Wm^{-2}) at both smaller AOT and SSA (the latter could be smaller due to increase in BC/PM ratio).

- Median urban component of AOD in Moscow is about 0.01 according to both modelling (with TNO2010 emissions) and measurements (also in agreement with satellite estimates [Zhdanova et al., 2020]), however, in some conditions COSMO-ART model provides an unrealistic increase of urban AOD aerosol up to 0.12 (>90% of total measured AOD). Using IPD indicators we showed an important role of meteorology in urban aerosol accumulation - urban AOD fraction changes from 18% in unstable atmospheric conditions to 34% in stable ones.

Acknowledgements.

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