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Atmospheric aerosol and its radiative forcing in conditions with high surface albedo using ground-based measurements and modeling

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Atmospheric aerosols have a noticeable cooling effect on climate, which comes from its negative radiative forcing (IPCC, 2021). At the same time, it is known that in conditions with high surface albedo, aerosol radiative forcing can differ significantly from the IPCC estimates and even have a positive value.

To study the aerosol radiative effects, a series of numeric experiments were carried out for Moscow region using COSMO-ART chemical transport model. The experiments covered a period from 24.02.2025 to 28.02.2025, when the weather in Moscow was mostly sunny and surface albedo was high (a=0.68) because of snow cover. Modeling results reproduced not only aerosols and its surface concentrations, but also aerosol effects on radiation in given conditions (high albedo) and in standard surface albedo conditions for Moscow (A=0.4). In addition, calculations using the autonomous ecRAD model version (Hogan, Bozzo, 2018) were used for the analysis. Modeled aerosol mass concentrations (PM10 and PM2.5) were compared with measurements at the Mosecomonitoring sites. Modeling results were also compared with radiative measurements of the BSRN type MSU-RAD complex at the MSU Meteorological Observatory.

According to the Mosecomonitoring data, surface concentrations of PM10 and PM2.5 increased by 2-2.5 times on February 28th in comparison with February 24th due to prevailing anticyclonic weather during this period. At some hours on February 25th and at night between February 27th and February 28th surface aerosol concentrations were higher than the 24-hour maximum allowable concentration. Small negative correlation was found between PM10 and PM2.5 concentrations and wind speed, inversion height and planetary boundary layer height. Comparison between modeling results and measurements showed that modeled surface aerosol concentrations were significantly overestimated at most sites. This is probably caused by uncertainties in industrial emissions dataset, which was used as the model input. It is important to note that in the experiments with high surface albedo (A=0.7), surface aerosol concentrations were about 10-15% higher than in the experiments with standard surface albedo (A=0.4), probably due to a decrease in mixing layer height.

Net shortwave radiation at TOA and BOA simulated by the COSMO-ART is in a satisfactory agreement (within 20-30 W/m^2 interval) between the ECRAD model and measurements. Comparison of net radiation components between modeling and measurements allowed us to identify some features. Global solar radiation in the COSMO-ART experiments is 1-5% higher on average than the measured values. Reflected solar radiation was relatively close to measured values in the experiment with high surface albedo (A=0.7). Longwave radiation was to some extent underestimated, because modeled surface and air temperatures were lower than the observed values.

Shortwave radiative forcing of Moscow urban aerosol in typical winter conditions (aerosol optical thickness 0.08, surface albedo — 0.4, Sun height — 20°) reaches -0,5 W/m^2 at TOA and -6 W/m^2 at BOA. In conditions with surface albedo close to 0.7 aerosol radiative forcing reaches +3 W/m^2 at TOA and -3 W/m^2 at BOA. Thus, according to model estimates, in conditions with high surface albedo aerosol shortwave radiative forcing at TOA has a noticeable positive value.