Influence of aerosols on the meteorological regime of Northern Eurasia according to COSMO-Ru Model

A A Poliukhov\textsuperscript{1,2} and D V Blinov\textsuperscript{2}

\textsuperscript{1}Lomonosov Moscow State University, Leninskie Gory 1, Moscow, 119991, Russia
\textsuperscript{2}Hydrometcenter of Russia, Bolshoy Predtechensky per., Moscow, 123242, Russia

email: aeromsu@gmail.com

Abstract. We provided the estimation of the aerosols effect at the surface and at the top of the atmosphere, as well as on the sensible and latent heat flux for the Northern Eurasia using the MACv2 aerosol climatology. The numerical experiments were performed with the COSMO-Ru model for the January and July in 2017. It is found that the aerosol radiation effect on the surface can reach -50 W/m\textsuperscript{2}. At the same time, it is shown that the net shortwave radiation increase does not unequivocally lead to the air temperature at two meters increase. We revealed that the temperature at 2 meters decreases on -0.5±0.1 degrees per 100 W/m\textsuperscript{2} in the clear sky condition for Mediterranean, Red, Black and Caspian seas areas. The temperature sensitivity is positive and equals 0.9±0.3 degrees per 100 W/m\textsuperscript{2} for Middle East and southern Europe and 1.7±0.7 degrees per 100 W/m\textsuperscript{2} for northern Africa.

1. Introduction
Aerosols affect the climate system through several physical mechanisms. The direct aerosol effect associated with the absorption and scattering of solar radiation has the most significant influence [1]. The aerosol radiation effect is defined as a change in the net radiation caused by the combined scattering and absorption of radiation by anthropogenic and natural aerosols relative to the non-aerosol atmosphere at the top of the atmosphere.

The first studies of the aerosol radiation effect have been started since the 60s -70s of the XX century. The main goal was to evaluate the hypothesis that aerosols reduce solar radiation on a global scale [2, 3]. For some cases, the contribution of the aerosol to the downward shortwave radiation fluxes may exceed 100 W/m\textsuperscript{2}. For example, such assessments were obtained during the aircraft measurements in a mineral dust plume over the ocean [4].

The quantitative assessment of the aerosols direct effect is often complicated due to aerosol high spatial and temporal variability. However, ground- and satellite-based observations as well as the theoretical modelling developments have helped to reduce estimation uncertainty significantly. Furthermore, the set of complex chemical transport models have been developed to reproduce the entire life cycle of various aerosol types from their formation to deposition [5, 6]. Various aerosol climatologies have been created using the output from these models [7-10]. Usage of aerosol climatologies is necessary for evaluation of the aerosol impact in numerical weather prediction (NWP) models. In recent decades, the approach to describing aerosols' properties for NWP models has changed
significantly from semi-empirical formulas to ensemble calculations using chemical transport models and correction from observational data.

The inclusion of new aerosol climatologies in weather forecasting models inevitably modify the calculation processes of radiation fluxes, heat balance, and, as a result, the surface air temperature. Previously, the positive experience of replacing the aerosol climatology Tarané [11] with Tegen [10] in the ALADIN-HIRLAM model [12] was noted. A significant aerosols effect on surface air temperature simulation quality was also shown [13].

Up-to-date MACv2 aerosol climatology is taken into account in COSMO-Ru model. Significant improvement of the surface temperature forecast was obtained for the simulations using MACv2 climatology compared to using Tarané’s one [14].

This work aims to evaluate the effect of MACv2 aerosol climatology on the surface heat balance and the sensitivity of the surface air temperature to changes in the surface net shortwave radiation in the COSMO-Ru model.

2. Data and methods

2.1. COSMO-Ru Model

We performed the simulations with the COSMO-Ru mesoscale nonhydrostatic model [15]. The model radiation scheme [16] is based on the two-stream approximation. The spectrum was divided into three intervals in the solar range and five intervals in the far infrared range. The AFGL 1982 spectroscopic database was used to calculate the radiation flux density extinction by different gases [17]. The radiation absorption by water vapor, methane, carbon dioxide, and nitrogen oxide was considered.

Previous studies have evaluated the estimation of the calculation error for the total radiation in this algorithm compared to ground-based measurements and the two-stream CLIRAD(FC05)-SW algorithm [18]. It was shown the error does not exceed 5% for different climatic regions [19,20].

2.2. Experimental setup

The COSMO-Ru model experiments were performed for the territory of Northern Eurasia with adjacent regions. We used the horizontal grid resolution of about 13 km, and 40 vertical levels for 24 hours experiment with the integration time step of 120 seconds. The forecast was calculated for January and July 2017. The ICON global model data were used as lateral boundary and initial conditions [21]. The calculations were carried out on the Roshydromet supercomputer CRAY-XC40.

Two experiments were performed, including the control experiment with AOT=0 and with MACv2 aerosol climatology.

The MACv2 climatology [7, 8] has a spatial resolution of 1°x1°. Monthly mean values of aerosol optical thickness, single scattering albedo, and asymmetry factor were considered for the following wavelengths 0.29, 0.32, 0.55, 0.87, 1.47, 2.0, 2.6 microns. That values are correspond to 2005 year. The results of calculations of 14 chemo-transport models of the AeroCom project are used [6]. Ground station measurements of AERONET [22] from 1995 to 2015 are used to correct model data for climatology.

3. Results

The average monthly values of the net shortwave radiation at the top of the atmosphere (TOA) and the surface (figure 1), the sensible and latent heat fluxes (figure 2), and the surface air temperature (figure 3) were calculated for each month. Furthermore, the sample included not only daytime as well as nighttime and the cases with clouds.

According to the COSMO-Ru model, the MACv2 aerosol climatology results in the average radiation effect of aerosols is 0.4 W/m² in January and -2.1 W/m² in July at the TOA for the selected area. At the same time, the positive radiation effect (up to 10 W/m²) is observed over Central Asia in January. That effect could be because a large mineral aerosol concentration over a bright surface causes to decrease in the surface albedo due to the radiation absorption [23].
Figure 1. Differences between MACv2 and AOT= 0 experiments for the net shortwave radiation on the TOA (a,b) and at the surface (c,d) in January (a,c), and in July (b,d).

The difference in the net shortwave radiation is on average -3.2 W/m² in January and -9.1 W/m² in July at the surface. The maximum effect (up to -50 W/m²) is observed for the territory of Southern Europe and the Mediterranean Sea. The same decrease in the net shortwave radiation is obtained for the territory of the Gulf of Ob, probably due to an increase in the cloud cover due to the semidirect effect.

Thus, the radiation effect of the aerosol at the surface are less than those at the TOA due to the absorption of radiation by aerosols in the atmosphere.
Figure 2. Differences between MACv2 and AOT= 0 experiments of the sensible heat flux (a,b) and the latent heat flux (c,d) in January (a,c) in July (b,d).

The decrease of the net shortwave radiation leads to an increase in the sensible heat flux from the surface by 10-20 W/m$^2$. The absolute values of the sensible heat flux decrease during the surface temperature continues to decrease too. Notable, the sensible heat flux does not change over the ocean if the constant value of the ocean surface temperature is set. Also, the latent heat flux increases from the surface by 5-15 W/m$^2$. The sensible and latent heat fluxes increase for the territory of the Gulf of Ob. So, this feature requires an additional research.

The aerosol effect on the surface air temperature has the opposite response sign over land and over the sea (figure 3). The surface air temperature over the land decreases due to the decrease of the net shortwave radiation. The most significant changes are observed in July in Africa and the Middle East (up to 1 degree). The temperature decrease reaches 0.3 degrees in January. However, the temperature increase is combined with the sensible heat flux decrease in Mongolia and Eastern Siberia.
The surface air temperature over the oceans depends primarily on the ocean surface temperature, which is derived from the global model data and assumed to be constant during forecasting period. However, the temperature at the lower model level could increase due to increased radiation absorption. Therefore, the surface air temperature should be permitted to increase even with a decrease in the net shortwave radiation. For example, this effect reaches 0.2 degrees in the Red and Caspian Seas and the western part of the Mediterranean in January.

Figure 3. The monthly average surface air temperature in AOT= 0 experiment (a,b) and temperature differences between MACv2 and AOT= 0 experiments (c,d) in January (a,c), and in July (b,d).

The surface air temperature is one of the most important characteristics of the weather forecast. The surface temperature computation procedure in NWP models primarily depends on the radiation balance of the surface, advection, parametrization of heat transfer within the surface layer, and the soil layer parametrizations.
Previously, the changes in the surface air temperature for the cloudless conditions were estimated due to the aerosol radiation effect at the 4 stations located in different climatic zones. The sensitivity is amounted to 0.9±0.2 degrees per 100 W/m² [24].

We selected clear sky conditions in the area (defined as cloud cover is less than 1%), and with the net shortwave radiation of more than 100 W/m². Thus, the night and morning hours were removed. Also, we calculated linear approximation coefficients and estimated their statistical significance.

Because of the small number of clear sky condition cases in our study area, a statistically significant relationship (at the level of 0.05) was obtained only for Northern Africa, the Mediterranean Sea, southern Europe and the Middle East (figure 4).

![Figure 4](image-url)

**Figure 4.** The sensitivity of the surface air temperature to changes in the net shortwave radiation in January (a) and July (b) (degree/100 W/m²). The white color inside the calculation boundaries indicates the insignificant sensitivity.

In clear sky conditions, the effect of multidirectional changes in surface air temperature over the ocean and land area is most pronounced. The temperature sensitivity is -0.5±0.1 degrees per 100 W/m² over the ocean in January and July. The sensitivity has a larger variability over the land. For Middle East, Southern Europe and Central Asia, the temperature sensitivity is 0.9±0.3 degrees per 100 W/m², which confirms the previous work conclusions [24]. However, the temperature sensitivity can exceed 2 degrees per 100 W/m², and on average is 1.7±0.7 degrees per 100 W/m² in July over the North Africa. This may be due to the extremely low moisture content in the region. In January, the temperature sensitivity decreases to 1.2±0.2 degrees per 100 W/m² for the territory of North Africa.

**4. Conclusions**

In this paper we evaluated the impact of the MACv2 aerosol climatology on the calculation of radiation fluxes and sensible and latent heat fluxes for the territory of Northern Eurasia by the COSMO-Ru model.

Experiments have shown the aerosol radiation effect at TOA of about -2.1 W/m² in July. The aerosol radiation effect at the surface is greater (-9.1 W/m²), and in some grid points reaches -50 W/m². Changes in the net shortwave radiation lead to an increase in the sensible and latent heat fluxes by 5-15 W/m². It was also found that the air temperature at 2 meters decreases by 0.3 degrees in January and by 0.8-1 degrees in July in the North Africa and the Middle East. However, the air temperature at 2 meters above the ocean could increase by 0.1-0.2 degrees due to the constant surface temperature during forecasting period.

We estimated the temperature change due to the difference in the net shortwave radiation in clear sky conditions. The temperature sensitivity is 0.9±0.3 degrees per 100 W/m² for Middle East and...
southern Europe, and 1.7±0.7 degrees per 100 W/m² for northern Africa. The changes are opposite and about -0.5±0.1 degrees per 100 W/m² for Mediterranean, Red, Black and Caspian seas.

Acknowledgements

The model simulation was funded by the Roshydromet project AAAA-A20-120021490079-3. The analysis of aerosol effects was funded by RFBR, project number 19-35-90129.

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