Comparison between calculations of shortwave radiation with different aerosol datasets and measured data at the MSU MO (Russia)

Aleksei Poliukhov, Natalia Chubarova, Stephan Kinne, Gdaliy Rivin, Marina Shatunova, and Tatiana Tarasova

Comparison Between Calculations Of Shortwave Radiation With Different Aerosol Datasets And Measured Data At The MSU MO (Russia)

Aleksei Poliukhov[1, 2, a)], Natalia Chubarova[1, 2, b)], Stephan Kinne[3], Gdaliy Rivin[1, 2], Marina Shatunova[2], Tatiana Tarasova[4]

[1]*Lomonosov Moscow State University, Moscow, Russia*
[2]*Hydrometeocentre of Russia, Moscow, Russia*
[3]*Atmosphere in the Earth System, Max Planck Institute for Meteorology, Hamburg, Germany*
[4]*Centro de Previsao de Tempo e EstudosClimaticos/Instituto Nacional de PesquisasEspaciais, CachoeiraPaulista, SP, Brazil*

[a)]Corresponding author: aeromsu@gmail.com
[b)] natalia.chubarova@gmail.com

Abstract. The radiation block of the COSMO non-hydrostatic mesoscale model of the atmosphere and soil active layer was tested against a relatively new effective CLIRAD(FC05)-SW radiation model and radiative measurements at the Moscow State University Meteorological Observatory (MSU MO, 55.7N, 37.5E) using different aerosol datasets in cloudless conditions. We used the data of shortwave radiation components from the Kipp&Zonen net radiometer CNR4. The model simulations were performed with the application of various aerosol climatologies including the new MACv2 climatology and the aerosol and water vapor dataset from CIMEL (AERONET) sun photometer measurements. The application of the new MACv2 climatology in the CLIRAD(FC05)-SW radiation model provides the annual average relative error of the total global radiation of -3% varying from 0.5% in May to -7.7% in December. The uncertainty of radiative calculations in the COSMO model according to preliminary estimates changes from 1.4% to 8.4%. against CLIRAD(FC05)-SW radiation model with the same parameters. We showed that in clear sky conditions the sensitivity of air temperature at 2 meters to shortwave net radiation changes is about 0.7-0.9°C per100 W/m^2 due to the application of aerosol climatologies over Moscow.

INTRODUCTION

The COSMO-Model is a non-hydrostatic mesoscale atmospheric model which is widely used in different countries for the weather forecasting and climate modelling [1]. However, the radiation block of the model utilizes relatively old method and datasets [2]. The objective of this work was to test the radiative scheme of the operational Russian COSMO-Ru NWP model with different aerosol climatologies in cloudless conditions against the accurate CLIRAD(FC05)-SW model [3], the ground-based radiative measurements of the Moscow State University Meteorological Observatory (MSU MO) and to evaluate aerosol radiative effect on air temperature at 2 meters.

MODEL AND DATASET DESCRIPTION

Two radiative transfer models were used in this work: the model, which has been implemented in the radiation block of the COSMO non-hydrostatic mesoscale model and a relatively new effective CLIRAD(FC05)-SW radiation model. The radiation algorithm of COSMO model is based on the two-stream approach, proposed in 1980 by Zdunkovski [4]. The spectrum of the solar radiation is divided into3 intervals (0.25–0.70, 0.70–1.53, 1.53–4.64 μm). The spectroscopic database AFGL-1982 is used for the calculation of extinction of the radiation flux density by different gases. The absorption of water vapor, oxygen, ozone, nitrous oxide and methane are considered.

Radiation Processes in the Atmosphere and Ocean (IRS2016)
AIP Conf. Proc. 1810, 100006-1–100006-4; doi: 10.1063/1.4975561
Published by AIP Publishing. 978-0-7354-1478-5/$30.00

The CLIRAD(FC05)-SW model is the update of the CLIRAD-SW model scheme, which has been developed at Goddard Space Flight Center [5]. The spectrum of the solar radiation is divided into 8 intervals (0.2-0.303, 0.303-0.323, 0.323-0.7, 0.323-1.22,0.7-1.22,1.22-10, 1.22-2.27, 2.27-10).Coefficients of reflection and transmission of each layer of the atmosphere are calculated using the δ-Eddington approximation.The absorption of water vapor, oxygen, ozone, carbon dioxide was accounted using the spectroscopic HITRAN-2004 database.The accuracy of the CLIRAD(FC05)-SW model was checked with the help of high-precision Monte-Carlo model developed at the “Kurchatov Research Center” [6]. For its evaluating the temperature, water vapor and ozone profiles were taken from «midlatitude summer» model [7] with CONT-I [8] aerosol model. We showed that the uncertainty of the CLIRAD(FC05)-SW radiation model lies within 2% within typical aerosol conditions in Moscow.

The atmospheric aerosol properties were used as the input parameters for model simulations. One dataset consisted of the AERONET (Aerosol Robotic NETwork [9]) measurements at the MSU MO which have been in operation since August 2001 [10]. For improving the data quality the additional NO_2 and cloud filter correction methods had been developed, which was applied the whole dataset [11]. Water vapor content was also used from AERONET measurements.

In addition, several other aerosol climatologies were used as the input parameters for model simulations [12][13][14]. The new MACv2 climatology updated from MACv1 [14] is the newest aerosol dataset. This climatology is based on model simulations and ground-based aerosol measurements. The MACv2 has a spatial resolution of 1°x1°. Average monthly values of aerosol optical thickness, single scattering albedo and asymmetry factor for different wavelengths are available from MACv1 climatology. We used aerosol properties for several effective wavelengths in COSMO-Ru and CLIRAD(FC05)-SW models: 0.29, 0.32, 0.55, 0.87, 1.47, 2.0, 2.6 μm.

The measurements of shortwave irradiance from the CNR4 Kipp&Zonen net radiometer at the MSU MO were used for the comparisons with model simulations. For testing the radiation scheme in COSMO-RU model with the grid resolution of 1.1 km [15][16] visual hourly cloud observations were used. Clear sky conditions of not less than 5 hours were chosen from both observations and COSMO-RU model output.

RESULTS

Comparisons of Different Aerosol Datasets

The aerosol optical thickness (AOT) seasonal cycle by in-situ measurements is characterized by a pronounced summer maximum in August, an additional maximum in April, and a minimum in December and January (Figure 1). In winter, there is a minimum in AOT due to wet deposition of aerosol during the active cyclonic processes and the absence of favorable conditions for second aerosol generation. The AOT maximum in spring can be explained by the circulation pattern from southeast of Russia and Kazakhstan with dust advection from semi deserts and steppes. The local June minimum is observed due to the increase in precipitation, and dominating the northern air advection from Scandinavian regions. According to monthly mean data, the summer AOT550 maximum is observed in August due to extremely high aerosol loading during forest fires in August 2002 and 2010. The AOT550 50% quantile, which characterizes typical aerosol seasonal changes has a maximum in July, when the high temperature provides favorable conditions for the second aerosol generation and for the accumulation of aerosol [10][11]. The MACv2 climatology better reveals the features of the seasonal cycle compared with the Tegen climatology. However, it is worth noting that both climatologies significantly overestimate AOT during the winter months due to probably the influence of the upper level clouds in the standard AERONET algorithm which had been used as a source for creating the MACv2 climatology. In addition, the local minimum is observed in July in the Tegen climatology and in May – in the MACv2 climatology. Forest fires do not affect the MACv2 climatology, so the better agreement is with the 50% quantile values, which are more resistant to these anomalies.

The MACv2 climatology overestimates the single scattering albedo in winter months, for example in January on 0.126. This is likely related to the fact that the climatology does not consider urban pollution, which is most pronounced in winter. For the asymmetry factor, we observed a good agreement between the measurements and the MACv2 climatology for the fine fraction and for the total aerosol. The absolute error varies from -0.06 to 0.06.

However, we observed a significant underestimation in asymmetry factor for the aerosol coarse mode. For the coarse mode single scattering albedo and the asymmetry factor are the constant values throughout the whole year (0.939 and 0.74 at λ=550nm respectively).

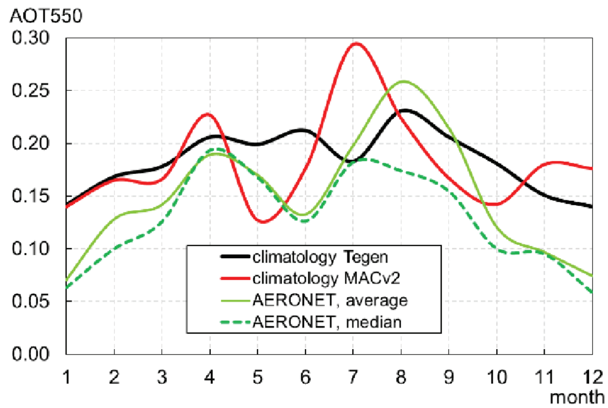

FIGURE 1. Seasonal cycle of aerosol optical thickness at 550 nm recalculated from AERONET (with the additional NO_2 and cloud correction, 2001-2014, green lines [11]), from the Tegen climatology (black line) [13] and from the MACv2 climatology (red line) [14]

The Uncertainty in Total Shortwave Irradiance Simulations Due to the Application of MACv2 Aerosol Climatology at the Moscow MSU MO

The total shortwave radiation was calculated via CLIRAD(FC05)-SW model using the MACv2 climatology and AERONET dataset for noon middle month conditions during the year. The surface albedo was equal to 0.7 from November to March and 0.2 from April to October. On average, the MACv2 aerosol climatology overestimates annual AOT550 on 0.046, which results in the underestimation of total shortwave radiation on 10.4 W/m^2. In some months this value varies from -22.7 W/m^2 (in Juli) to 4.1 W/m^2 (in May). The largest relative uncertainty is observed in winter (up to -7.7%), the smallest – in May (0.5%), annual average value is equal to -3%.

We chose 4 days for the analysis: August 22nd 2012, March 29th 2014, July 27th 2014 and September 16th 2014 which were characterized by clear sky conditions. It was shown that total shortwave radiation relative error increases with the increase of solar zenith angle. However, for the radiative calculations with AERONET dataset the error does not exceed 5%. In addition, it was found that in all cases COSMO-Ru model overestimates the total shortwave radiation compared with that from CLIRAD(FC05)-SW model by 4% on average varying from 1.4% to 8.4%. Since the connection between COSMO-Ru overestimation and solar height was detected (with correlation coefficient 0.431) this can be explained by too small number of spectral intervals in the COSMO radiation algorithm.

Testing the difference in shortwave radiation calculations by the CLIRAD(FC05)-SW model with the application of the Tegen or the MACv2 aerosol climatologies against calculations with the AERONET dataset revealed better results for MACv2 climatology than that for the Tegen climatology (Figure 2).

Radiative effect on Air Temperature according to the COSMO model experiments

The application of different aerosol properties in the radiative simulations can influence the estimated air temperature at 2 meters. To assess this effect we estimated the difference between shortwave net radiation in aerosol and aerosol-free atmosphere (Figure. 3). We showed that the change in shortwave net radiation by 100 W/m^2 due to the application of different aerosol climatologies [12], [13] provides the 0.7–0.9 °C change in 2-meter air temperature.

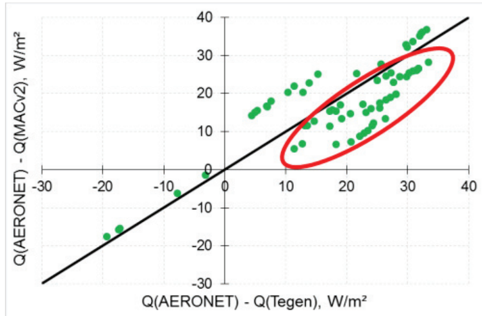

FIGURE 2. The difference between total shortwave radiation calculations by CLIRAD(FC05)-SW model with different aerosol datasets

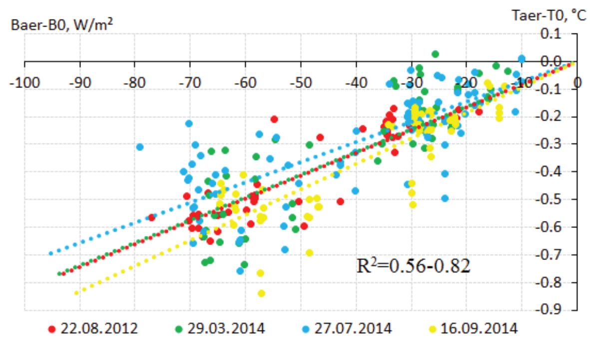

FIGURE 3. Sensitivity of 2-meter air temperature in COSMO-Ru1 model to the change in shortwave net radiation due to aerosols. AtX axis the difference between radiation balance with aerosol and without is represented, at Y axis – difference in air temperature at corresponding conditions

ACKNOWLEDGMENTS

The work was partially supported by the by RFBR grant No. 16-05-00985. This work is carried out within the framework of the COSMO consortia Priority project - $T^2(RC)^2$ **T**esting&**T**uning of **R**evised **C**loud **R**adiation **C**oupling.

REFERENCES

1. Doms G. et.al., A Description of the Nonhydrostatic Regional COSMO Model. Part II: Physical Parameterization. Offenbach, Germany: Deutscher Wetterdienst, 2011, 154 p.
2. Ritter B., Geleyn J. F, Monthly Weather Review, 1992, 120, 2, 303-325.
3. Tarasova T. A., Fomin B. A., Journal of Atmospheric and Oceanic Technology, 2007, 24, 6, 1157-1162.
4. Zdunkowski W. G.et al., BeiträgezurPhysik der Atmosphäre, 1980, 53, 2, 147-166.
5. Chou M.D Suarez M.J, NASA/TM-1999-10460, Vol. 15, 2002
6. Rublev, A. N.et al., A. Deepak Publishing, Hampton, Virginia. 1105-1108.
7. Mc'Clatchey et al., Report AFCRL-72-0497, Mass., 1972.
8. WMO, Radiation Commission WCP, 1986, 112.
9. Holben B. N. et al., Remote sensing of environment, 1998, 66,1, 1-16.
10. Chubarova N. et.al., Geography, environment, sustainability, 2011, 4, 1, 19-32.
11. Chubarova N. Y. et.al., Atmospheric Measurement Techniques, 2016, 9, 2, 313-334.
12. Tanre D.et al., Aerosols and their climatic effects, 1984, 133-177.
13. Tegen I. et al., Journal of Geophysical Research: Atmospheres, 1997, 102, D20, 23895-23915.
14. Kinne S. et al., Journal of Advances in Modeling Earth Systems, 2013, 5, 4, 704-740.
15. Rivin G.S.et.al., Russian Meteorology and Hydrology, 2015, 40, 6, 400-410.
16. Shatunova M.V. et al., Russian Meteorology and Hydrology, 2015, 40, 8, 523-530.