Assessment of present-day aerosol optical depth from modern aerosol-climate models, reanalyses, and satellite products

Annika Vogel¹,²,⁷, Ghazi Alessa³, Robert Scheele¹, Lisa Weber¹,⁴, Oleg Dubovik⁵, Peter North⁶, and Stephanie Fiedler¹,³,⁴⁷

¹University of Cologne, Institute of Geophysics and Meteorology, Cologne, Germany (av@eurad.uni-koeln.de)
²Rhenish Institute for Environmental Research at the University of Cologne, Cologne, Germany
³formerly at Max-Planck-Institute for Meteorology, Hamburg, Germany
⁴Hans-Ertel-Centre for Weather Research, Climate Monitoring and Diagnostics, Bonn/Cologne, Germany
⁵University Lille, CNRS, UMR 8518 (LOA Laboratoire d’Optique Atmosphérique, Lille, France
⁶Swansea University, Department of Geography, Global Environmental Modelling and Earth Observation (GEMEO), Swansea, United Kingdom
⁷now at: Air Quality Research Division, Environment and Climate Change Canada, Dorval QC, Canada

Despite the implication of aerosols for radiative forcing, there are differences in aerosol estimates from both, observations and models. This study quantifies differences between current estimates of aerosol optical depth (AOD) to address two questions: (1) How well do we know the large-scale spatio-temporal pattern of present-day AOD across state-of-the-art data? (2) Has the representation of AOD improved across phases of aerosol-climate model intercomparison projects? To answer these questions, we analyze spatio-temporal patterns of the present-day monthly mean AOD from 94 global datasets. The data is taken from eight satellite retrievals, four aerosol-climate model intercomparison projects, two global reanalyses, one operational ensemble product, one climatology and one merged satellite product covering periods between 1998 and 2019. The evaluation includes new satellite data from SLSTR and aerosol-climate models of CMIP6 and AeroCom-III. The comprehensive data assessment allows us to evaluate the performance of individual products and models concerning different spatial and temporal aspects. Our assessment is based on metrics for a detailed investigation with respect to different spatio-temporal characteristics of AOD.

Our results highlight spatio-temporal differences in AOD across datasets, were the performance of individual data sets varies with respect to the different spatio-temporal metrics assessed. Global mean AOD of individual satellites ranges between -11% to +17% around a satellite mean of 0.14. The ensemble means from the aerosol-climate model intercomparison projects fall within the satellite range, but individual models can differ considerably. Reanalyses and climalogies are typically closer to the satellite mean than aerosol-climate models. No systematic improvement from earlier to later phases of CMIP and AeroCom is found, although some regional biases have been reduced. Compared to the satellite and reanalysis data, all aerosol-climate ensemble means tend to overestimate AOD along extra-tropical storm tracks and underestimate AOD in regions of...
high aerosol load in South America, South Africa, India, and Southeast Asia. The identified differences may be used to guide further efforts to improve satellite retrievals and model simulations for aerosols. In addition, the uncertainty in observed AOD implies that a model evaluation based on a single satellite product might draw biased conclusions. This underlines the need for continued efforts to improve both model and satellite estimates of AOD to facilitate a better understanding of aerosol effects in the Earth system. At the same time, our analysis suggests that an assimilation of multiple satellite products for AOD would be beneficial to account for observational uncertainty.