Replacing OPAC with MERRA2 Aerosols for the UFS

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1. Motivation

Aerosols play an important role in the energy budget of the Earth-atmosphere system. They directly scatter and absorb electromagnetic radiation (aerosol direct effect) and indirectly interact with cloud macro- and micro-physics (aerosol indirect effect). Non-absorbing aerosols, such as sulfate and organic carbon, scatter solar radiation back to space producing a cooling effect on the climate system. Aerosols also contain absorbing material, such as black carbon, that absorbs solar radiation leading to a warming effect that partly offsets the aerosol scattering effect.

NOAA is currently developing the next generation coupled Unified Forecast System (UFS) for weather, sub-seasonal and seasonal predictions. The aerosols prescribed in the UFS are still adopted from the Optical Properties of Aerosols and Clouds (OPAC) dataset (Hess *et al.*, 1998), which only represents aerosol distributions in 1990's. It also has a very coarse 5x5-deg horizontal resolution. Aerosol concentration is a mixture of different predefined components. An exponential profile is used to define the distribution of aerosol particles with height.

To improve the representation of aerosols in the UFS, the Modern-Era Retrospective Analysis for Research and Applications Version 2 (MERRA2) will be used to replace OPAC. MERRA2 was produced using the three-dimensional variational data analysis (3DVAR) Gridpoint Statistical Interpolation (GSI) meteorological analysis scheme and the GEOS-5 atmospheric model. The MERRA-2 meteorological observing system includes Moderate Resolution Imaging Spectroradiometer (MODIS), the Advanced Very High Resolution Radiometer (AVHRR) instruments, Multi-angle Imaging SpectroRadiometer (MISR), ground-based Aerosol Robotic Network (AERONET), and other bias-corrected observational data as well. MERRA2 has a horizontal resolution of 0.5° latitude by 0.625° longitude, and has 72 levels in the vertical extending from the surface to one pascal. So it has a much higher spatial resolution than OPAC. MERRA2 aerosols consist of 15 modes, five bins of dust and sea salts, two bins of organic carbon and black carbon, and one bin of sulfate, respectively. Described in the following is an evaluation of medium-range weather forecast skill in the UFS atmospheric model, the Global Forecast System version 16 (GFS.v16), with OPAC aerosols being repealed by MERRA2.

2. Results

GFS.v16 has a horizontal resolution of 13 km and has 127 layers in the vertical extending from the surface to the mesopause. To assess the impact of replacing OPAC with MERRA2 aerosols on GFS forecast skill, two control experiments with OPAC aerosols and two sensitivity experiments with MERRA2 aerosols were conducted for one summer and one winter case, respectively. The winter case covers the period from 1 December 2019 through 1 March 2020, and the summer case for the period from 1 June 2019 through 1 September 2019. Each experiment is initialized with GFS.v16 initial conditions at the 00Z cycle, once for every 5 days in each winter and summer time period.

The most notable effects are changes in radiative warming/cooling at the surface and the top of the atmosphere (TOA) induced by aerosol reflection and extinction. MERRA2 has less aerosol loading than OPAC over most of the continents due to a reduction in anthropological emissions, and much less sea salt in the Southern and Northern Hemisphere storm track regions. On the other hand, MERRA2 dust aerosol loading from the Sahara desert is much higher than OPAC over northwest Africa. Over East Asia, MERRA2 organic carbon and sulfate aerosol loading are also higher. Normally large aerosol number concentrations are only found in the lower troposphere. Shortwave radiation reflected back by aerosols warms the atmosphere above the aerosol layer. The extinction of shortwave radiation by the aerosol layer also leads to reduced shortwave (SW) flux at the surface. The reduction can reach as large as 30 W/m^2 over northwest Africa. The absorption of longwave radiation by black carbon and large particles of dust, etc. can warm the aerosol layer and thus increase the outgoing longwave radiation (OLR) at the top of the atmosphere and the downward longwave (LW) flux at the surface. Overall, the magnitude of aerosol longwave radiation forcing is much smaller than that of aerosol shortwave radiation forcing.

It was found from this study that Asian monsoon was also more realistically depicted with MERRA2 aerosols. Aerosols over the Arabian peninsula and Indian subcontinent cause lower troposphere cooling and upper troposphere warming. With MERRA2 aerosols, the sea level pressure increased over the continent and decreased over the ocean in the monsoon region. The Monsoon circulation was stronger and compared better with observations.

The evaluation of medium-range weather forecast skill shows that 500-hPa height anomaly correlations are improved for the Northern Hemisphere and the Pacific and North America (PNA) regions in both winter and summer (Figure 1), with some of the scores passing the 95% confidence Student-t test.

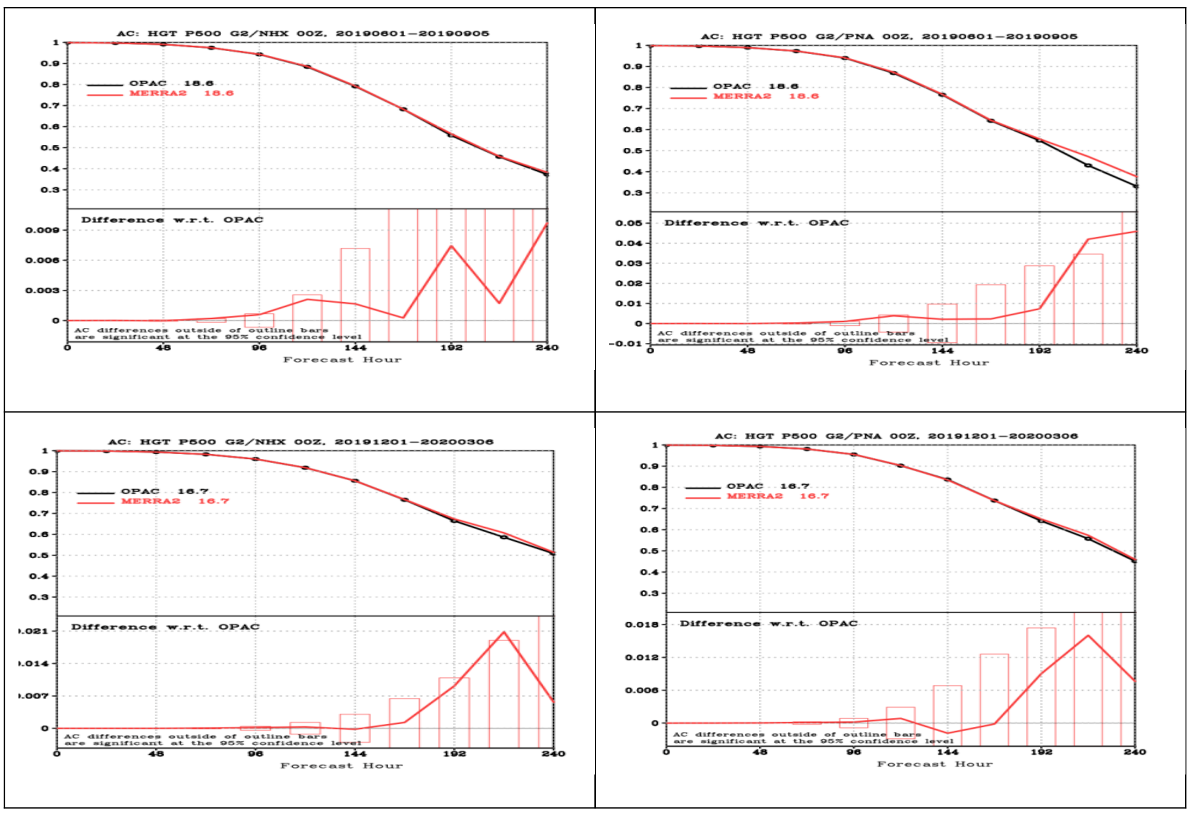

Figure 1. 500-hPa height anomaly correlations for the Northern Hemisphere (left panels) and the Pacific North America (right panels) in summer (upper row) and winter (lower rows), respectively.

References

Buchard,V., C. A. Randles, A. M. da Silva, and et al. 2017, The MERRA-2 aerosol reanalysis, 1980 onward. Part II: Evaluation and case studies. *J. Climate*, **30**,6851–6872.

Hess M., P. Koepke, and I. Schult, 1998, Optical Properties of Aerosols and Clouds: The Software Package OPAC, *Bull. Am. Meteor. Soc.*, **79**, 831-844.

Randles, C. A., A. M. da Silva, V. Buchard, and et al. 2017, The MERRA-2 aerosol reanalysis, 1980 onward. Part I: System description and data assimilation evaluation. *J. Climate*, **30**,6823–6850.