Impact of Updating Aerosol Climatology on GFS Forecast

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Introduction

The Modern-Era Retrospective analysis for Research and Applications Version 2 (MERRA2, Buchard et al, 2017; Randles et al, 2017) aerosol climatology uses the three-dimensional variational data analysis (3DVAR) Gridpoint Statistical Interpolation (GSI) meteorological analysis scheme and GEOS-5 atmospheric model to assimilate observational data. The MERRA2 meteorological observing system includes the Moderate Resolution Imaging Spectroradiometer (MODIS) and Advanced Very High Resolution Radiometer (AVHRR) instruments, the Multi Angle Imaging SpectroRadiometer (MISR) and ground-based Aerosol Robotic Network (AERONET), and other numerous additions and bias-corrected systems.

The MERRA2 hourly dataset can be downloaded from NASA's GES DISC and covers the period from January 1, 1980, to the present. The MERRA2 climatology used by the GFS for driving radiation and coupling with microphysics is based on data from 2003 to 2014, which is now outdated. We have downloaded and processed data from January 1, 1980, to January 1, 2024, creating a monthly mean format suitable for GFS usage. This 45-year dataset is valuable for studying recent trends in aerosols and their influence on forecast skill and climate change, as highlighted by the Intergovernmental Panel on Climate Change (IPCC). The aerosols in the MERRA2 climatology include 15 modes: five bins of dust and sea salt, hydrophilic organic carbon, hydrophobic organic carbon, hydrophilic black carbon, hydrophobic black carbon, and sulfate.

This article has two main objectives: 1) to briefly describe the trends and variations in aerosols over the past 45 years, and 2) to investigate the impacts of aerosols on forecast skill within the Unified Forecast System (UFS).

Experiment Design

The numerical weather prediction (NWP) model used in this study is the atmosphere model of the NOAA Global Unified Forecast System (GFS), which features a horizontal resolution of 13 km and extends vertically to the mesopause with 127 levels (C768L128 UFS). The physics package for this study includes the Thompson microphysics scheme, a double-moment approach, along with the Rapid Radiation Transfer Model for GCM (RRTMG). MERRA2 aerosol climatology is utilized to drive the RRTMG radiation and to activate the ice nuclei (IN) or cloud condensation nuclei (CCN) in the microphysics scheme.

To explore the impact of MERRA2 aerosols on forecast skill, four experiments were conducted during the summer of 2020, starting on June 1st with a 00Z cycle for free forecasting over 10 days, and then repeated every three days until September 1st. The experiments are as follows: Experiment 1 (EXP 80s) uses the monthly mean aerosol from January 1980 to December 1993; Experiment 2 (EXP 90s) utilizes the monthly mean aerosol from January 1994 to December 2003; Experiment 3 (EXP CTL) employs the monthly mean aerosol from January 2004 to December 2013; Experiment 4 (EXP 21s) incorporates the monthly mean aerosol from January 2014 to December 2023.

Results

All aerosol modes have experienced a slight increase over the past 45 years, accompanied by significant year-to-year variations, except for sulfate, which has declined, likely due to emissions regulations (Figure 1a). Notably, dust and sea salt concentrations are an order of magnitude higher than those of organic carbon, black carbon, and sulfate. Sulfate levels show considerable regional variation (Figure 1b). In North America and Europe, sulfate concentrations have decreased steadily over the last 45 years. In contrast, East Asia saw an increase from the 1980s to 2006, followed by a decrease from 2006 to the present. Additionally, East Asia exhibits much higher sulfate concentrations compared to North America and Europe.

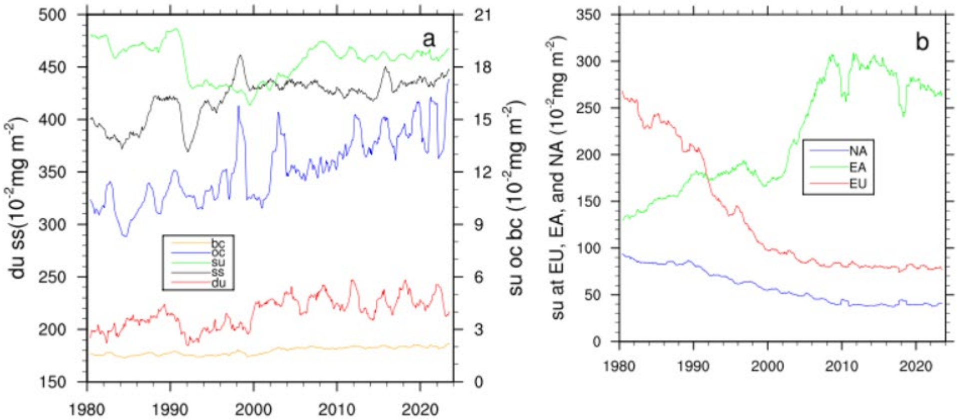

Figure 1. Time variations of the global mean vertically integrated dust, sea salt, sulfate, organic carbon, and black carbon concentrations near the surface are shown in panel (a). Panel (b) presents the time series of sulfate levels for three regions: North America (NA, 30°N to 50°N and 230°E to 300°E), Europe (EU, 40°N to 60°N and 0°E to 40°E), and East Asia (EA, 30°N to 50°N and 110°E to 130°E).

The 500-hPa height anomaly correlation (AC) score is employed to objectively assess the impact of different MERRA2 climatologies on UFS forecast skill. While the effects of the three datasets do not achieve statistical significance at the 95% confidence level relative to EXP CTL, overall improvements in the AC score are observed when using the mean climatologies from the 80s, 90s, 20s, and 21s, with the 21s dataset yielding the best AC score. This suggests that the model's response to the datasets is both realistic and reasonable, indicating that updating to the most recent ten-year mean is more beneficial for current forecasts than relying on older climatologies. Thus, updating the MERRA2 dataset is essential.

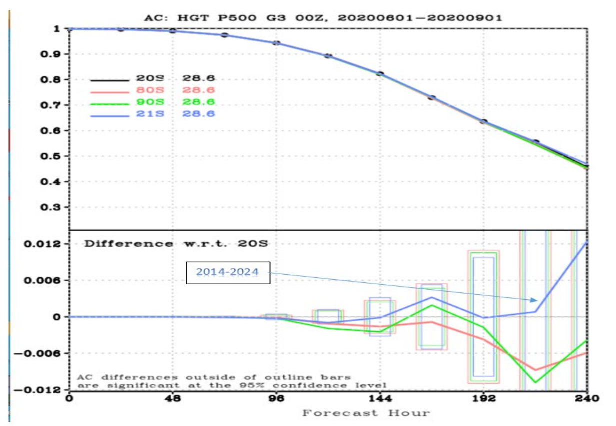

Figure 2. The upper panel shows the 500-hPa height anomaly correlation (AC) scores from the four experiments conducted during the summer of 2020. The lower panels display the AC score differences between the three sensitivity experiments and the EXP CTL. Differences outside the outlined bars are statistically significant at the 95% confidence level based on the Student's t-test.

References

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