From Column to Surface: Connecting the Performance in Simulating Aerosol Optical Properties and $PM_{2.5}$ Concentrations in the NASA GEOS-CCM Model

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1. INTRODUCTION

BACKGROUND

- Aerosols are a key climate forcer and, at the surface, harmful to human health.
- We use **chemistry-climate models** to project the impacts of changing emissions of aerosols and trace gases on quantities such as radiative forcing and air quality.
- In order to have **confidence** in these models, we evaluate them with respect to different **observations**.

OBJECTIVES

In this work we are **analyzing an hindcast simulation** of the NASA Goddard Earth Observing System Chemistry Climate Model (**GEOSCCM)** and investigate the **drivers of uncertainties of GEOSCCM** in simulating:

- global and regional long-term trends for **aerosol loading** and **surface fine particulate matter** ($PM_{2.5}$) concentrations.
- Assumed **relationships** between simulated **aerosol mass** and **optical properties.**

2. DATA AND METHODS

GEOSCCM MODEL

GEOSCCM is the NASA **general circulation model** with various **chemical packages** with **interactive chemistry components**, i.e. chemistry-climate feedbacks are allowed.

Run ID	period	lat, lon, vertical resolution	chemistry	aerosols	emissions	meteorology	boundary conditions
REFD1	1958-2018	1° x 1°, 72	online GMI	online GOCART	CMIP6	free running atmosphere	- prescribed SST - no data assimilation

Table: Configuration of the GEOSCCM model.

OBSERVATIONS & DATASETS

We compare a model hindcast with **satellite, ground-based and model-data fusion** observations spanning two decades.

observations	platform	source	time coverage	spatial coverage
surface $PM_{2.5}$ and components mass	ground-based	IMPROVE network	2001-2018	USA
surface $PM_{2.5}$ mass	data-model fusion	U. Washington, St Louis Atmospheric Composition Analysis Group	1998-2018	global
surface aerosol scattering coefficient	ground-based	IMPROVE network	2001-2018	USA
Aerosol Optical Depth	satellite	MODIS Aqua (NNR retrieval)	2003-2018	global

Table: Observations and datasets used to evaluate GEOSCCM aerosols.

Because the model run is **not driven by real meteorology,** we focus our analysis on **monthly and yearly** time-scales.

3. EVALUATING COLUMN AOD AND SURFACE $PM_{2.5}$

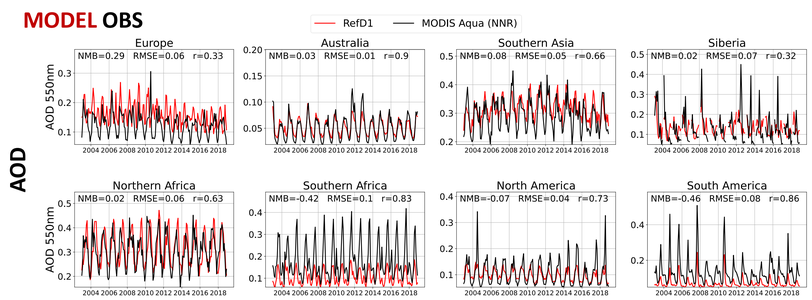


Figure: comparison of regional mean monthly timeseries of AOD between Ref-D1 and MODIS.

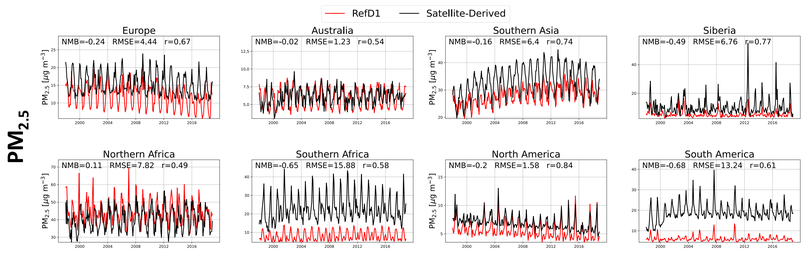


Figure: comparison of regional mean monthly timeseries of $PM_{2.5}$ between Ref-D1 and satellite-derived $PM_{2.5}$.

- **GEOSCCM reproduces month-to month variability of AOD over land** for all regions ($0.6 < r < 0.9$, except in Europe and Siberia: $r \simeq 0.3$), **and of $PM_{2.5}$** ($r > 0.5$).
- There are **strong regionally and seasonally varying biases** evident in AOD and $PM_{2.5}$ e.g. GEOSCCM is **biased low in biomass burning (10% to 70%).**
- Over Europe, the model better capture variability of $PM_{2.5}$ (r=0.8) than for AOD (r=0.33), suggesting some **disconnect between the modeled mass at the surface and the aerosols optical properties at the column level**.

4. EVALUATING SURFACE $PM_{2.5}$ COMPOSITION

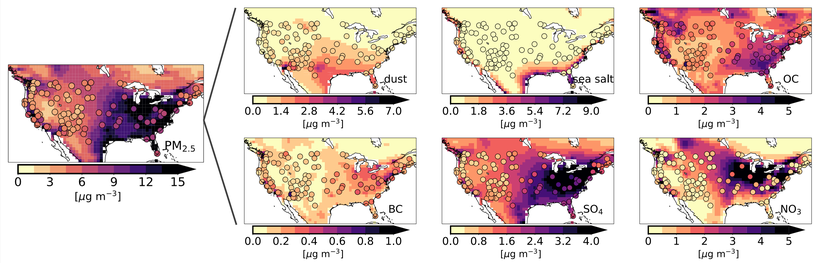
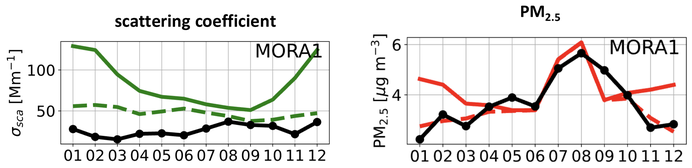


Figure: modelled vs observed (circles, IMPROVE) yearly average of surface $PM_{2.5}$ and composition over the US.

- Performance for speciated $PM_{2.5}$ varies. GEOSCCM is **able to capture spatial variability** of most components.
- In particular, GEOSCCM shows a **high bias in secondary inorganic $PM_{2.5}$** simulated concentrations over CONUS, **especially nitrate** in winter (NMB=7.43).
- The model overestimates Coastal sea-salt (NMB=3) and summertime dust (NMB=0.3).
- The model performs well for carbonaceous species (OA and BC, NMB < 0.25).

5. CONNECTING $PM_{2.5}$ AND SCATTERING COEFFICIENT



Seasonal cycle of surface scattering coefficient (green, left) and total $PM_{2.5}$ (red, right) at selected IMPROVE sites (here MORA1 Mount Renier is shown) . Black lines: IMPROVE observations, solid lines: Ref-D1, dashed lines: Ref-D1 with nitrate component removed.

- The model is able to better capture the seasonal variability of of $PM_{2.5}$ ($r < 0.59$) compared to the scattering coefficient at all sites ($r < 0.2$).
- The **performance of the model improves** significantly **when removing the nitrate.**

We **reconstruct the observed scattering** coefficient using GEOSCCM assumed scattering efficiencies (optical tables, OT) for **different combinations** of modeled and observed RH and PM composition to **isolate the importance of modeled scattering efficiencies, RH and PM composition in simulating the scattering coefficient.**

SCATTERING COEFF = *f*(scattering efficiency, PM species mass, RH)

R1: RECONSTRUCT SCATTERING COEFF = *f* (scattering efficiency **MODEL**, PM species mass **OBS**, RH **OBS**)

R2: RECONSTRUCT SCATTERING COEFF = *f* (scattering efficiency **MODEL**, aerosol PM mass **OBS**, RH **MODEL**)

R3: RECONSTRUCT SCATTERING COEFF= *f* (scattering efficiency **MODEL**, PM species mass **MOD**, RH **OBS)**

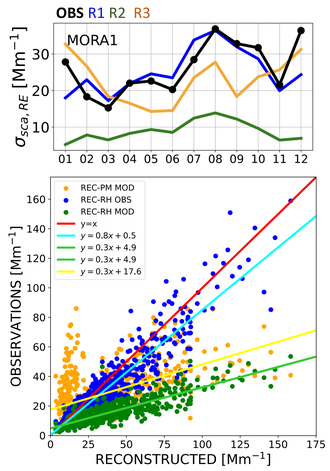


Figure: Reconstructed scattering for 3 different combinations of modelled and observed RH, $PM_{2.5}$ and scattering efficiency (OT).

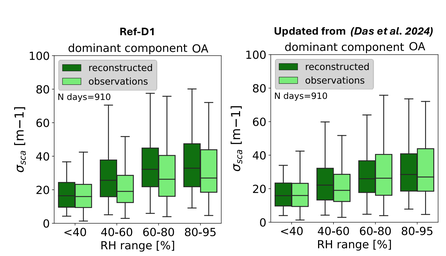


Figure: comparison between the observed and reconstructed scattering for different RH ranges when OC is dominant component in the $PM_{2.5}$ (fraction > 0.5) . Left: using current OT , right updated OT.

- scattering efficiency assumptions **(optical properties, OT) are compatible with observations,** so that **errors in simulated scattering** are more **related to simulated aerosol mass and RH** than the OT and size distribution assumptions in GEOSCCM.

6. CONCLUSIONS

- Our findings suggest that aerosol mass loading and optical properties could both be improved in GEOSCCM by updating the emission inventories, especially over biomass burning regions.
- Biases in $PM_{2.5}$ mass can be reduced by reducing biases in nitrate mass loading component.
- Improving RH simulation could substantially improve the representation of the aerosol scattering coefficient in GEOSCCM.

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