The Representation of Aerosols in GMAO's Newest Reanalyses

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Introduction

- Advancements in model development and data assimilation techniques, as well as evolving observing system types have necessitated the need for updated reanalysis products using the Goddard Earth Observing System (GEOS)
- Each reanalysis has a configuration designed its intended use case, building upon innovations since production began for the MERRA-2 reanalysis in 2015
- MERRA-21C is still completing its initial spin up and will be the first GEOS product that uses GOCART Second Generation (GOCART-2G; Collow et al., 2024)

Table 1: Aerosol model and data assimilation configurations used to produce MERRA-2, GEOS-IT, GiOcean, and MERRA-21C

Reanalysis	MERRA-2	GEOS-IT	GiOcean	MERRA-21C
Description	Described by Gelaro et al., 2016	Atmospheric conditions for NASA instrument team retrievals with NRT latency	Initial conditions for seasonal to subseasonal prediction; One way weakly coupled	Stepping stone toward a two-way coupled Earth system reanalysis
GEOS ADAS Version	5.12.4	5.29.4	GEOS S2S-3	5.30.3
Atmospheric Data Assimilation	3D Variational	3D Variational	Replay to GEOS-IT	Hybrid 4D ensemble variational
Atmospheric Resolution	~50 km, 72 vertical levels	~50 km, 72 vertical levels	~50 km, 72 vertical levels	~25 km, 72 vertical levels
Aerosol Model	GOCART (5 species)	GOCART (+ Nitrate)	GOCART (+ Nitrate)	GOCART-2G (+ Nitrate and Brown Carbon)
Aerosol Scavenging	Controlled by GOCART, influenced by observation corrected precipitation (CPCU)	Controlled by moist physics	Controlled by GOCART, influenced by observation corrected precipitation (CPCU)	Controlled by moist physics, influenced by observation corrected precipitation (IMERG)
Biomass Burning Emissions	HFED->QFED 2.4r6	QFED 2.6r1	QFED 2.6r1	QFED 2.6r1(->QFED 3.1?)
Anthropogenic Emissions	Described by Randles et al. 2017	CEDS v2021_04_21	CEDS v2021_04_21	CEDS v2021_04_21
Observing System for 2D PSAS + LDE* Assimilation of Aerosol Optical Depth (AOD)	AVHRR, AERONET, MODIS Neural Net Retrieval for Dark Target, MISR	AERONET, MODIS Neural Net Retrieval for Dark Target and Deep Blue	Replay to GEOS-IT	AERONET, MODIS Neural Net Retrieval for Dark Target and Deep Blue

Results: Evaluation of AOD

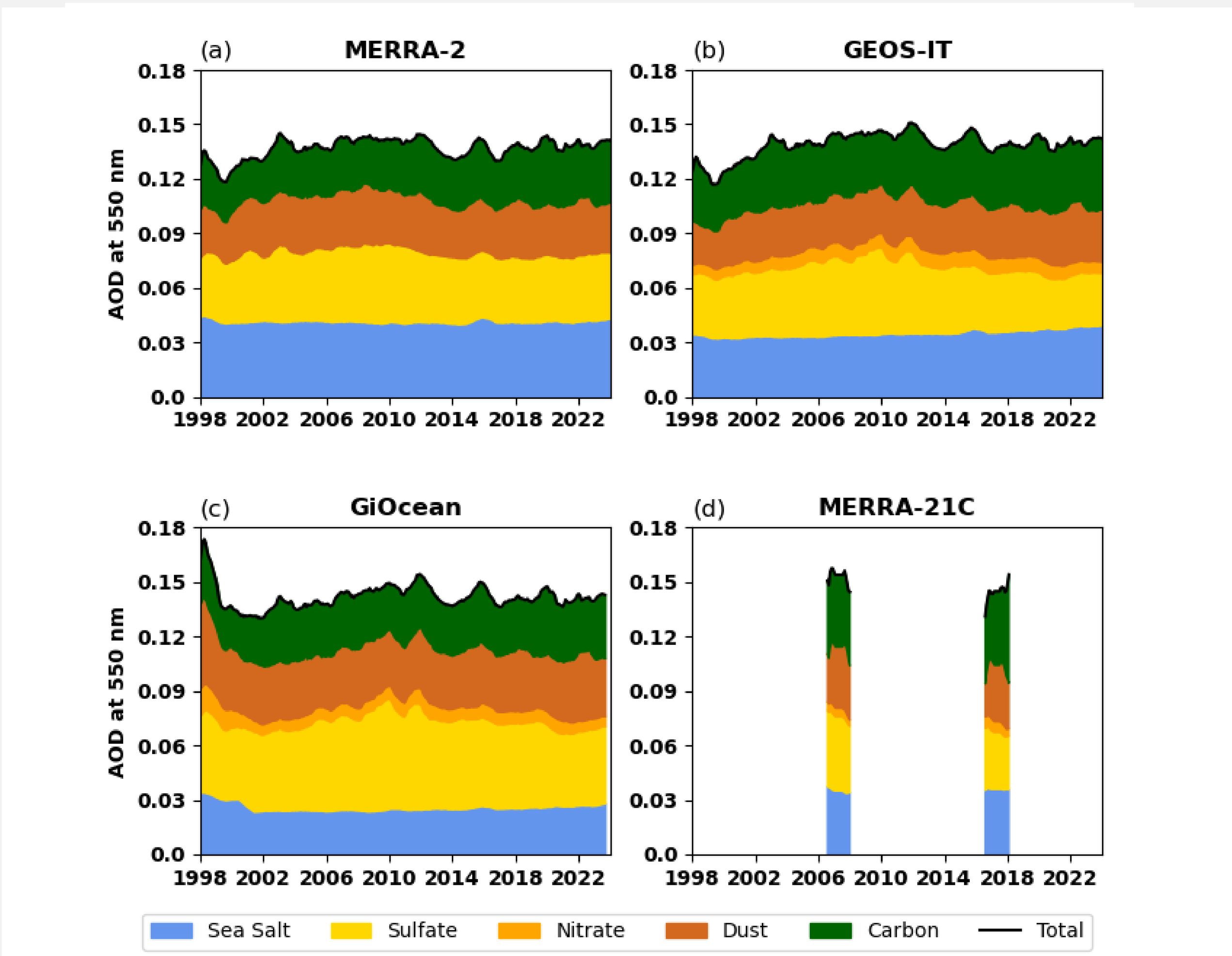

Figure 1: 12-month running mean timeseries of global mean speciated AOD at 550 nm in (a) MERRA-2, (b) GEOS-IT, (c) GiOcean, and (d) the spin up period for MERRA-21C

- Global mean total AOD is well correlated between the reanalysis products
- AOD is too high in GiOcean before MODIS data becomes available for assimilation, perhaps as a result of scavenging in a model with two-moment microphysics
- GEOS-IT and GiOcean have an increasing trend in sea salt due to wind speed, not present in MERRA-2
- Sulfate AOD is reduced in GEOS-IT after 2020 due to a lack of degassing volcanic emissions
- AOD has increased slightly in MERRA-21C

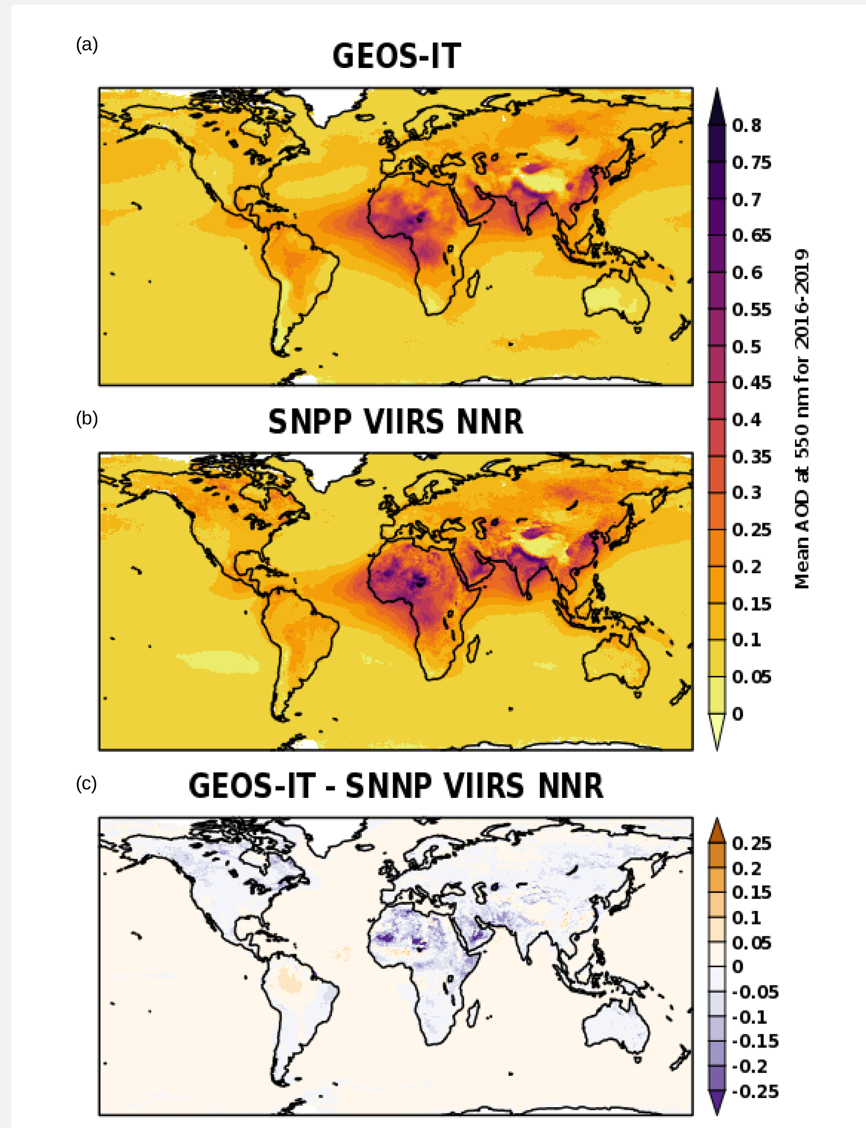

Figure 2: AOD at 550 nm averaged over January 2016 through December 2019 from (a) GEOS-IT, (b) SNPP VIIRS NNR, and (c) the difference between GEOS-IT and SNPP VIIRS NNR.

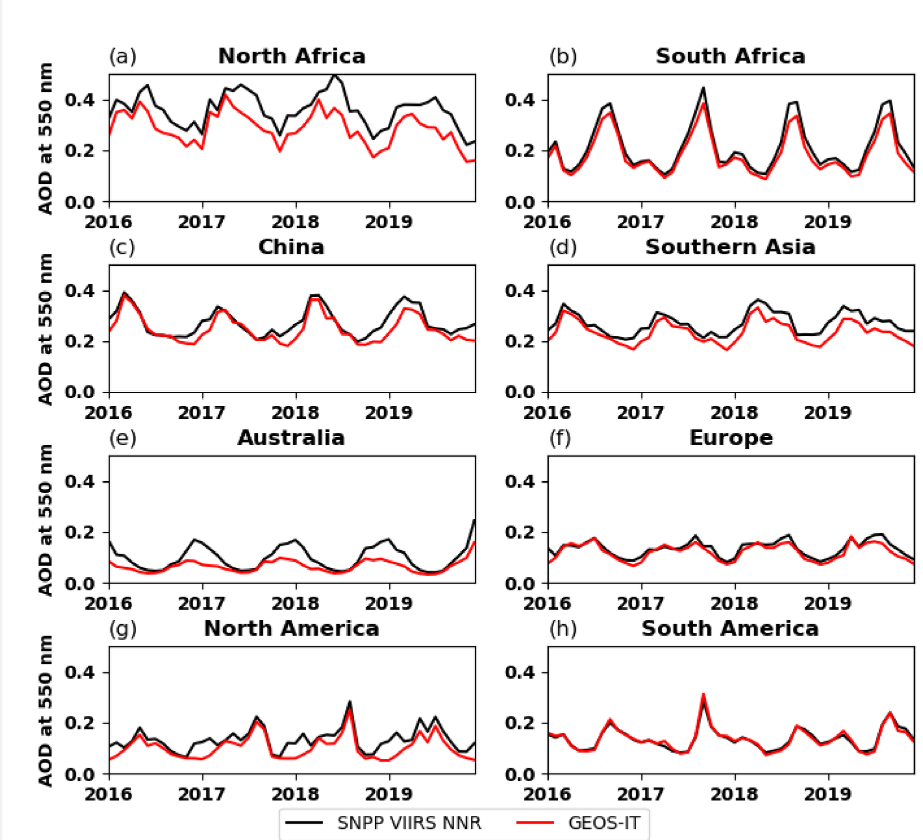

Figure 3: Area averaged regional timeseries of AOD at 550 nm for the period of January 2016 through December 2019 from GEOS-IT and SNPP VIIRS NNR for (a) North Africa, (b) South Africa, (c) China, (d) Southern Asia, (e) Australia, (f) Europe, (g) North America, and (h) South America.

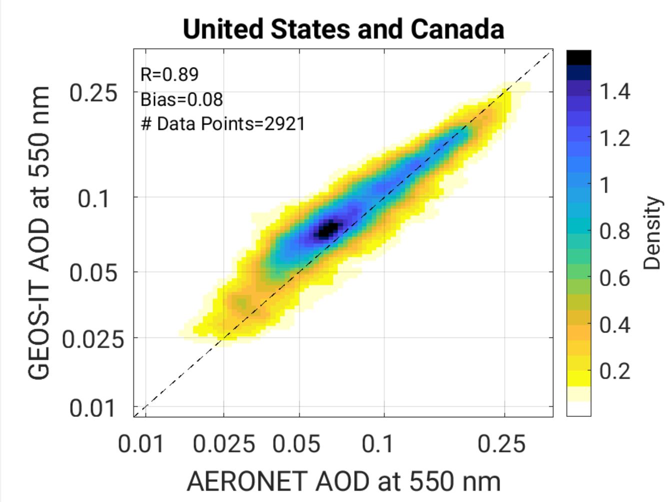

Figure 4: Kernel density estimate of monthly mean AOD in GEOS-IT for 2016 through 2019 against AERONET observations from 77 stations across the United States and Canada. Statistics are computed as log(AOD+0.01).

- In Figures 2 and 3, GEOS-IT is sampled according to the availability of SNPP VIIRS observations
- SNPP VIIRS NNR is bias corrected against AERONET observations and subsequently blended according to the observation count of dark target, deep blue, and ocean retrievals
- Despite the bias correction, AOD is higher in SNPP VIIRS NNR than MODIS NNR, leading to an underestimation of AOD at 550 nm over land regions in GEOS-IT
- The negative bias is year-round in Africa and isolated to the boreal winter months in North America, Australia, and Asia, disagreeing with an evaluation of GOCART-2G without AOD assimilation

Results: Surface $PM_{2.5}$ Across the United States

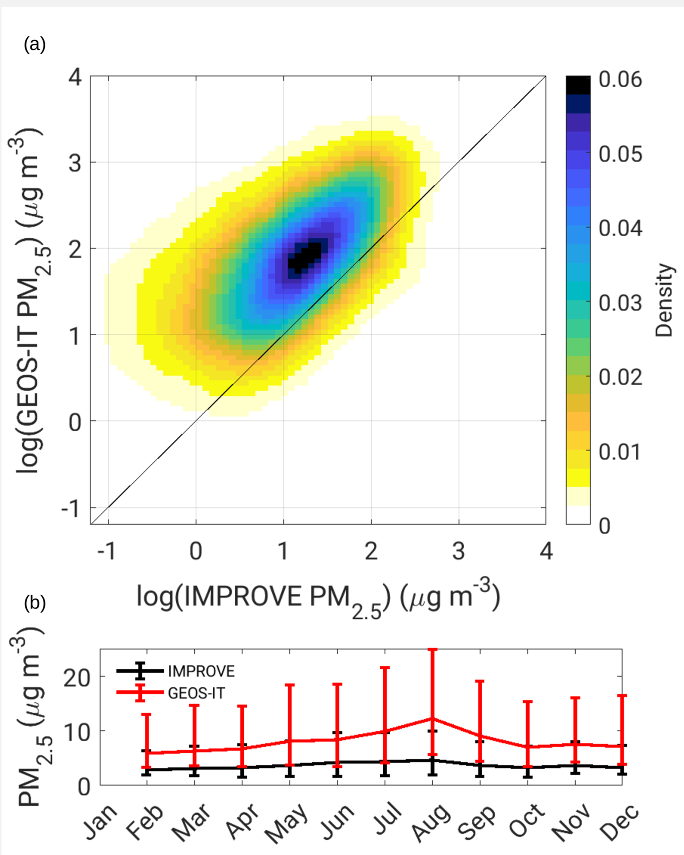

Figure 5: (a) Kernel density estimate for the log($PM_{2.5}$) in GEOS-IT against IMPROVE observations in the United States during the year 2016. (b) Monthly mean $PM_{2.5}$ in GEOS-IT and IMPROVE. Error bars indicate the 25th and 75th percentiles.

- Particulate matter smaller than 2.5 microns ($PM_{2.5}$) in GEOS-IT is the reconstructed mass accounting for an aerodynamic diameter and particle swelling at a relative humidity of 35% following Collow et al. (2024)
- IMPROVE stations are typically located in national parks and are indicative of background aerosol
- Further investigation is needed to understand the overestimate in $PM_{2.5}$ despite good agreement for AOD over the United States

Safeguarding Against the Loss of MODIS

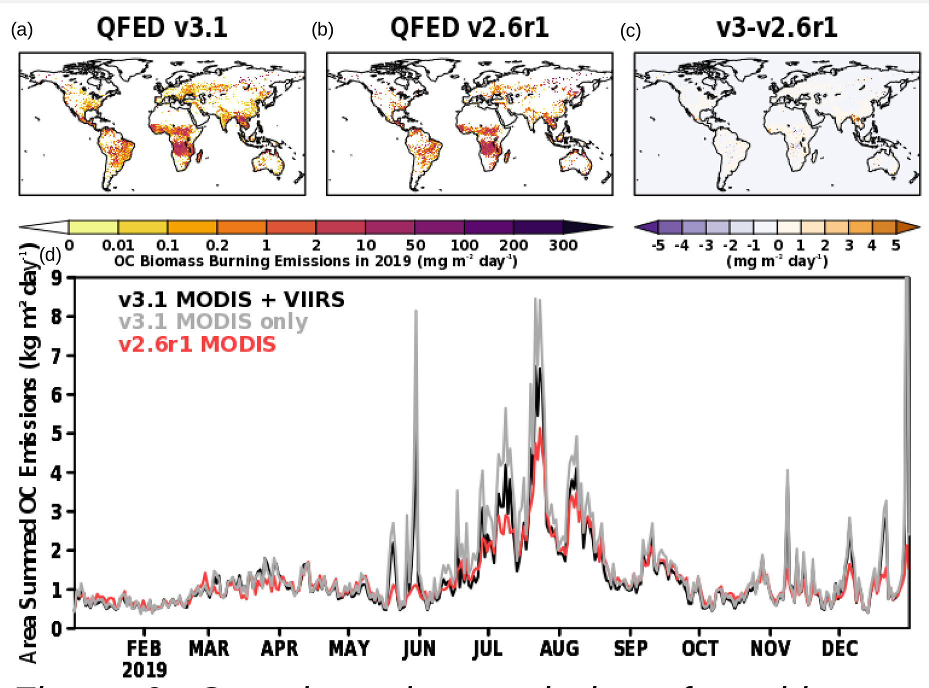

Figure 6: Organic carbon emissions from biomass burning from (a) QFED v3.1 (MODIS + VIIRS) and (b) QFED 2.6r1 (MODIS), and (c) their difference for 2019. (d) Timeseries of daily, global summed organic carbon emissions throughout 2019.

- MODIS is used for the assimilation of AOD and generating biomass burning emissions
- The goal is to have datasets for VIIRS that will result in minimal discontinuities should MODIS data no longer be available
- VIIRS has a different footprint that is capable of detecting more, smaller fires
- A new version of QFED is being tested in which annual mean emissions from VIIRS are scaled to match MODIS

*PSAS + LDE = Physical-space Statistical Analysis System Local Displacement Ensemble

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