JEDI-Based Ensemble-Variational Data Assimilation System for Global Aerosol Forecasting at NCEP: Near-Real-Time (NRT) Results and Future Plans

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[5]NOAA NESDIS STAR
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[7]CIRA, CSU

International Cooperative for Aerosol Predication (ICAP)
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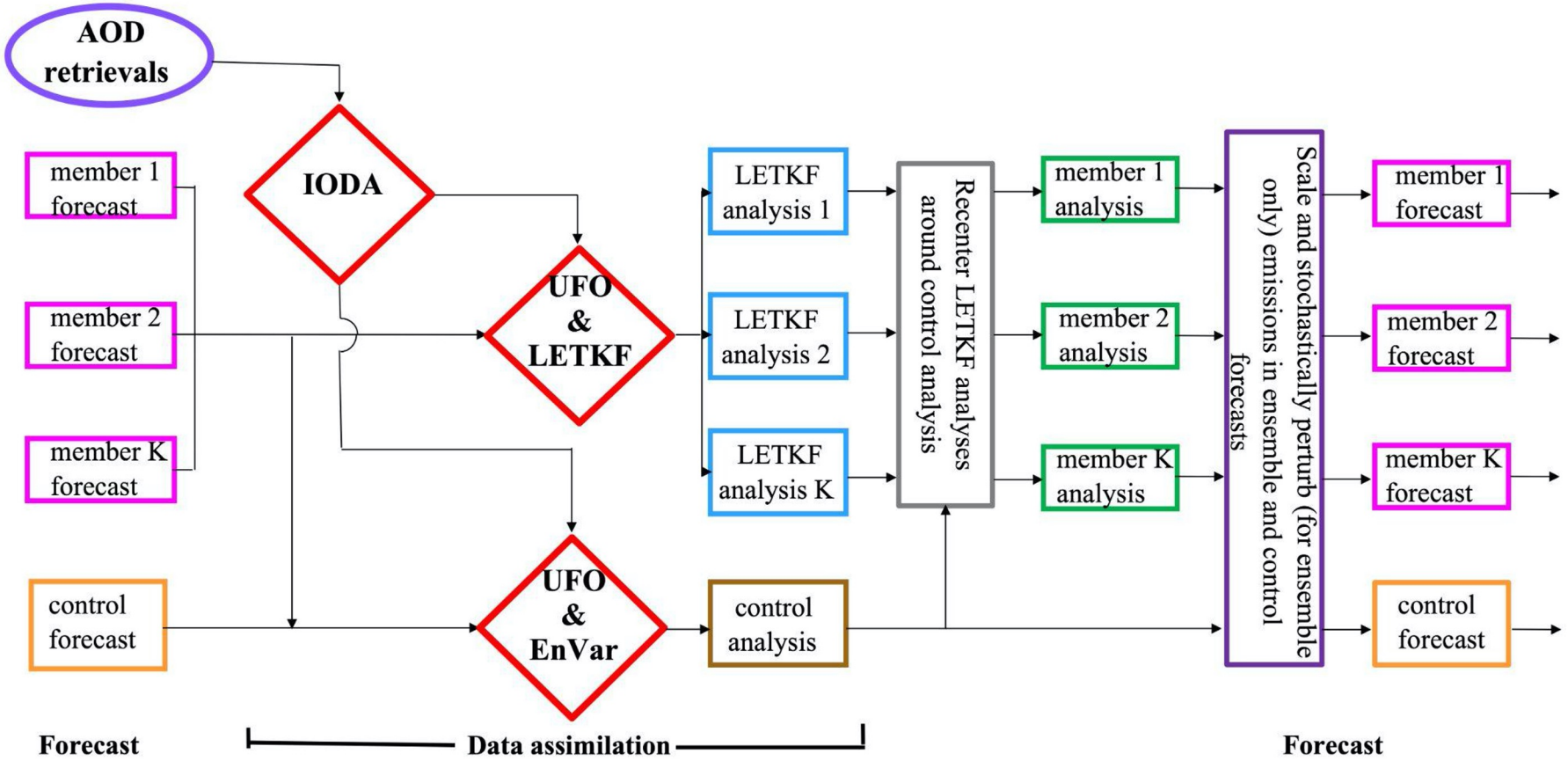
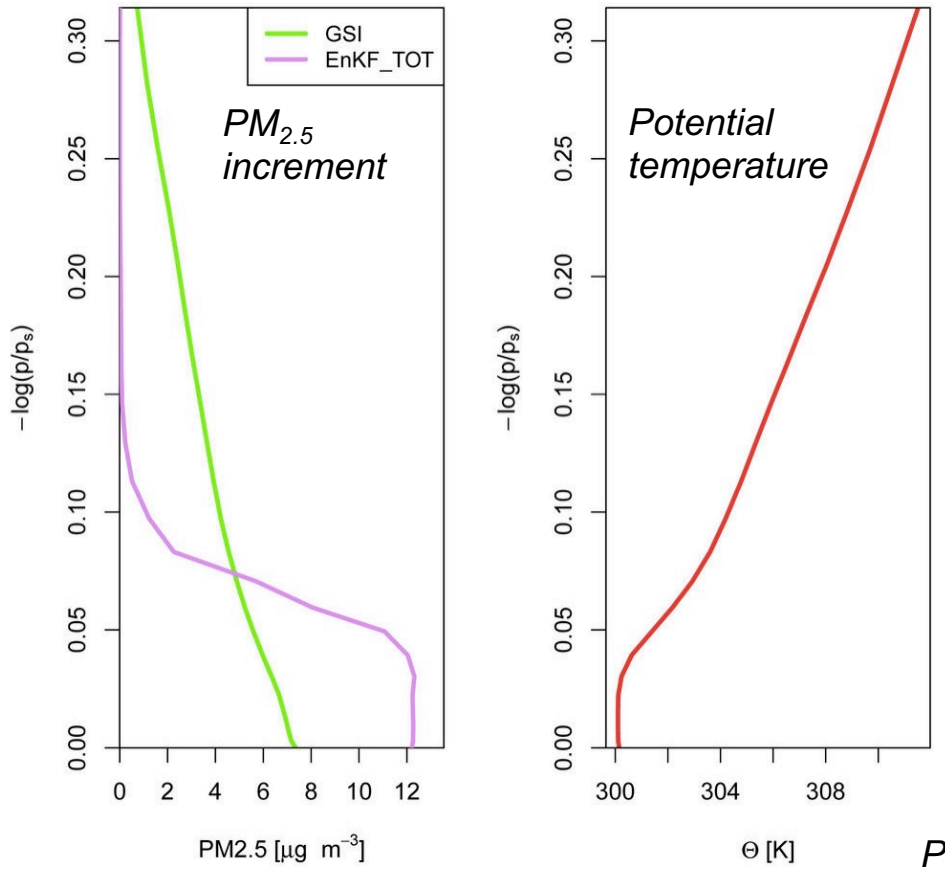
JEDI-based Ensemble-Variational Aerosol Data Assimilation (DA) System for GEFS-Aerosols Coupled with GOCART



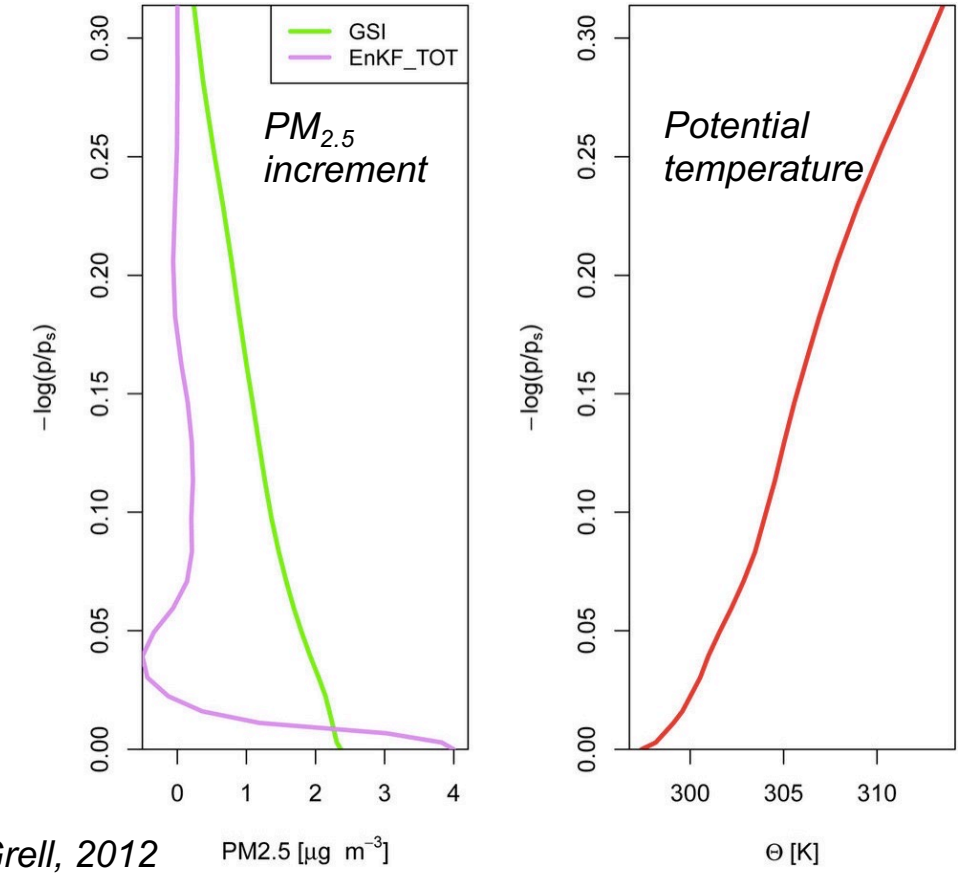
- **JEDI**: Joint Effort for Data assimilation Integration -- a collaborative effort led by JCSDA;
- **AOD**: Aerosol optical depth (AOD) at 550 nm (***currently from VIIRS and MODIS instruments***);
- **IODA**: Interface for Observation Data Access (***VIIRS/MODIS/AERONET AOD converters in Python available in JEDI/IODA***);
- **UFO**: Unified Forward Operator (***AOD forward operator and its tangent-linear and adjoint developed in JEDI/UFO using scattering lookup tables from CRTM and NASA***);
- **EnVar/LETKF**: Ensemble-Variational solver/Local Ensemble Transform Kalman Filter (***3D mass mixing ratios of 15 GOCART aerosol species are selected as control variables***).

Comparison of Surface PM2.5 Assimilation using 3DVar and EnKF

Dynamically **unstable** scenario



Dynamically **stable** scenario



Pagowski and Grell, 2012

- **3DVar adopting static background error covariances** produces similar $PM_{2.5}$ increment profile structure in these two scenarios.
- **EnKF using flow-dependent background error covariances** produces more realistic $PM_{2.5}$ increments that vary with meteorological conditions.

Stochastically-Perturbed Emissions (SPE, currently implemented in CCPP-based GEFS-Aerosols) based on ECMWF's Stochastically Perturbed Parametrization Tendency (SPPT) Scheme to Account for Aerosol Emission Uncertainty

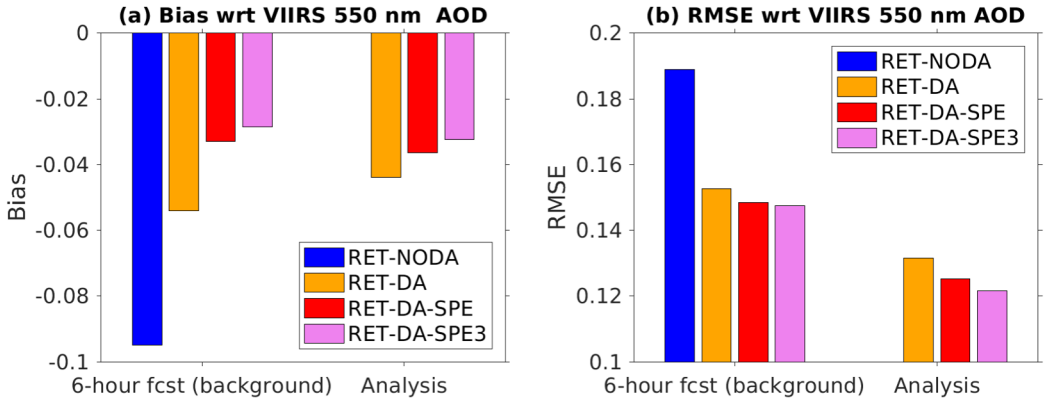
Emission scaling factor mainly to reduce modeled AOD bias

Emission perturbation standard deviation to increase aerosol ensemble spread

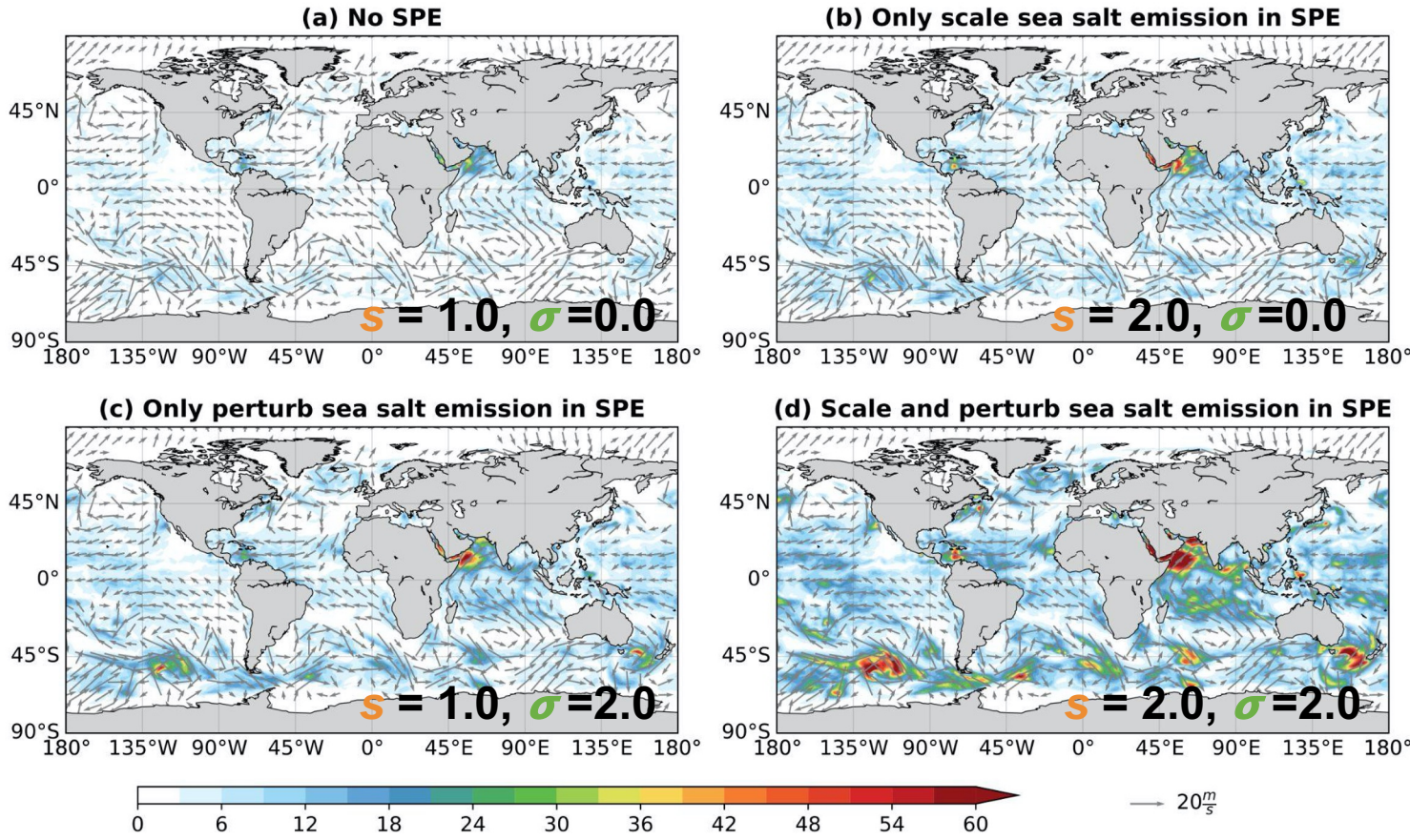
$$f = s(1 + w\sigma)$$

Normally-distributed random noise used in SPPT

Innovation stats from one-month cycled assimilation of VIIRS AOD in June 2016

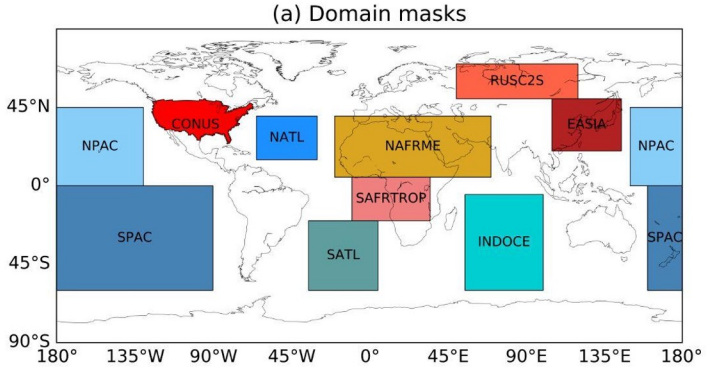


Spread of total sea salt mass mixing ratios at 1000 hPa from twenty-member GEFS-Aerosols 6-hour forecast

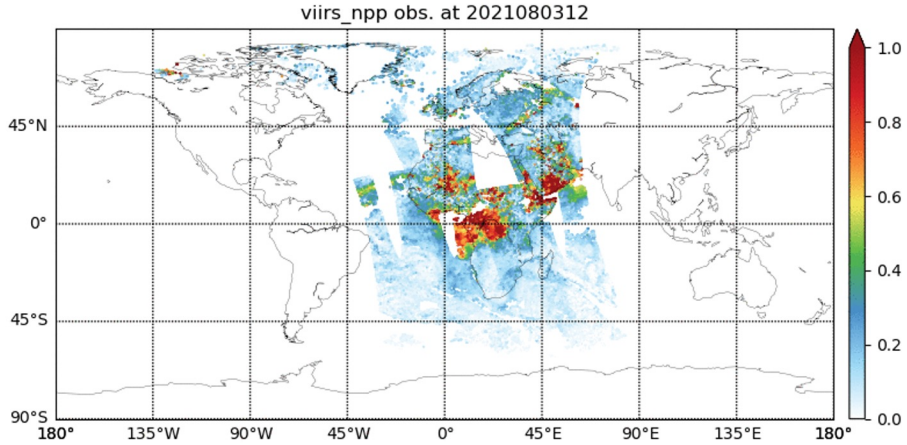


NRT AOD Assimilation Experiment at NOAA/OAR/GSL

- **The JEDI-based global aerosol DA system has been evaluated in near real-time (NRT) at NOAA/OAR/GSL since July 2021.**
  - Six-hourly assimilation of VIIRS 550 nm AOD retrievals derived from NOAA Suomi-NPP satellite;
  - 3D-EnVar and EnKF (LETKF) for aerosol update;
  - EnKF (LETKF) analysis recentered around EnVar analysis;
  - NASA-LUTs for AOD forward operator calculation;
  - Meteorological variables corrected by adding regridded increments from operational GDAS analyses;
  - 1-control plus 20-member ensemble at C96 (~100km) using GSL's CCPP version of GEFS-Aerosols model for aerosol forecasts.



NOAA S-NPP VIIRS AOD retrievals at 550 nm



	AOD DA	Ensemble members	Stochastically-perturbed emissions	
NRT-NODA	No	N/A	No	
NRT-DA-SPE	Yes	20	Scaling factors /perturbation SD	
			Dust	1.2 / 2.0
			Sea salt	1.5 / 2.0
			Anthropogenic	1.2 / 2.0
			Biomass burning	1.0 / 2.0

Online Display of NRT Diagnostics at NOAA/OAR/GSL (10/01/2021- present)

System description: https://ruc.noaa.gov/projects/nrt/
NRT diagnostics: https://ruc.noaa.gov/projects/nrt/Aerosol-DA/

U.S. Department of Commerce I National Oceanic & Atmospheric Administration I NOAA Research

Global Systems Laboratory
Research today for better forecasts tomorrow

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Aerosol-DA Home Info Page

Current and Forecast Graphics

GSL Aerosol-DA Page

JEDI Info

About JEDI

GEFS-Aerosols

About GEFS-Aerosols

GEFS-Aerosols Data Assimilation Statistics

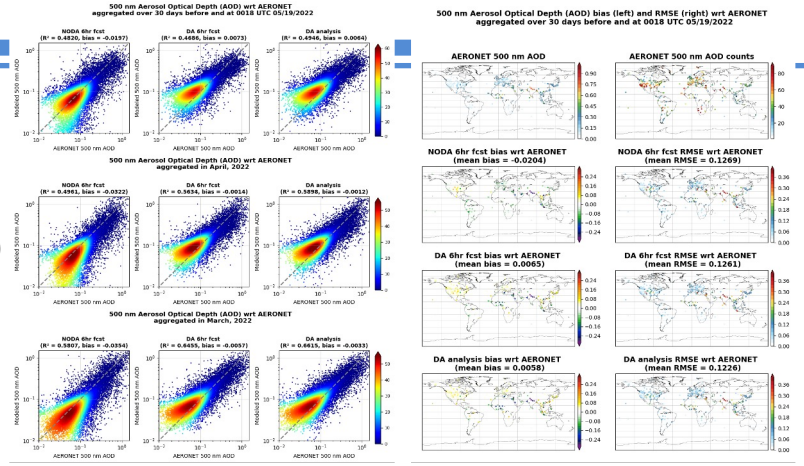
Model: Aerosol-DA Area: Full Date: 19 May 2022 - 00Z

Model: Aerosol-DA **Domain:** Full **Date:** 19 May 2022 - 00Z

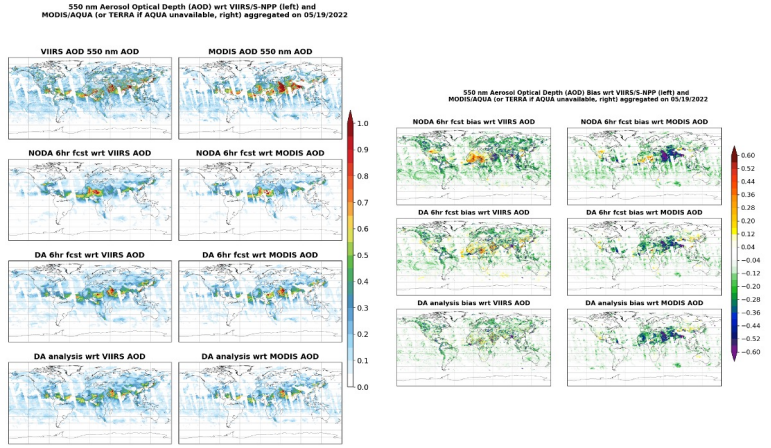
	All times	Loop	Valid Time: Thu 00 / Forecast: 000	
all fields			000	all fields
AERONET AOD Scatterplots	✓	✓	000	AERONET AOD Scatterplots
AERONET AOD Stats	✓	✓	000	AERONET AOD Stats
VIIRS/MODIS AOD	✓	✓	000	VIIRS/MODIS AOD
VIIRS/MODIS AOD Bias	✓	✓	000	VIIRS/MODIS AOD Bias
GEOS/CAMS AOD	✓	✓	000	GEOS/CAMS AOD
GEOS/CAMS AOD Bias	✓	✓	000	GEOS/CAMS AOD Bias
GEOS/CAMS AOD RMSE	✓	✓	000	GEOS/CAMS AOD RMSE

U.S. Department of Commerce I National Oceanic and Atmospheric Administration
Earth System Research Laboratories I Global Systems Laboratory
https://ruc.noaa.gov/projects/nrt/Aerosol-DA/Welcome.cgi
Last Modified: 03/31/2022 14:46 UTC

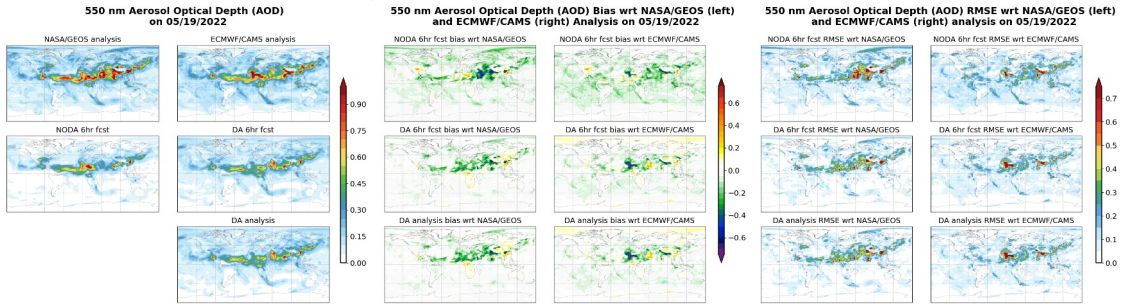
AERONET 500 nm AOD



VIIRS/MODIS 550 nm AOD



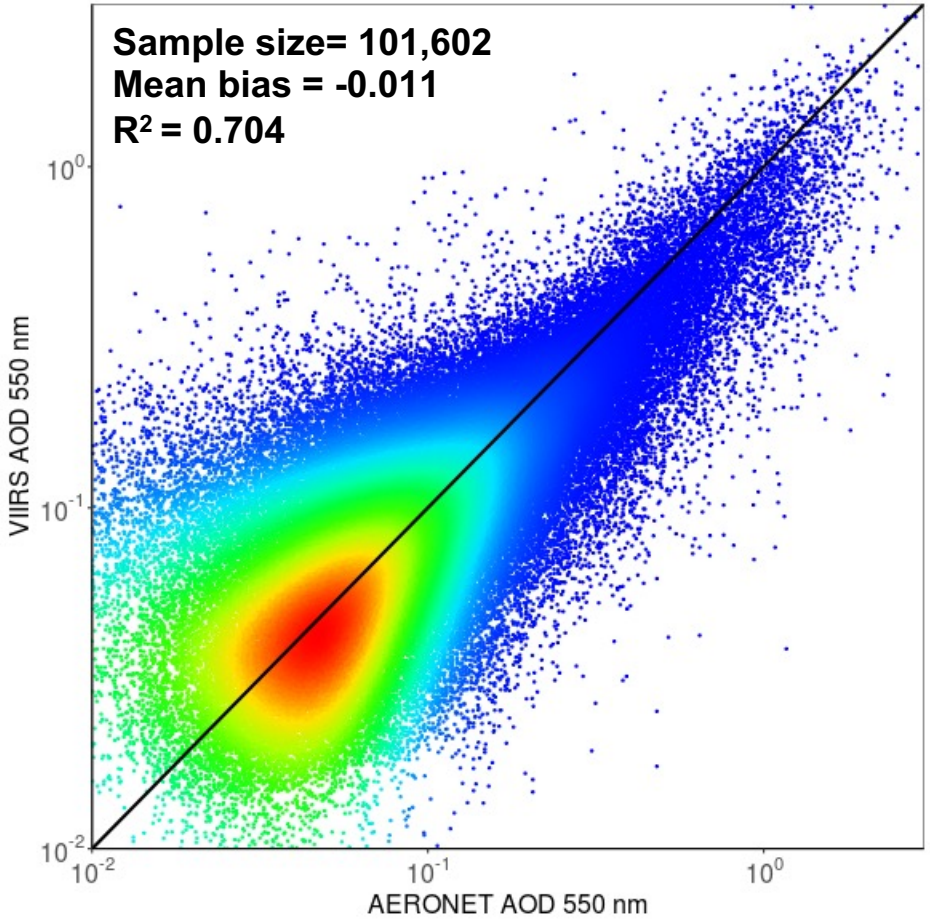
NASA/GEOS and ECMWF/CAMS 550 nm AOD analysis



We also plan to include more evaluation against **NRL's NAAPS** products and **ICAP AOD** product in the future.

550 nm AOD of VIIRS/S-NPP and NOAA20 versus AERONET Level 1.5

- 550 nm AOD of VIIRS/S-NPP and NOAA20 versus AERONET Level 1.5 in October, 2021 – September 2022
- VIIRS AOD samples were collected by averaging high-quality VIIRS AOD retrievals in a 10 km radius circle in a 1-hour time window around valid AERONET sample.
- In the circle, the total count of available high-quality VIIRS AOD retrievals is at least 75% its allowable maximum (~533 for a 10-km circle) in the circle.



*Note that the near-real-time AERONET Level 1.5 AOD on average has **a bias of +0.02** and **one sigma uncertainty of up to 0.02** (Giles et al., 2019).*

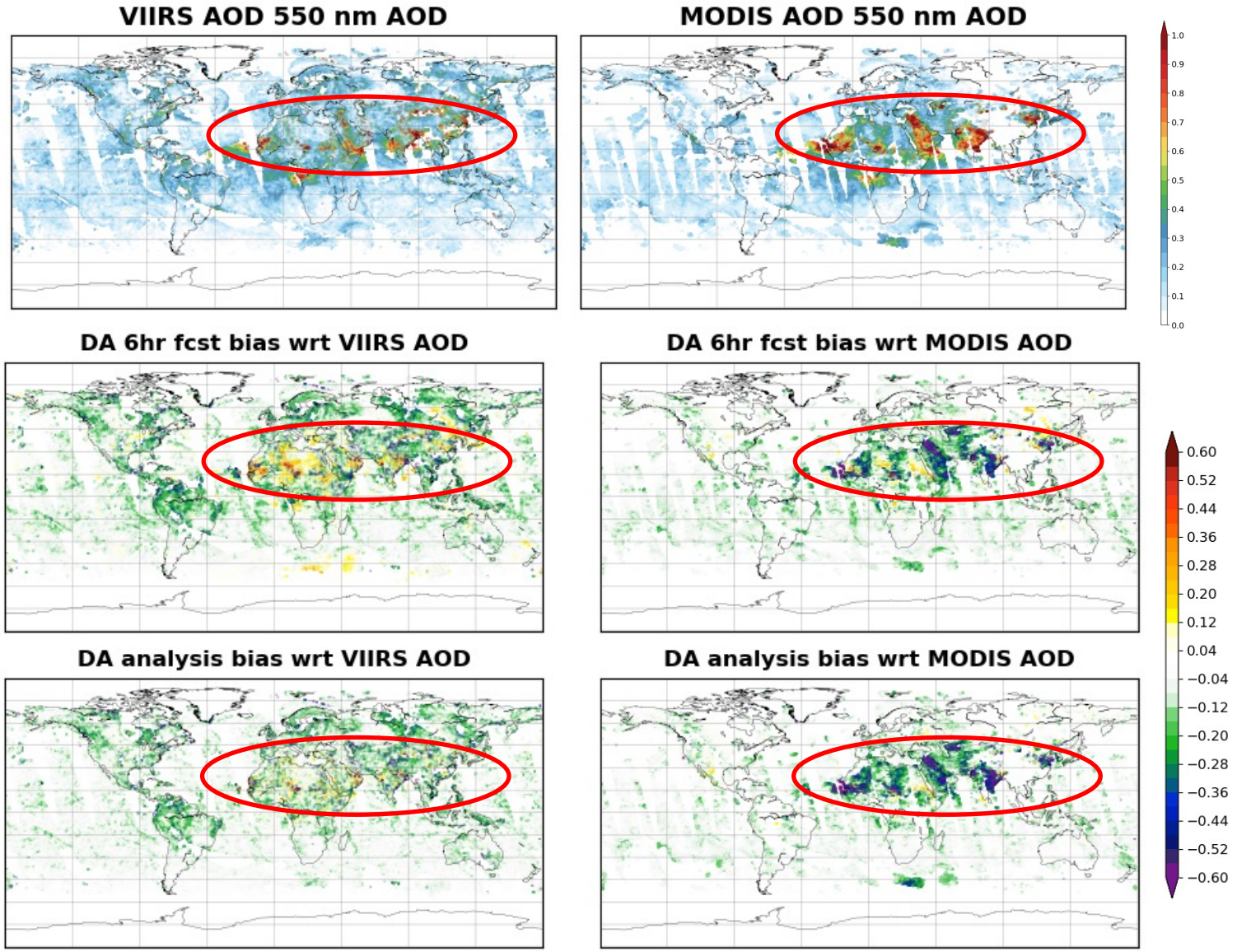
550 nm AOD Retrievals from VIIRS/S-NPP and MODIS/Aqua

Aggregated 550 nm AOD from VIIRS/S-NPP and MODIS/Aqua on 06/02, 2022

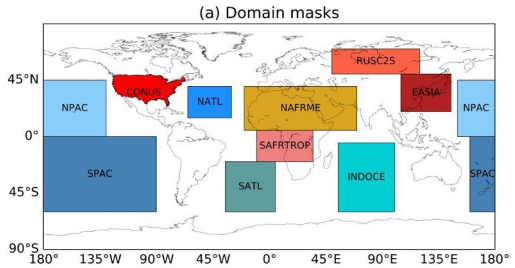
NRT-DA-SPE 6h fcst bias

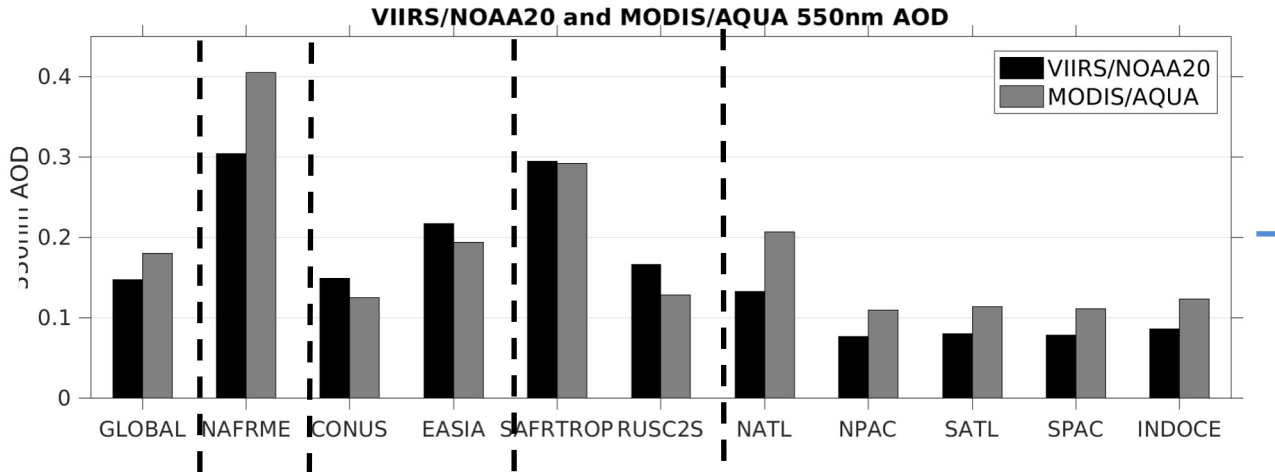
Assimilate VIIRS/S-NPP 550 nm AOD

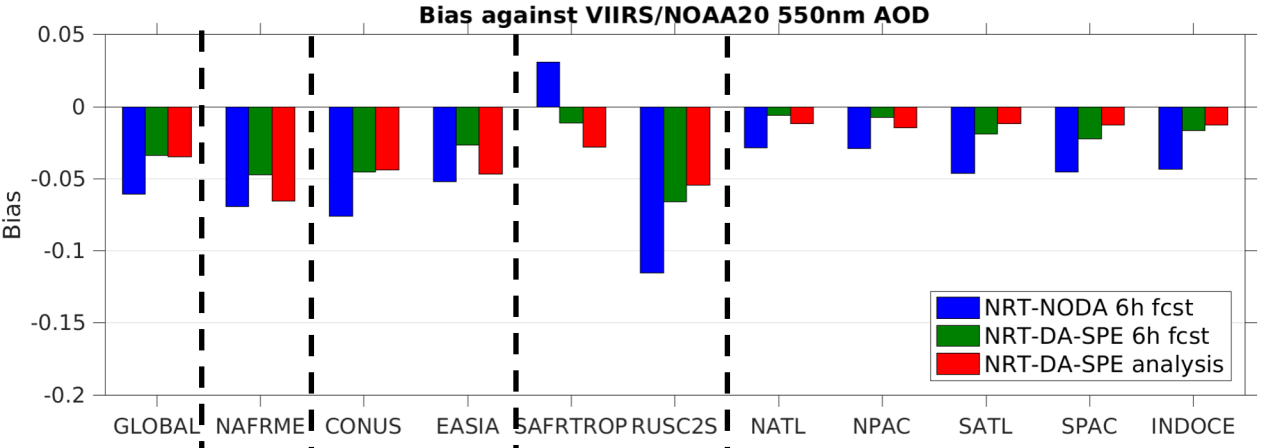
NRT-DA-SPE analysis bias

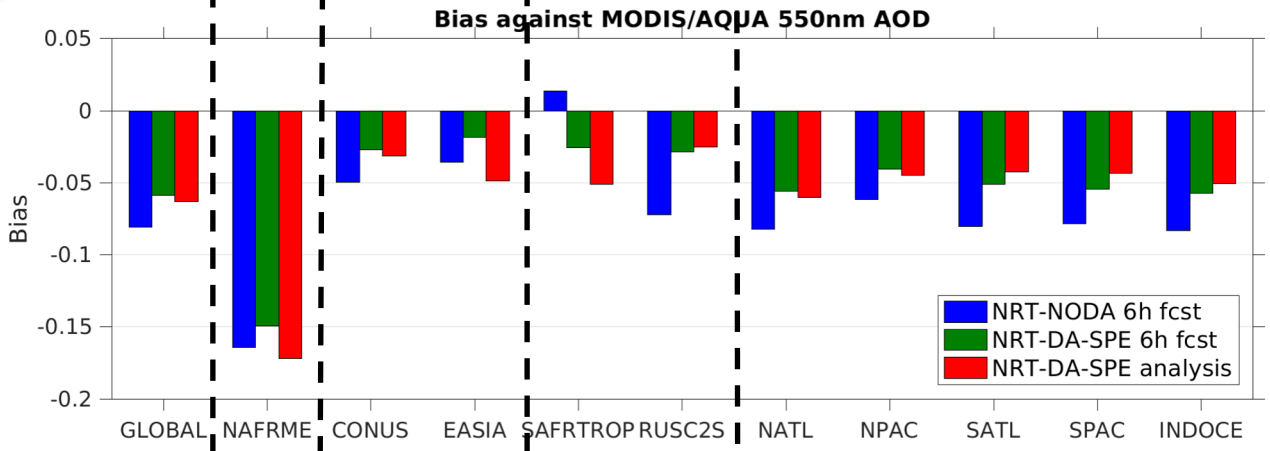


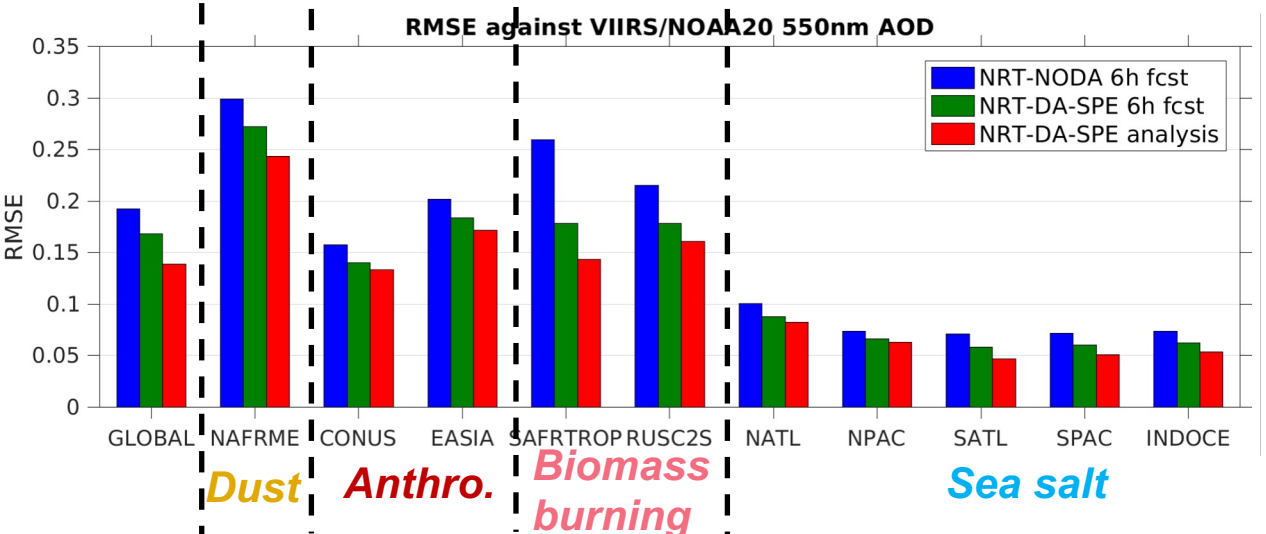
Regional average of bias and RMSE against independent VIIRS/NOAA20 and MODIS/AQUA 550 nm AOD in June-August, 2022

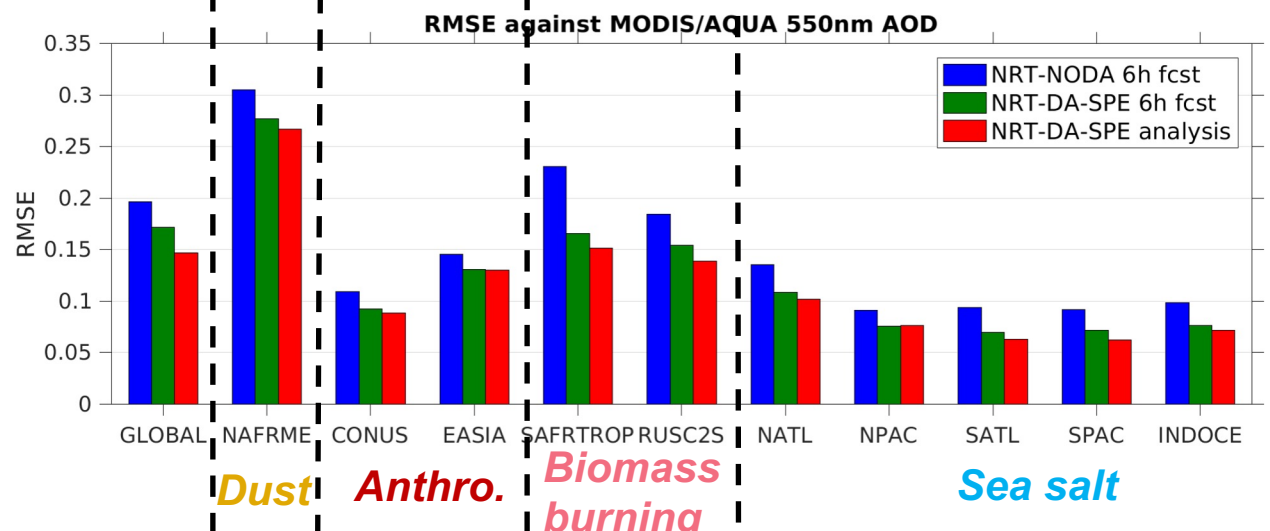






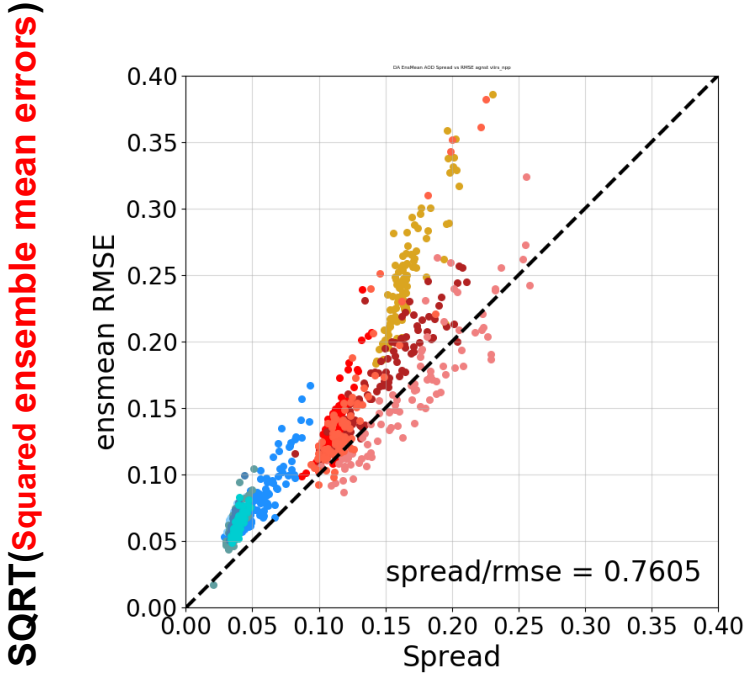




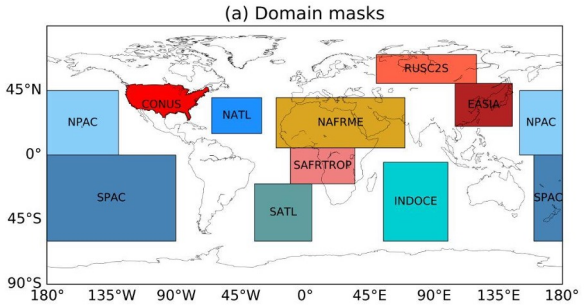


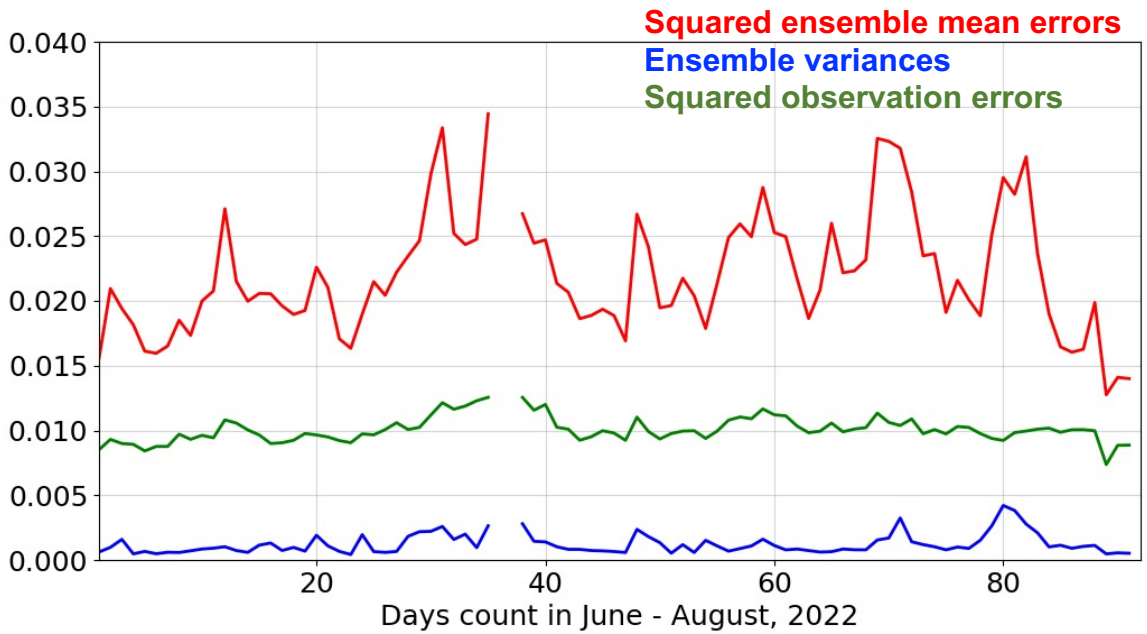
Evaluation of Ensemble Error-Spread Consistency against VIIRS/S-NPP 550 nm AOD retrievals

A robust ensemble system is expected to maintain a good error-spread consistency (Houtekamer and Mitchell, 2005), i.e., Sqrt(Squared ensemble mean errors) = Sqrt(Ensemble variances + Squared observation errors)



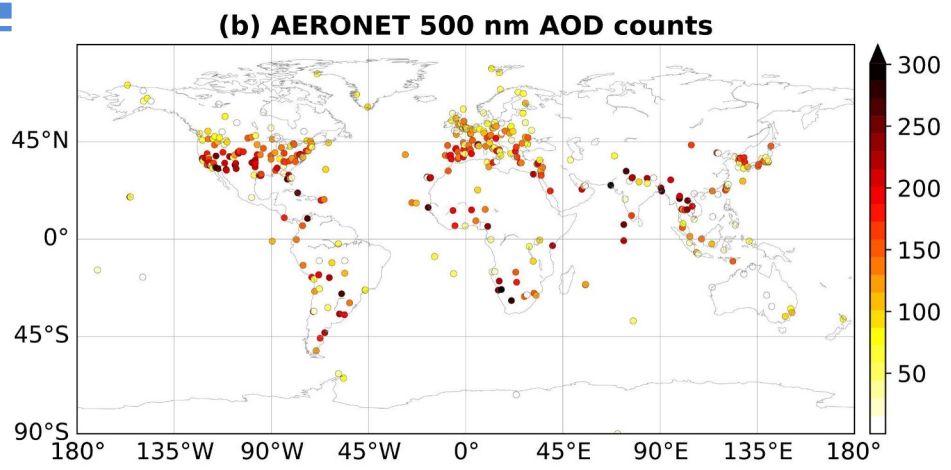
SQRT(Ensemble variances + Squared observation errors)





- Ensemble spread (sqrt(blue plus green)) is smaller than ensemble mean error (sqrt(red)) suggesting an under-dispersive ensemble, which restricts the correction from observations to model variables.
- Ensemble variances too small (to perturb aerosol physical parameterizations may likely help), although it in general follows similar evolution pattern as squared ensemble mean error (this is desirable).
- Estimated AOD retrieval uncertainty (= a + b*AOD) too large?

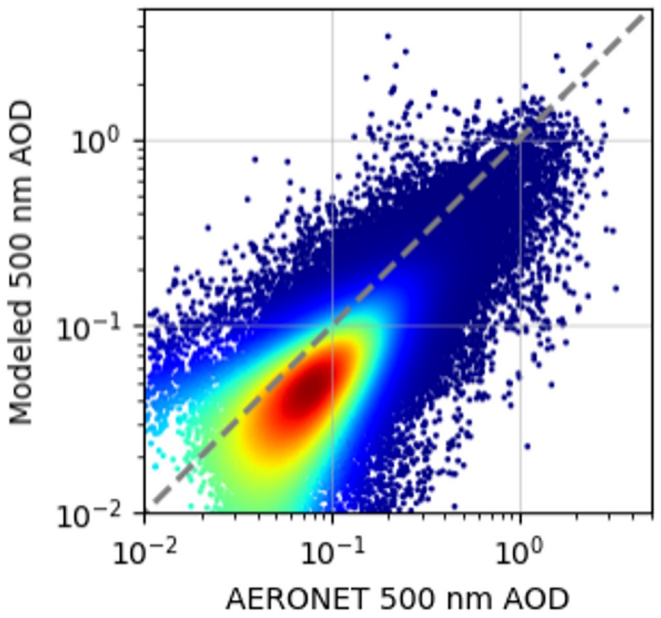
Comparison with independent AERONET Level 1.5 500 nm AOD in June– August, 2022



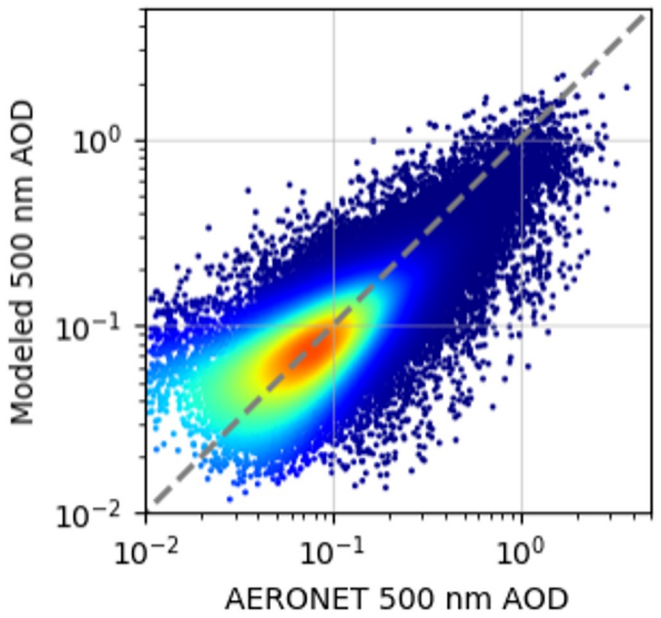
Note 550 nm AOD of VIIRS/S-NPP and NOAA20 versus AERONET Level 1.5 in Oct 2021 – Sept. 2022 on Slide 7 has

- ***a bias of -0.011***
- ***and R^2 of 0.704.***

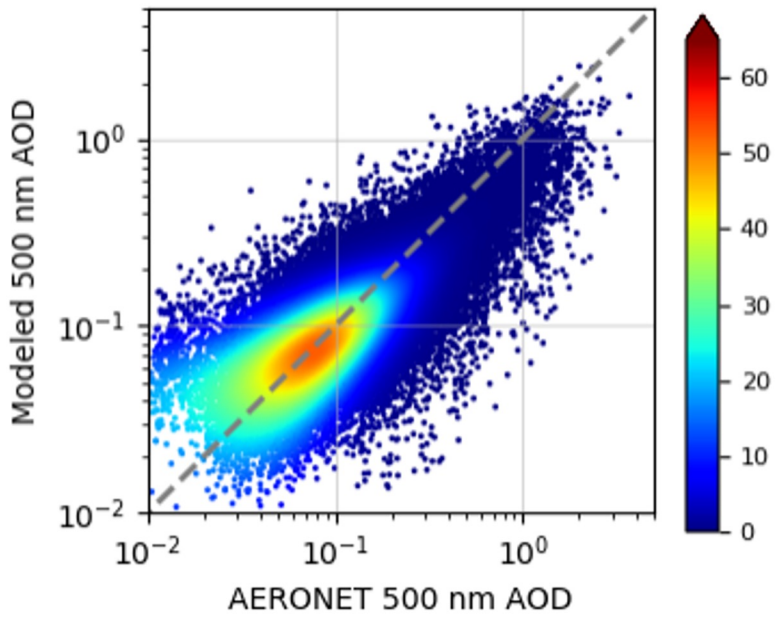
NRT-NODA 6h fcst



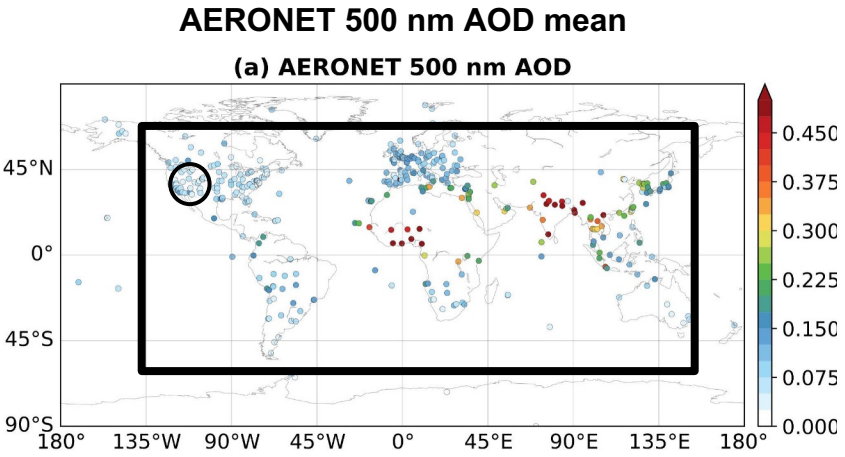
NRT-DA-SPE 6h fcst

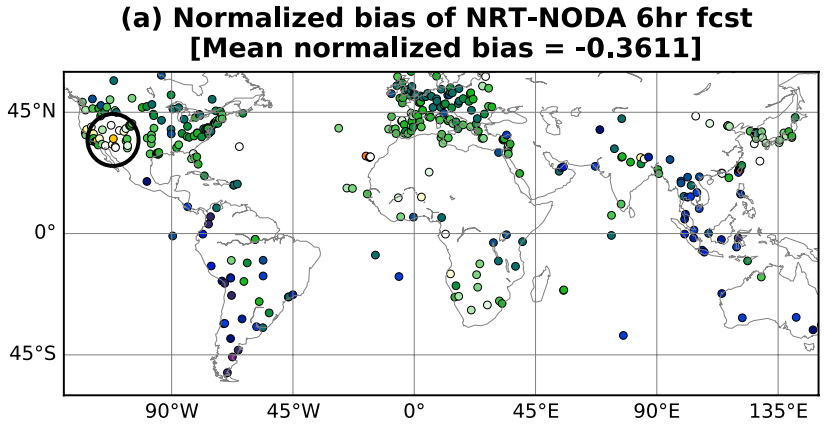


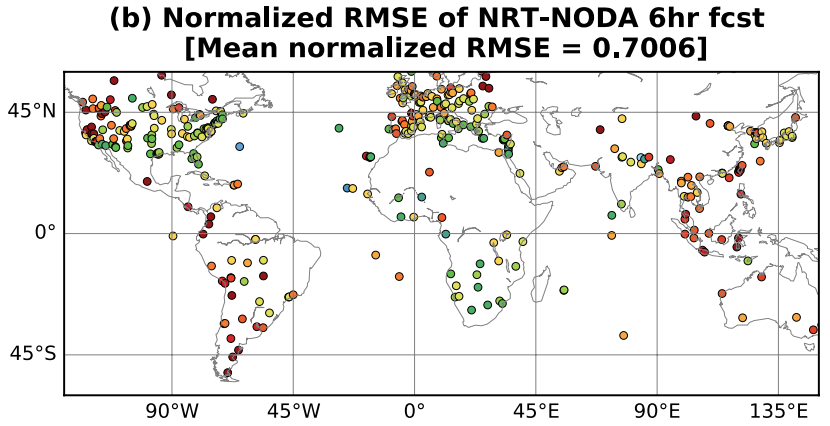
NRT-DA-SPE analysis

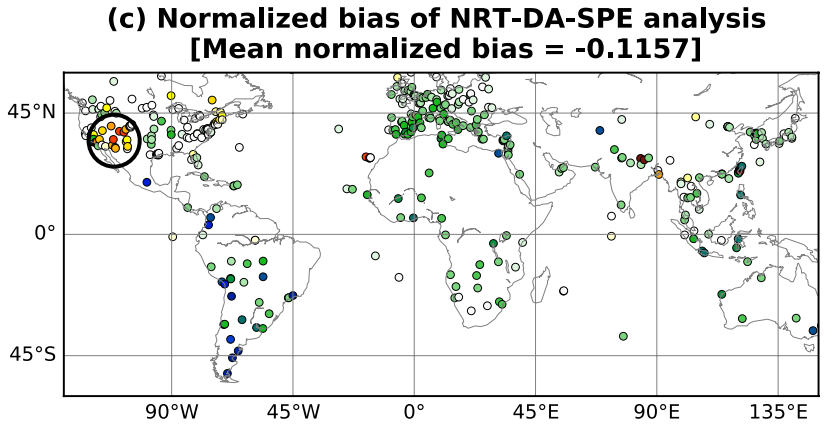


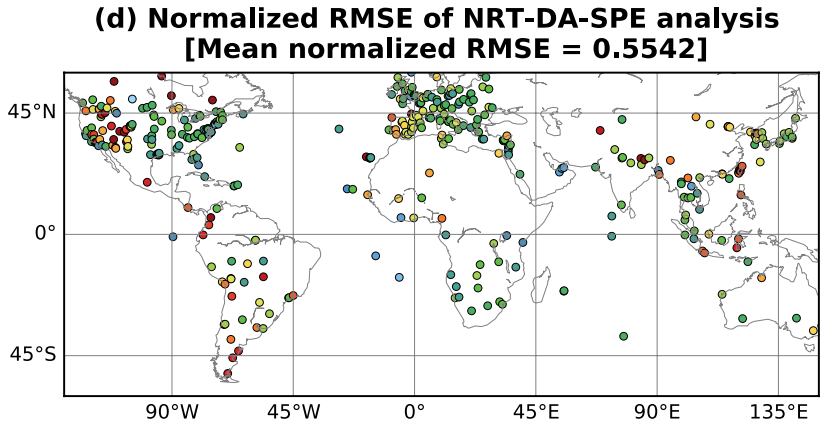
Normalized bias and RMSE against independent AERONET Level 1.5 500 nm AOD in June– August, 2022

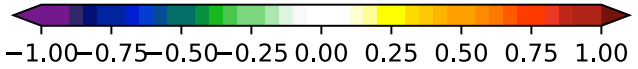


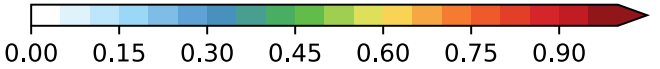










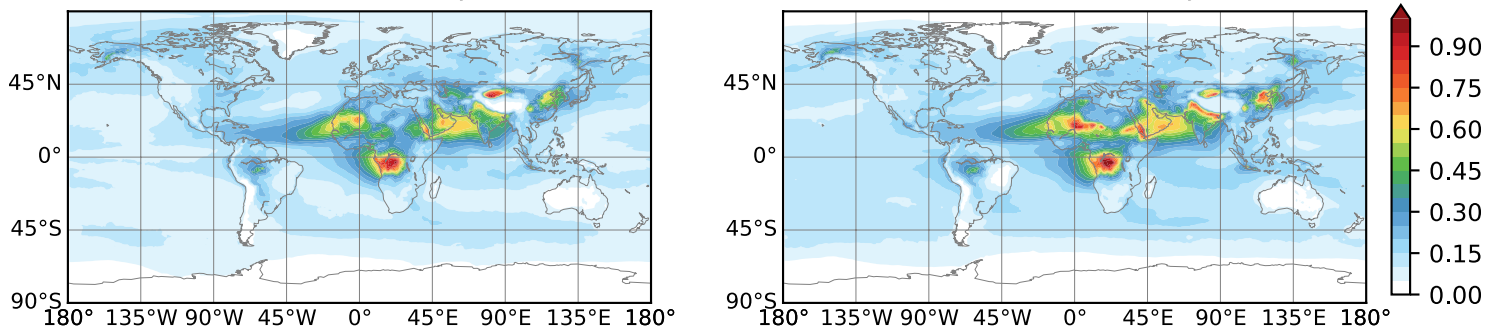


- Bias and RMSE normalized by the AERONET 500 nm AOD
- NRT-DA-SPE 6-hour forecast shows similar bias and RMSE as NRT-DA-SPE analysis.

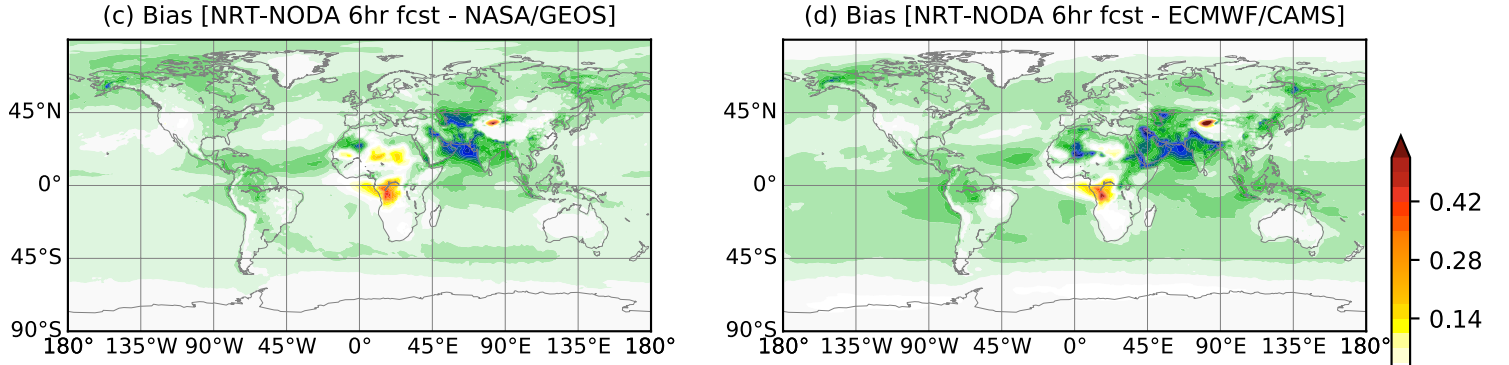
Averaged 550nm AOD bias against NASA/GEOS and ECMWF/CAMS analyses in June – August 2022

NASA/GEOS | **ECMWF/CAMS**

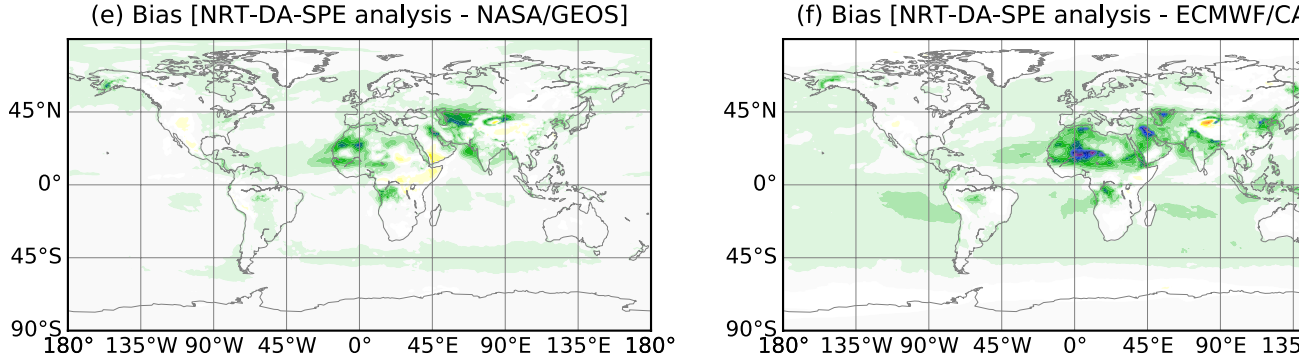
550 nm AOD analysis



NRT-NODA 6h fcst bias



NRT-DA-SPE analysis bias



- RMSE difference is similar to bias difference (not shown).
- NRT-DA-SPE 6h fcst show very similar bias and RMSE as NRT-DA-SPE analysis (not shown).

Evaluation of GEFS-Aerosols AOD Reanalysis of Assimilating MODIS NNR 550 nm AOD Retrievals in Year 2016 in Collaboration with Arlindo da Silva (NASA), Sarah Lu (JCSDA and UAlbany), and Shih-Wei Wei (UAlbany)

CIRES

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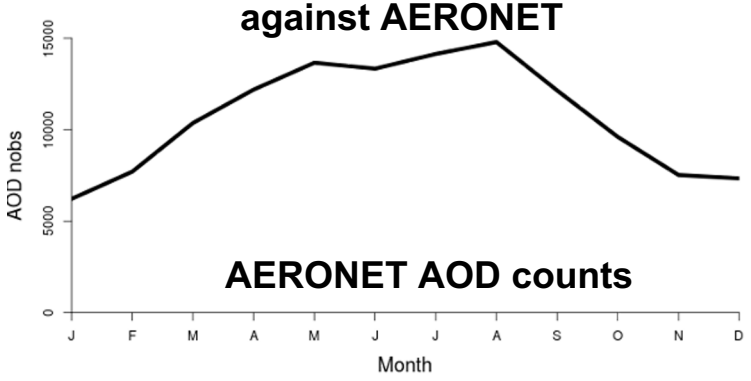
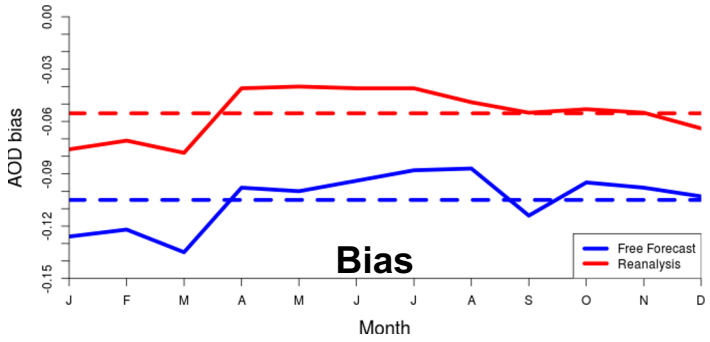
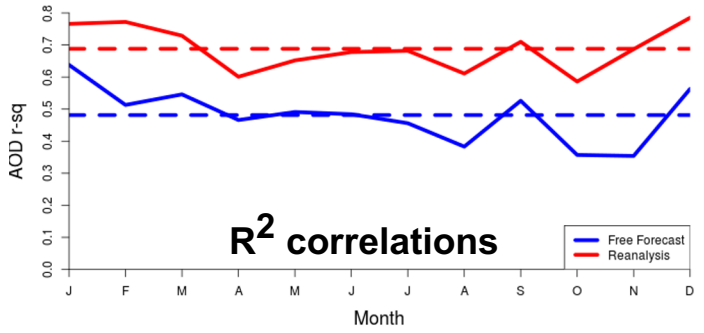
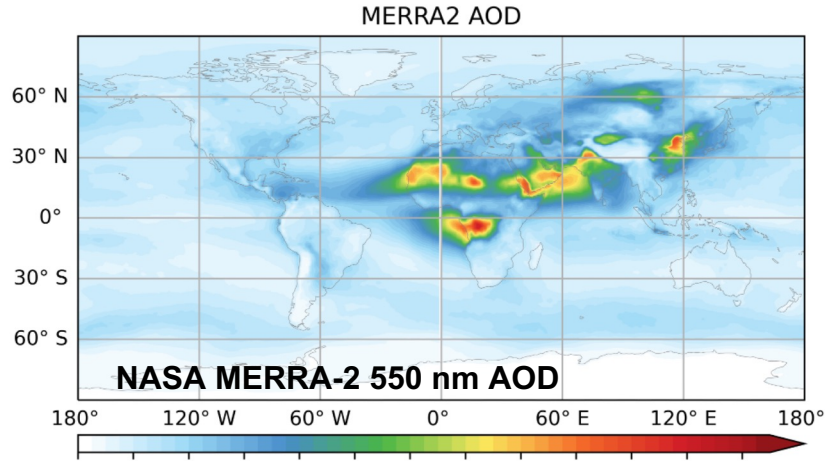
Monthly Time-Series of verification against AERONET

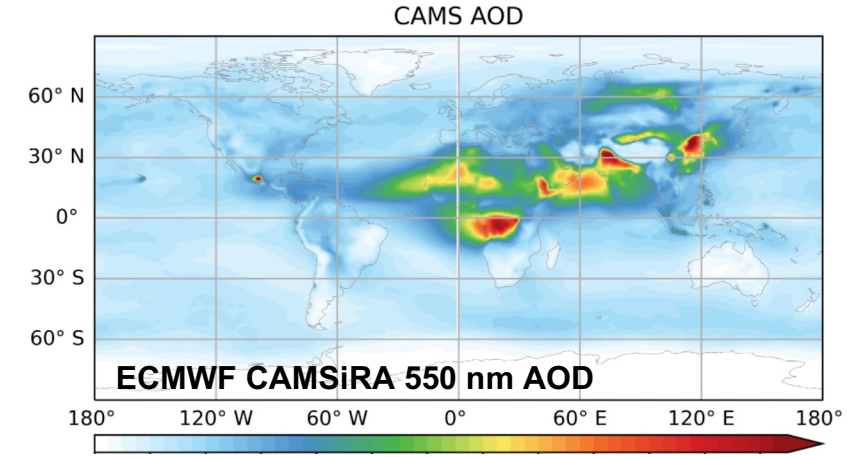


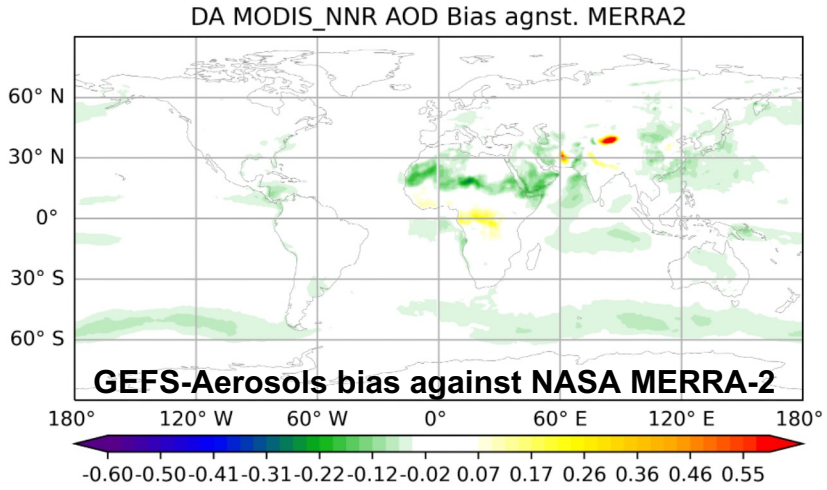


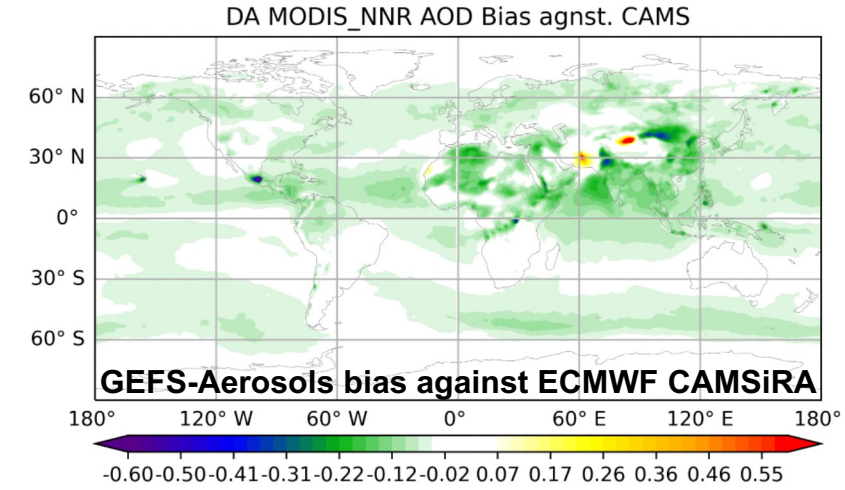


550 nm AOD reanalysis comparison among GEFS-Aerosols, NASA MERRA-2 and ECMWF CAMSiRA in June - August 2016





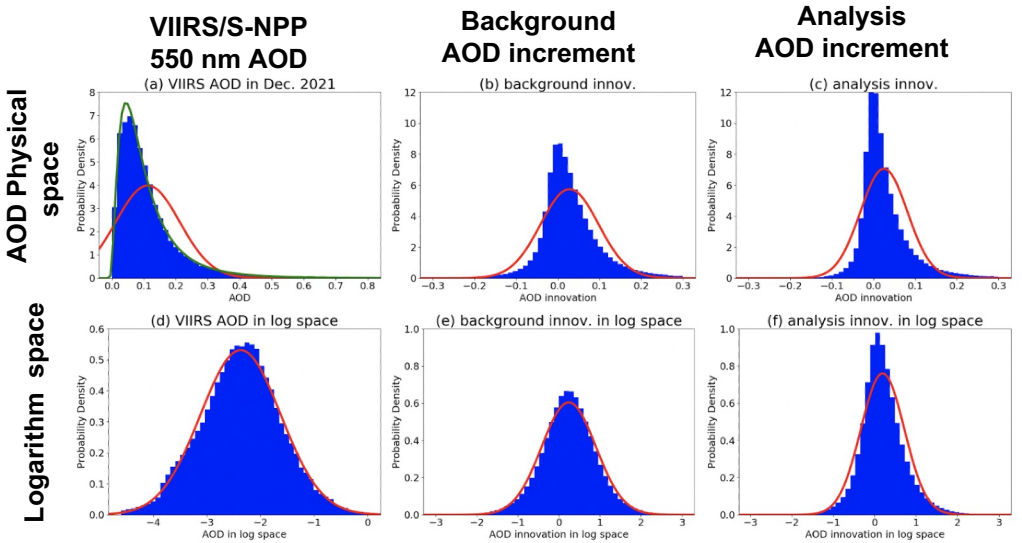




Ongoing and Future Efforts

- **Extend the JEDI-based aerosol DA system to UFS-Aerosols with NASA's GOCART2G aerosol model that will replace GEFS-Aerosols for operations at NCEP/EMC in the future;**

- **Addressing the limitations and deficiencies of the current DA System**
  - Improve ensemble spread and VIIRS AOD error estimation.
  - Implement assimilating log-transformed AOD in JEDI to better satisfy the Gaussian assumption in the assimilation.
  - To mitigate systematic model bias in terms of AOD.

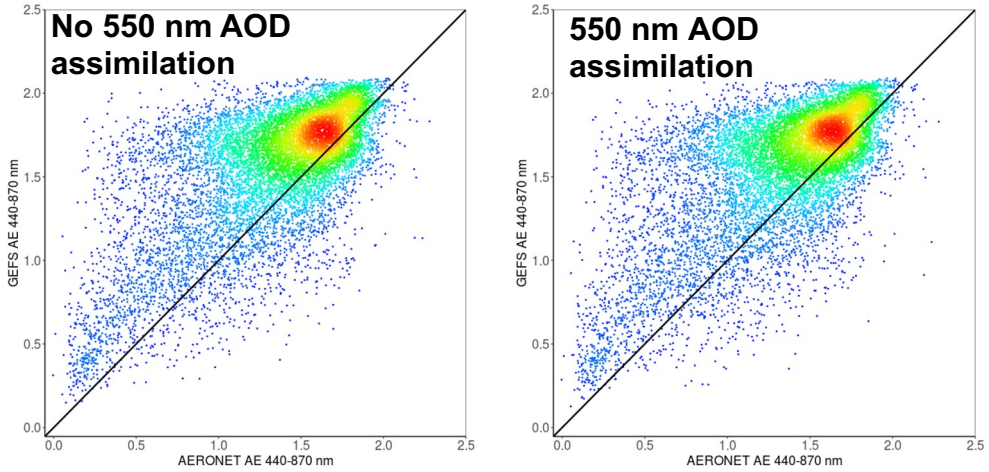


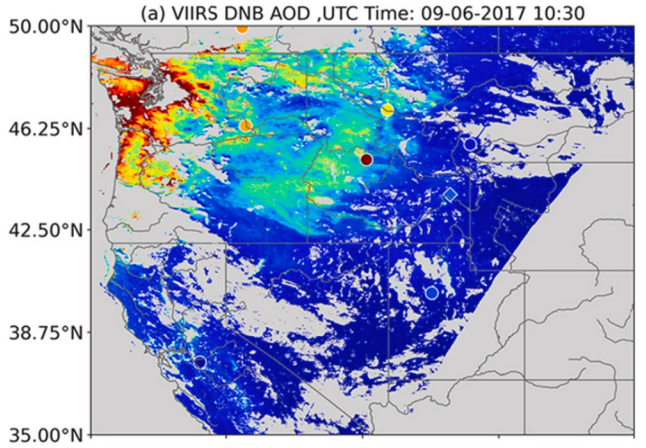
Ongoing and Future Efforts

- **Assimilate advanced aerosol retrievals from NASA PACE mission within JEDI to improve aerosol characterization, e.g., multi-wavelength AOD retrievals, single scatter albedo (SSA), aerosol fine mode fraction** in collaboration with Andrew M. Sayer (UMBC and NASA), Lorraine A. Remer (UMBC), Xiaoguang Xu (UMBC), and Otto P. Hasekamp (SRON).

- **Complement assimilating nighttime 550 nm AOD retrievals within JEDI to better capture the diurnal variation of aerosol events (e.g., smoke transport)** in collaboration with Jun Wang and Meng Zhou (University of Iowa).

Angstrom Exponent comparison against AERONET





Nighttime AOD derived from VIIRS DNB (*adapted from Zhou et al. (2021)*).

Thanks for your attention!

Questions?

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- *Huang, B., M. Pagowski, S. Trahan, C. Martin, A. Tangborn, S. Kondragunta, D. Kleist, 2022: JEDI-Based Three-Dimensional Ensemble-Variational Data Assimilation System for Global Aerosol Forecasting at NCEP,* ***under review in JAMES****.*