JEDI-Based Ensemble-Variational Data Assimilation System for Global Aerosol Forecasting at NCEP

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[8]NASA/GMAO
[9]CIRA, CSU
[10]NOAA/OAR/PSL
[11]NOAA/OAR/GML

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Outlines

- **System Development**
- **Near-Real-Time VIIRS 550 nm AOD Assimilation Experiment at NOAA/OAR/GSL**
- **Development of Global Aerosol Reanalysis in 2016 from Assimilating MODIS 550 nm AOD Retrievals**

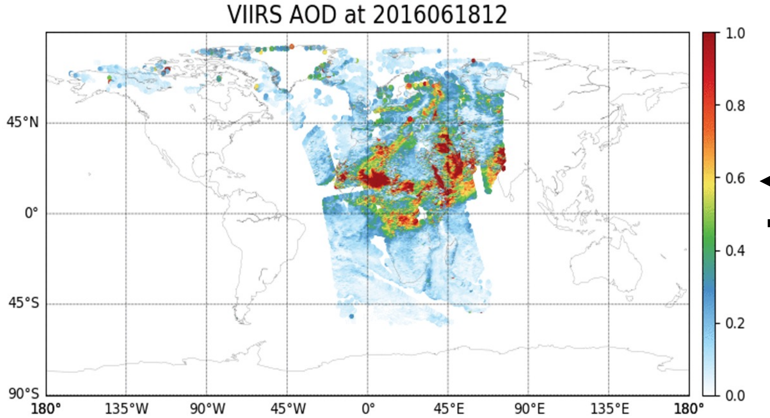
Assimilation of 550 nm AOD retrievals in GEFS-Aerosols

- **Column-integrated AOD** calculation (Eq.1 of Randles et al. 2017):

$$\tau^f = \sum_{z,i} x_i \times b_{\text{ext},i}(\text{RH},\ \lambda) \times \delta z,$$

τ: column-integrated AOD
x_i: mass mixing ratio of aerosol species
$b_{ext,i}$:species-specific extinction coefficients as a function of wavelength (λ) and relative humidity (RH)
δz: layer depth

NOAA S-NPP VIIRS AOD retrievals at 550 nm (~ 50 km resolution)



Simulation

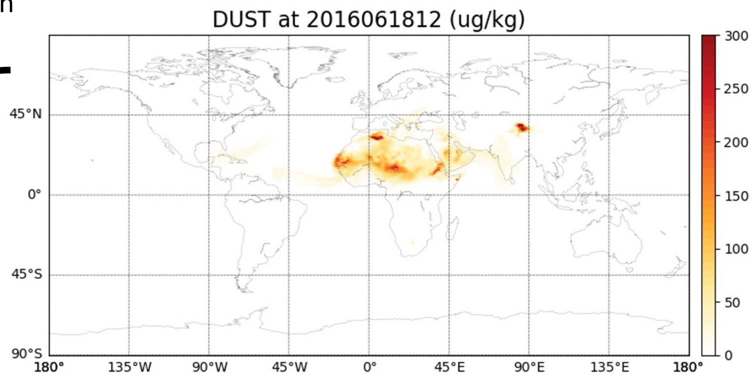
Correction

- **AOD bias and uncertainty estimate:**

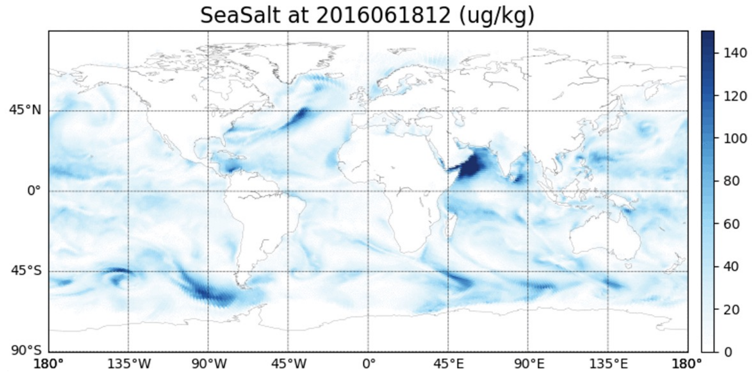
bias = ab + bb*AOD
uncertainty = au + bu*AOD

GEFS-Aerosols 6-hour aerosol mixing ratio forecast at lowest model level

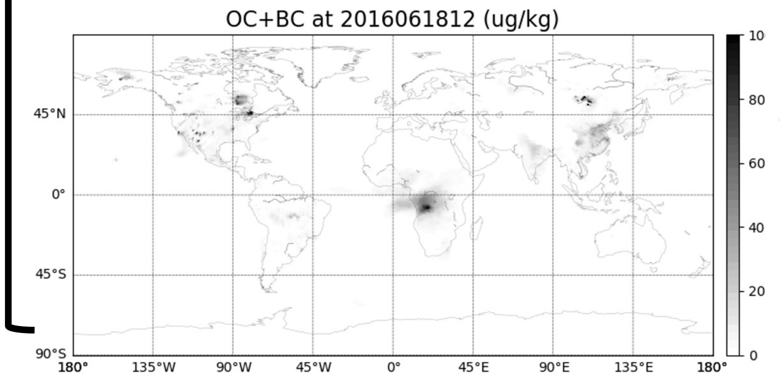
Dust



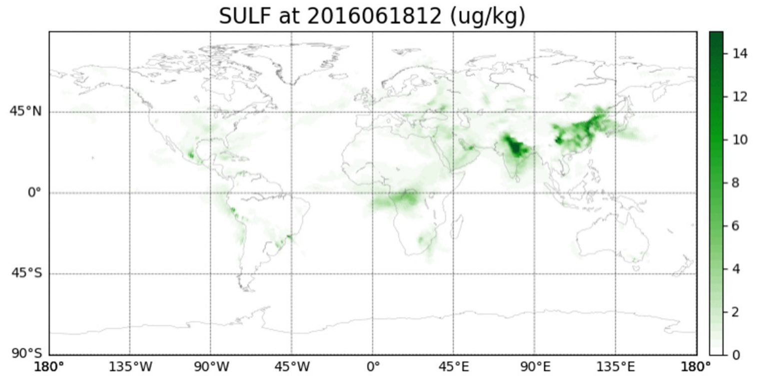
Sea salt



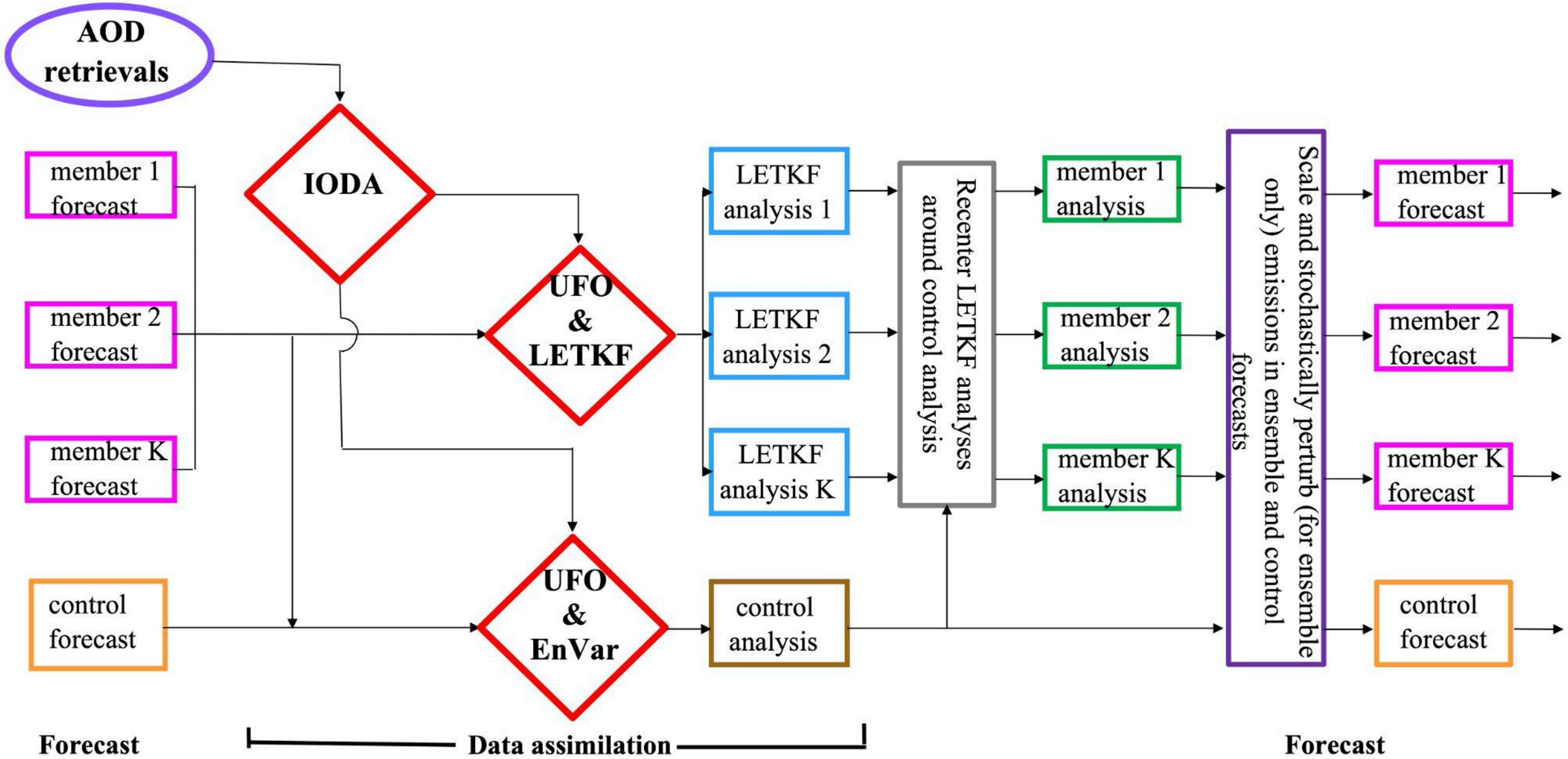
Total black and organic carbon



Sulfate



JEDI-based Ensemble-Variational Aerosol Data Assimilation (DA) System for GEFS-Aerosols



- **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***).

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

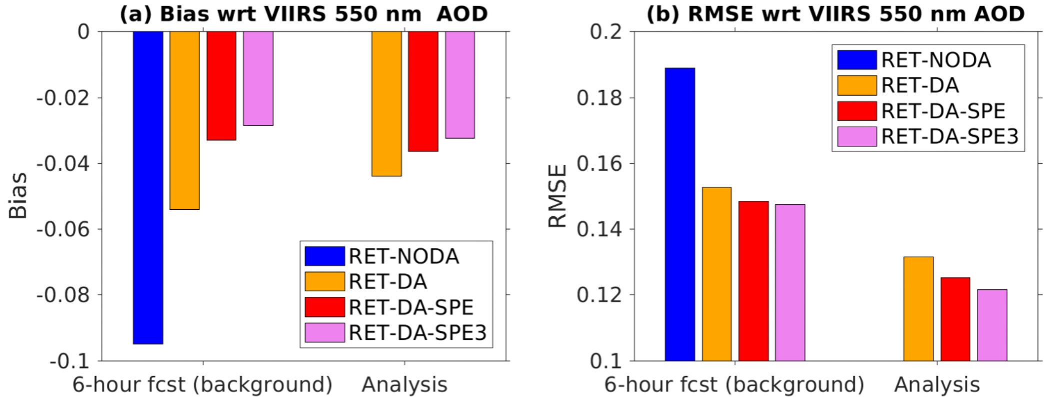
Emission scaling factor mainly to reduce modeled AOD bias

Emission perturbation standard deviation to increase aerosol ensemble spread

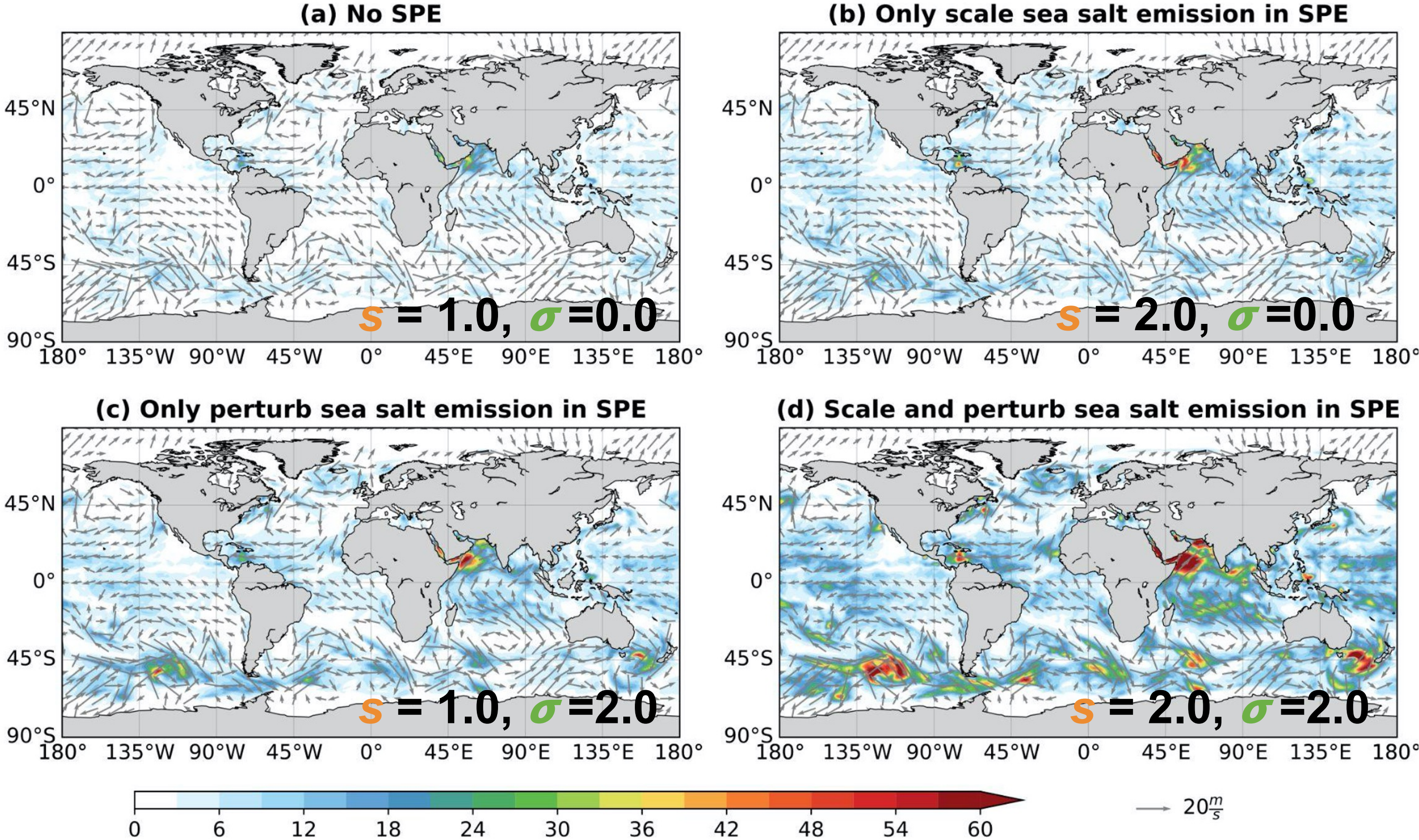
$$f = s(1 + w\sigma)$$

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



Outlines

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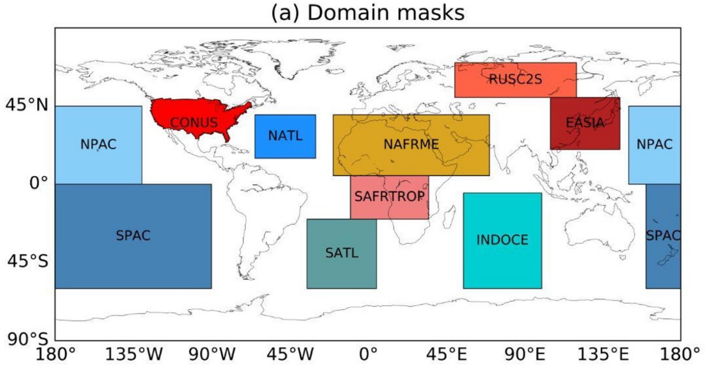
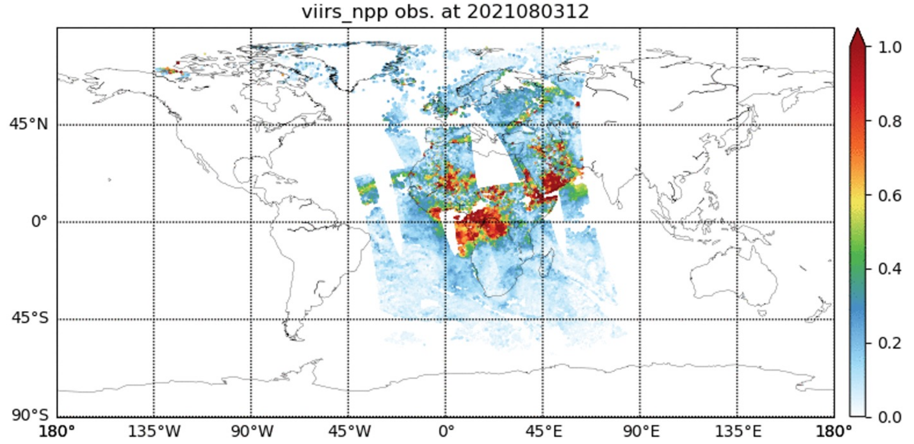
NRT Experiment Design

- **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 LETKF for aerosol update;
  - 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 (10/01/2021- present)

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

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Global Systems Laboratory
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Assimilation and Verification Innovation Division (AVID) Projects GSL Home ESRL Home

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

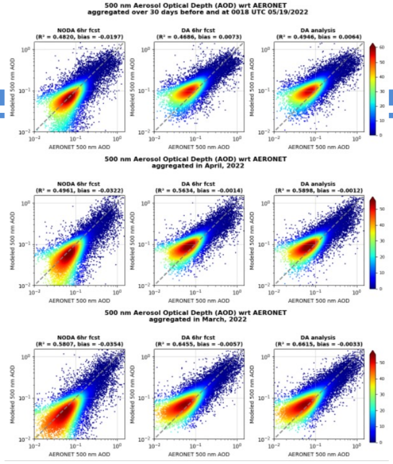
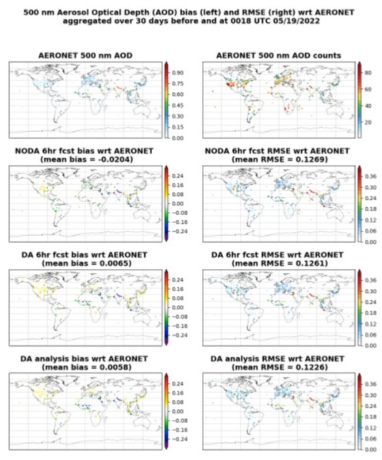
Model: Aerosol-DA Area: Full Date: 19 May 2022 - 00Z

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

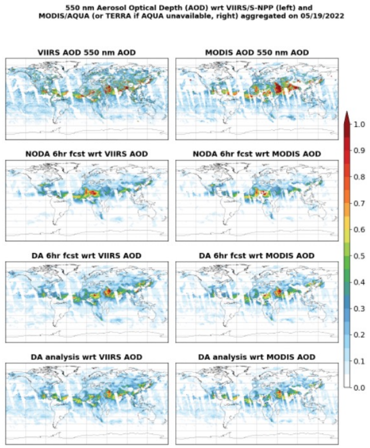
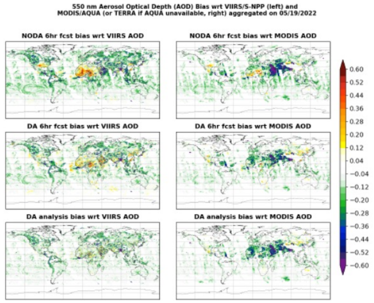
	All times	Loop	Valid Time Thu 00 Forecast 000	
all fields			000	all fields
AERONET AOD Scatterplots	✔	✔	000	AERONET AOD Scatterplots
AERONET AOD Stats	✔	✔	000	AERONET AOD Stats
VIIRS/MODIS AOD	✔	✔	000	VIIRS/MODIS AOD
VIIRS/MODIS AOD Bias	✔	✔	000	VIIRS/MODIS AOD Bias
GEOS/CAMS AOD	✔	✔	000	GEOS/CAMS AOD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

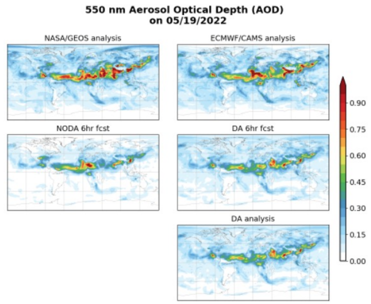
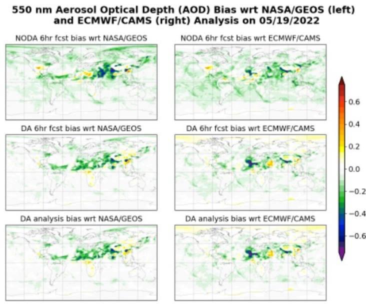
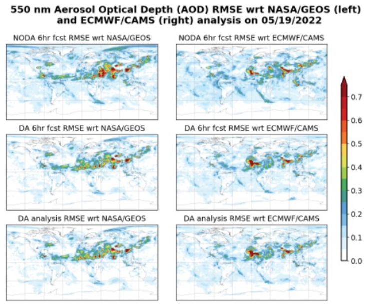
AERONET 500 nm AOD

VIIRS/MODIS 550 nm AOD

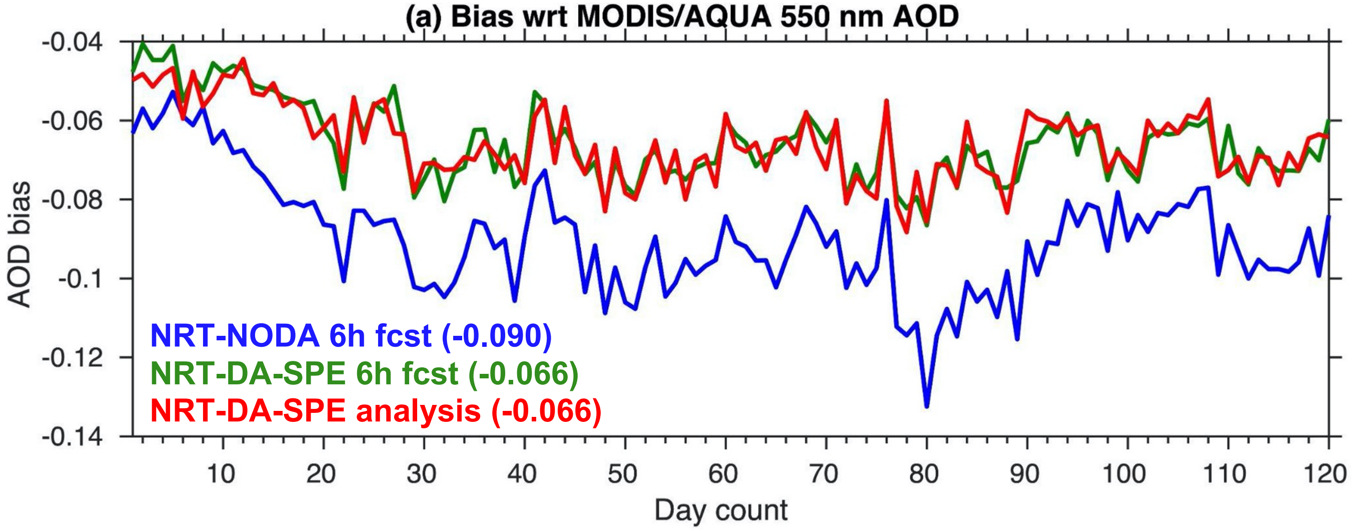
NASA/GEOS and ECMWF/CAMS 550 nm AOD analysis

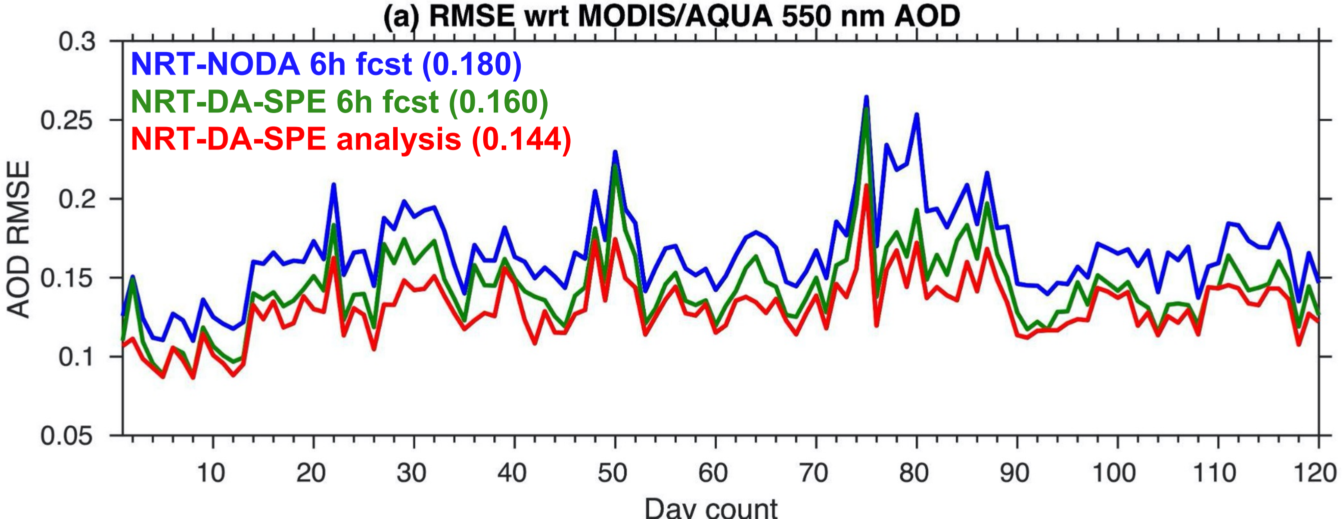
Innovation Statistics (01/01 - 04/30, 2022)

Time Series of daily globally mean bias and RMSE against MODIS/Aqua 550 nm AOD

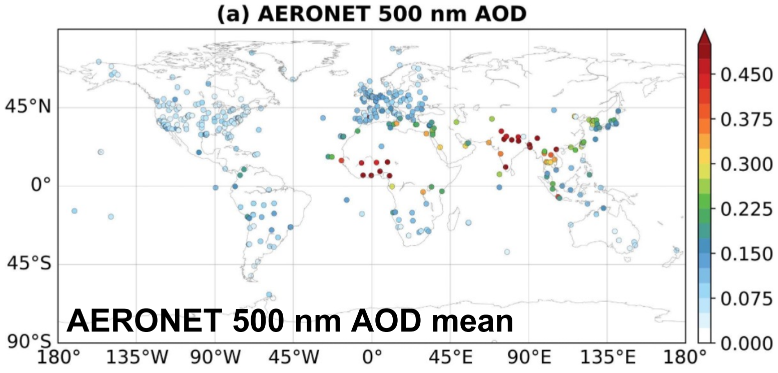
Bias

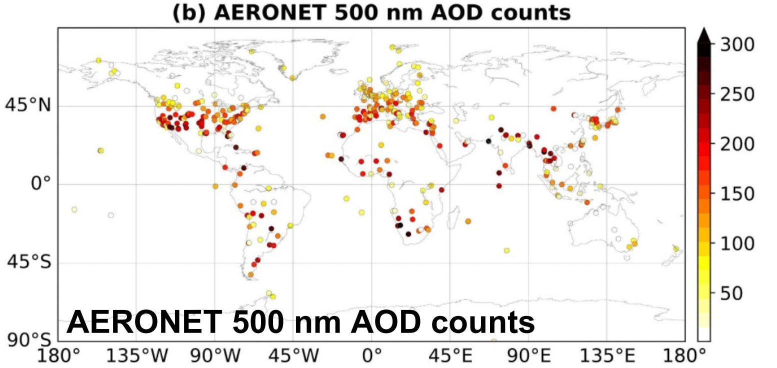


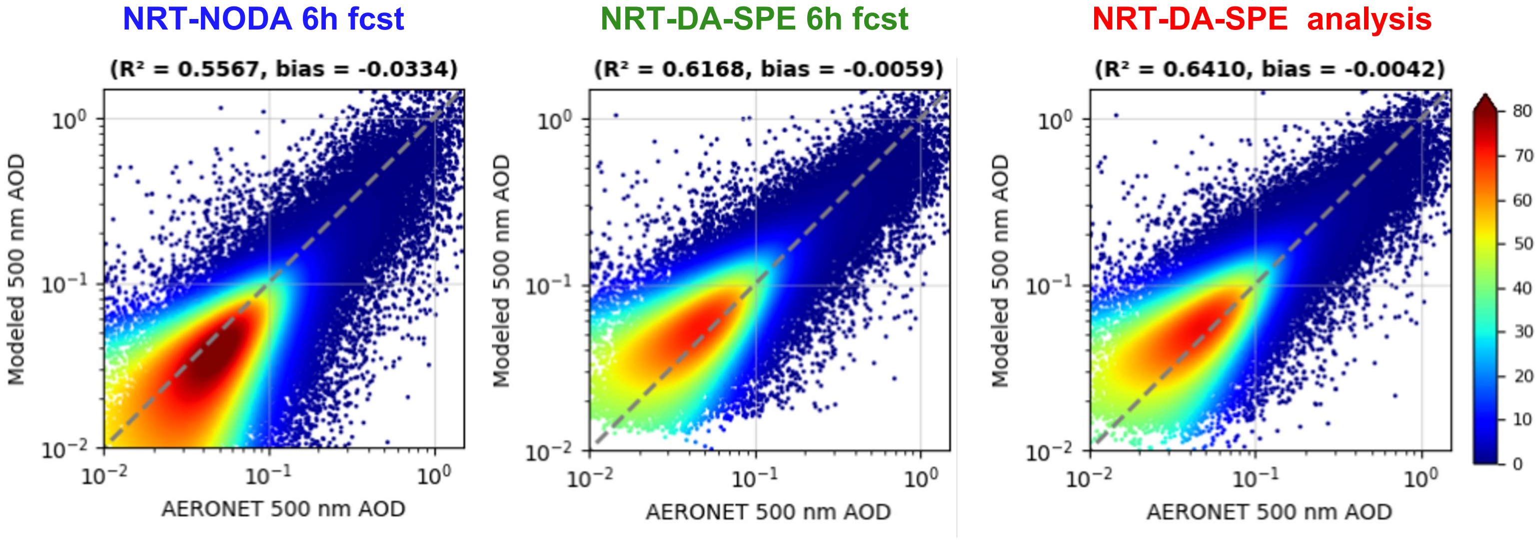
RMSE



Bias and RMSE against independent AERONET 500nm AOD (01/01 - 04/30, 2022)







- Benefit of AOD assimilation against AERONET 500 nm AOD is more pronounced in Oct. – Dec. 2021, e.g., **R2 of NRT-DA-SPE analysis is about 0.24 higher than NRT-NODA 6-hour forecast** (*Huang et al., 2022 under review in JAMES*).

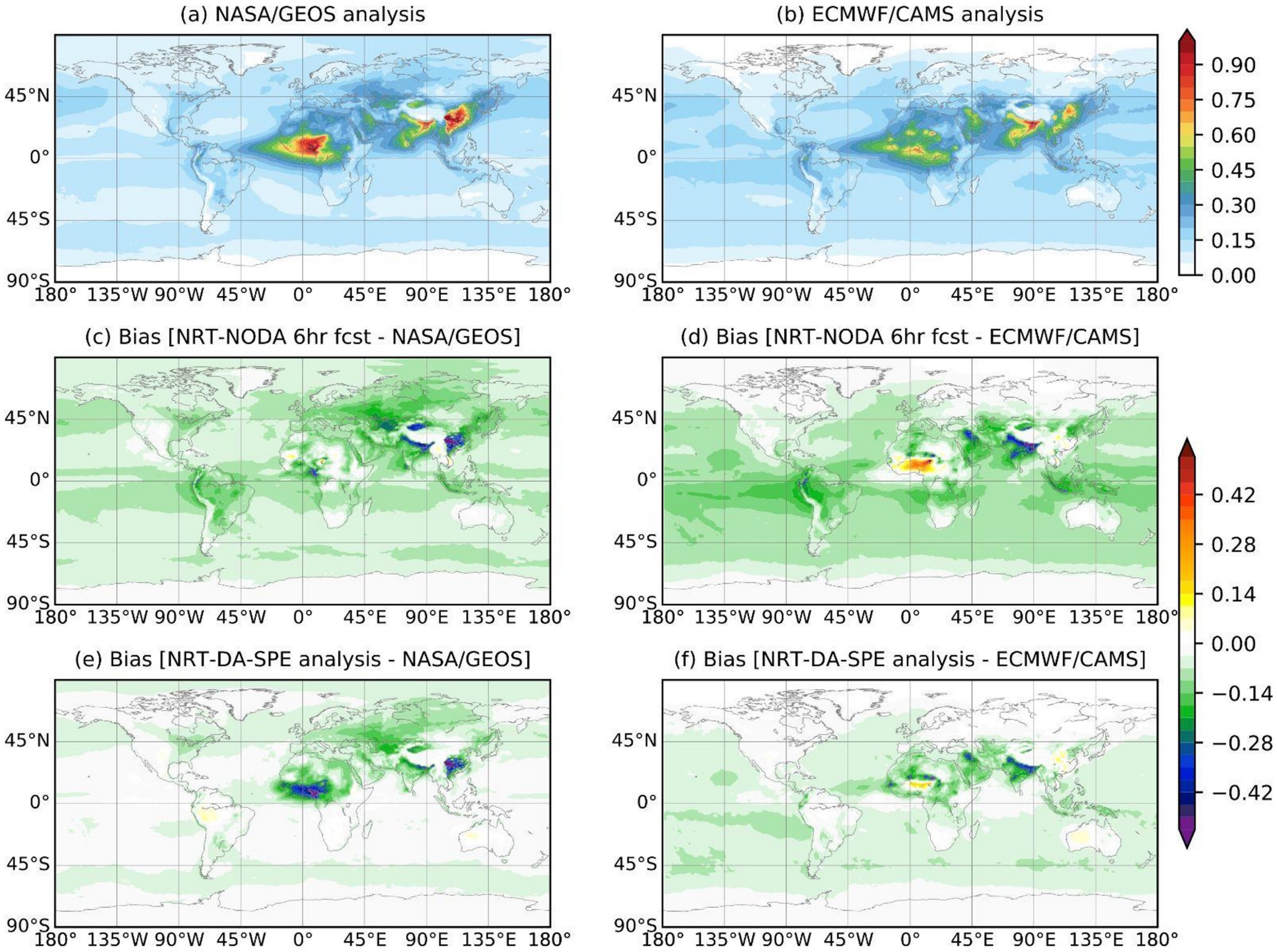
Averaged 550nm AOD bias against NASA/GEOS and ECMWF/CAMS analyses (01/01 - 04/30, 2022)

NASA/GEOS **ECMWF/CAMS**

AOD analysis

NRT-NODA 6h fcst
AOD bias

NRT-DA-SPE analysis
AOD 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).
- When against NASA/GEOS AOD analysis, larger negative bias in NRT-DA-SPE analysis in northern Africa is mainly because VIIRS AOD is smaller than MODIS AOD in this region that is assimilated in NASA/GEOS.

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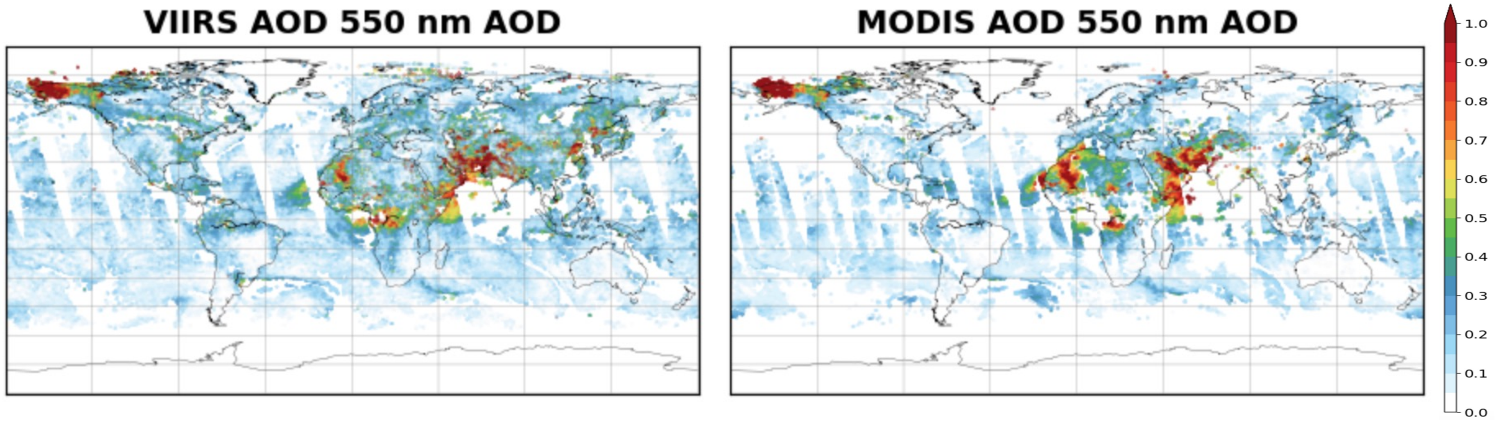
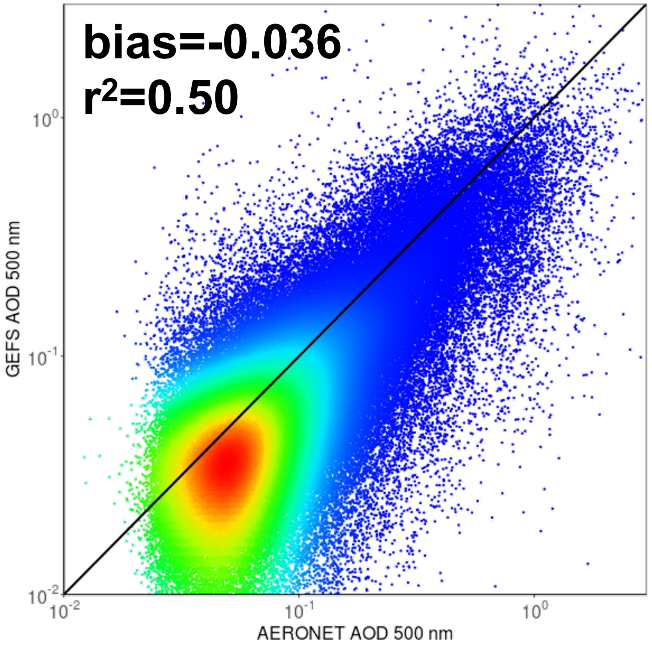


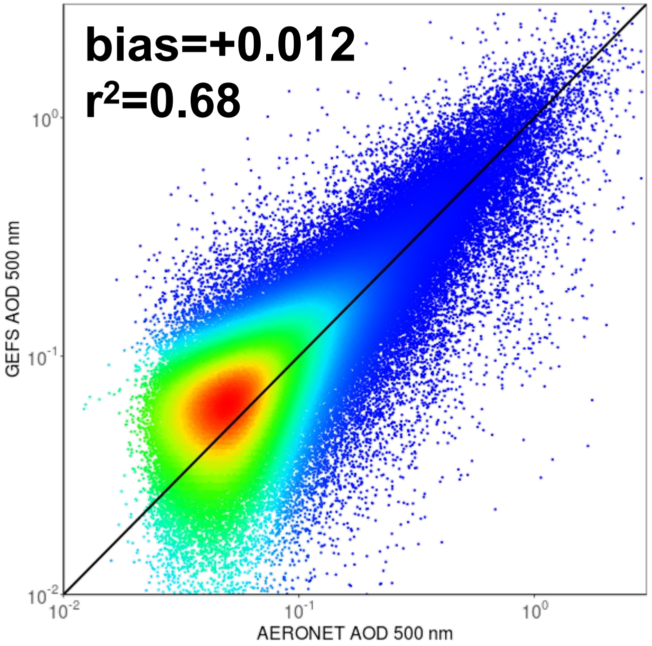
- VIIRS (left) and MODIS (right) 550 nm AOD aggregated on July 4, 2022.

AERONET AOD@500 nm Statistics for Year 2016

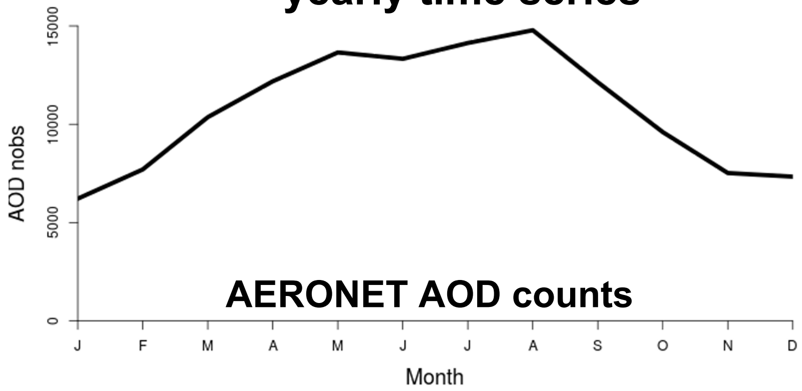
noDA

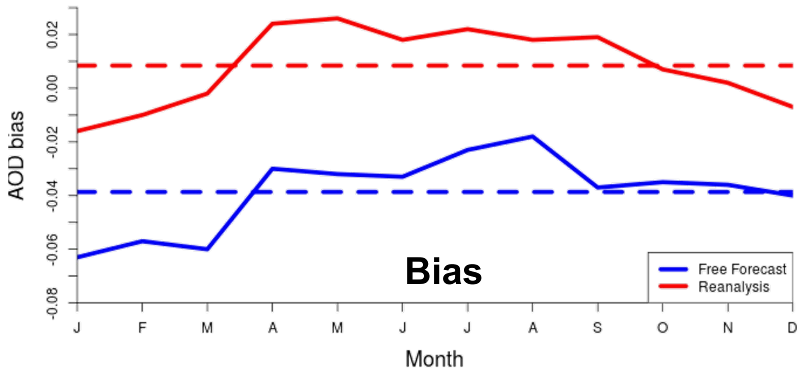


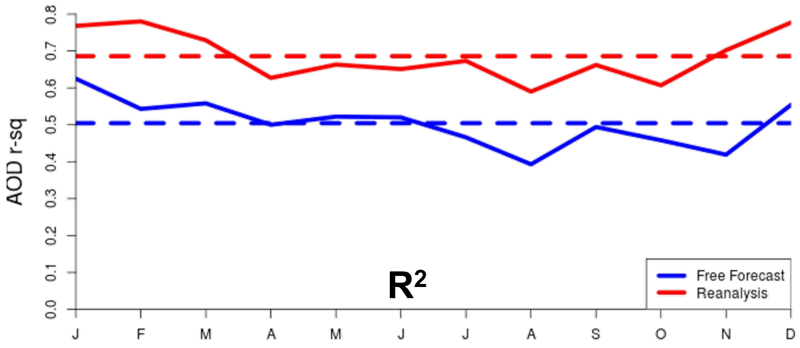
DA



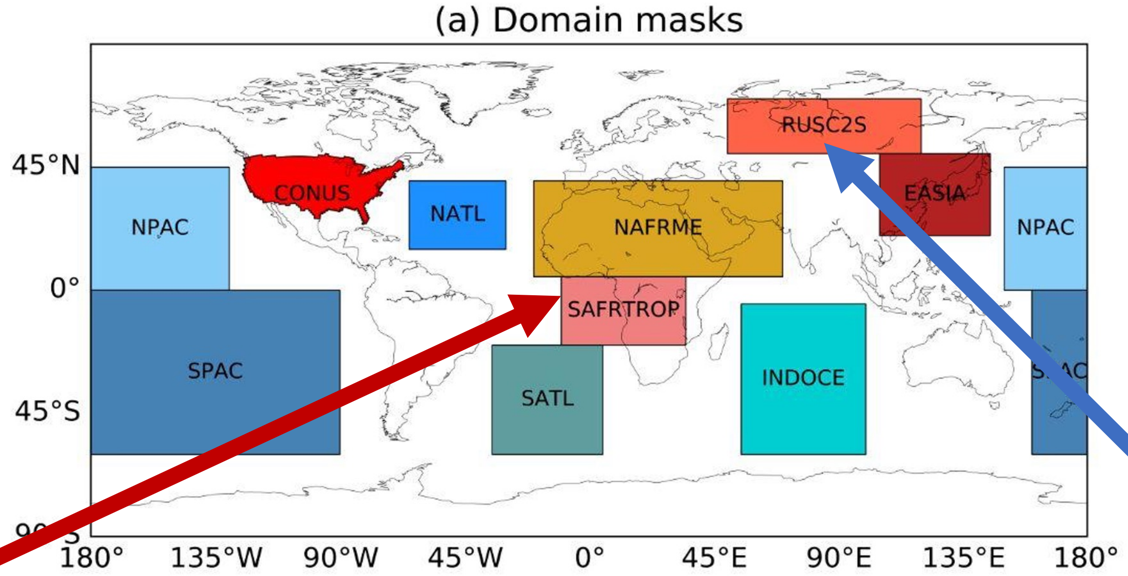
yearly time series

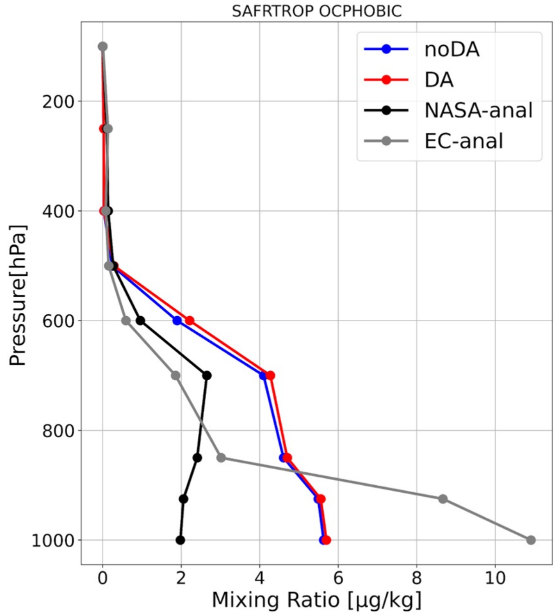


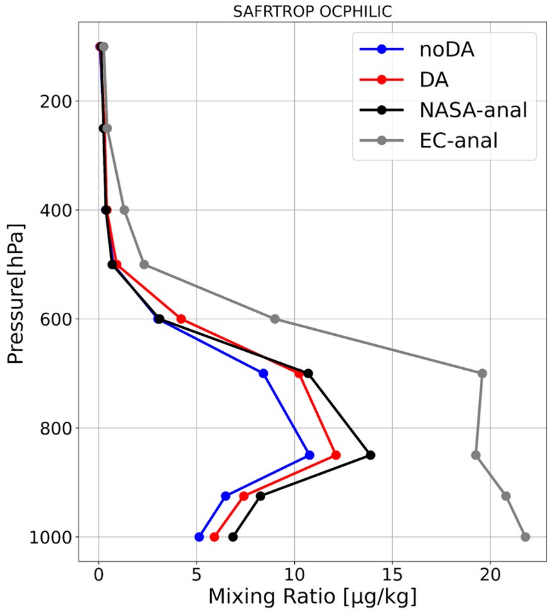


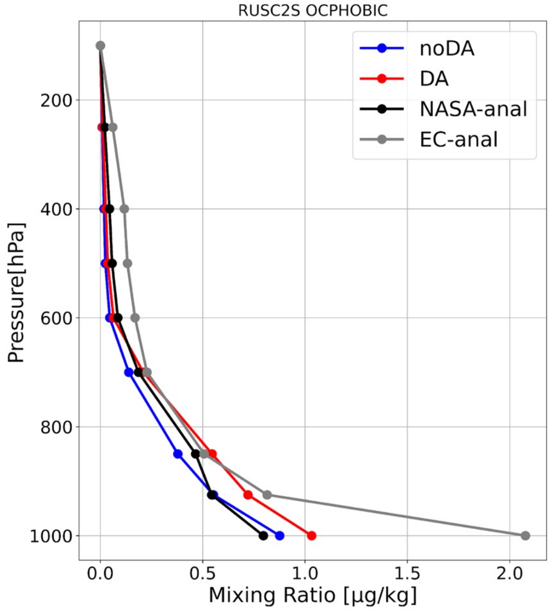


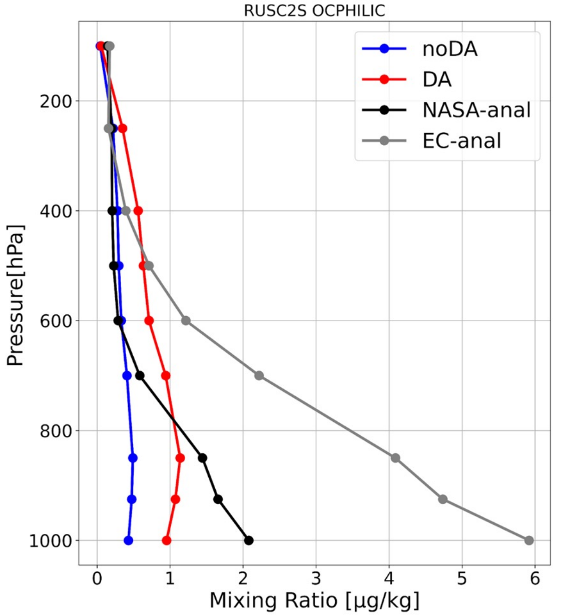
Comparison of Profiles in MERRA-2, CAMSiRA, and GEFS-Aerosols in August, 2016









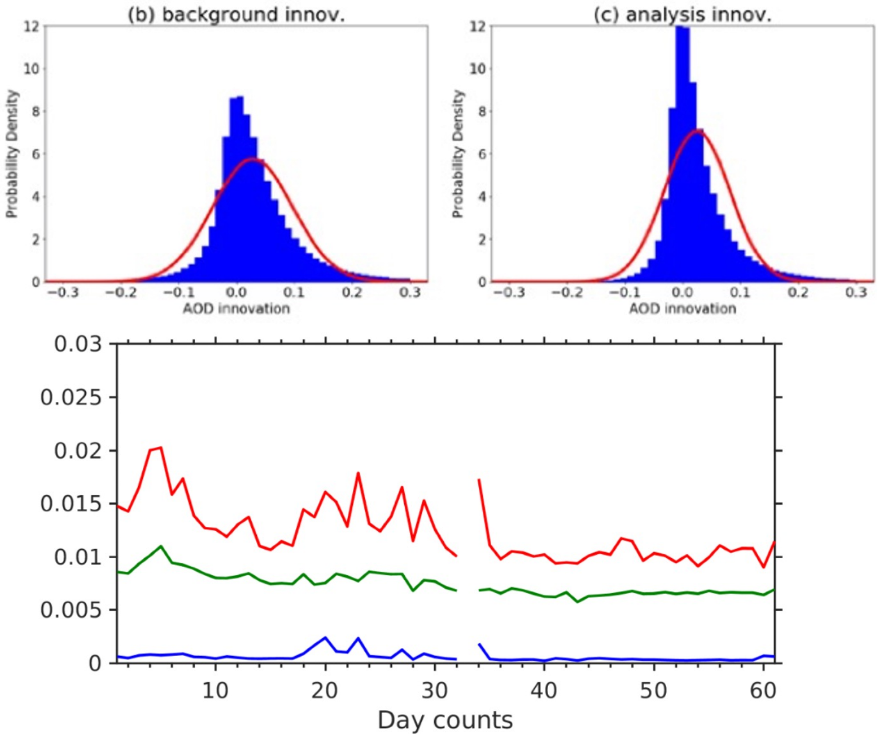


Ongoing and Future Efforts

- **Extending the JEDI-based aerosol DA system to UFS-Aerosols that will replace GEFS-Aerosols for operations at NCEP/EMC in the future;**

- **Developing a 2018-2022 global aerosol reanalysis using UFS-Aerosols** (funded by WPO/CTB)**;**

- **Addressing the limitations and deficiencies of the current DA System**
    - Non-Gaussian distributions of observation (for retrievals typically δAOD = $\alpha \cdot$ AOD + β) and model errors (which requires transformation of variables);
    - Undetermined magnitudes of observation errors (which requires diagnosis and further development of tools for thinning/super-obbing);
    - Insufficient ensemble spread (which requires further development of stochastic parameterizations);
    - No account for systematic model biases (which requires a systemic approach);
    - Significant uncertainties in aerosol scattering/absorbing properties (especially important for aerosol-radiation interactions, current GOCART may be intrinsically deficient).



Daily average of AOD ensemble mean squared error, observation squared error, and ensemble variance, in March-April, 2022

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**.*