Collaborative Efforts Towards Advancing Aerosol Assimilation and Prediction in Unified Forecast System at NOAA

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Session of *Emerging Applications 3 - Air Quality*, July 26, 2023

Outline

- Near-real-time (NRT) evaluation of JEDI-based 3D-EnVar aerosol assimilation system using intermediate CCPP-based GEFS-Aerosols at NOAA/OAR/GSL
- Extension of JEDI-based 3D-EnVar aerosol assimilation system for NOAA's future operational UFS-Aerosols
- Ongoing collaborations to enhance JEDI-based aerosol assimilation system

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Near-real-time (NRT) evaluation of JEDI-based 3D-EnVar aerosol assimilation system using intermediate CCPP-based GEFS-Aerosols at NOAA/OAR/GSL funded by

- "Development of the National Global Data Assimilation Ensemble-based System for Forecasting of Aerosols" funded by **NOAA/WPO/Air Quality program (2019-2022)**

- "Joint NOAA-NASA Development of a Data Assimilation System for Aerosol Reanalysis and Forecasting" funded by **NOAA/CPO/MAPP (2018-2022)**

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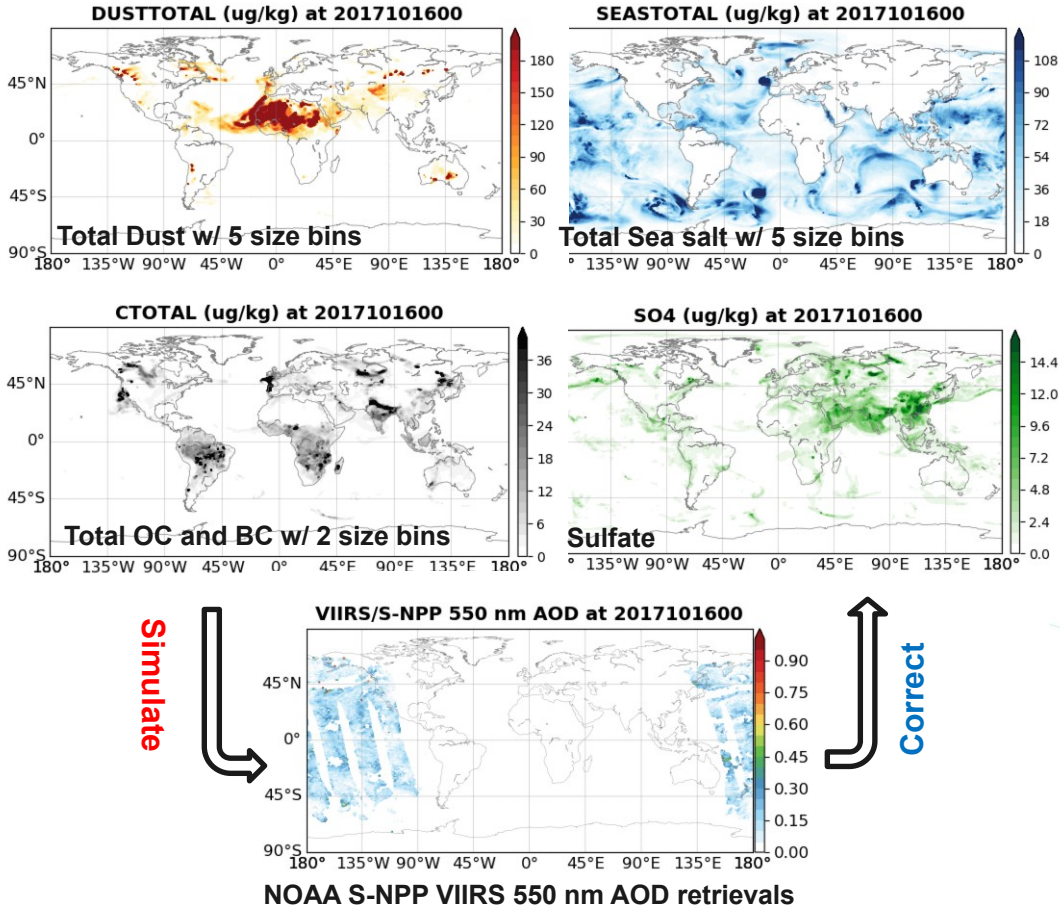
Background

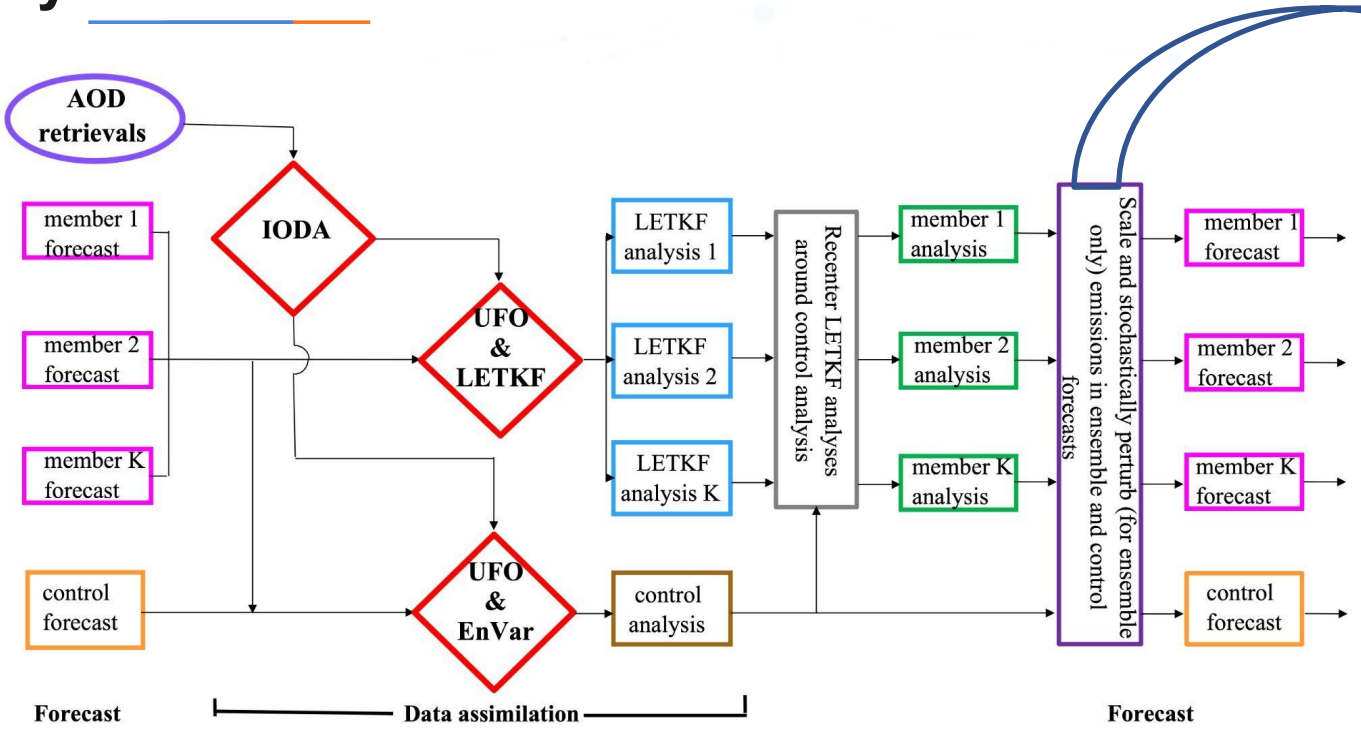
- **Global Ensemble Forecast System - Aerosols (GEFS-Aerosols,** Zhang et al., 2022) as one GEFS member went operational for global aerosol forecasting at NOAA since September 2020 that is based on **NASA's Goddard Chemistry Aerosol Radiance and Transport (GOCART) model** (Chin et al., 2002) with 15 aerosol tracers.

- **2D Column-integrated aerosol optical depth (AOD)** that represents total distinction of solar (or lunar) radiation by aerosols over an atmospheric column.

- **Near-real time (NRT) AOD assimilation** for aerosol forecasting or **aerosol reanalysis production.**
  - ECMWF – 4DVar (Benedetti et al., 2009)
  - NASA – Physical space analysis (Randles et al., 2017)
  - NRL - EAKF (Rubin et al., 2016)
  - JMA – 2DVar (Yumimoto et al., 2017)
  - NOAA/GSL – 3D-EnVar (Huang et al., 2023; Wei et al., 2023)



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



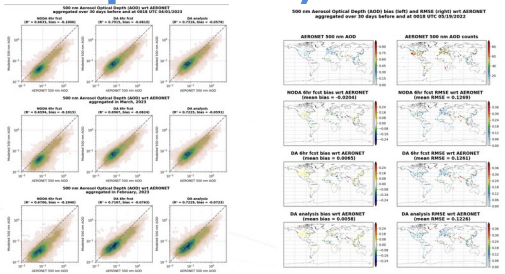
Aerosol emissions were **scaled and stochastically perturbed in ensemble forecasts to account for aerosol emission** uncertainty based on the SPPT scheme for meteorological fields in GEFS.

Huang et al., 2023, JAMES (https://doi.org/10.1029/2022MS003232)

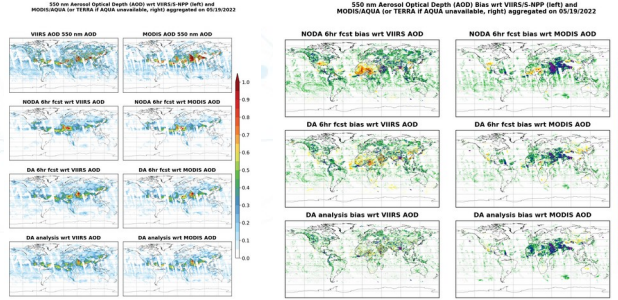
NRT VIIRS 550 nm AOD Assimilation at NOAA/OAR/GSL

--- Online NRT Diagnostic Display (10/01/2021- present)

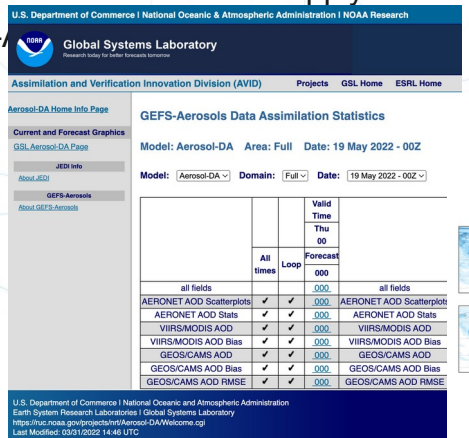
- **FreeRun** runs one-member aerosol forecast initialized every six hours.
- **AeroDA** runs a six-hourly assimilation of **NOAA/NESDIS VIIRS 550 nm AOD** retrievals derived from Suomi-NPP (S-NPP) satellite and **20+1** forecasts at C96L64, and **scales and stochastically perturbs aerosol emissions.**
- **GSL's intermediate CCPP-based GEFS-Aerosols model is used** for aerosol forecasts (need to upgrade to recent model version). DA impact derived from the CCPP version will apply to the operational NUOPC-based GEFS-A

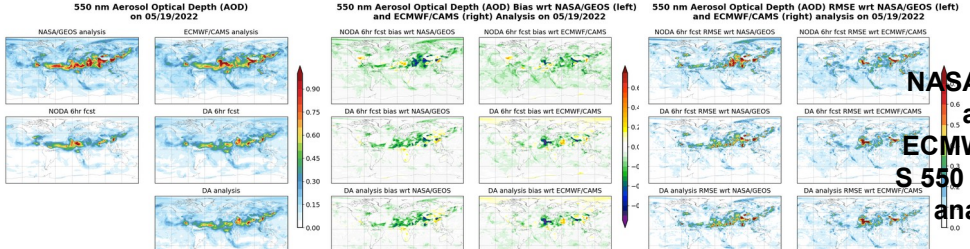


AERONET 500 nm AOD



NOAA/VIIRS and NASA/MODIS 550 nm AOD





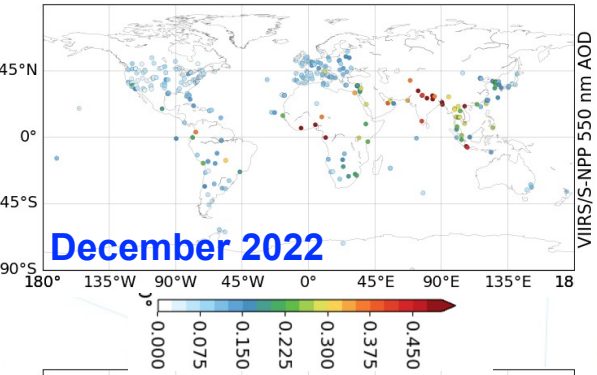
NASA/GEOS and ECMWF/CAMS 550 nm AOD analysis

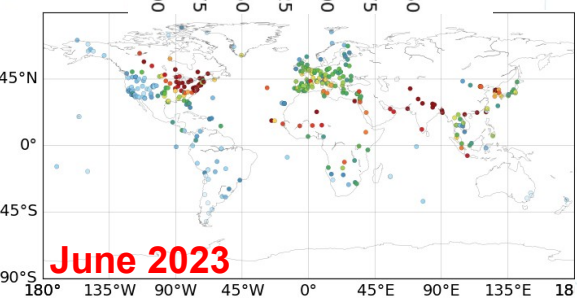
System description:
https://ruc.noaa.gov/projects/nrt/
NRT diagnostics:
https://ruc.noaa.gov/projects/nrt/Aerosol-DA/

NRT VIIRS 550 nm AOD Assimilation at NOAA/OAR/GSL

--- Comparison with Ground-Truth NASA's AERONET Level 1.5 AOD

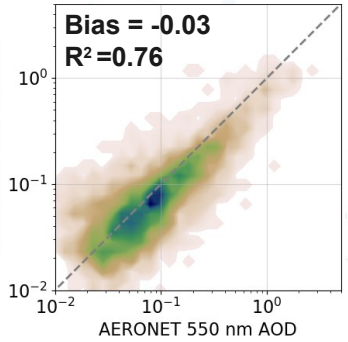
NASA's AERONET L1.5 500 nm AOD
(https://aeronet.gsfc.nasa.gov/)

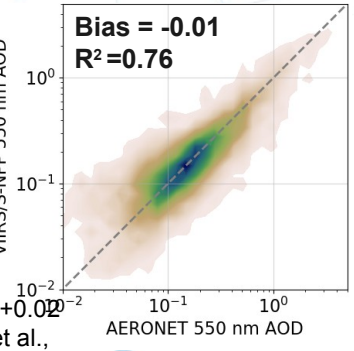




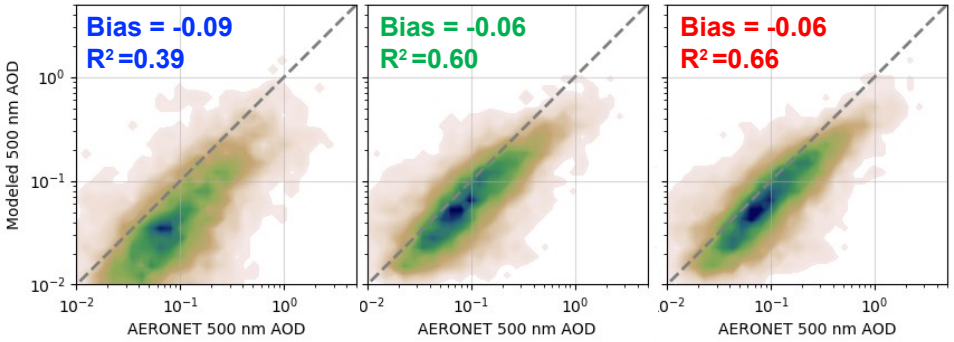
NRT AERONET Level 1.5 AOD has a mean bias of +0.02 and one sigma uncertainty of up to 0.02 (Giles et al.,

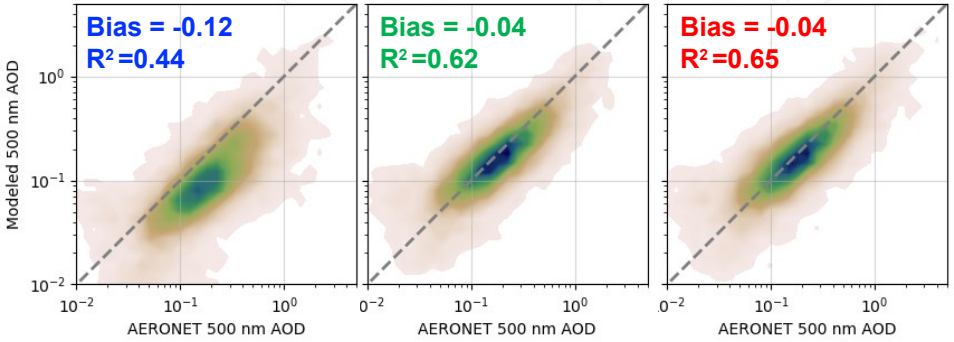
VIIRS/S-NPP vs AERONET 550 nm AOD





FreeRun 6h fcst **AeroDA 6h fcst** **AeroDA analysis**
vs AERONET 500 nm AOD





Extension of JEDI-based 3D-EnVar aerosol assimilation system for NOAA's future operational UFS-Aerosols funded by

- "Development of a Global Aerosol Reanalysis at NOAA in Support of Climate Monitoring and Prediction" funded **by NOAA/OAR/WPO (2022-2024)**
- "Extending JEDI-based Global Aerosol Data Assimilation System to UFS-Aerosols" funded by **NOAA/OAR/GSL Director's Directed Research Funds (2022 –2023)**
- **UFS R20 Atmospheric Composition Project (2022-2023)**

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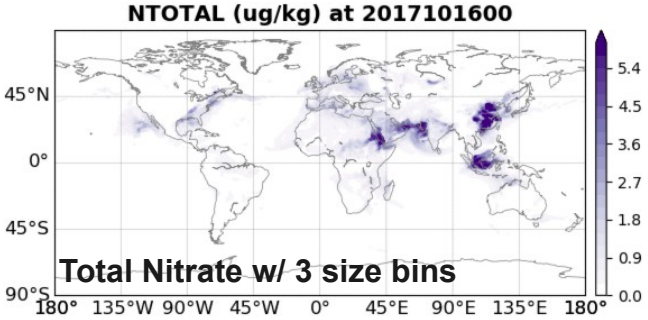
Extend JEDI-Based Aerosol Assimilation System to UFS-Aerosols

- The Unified Forecast System – Aerosols (UFS-Aerosols) is under development at NOAA using an updated version of GOCART from NASA. It is planned to replace GEFS-Aerosols for operations in near future.

- Extended AOD forward operator and its tangent linear and adjoint s in JEDI UFO to accommodate additional **nitrate aerosol species in three size bins** in UFS-Aerosols (merged to JEDI).



Model comparisons between UFS-Aerosols and GEFS-Aerosols v12.3

	UFS-Aerosols		GEFS-Aerosols v12.3
Emissions from nature source (e.g. dust and sea salt)	NASA sea salt scheme, Fengsha dust with updates	Fengsha version	NASA sea salt scheme, Fengsha dust
Emission from Anthropogenic emission	CEDS_2019 version, aviation emission etc.	Different	CEDS_2019 version
Fire emission (Fire Plume-rise module)	GBBEPx or QFED (within PBL)	Part different	GBBEPx with FRP and plume-rise
Dry deposition	Based on NASA_GOCART	Similar	Based on WRF-Chem GOCART
Large Wet removal and settling	Based on NASA_GOCART (Thompson MP)	Different	Based on WRF-Chem GOCART (GFDL MP)
Convective wet scavenging	Based on FV3GFS updated SAS	Similar, SAS version	Based on FV3GFS SAS
Simple chemical reactions (sulfate, OC, BC)	Based on NASA_GOCART	Similar	Based on WRF-Chem GOCART
Other Aerosol species (include nitrate and ammonium, or include unspecific PM)	Nitrate and ammonium	Different	unspecific PM2.5 and PM10
AOD computation based on NASA look-up table	Online calculation (capability of aerosol radiative feedback in GFS)	Similar	Offline calculation (UPP)

Adapted from Zhang, Li's talk in AMS 2023, Denver, USA. "NOAA's Global Aerosol Forecast Capabilities: GEFS-Aerosols and UFS-Aerosols".

UFS-Aerosols Modeled 550 nm AOD .vs. VIIRS AOD Retrievals

-- October 06 – 27, 2017

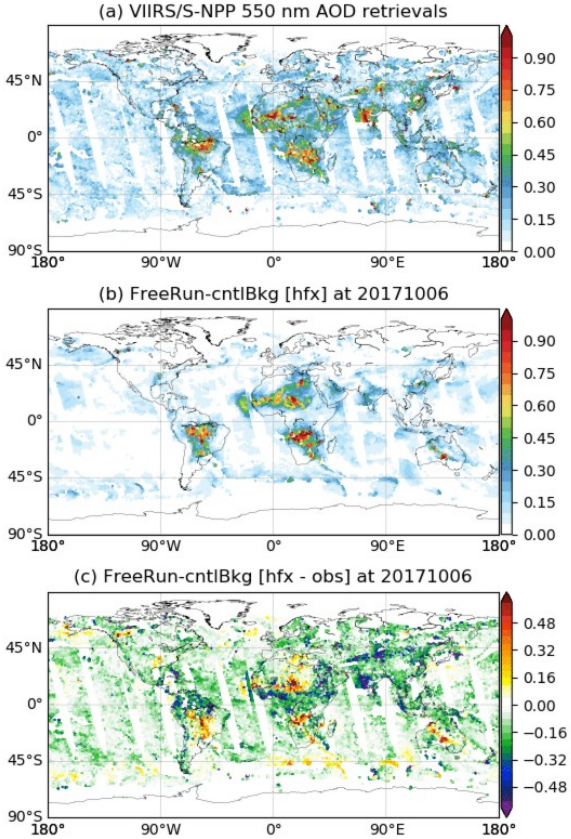
- **FreeRun** runs one-member aerosol forecast initialized every six hours.
- **AeroDA** runs a six-hourly assimilation of **NOAA/NESDIS VIIRS 550 nm AOD** retrievals derived from Suomi-NPP (S-NPP) satellite and **20+1** forecasts at **C192L127**. (Aerosol emissions are not scaled or stochastically perturbed yet**).**
- **UFS-Aerosols** is used for aerosol forecasts.

VIIRS AOD

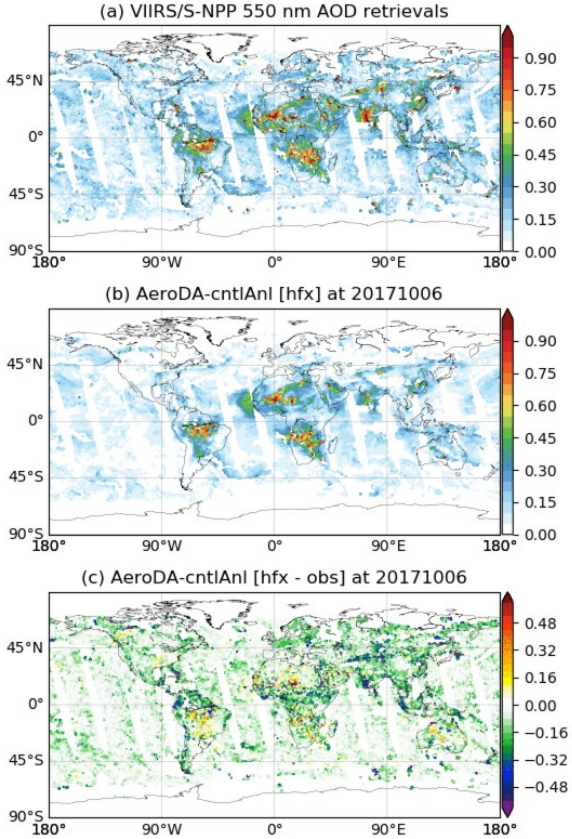
Modeled AOD

Model minus VIIRS

FreeRun



AeroDA



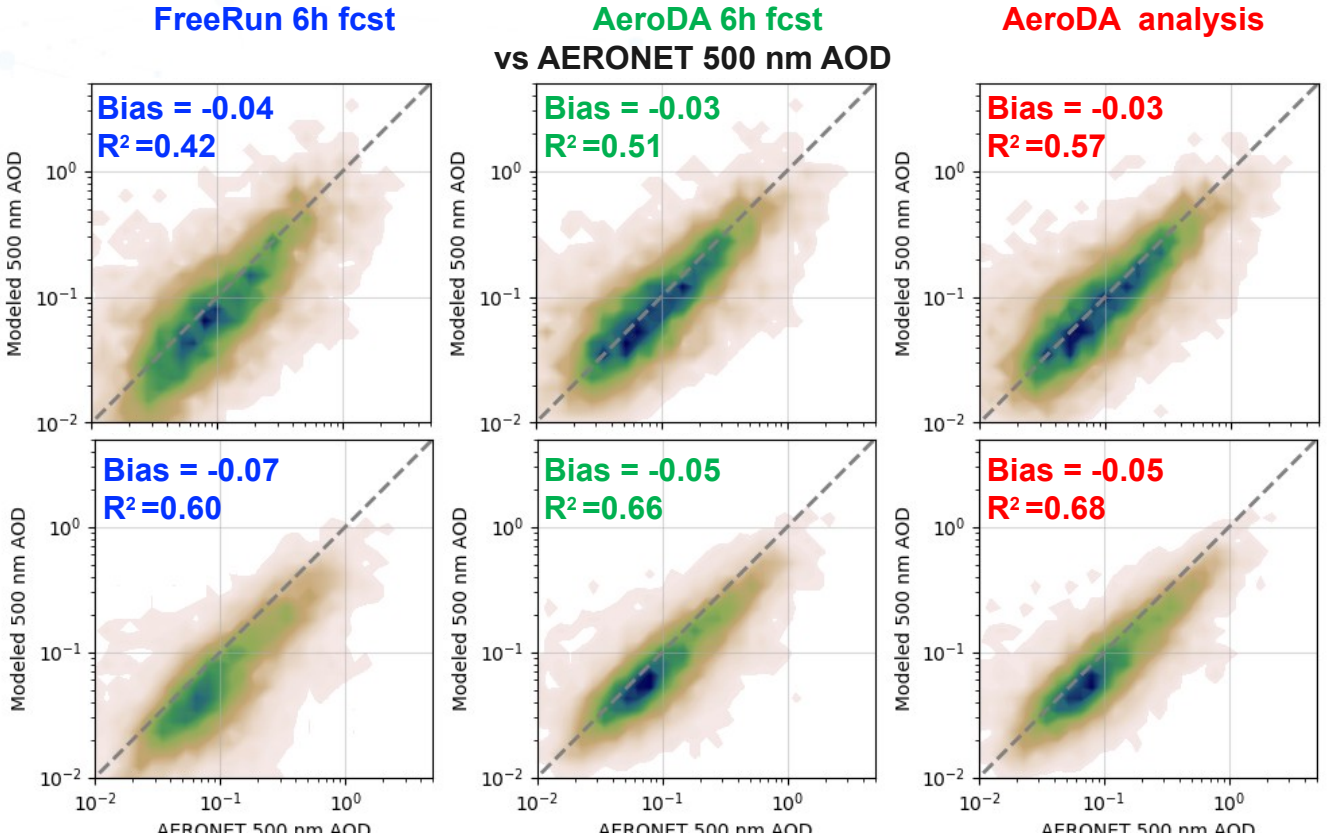
UFS-Aerosols and GEFS-Aerosols Modeled 500 nm AOD .vs. Ground Truth NASA AERONET L1.5 AOD

UFS-Aerosols

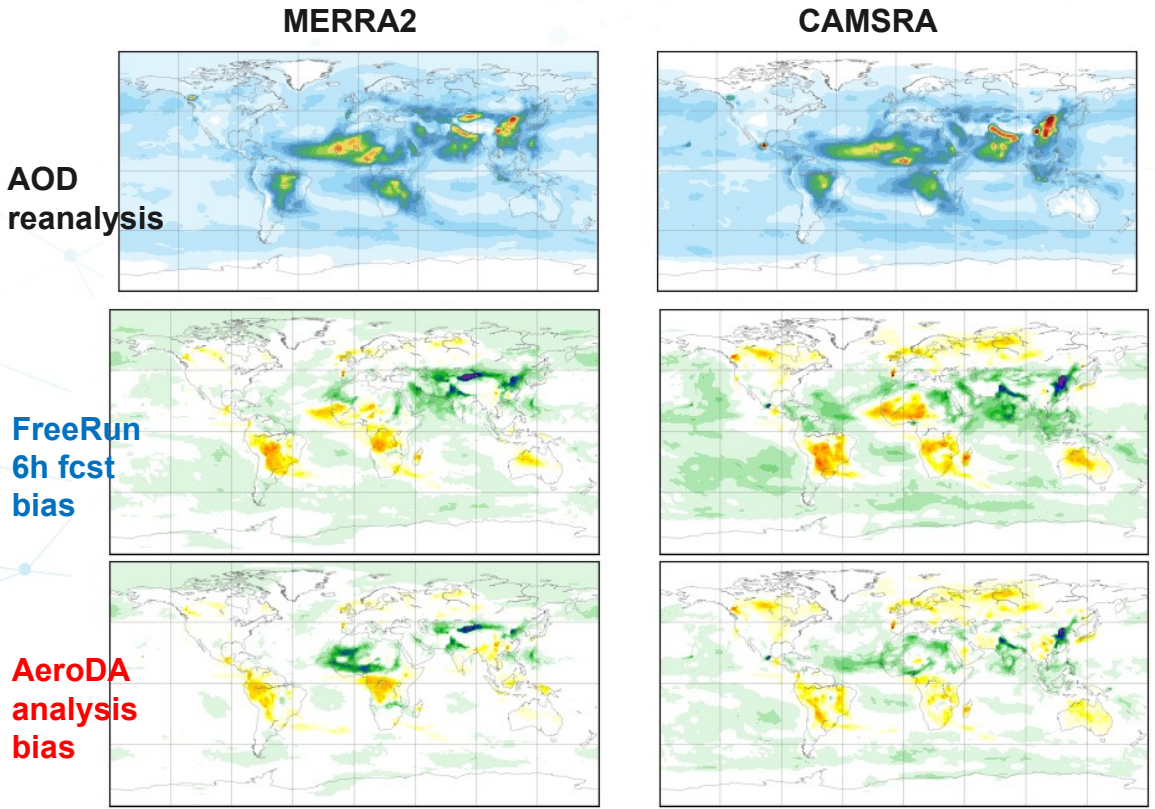
- **Emission not scaled or stochastically perturbed**
- 20+1 members at C192L127
- October 10 - 27, 2017

CCPP-based GEFS-Aerosols (intermediate version)

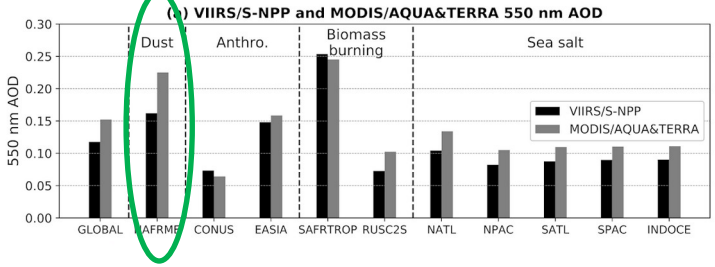
- Emission scaled and stochastically perturbed
- 20+1 members at C96L64
- October 01 - 31, 2022



UFS-Aerosols AOD Analysis against MERRA2 and CAMSRA Reanalysis in Oct 2017



Larger negative AOD bias over northern Africa in our analysis (lower panel) is related to that **NOAA VIIRS 550 nm AOD retrievals is of lower magnitude in this region than NASA MODIS AOD retrievals operationally assimilated in NASA and ECMWF aerosol reanalyses**.

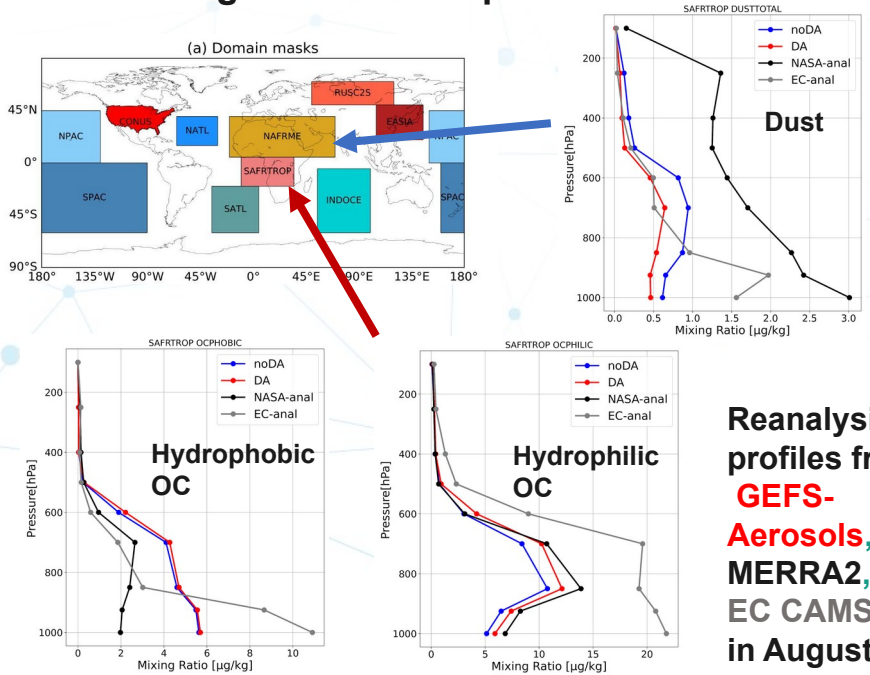


Oct. – Dec. 2021
(Huang et al. 2023)

Ongoing collaborations to enhance JEDI-based aerosol assimilation system

Assimilate Advanced Aerosol Retrievals from NASA PACE to Improve Aerosol Representation in UFS-Aerosols in collaboration with NASA, UMBC and SRON at Netherlands (funded by NOAA/CPO/ERB, AC4, and/or CVP program (2023-2026))

- **Assimilation of the integral AOD retrievals at 550 nm alone is incapable of properly constraining 3D aerosol species in the model.**

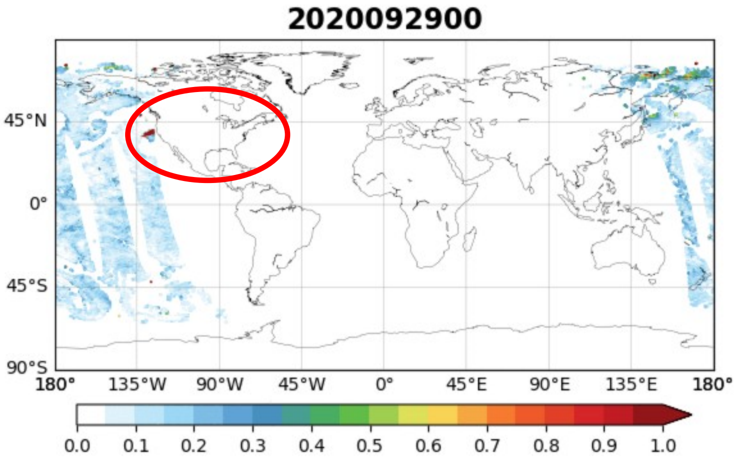


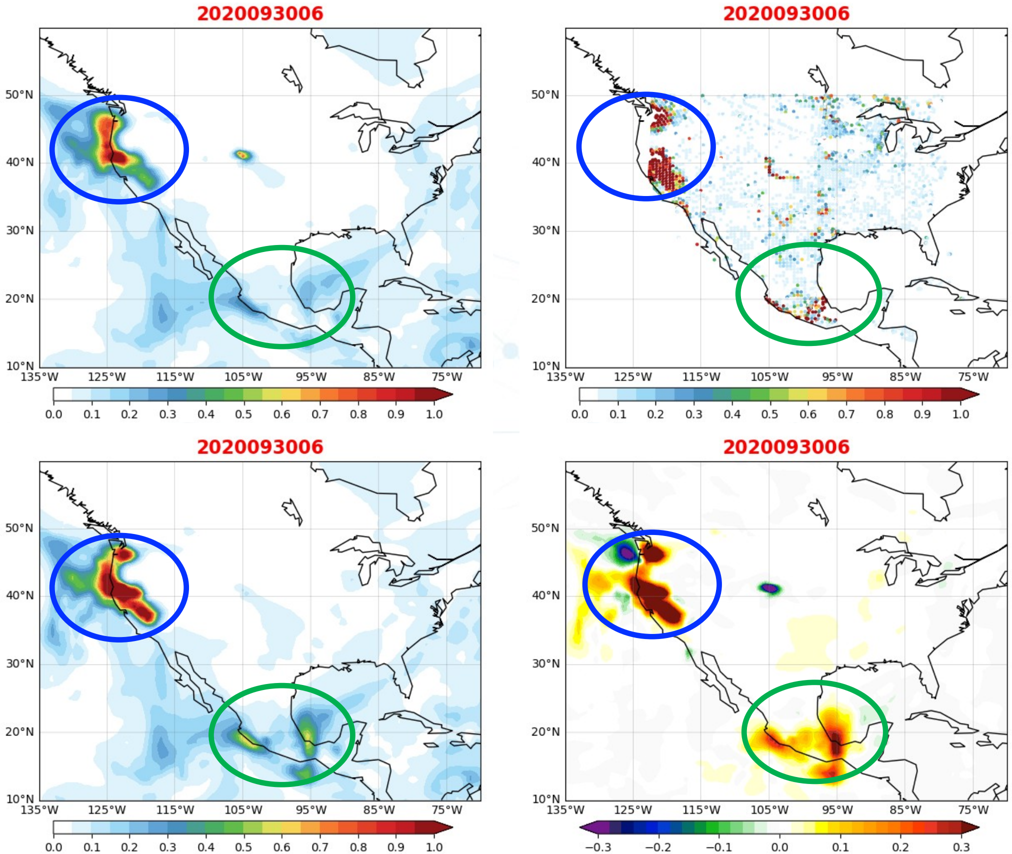
Reanalysis profiles from GEFS-Aerosols, NASA MERRA2, EC CAMSRA in August 2016

- NASA's Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission with the primary Ocean Color Instrument (OCI) and two complementary **multi-wavelength multi-angular polarimeters (MAPs)** is scheduled for launch in Jan 2024. It presents an exceptional opportunity to retrieve more detailed aerosol characterization with unprecedented accuracy from space.
  - 550 nm AOD retrievals from PACE OCI that will replace MODIS to retire in 2023.
  - Multi-wavelength AOD retrievals including UV band
  - Fine-mode fraction of AOD
  - Single scattering albedo
  - and more ……

Complement Assimilating Nocturnal 550 nm AOD Retrievals in JEDI to Capture Aerosol Diurnal Variational Feature in collaboration with University of Iowa

VIIRS solar AOD complemented with **lunar AOD derived from VIIRS moonlight observations** (Zhou et al., 2021) **over US at 06Z and 12Z**



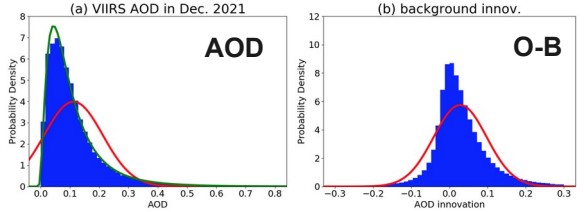


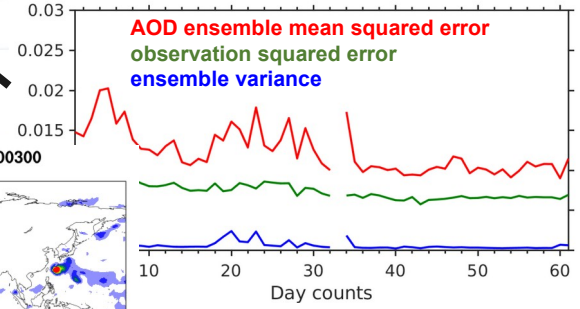
Address Inherent Deficiencies in the Current Aerosol Assimilation System

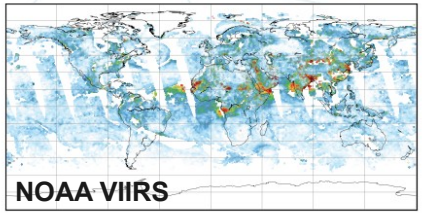
- Account for Non-Gaussian distributions of observation (for retrievals typically δAOD = $\alpha \cdot$ AOD + β) and model errors (requires transformation of variables);
- Develop stochastic parameterization to improve ensemble spread;
- Improve estimation of observation errors (requires diagnosis and further development of tools for thinning/super-obing);
- Address systematic model biases and observation uncertainties

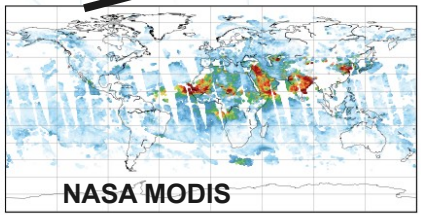
Physical space

Log space

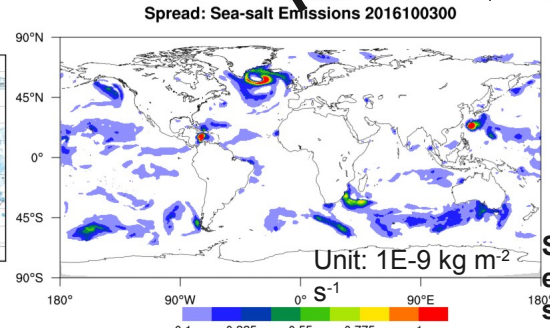








Aggregated 550 nm AOD on July 4, 2022



Spread of sea salt emissions by perturbed stochastically

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Thank you!

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