UFS-R2O Progress & Year 3 Plan

Atmospheric Composition Development Cross Cutting Team

6&7 December 2021

EMC, PSL, GSL, CSL, NSSL, ARL, NESDIS

Atmospheric Composition - Description and Goal

Project Scope: Improved representation of aerosol distribution and initial inclusion of aerosol-radiation interactions on S2S timescales for GEFSv13

Team:

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Subproject Leads, Subproject PI's, *NOAA Affiliated Scientists

The UFS R2O Atmospheric Composition subproject team **builds on the strong collaboration that developed GEFS-Aerosols**, which has been producing 120-hr global aerosol forecasts 4 times per day operationally at NCEP since September 2020.

Atmospheric Composition - Progress and status update

Milestones and Deliverables	End Date	Health
Model upgrades to produce a NUOPC-compliant coupled atmosphere-aerosol application with aerosol-radiation interactions	06/30/22	On Track
Global aerosol emissions processing system based on HEMCO for GEFS v13	06/30/22	On Track
Biomass burning emissions for S2S timescales for GEFS v13	06/30/22	At Risk
Quality control and bias correction procedures for AOD data assimilation for GEFS v13	06/30/22	On Track
Assist AOD data assimilation system development with focus on improved representation of aerosol species and vertical profiles for GEFS v13	06/30/22	On Track

Atmospheric Composition - Major Accomplishments (1)

Model infrastructure upgrades

- Developed UFS-Aerosols, a fully NUOPC-compliant coupled atmosphere-aerosol application in the UFS framework
- UFS-Aerosols uses latest version of NASA's GOCART aerosol model and integrates NASA's MAPL coupler
- Global CROW workflow was extended to include aerosols in UFS-Aerosols
- Successfully operating UFS-Aerosols on Orion, Hera and WCOSS
- Now testing, tuning and evaluating UFS-Aerosols in atmosphere-only and in Prototype simulations that couple UFS-Aerosols to atmosphere, ocean, sea ice and wave models

Aerosol-radiation interactions

- Evaluated aerosol-radiation feedbacks with CCPP coupling of predictive aerosols to physics
- Identified and corrected errors in Unified Post-Processor calculation of aerosol optical depth (AOD), including in the currently operational GEFS-Aerosols runs
- Evaluated NASA look-up tables relating aerosol mass & speciation to optical properties
- Continuing evaluations of aerosol-radiation feedbacks at MRW/S2S scales with UFS-Aerosols

Atmospheric Composition - Major Accomplishments (2)

Emissions

- Updated, tuned and evaluated Fengsha dust scheme, an improved description of global dust sources that is not available in NASA's GOCART aerosol model
- Developed NEXUS anthropogenic emissions processing system based on HEMCO
- Updated anthropogenic emissions inventories to more recent years and evaluated them
- Prepared and evaluated biomass burning emissions for retrospective and real-time simulation periods at different grid resolutions

Aerosol Data Assimilation (ADA)

- Compiled ADA error statistics for satellite AOD using AERONET remote sensing observations
- Evaluated ADA aerosol speciation and vertical profiles with unique aircraft field dataset
- Developing JEDI-based assimilation system for satellite AOD (through in-kind support)
- Included JEDI ADA in prototype workflow (through in-kind support)
- Compared skill of ADA to forecasts without ADA and NASA MERRA-2 reanalysis (through in-kind support)
- Implemented near-real-time ensemble-variational ADA (through in-kind support)

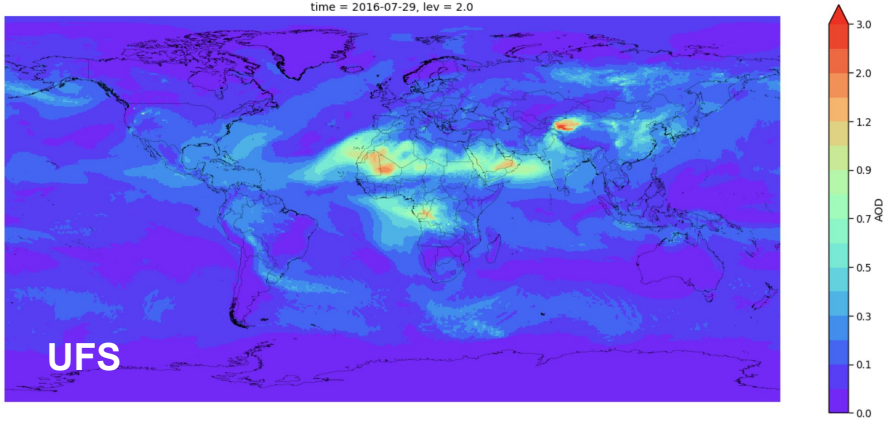
AC Results: Coupled Prognostic Aerosol Simulations (Leads: GSL, EMC, ARL)

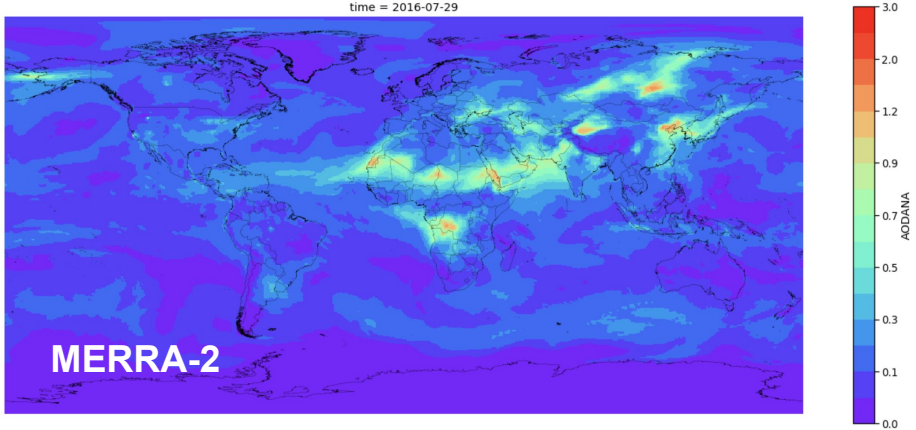
Coupled Prototype 7.1: FV3GFSv16 + MOM6 + CICE6 + WW3 + UFS-Aerosols Prognostic Aerosol Component

- GOCART aerosols from NASA repository, fully NUOPC compliant, in UFS authoritative repository
- Built through NOAA collaboration with NASA; extends MAPL infrastructure
- Initialize on: 1/1/13, 3/1/13, 7/1/13, 10/1/13, 1/1/16, 3/1/16, 5/1/16, 7/1/16, 10/1/16, 1/1/18, 3/1/18
- C384L127. Aerosol ICs = MERRA-2 reanalysis.
- 31-day integration free run (achievable within 8 hrs of wall clock time)
- Aerosol-radiation interactions not enabled currently, but will be after testing and tuning completed.

Results shown below compare **UFS-Aerosols free forecasts of AOD at week 4** (from 7/1/16 start) to MERRA-2 reanalysis.

- These are free runs, so some drift is expected relative to reanalysis.
- Nonetheless, predictive aerosol simulation looks remarkably similar to reanalysis. Tuning, which remains to be done, will only improve these results.





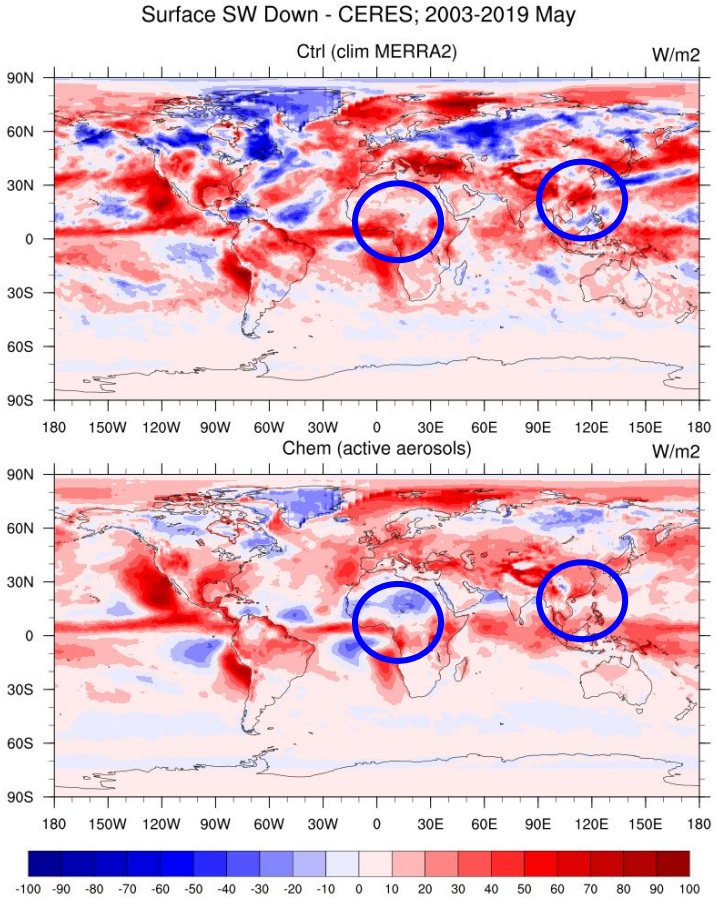
AC Results: Aerosol-Radiation Interactions (Lead: GSL)

Coupled Prototype 6+: FV3GFSv16 + MOM6 + CICE6 + WW3 + CCPP-Aerosols Prognostic Aerosol Component

- Aerosols based on GEFS-Aerosol, with GOCART aerosol scheme coupled to physics via CCPP
- Carried out as part of Working Group on Numerical Experimentation (WGNE) S2S experiments
- Initialize on 1 May & 1 Sept, 2003-2019.
- C384L64. Aerosol ICs = 30-day no-cycling cold run with zero aerosol to start.
- 32-day integration free run (per WGNE protocol; P6+ CCPP-Aero can run ~2 months w/in 8 hrs wall clock time)
- Aerosol-radiation interactions enabled

Results shown at right demonstrate **the bias in mean downward surface shortwave flux relative to observations from NASA's Clouds and the Earth's Radiant Energy System (CERES) satellite**.

- Top plot: Control run using NASA's MERRA-2 aerosol climatology
- Bottom plot: Chemistry run using CCPP-coupled predictive aerosols
- In blue circled areas with high aerosol loadings, warmer biases in the control runs are reduced in the chemistry runs



AC Results: Anthropogenic Emissions (Lead: ARL)

Results show decrease in bias over Eastern Asia with CEDS2019 (preliminary) versus CEDS2014 for Sep 2019 - Feb 2020.

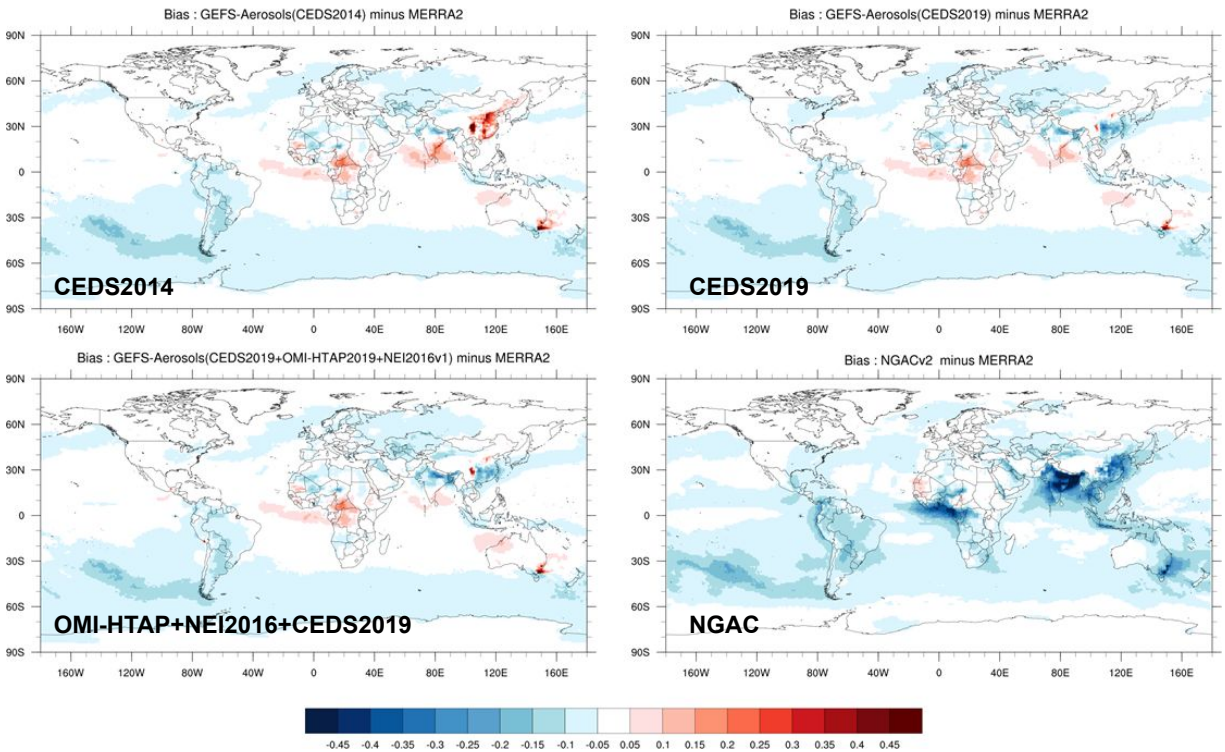
A parallel simulation using a combined emissions dataset of CEDS2019 (preliminary)+ OMI-HTAP + NEI2016 shows similar results.

Increased correlation vs AERONET for SON and DJF.

If results hold, a CEDS2019-based dataset could be recommended for use operationally in GEFS-Aerosol.

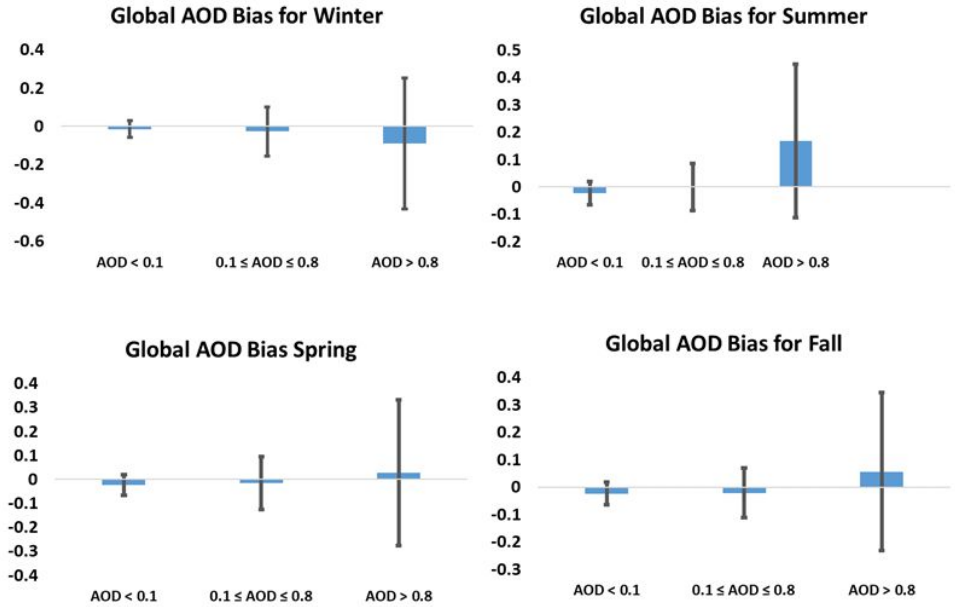
Analysis shows overall decrease in SO_2 emissions between CEDS2014 and CEDS2019, mainly in industrial, waste and shipping sectors.

Total AOD (550 nm) Day 1 Forecast Bias vs MERRA-2
12/1/19-2/29/20



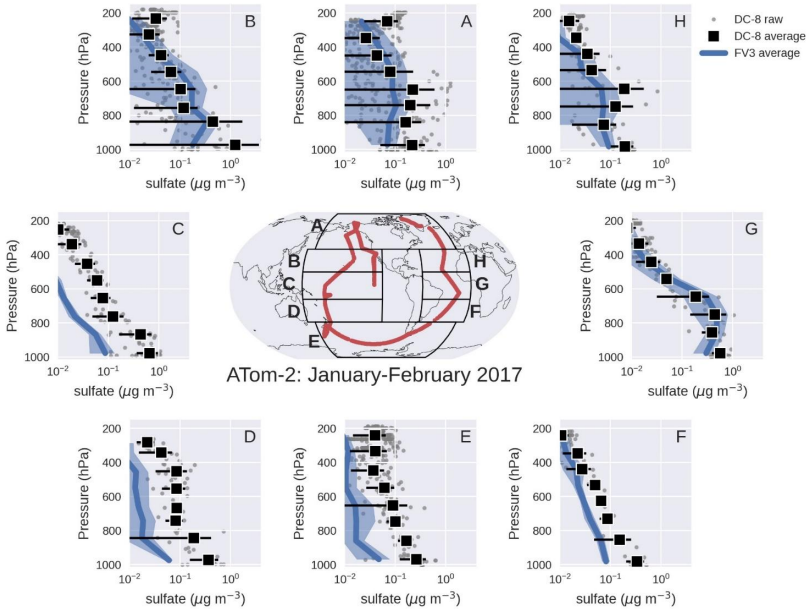
AC Results: Error Statistics for Assimilation of Satellite AOD (Lead: STAR)

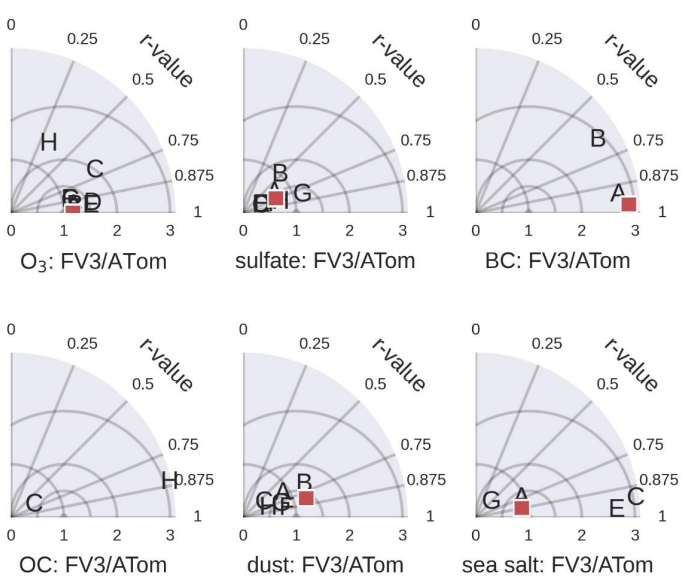
- **Evaluation of Suomi NPP VIIRS aerosol optical depth (AOD) using 2017 – 2020 AERONET data as reference** was completed.
- Bias and standard deviation of bias for three different AOD ranges (as required by JPSS Level 1 Requirements Document) were estimated. The sample size is large enough for the estimates to be statistically valid.
- Powerpoint slides with tables for different regions was provided to the DA team via email. At right is example of the global AOD biases for different seasons.

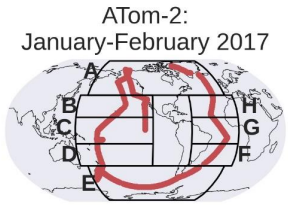


Bias and standard deviation of bias for the globe and several different regions of the globe (East CONUS, West CONUS, South America, Europe, Central Africa, South Africa, India, and China) were computed using a network of sun photometers (NASA AERONET data).

AC Results: Evaluations with Aircraft Aerosol Data (Lead: CSL)



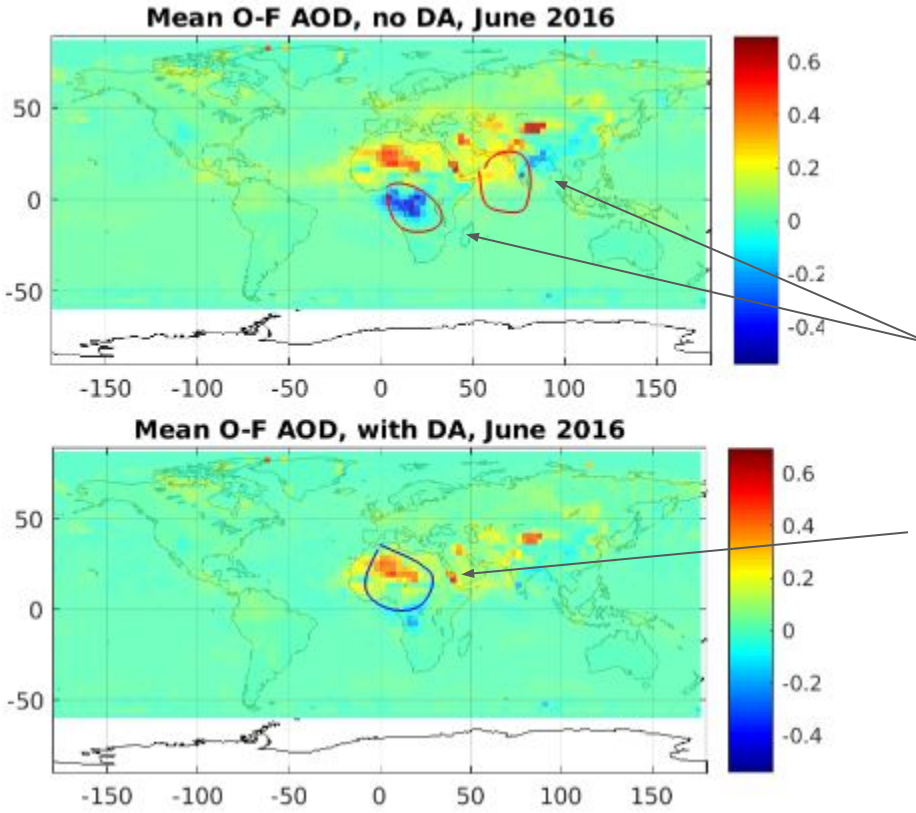




Observations of aerosol speciation and vertical profiles were collected by aircraft in the Atmospheric Tomography (ATom) campaign in 2016 - 2018.

The same evaluation and statistical analysis is available for all four ATom deployments (ATom-1 thru ATom-4). **These evaluations will be critical information for aerosol data assimilation efforts.**

AC Results: Assimilation of Aerosol Optical Depth (Lead: EMC)



EMC assimilated aerosol optical depth (AOD) for June 2016:

One month data assimilation (DA) cycling experiment is compared to control model run (without DA). DA reduces biases in the system.

Assimilation of MODIS AOD observations reduces forecast overestimates in Western Africa and underestimates in the Arabian Sea (red circled regions in upper plot).

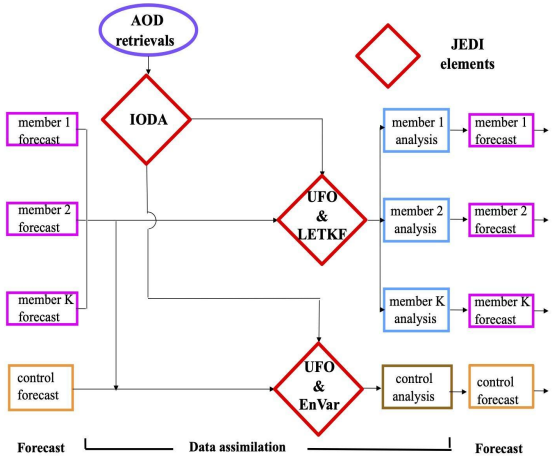
AOD underestimation in Northern Africa shows a smaller reduction (blue circle), likely due to higher observation errors over high albedo desert regions. This is an area of current research focus.

The time period chosen is a spinup to the first ATom deployment in July-August 2016 to coordinate DA system evaluation with speciated vertically resolved ATom data.

AC Results: Global Aerosol Data Assimilation System (Lead: GSL)

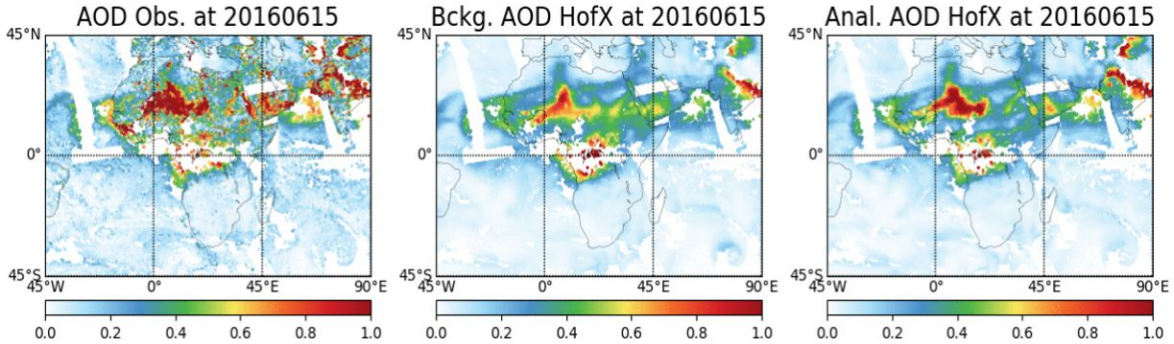
JEDI-based system imbedded in a workflow for real-time application and reanalysis

- Observations: satellite retrievals of 550-nm Aerosol Optical Depth;
- Model: GEFS-Aerosol;
- Assimilation: Hybrid Variational - Ensemble Kalman Filter.

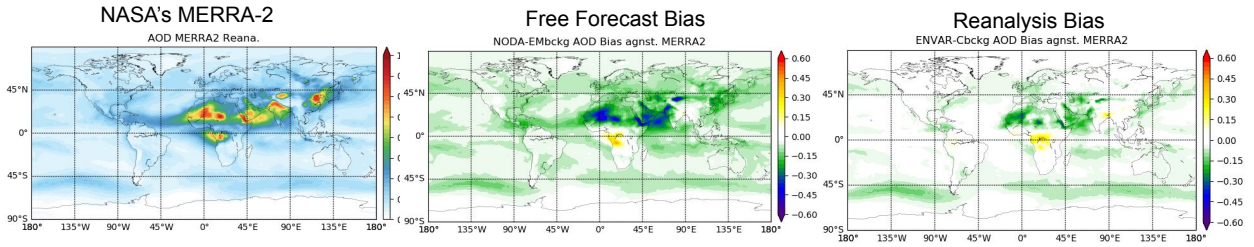


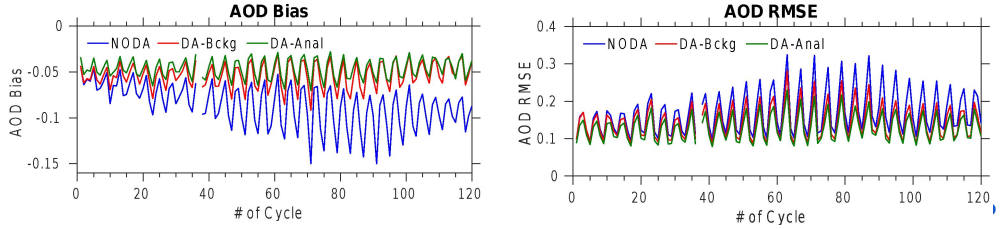
- **AOD**: Aerosol Optical Depth;
- **JEDI**: Joint Effort for Data assimilation Integration;
- **IODA**: Interface for Observation Data Access;
- **UFO**: Unified Forward Operator;
- **LETKF**: Local Ensemble Transform Kalman Filter;
- **EnVar**: Ensemble-Variational solver.

The System Assimilating VIIRS AOD Retrievals in Action during Dust Storm over North Africa



Evaluation Statistics for June 2016





Atmospheric Composition - Major Challenges

- Upgrades to Physics components require close attention from the AC subproject, given the tight coupling between aerosols and physics.
- More work lies ahead to seamlessly blend biomass burning predictions with climatological descriptions of fire emissions.
- Numerous issues with aerosol DA require additional effort, including:
  - Adequately translating AOD, a single integrated quantity, into credible adjustments to speciated aerosol spatial distributions;
  - Accurately relating the forward AOD operator to modeled aerosol properties.
- Additional compute resources have been needed throughout the project. Orion should help to ease this burden, although instabilities in Orion are currently causing difficulties.
- Need to improve computational performance of UFS-Aerosols in coupled prototype simulations in order to consistently complete 35-day simulations within 8 hrs of wall clock time. Solving instability issues on Orion and assigning more nodes to atmosphere calculation should help solve this challenge.
- Workflow complexity made upgrades to include aerosols difficult and time consuming.
- Most aerosol DA work was carried out through in-kind support. We are seeking direct support for ADA efforts in Year 3.

Atmospheric Composition - Work Plan for Year 3

Tasks	Lead FMCs	Dependencies	Impact if not funded
Test and evaluate aerosol coupling with radiation and microphysics	GSL, EMC	Physics, Infrastructure	Inconsistent approach to direct and indirect aerosol impacts on meteorology
Enhance accuracy and timeliness of aerosol and precursor emissions and distributions	ARL, GSL, STAR	Physics, Marine, Infrastructure	Unrealistic simulations of aerosol distributions and aerosol impacts on meteorology
Atmospheric composition model integration, testing and evaluation	EMC, CSL, ARL	Verification & Post-Processing, Infrastructure	Inability to demonstrate improved performance of predictive aerosols
Advance AOD assimilation	EMC, GSL, JCSDA	Data Assimilation, Infrastructure	Unrealistic simulations of aerosol distributions and impacts on meteorology
Develop RRFS-CMAQ development for RRFSv2	EMC, ARL, GSL, CSL, PSL	DSUP, FY22 WSUP projects	Inconsistent global and regional approaches to atmospheric composition
Prepare for constraints of aerosol and trace gas distributions from additional satellite data	CSL, EMC, ARL	Data availability	Unrealized opportunities for evaluation and improvement of UFS Atmospheric Composition component

Atmospheric Composition - Compute Requirements

- Hera: at least 500K core hours
- Orion: 1M core hours
- WCOSS: at least 500K core hours

Atmospheric Composition: Possible in-kind efforts

- FY19 Disaster Supplement WF-1, WF-2, WF-3
- FY22 Wildfire Supplemental
- WPO JTTI proposals
- OSTI FY22 proposals?

Atmospheric Composition - Summary & Closing Remarks

- Atmospheric Composition (AC) is a fundamental part of the Earth System. Atmospheric composition prediction should be included in UFS forecasts at all scales.
- Prognostic aerosols are now included in fully coupled UFS R2O MRW/S2S simulations, a key goal of the AC subproject that could lead to a major advance in NOAA's operational predictions.
- The AC subproject's work builds on existing strong collaborations and evaluated model components that have demonstrated operational performance.
- The performance of the coupled model prognostic aerosol MRW/S2S forecasts relative to the use of aerosol climatologies is now being evaluated, in order to demonstrate the value of the additional expense to predict aerosol distributions and impacts.
- More discussion and extensive coordination is needed to understand how proposed new UFS-R2O project structure will advance global and regional UFS atmospheric composition development.