Science, Service, Stewardship

UFS-Aerosol, the Unified Forecast System's global aerosol component

Gregory Frost, on behalf of the UFS R2O Atmospheric Composition Team

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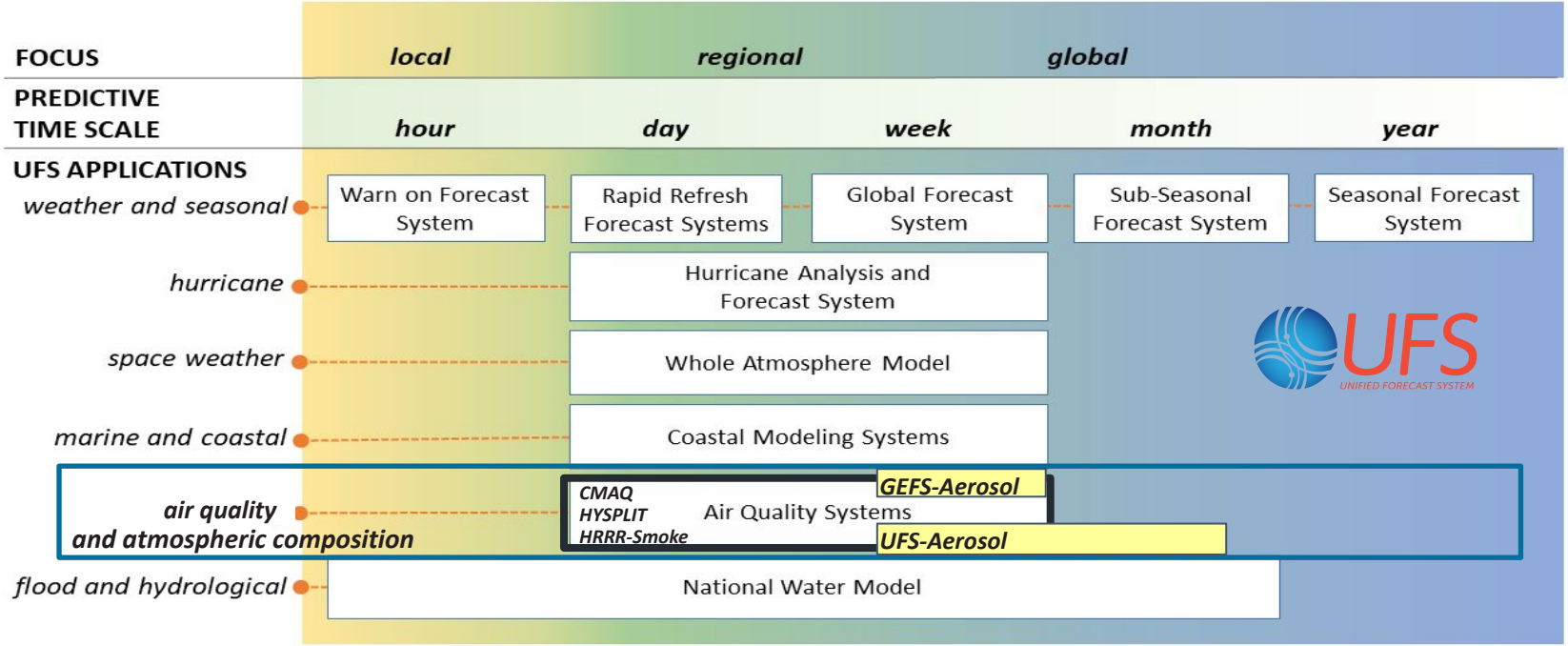
Unified Forecast System (UFS) - https://ufscommunity.org/

- Unification of many previously disparate systems under a single framework
- Reliance on community modeling and community components



Community modeling has been the basis of operational air quality and atmospheric composition predictions from CMAQ (EPA) and GOCART (NASA)

Development of NOAA's global aerosol forecasts results from successful collaborative effort by 3 NOAA Line Offices, their partners, and their collaborators

OAR

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Collaborators

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MRW/S2S

NWS NCEP EMC:
MDAB
EIB

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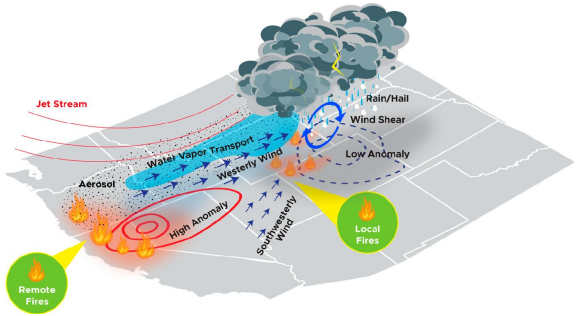
[5]Also at South Dakota State University

**UFS R2O Atmospheric Composition Team Leads*
UFS R2O Atmospheric Composition Team Principal Investigators

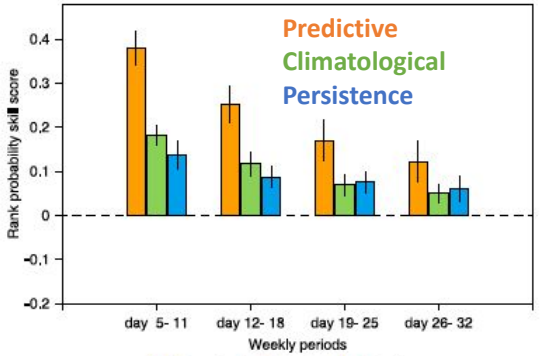
Motivations for including realistic representations of aerosols in NOAA's global forecasting system

Aerosols impact radiation and cloud microphysics on short-range, S2, and longer timescales.



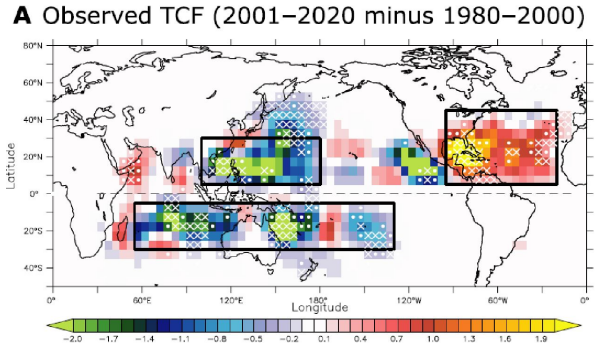
Zhang et al., PNAS, 2022

Heat and aerosols from Western US wildfires work together to increase occurrences of heavy precipitation and hail downstream.



Benedetti and Vitart, MWR, 2018

Including direct effect with predictive aerosols improves S2S predictions over aerosol climatology at monthly scales for the spring/summer season.



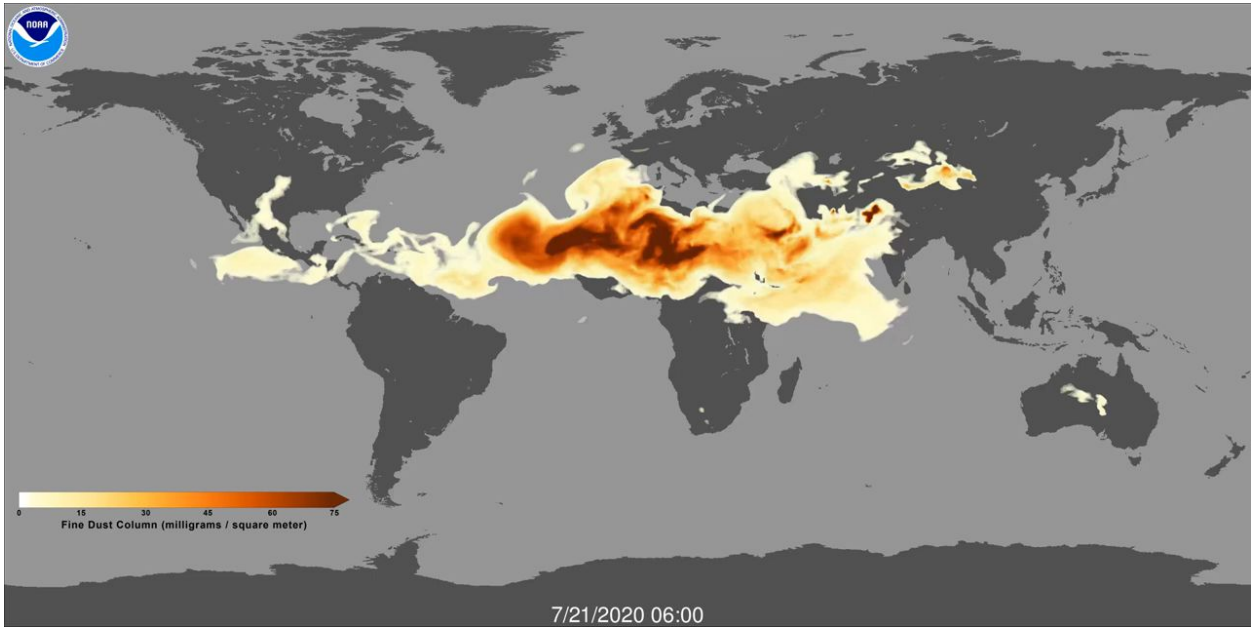
Murakami, Sci. Adv., 2022

Decreasing aerosols over Europe and the US contributed to decreases in tropical cyclones (TCs) over Southern Hemisphere and increases in TCs over North Atlantic, while increases in aerosols in South and East Asia led to decreases in TCs over western North Pacific.

NOAA's current global aerosol forecast

Global **E**nsemble **F**orecast **S**ystem **v**ersion **12** with **Aerosol** = **GEFSv12-Aerosol**

- Developed under NGGPS Program beginning in 2015
- NOAA LOs, Labs, and Centers involved were same as in UFS work
- Operational since September 2020
- Single member of GEFSv12
- 5-day forecast
- Provides global aerosols and lateral boundary conditions for regional air quality predictions



NOAA's next-generation global aerosol forecast

UFS-Aerosol is the aerosol component of the UFS 6-way coupled system developed within the UFS R2O Program as a prototype for global subseasonal prediction in GEFSv13.

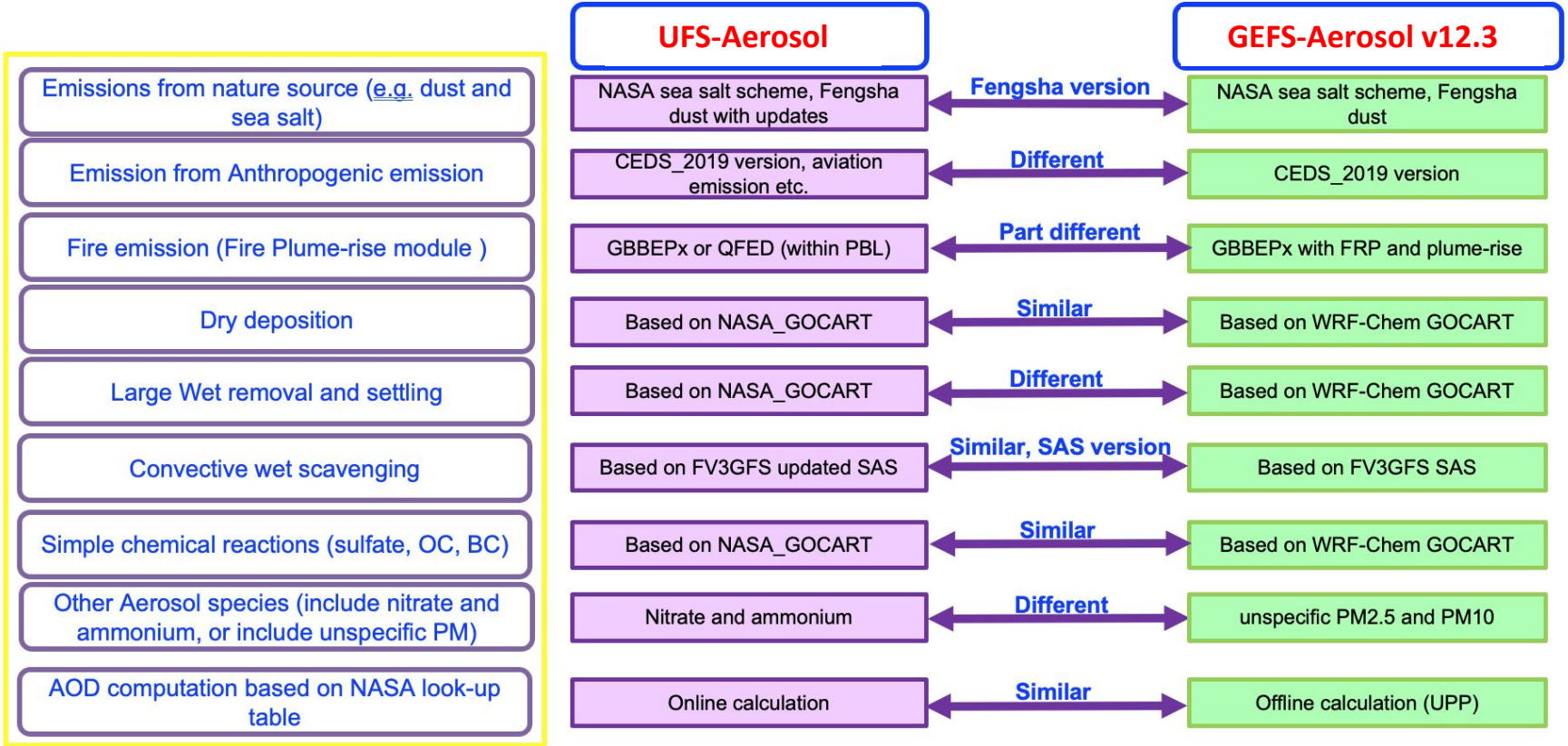
Community components used in this coupled system:

- Finite Volume cubed sphere (FV3) dynamical core for atmosphere
- Global Forecast System (GFS) physics for atmosphere
- Modular Ocean Model (MOM6)
- Los Alamos Sea Ice Model (CICE6)
- WAVEWATCH III for waves
- NOAH-MP for land
- Goddard Chemistry Aerosol Radiation and Transport (GOCART) model for atmospheric aerosols (from NASA's repository)
- NUOPC/ESMF compliant coupling infrastructure

Expected benefits and outcomes of UFS-Aerosol:

- Improved aerosol process descriptions
- Realistic aerosol spatial distributions and temporal variability
- Realistic representation of aerosol radiative impacts on meteorology
- Solid foundation for NOAA's next-generation state-of-the-art operational S2S forecast system

UFS-Aerosol vs. Operational GEFS-Aerosol



Some accomplishments in UFS-Aerosol development

Developed UFS-Aerosol, a fully NUOPC-compliant aerosol application based on latest version of GOCART from NASA's repository that integrates MAPL coupling framework

- Coupled UFS-Aerosol to the atmospheric component in UFS framework
- Made available in authoritative repository for the UFS weather model
- Extended UFS global workflow to include aerosols
- Wrote UFS-Aerosol concept of operations and evaluation plan targeted for GEFSv13

Improved aerosol process descriptions in UFS-Aerosol

- Included and optimized Fengsha dust scheme (not available in NASA's GOCART)
- Connected UFS-Aerosol with updated SAS convective wet scavenging scheme
- Connected large-scale aerosol precipitation flux in Thompson microphysics to UFS-Aerosol
- Implemented aerosol direct radiative feedback in UFS-Aerosol

Testing and evaluating UFS-Aerosol

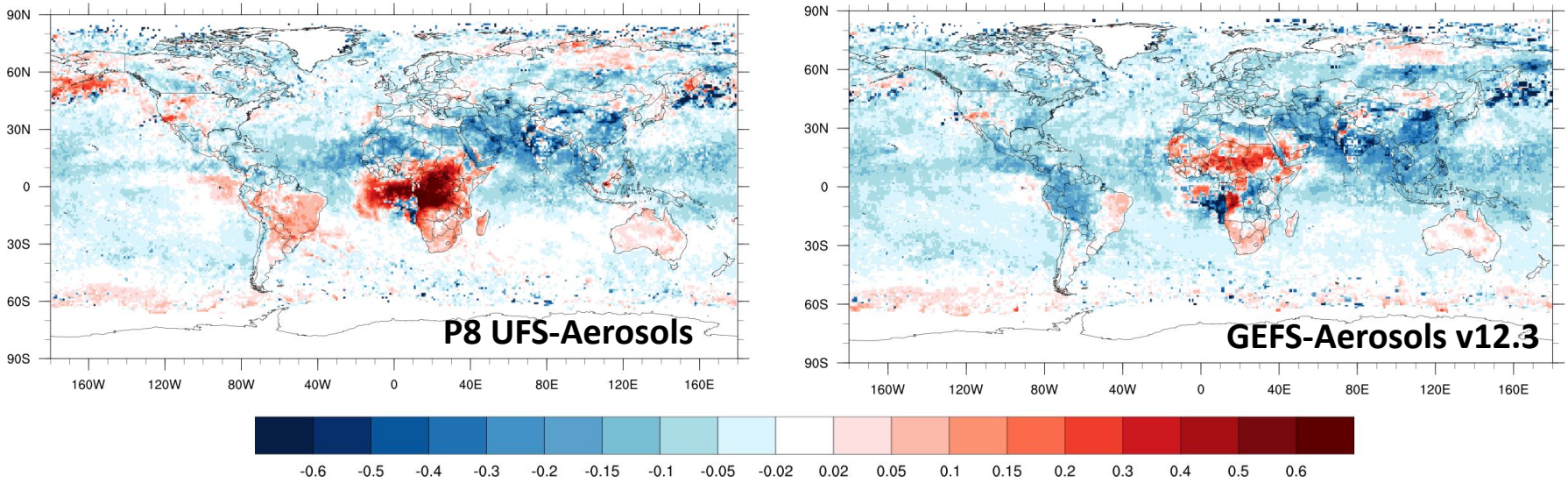
- Included UFS-Aerosol prognostic aerosols in Coupled Prototype 8 simulations (168 35-day free runs starting on 1^{st}/15^{th} of each month in 2011-2018)
- Included UFS-Aerosol aerosol-radiation interactions in 28-simulation (1/season) P8 subset
- Carrying out detailed evaluations of aerosols and their impacts on meteorological forecast skill

Evaluating UFS-Aerosol predictions of aerosols

UFS-Aerosols predicted aerosol spatial distributions and magnitude are comparable to those of current GEFS-Aerosols operational forecasts.
Both simulations compare reasonably well to satellite observations.
GOCART diagnostic output bug fix and further tuning of emissions will reduce existing biases.

Total Aerosol Optical Depth (AOD) Day 1 forecast bias vs MODIS

August 2016 atmosphere-only cycling runs

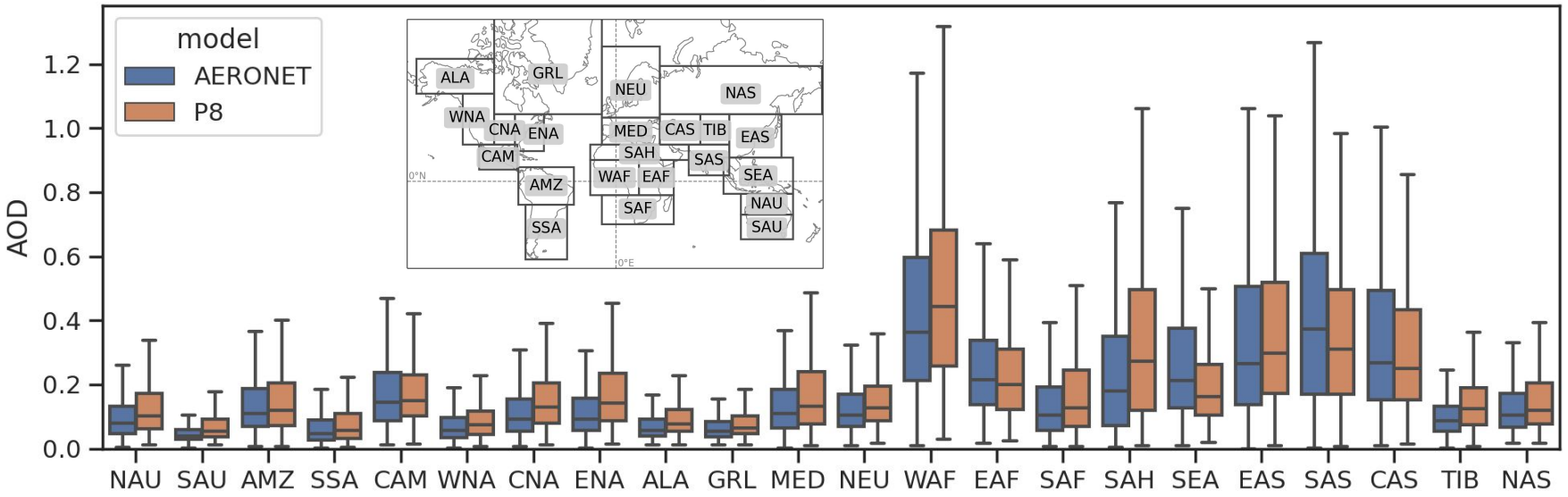


Analysis by Kate (Li) Zhang and Partha Bhattacharjee

Evaluating UFS-Aerosol predictions of aerosols

UFS-Aerosols predictions of aerosol spatial distributions and magnitude are comparable to ground-based AERONET remote-sensing observations from sites around the world.
GOCART diagnostic output bug fix and further tuning of emissions will reduce existing biases.

Regional comparisons of **P8 Weeks 1-4 UFS-Aerosols** to **AERONET Total AOD**

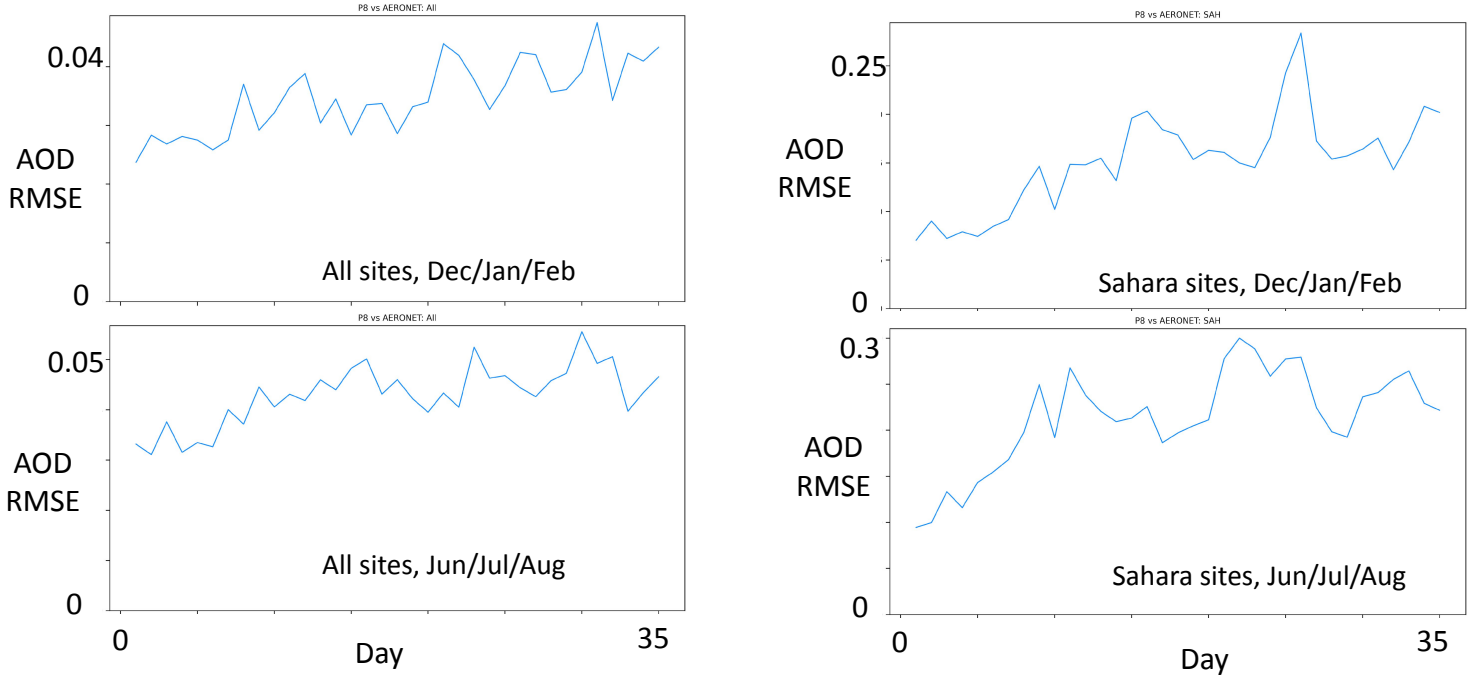


Analysis by Jian He, Zach Moon, and Barry Baker

Evaluating UFS-Aerosol predictions of aerosols

Root-mean-square errors between P8 UFS-Aerosols and AERONET AOD tend to increase in the first 2-3 weeks of simulation and then level off.
Drift over time is to be expected, particularly for meteorologically driven dust emissions.

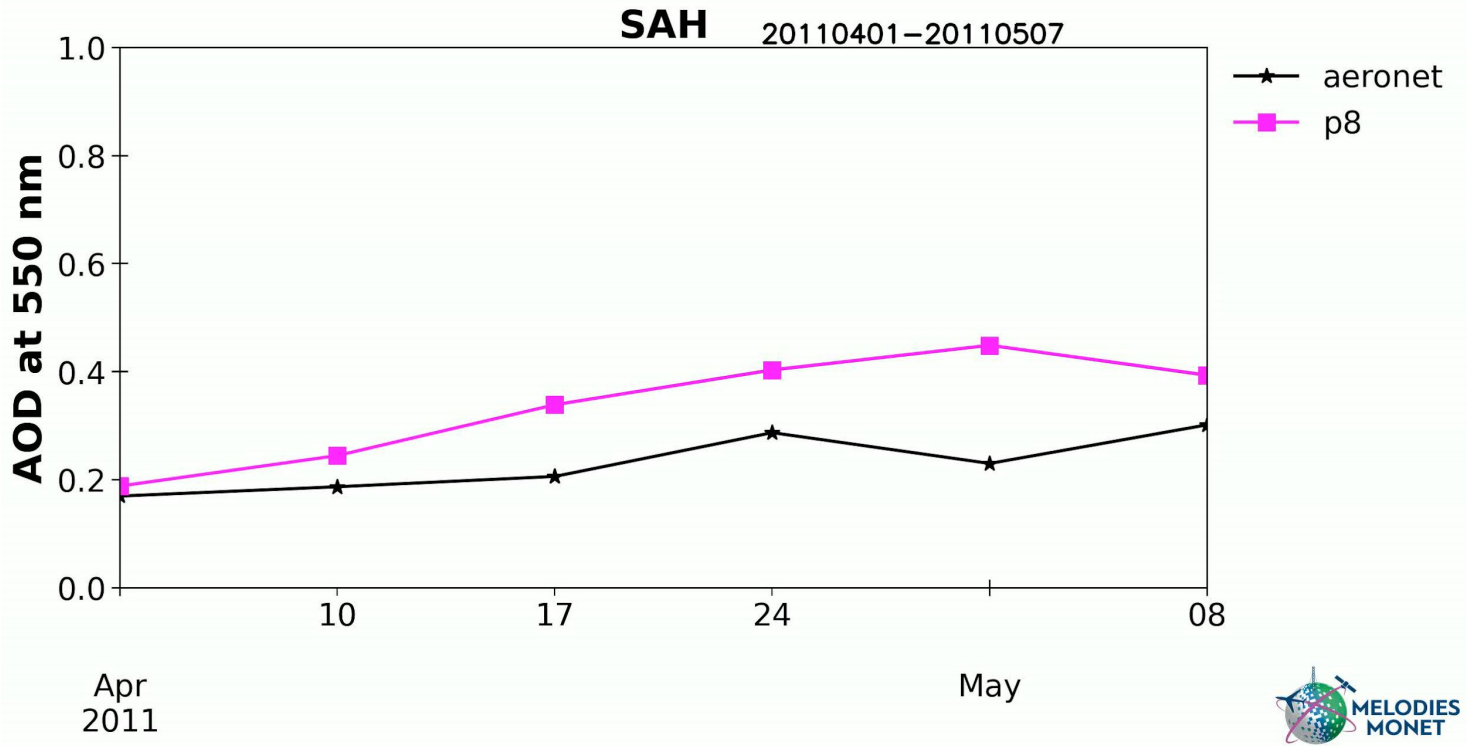
Root Mean Square Error between **UFS-Aerosols** and **AERONET Total AOD** as a function of forecast length



Analysis by Jian He, Zach Moon, and Barry Baker

Evaluating UFS-Aerosol predictions of aerosols

UFS-Aerosols AOD generally correlates well with AERONET AOD throughout the 35-day P8 simulations, demonstrating that process descriptions and meteorological predictions have skill. Drift over time is to be expected, particularly for meteorologically driven dust emissions.



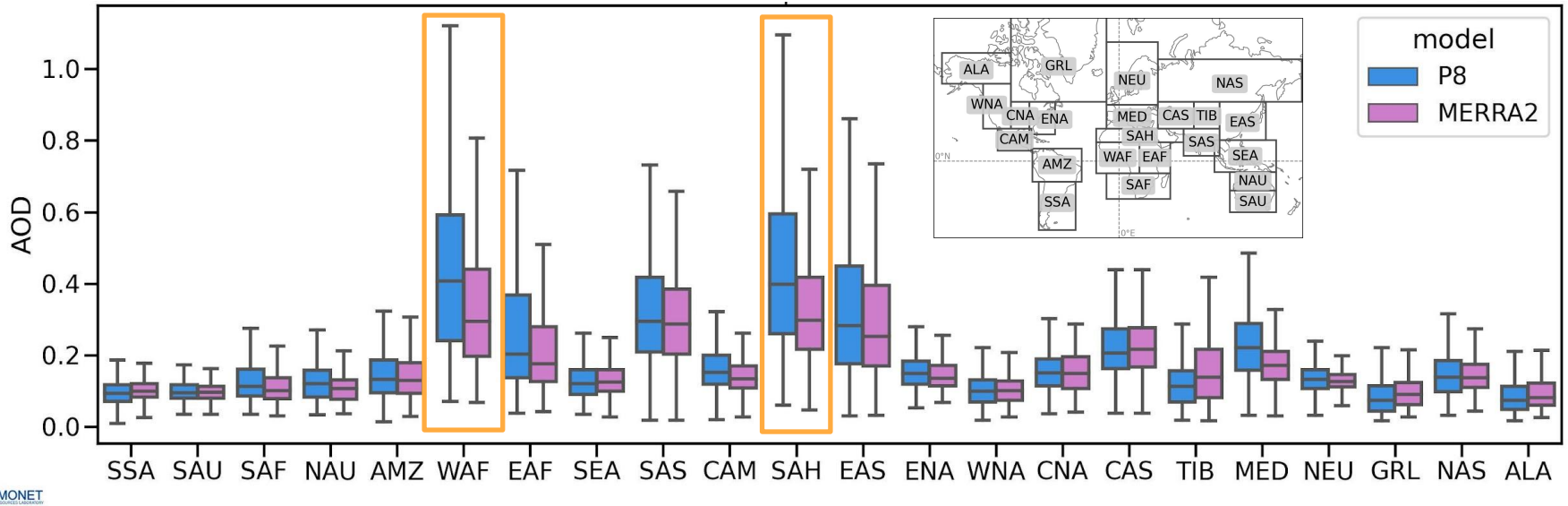
Analysis by Jian He, Zach Moon, and Barry Baker

Evaluating UFS-Aerosol predictions of aerosols

UFS-Aerosols predictions of aerosol spatial distributions, magnitude, and speciation are comparable to NASA's MERRA-2 reanalysis dataset.

Largest biases are in regions with strong biomass burning and dust emissions. Some of these biases will decrease when GOCART diagnostic output bug fixed.

Regional comparisons of **P8 Weeks 1-4 UFS-Aerosols** Total AOD to **MERRA-2 Total** AOD

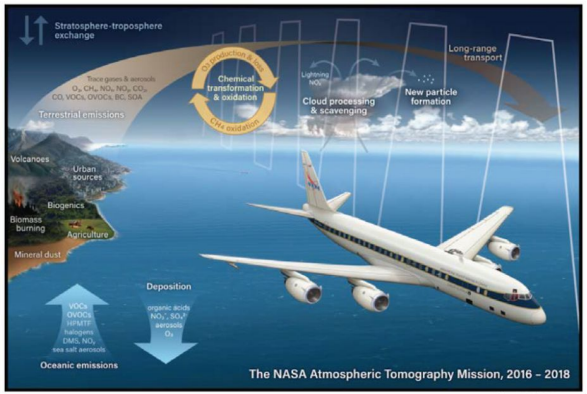


Analysis by Colin Harkins, Jian He, Zach Moon, and Barry Baker

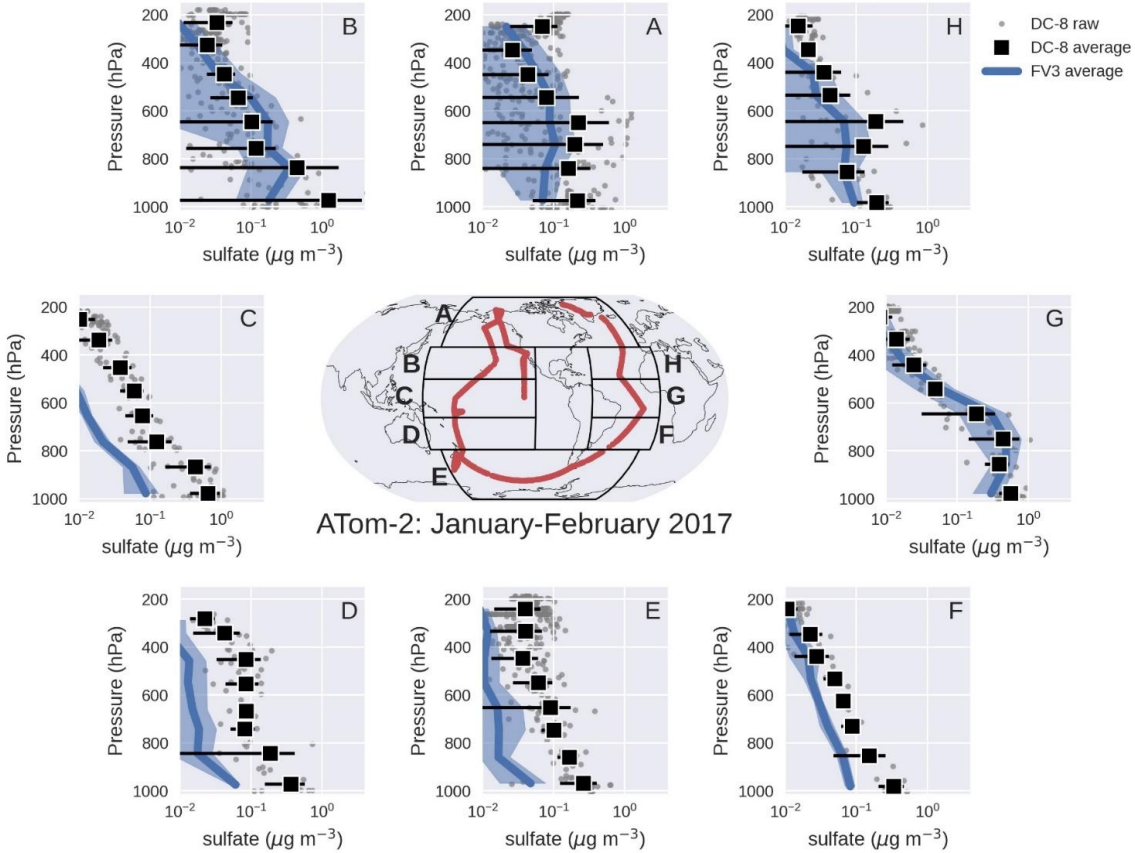
Evaluating UFS-Aerosol predictions of aerosols

UFS-Aerosols predictions of aerosol vertical profiles, speciation, size distributions, and optical properties are compared to aircraft observations collected in the Atmospheric Tomography (ATom) campaign in 2016 - 2018.

NASA Atmospheric Tomography Mission



Sulfate vertical profiles

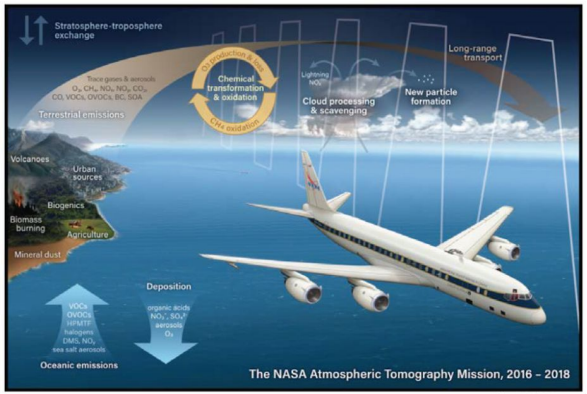


Analysis by Siyuan Wang

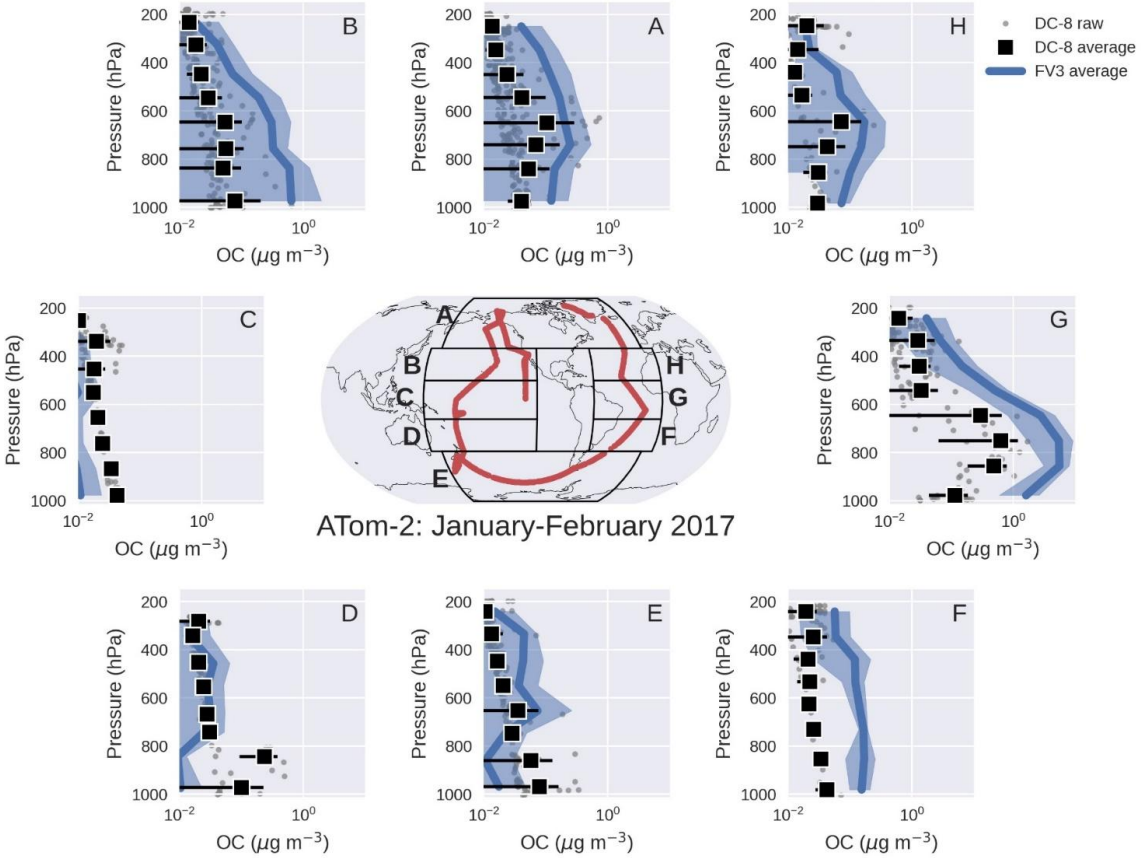
Evaluating UFS-Aerosol predictions of aerosols

Evaluations with ATom observations enabled tuning of aerosol emissions and assessment of the accuracy of aerosol size and optical properties for different aerosol species.

NASA Atmospheric Tomography Mission



Organic Carbon vertical profiles



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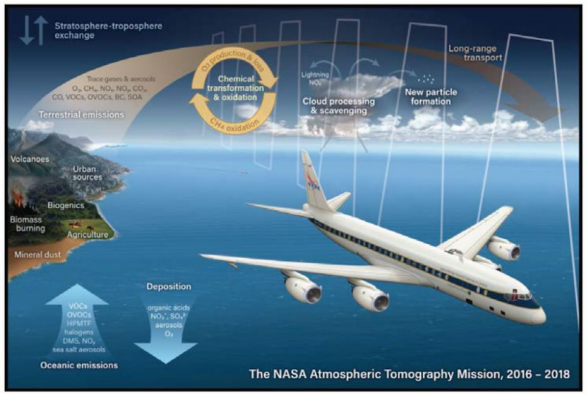
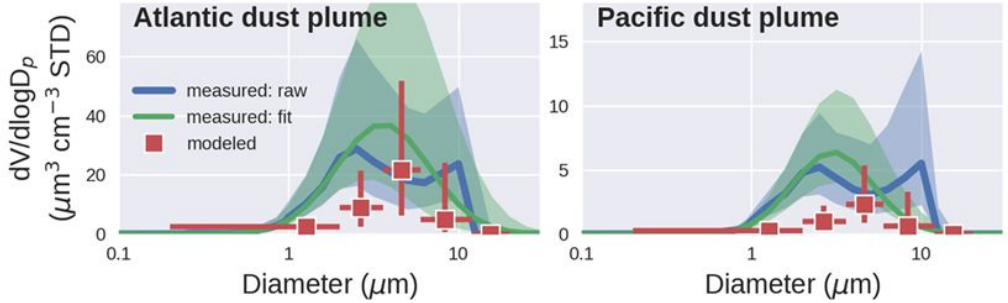
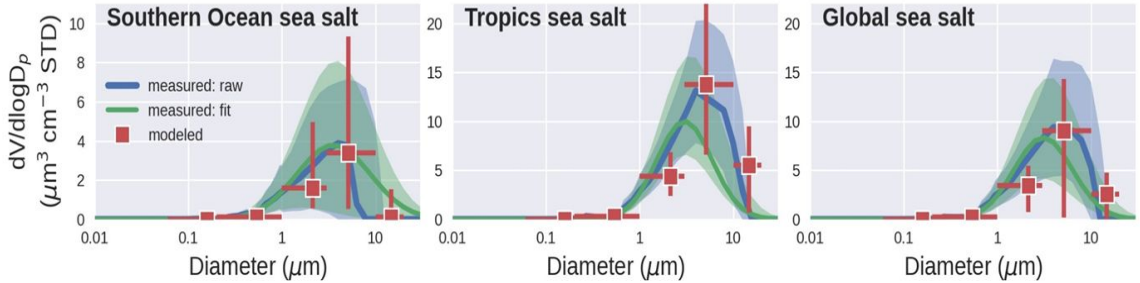


Dust size distributions



Sea Salt size distributions



Analysis by Siyuan Wang

Assessing impact of UFS-Aerosol on meteorology at sub-seasonal timescales

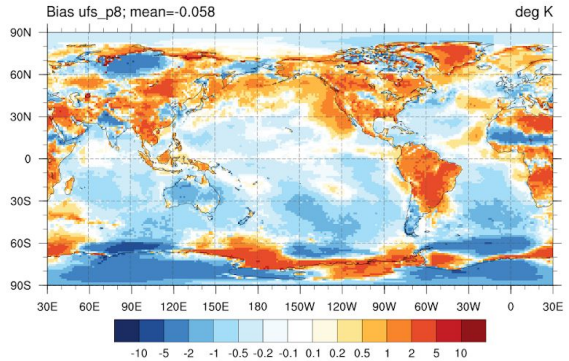
Initial evaluations of meteorological impacts from radiation interactions with UFS-Aerosol prognostic aerosols relative to MERRA-2 aerosol climatology are underway for a 28-simulation subset of P8.

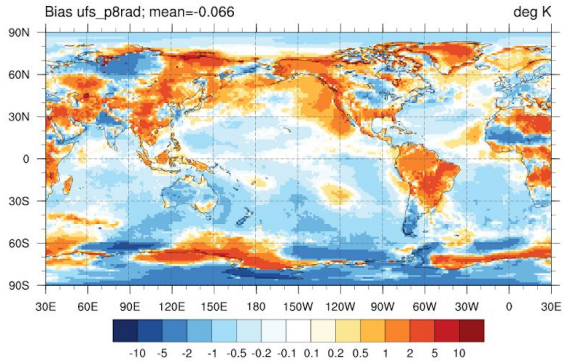
Inclusion of interactive prognostic aerosols generally **improves** mid-latitude and tropical surface temperature predictions in Weeks 3&4 relative to climatology.

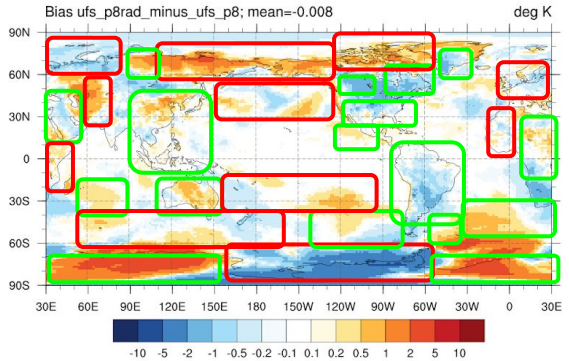
Interactive prognostic aerosols have minor impact on Week 1 meteorological predictions compared to climatology in the absence of major aerosol- generated events (*not shown*).

Climatological aerosols | **Prognostic aerosols** | **Prog - Clim Difference**

Weeks 3&4 July ICs 2-m T bias vs GEFSv12 reanalysis







Boxes = Prognostic aerosols
improve*/*degrade *skill w.r.t. climatology*

Analysis by Lydia Stefanova

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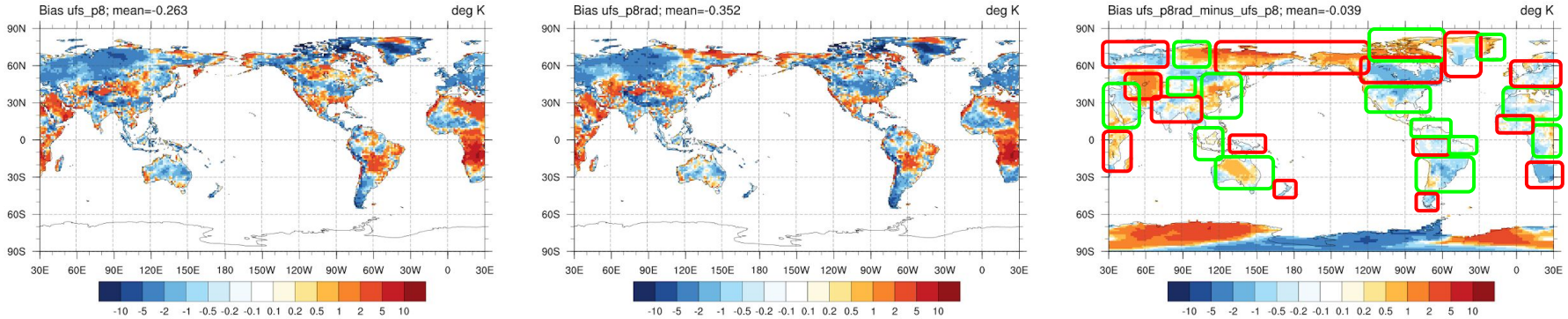
Climatological aerosols | **Prognostic aerosols** | **Prog - Clim Difference**

Weeks 3&4 July ICs max 2-m T bias vs CPC gridded obs



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Analysis by Lydia Stefanova

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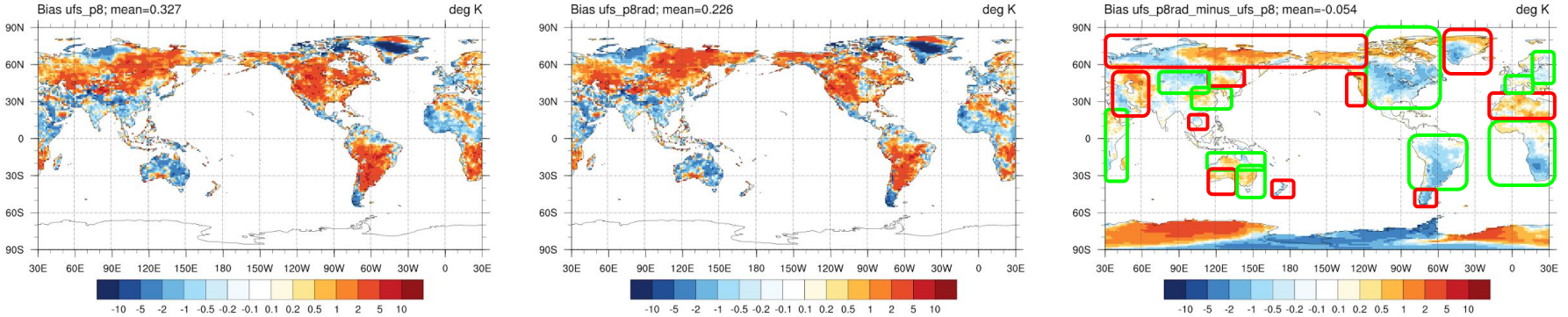


Boxes = Prognostic aerosols
improve*/*degrade *skill w.r.t. climatology*

Analysis by Lydia Stefanova

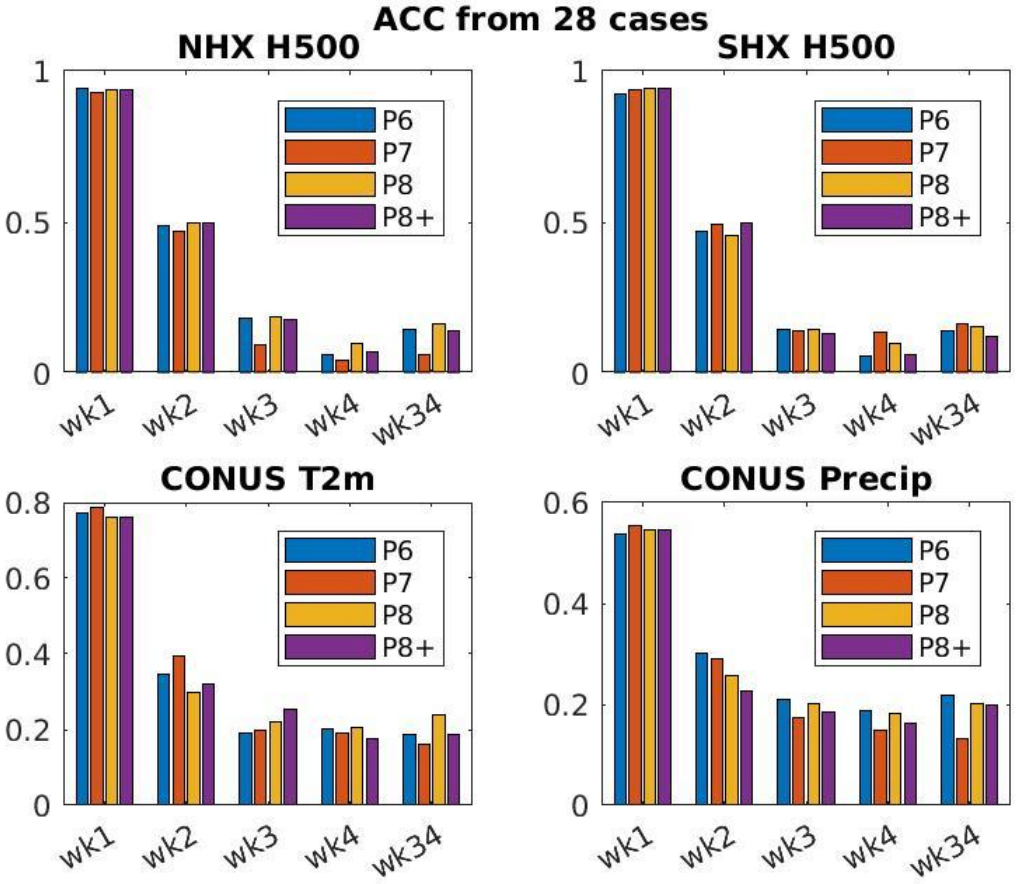
Assessing impact of UFS-Aerosol on meteorology at sub-seasonal timescales

Anomaly correlation coefficients (ACCs) from a 28-simulation P8 subset for 500-mbar geopotential heights, 2-m temperatures and precipitation produced with UFS-Aerosol interactive prognostic aerosols are **comparable** to those from P8 simulations using the MERRA-2 climatology.

Significance of these results limited by small sample size.

$$ACC = \frac{\overline{(f-c)(a-c)}}{\sqrt{\overline{(f-c)^2}\ \overline{(a-c)^2}}}$$

where f is from model, a is analysis/ observations (CPC gridded datasets for T2m and precipitation, and CFSR for H500), and c is monthly climatology.



Analysis by Shan Sun and Lydia Stefanova

Looking ahead

Near term (now through June 2023)

- Compile detailed evaluation metrics for aerosols and their meteorological impacts in Coupled Prototype 8 experiments and in atmosphere-only physics protocol test periods
- Include interactive prognostic aerosols in ensemble prototype experiments
- Include interactive prognostic aerosols in 30-year GFS replay/reforecasts
- Developing JEDI-based 3DVar and ensemble aerosol data assimilation capabilities in UFS-Aerosols
- Improve aerosol speciation and vertical profiles for aerosol data assimilation
- Develop biomass burning and UFS-Aerosols aerosol climatologies

Longer term (July 2023 – June 2026)

- Update and evaluate aerosol data assimilation by incorporating an ensemble Kalman filter approach and improving the use of satellite aerosol optical depth data
- Incorporate and evaluate predictions of biomass burning emissions and blend these predictions seamlessly into a climatological emissions treatment at longer timescales
- Incorporate and evaluate prognostic aerosol microphysical impacts on clouds

All of the above can be accomplished because of strong collaborations within the Atmospheric Composition Team and with the other UFS R2O Teams and EMC.