Capabilities of NOAA's global chemical forecast systems: GEFS-Aerosols, UFS-Aerosols, and UFS-Chem

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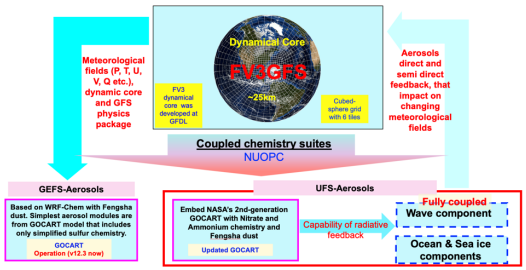
Introduction

- **GEFS-Aerosols:** the first generation of a coupled aerosol model component was developed in a collaboration between NOAA's Oceanic and Atmospheric Research(OAR) laboratories (GSL, CSL, ARL, EMC, and STAR) and EMC has been operational since September 2020 as one of the ensemble members of the Global Ensemble Forecast System (GEFS v12.0), with recent updates implemented operationally into the GEFSv12.3 in January 2023.
- **UFS-Aerosols:** the second-generation of UFS coupled aerosol system has been collaboratively developed for the UFS by NOAA and NASA's Global Modeling and Assimilation Office (GMAO) since 2021 and is planned to be implemented into Global Ensemble Forecast System (GEFS) v13.0 in the coming years
- **UFS-Chem:** an innovative community model with the potential for improving chemistry and aerosol processes and thereby predictions of air quality and atmospheric composition. Its initial development, which is a wide collaboration between NOAA OAR laboratories and NCAR, utilizes the Common Community Physics Package (CCPP) infrastructure to link the gas and aerosol chemistry modules to the rest of the model.

GEFS-Aerosols and UFS-Aerosols Coupling Structure



Aerosols Forecast

- **Transport:** Grid-scale transport provided by FV3 dynamical core. Sub-grid transport by PBL and convection in GFS physics. Tracer convective transport and wet scavenging are included in Simplified Arakawa-Schubert (SAS) scheme.
- **GEFS-Aerosols Chemistry:** simplified parameterization of sulfur/sulfate chemistry, hydrophobic and hydrophilic black and organic carbon, 5-bin sea salt, 5-bin dust, volcanic ash, no aerosol radiative feedback from aerosol component.
- **UFS-Aerosols Chemistry:** simplified parameterization of sulfur/sulfate, nitrate and ammonium chemistry, hydrophobic and hydrophilic black and organic carbon, 5-bin sea salt, 5-bin dust, capability of including aerosol radiative feedback from aerosol component.
- **Emission:** Global CEDS (2014 or2019) anthropogenic emission. NESDIS Global Biomass Burning Emission Product (GBBEPx) with FRP used for fire size and location. 1D cloud model is used to calculate injection heights and plume rise emission rates online. Quick Fire Emissions Dataset (QFED). Volcanic ash.
- **Sea-salt and Marine Dimethyl Sulfide:** NASA GEOS-5 GOCART sea salt scheme. GOCART monthly values of marine dimethyl sulfide as in Lana et al. (2011)
- **Dust:** 5 size bins. FENGSHA dust scheme: Empirical model based solely on soil type for saltation and used in current NAQFC (Tong et al; Baker et al.); **Meteorological initial conditions from FV3GFS analysis every 24 hours**
- **Weather Forecast:** C384 (~25km) run with. Aerosols are cycled as the initial conditions of next time. 2 weeks spin-up time before analysis.

RMSE and correlation coefficients of GEFS-Aerosols daily AOD (v12 and v12.3) with respect to AERONET (August 2021)

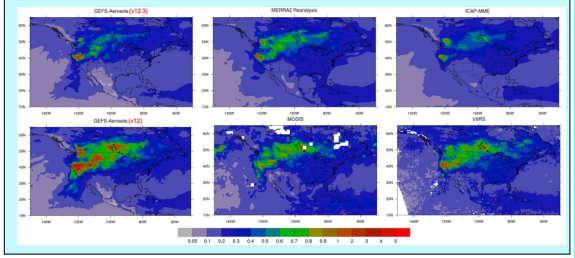
	RMSE			Correlations		
	GEFSv12	GEFS (v12.3)	MERRA2	GEFSv12	GEFS (v12.3)	MERRA2
Univ. of Reno	2.44	0.844	0.637	0.601	0.546	0.665
Neon_Wref	0.314	0.348	0.3058	0.8425	0.858	0.862
PNNL	1.282	0.455	0.499	0.365	0.721	0.656
Meridian	0.77	0.552	0.552	0.599	0.724	0.553
Cascade Airport	0.65	0.63	0.627	0.498	0.575	0.539
Taylor Ranch	1.6	0.66	0.61	0.411	0.686	0.684
Lewis Clark	1.14	0.64	0.506	0.42	0.56	0.67
Pinehurst	0.769	0.602	0.5752	0.507	0.69	0.608
Missoula	0.541	0.455	0.4305	0.61	0.675	0.643
Bozeman	2.19	0.4498	0.29	0.588	0.677	0.789
Rexburg Idaho	3.414	0.473	0.465	0.493	0.697	0.661

	RMSE			Correlations		
	GEFSv12	GEFS (v12.3)	MERRA2	GEFSv12	GEFS (v12.3)	MERRA2
Bakersfield	1.19	0.288	0.257	0.729	0.734	0.745
Monterey	1.52	0.4	0.32	0.814	0.847	0.87
NASA AMES	1.64	0.32	0.28	0.863	0.828	0.838
Railroad Valley	0.954	0.418	0.478	0.395	0.732	0.538
Neon Wood	0.643	0.336	0.228	0.482	0.751	0.757
U. of Wisconsin	0.28	0.213	0.1	0.76	0.64	0.86
GSFC	0.172	0.12	0.09	0.485	0.575	0.8
Canel (NY)	0.255	0.253	0.138	0.648	0.69	0.9
Toronto	0.311	0.179	0.09	0.45	0.55	0.92
Appalachian	0.097	0.097	0.06	0.737	0.719	0.726
Tucson	0.05	0.05	0.04	0.52	0.54	0.62

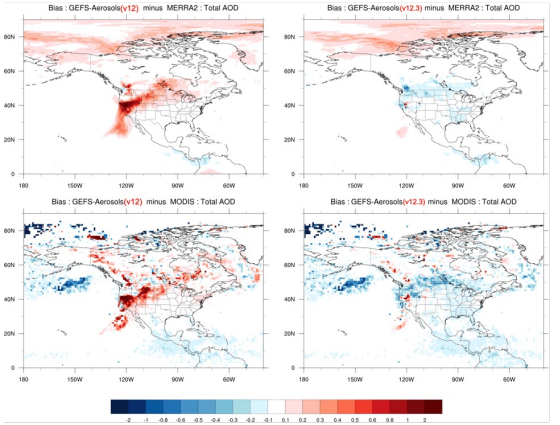
Major updates in v12.3: 1) CEDS anthropogenic emission was updated from 2014 to 2019 version; 2) Fixed bug in Fengsha dust scheme; 3) Updated large scale wet deposition and scavenging factors; 4) Fixed bug in AOD calculation.

Comparisons between GEFS-Aerosols v12 and v12.3

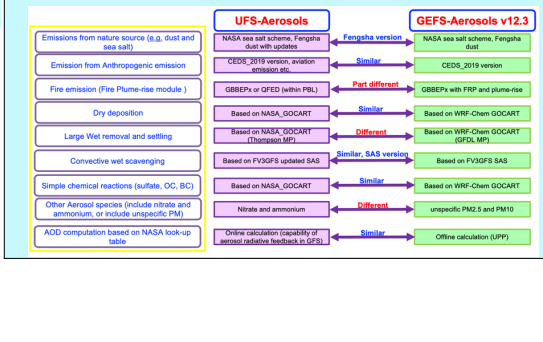
Comparisons between GEFS-Aerosols v12 and v12.3 for monthly mean of Day 1 AOD forecast, August 2021



Biases of Day 1 total AOD forecast averaged for August 2021 validated against MERRA-2 and MODIS

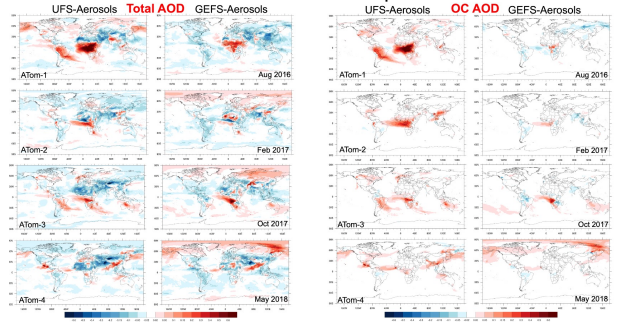


Comparisons between UFS-Aerosols and GEFS-Aerosols

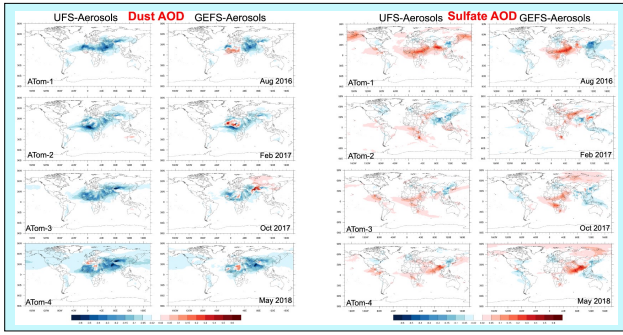


Comparisons between GEFS-Aerosols v12.3 and UFS-Aerosols

Biases of Day1 forecast of UFS-Aerosols and GEFS-Aerosols v12.3 validated against MERRA-2 averaged for ATom1-4 periods



UFS-Aerosols experiments show significant overpredictions of total AOD over southern African fire regions when using GBBEPx fire emission, which is mainly due to overpredicted OC AOD. GEFS-Aerosols v12.3 shows much better performance.

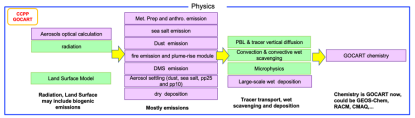


Dust AOD is the major underprediction for both UFS-Aerosols model and GEFS-Aerosols v12.3. Sulfate AOD is the major overprediction over central African and Indian for both UFS-Aerosols model and GEFS-Aerosols v12.3 in ATom-1and ATom-4.

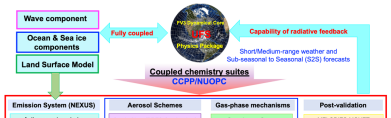
UFS-Chem development

CCPP infrastructure for GOCART coupling

Considering the interactive and strongly couple nature of chemistry and physics, it is better to insert the atmospheric composition modules directly inside the physics suite. The GOCART modules as GEFS-Aerosols model was broken up and embedded into UFS physics using the Common Community Physics Package (CCPP) infrastructure.



UFS-Chem framework



- Plan to develop a chemistry package with different suites, which will be a submodule of the UFS model named as UFS-Chem.
- UFS-Chem will be flexible and configurable where users can choose different aerosol scheme and gas-phase chemical mechanism using different way to embed into physics package for their desired application or science question:

1) Options to use gas and aerosol chemical mechanisms of varying complexity.
2) Capabilities to easily couple different chemical mechanisms to different physics options.
3) Flexibilities in emissions processing system.
4) Applications of evaluation/validation tools to efficiently compare model results against a variety of observations.