Development of GEFS-Aerosols into NOAA's Unified Forecast System (UFS)

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Introduction

- **FV3GFS was coupled online with aerosol component, which is based on WRF-Chem with aerosol modules from Goddard Chemistry Aerosol Radiation and Transport model (GOCART). It has replaced the current operational global aerosol prediction NGAC system at NCEP (Fall of 2020).**
- **GEFS-Aerosols was placed as an ensemble member in the Global Ensemble Forecast System (GEFS) at NCEP operational system. It is also used at NOAA ESRL GSL to provide real-time experimental aerosol forecasts at ~25km horizontal resolution globally from the surface to the top of atmosphere (https://fim.noaa.gov/FV3chem/).**

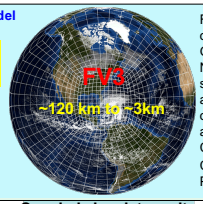
GEFS-Aerosols Model

Meteorological fields (P, T, U, V, Q etc.), dynamic core and GFS physics package

Atmospheric model

Developed at GFDL of NOAA

Cubed-sphere grid with 6 tiles



FV3GFS has been online coupled with GOCART through NUOPC in NEMS system. Other more advanced physics options are available through Common Community Physics Package (CCPP)

In Progress

Aerosols direct and semi direct feedback, that impact on changing the meteorological fields

Coupled chemistry suites!

GSDChem (WRF-Chem-based)

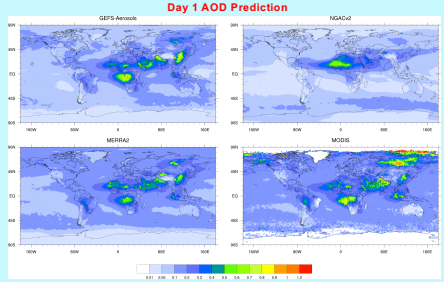
Short-term chemical weather forecast and long-term S2S simulation

NUOPC			CCPP
Simplest aerosol modules are from the GOCART model that includes only simplified sulfur chemistry.	Photochemical gas-phase mechanism RACM included to determine the impact of the additional complexity on the aerosol simulation	Sophistication within the aerosol modules includes secondary organic aerosols (SOA) based on the VBS approach.	GSDChem was broken up and all chemical modules were embedded into FV3 as subroutine of physics.
GOCART Operational	GOCART-RACM	RACM-SOA-VBS	GOCART Real-time Forecast

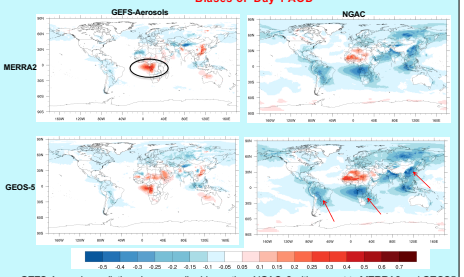
- **Transport:** Grid-scale transport provided by meteorological model FV3 using GFS physics and GFDL microphysics scheme. Sub-grid transport by PBL and convection in GFS physics. Tracer transport and wet scavenging are included in Simplified Arakawa-Schubert (SAS) scheme.
- **GOCART Chemistry:** Simplified parameterization of sulfur/sulfate chemistry, hydrophobic and hydrophilic black and organic carbon, a 5-bin sea salt, 5-bin dust, volcanic ash.
- **Emission:** Global CEDS and HTAP anthropogenic emission. NESDIS Global Biomass Burning Emission Product (GBBEPx) used for fire size and location. Also have the 3BEM fires globally based on MODIS observation and replaced by WFABBA for North America. 1D cloud model is used to calculate injection heights and plume rise emission rates online. MEGAN biogenic emissions. Volcanic emission.
- **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:** FENGSHA dust scheme: Empirical model based solely on soil type for saltation and used in current NAQFC (Tong et al; Baker et al.)
- **Forecast:** Meteorological initial conditions from FV3GFS analysis. **Aerosols are cycled as the initial conditions of next time.**

➢Computation at HERA: ~25km (C384), 64 vertical layers, 7 days forecast, less than 3.5 hours, with 264*2 cores

Evaluation of Global Day 1 AOD Prediction for Jul.-Nov. 2019



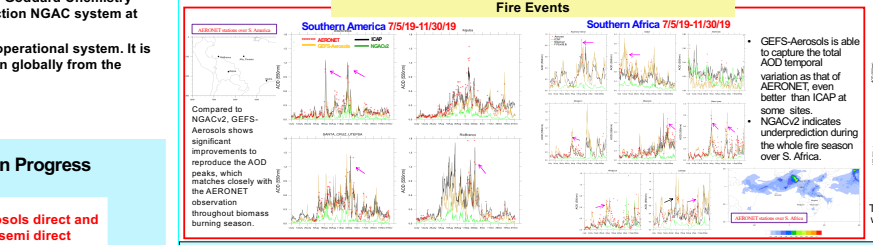
GEFS-Aerosols is able to capture the major polluted areas with high AOD matching MERRA-2 and MODIS with smaller bias than NGACv2.



GEFS-Aerosols prediction shows smaller biases than NGACv2 with respect to MERRA2 and GEOS5. Large improvements are seen over eastern Asia and southern Africa.

Evaluation of Predicted AOD Versus AERONET, ICAP, MERRA2, GEOS5, NGACv2 and VIIRS

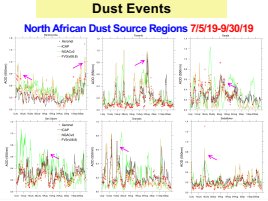
Fire Events



Compared to NGACv2, GEFS-Aerosols shows significant improvements to reproduce the AOD peaks, which matches closely with the AERONET observation throughout biomass burning season.

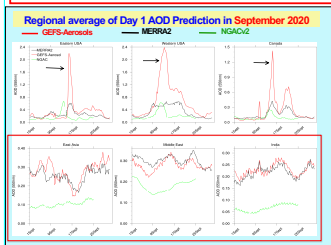
- GEFS-Aerosols is able to capture the total AOD temporal variation as that of AERONET, even better than ICAP at some sites.
- NGACv2 indicates underprediction during the whole fire season over S. Africa.

Dust Events



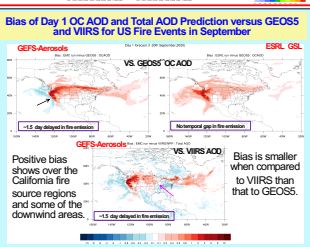
The high AOD caused by dust events have been reproduced well by the GEFS-Aerosols and the AOD temporal variation shows good agreement as that of AERONET.

Regional average of Day 1 AOD Prediction in September 2020



The AOD prediction of GEFS-Aerosol is overestimated for the US fire events, while it shows consistent as the MERRA2 analysis over the regions of Asia and Middle East

Bias of Day 1 OC AOD and Total AOD Prediction versus GEOS5 and VIIRS for US Fire Events in September

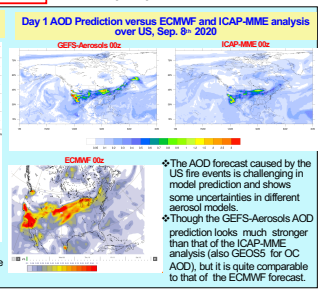


Positive bias shows over the California fire source regions and some of the downwind areas.

Bias is smaller when compared to VIIRS than that to GEOS5.

Fire emission is based on real-time satellite observation, the temporal inconsistent of fire emission may cause much higher positive bias in the AOD predictions, which is unavoidable in the operational forecast.

Day 1 AOD Prediction versus ECMWF and ICAP-MME analysis over US, Sep. 8th 2020



- The AOD forecast caused by the US fire events is challenging in model prediction and shows some uncertainties in different aerosol models.
- Though the GEFS-Aerosols AOD prediction looks much stronger than that of the ICAP-MME analysis (also GEOS5 for OC AOD), but it is quite comparable to that of the ECMWF forecast.

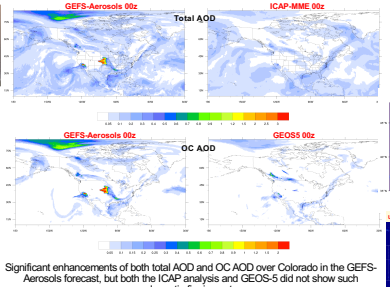
Model Performance and Uncertainties in AOD Prediction of 2020 Colorado Fire Events.

Strong Fire Plumes during Boulder Calwood Fires Oct. 17th

Colorado Fire at Boulder Calwood, which started from Oct. 17th, 2020 and burned through 8,788 acres in the next couple of days.

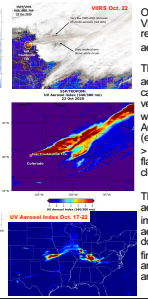
Calwood fire is the smallest one, the fire plume is so dramatic to impact on local air quality.

Day 1 AOD and OC AOD Prediction versus ICAP-MME and GEOS5 for Colorado Fire, Oct. 17th 2020



Significant enhancements of both total AOD and OC AOD over Colorado in the GEFS-Aerosols forecast, but both the ICAP analysis and GEOS-5 did not show such dramatic fire impact.

Satellite Observation Oct. 17-22, 2020

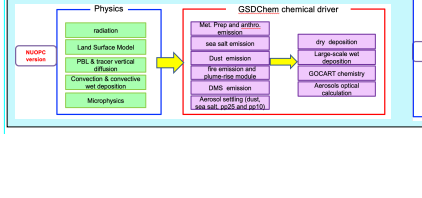


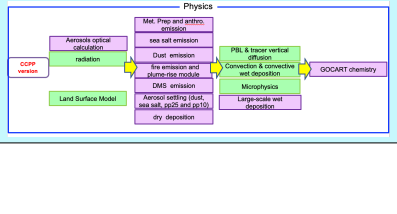
Only see very few VIIRS AOD retrievals of smoke aerosols (red dots).

TROPOMI UV aerosol index captures the plume very well. Smoke was too thick for AOD retrievals (either out of range, > 5 or cloud mask flagged smoke as cloud).

TROPOMI UV aerosol index, the impact of enhanced aerosol are very dominated over the fire source region and downwind areas

Next Step and in Progress





Due to the interactive and strongly couple nature of chemistry and physics, it it better to call the atmospheric composition modules directly from inside the physics suite.

In a second more developed CCPP version, GSDChem was broken up and all the chemical modules were embedded into FV3 as subroutines of physics.