GEFS Aerosols Forecast Model

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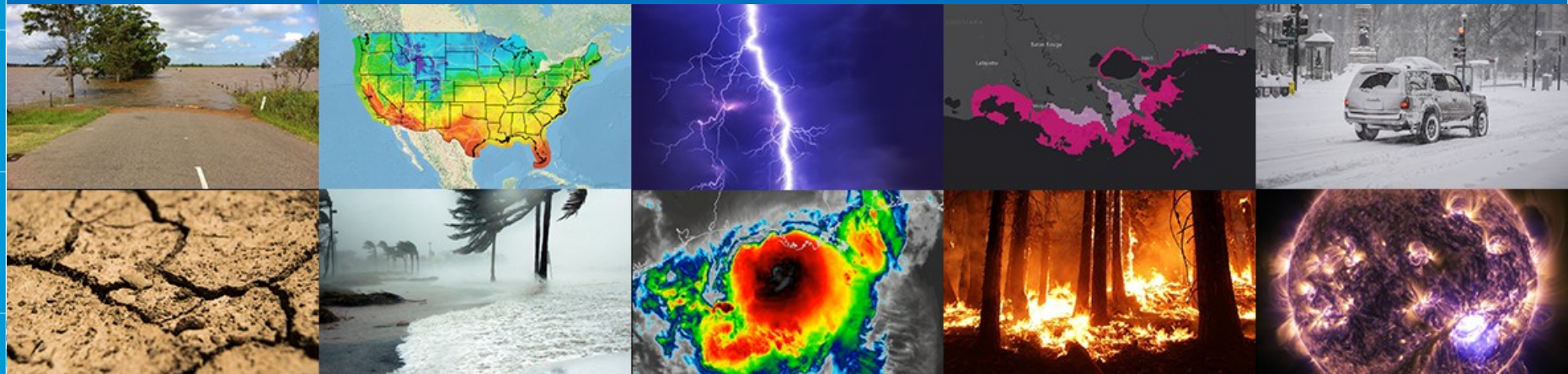


Outline

- Global Aerosol model developments at NCEP/EMC
- Current operational global aerosol model
- Products, verification
- Future model development activities
- Conclusion

- Prognostic aerosol capacity in NCEP global models started in 2012 (collaboration with NASA/GSFC)
- Over the years multiple NOAA labs (GSL, ARL, NESDIS) and NASA collaborate with EMC in the development of the model

	Model	Resolution and forecast length	Dust emission	Smoke emission	General comments
NGAC v1 (dust only)	Global Spectral Model (GSM GFS)	T126 (~1 deg), globally upto 5 days	GOCART dust	No fire emission	Operational in 2012 (Lu et al., 2016)
NGAC v2 (dust, black and organic carbon, seasalt and sulfate)	GSM-GFS	T126 (~1 deg), globally upto 5 days	GOCART dust	GBBePX fire emission from NESDIS	Operational in 2018 (Wang et al., 2018)
GEFS-Aerosols (v1) (5 species)	**FV3 GEFS (single member in GEFS v12)**	**C384 (~0.25 deg), globally upto 5 days**	**FENGSHA dust**	**GBBePX fire emission (v3)**	**Operational in 2020 (Zhang et al., 2022)**
GEFS-Aerosols (v2) or UFS Aerosol with Aerosol DA (experimental)	FV3 GEFSv13	C384 (~0.25 deg), globally upto 35 days	FENGSHA dust (with updates)	GBBePX fire emission with updates, use of blended fire emission	Planned implementation in 2026

Current Operational Model

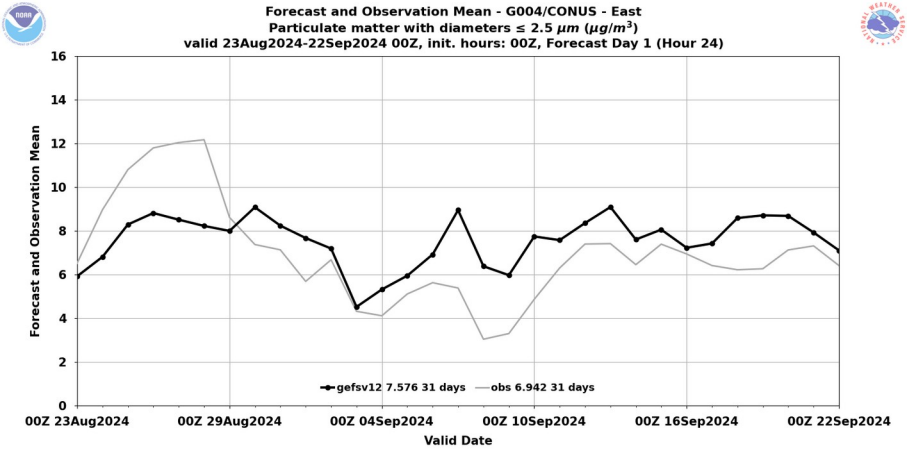
- One additional member of GEFSv12 for aerosols (deterministic)
- GEFS meteorology (based on GFSv15) at C384 (~25 km), 64 levels, to 120 hrs, 4x/day
- Inline aerosol representation based on NASA/GSFC GOCART (WRF-Chem)
- Emissions: CEDS-2019 (SO2, PSO4, POC, PEC), GBBEPx biomass burning, FENGSHA dust, GEOS-5 sea salt, marine DMS
- Initial conditions: chemical tracers are cycled from the output of a previous forecast as the initial condition
- Smoke plume rise: Wind shear dependent 1-d cloud model to simulate tilt of plume. Fire radiative power is used to calculate convective heat flux and determine injection height
- Tracer transport and wet scavenging are included in Simplified Arakawa-Schubert (SAS) scheme. Fluxes are calculated positive definite.

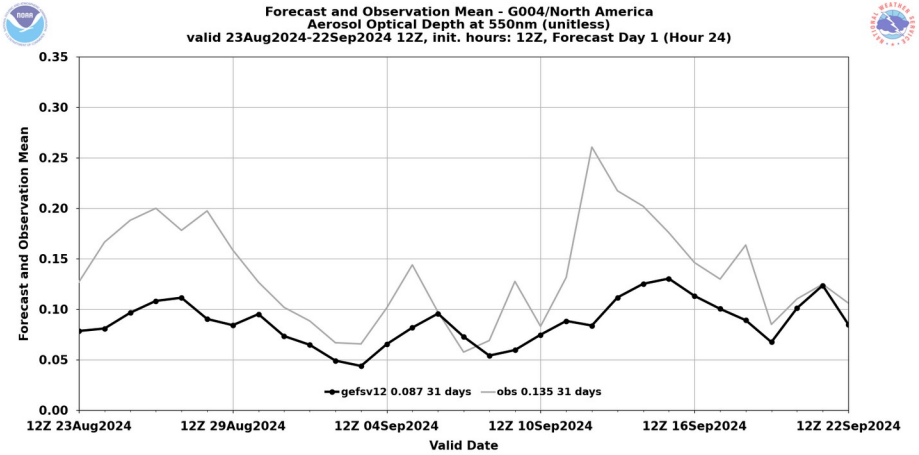
Current Operational Model Products and Verification

- 3-hourly 0.25 deg grib2 forecast data (upto 5 days) contain total AOD, species AOD, Total and Dust PM2.5 and PM10, along with total column density of aerosol species.
- 3-hourly 0.5 deg. grib2 forecast data (upto 5 days) contain vertical mixing ratios of aerosol species (all 64 model levels)
- Data available through NOMADS ftp : https://nomads.ncep.noaa.gov/pub/data/nccf/com/gens/v12.3
- Barcelona Supercomputing Center (BSC) uses near real time GEFS-Aerosols AOD, PM along with other models for dust forecast over N. Africa, Europe and Mediterranean region (part of WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) (https://dust.aemet.es/products/daily-dust-products).
- CPC uses AOD and SSA at 340nm for UV index forecast product
- GEFS-Aerosols total PM2.5 data is used in WMO program GAFIS (Global Air Quality Forecasting and Information System (GAFIS) : over East Asia and India. https://community.wmo.int/en/activity-areas/gaw/science-for-services/gafis
- Both point and grid based verification of AOD and PM forecasts are done using DTC METplus tool using observations (AEORNET, AIRNOW, Satellites VIIRS, GOES, reanalysis products MERRA2, CAMS).
- Other fields (like AOD in UV wavelengths, PM species, vertical mixing ratios) needs to be verified

GEFS-Aerosols verification update

EMC Verification System (EVS) which uses METplus, added GEFS-Aerosols verifications (against PM2.5 and AERONET AOD) in real time parallel (will be incorporated in operations in EVS v2 (May, 2025).
AERONET AOD : https://www.emc.ncep.noaa.gov/users/verification/global/gefs/dev/chem/grid2obs/aeronet_aod/
Total PM2.5 : https://www.emc.ncep.noaa.gov/users/verification/global/gefs/dev/chem/grid2obs/airnow_pm25/





Daily forecast verification maps (against Multi-model Ensemble), comparison against satellite AOD :
https://www.emc.ncep.noaa.gov/gc_wmb/parthab/NCO-GEFSAerosol/html/fv3_aod_png.html#picture
https://www.emc.ncep.noaa.gov/gc_wmb/parthab/NCO-GEFSAerosol/html/fv3_viirsstat_png.html
https://www.emc.ncep.noaa.gov/gc_wmb/parthab/NCO-GEFSAerosol/html/fv3_geos5stat_png.html

GEFS-Aerosols verification update

- GEFS-Aerosols performance in year 2023 from WMO SDS-WAS https://dust.aemet.es/products/daily-dust-products?tab=evaluation
- Total AOD verified against ground AERONET stations

Correlation	CAMS	NASA-GOES	MetOffice	Silam	GEFS-Aerosols
N. Africa	0.5	0.83	0.79	0.73	0.74
Mediterranean	0.67	0.7	0.73	0.76	0.69
Middle East	0.79	0.79	0.81	0.79	0.71
Europe	0.26	0.34	0.38	0.24	0.32

RMSE	CAMS	NASA-GOES	MetOffice	Silam	GEFS-Aerosols
N. Africa	0.29	0.19	0.19	0.25	0.23
Mediterranean	0.15	0.14	0.11	0.16	0.16
Middle East	0.2	0.18	0.14	0.24	0.24
Europe	0.17	0.15	0.14	0.17	0.17

MBE	CAMS	NASA-GOES	MetOffice	Silam	GEFS-Aerosols
N. Africa	-0.13	-0.07	-0.03	-0.14	-0.1
Mediterranean	-0.11	-0.09	-0.05	-0.13	-0.12
Middle East	-0.16	-0.12	0.03	-0.2	-0.18
Europe	-0.13	-0.12	-0.11	-0.14	-0.14

GEFS-Aerosols, without any aerosol DA, performance comparable against other global models (some of them use DA)

Current development for GEFSv13

- NOAA's Unified Forecast System (UFS) modeling applications currently in development as a coupled model for global prediction of weather to seasonal time scales, targeting GFSv17 (medium range), GEFSv13 (sub-seasonal) and SFSv1 (seasonal) forecasting systems.
- In the global coupled UFS development phase, discrete system prototypes were defined and evaluated within a fixed benchmark framework and evaluation findings were used to inform subsequent development.

ufs-weather-model https://github.com/ufs-community/ufs-weather-model

Atmosphere
- FV3 dynamical core
- GFS Physics with Thompson microphysics
- CCPP physics driver
- C384 (~25km), 127 levels

Ocean
- MOM6 Modular Ocean Model
- ¼ degree tripolar grid, 75 hybrid levels
- OM4 Set up [Adcroft, 2019]

Waves
- WAVEWATCH III
- ½ degree regular lat/lon grid
- ST4 Physics [Ardhuin, 2010]

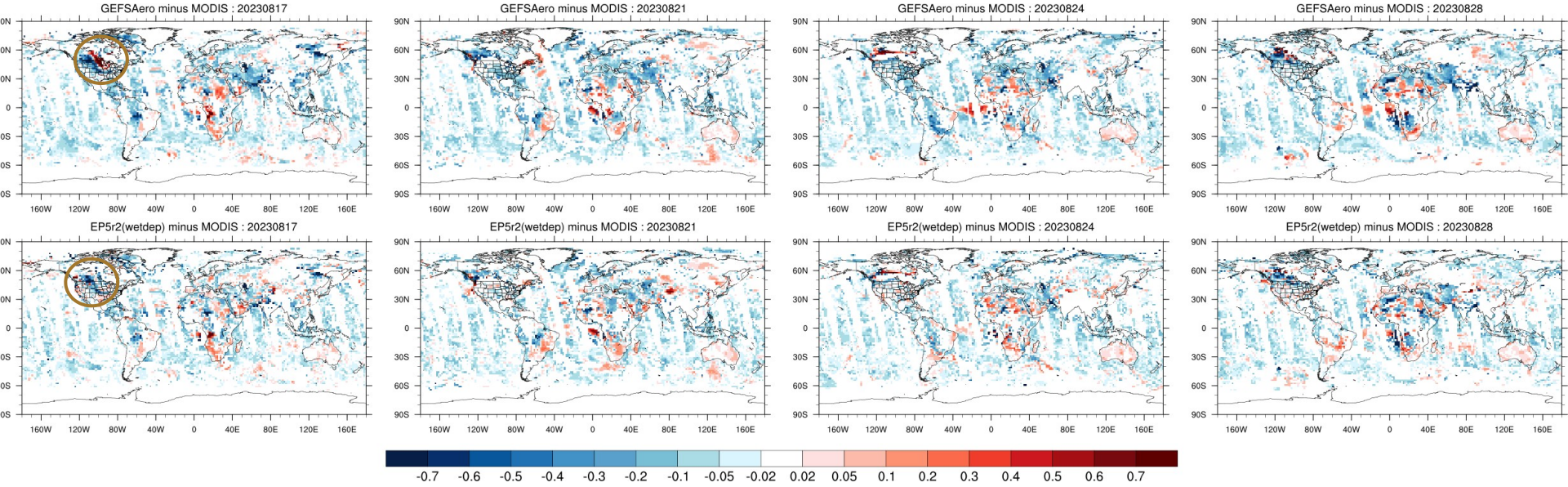
Ice
- CICE6 Los Alamos Sea Ice Model
- ¼ degree tripolar grid (same as ocean)
- 5 thickness categories
- Mushy thermodynamics on (P7 onward)

Aerosols
- NASA GOCART2G
- Emissions: CEDS-2019 (SO2, PSO4, POC, PEC), QFED biomass burning, FENGSHA dust, GEOS-5 sea salt, marine DMS
- Blend fire emission to climatology after 5 days
- Sulfate, Organic Carbon, Black Carbon, Dust, Sea Salt, Nitrogen
- MERRA2 ICs

Driver/Mediator
- NEMS driver
- CMEPS mediator

GEFS-Aerosols (v13) replaces GEFS-Aerosols v12.3, changes include meteorological model upgrades (GFS from v15 to v17) and chemical model changes (GOCART replaces WRF-CHEM)

The preliminary results for v13 are comparable to v12, which is encouraging. Tuning of large scale wet deposition scheme in the experimental version improve accumulation of aerosol in higher latitude



Plan to perform evaluation of AOD and PM2.5 against operational model between October of 2022 to December of 2024

Aerosol data assimilation will be included in GEFS-Aerosols v13

- **Currently one of the few (only?) operational centers to not have aerosol DA initializing their aerosol prediction system**
- **6-hourly cycles 4x a day with early and late cycles**
  - Early cycle to initialize the GEFS long forecasts (one deterministic aerosol analysis provided from the cycling DA system)
  - Late cycle to initialize the high resolution GDAS forecast (without radiative feedback)
- **Analysis resolution C192L127 (~0.5 deg); background resolution C1152L127 (~9km)**
- **3DVar FGAT with 3-hourly backgrounds**
- **VIIRS EPS 550nm AOD from S-NPP, N20, N21**
- **"DA is improving the forecast, but still more tuning is needed !" (Andy Tangborn)**

Slide courtesy : Cory R. Martin

Conclusion

- Current global aerosol model operational at NOAA since 2020 and uses GFSv15, it is one member of GEFSv12.
- AQM uses GEFS-Aerosols boundary conditions.
- Forecast validation of AOD and PM2.5 currently uses METplus tool and soon to be implemented in EMC Verification System (EVS)
- Development work is underway for next model update to GEFSv13, with changes in meteorology from GFSv15 to GFSv17, physics and land surface updates and various aerosol updates.
- Addition of 3Dvar Aerosol DA in GEFSv13
- Planned evaluation of AOD and PM2.5 from GEFSv13 against current operational model.