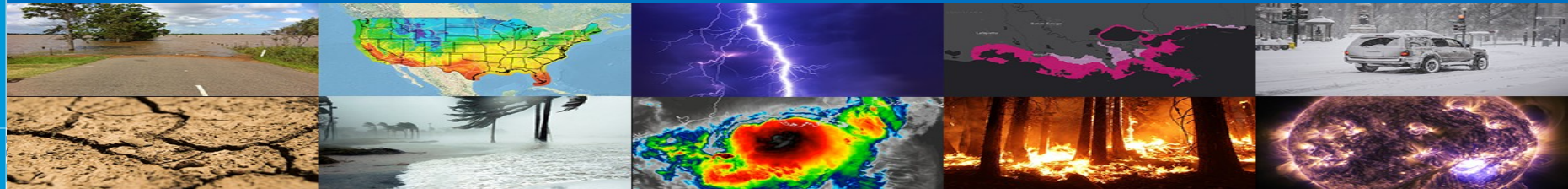
Air Quality Forecaster Focus Group Workshop, College Park, Maryland, October 9-10, 2024

NATIONAL WEATHER SERVICE

Overview of NCEP Atmospheric Composition and Air Quality Modeling Activities

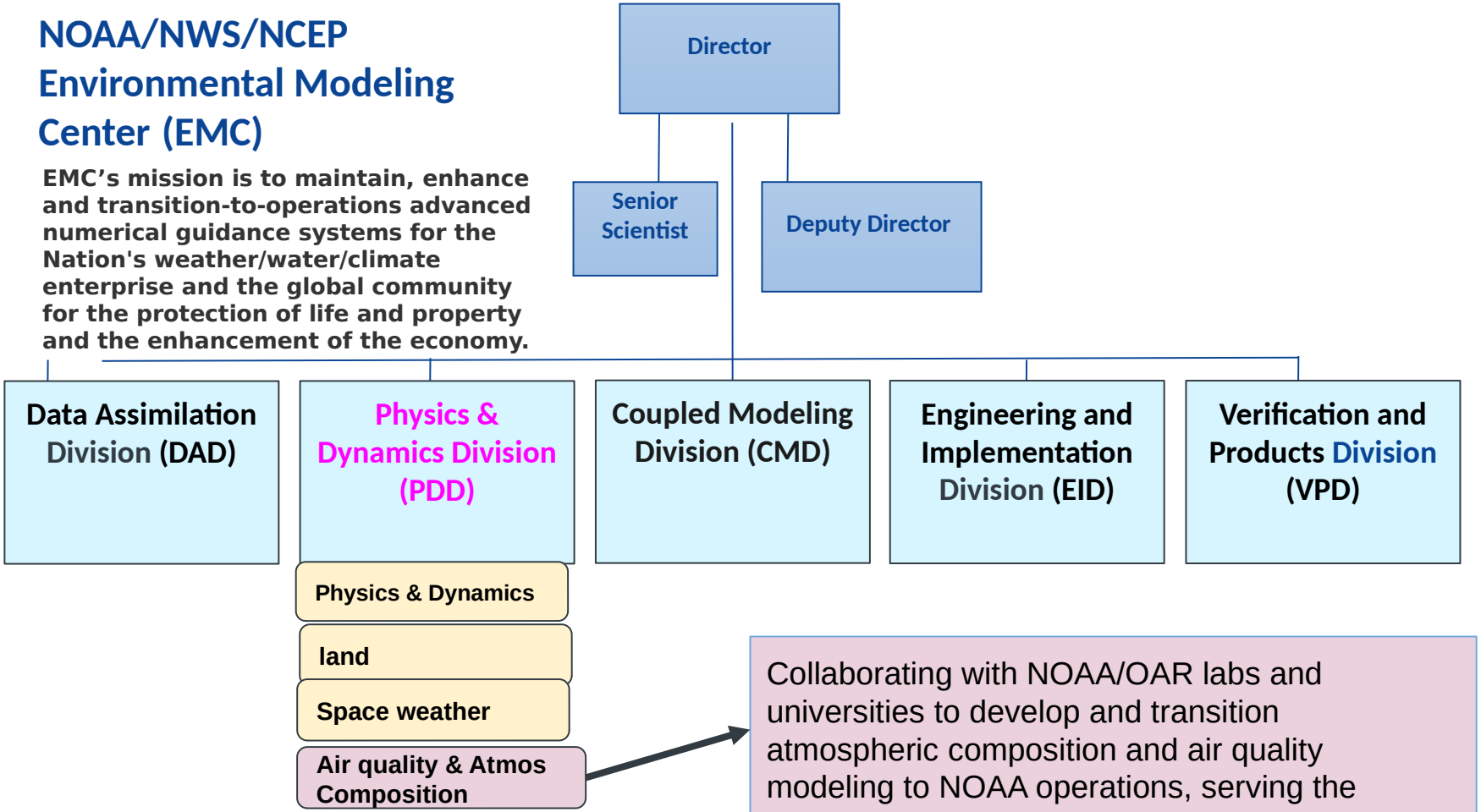
Fanglin Yang
Chief, Physics and Dynamics Division
NWS/NCEP Environmental Modeling Center

Acknowledgement: I would like to thank Jianping Huang, Jeff McQueen, Pan Li, Partha Bhattacharjee, Cory Martin, Ravan Ahmadov, Binyu Wang and Mark Cohen for providing some of the materials included in this presentation. Additionally, EMC collaborates with NWS/OSTI program office, OAR labs, NESDIS, and various universities for the development and operational transition of NCEP atmospheric composition and air quality models.

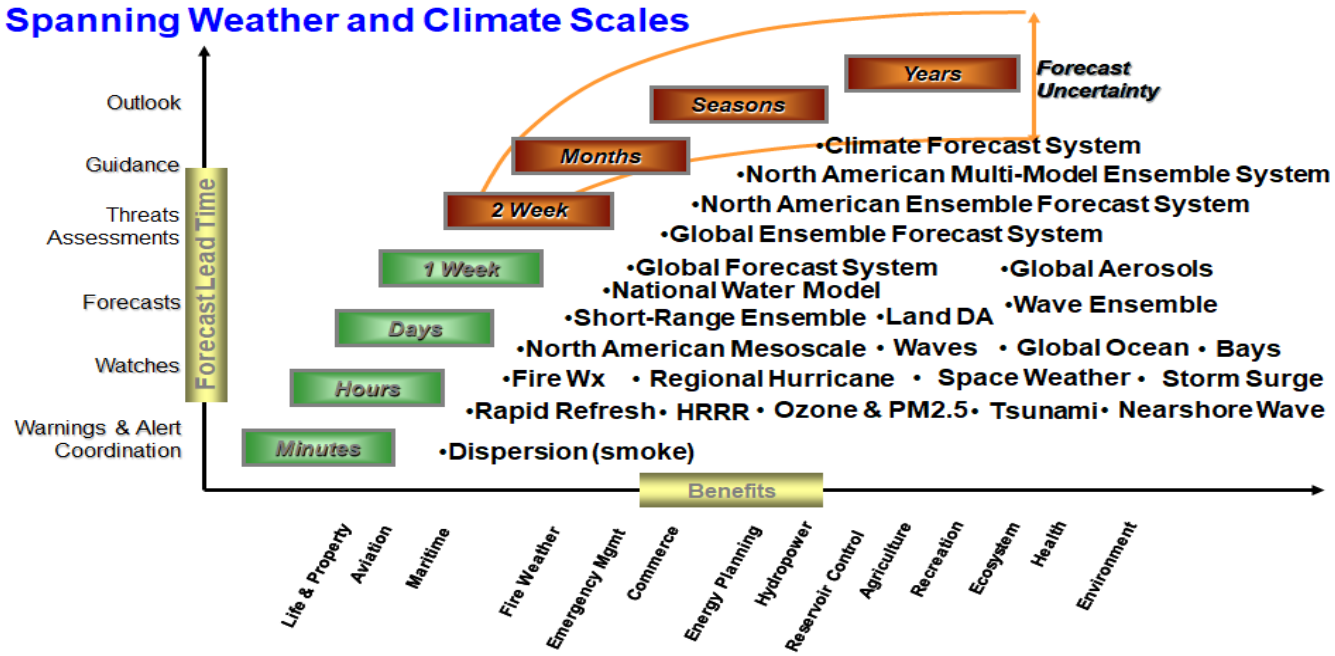


NOAA/NWS/NCEP Environmental Modeling Center (EMC)

EMC's mission is to maintain, enhance and transition-to-operations advanced numerical guidance systems for the Nation's weather/water/climate enterprise and the global community for the protection of life and property and the enhancement of the economy.



NOAA/NWS/NCEP Environmental Modeling Center (EMC)



Domain scope:

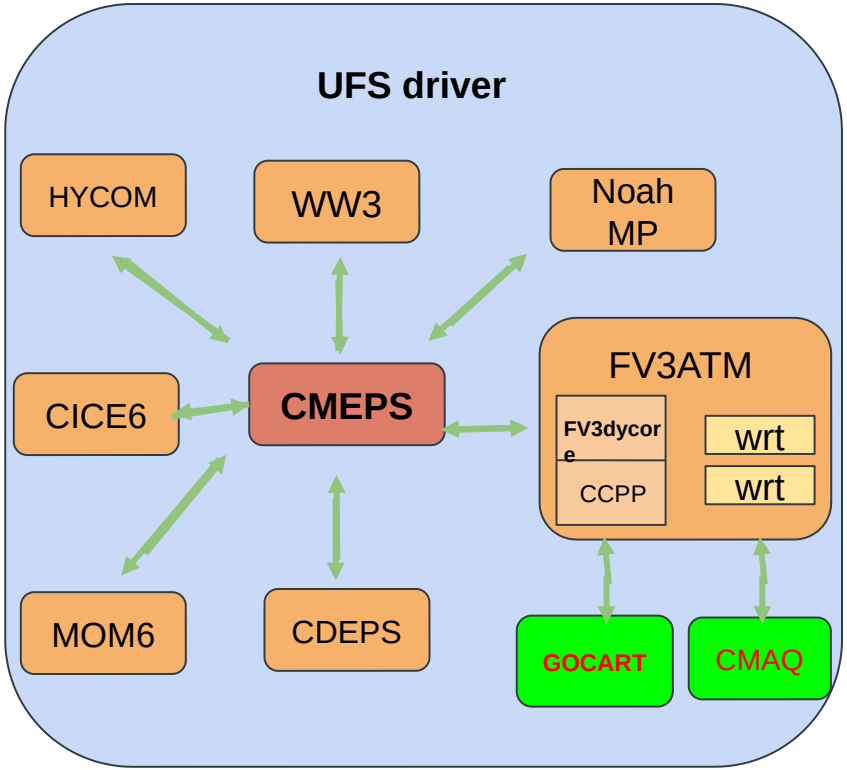
- Earth system - multiple components

Role:

- Integrate research and development into operations
- Validate observing requirements and data impacts

***EMC** develops and implements the prediction systems that provide operational numerical guidance, **spanning weather and climate**, for use across the NWS and its worldwide partners.*

Moving Towards a Unified Forecast System (UFS)



The UFS is open source software supporting both research and operation for many different modeling applications.

Global:

GFS - Medium-Range Deterministic Weather Forecast Model (9 km)

GEFS- Global Ensemble Sub-Seasonal Forecast System (25 km)

Including global aerosol modeling

SFS - Seasonal Forecast System (50 km)

WAM - Whole Atmospheric Model (up to 500 km; 50 km)

Regional:

HAFS - Hurricane Analysis and Forecast System (parent 3km; nest 1.8 km)

RRFS - North America Rapid Refresh Forecast System (3km)

Including simplified smoke and dust modules

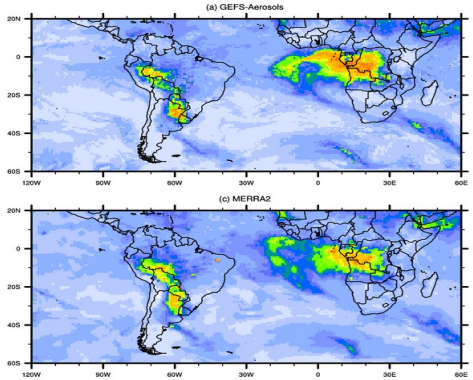
UFS-CMAQ - North American Air Quality Model (12km)

Global Aerosol Predictions

NGAC: The NCEP GFS Aerosol Component (NGAC), implemented into operation in **2012**, was the first global system to allow for interactive aerosol forecasting at NCEP. It was developed by EMC and GSFC using the NASA GOCART aerosol model.

GEFSv12 - Aerosol

- Aerosol component module was developed through collaboration between EMC and OAR labs (GSL, CSL, and ARL) and was integrated online with FV3-based GFS within the NEMS/NUOPC framework.
- It was based on **WRF-Chem** and incorporated several key elements: the bulk modulus from GOCART, the biomass burning plume rise module from HRRR-Smoke, the FENGSHA dust scheme developed by ARL, GBBEPx.v3 for biomass burning emissions, and the CDES global anthropogenic emission inventory.
- Sub-grid-scale transport, wet scavenging and deposition were handled inside the atmospheric physics routines. with updates to AOD and wet scavenging computations
- It was implemented into NCEP operations as part of the GEFS ensemble in **September 2020**, utilizing a 25-km resolution, 4 cycles per day, and forecast up to 5 days.
- Forecasts are PM2.5 and PM10



Total AOD, August 25, 2019
(Zhang et al., GMD, 2022)

GEFSv13 Aerosol is still under development

GEFSv12 vs GEFSv13

(See Partha Bhattacharjee's presentation)

Components		V12 (Sep 23. 2020)	
Atmos	Dynamics	FV3 (Finite-Vol Cubed-Sphere) GFSv15	FV3 (Finite-Vol Cubed-Sphere) GFSv17
	Physics	saSAS, GFDL-MP, K-EDMF, oroGWD	saSAS, Thompson-MP, sa-TKE-EDMF, uGWD
	Initial perturbation	EnKF f06 (previous cycle)	EnKF f00 (early cycle)
	Model uncertainty	5-scale SPPT and SKEB	5-scale SPPT, SKEB, SPP, CA
	Boundary (ocean surface)	NSST + 2-tiered SST	NSST
	Resolutions	C384L64 (25km)	C384L127 (25km)
Land	Model	NOAH-LSM	NOAH-MP
	Initial perturbation	N/A	Soil moisture
Ocean	Model	N/A	MOM6 (0.25°L75)
	Initial perturbation		SOCA-Ens
	Model uncertainty		5-scale oSPPT and ePBL
Ice	Model		CICE6 (0.25°)
	Initial perturbation		SOCA-Ens
Wave	Model	WW3 (1-way) (0.5°)	WW3 (2-way) (0.25° lat/lon grid)

GFS -- Stratospheric Ozone Prediction

McCormack et al. (2006)
Parametrization for Ozone Forecast

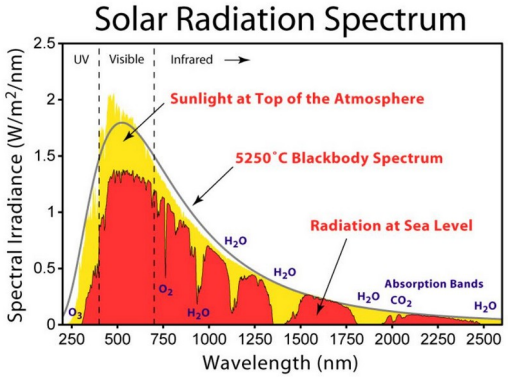
First-order Taylor series in three variables for the ozone rate of change

$$dr_{O3}/dt = P\text{-}L = (P\text{-}L)_0 + d(P\text{-}L)/dr_{O3}|_0 (r_{O3} - r_{O3,0}) + d(P\text{-}L)/dT|_0 (T - T_0) + d(P\text{-}L)/dS_{O3}|_0 (S_{O3} - S_{O3,0})$$

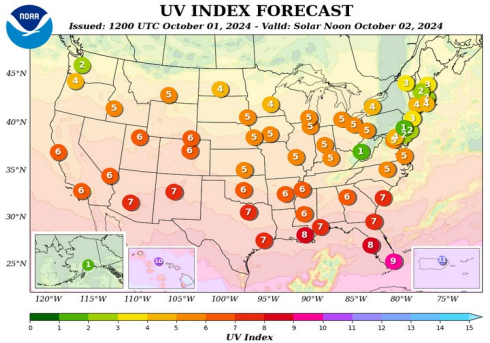
S is partial column ozone above that point

All terms calculated using 2-D chemistry model CHEM2D

For **O3 initialization**, GFS/GDAS assimilates retrievals from OMI on Aura and OMPS on NPP and NOAA-21 satellite observations. The OMPS products are both a profile and a total column.



Stratospheric Ozone contributes significantly to model radiation balance

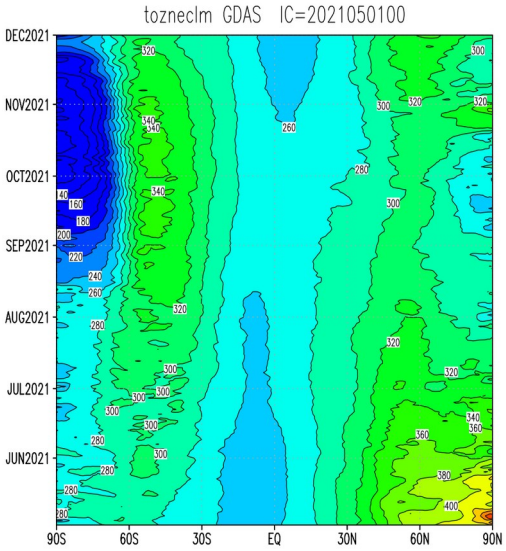


NCEP/CPC uses GFS ozone forecast as input for predicting UV index

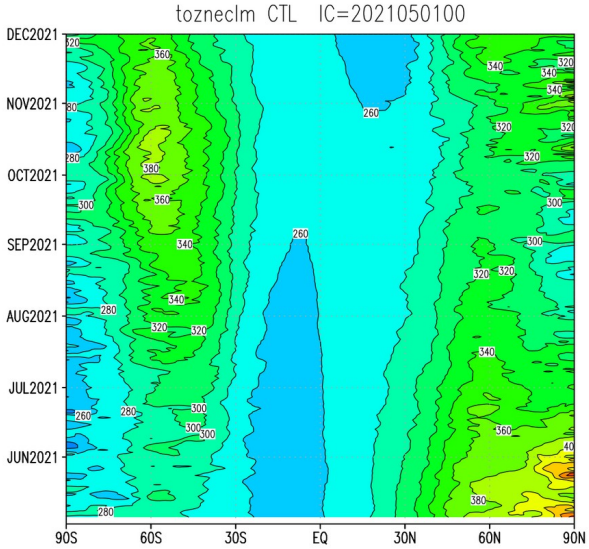
https://www.cpc.ncep.noaa.gov/

The McCormack parameterization employed by current GFS **is not** able to capture the Ozone Hole in the Southern Polar Stratosphere

GDAS Analysis



GFS Free Forecast (50-km resolution)



Credit: Wesloh, Zhou and Yang (EMC)

Need to develop gas-phase chemistry to better simulate trace gases for NOAA global modeling at the S2S time scale

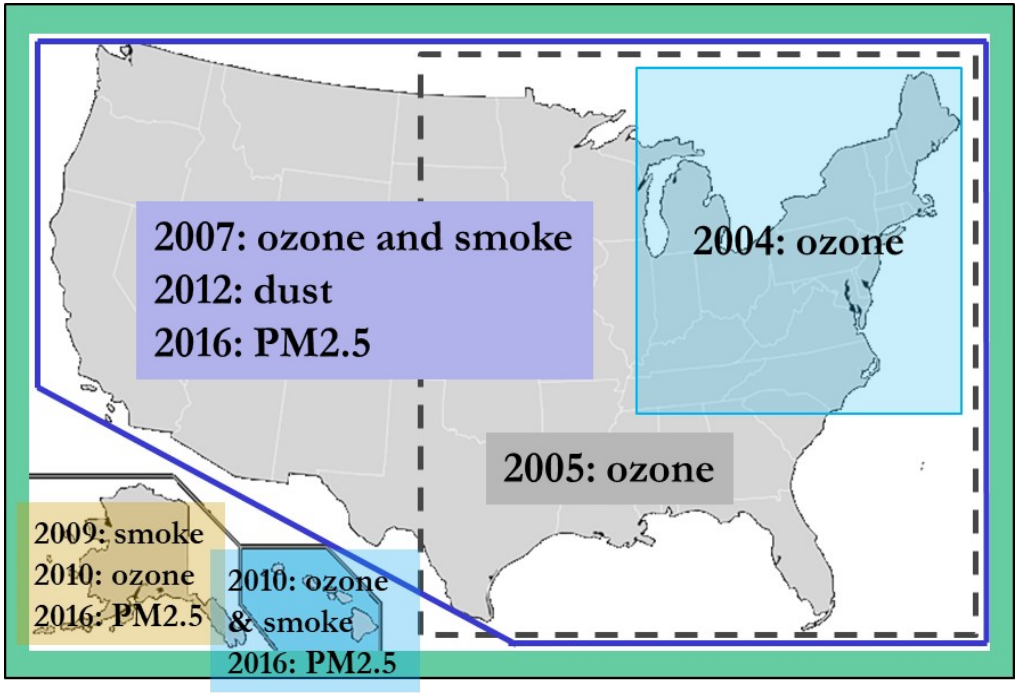
AQM -- Regional Air Quality Forecast Model

Jianping Huang's presentation

- **Chemistry model**: EPA Community Multiscale Air Quality (**CMAQ**) model: gas-chemistry mechanisms (e.g., CB6) and aerosol module (e.g., Aero6)
- **Meteorological model:**
  - NOAA/NCEP North American Mesoscale (**NAM**) numerical weather prediction models: Eta, WRF/NMM, NMMB
  - NOAA/NCEP Global Forecast System (**GFS**)

Forecast Guidance:

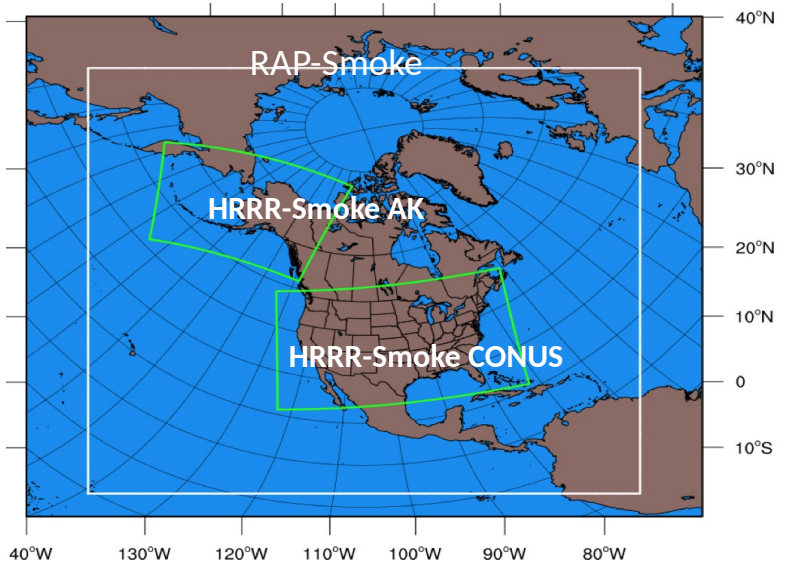
- **O_3, $PM_{2.5}$, and smoke: nationwide**
- **Dust: CONUS**



- **AMQ v6 and earlier: GFS-CMAQ offline system**
- **AQM v7: UFS-CMAQ online system**
- **AQM v8: under development, scheduled for Q1FY26**

RAP/HRRR -- Operational Regional Smoke/Dust Modeling

- A **smoke tracer** is added to the operational RAP/HRRR weather forecast models in late **2020**
- The **satellite fire radiative power** (FRP) data are used to estimate the fire emissions and heat fluxes in real time
- **RAP-Smoke (13km)** enables simulating smoke transport over Central and North Americas, and provides lateral boundary conditions of smoke to HRRR-Smoke.
- The **HRRR-Smoke (3km)** model is able to capture the mesoscale flows and smoke transport in complex terrain
- **Smoke feedbacks** on radiation and visibility are included in these models



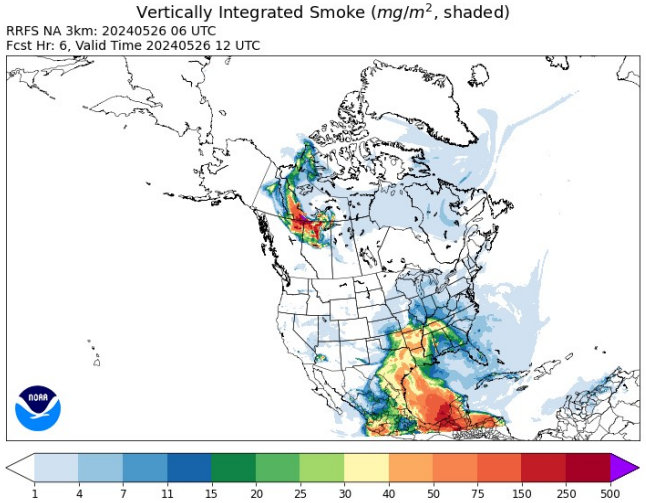
Rapid Refresh (RAP), 13.5km resolution
High-Resolution Rapid Refresh (HRRR), **3km** res.
(https://rapidrefresh.noaa.gov/)

See Ravan Ahmadov's presentation

Transitioning to RRFS-Smoke-Dust (RRFS-SD)

- Smoke (primary PM2.5 from wildland fire emissions) and fine and coarse dust aerosols are included.
- The smoke emissions are based on the **VIIRS and GOES-16/17 fire radiative data.**
- A new forecast is generated every hour. It goes out to **60 hours 4 times a day,** 18 hours for other cycles.
- The impact of smoke and dust aerosols on radiation and visibility is included.
- **A new fire weather index – Hourly Wildfire Potential is provided by the model to the users.**
- The RRFS-SD model is being tested in real-time by EMC.
- The fire weather, smoke, and dust fields are displayed on a public website: **https://rapidrefresh.noaa.gov/RRFS-SD/**

3 km RRFS limited area model domain



NOAA's new NWP model:
Rapid Refresh Forecasting System (RRFS)

HYSPLIT -- Atmospheric transport and dispersion modeling

- Atmospheric transport and dispersion modeling is critical for emergency response and assessment for pollutants released to the air
- HYSPLIT is driven by weather model outputs from NOAA operational models, including GFS, GDAS, GEFS, HRRR, NAM, HREF
- **HYSPLIT** model has been under continuous development at NOAA ARL for more than 40 years
- **EMC collaborates with ARL for the transition of HYSPLIT upgrades into NCEP operation**

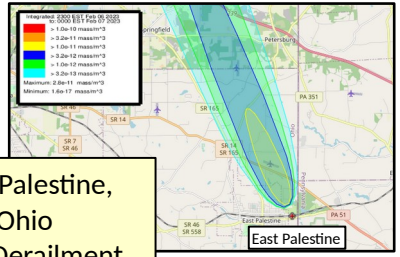
Courtesy of OAR/ARL

A plume of air pollutants emitted from an industrial fire in Deer Park, Texas, March 2019. AP Photo: David J. Philip

The HYSPLIT Model: Spy Balloons, Train Derailments, Greenhouse Gases, and more

Mark Cohen, Leader of the HYSPLIT Modeling Group, NOAA Air Resources Laboratory

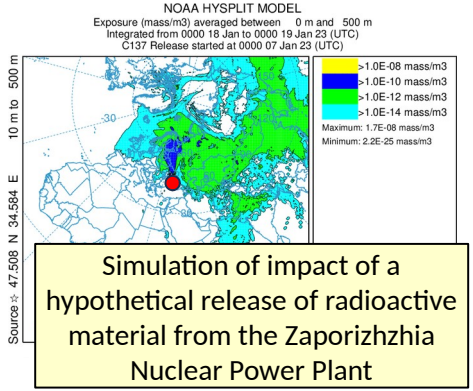
Where do things in the air go?



East Palestine, Ohio
Train Derailment
Feb 2023

Raikoke eruption, Kurile islands, June 2019; Picture taken from International Space Station (CNN)

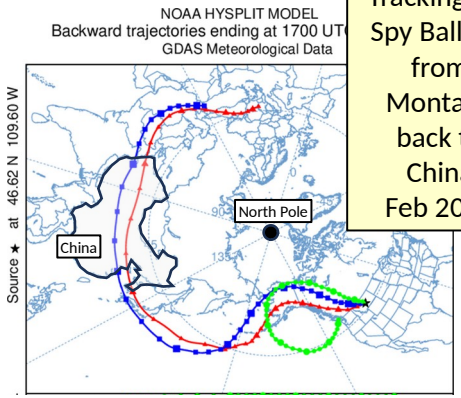
Zaporizhzhia Nuclear Power Plant, Unit 2, Ukraine



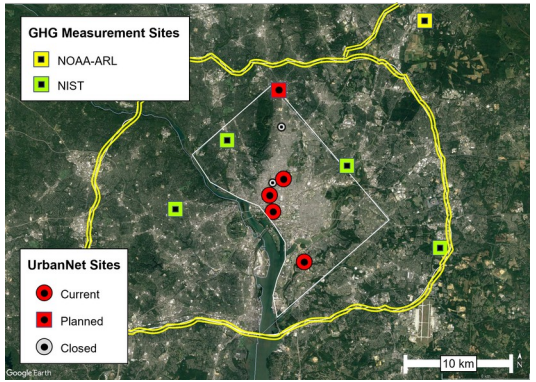
Simulation of impact of a hypothetical release of radioactive material from the Zaporizhzhia Nuclear Power Plant

- Research, development, and transition to operations for ~75 years
- Driven by NOAA meteorological models (and others)
- Used at NOAA and around the world for emergency response, planning, assessment, and for estimating emissions

Where do things in the air come from?



Tracking the Spy Balloon from Montana back to China
Feb 2023



- Run the model backwards from Green House Gas (GHG) measurement sites
- Estimate the emissions of GHG in the Washington DC area
- Independently check progress on emissions reduction

HYSPLIT.v9 Implementation in Q3FY25

- **Inclusion of Transfer Coefficient Matrix (TCM) methodology for Radiological RSMC and Volcanic Ash capabilities** -- *The TCM method computes atmospheric transport and dispersion, and if emissions are updated, the downwind impacts can be easily updated, without having to redo the transport and dispersion simulations.* RSMC: 2 weeks of emission, 3 weeks of post-emission transport for two simultaneous nuclear events. 31 h runs for 10 volcano sites 4x per day
- **Change HYSPLIT packed fields for GFS**
  - For the GFS 1 degree: Increase the number of vertical levels from 21 levels (up to 100 mb) to 41 levels (up to 0.01 mb).
  - For the GFS 0.25 degree: increase the number of vertical levels from 56 to 60 levels. extend the forecast period from 3.5 days to 15 days.
- **Change HYSPLIT packed fields for GEFS**: extend the forecast period from 84 hours to 15 days.
- **Upgrade of HYSPLIT code to ARL v5.3**

Cory Martin's presentation

Data Assimilation of Atmospheric Composition

GFSv17 DA for aerosols: **first time** to include aerosol initializing in NCEP GEFS-aerosol prediction system

- 6-hourly cycles 4x a day with early and late cycles
- Analysis resolution C384L127 (~0.25 deg); background resolution C1152L127 (~9km)
- 3DVar FGAT with 3-hourly backgrounds
- VIIRS EPS 550nm AOD from S-NPP, N20, N21

Regional DA for AQM: AQMv7 has no DA for initialization. R&D includes

- Nitrogen dioxide (NO_2) from TROPOMI (EMC)
- TEMPO (JCSDA + EMC)
- AOD and PM (GSL)
- Future: state + emissions adjustment through strongly coupled DA; GeoXO

Current AC and AQ Modeling in a few International Centers

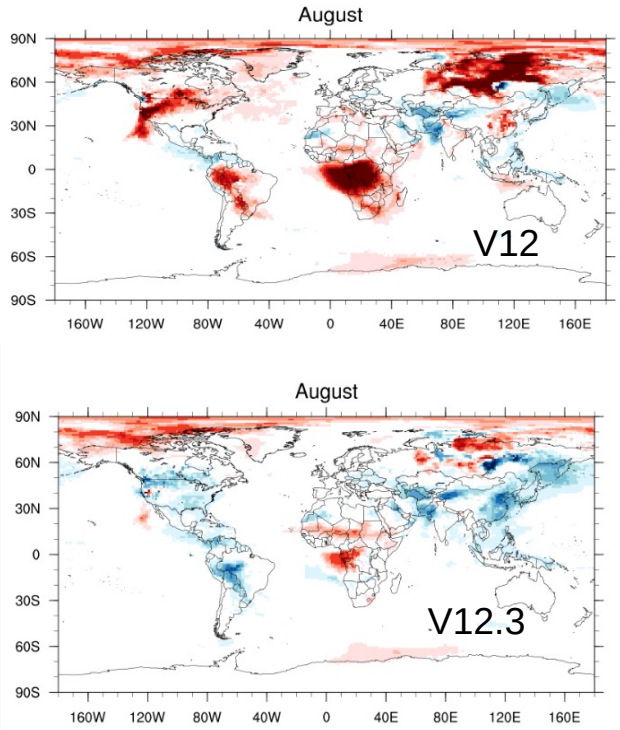
ECMWF	**Global**: T511 (50km) **CAMS** global analyses and reanalyses, including O3, NOx, SO2, CO, CH4, NH3, various aerosol components (including dust, sea salt, sulfate, black carbon, and organic matter). **Other high-res models use CAMS analyses or climatology**
Met Office	**Global**: Interactive prognostic dust (climatologies of other aerosols): Global 10km L70 & 20km L70 EPS **Regional**: 12km L70 online chemistry and aerosol model (UM + UKCA). Once per day T+120h forecast.
Météo France	**Global and regional**: Chemistry-transport model **MOCAGE** : tropo&stratospheric chemistry; aerosols, Assimilates aerosols AOD, for volcanic SO2 (sat. Total columns) and for ozone (sat. Infrared radiances).
DWD	**Global and regional**: **ICON-ART** mineral dust forecasts system
Navy/NRL	**Global:** off-line Dust, Smoke, Pollution, Sea Salt, including DA **Regional**: In-line Dust, Smoke, Pollution, Sea Salt. Initialized off global DA

Future Development of AC and AQ Modeling at EMC

- **Regional**:
  - Km-scale High resolution UFS-based AQ modeling
  - A unified regional AQ prediction system
- **Global**: expand aerosol prediction system to include gas-phase chemistry, providing lateral and boundary conditions for regional modeling
- Develop AQ/AC data assimilation
- Use AI/ML for AQ/AC modeling, bias correction, and down scaling
- Secure additional funding, and collaborate with the community, especially OAR labs and the user community, to enhance AQ/AC modeling capacity and improve forecast accuracy.

Thank You

GEFS-Aerosol Version 12



Monthly average AOD bias vs MERRA-2 analysis for **August 2021** day 1 forecasts.

- One additional member of GEFSv12 for aerosols (V12 implementation date 9/23/2020)
- GEFS meteorology (based on GFSv15) at C384 (~25 km), 64 levels, to 120 hrs, 4x/day
- Inline aerosol representation based on GOCART (GSL-Chem): Sulfate, Organic Carbon, Black Carbon, Dust, Sea Salt
- Emissions: CEDS-2019 , GBBEPx biomass burning, FENGSHA dust, GEOS-5 sea salt
- Smoke plume rise: Wind shear dependent 1-d cloud model to simulate tilt of plume.
- V12.3: Improvements to AOD calculation and wet scavenging

Recent EMC Modeling Achievements

Model version#	Implementation date
RTMA/URMAv2.10.5	1/24/2023
GLWUv2	5/9/2023
HAFSv1	6/27/2023
HAFSv2	7/16/2024
NAEFSv7	12/5/2023
EVSv1	3/26/2024

Model version#	Implementation date
AQMv7	5/14/2024
AQMv7.08 (RAVE2)	10/1/2024
HYSPLIT v8	12/6/2022
GEFS-aerosol (v12.3)	12/01/2022
GFS.v16.3	11/29/2022

https://www.nco.ncep.noaa.gov/pmb/changes/