The UFS-AQM Online Prediction System for Enhanced Fire Predictability

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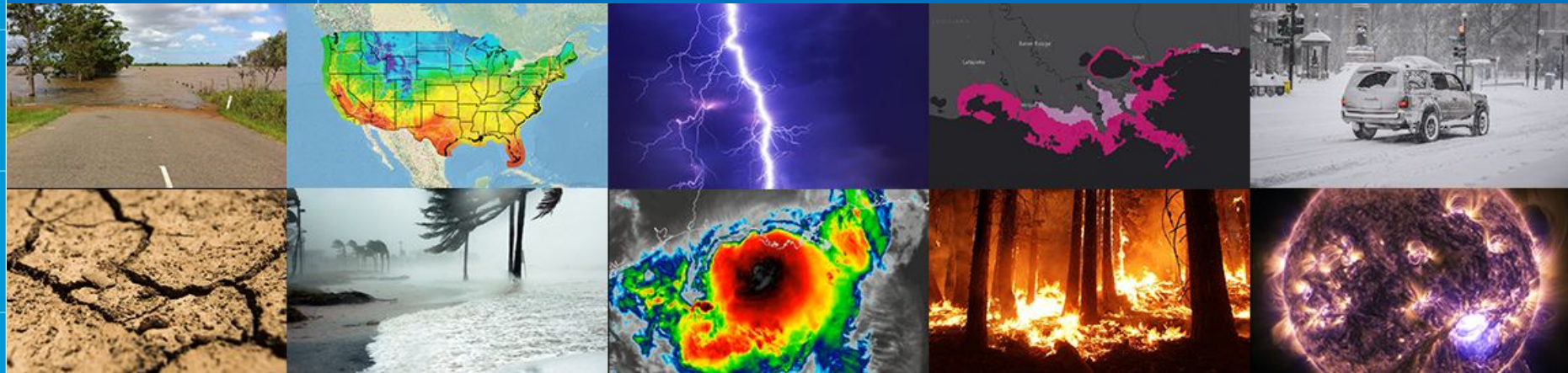
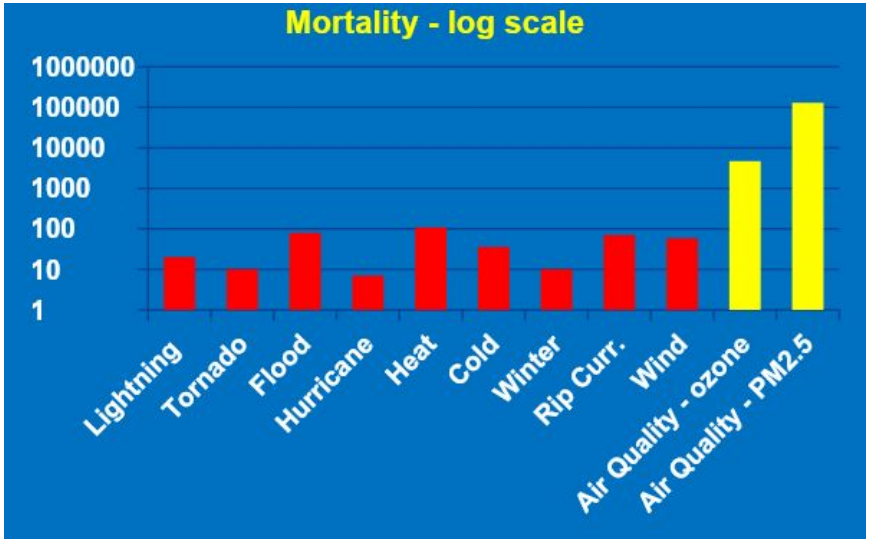
NATIONAL WEATHER SERVICE

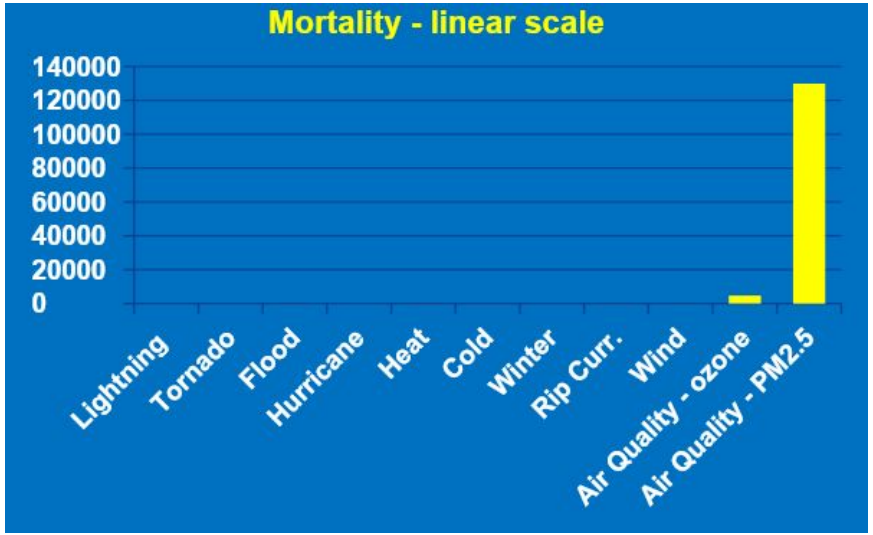
UFS Webinar Series with STI-Modeling Program

April 11, 2024



Why: Societal Impacts of Weather and Air Quality





Red: Weather fatalities for 2018 (source: https://www.weather.gov/hazstat/)

Yellow: Air Quality mortality for 2005 (source: Fann et al., Risk Analysis, 2012 https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1539-6924.2011.01630.x)

same data - linear scale

In the United States, annual mortality from poor air quality (over 100,000) substantially exceeds mortality from all other weather phenomena (530).

AQ prediction customers include: general public, state and local environmental agencies, EPA, CDC

Courtesy Ivanka Stajner, EMC

Societal Impacts of Wildfires and Trend of Burning Areas

FLOODING

EVENT, YEAR	COST
1. Midwest flooding (2008)	$12.1B
2. Louisiana flooding (2016)	$10.8B
3. Mississippi River (2011)	$3.5B
4. Houston flooding (2016)	$2.9B
5. Texas/Oklahoma flooding (2015)	$2.8B

WINTER STORMS

EVENT, YEAR	COST
1. Central/Eastern storm (2015)	$3.3B
2. Freeze (2007)	$2.6B
3. Midwest/Eastern storm (2014)	$2.4B
4. Northeast storm (2018)	$2.3B
5. Groundhog Day blizzard (2011)	$2.1B

WILDFIRES

EVENT, YEAR	COST
1. Camp Fire, others (2018)	$24.5B
2. Tubbs Fire, others (2017)	$18.7B
3. Western wildfires (2007)	$3.5B
4. Western/Alaskan wildfires (2015)	$3.3B
5. Western fires/Gatlinburg, TN (2016)	$2.6B

HURRICANES

EVENT, YEAR	COST
1. Hurricane Katrina (2005)	$168.8B
2. Hurricane Harvey (2017)	$130.0B
3. Hurricane Maria (2017)	$93.6B
4. Hurricane Sandy (2012)	$73.5B
5. Hurricane Irma (2017)	$52.0B

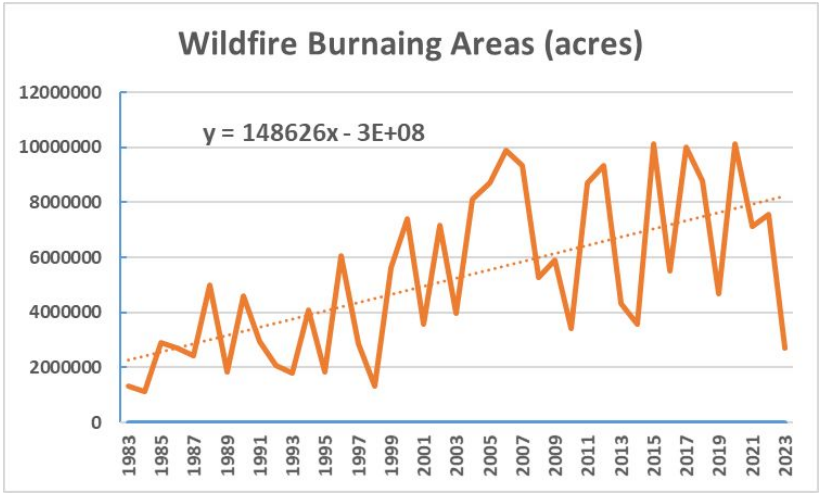
HEAT/DROUGHT

EVENT, YEAR	COST
1. Heat/drought (2012)	$33.9B
2. Southern Plains drought (2011)	$13.9B
3. Western Plains drought (2013)	$11.6B
4. U.S. drought (2008)	$8.6B
5. Midwest Plains drought (2006)	$7.7B

NOTE: Costs from hurricanes Dorian and Imelda (both Sept. 2019) and 2019 Midwest flooding events are still TBD. Costs are in CPI-adjusted dollars.

SOURCE: NOAA

InsideClimate News



Source: National Interagency Fire Center

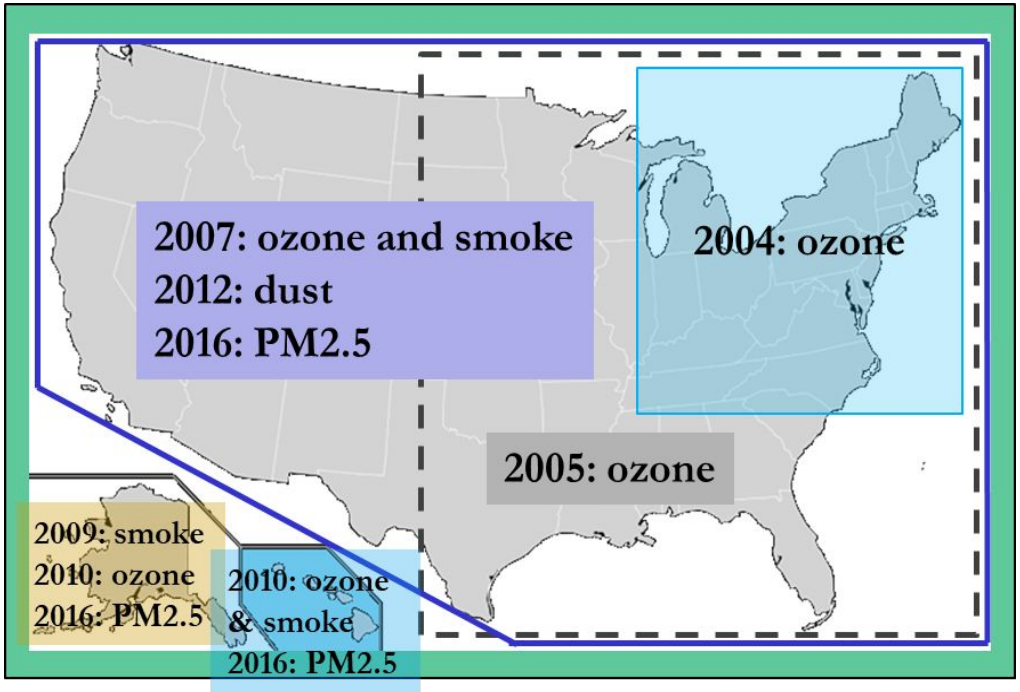
Evolution of National Air Quality Forecast Capabilities

Prediction systems

- **Chemistry model(s)**: EPA Community Multiscale Air Quality (**CMAQ**) model: gas-chemistry mechanisms (e.g., CB06) and aerosol module (e.g., Aero7)
- **Meteorological models:**
  - NOAA/NCEP North American Mesoscale (**NAM**) numerical weather prediction models: Eta, WRF/NMM, NMMB
  - NOAA/NCEP Global Forecast System (**GFS**)
- **Meteorology-Chemistry Coupling:** Offline

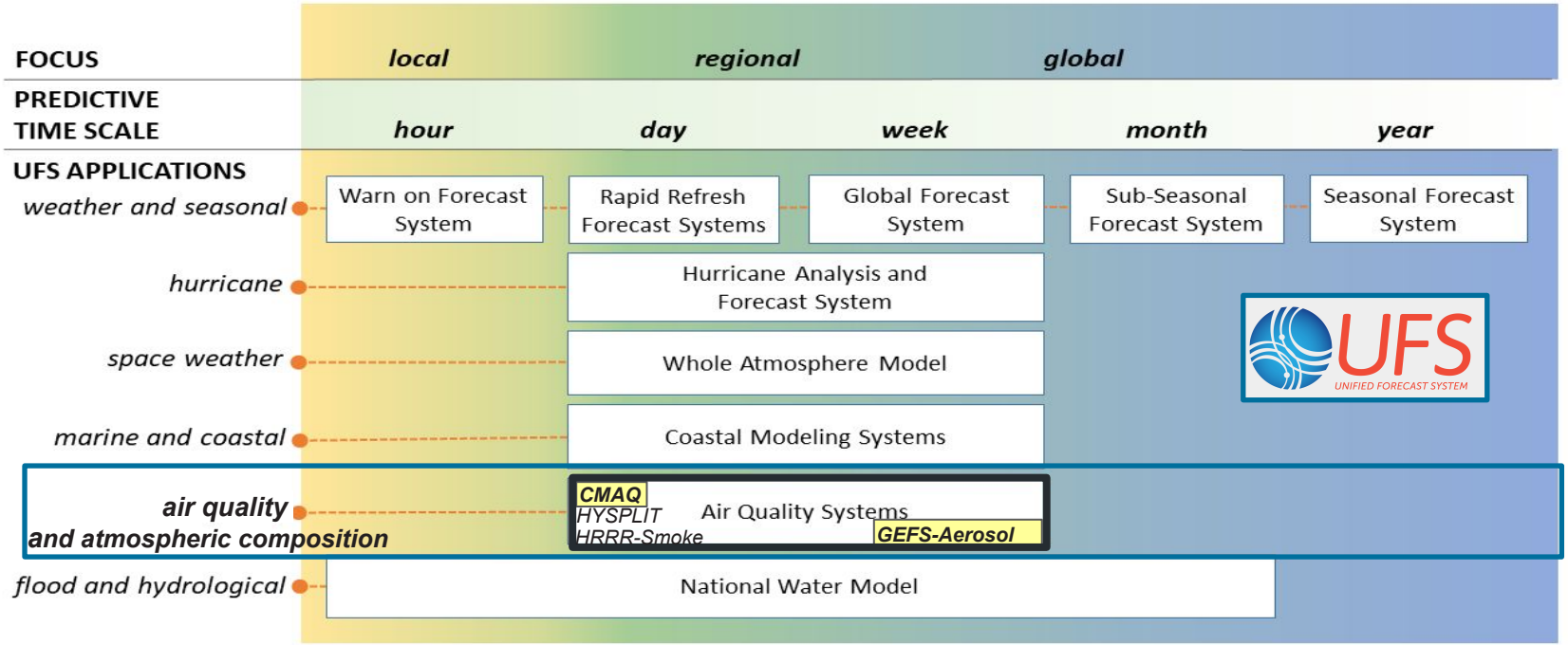
Forecast Guidance:

- O3, PM2.5, and smoke: nationwide
- Dust: CONUS



How: Unified Forecast System - https://ufscommunity.org/

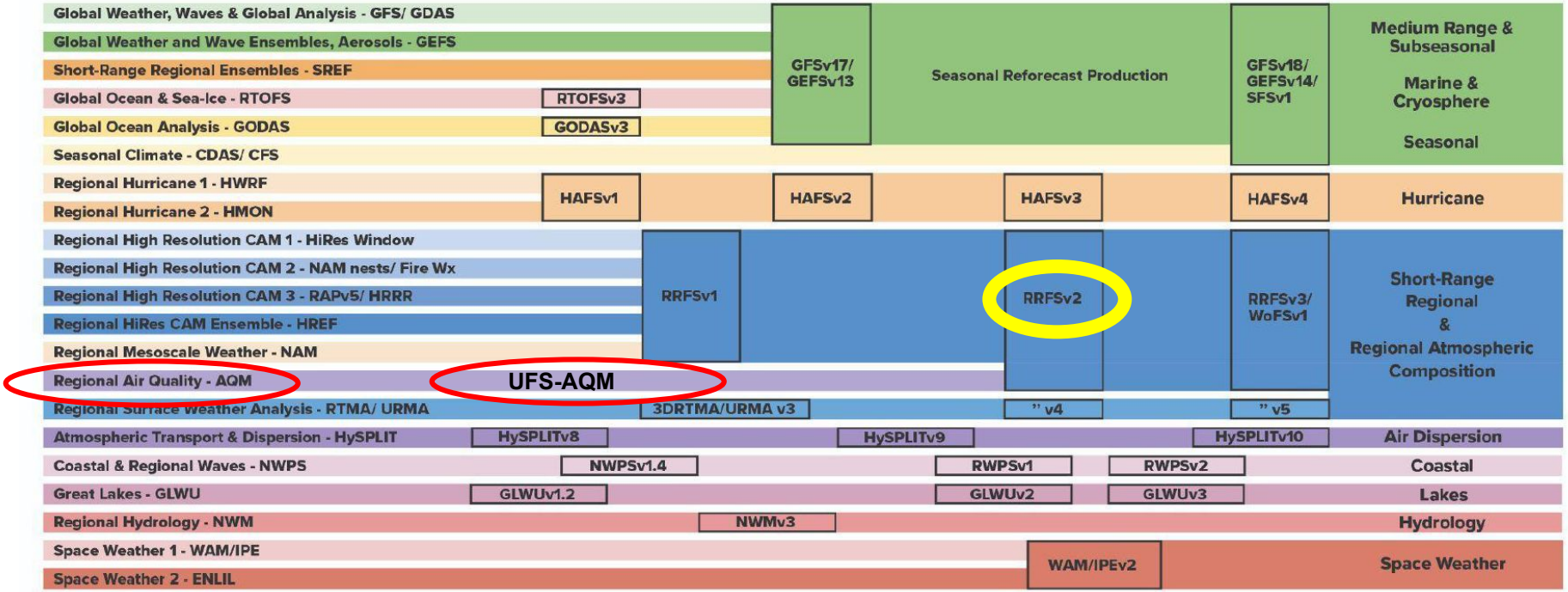
- Unification of many previously disparate systems under a single framework
- Reliance on community modeling and community components



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

Courtesy Ivanka Stajner, EMC

Transition from many operational modeling systems to UFS Applications

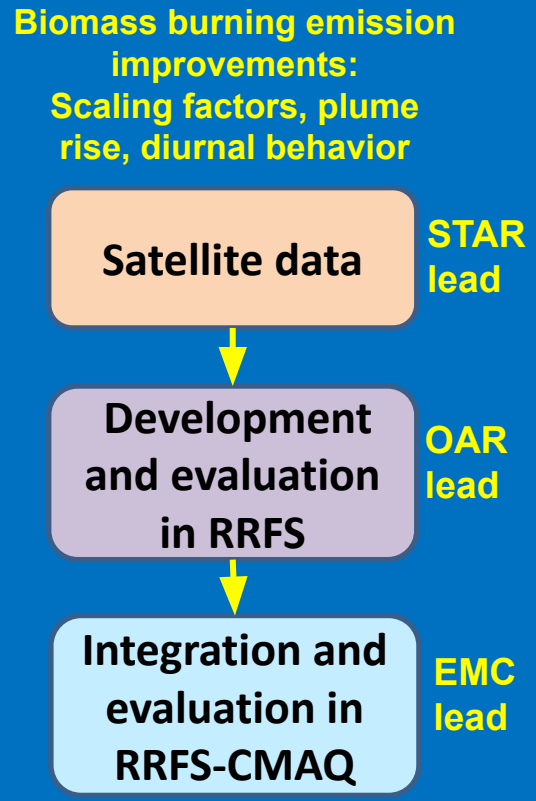


AQM will be included in the short range regional application. Progress to date focuses on including CMAQ chemistry online in the regional UFS application.

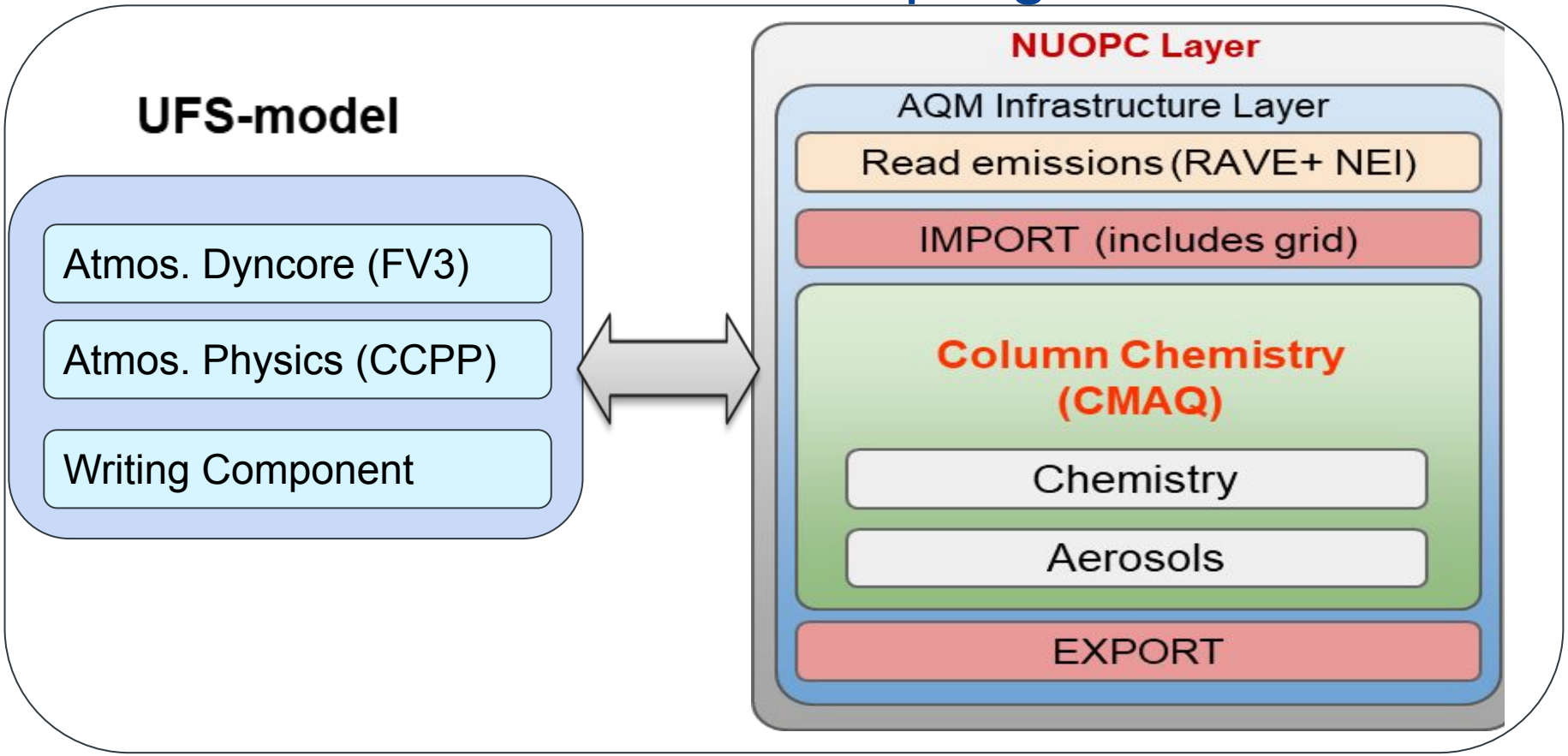
Longer term plans: AQ Prediction with RRFS

- Unification around high resolution Rapid Refresh Forecast System (RRFS) - short-term weather regional UFS application
- CMAQ online in RRFS for wildfire impacts on air quality: PM2.5 and ozone
- Improved speciation and plume rise for fire emissions
- Improved initialization: assimilation of AOD and NO_2 data
- Machine learning emulator for air quality forecasts
- Coordinated with development of an RRFS smoke tracer for fire emissions and Fire Weather Index, including improved diurnal cycle and plume rise
- Models are evaluated using filed campaign data (e.g., FIREX-AQ) and AirNow observations.

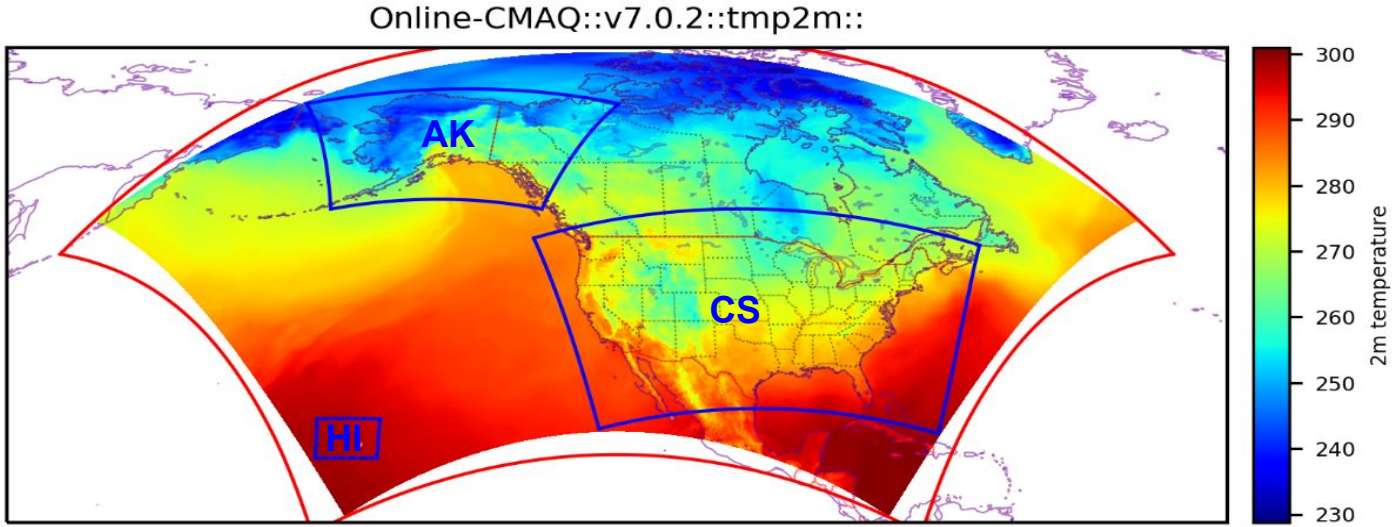
- This is a highly coordinated NOAA effort among EMC, NESDIS-STAR, several OAR labs and university partners.



UFS-AQM Online-coupling Model



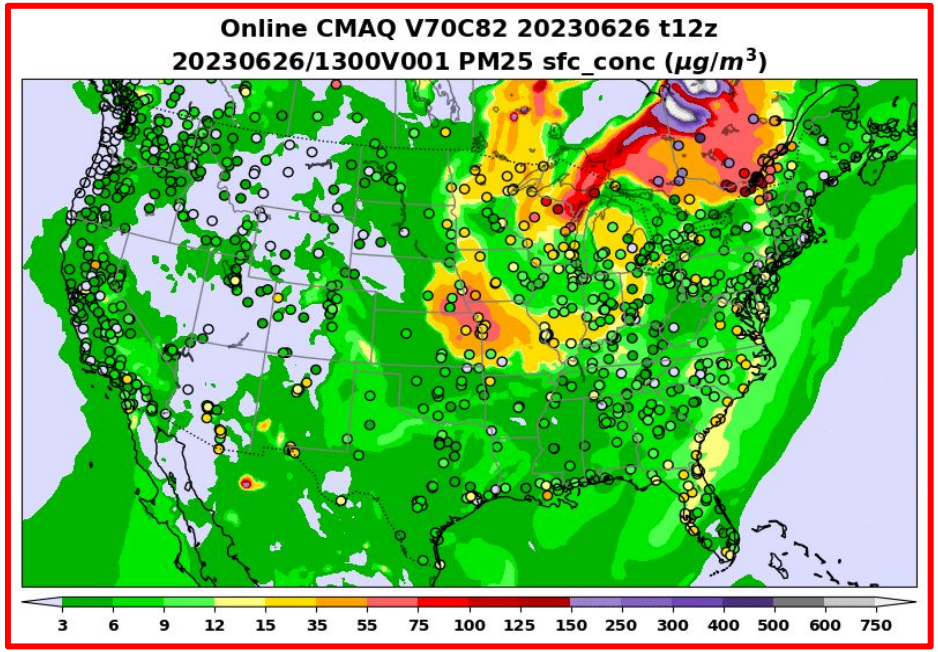
AQMv7: a single North American domain (13 km)



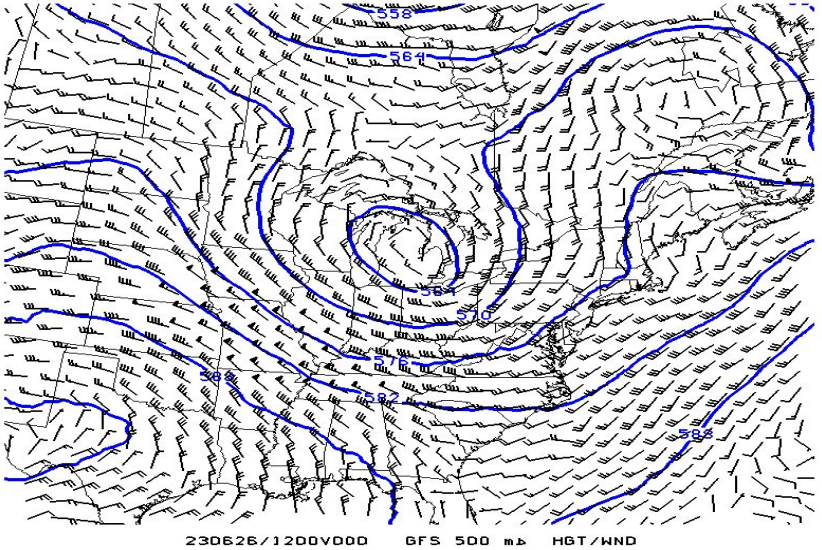
The candidate for operations at 13 km resolution

- **UFS-AQM online prediction system has been running in near-real-time since July, 2022 over the North American large domain (red line) that covers all 3 current operational product domains: CONUS, AK and HI.**
- **Updates have been integrated into this near-real-time run.**
- Physics Suite: CCPP for GFSv16
- Anthropogenic and biogenic emissions for the large domain (NEIC 2016v1 plus global)
- **Hourly RAVE wildfire emissions and Sofiev plume-rise algorithm**
- Updated LBC (AM4 + GEFS-Aerosols) and wet deposition
- Fengsha dust module
- Bias correction
- Post-processing for 8h ozone maximum and daily average $PM_{2.5}$

$PM_{2.5}$ predictions during Quebec wildfires June 26, 2023



Geopotential Heights and Winds at 500 hPa

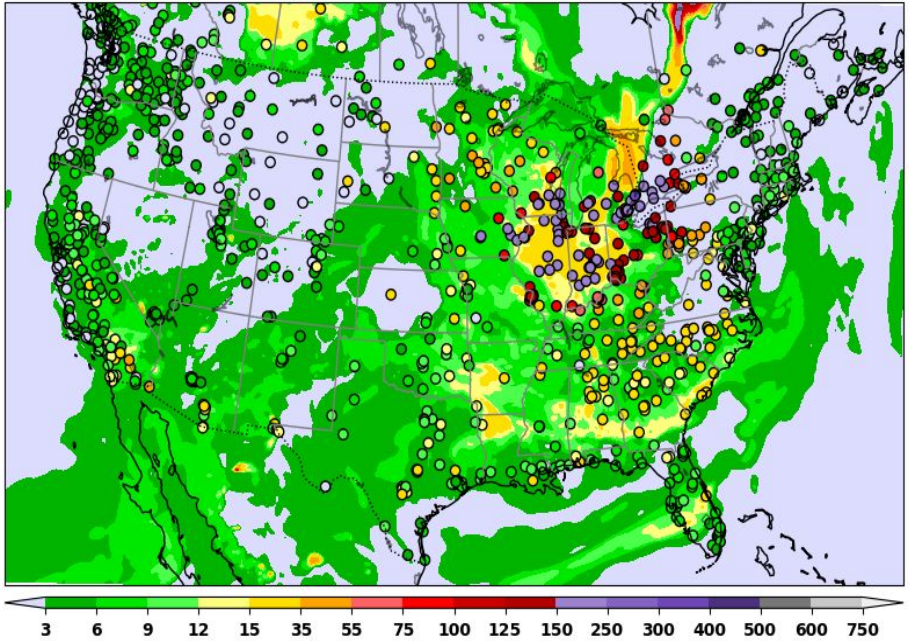


- A storm system located northeast of the Great Lakes produced a counterclockwise wind, channeling the smoke produced by wildfires in Canada south into US, affecting air quality in the Midwest regions substantially.
- Evolution of predicted $PM_{2.5}$ is shown for 72-hour predictions initialized on June 26, 2023 together with independent AirNow observations of $PM_{2.5}$ (in filled circles). High values of $PM_{2.5}$ were attributed to wildfires.

UFS-AQM improves $PM_{2.5}$ prediction during Quebec Fires in June 2023

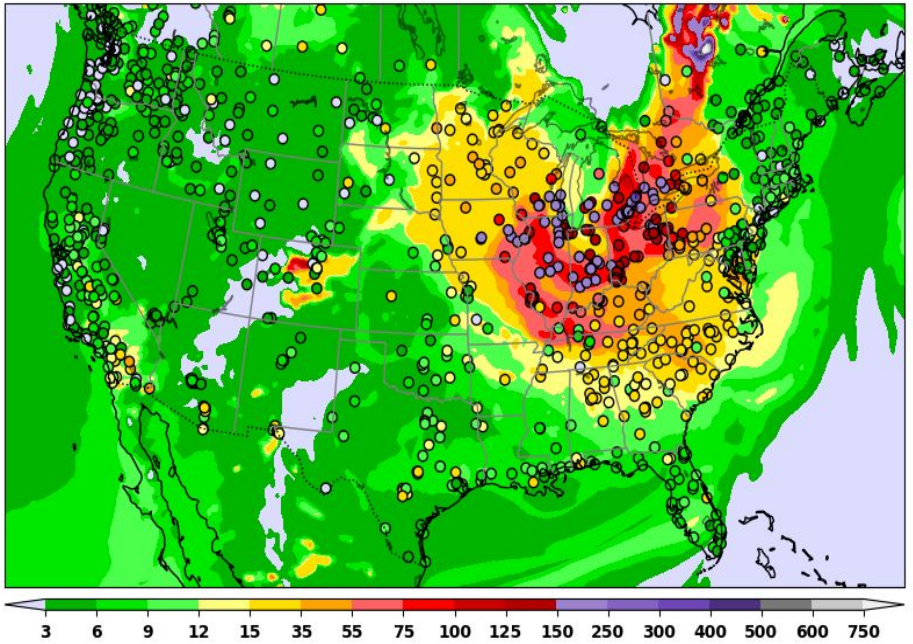
Operational

CMAQ PROD 20230626 t06z
20230628/0600V048 PM25 sfc_conc ($\mu g/m^3$)

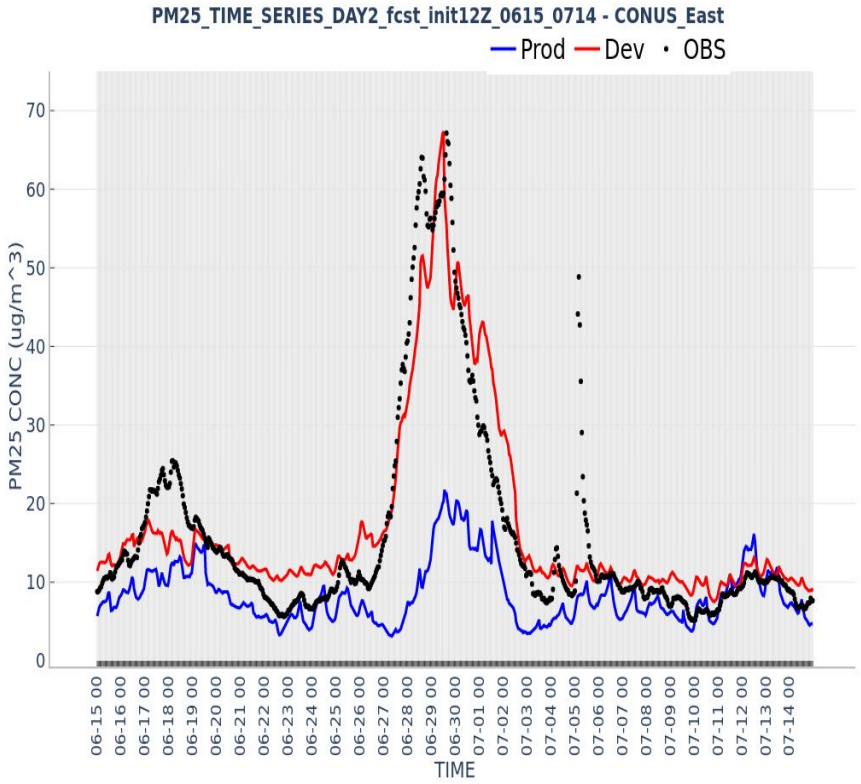


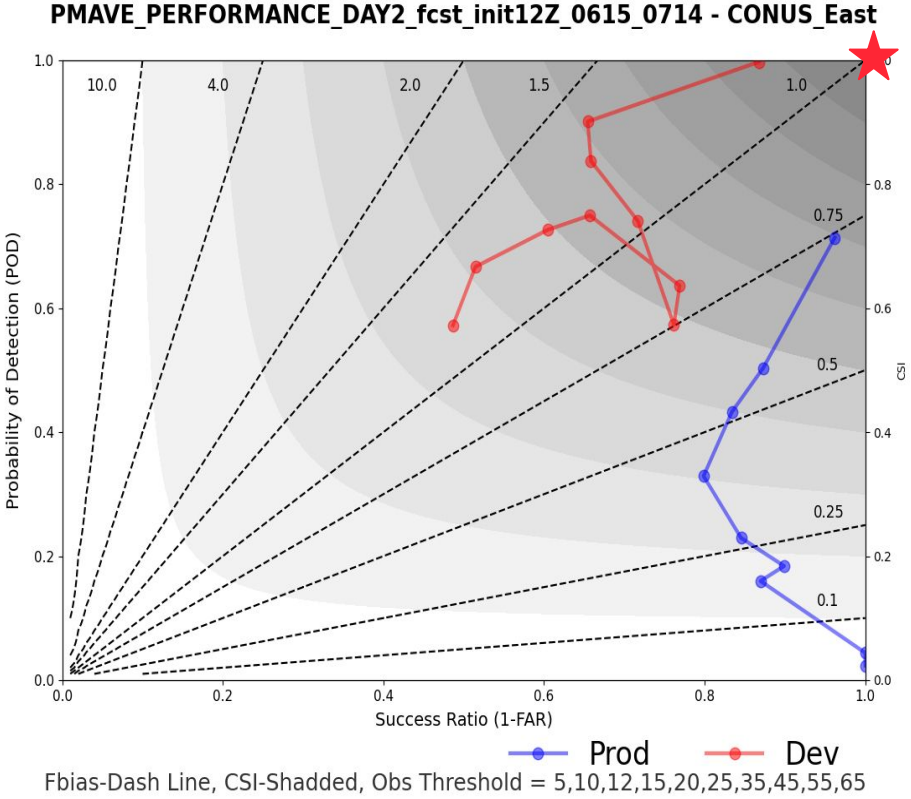
UFS-AQM

Online CMAQ V70C84 20230626 t06z
20230628/0600V048 PM25 sfc_conc ($\mu g/m^3$)



UFS-AQM (Dev) improves $PM_{2.5}$ during Quebec Fire 2023

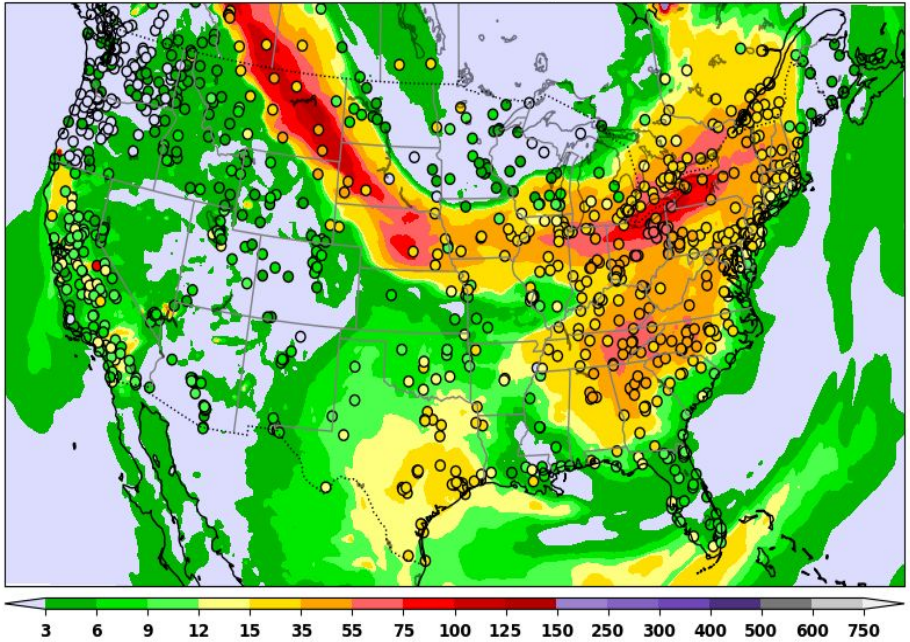




UFS-AQM improves $PM_{2.5}$ over-predictions by Operational model during the Alberta fire smoke intrusion (July 17, 2023)

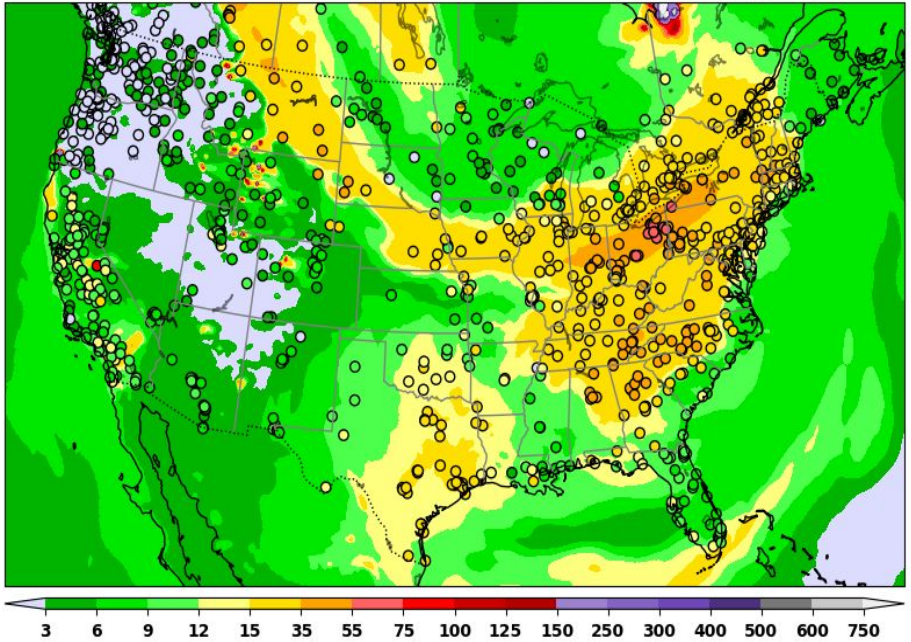
Operational

CMAQ PROD 20230717 t12z
05Z17JUL2023-04Z18JUL2023 ave_24hr_pm25 ($\mu g/m^3$)



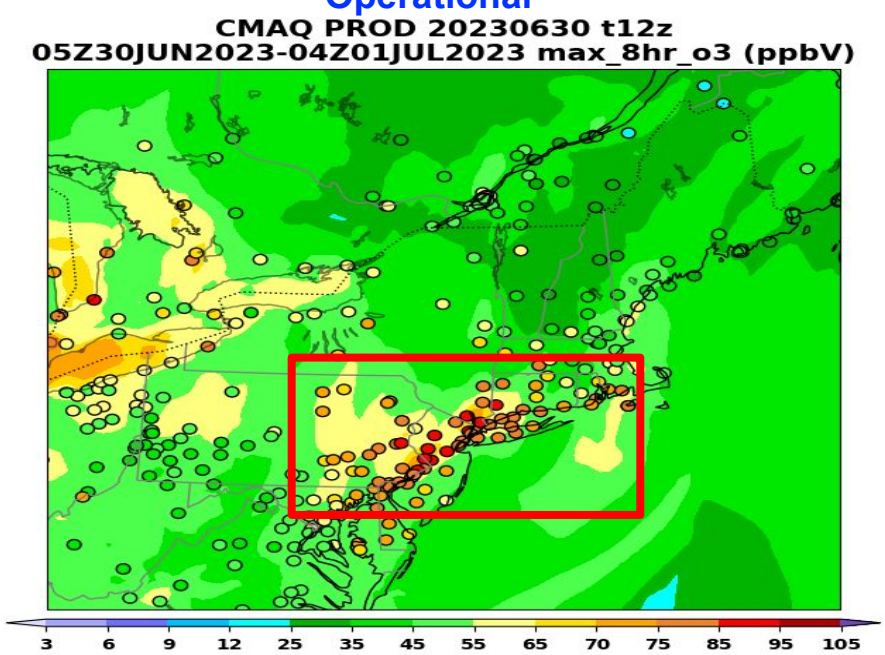
UFS-AQM

Online CMAQ V70C84 20230717 t12z
05Z17JUL2023-04Z18JUL2023 ave_24hr_pm25 ($\mu g/m^3$)

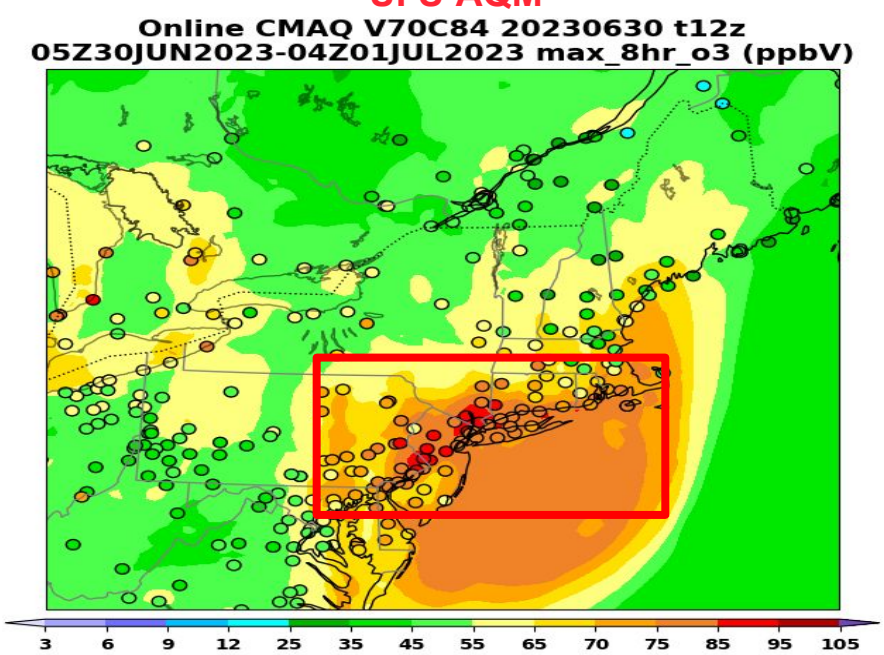


Evaluation of UFS-AQM predictions: O_3 episodes

Operational



UFS-AQM



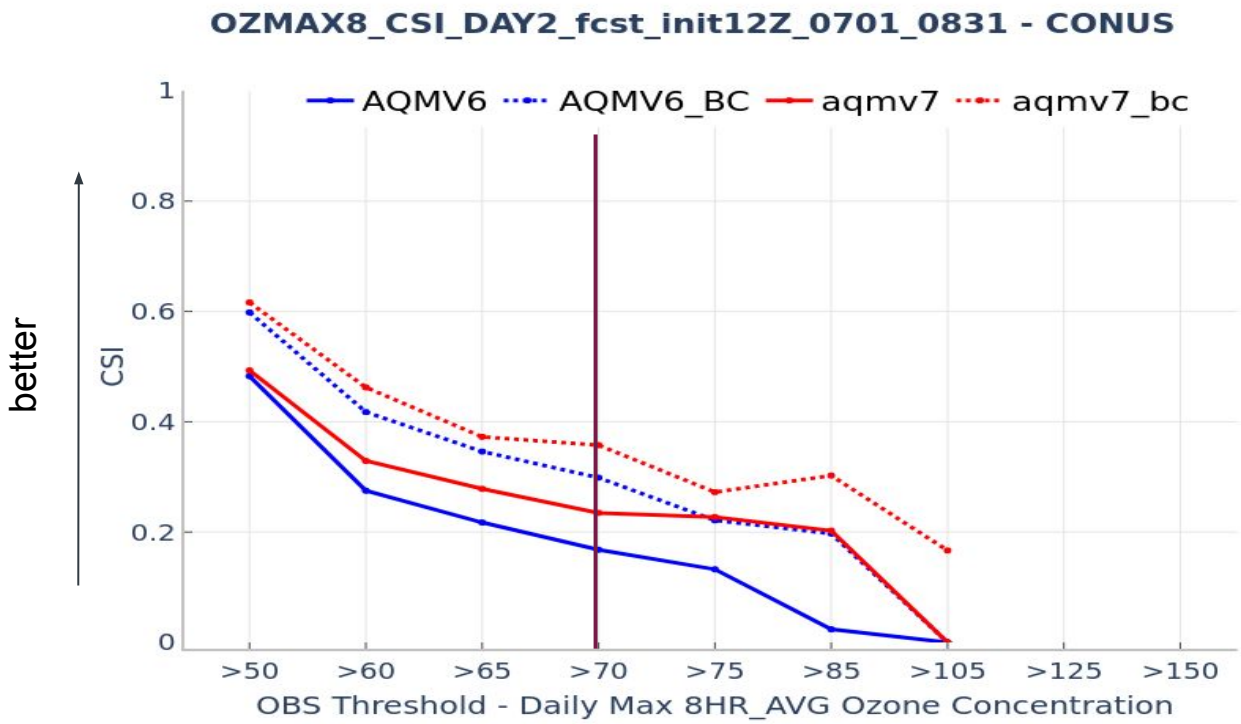
- Several O_3 exceedance events were observed over the affected region during dissipation stage of Quebec fire events.
- UFS-AQM predicts higher O_3 than the operational model over northeast coastal region such as Long Island Sound on June 30, 2023 in closer accordance with observations.

AQMv7 (UFS-AQM) Evaluation Details

- Statistics and Example Cases from Retrospective runs
  - Time periods:
    - Summer: July-Aug. 2022
    - Winter: Dec. 2022, Jan. 2023
    - Month with intense fires: Sept. 2020
  - Products: Daily maximum 8-hour average O_3, 24-hr average $PM_{2.5}$
  - Statistics: time series, category performance
- Summary of Statistics

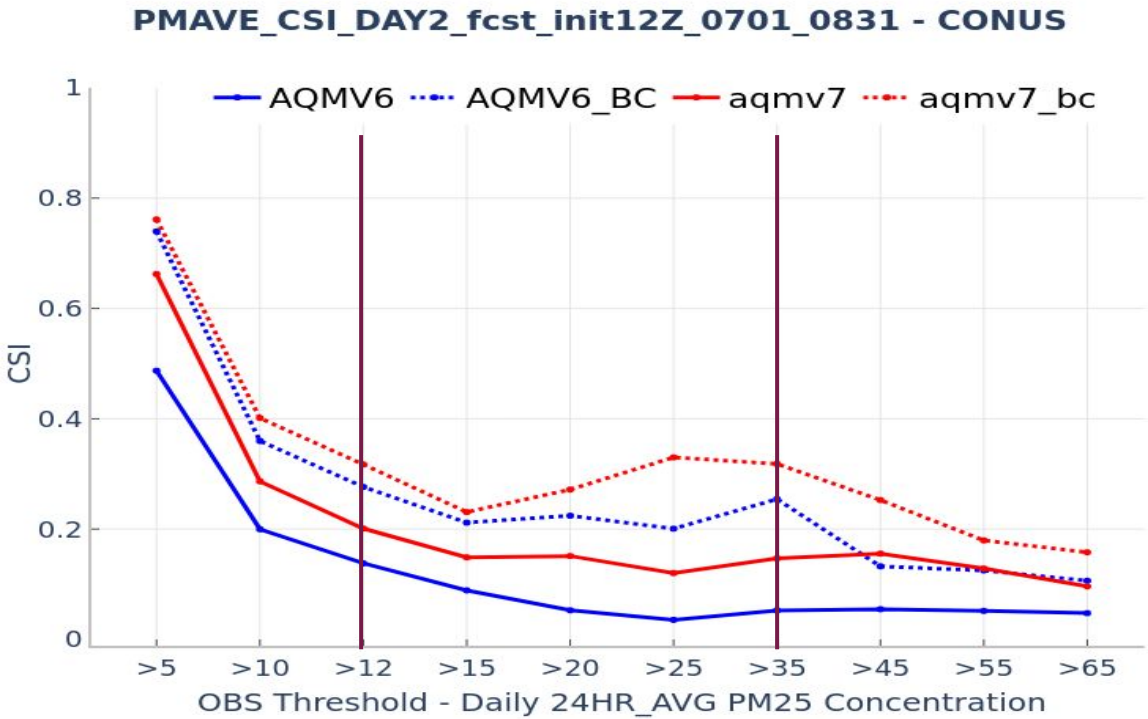
AQMv7 improves O_3 exceedance predictions in summer

- AQMv7 demonstrates higher Critical Success Index (CSI) values for daily max. 8-hour ave. O_3 for both the raw model (solid) and bias-corrected (BC) products (dashed) than AQMv6.
- AQMv7 exhibits enhanced predictive capabilities for O_3 exceedance events (≥70 ppb).



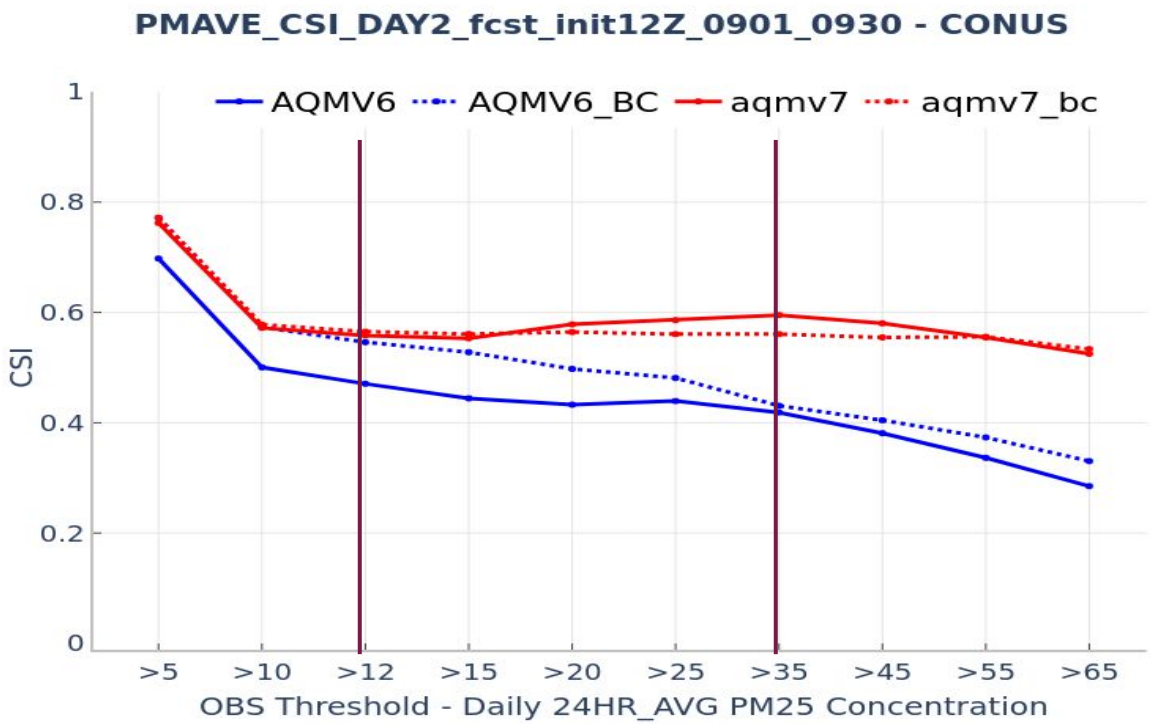
AQMv7 improves 24-hr ave. $PM_{2.5}$ in summer

- AQMv7 demonstrates higher CSI values for 24-hr ave. $PM_{2.5}$ for both the raw model and bias-corrected (BC) products (dashed) than AQMv6.
- AQMv7 exhibits enhanced predictive capabilities for $PM_{2.5}$ exceedance events (≥35 ug/m^3).



AQMv7 improves $PM_{2.5}$ in fire season

- AQMv7 demonstrates higher CSI values for 24-hr ave. $PM_{2.5}$ for both the raw model and bias-corrected (BC) products (dashed) than AQMv6.
- AQMv7 exhibits enhanced predictive capabilities for $PM_{2.5}$ exceedance events (≥35 ug/m^3).



Summary of AQMv7 Verification Statistics

Summer 2022					
Region	**Parameter**	**Average Forecast**	**CSI**	**POD**	**FAR**
CONUS East	Ozone	Neutral	R: Neutral BC: Degraded	Improved	Neutral
	PM2.5	Notably Improved	R: Neutral BC: Improved	Improved	Neutral
CONUS West	Ozone	Notably Improved	Notably Improved	Improved	Neutral
	PM2.5	Notably Improved	Notably Improved	Improved	Improved

Summary of AQMv7 Verification Statistics

Winter 2022					
Region	**Parameter**	**Average Forecast**	**CSI**	**POD**	**FAR**
CONUS East	Ozone	R: Degraded BC: Neutral	N/A	N/A	N/A
	PM2.5	Neutral	Slightly degraded	R: Slightly improved BC: Neutral	R: Slightly degraded BC: Neutral
CONUS West	Ozone	R: Degraded BC: Slightly improved	BC: Improved	BC: Slightly improved	BC: Slightly improved
	PM2.5	Improved	Improved	Neutral	Slightly improved

Summary of AQMv7 Verification Statistics

September 2020 (Fire event)					
Region	**Parameter**	**Average Forecast**	**CSI**	**POD**	**FAR**
CONUS East	Ozone	R: Improved	R: Slightly degraded	R: Improved	R: Slightly degraded
	PM2.5	R: Slightly Improved	R: Improved	R: Neutral	R: Slightly Improved
CONUS West	Ozone	R: Slightly Improved	R: Notably Improved	R: Notably Improved	R: Degraded
	PM2.5	R: Notably Improved	R: Notably Improved	R: Notably Improved	R: Slightly degraded

Summary

- NOAA has developed an AQM online prediction system within the UFS framework to enhance representation of wildfire emissions and their impact on air quality predictions.
- The UFS-AQM, incorporating hourly RAVE data, significantly improved $PM_{2.5}$ predictions compared to the operational system.
- Moreover, the UFS-AQM exhibited superior performance in capturing O_3 episodes when compared to the operational model.
- The UFS-AQM online systems, has been approved as a replacement for the existing operational air quality forecast system with implementation planned in May, 2024.

Next steps

- Will develop the RRFS-AQM online system (3km) to address prediction challenges over complex terrain and coastal regions.
- Will develop machine learning emulator to improve computational efficiency
- Will upgrade the CMAQ model along with anthropogenic emissions, refine wildfire emissions and plume rise algorithm, and utilize more advanced CCPP, data assimilation techniques as well as short-period training for bias correction to further improve wildfire and AQ predictions.