An Improved National Air Quality Forecasting Capability Using the NOAA Global Forecast System. Part I: Model Development and Community Application

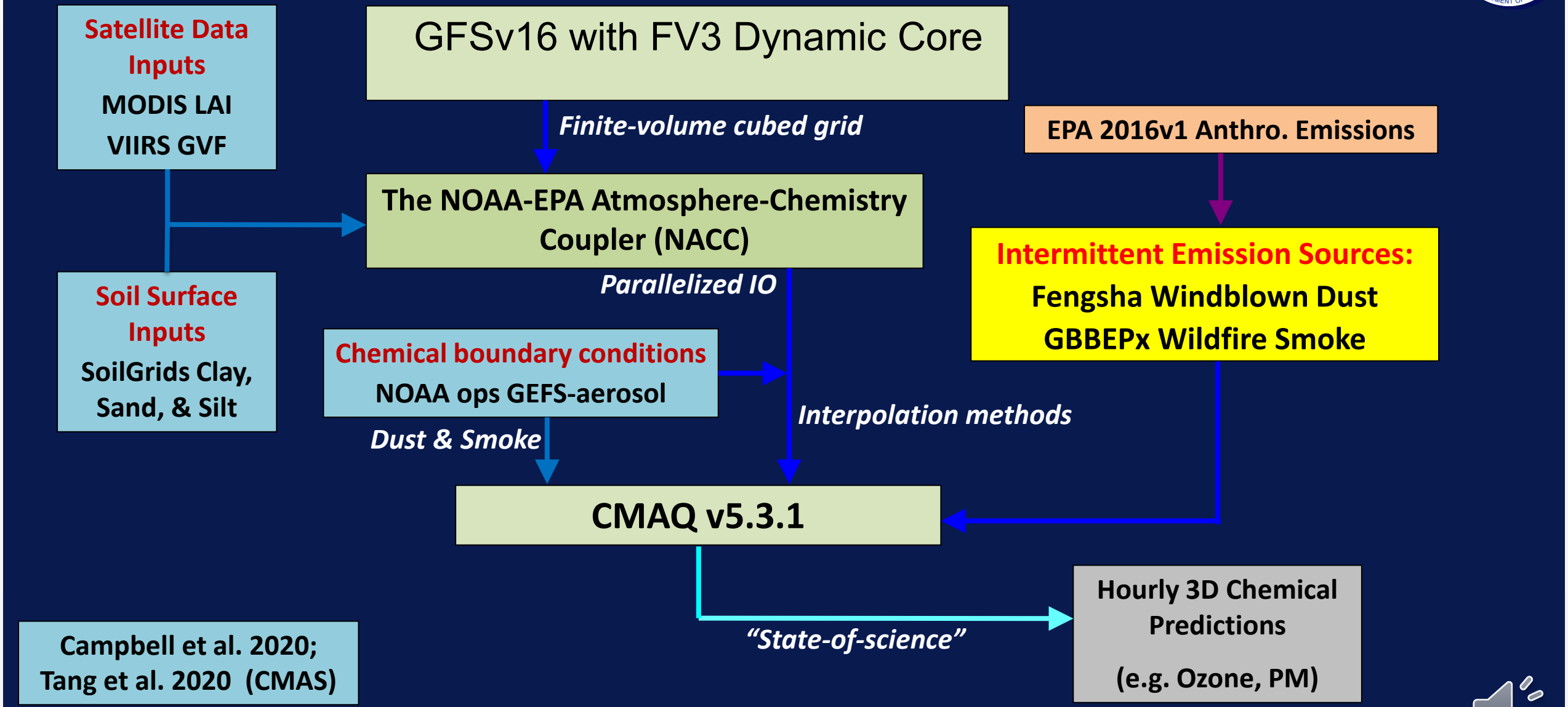
Patrick C. Campbell[1,2], Youhua Tang[1,2], Pius Lee[1], Barry Baker[1,2], Daniel Tong[1,2], Rick Saylor[1], Ariel Stein[1], Jianping Huang[3,4], Ho-Chun Huang[3,4], Edward Strobach[3,4], Jeff McQueen[3], Ivanka Stajner[3], Dorothy Koch[5], Jose Tirado-Delgado[5,6], and Youngsun Jung[5]

1. NOAA Air Resources Laboratory (ARL), College Park, MD.
2. Center for Spatial Information Science and Systems, George Mason University, Fairfax, VA.
3. NOAA National Centers for Environmental Prediction (NCEP), College Park, MD
4. I.M. Systems Group Inc., Rockville, MD
5. NOAA NWS/STI
6. Eastern Research Group, Inc (ERG)

Introduction & Motivation

- The National Air Quality Forecasting Capability (NAQFC) has been operational since 2004.
- Transition to the Finite Volume Cubed-Sphere (FV3) dynamical core in the NOAA Global Forecast System (GFS).
- Major NOAA upgrade of GFS from version 15 to 16 (GFSv16).
- Need for streamlined development of the GFSv16 for a next-generation, state-of-science, NAQFC.
- Improve community options to use NOAA GFSv16 product(s) for CMAQ.

The Next NAQFC: NACC-CMAQ



What is NACC?

- The **N**OAA-EPA **A**tmosphere-**C**hemistry **C**oupler (NACC) (i.e., *"knack": meaning an acquired skill*) is adapted from the EPA's Meteorology-Chemistry Interface Processor (MCIP) version 5 (Otte and Pleim, 2010).

- NACC couples the FV3-GFSv16 with the Community Multiscale Air Quality Model, version 5.3.1 (CMAQv5.3.1).

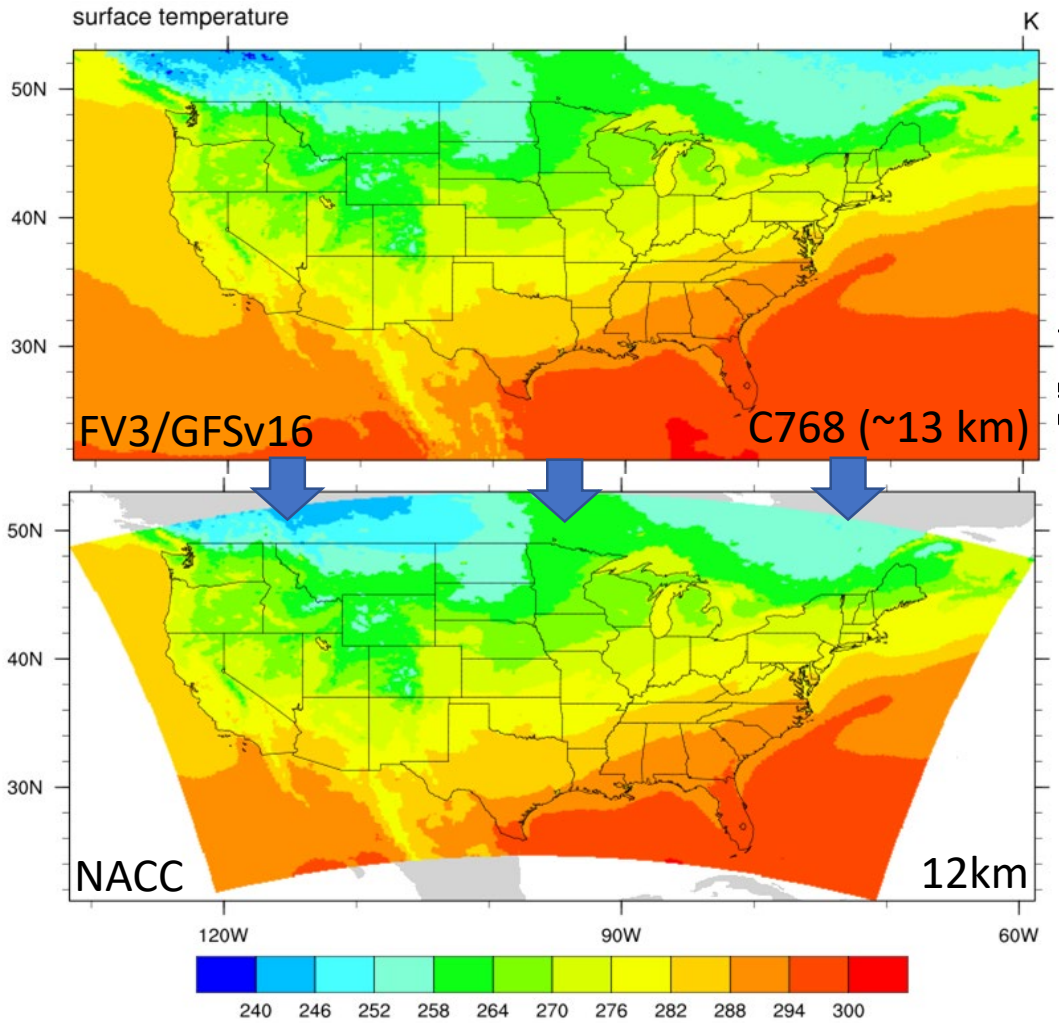
- NACC is being developed for NOAA's operational NAQFC and is available to the greater scientific community at: https://github.com/noaa-oar-arl/NACC .

What are the advantages of NACC-CMAQ?

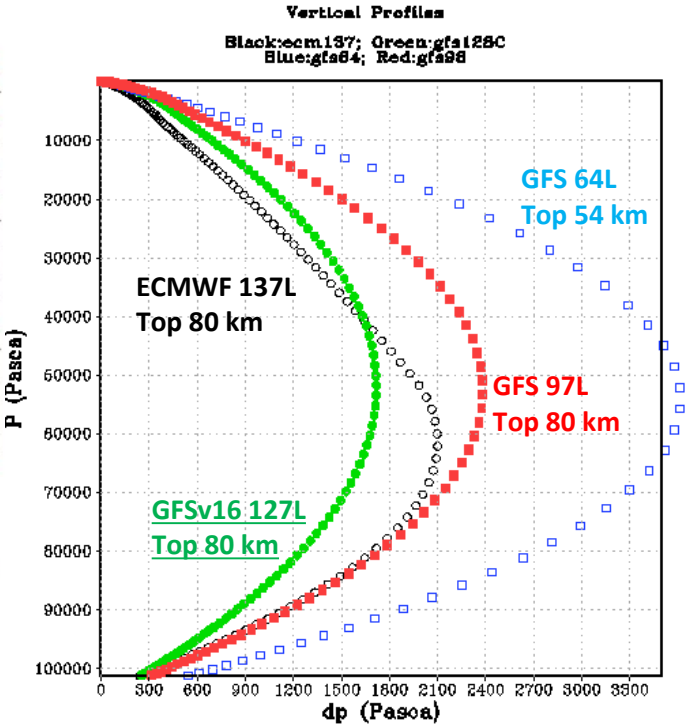
- Interfaces NOAA's global FV3-GFSv16 meteorological to latest CMAQv5.3.1.
- Processes high-resolution satellite vegetation and soil data inputs for CMAQ.
- User-defined vertical layers; run CMAQ with native GFS or collapsed layers.
- Github integration allows for streamlined future updates to NACC-CMAQ.
- Advanced intermittent emissions sources and aerosol boundary conditions.
- NACC parallellization with MPI speeds up I/O drastically and is easily portable.

Fundamental NACC Structural Changes

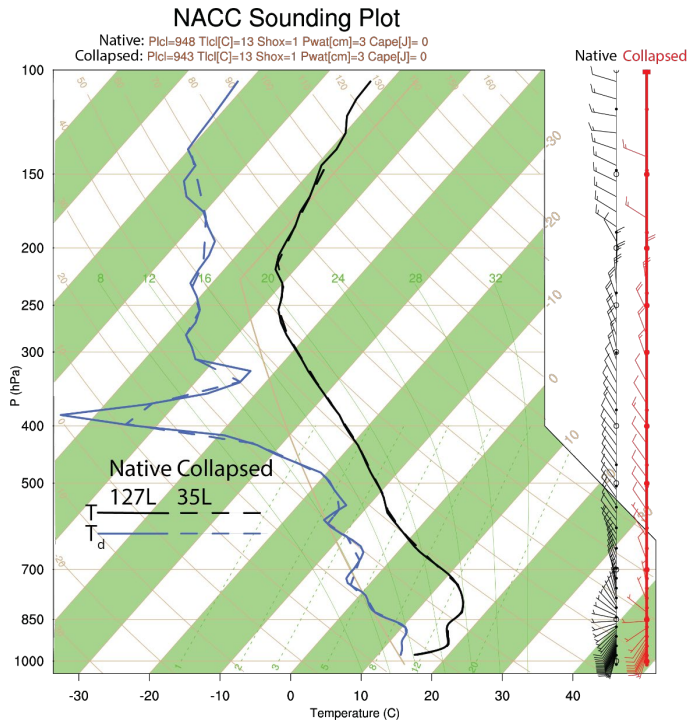
Directly Interpolated Fields



Redefined Vertical Structure



GFSv16 has higher vertical resolution with 127L and thinner 1st layer (20 m thick) than previous GFS.



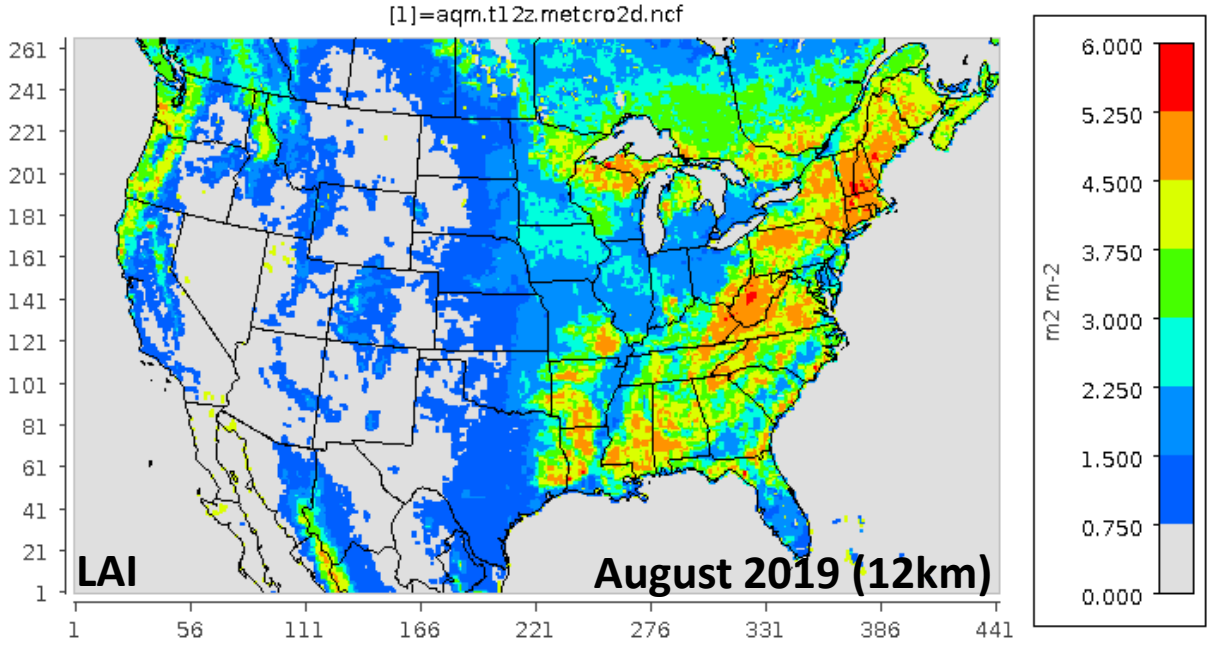
NACC uses either native or collapsed GFSv16 layers, and there is good agreement in structure.

Other NACC-CMAQ Advancements

Updated Satellite Land Cover Characterization

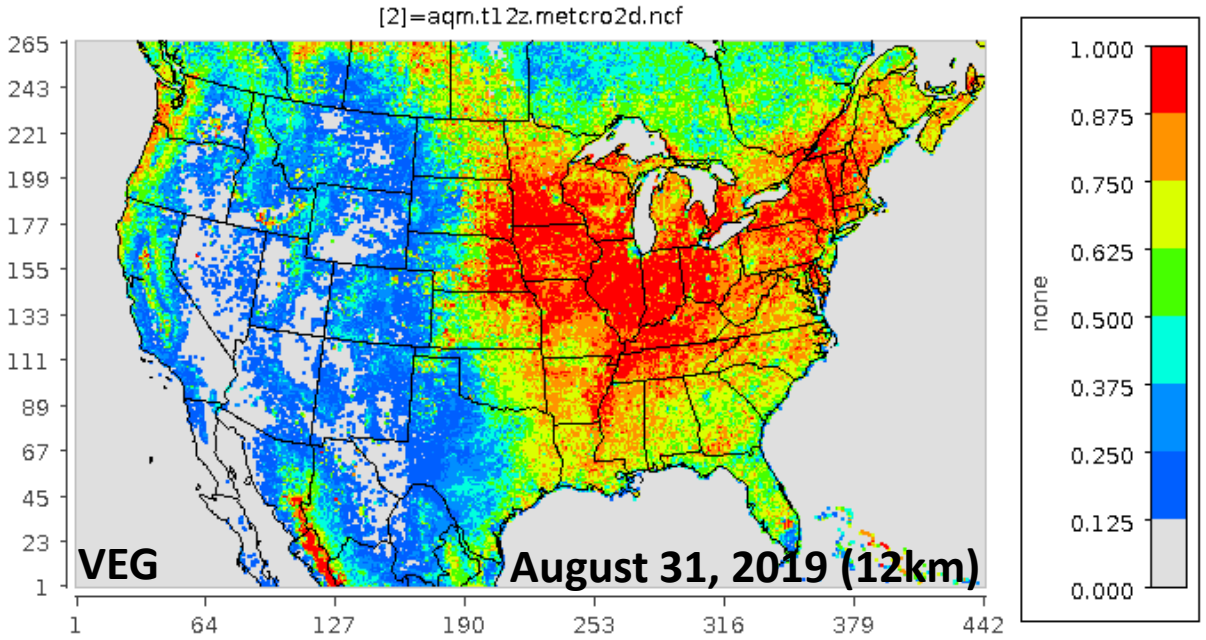
- Currently, NACC-CMAQ uses a 12-month MODIS LAI climatology and a NOAA weekly VIIRS GVF product.
- Plan for NACC-CMAQ to eventually use weekly VIIRS LAI product instead of MODIS climatology.

MODIS Leaf Area Index



Input gridded MODIS resolution ~ 10 km

VIIRS Greeness Vegetation Fraction



Input gridded VIIRS resolution ~ 4 km

https://www.ospo.noaa.gov/Products/land/gvf/

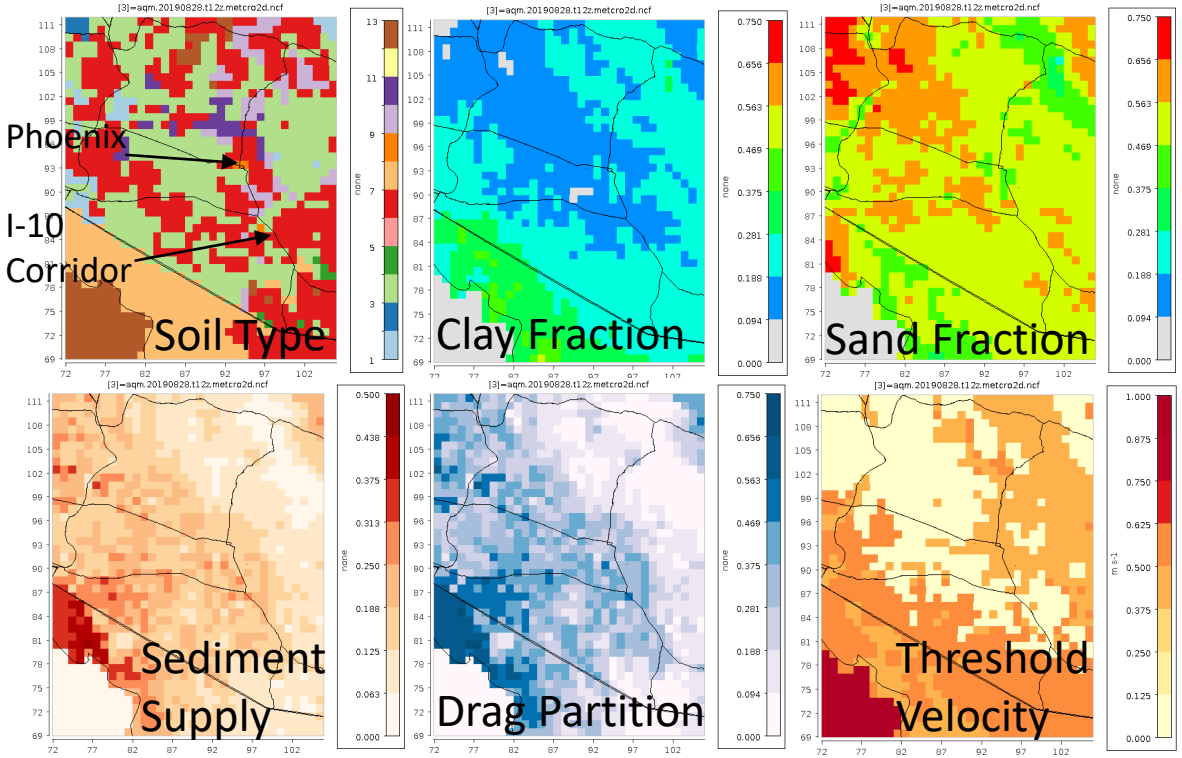
Dynamic land cover to improve air-surface exchange and deposition in NACC-CMAQ.
Currently undergoing testing in real-time simulations.

Fengsha Inline Windblown Dust Emissions

$$F = \sum_{i=1}^{M}\sum_{j=1}^{N} K \times A \times \frac{\rho}{g} \times S_i \times SEP \times u_* \times \left(u_*^2 - u_{*ti,j}^2\right)$$

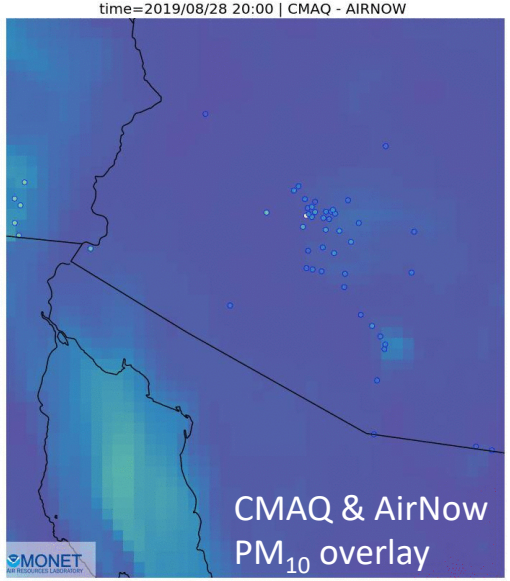
NACC Processed Soil Properties: Based on SoilGRIDS 250 m Data

https://soilgrids.org/

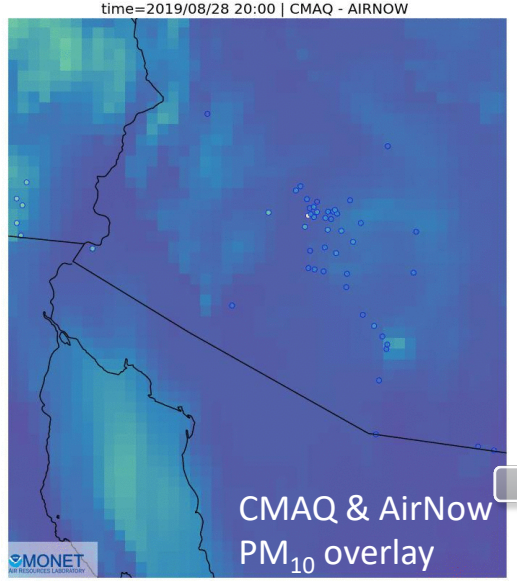


Phoenix AZ Dust Event, August 28-29, 2019

NACC-CMAQ No Dust

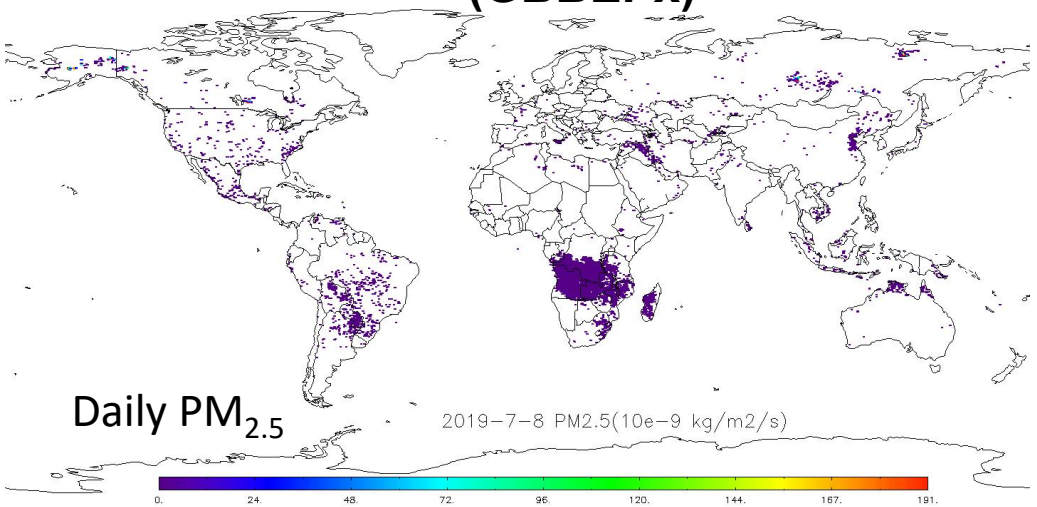


NACC-CMAQ Fengsha Inline Dust

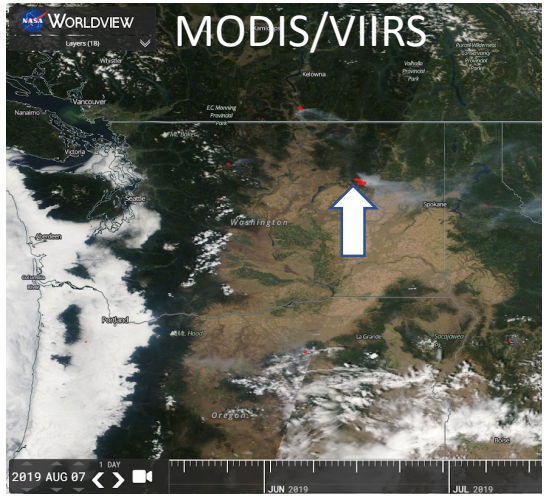


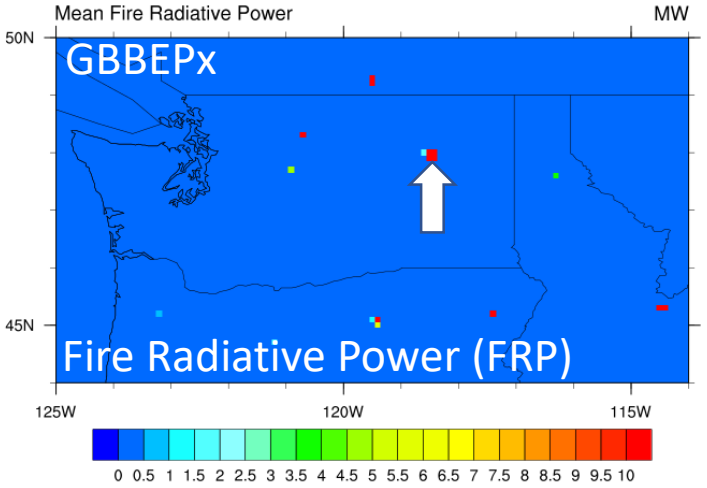
GBBEPx Wildfire Smoke Emissions

The Global Biomass Burning Emissions Product (GBBEPx)

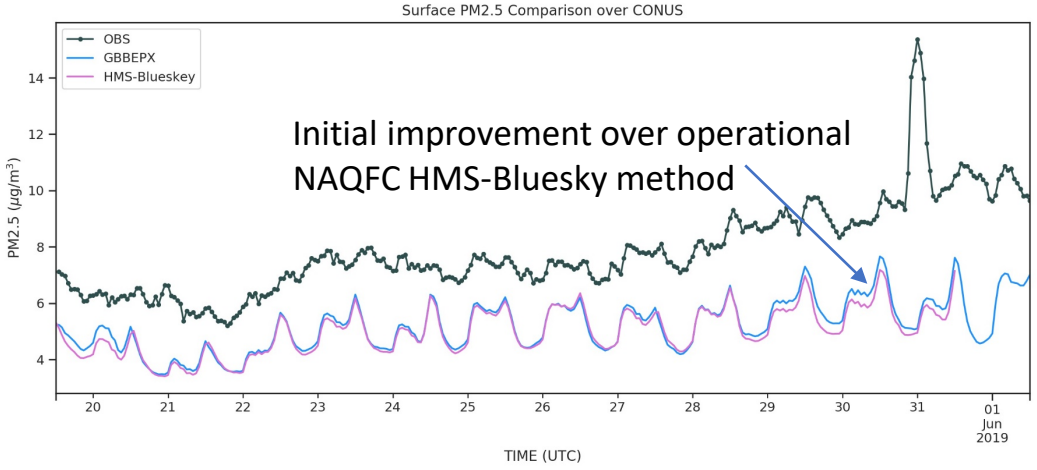


Williams Flats Fires, August 07, 2019





GBBEPX 0.1°x0.1° Emission testing in a real-time $PM_{2.5}$ forecast



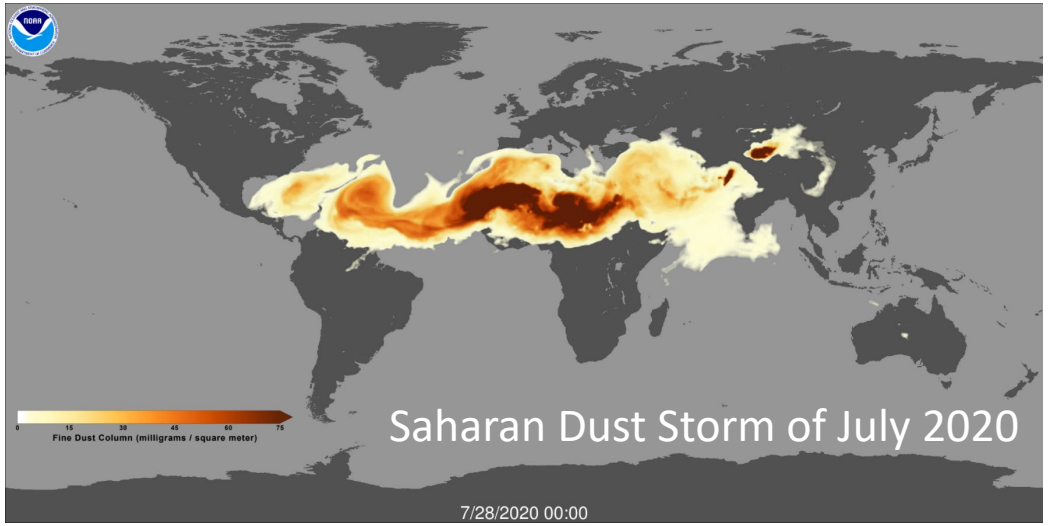
- Speciated wildfire emissions
- Diurnal variation/daily ratio
- Duration when forest fraction > 0.4
- Inline plume rise using Briggs or Sofiev
- Heat flux derived from FRP
- Burn area is 10% of gridded area

FIREX-AQ NOAA NASA

See Dr. Pius Lee's talk (Wildfire Emissions and Air Quality) for more details on NOAA's GBBEPx wildfire emissions.

Dynamic Aerosol Boundary Conditions

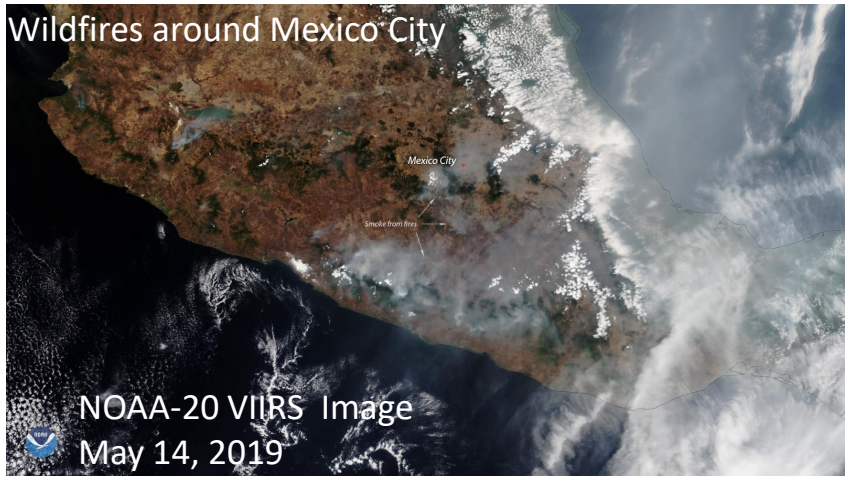
NOAA GEFS-Aerosol (GOCART)

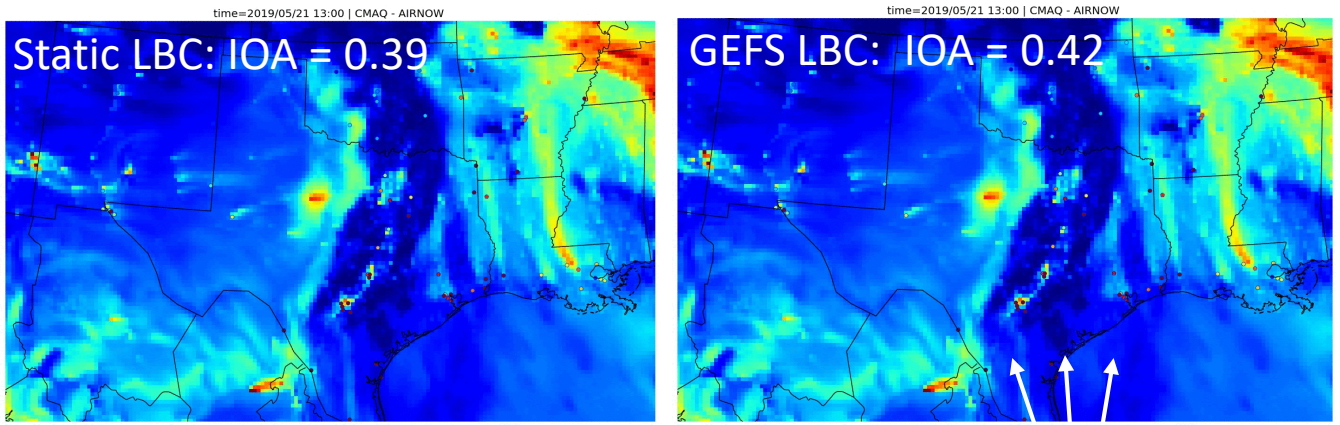


NOAA's operational (on September 23, 2020) GEFS-Aerosol member provides dynamic lateral boundary conditions (LBCs) 4x daily for smoke and dust aerosol sizes to regional NACC-CMAQ domain.

https://research.noaa.gov/article/ArtMID/587/ArticleID/2651/New-NOAA-research-model-improves-dust-air-quality-forecasts

Example Impact on CMAQ $PM_{2.5}$





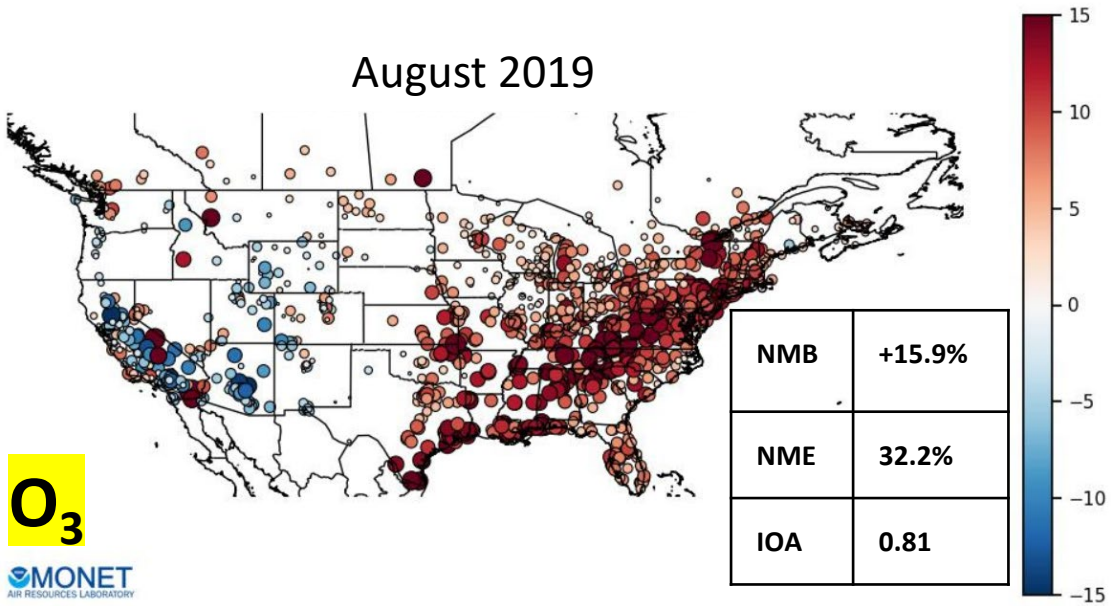
Wildfire smoke intrusion across southern boundary improves CMAQ $PM_{2.5}$ predictions in EPA Region 6 (South U.S.).

Community Applications and Research

Community Applications and Research

- Typically, the downscaled Weather Research and Forecasting (WRF) model is coupled to CMAQ (WRF-CMAQ).
- NACC-CMAQ is a new research option for direct coupling of NOAA's GFSv16 to CMAQ (i.e., avoid downscaling).

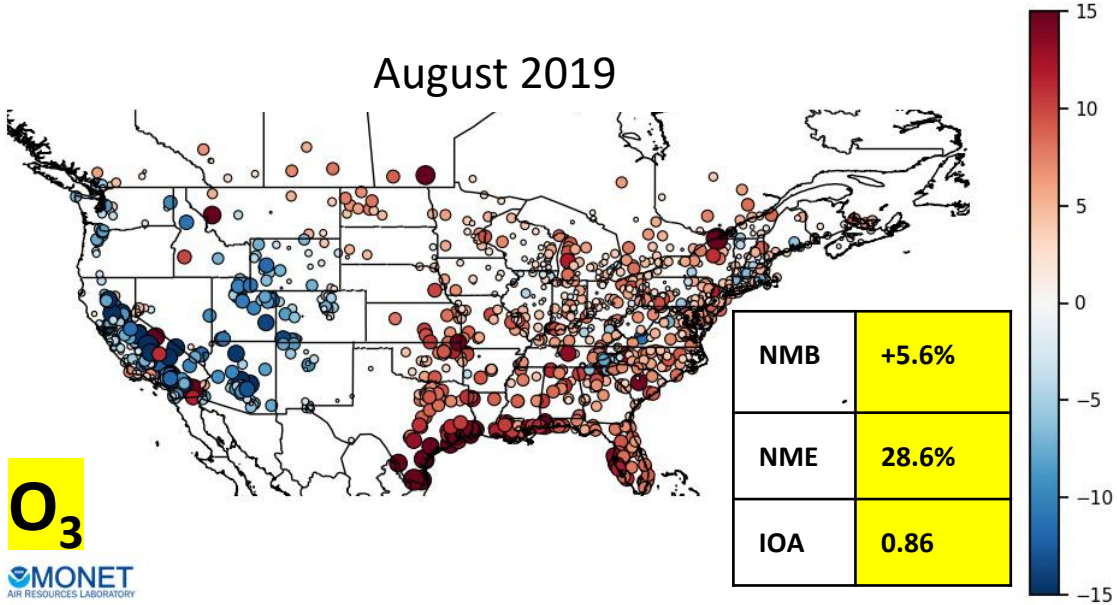
GFSv16/WRFv4.0.1-CMAQv5.3.1



NMB	+15.9%
NME	32.2%
IOA	0.81

WRF downscaling with different GFS vs. WRF physics to CMAQ

GFSv16→NACCv1-CMAQv5.3.1



NMB	+5.6%
NME	28.6%
IOA	0.86

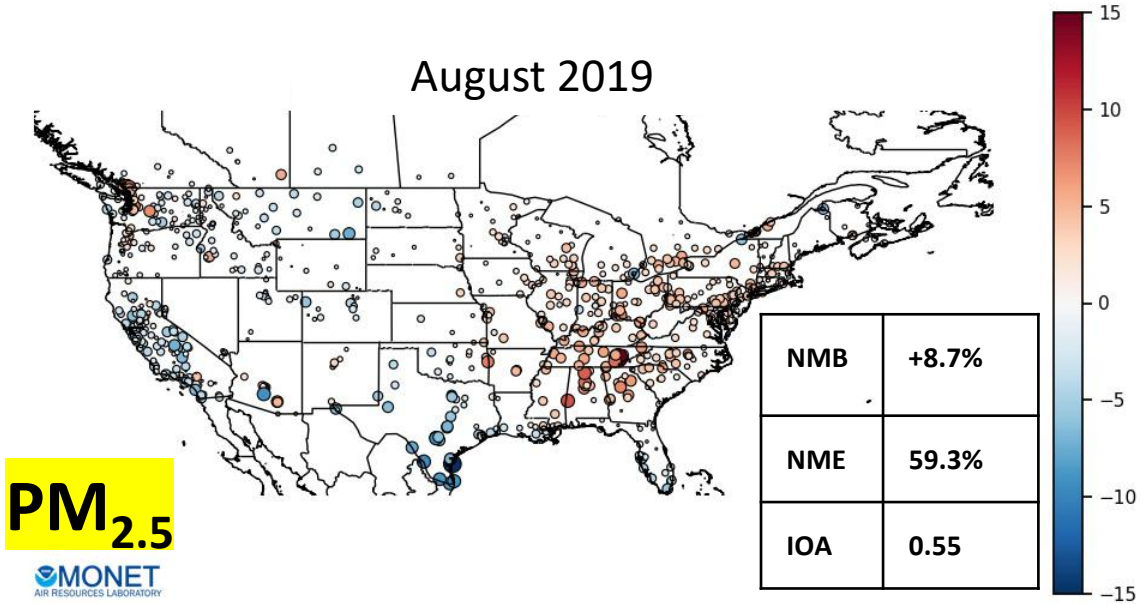
No downscaling, direct GFSv16 physics interpolation to CMAQ

Demonstrates generally improved model performance of NACC-CMAQ compared to WRF-CMAQ.

Community Applications and Research

- Typically, the downscaled Weather Research and Forecasting (WRF) model is coupled to CMAQ (WRF-CMAQ).
- NACC-CMAQ is a new research option for direct coupling of NOAA's GFSv16 to CMAQ (i.e., avoid downscaling).

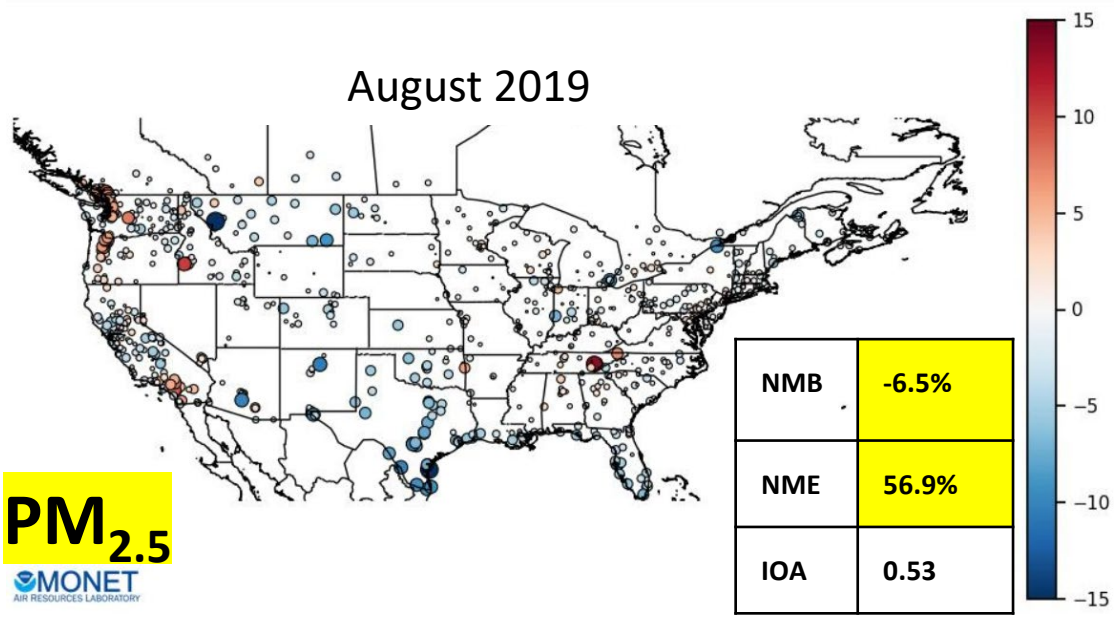
GFSv16/WRFv4.0.1-CMAQv5.3.1



NMB	+8.7%
NME	59.3%
IOA	0.55

WRF downscaling with different GFS vs. WRF physics to CMAQ

GFSv16→NACCv1-CMAQv5.3.1



NMB	-6.5%
NME	56.9%
IOA	0.53

No downscaling, direct GFSv16 physics interpolation to CMAQ

Demonstrates generally improved model performance of NACC-CMAQ compared to WRF-CMAQ.
Actively working to improve NACC-CMAQ PM2.5 predictions with CB6-Aero7.

See Part II of this talk (Dr. Youhua Tang; Science Advancements and Evaluations) for more details.

Community Applications and Research

- Developing a prototype for NACC I/O data to be available “In the Cloud”.

- Facilitates GFS-driven CMAQ applications for the greater research community:

1. Access CMAQ-ready NACC outputs for NAQFC domains (e.g. 12km CONUS).
2. Access GFS inputs to run “NACC-in-the-cloud” for any user-defined domain globally.

- Potential Benefits:

✓ Interface directly with a NOAA operational GFSv16 global dataset (no data download required).

✓ New research tool for any regional domain globally and avoid downscaling/running WRF.

✓ Rapid applications of CMAQ-ready meteorology for recent air quality events/applications.

- NACC is available at https://github.com/noaa-oar-arl/NACC

Summary and Ongoing Work

- The next-generation FV3-GFSv16/NACCv1-CMAQv5.3.1 is developed.
- The NACC-CMAQ system has numerous advantages over current NAQFC.
- NACC-CMAQ is currently being run experimentally in real-time at NOAA.
- Continued advancements and refinement tests are being done:
  - Updated satellite land cover/use, windblown dust emissions, and wildfire emissions.
- NACC-CMAQ is scheduled for implementation at NOAA in January 2022.
- Early NACC-CMAQ performance is consistent or better than WRFv4-CMAQ.
- NACC-CMAQ may be a new research option to avoid WRF downscaling.
- Potential for “NACC-in-the-cloud” and user-defined GFS-driven CMAQ.

Acknowledgments

We would like to acknowledge Tanya Spero and the U.S. EPA for their many years of development and collaboration on the PREMAQ and MCIP systems, which were pivotal to the development of NACC in this work.

Thank you all!!