An Improved National Air Quality Forecasting Capability Using the NOAA Global Forecast System. Part II: Science Advancements and Evaluations

Youhua Tang[1,2], Patrick C. Campbell[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.

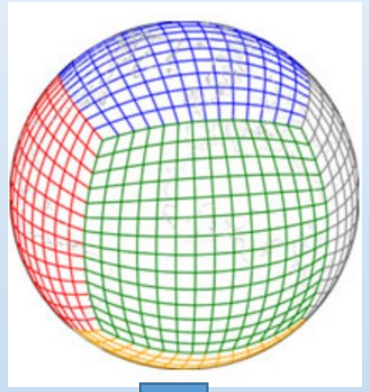
3. NOAA National Centers for Environmental Prediction (NCEP), College Park, MD 4. I.M. Systems Group Inc., Rockville, MD

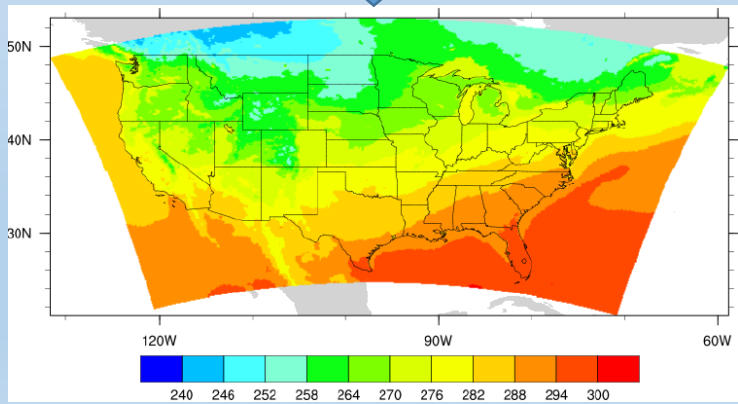
5. NOAA NWS/STI 6. Eastern Research Group, Inc (ERG)

Upgrading the National Air Quality Forecasting Capability (NAQFC) with the newer air quality model, emission and meteorology.

See Part I of this talk (Dr. Patrick Campbell; Model Development and Community Application) for more details

Some key changes about the meteorological preprocessor, NOAA-EPA Atmosphere-Chemistry Coupler (NACC), developed from MCIP.





- Allow flexible meteorological inputs other than WRF through the interpolation from non-native grids, such as the NOAA Global Forecast System (GFS) with the Finite Volume 3 (FV3) dynamic core in the global cubed sphere.
- Accommodates the user-defined vertical layers, native GFS or collapsed layers.

NACC Parallelization

This preprocessor is I/O intensified, and has its speed bottleneck in reading.

Methods Tested

- **Domain Splitting via MPI + NetCDF Parallel I/O and Parallel NetCDF**

Pros: Minimum change

Cons: PNetCDF library does not support NetCDF4-HDF5 on NOAA Cray machine. Limited timing improvement that also depends on machines and array sizes.

- **Time Step Splitting via MPI + NetCDF**

Pros: Drastically faster: about 4-5 minutes for 73 time steps.
Stable parallelization scaling.
Use standard MPICH and NetCDF libraries.

Cons: Need structure change. Need more memory per PE (increase nodes).

FV3 Interpolation versus WRF Downscaling

FV3-GFS v16 Configuration

C768L127 (~ 13 km dx, 127 vertical layers up to 80km)

PBL scheme:
Scale-aware (sa) turbulent kinetic energy (TKE) -based moist eddy-diffusivity mass-flux (EDMF) or Sa-TKE- EDMF

Land surface: Noah

Microphysics: updated GFDL MP

Radiation: updated RRTMG

WRF V4.0.1 Configuration

12km CONUS 35 vertical layers up to 100hPa

bl_pbl_physics: YSU

sf_surface_physics: Noah

mp_physics: Morrison 2-moment scheme

ra_lw_physics/ra_sw_physics: RRTMG

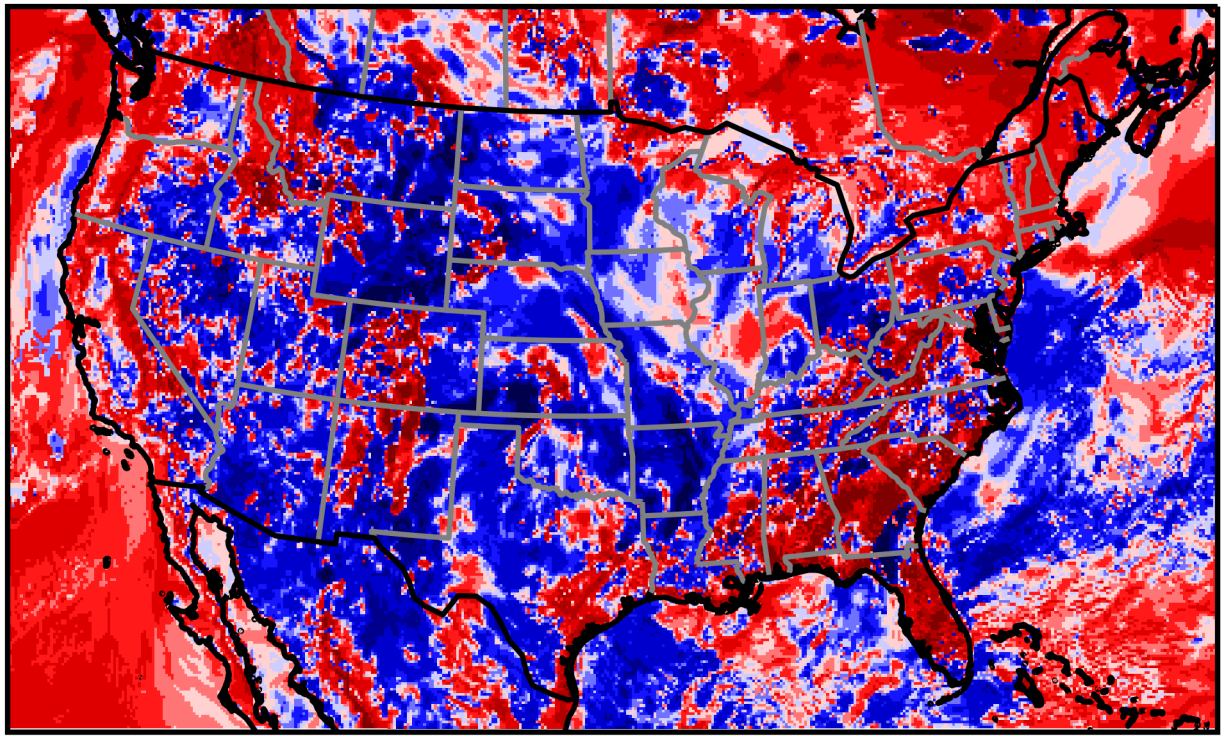
Cu_physics: Kain Fritsch multiscale

FDDA nudging: Enabled for T and Q for the whole domain, but only outside the PBL for U, V.

PBL Height Difference Between Interpolated FV3GFS and WRF-downscaling

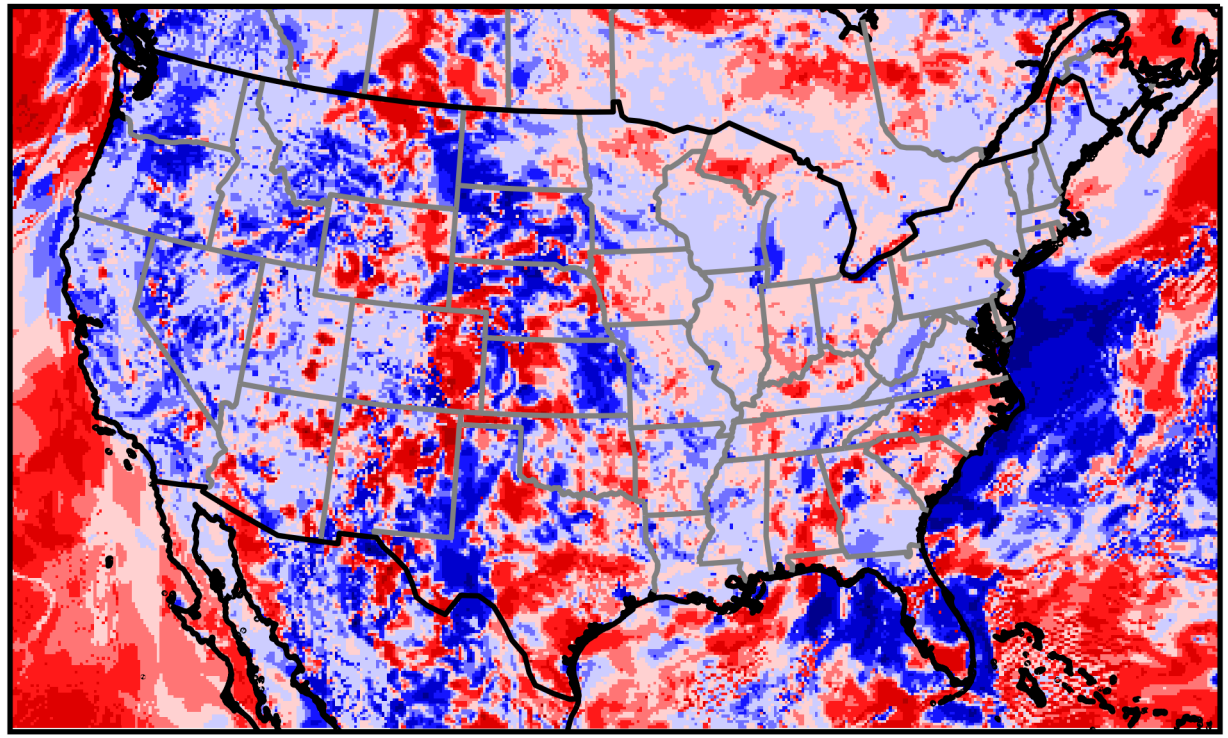
Daytime

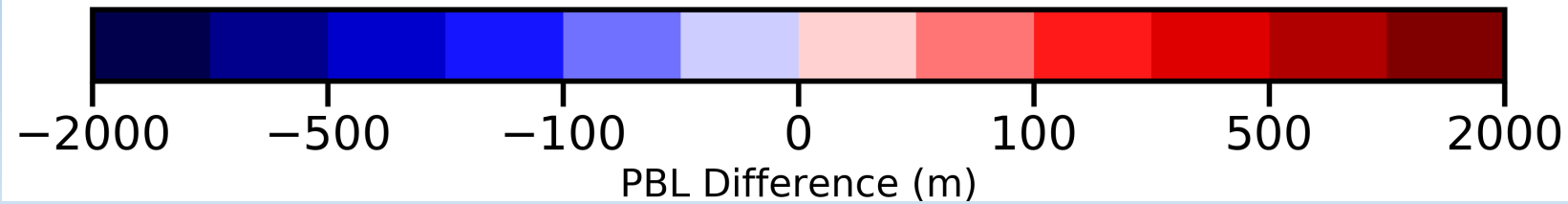
PBL Difference (FV3-WRF) at 18Z, 08/01/2019

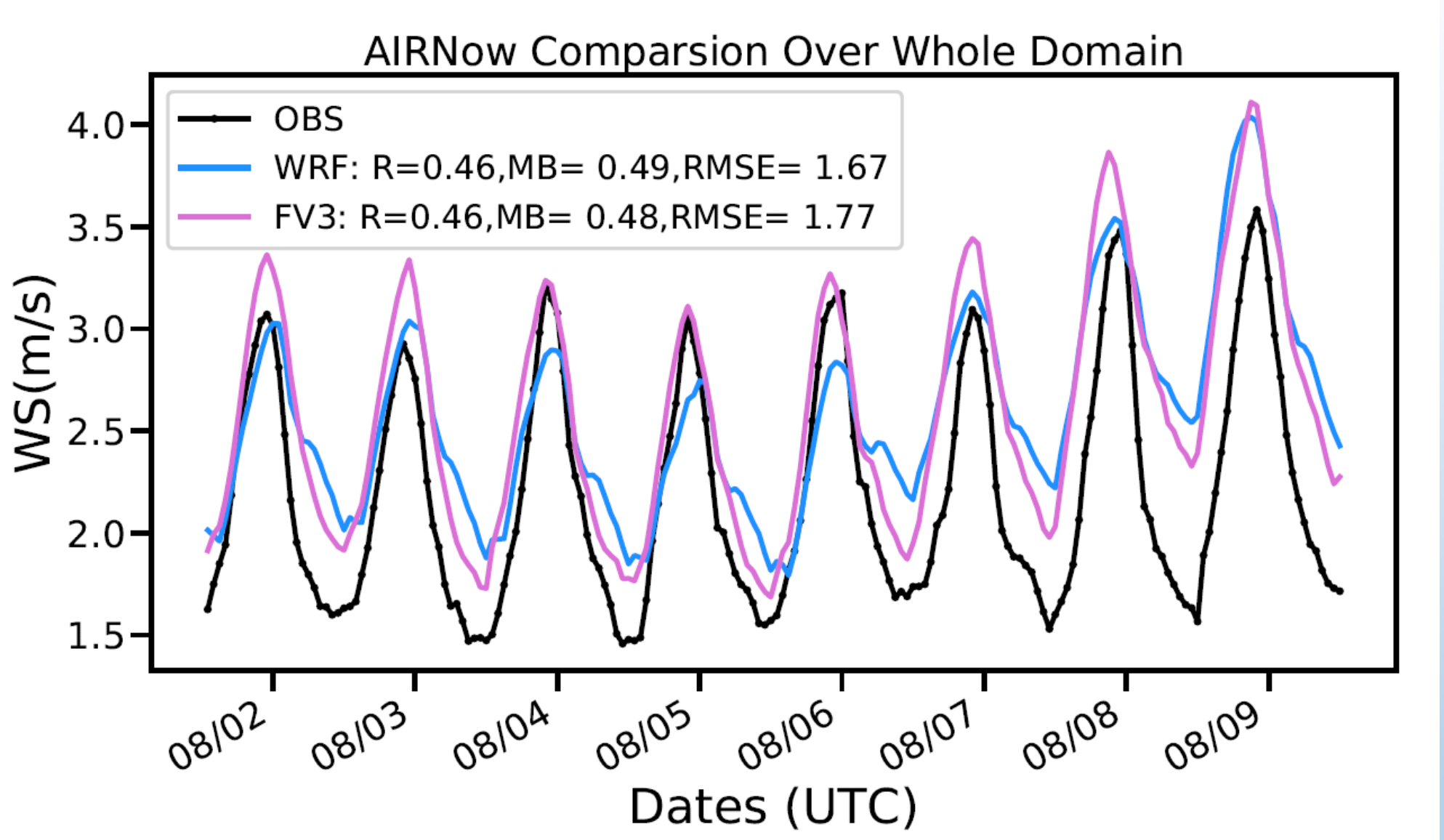


Nighttime

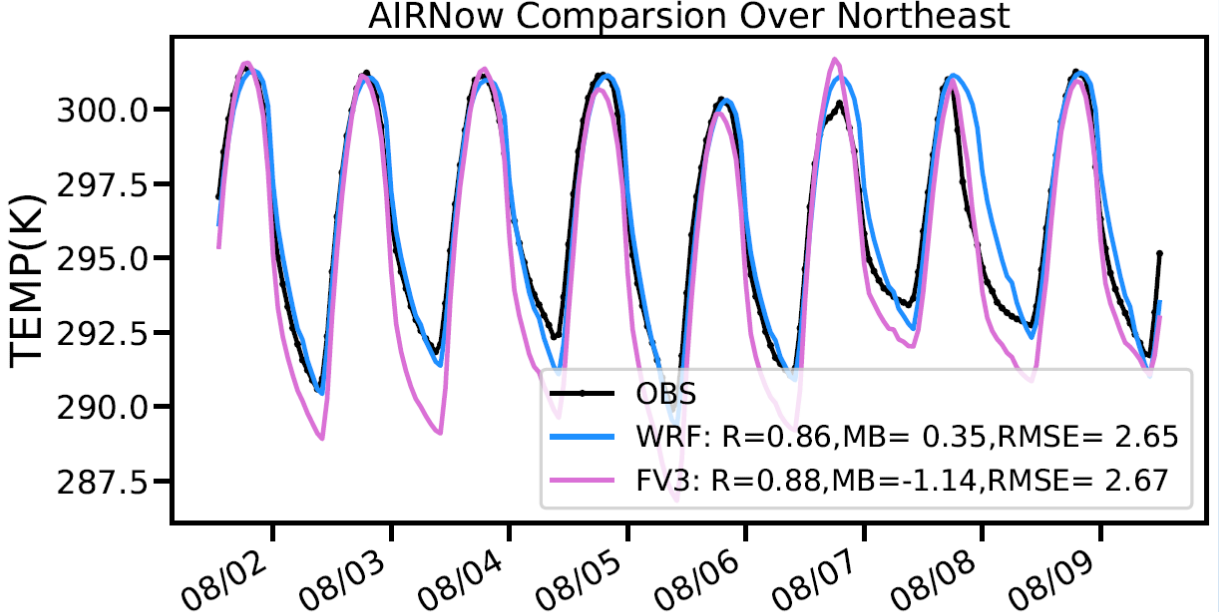
PBL Difference (FV3-WRF) at 06Z, 08/02/2019

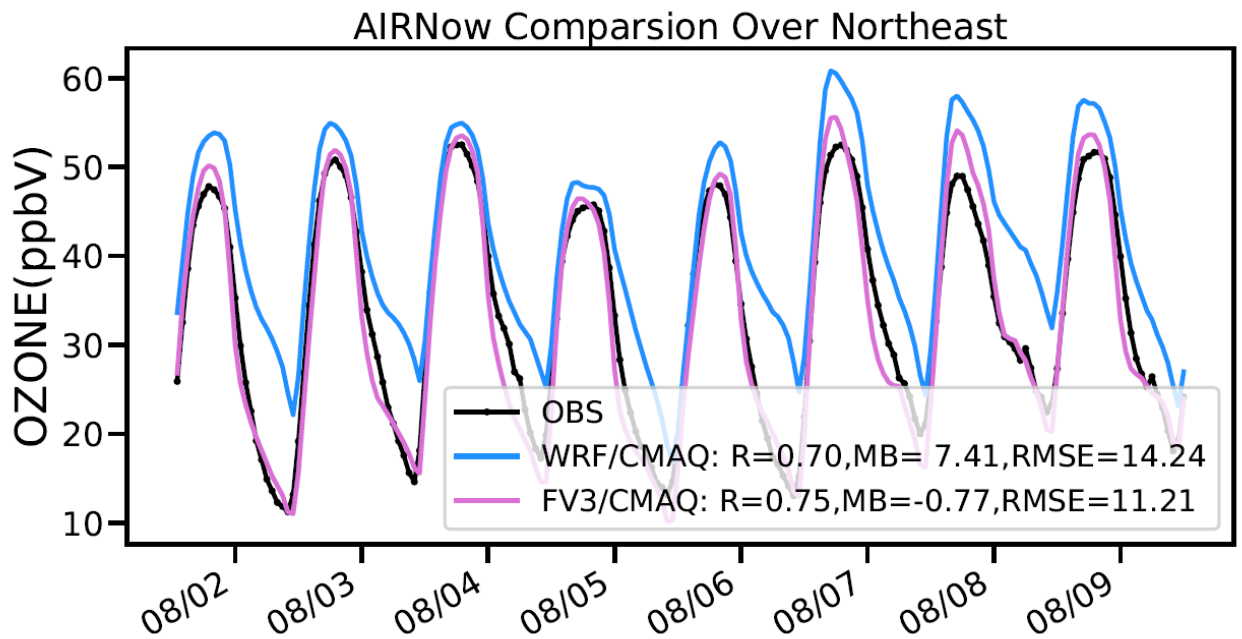


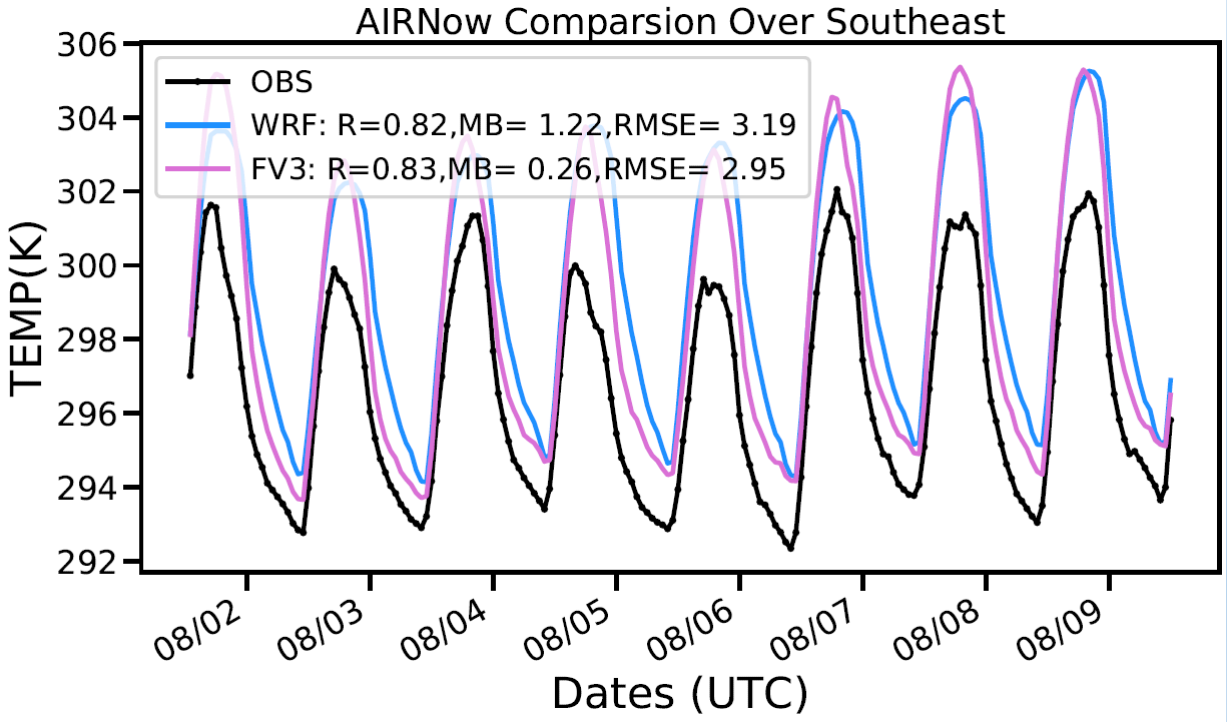


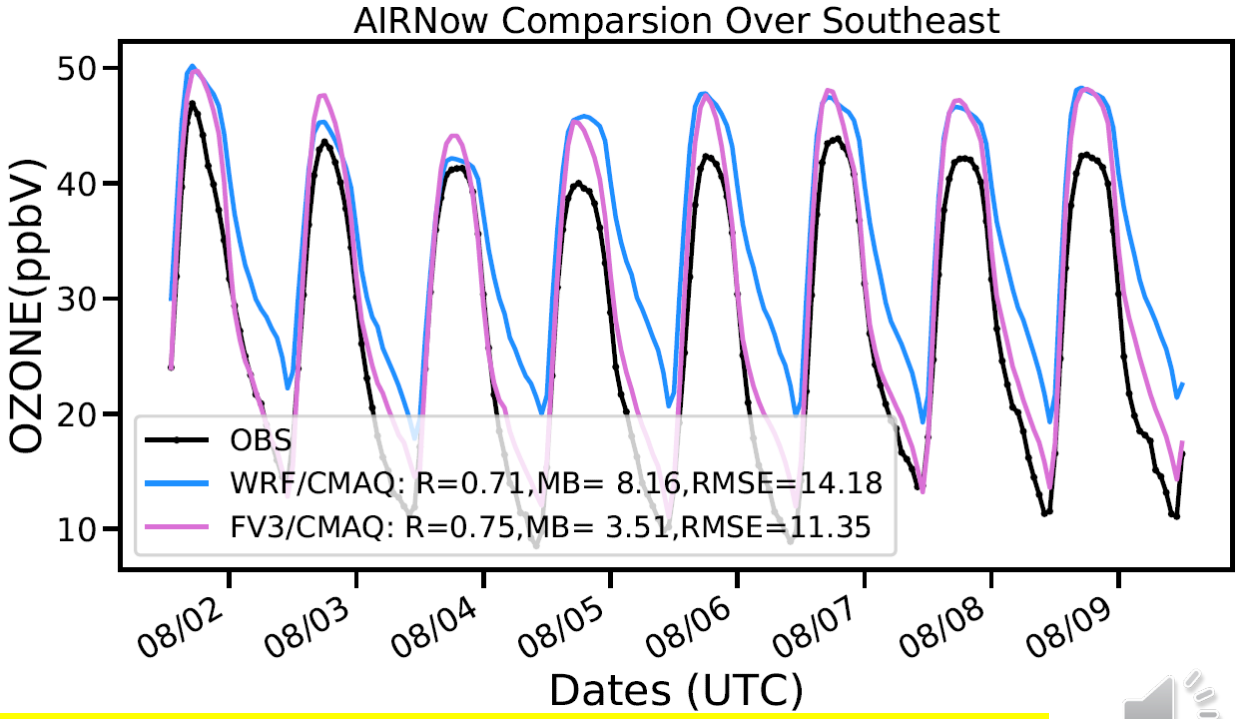


The FV3 tends to have stronger diurnal variation for the surface 10-m wind speed



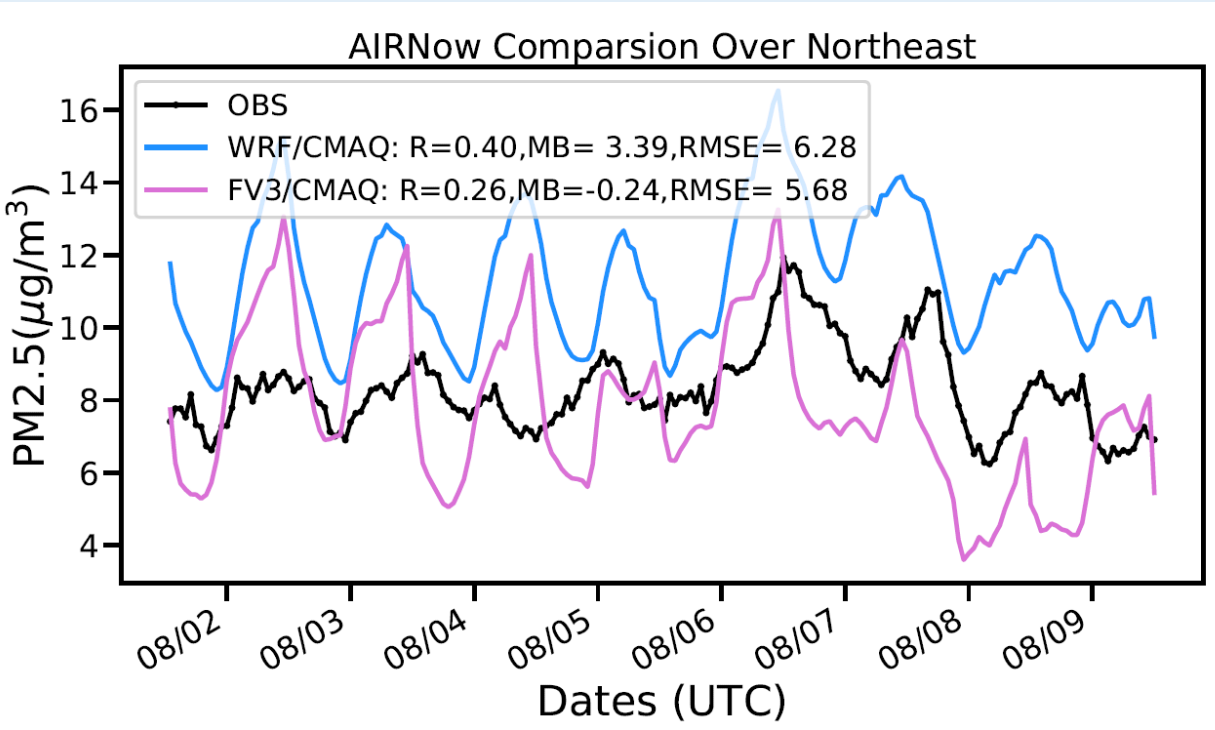


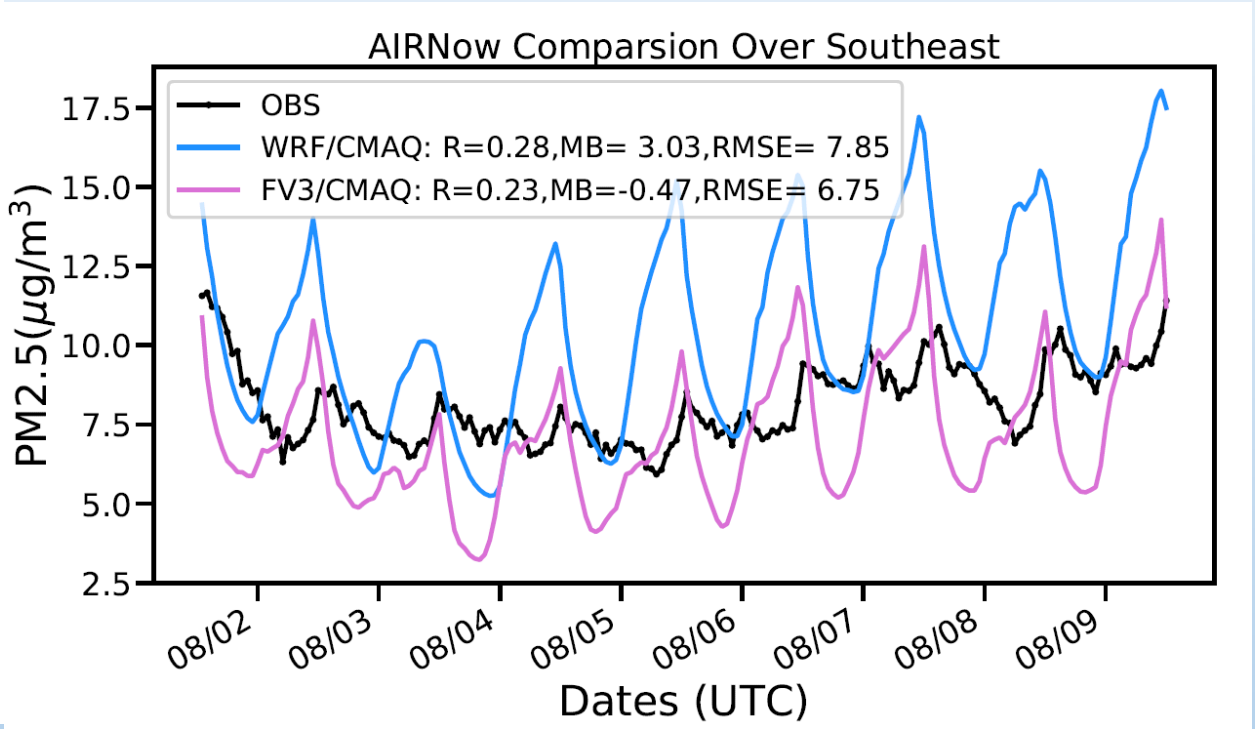




Their surface ozone predictions show correlation to the their 2-meter temperature performance

Comparison of PM2.5 prediction between GFS/NACC-CMAQ and WRF-CMAQ



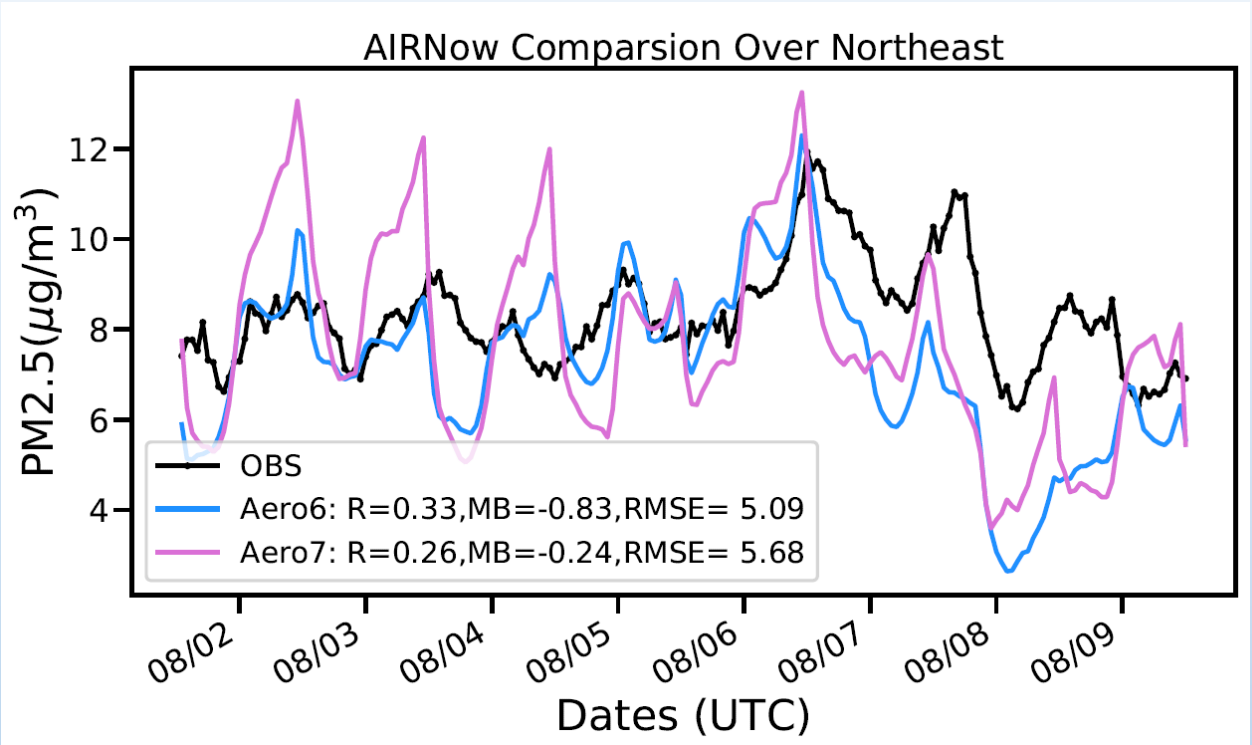


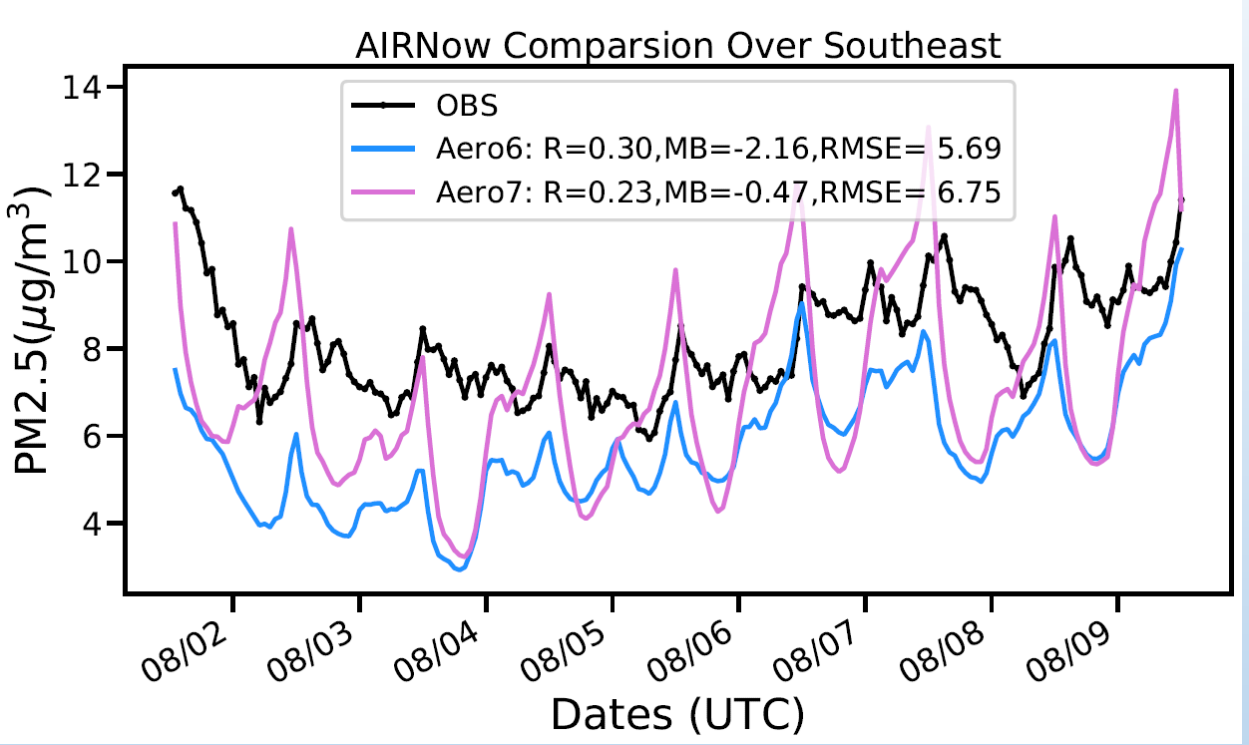
Surface PM2.5 predictions have similar trends, and both GFS/NACC-CMAQ and WRF-CMAQ have more variability compared to observations. WRF-CMAQ yields better correlations.

The NACC interpolation based meteorology can yield comparable results with WRF-CMAQ. Based on this framework, some CMAQ tunable options are tested.

1. Aero6 versus Aero7
2. BI-DI NH_3 : very little impact on PM2.5 and ozone (skip).
3. Fire emissions

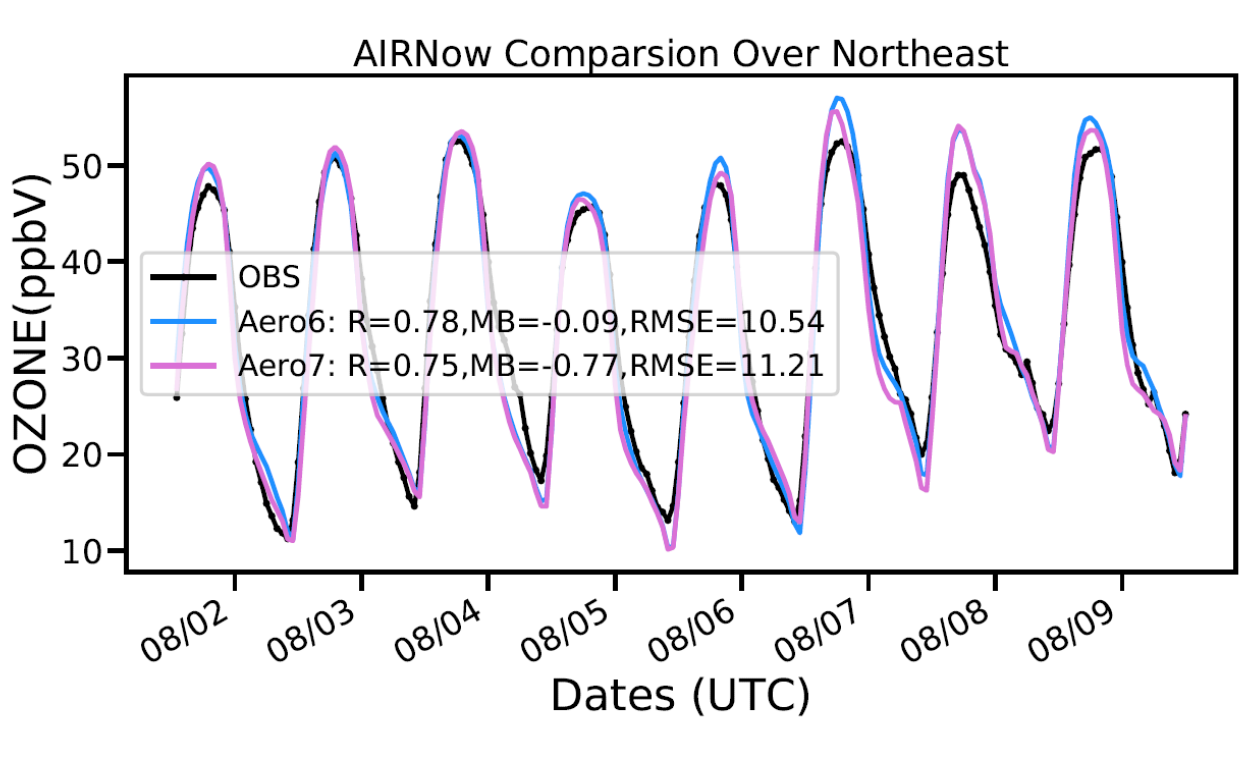
Aero6 vs Aero7

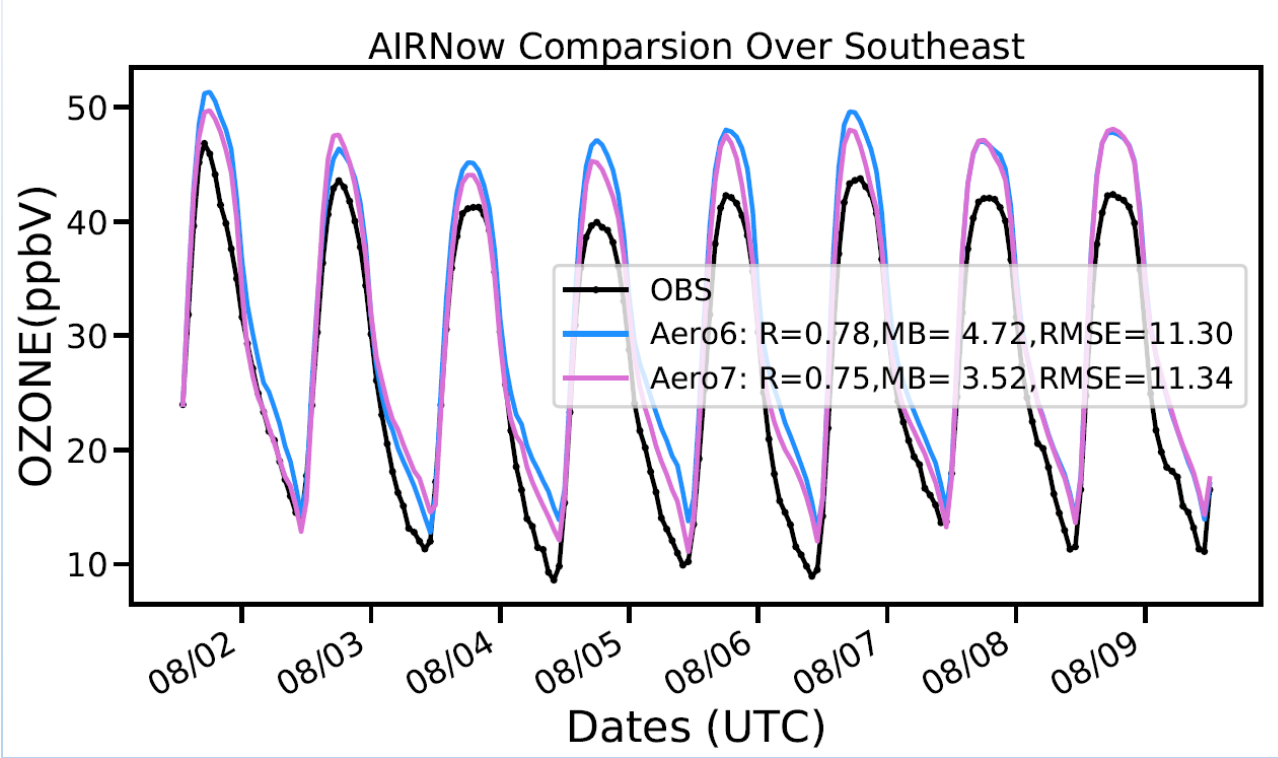




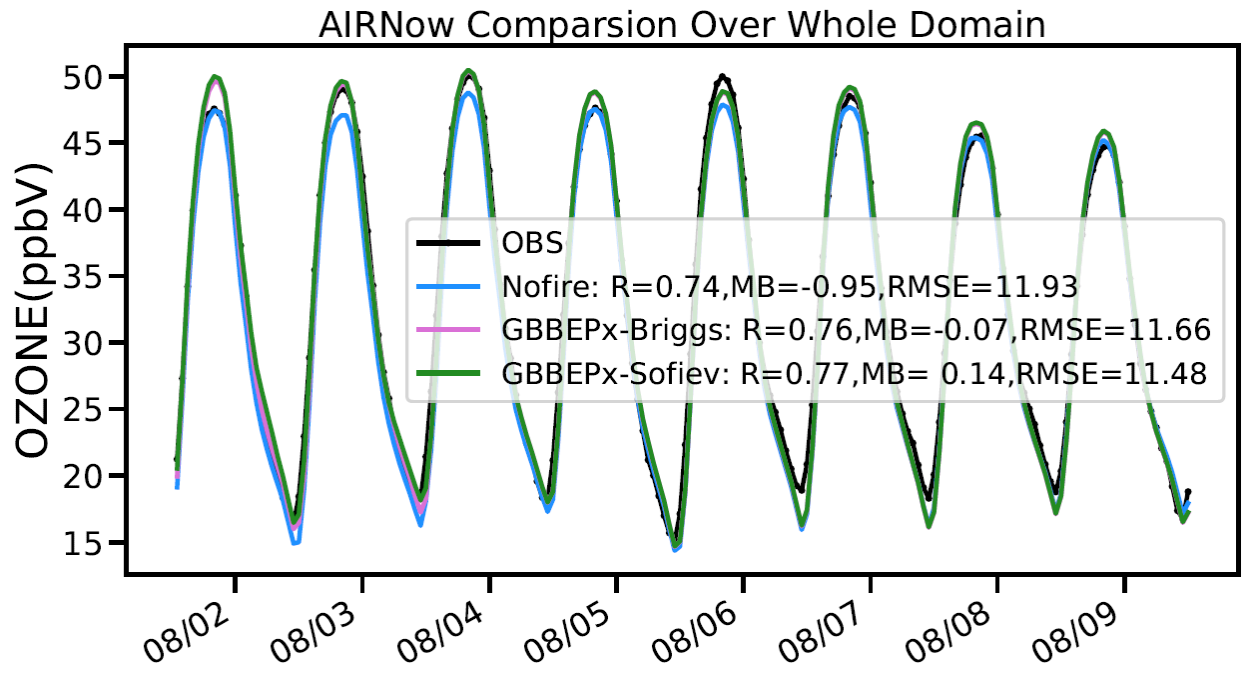
Aero7 yields higher PM2.5 than Aero6, which help reduce the underprediction bias, but has lower correlation coefficient and worse RMSE. Aero7 has more aggressive nighttime SOA formation.

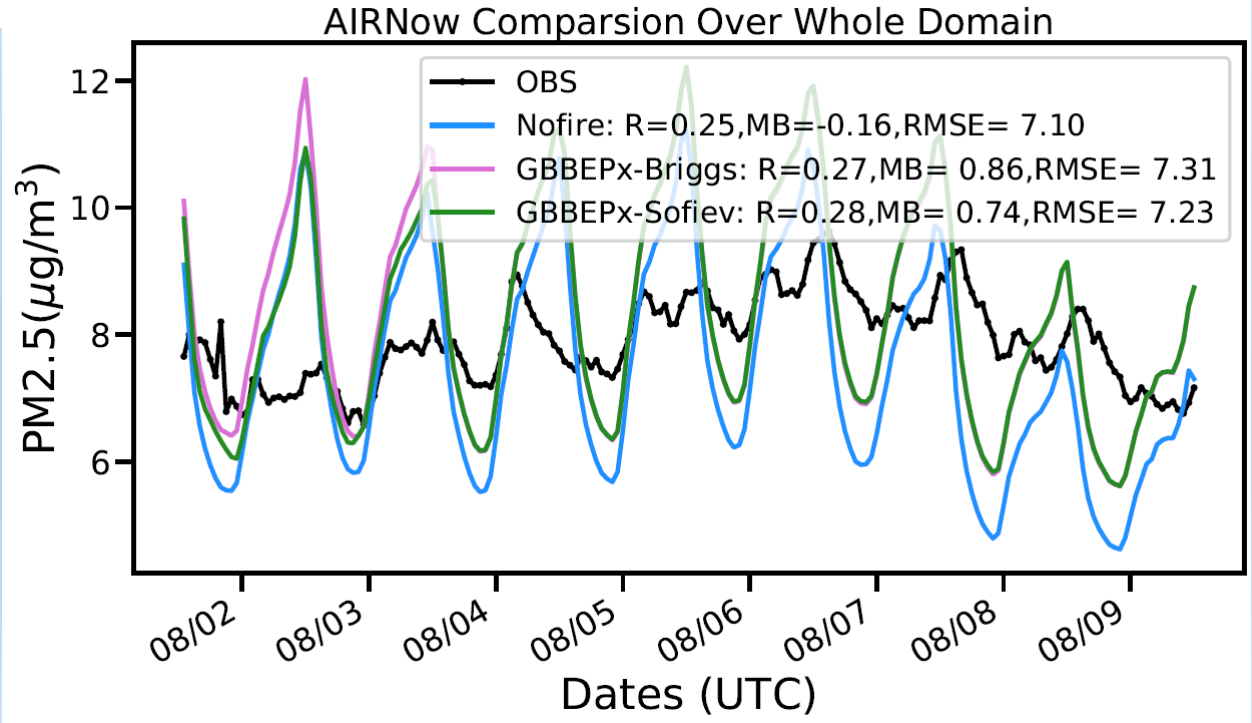
Aero6 vs Aero7 on Ozone





The small ozone difference between Aero6 and Aero7 is likely due to Aero7's higher aerosol loading and lower photolysis rates.





Wildfire emission and Its Plume rise

The Global Biomass Burning Emissions Product eXtended (GBBEPx) emission, estimated from fire radiative power (FRP).

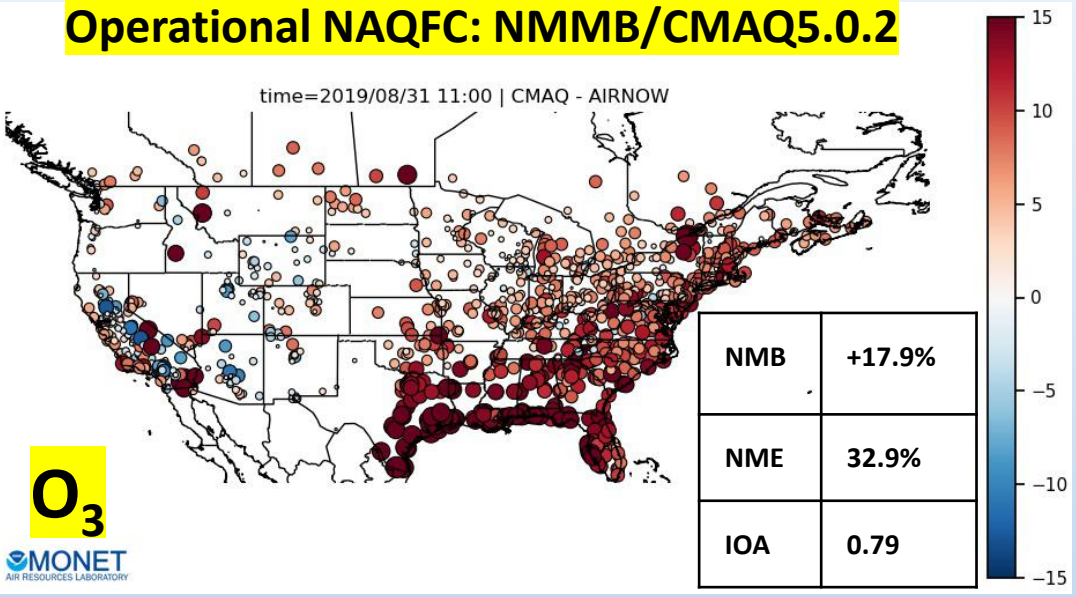
CMAQ's default plume rise is Briggs scheme(1969).

Sofiev (2012) developed a new smoke-injection height based on (FRP).

See presentations of Dr. Yunyao Li, and Dr. Pius Lee in Wildfire Emissions and Air Quality Session for more details

Preliminary Results of the GFS/NACC-CMAQ vs the operational NMMB/CMAQ5.0.2 for August 2019

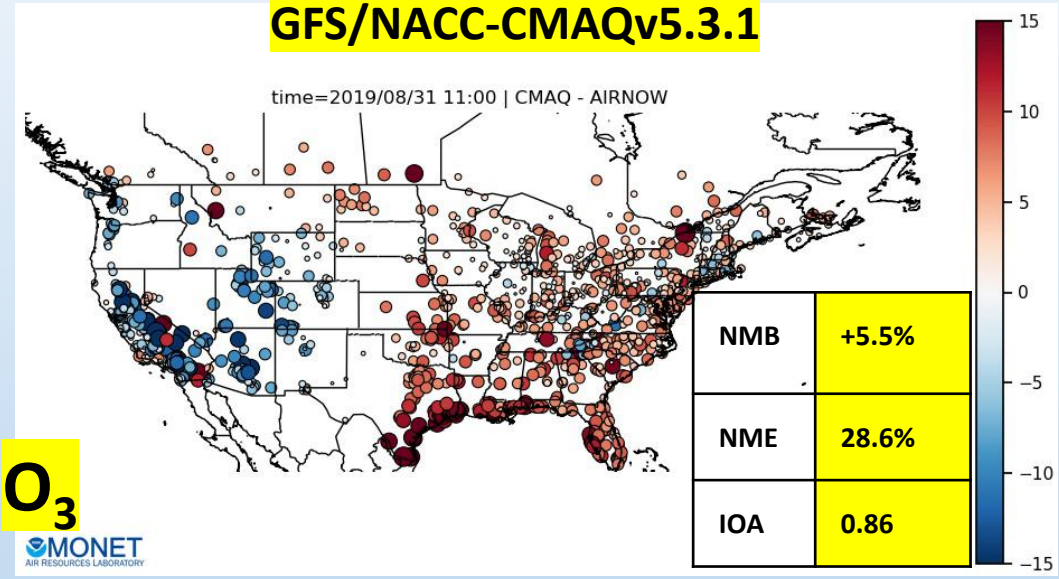
Operational NAQFC: NMMB/CMAQ5.0.2



O_3

NMB	+17.9%
NME	32.9%
IOA	0.79

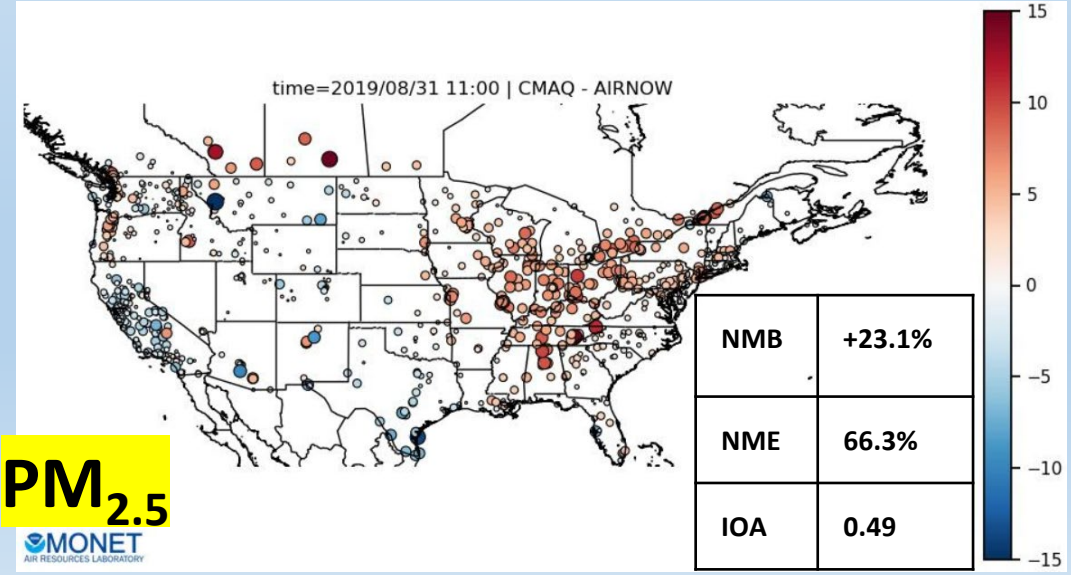
GFS/NACC-CMAQv5.3.1



O_3

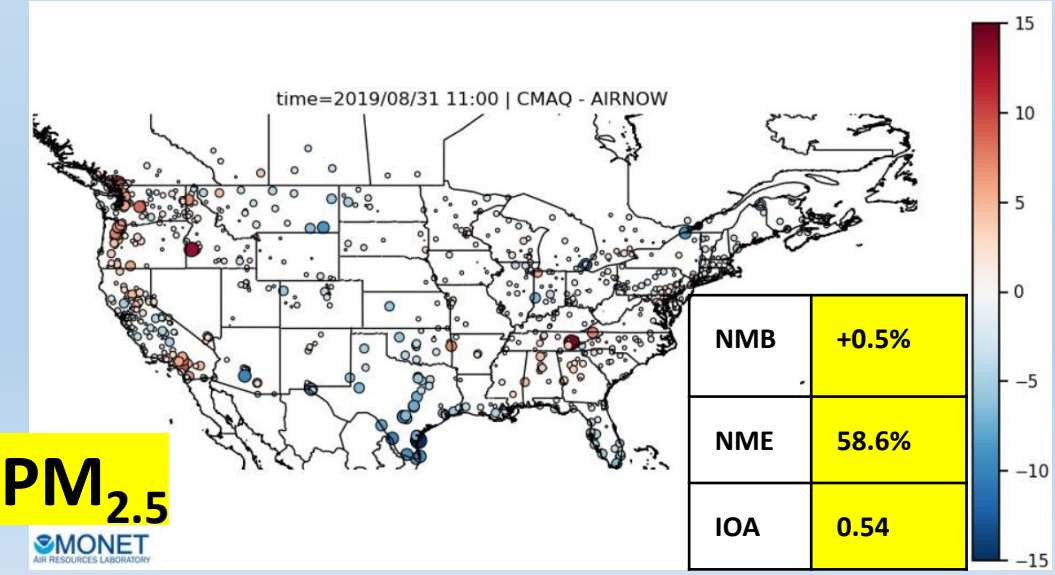
NMB	+5.5%
NME	28.6%
IOA	0.86

Overall lower bias and error and higher Index Of Agreement (IOA).



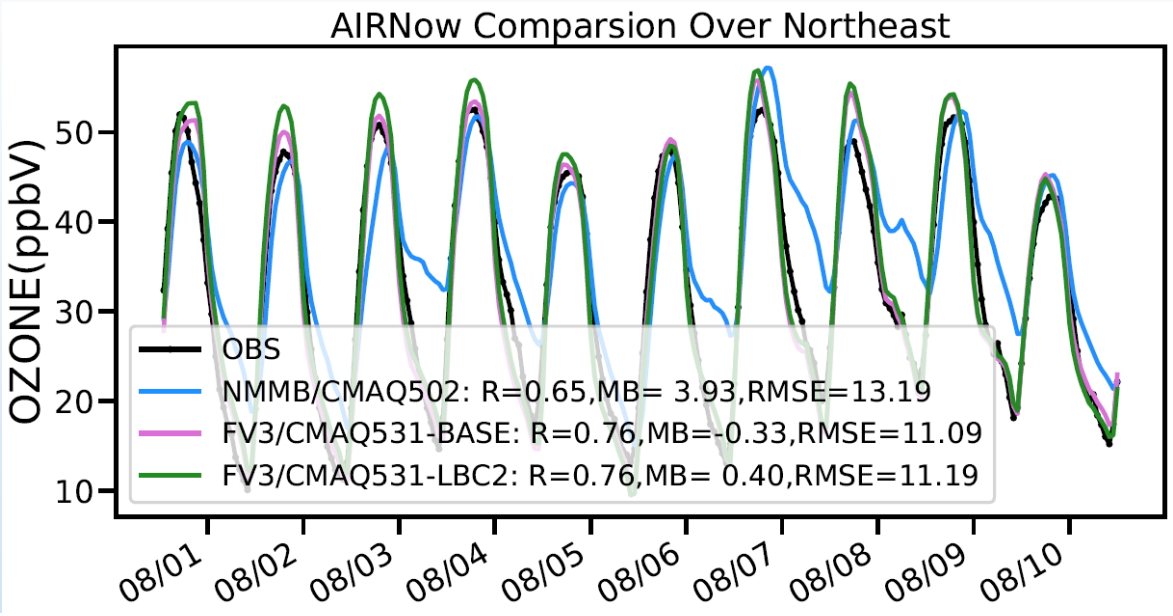
$PM_{2.5}$

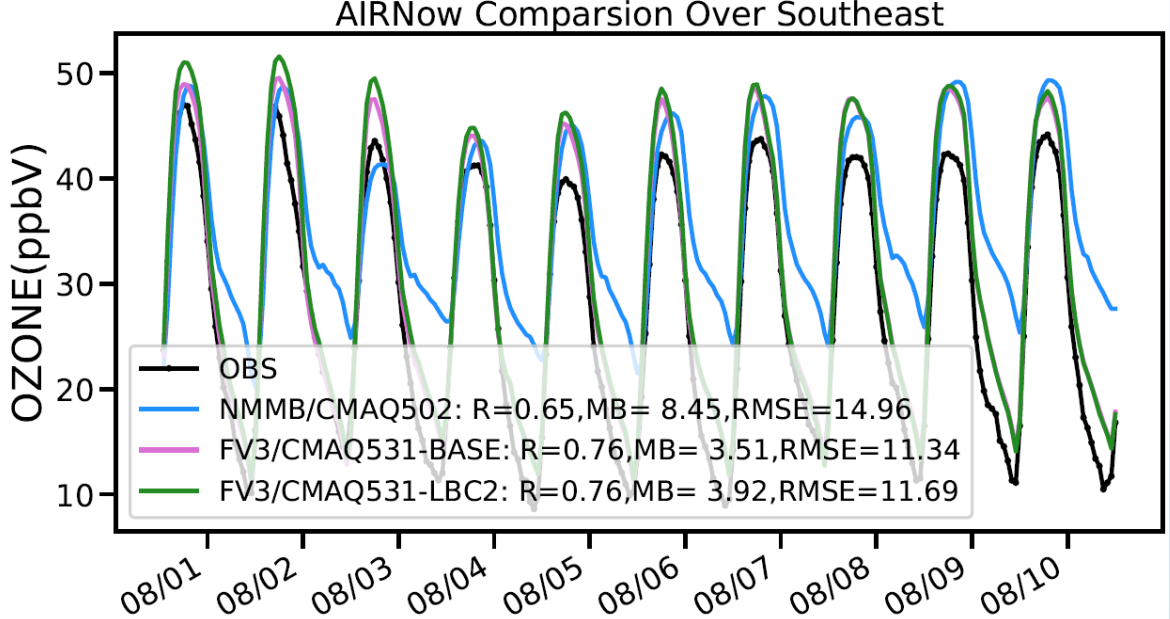
NMB	+23.1%
NME	66.3%
IOA	0.49

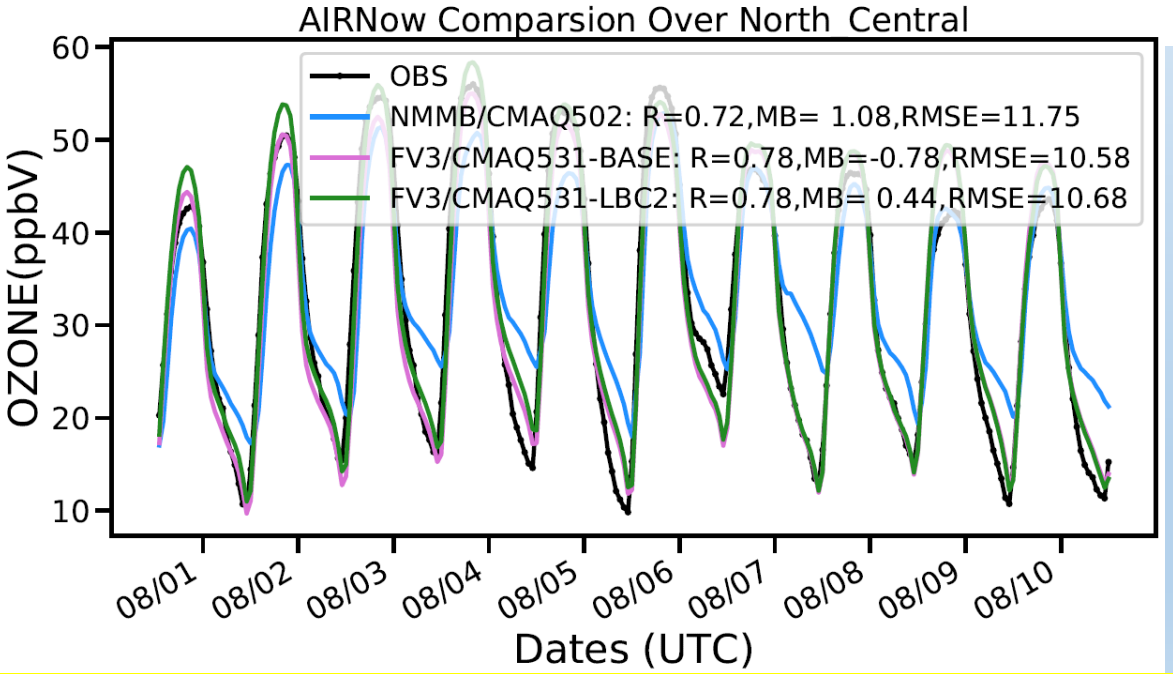


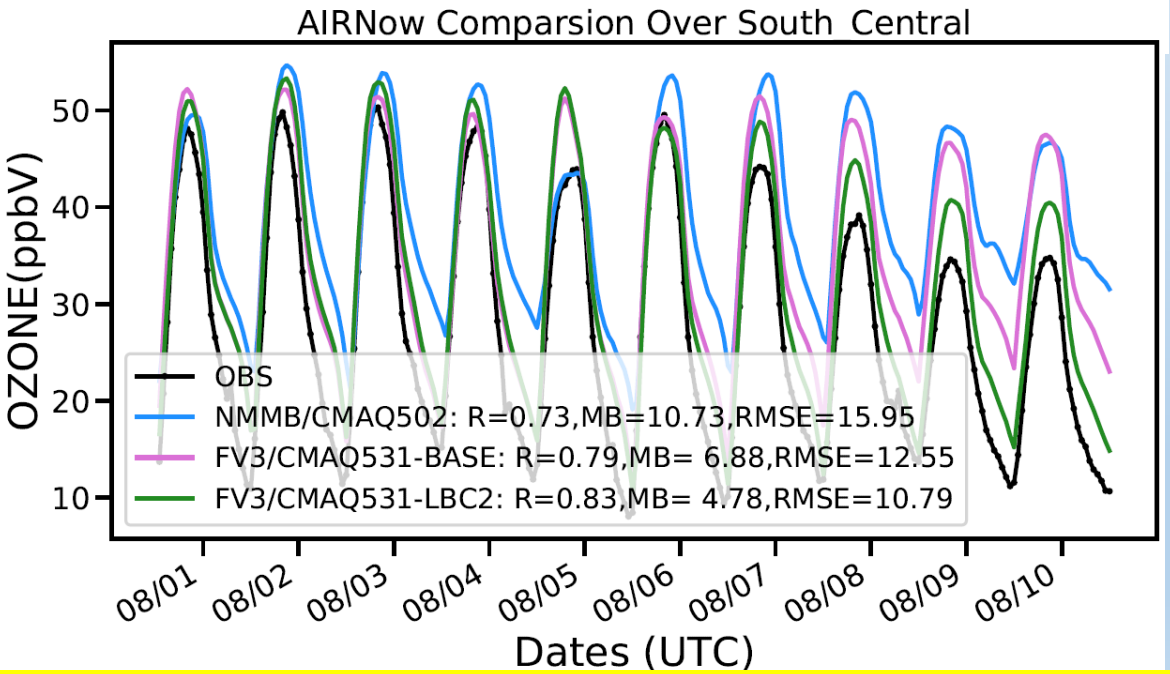
$PM_{2.5}$

NMB	+0.5%
NME	58.6%
IOA	0.54









- Nighttime ozone production is significantly improved in NACC-CMAQ (FV3/CMAQ531-BASE).

- Adjusting the lateral boundary conditions further improves NACC-CMAQ ozone predictions (FV3/CMAQ531-LBC2)

Summary

- An interpolation based meteorological preprocessor, NACC, is developed from the MCIPv5, and enable us to use global meteorological model to drive CMAQ5.3.1.
- The GFS/NACC-CMAQ shows very reasonable performance compared to the WRF-CMAQ downscaling method, and the NACC interpolated meteorology is more consistent with driving meteorological model.
- The new system significantly outperforms the current operational NMMB-CMAQv5.0.2, especially for predicting the surface nighttime ozone.
- Early science tests show that Aero6 performs better than Aero7 in NACC-CMAQ for PM2.5 during summer 2019, and more tests are necessary.

Ongoing Works

- Continue testing and evaluating NACC-CMAQ, including the inline Fengsha windblown dust emission, updated GBBEPx wildfire smoke emissions, lateral boundary conditions, and data assimilation etc.
- Test the impact of ongoing FV3-GFSv16 model changes on NACC-CMAQ framework.
- The new system will be implemented in earlier 2022.