Evaluation of National Air Quality Forecast Capability: a Case Study of Summer 2019 Comparing to WRF/CMAQ

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

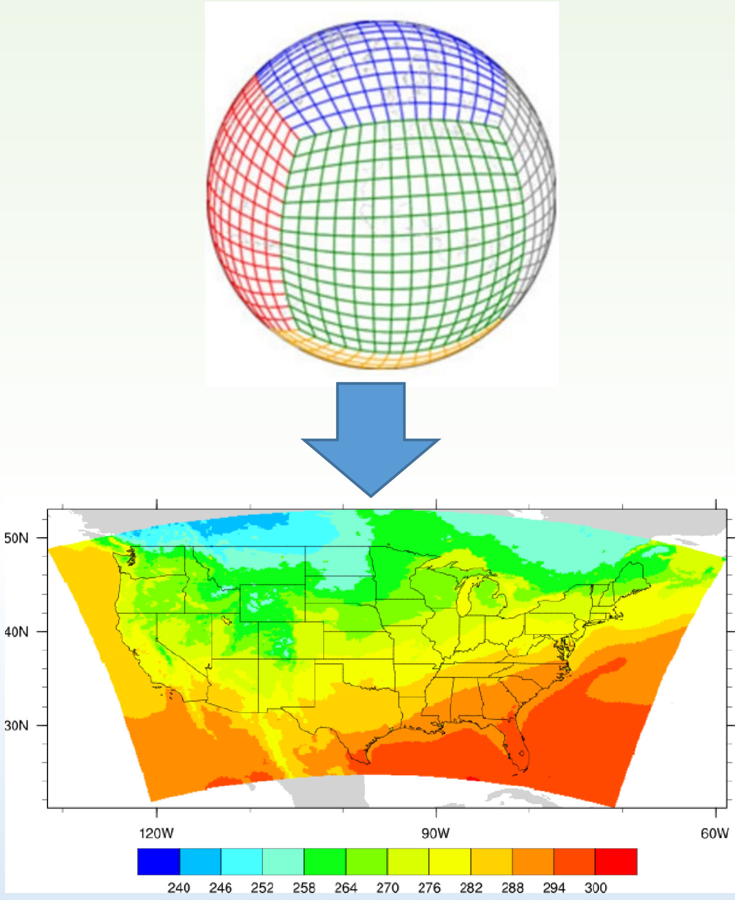
5. NOAA NWS/STI 6. Eastern Research Group, Inc (ERG)

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

See Dr. Campbell's presentation (#2610 of the model development session) for detail.

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.



To evaluate NAQFC vs traditional WRF-ARW/CMAQ, we conduct a case study comparison.

NAQFC Update and Configuration

Forecast Length: 48 → 72 hours

Meteorology: NMM-B → FV3GFS (latest operational *Version 16*)

Met coupler: PreMAQ → NACC (adapted from U.S. EPA's MCIP) with parellel capablity

CMAQ: 5.0.2 (cb5/Aero6) → 5.3.1 (cb6r3/Aero7)

Anthropogenic emission: NEI2014v2 → NEI2016v1

Wildfire emission: HMS/Bluesky → GBBEPx

Other Science Updates: Fengsha dust scheme, global aerosol LBCs, updated biogenics, BIDI-NH_3, LAI/GVF

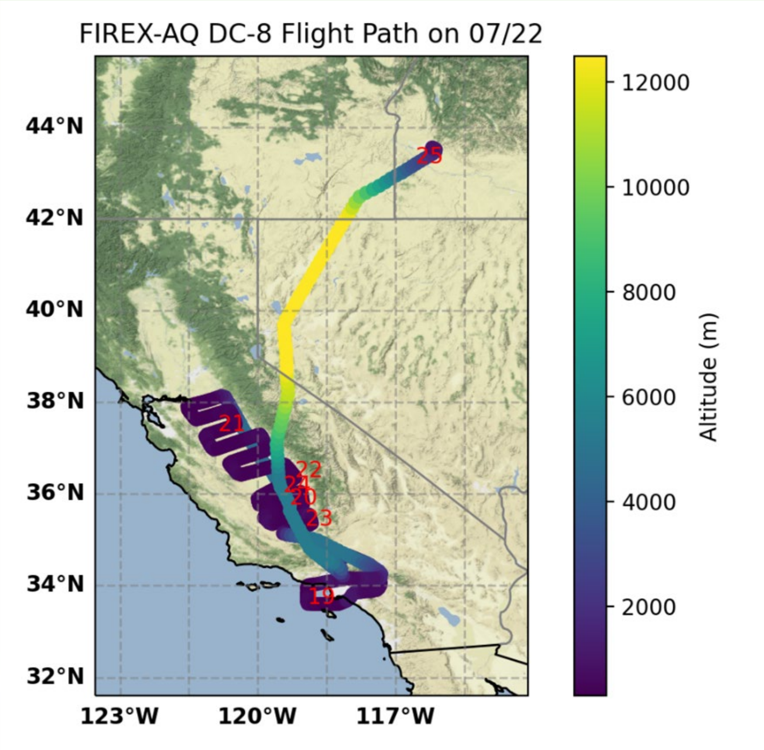
Meteorological Driver Comparison

Model Settings	FV3-GFSv16	WRF-ARWv4.0.1
Domain	Global C768L127 (~ 13 km horizontal resolution, 127 vertical layers up to 80km), interpolated to the 12km CONUS domain with 35-layers up to about 14km (60hPa)	12km CONUS 35 vertical layers up to 100hPa
Cloud Microphysics	GFDL six-category cloud microphysics scheme (Lin et al., 1983; Chen and Lin, 2011; Chen and Lin, 2013)	Morrison 2-moment scheme (Morrison et al., 2009)
PBL Physics Scheme	sa-TKE-EDMF (Han and Bretherton, 2019)	Yonsei University Scheme (Hong et al., 2006)
Cumulus Parameterization	SAS Scheme (Han et al. 2011; 2017)	Kain Fritsch multiscale (Kain, 2004)
Radiation	RRTMG	RRTMG
Land Surface Model	Noah	Noah
Surface Layer	Monin-Obukhov (Monin-Obukhov 1954; Grell et al. 1994; Jimenez et al. 2012)	Revised MM5 Scheme (Jimenez et al., 2012)
Other treatment		FDDA nudging is enabled for temperature and specific humidity whole domain, and for wind components (U, V) outside the PBL.

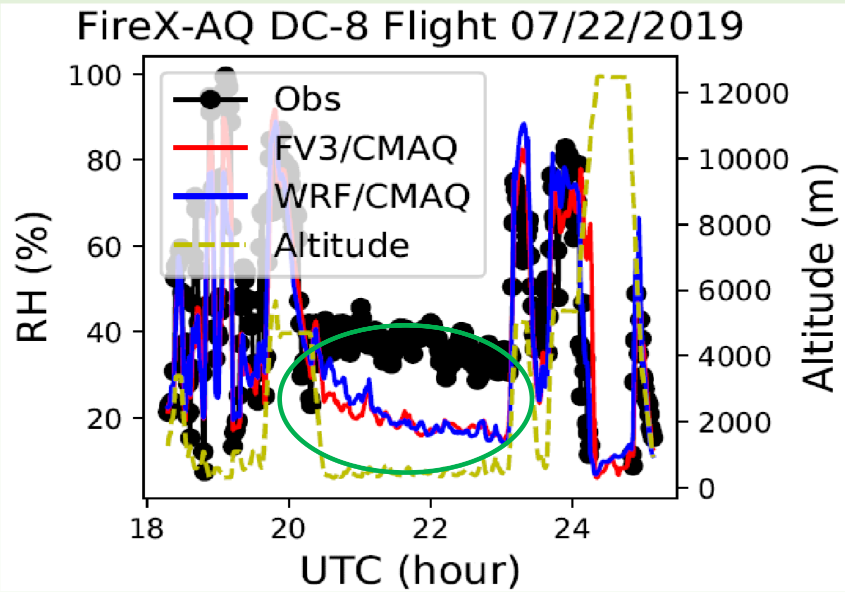
Evaluation of *non-fire* events during FIREX-AQ 2019

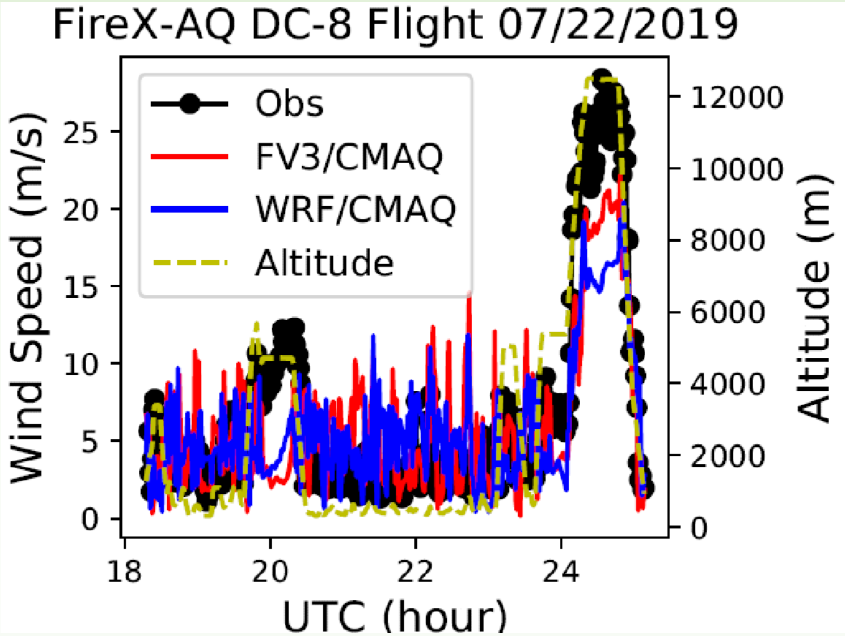
Case study for FIREX-AQ DC-8 Flight on July 22, 2019.

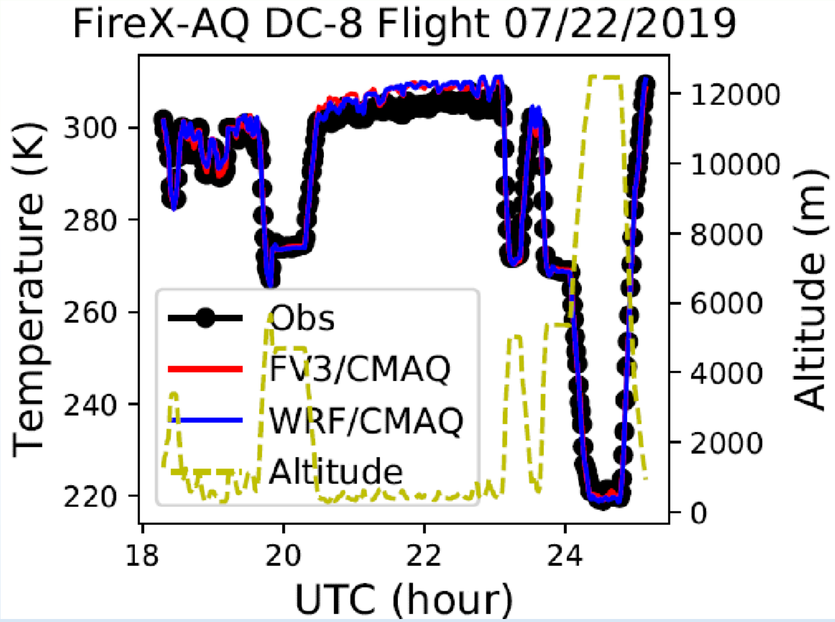
Meteorology comparison for DC-8 Flight on 07/22/2019

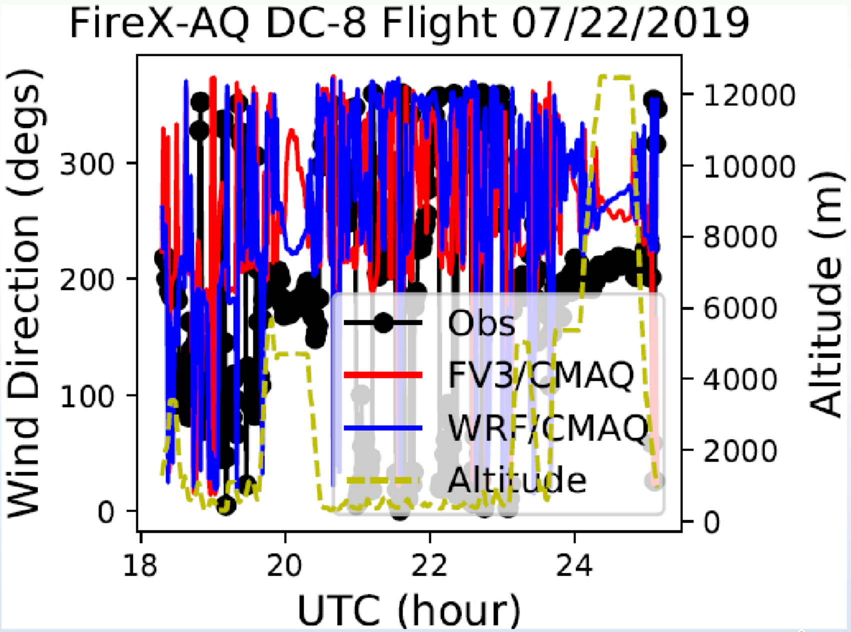


Compared to the DC-8 Flight over the California central valley, both meteorological models had dry bias.

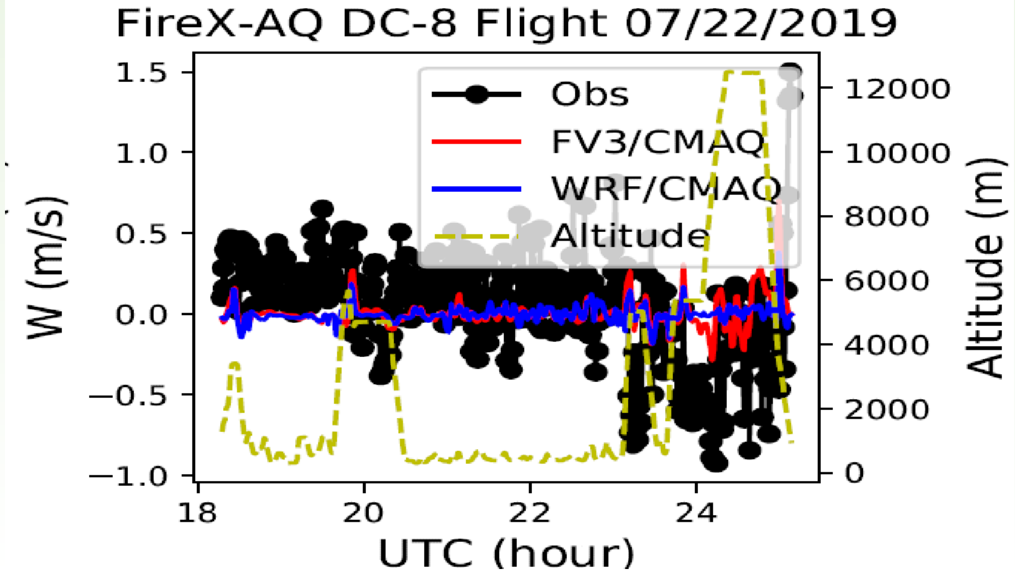




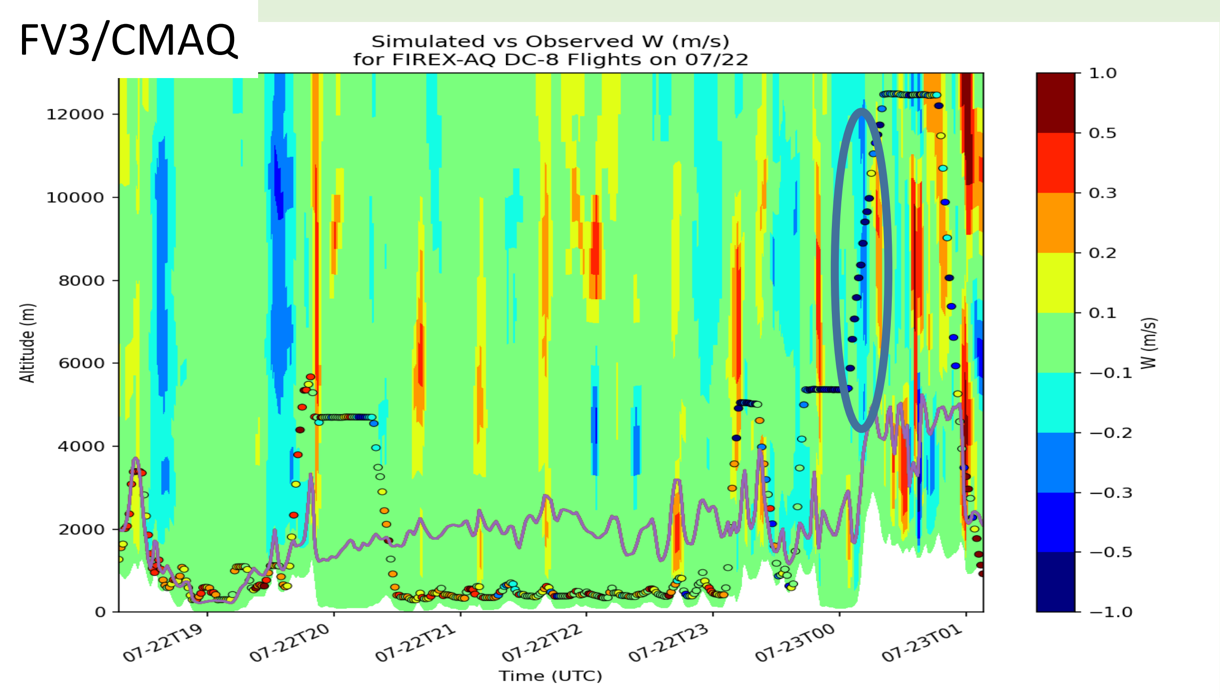


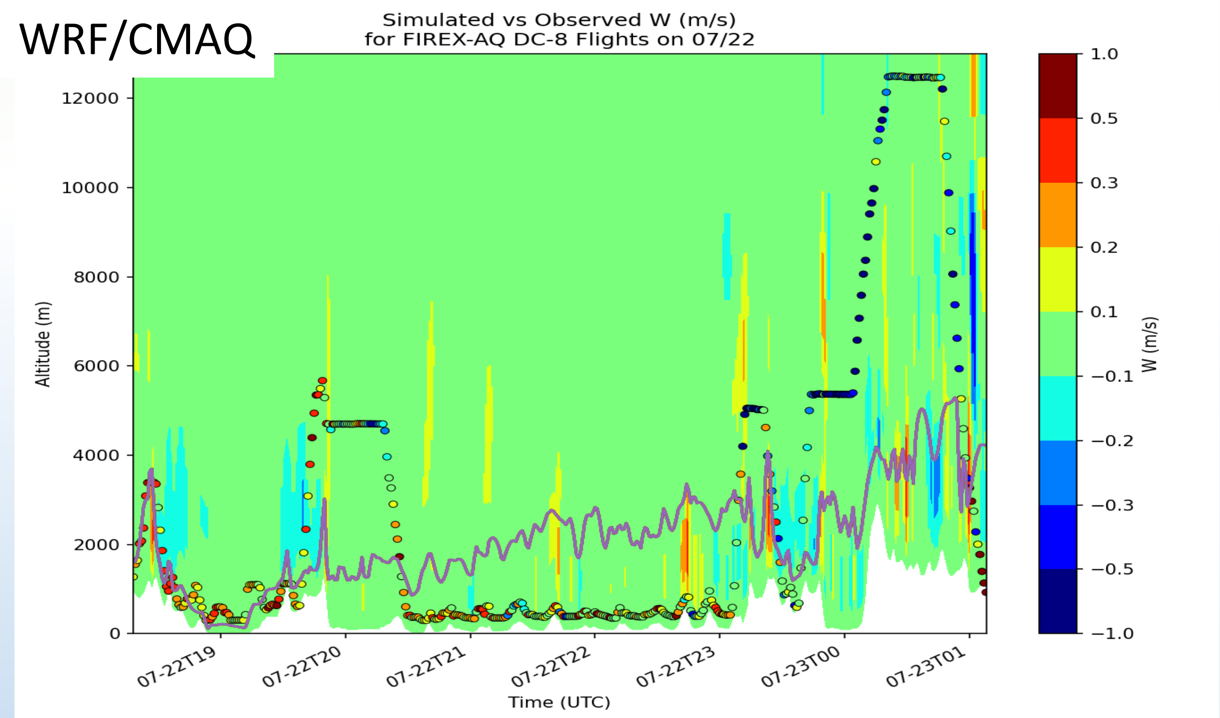


Comparison for diagnosed vertical velocities

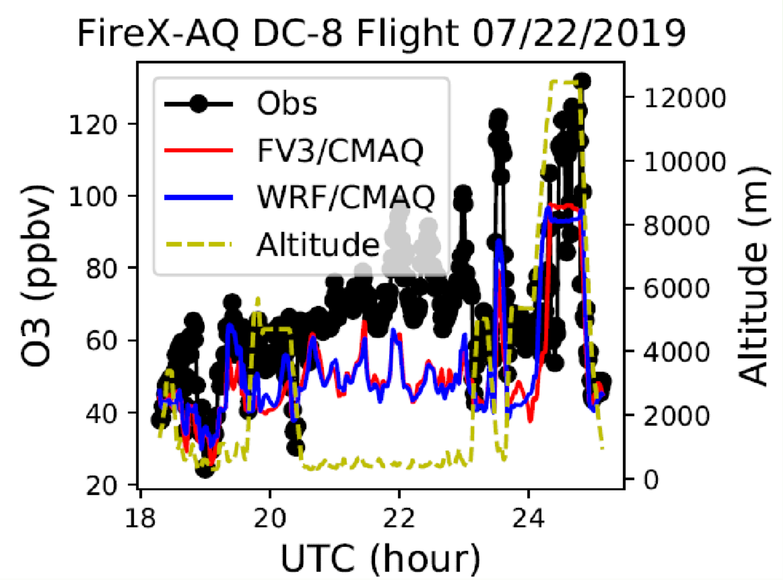


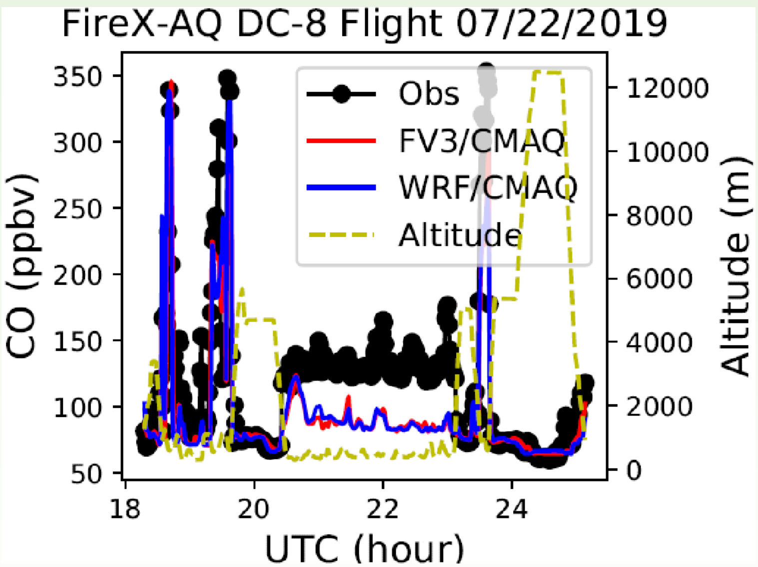
FV3/CMAQ showed a larger vertical velocity (diagnosed from horizontal winds) than that of WRF/CMAQ, though both models yielded much weaker vertical motions than the observation, especially within PBL.

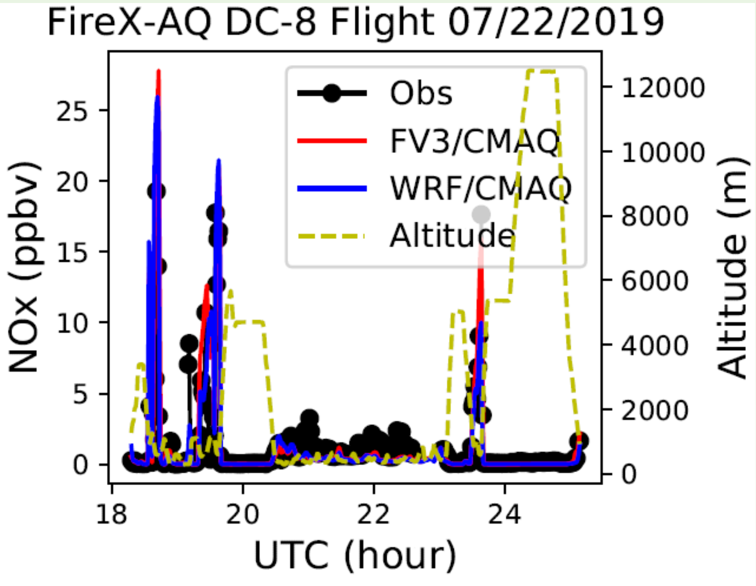


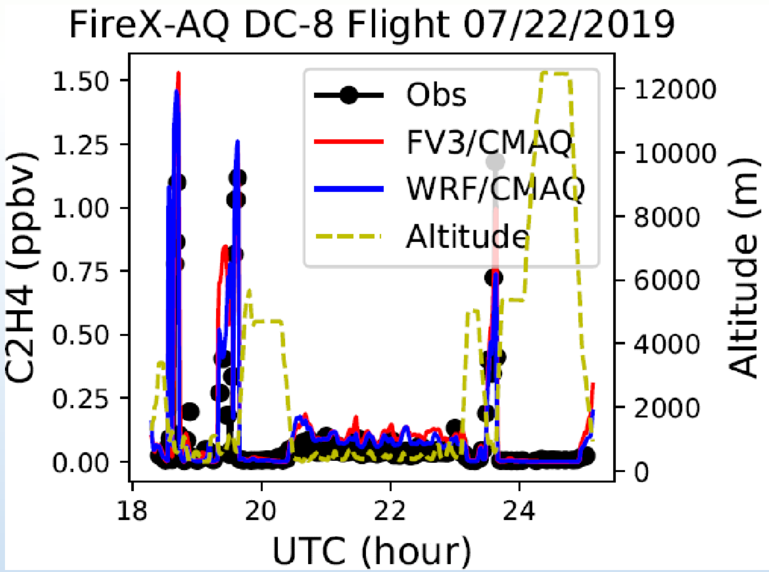


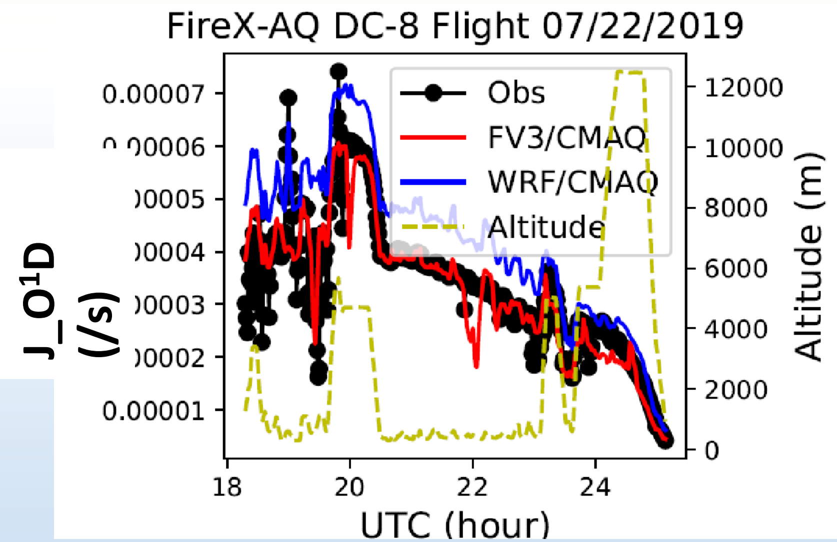
CMAQ Comparison for the Non-fire events on 07/22/2019

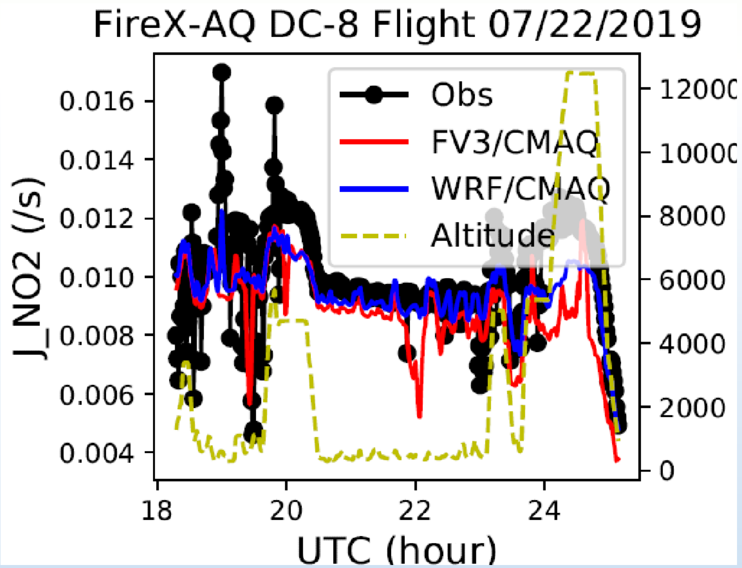










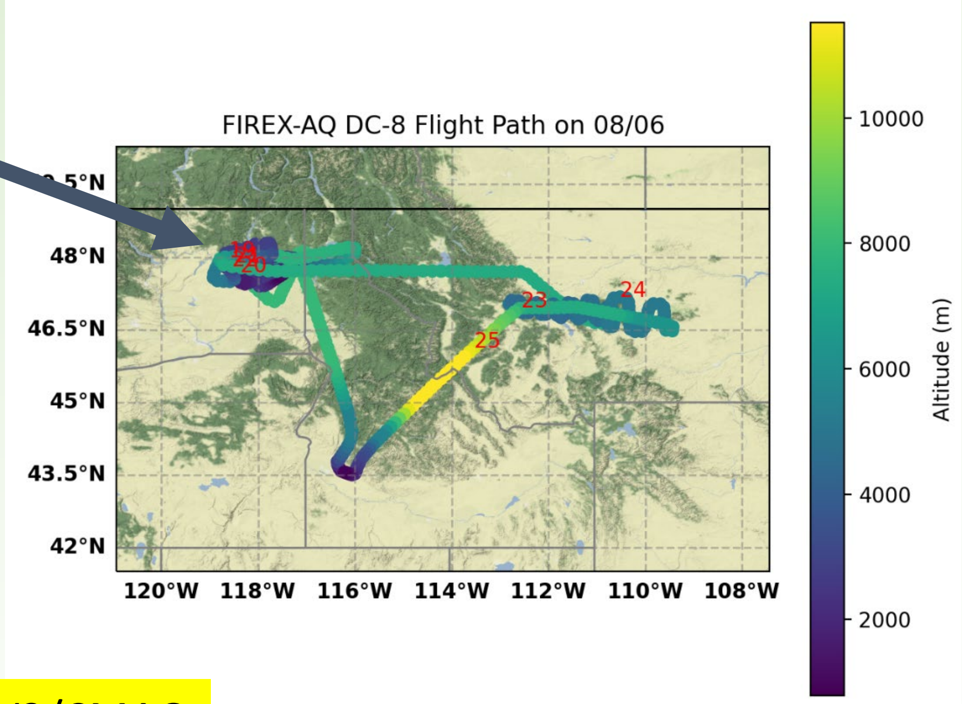


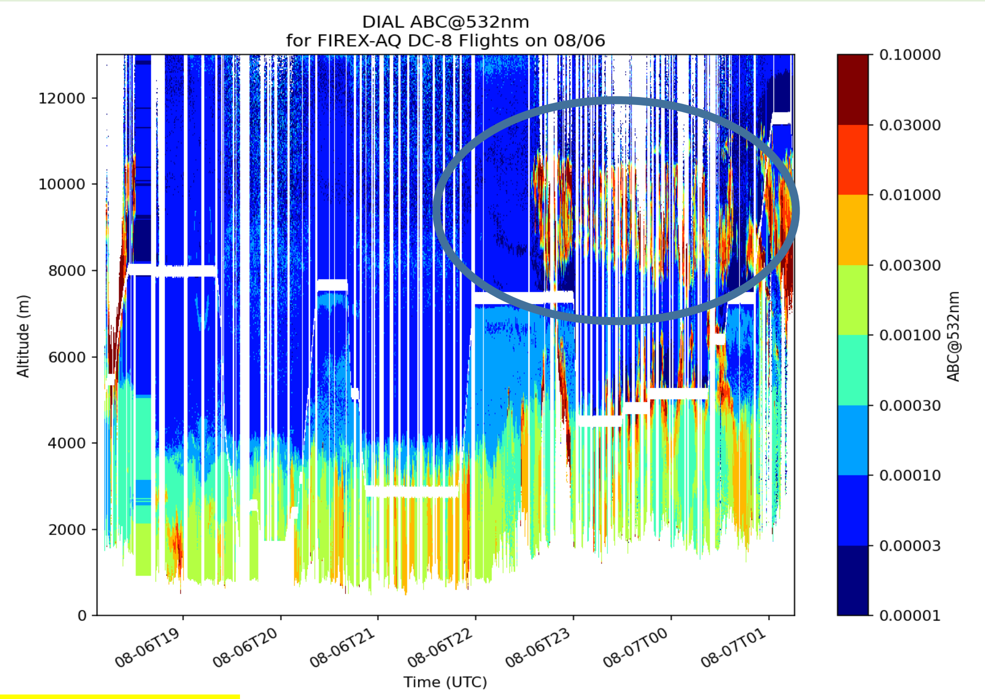
Evaluation of *fire* events during FIREX-AQ 2019

Williams Flats Fires: Washington and Montana

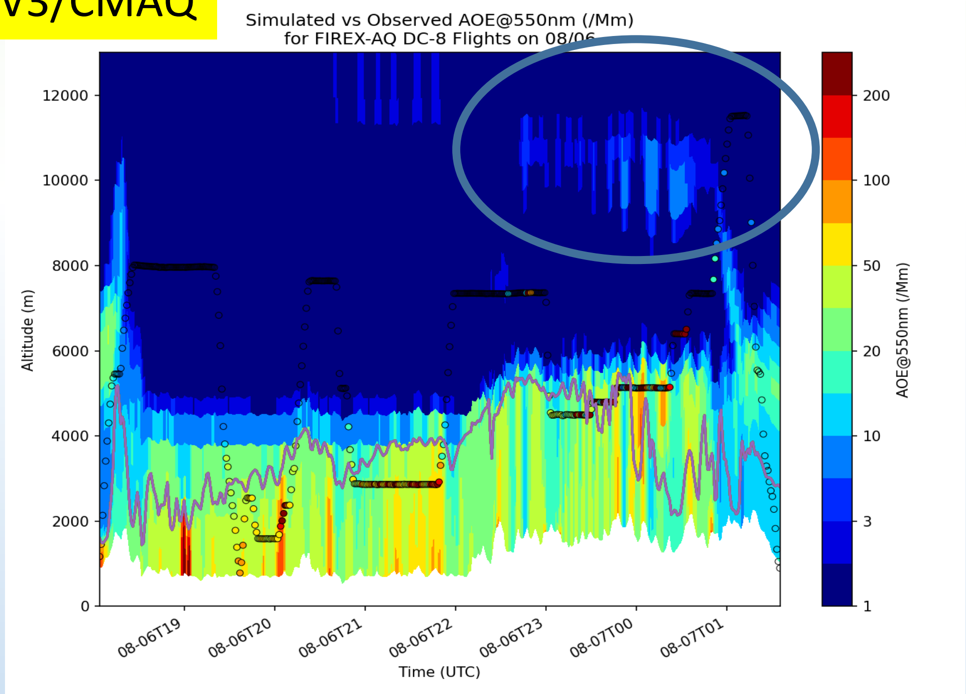
DC-8 Flights on August 03, 06, 07.

08/06 Flight over Williams Flats Fire

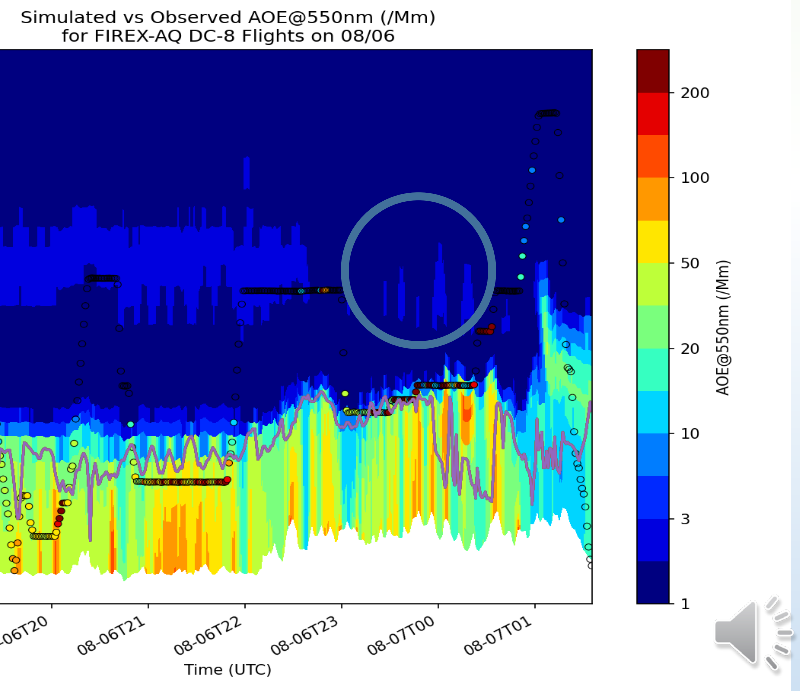




FV3/CMAQ

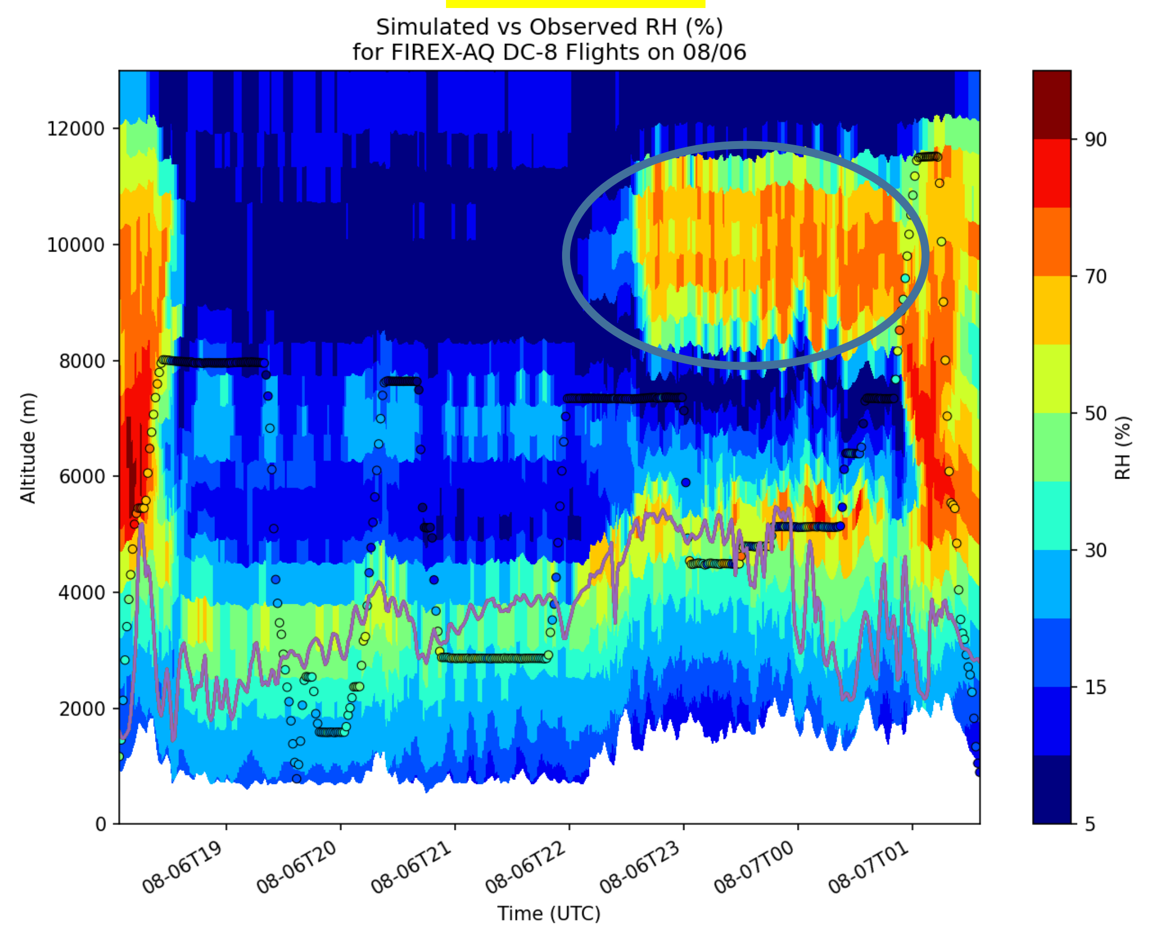


WRF/CMAQ

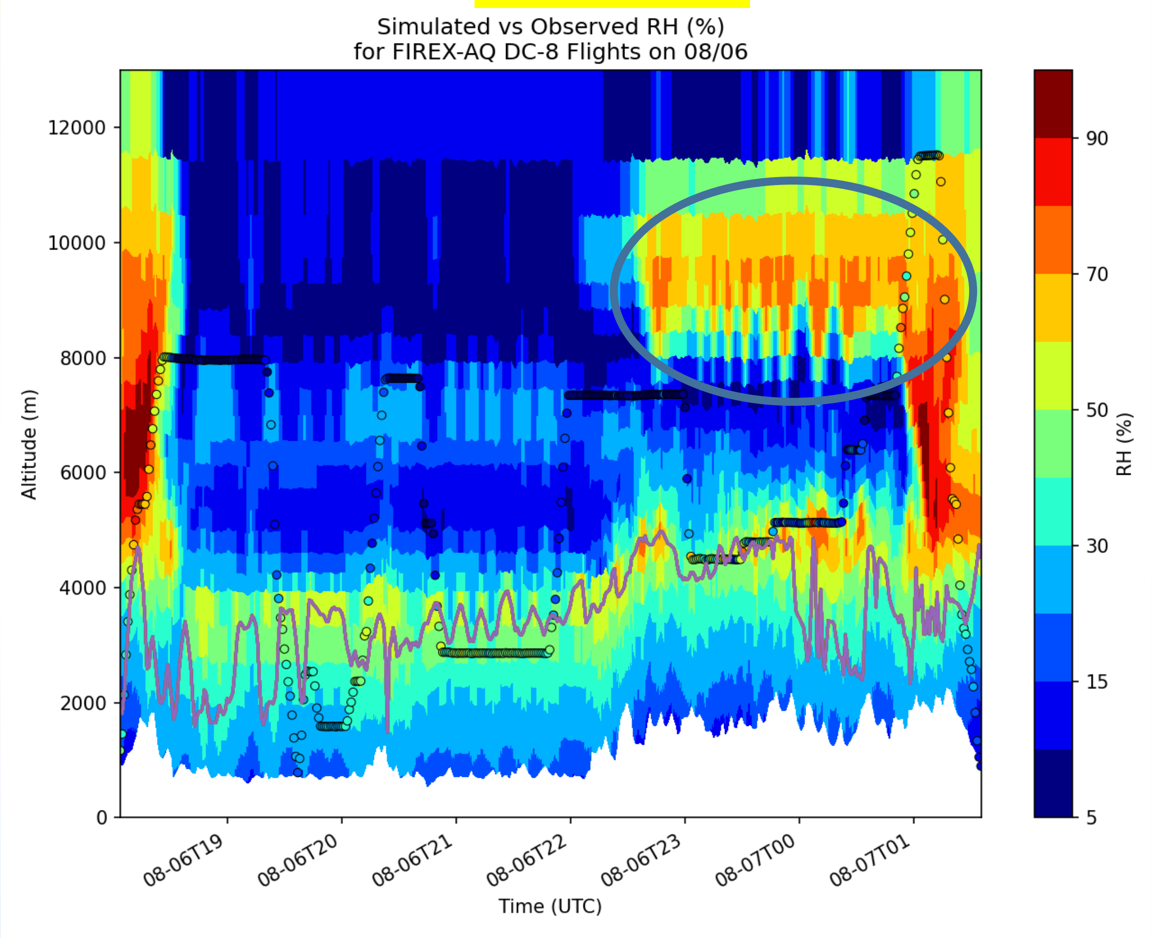


Model vs. Aircraft Curtain Plots of RH %

FV3/CMAQ

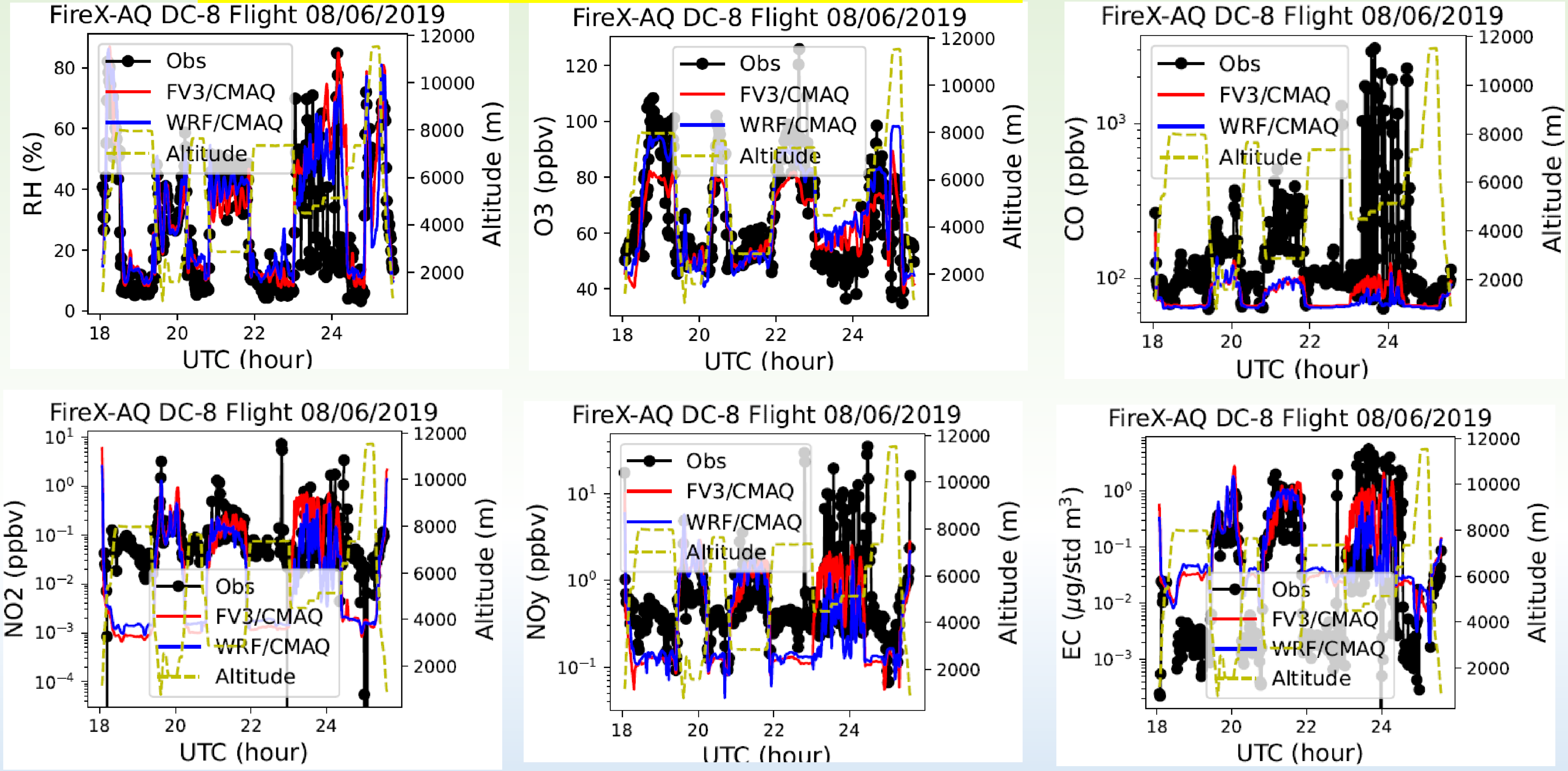


WRF/CMAQ



FV3 tends to have stronger convection than WRF.

CMAQ prediction comparison for the fire event



These two models tended to yield similar results. They underestimated wildfire emissions for NOx and CO, though the element carbon (EC) predictions were reasonable.

Statistic for non-fire events below 3km over west of -100°W

Variables	FV3/CMAQ MB	FV3/CMAQ RMSE	FV3/CMAQ R	FV3/CMAQ Slope	WRF/CMAQ MB	WRF/CMAQ RMSE	WRF/CMAQ R	WRF/CMAQ Slope
Temperature (K)	0.98	2	0.99	1.1	1.1	2.2	0.99	1.2
RH (%)	-7.3	12	0.78	0.72	-6	12	0.68	0.6
Wind Speed (m/s)	0.76	3.3	0.43	0.47	-0.051	2.9	0.42	0.38
O3 (ppbv)	-11	15	0.65	0.34	-11	14	0.71	0.39
CO (ppbv)	-38	53	0.65	0.57	-38	54	0.65	0.58
NOx (ppbv)	0.51	2.9	0.7	1.1	0.36	2.8	0.69	1.1
NOy (ppbv)	-0.042	3.1	0.74	0.89	-0.096	3.1	0.72	0.83
NOz (ppbv)	-0.47	1.2	0.78	0.55	-0.32	1.1	0.78	0.65
HNO3 (ppbv)	0.15	0.42	0.68	1.3	0.23	0.51	0.66	1.4
PAN (ppbv)	-0.25	0.42	0.67	0.22	-0.23	0.39	0.67	0.28
C2H4 (ppbv)	0.058	0.19	0.7	0.87	0.039	0.19	0.66	0.82
C2H2 (ppbv)	-0.073	0.14	0.78	0.5	-0.071	0.14	0.75	0.5
SO2 (ppbv)	-0.24	0.57	0.024	0.0083	-0.22	0.57	-0.012	-0.0045
Acetone (ppbv)	-2.3	2.5	0.69	0.19	-2.2	2.4	0.71	0.21
HCHO (ppbv)	-0.97	1.3	0.56	0.45	-0.92	1.3	0.52	0.46
Toluene (ppbv)	0.041	0.15	0.76	1.7	0.036	0.14	0.76	1.7
Isoprene (ppbv)	0.036	0.17	0.6	0.84	0.0059	0.14	0.64	0.77
EC (µg/std m3)	0.19	0.57	0.52	2.1	0.23	0.61	0.46	1.9
OA (µg/std m3)	-7.2	9.7	0.56	0.26	-6.7	9.7	0.47	0.24
SO4 (µg/std m3)	-0.78	1.1	0.086	0.019	-0.77	1.1	0.035	0.0068
NH4 (µg/std m3)	-0.62	0.81	0.42	0.1	-0.61	0.79	0.52	0.15
NO3 (µg/std m3)	-1.1	1.5	0.56	0.23	-1	1.4	0.56	0.28
AOE@550nm (/Mm)	-29	47	0.59	0.23	-27	46	0.59	0.23
J_O1D (/s)	-9.80E-07	4.90E-06	0.96	0.91	5.50E-06	8.10E-06	0.96	1.2
J_NO2 (/s)	-0.00086	0.0016	0.94	0.85	-0.00025	0.0012	0.96	0.89

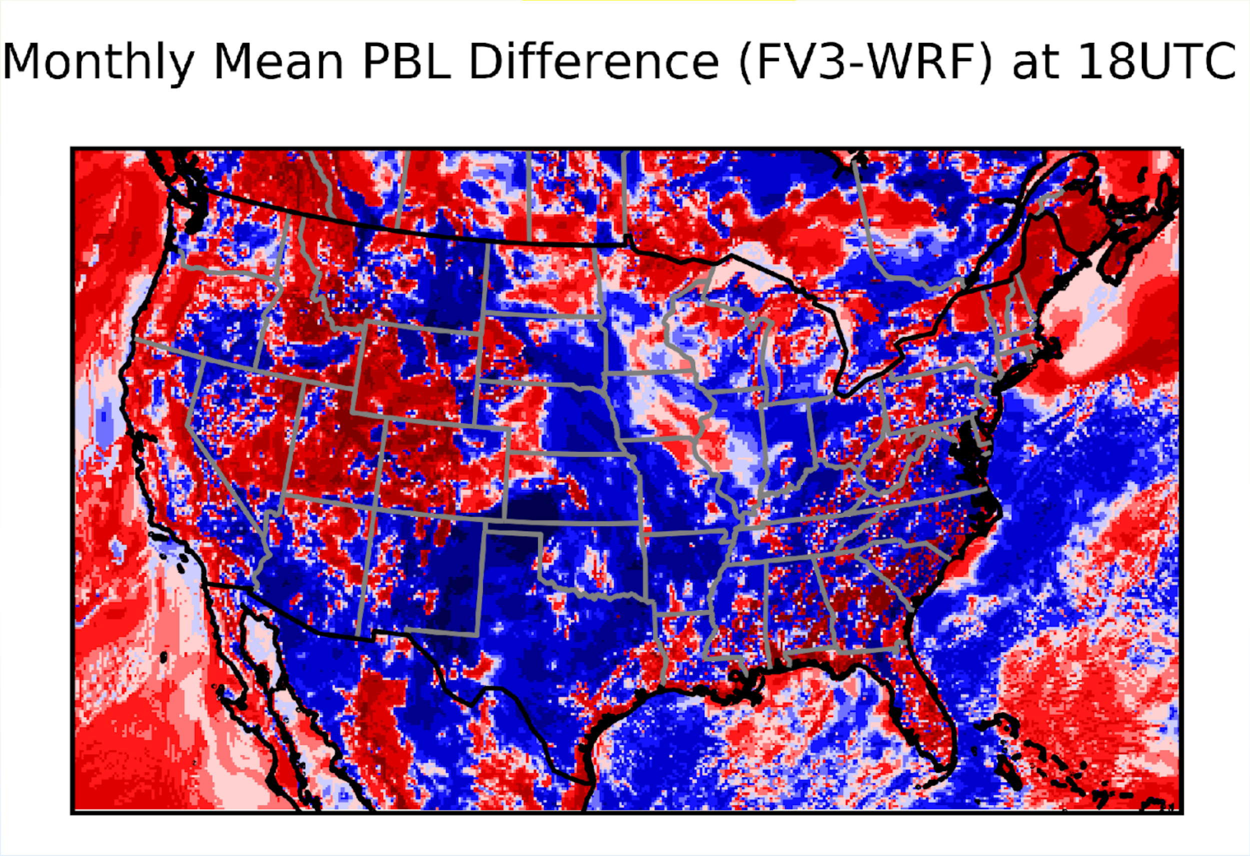
Statistic for fire events below 3km over west of -100°W

Variables	FV3/CMAQ MB	FV3/CMAQ RMSE	FV3/CMAQ R	FV3/CMAQ Slope	WRF/CMAQ MB	WRF/CMAQ RMSE	WRF/CMAQ R	WRF/CMAQ Slope
Temperature (K)	-0.39	0.7	1	1	-0.69	0.86	1	1
RH (%)	-0.76	7.8	0.71	0.55	4.3	11	0.56	0.54
Wind Speed (m/s)	0.77	2.2	0.61	0.62	-0.73	2.1	0.66	0.73
O3 (ppbv)	-6.6	12	0.59	0.26	-7	11	0.65	0.34
CO (ppbv)	-380.	870.	0.6	0.035	380.	880.	0.44	0.024
NOx (ppbv)	0.06	6.4	0.46	0.23	-0.62	7	0.31	0.15
NOy (ppbv)	-4.2	13	0.51	0.12	-4.7	14	0.31	0.073
NOz (ppbv)	-4.8	10	-0.19	-0.011	-4.7	10	-0.2	-0.012
HNO3 (ppbv)	0.15	0.26	0.53	1.1	0.18	0.28	0.4	0.77
PAN (ppbv)	-0.79	1.6	0.27	0.019	-0.77	1.6	0.28	0.026
C2H4 (ppbv)	-4.3	10	0.42	0.005	-4.4	10	0.14	0.0018
C2H2 (ppbv)	-1	2.1	0.53	0.0087	-1	2.1	0.36	0.0062
SO2 (ppbv)	-0.32	1.4	0.59	0.2	-0.39	1.5	0.43	0.13
Acetone (ppbv)	-3.2	4.6	0.13	0.0086	-3.2	4.5	0.14	0.011
HCHO (ppbv)	-7.1	18	0.23	0.0062	-7.2	18	0.12	0.003
Toluene (ppbv)	-0.44	1.4	0.4	0.0049	-0.44	1.4	0.19	0.0024
Isoprene (ppbv)	-0.0079	0.23	0.12	0.058	-0.033	0.24	-0.014	-0.0054
EC (µg/std m3)	-0.53	3.3	0.61	0.29	-0.79	3.7	0.45	0.2
OA (µg/std m3)	-150.	420.	0.61	0.017	-150.	420.	0.47	0.012
SO4 (µg/std m3)	-0.12	0.68	0.42	0.18	-0.21	0.73	0.32	0.13
NH4 (µg/std m3)	-0.59	0.93	0.77	0.35	-0.62	0.96	0.73	0.36
NO3 (µg/std m3)	-0.56	1.5	0.81	0.61	-0.63	1.6	0.77	0.6
AOE@550nm (/Mm)	-350.	990.	0.69	0.027	-360.	1000.	0.53	0.015
J_O1D (/s)	-4.00E-07	3.70E-06	0.98	0.84	3.20E-06	5.10E-06	0.97	1.1
J_NO2 (/s)	-0.0008	0.0016	0.95	0.8	1.10E-05	0.0016	0.93	0.81

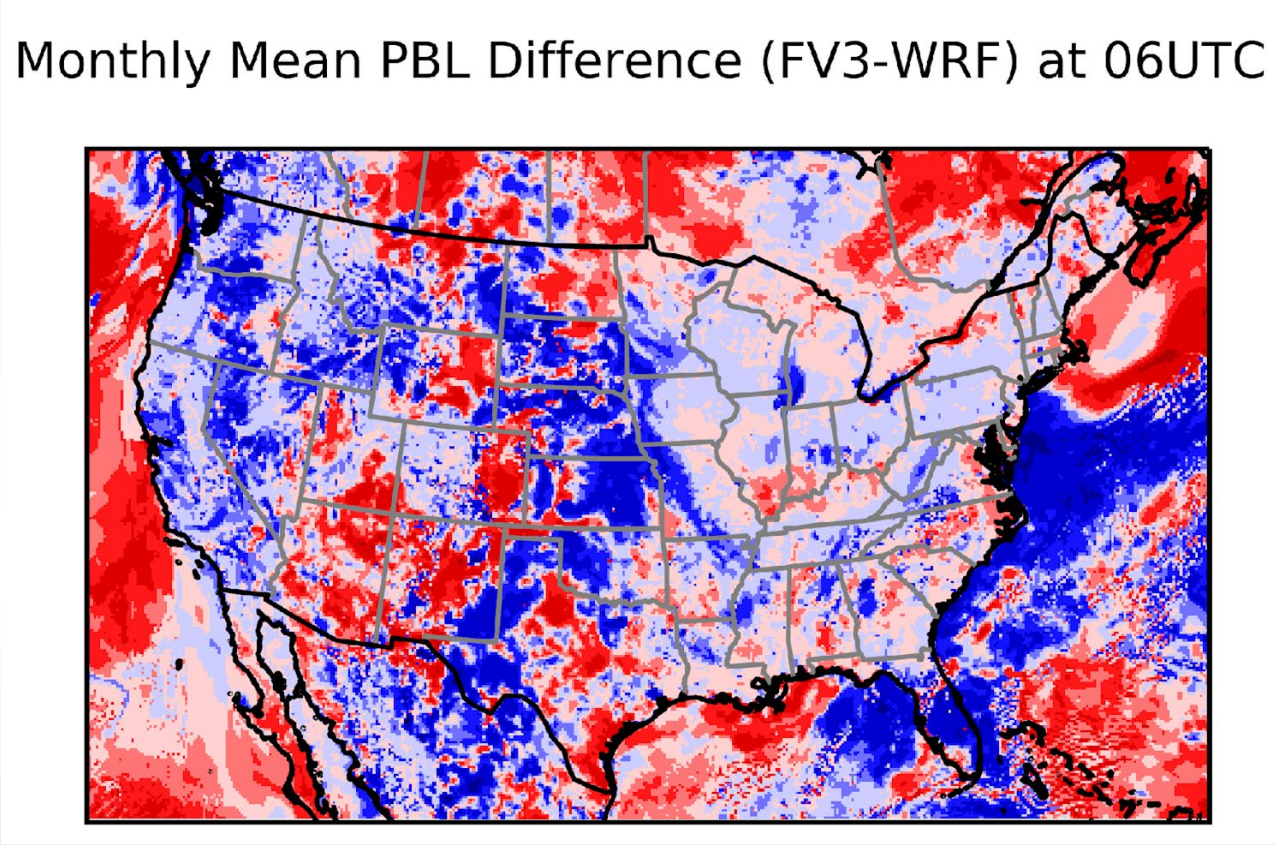
Comparison for the whole August, 2019

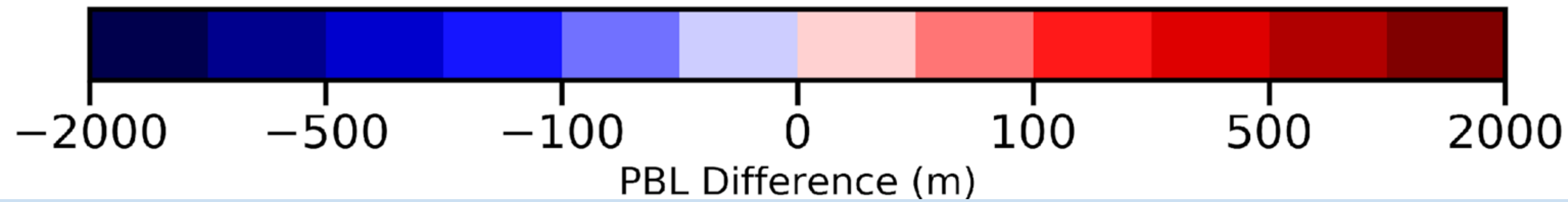
PBL Height Difference Between Interpolated FV3GFS and WRF-downscaling

Daytime



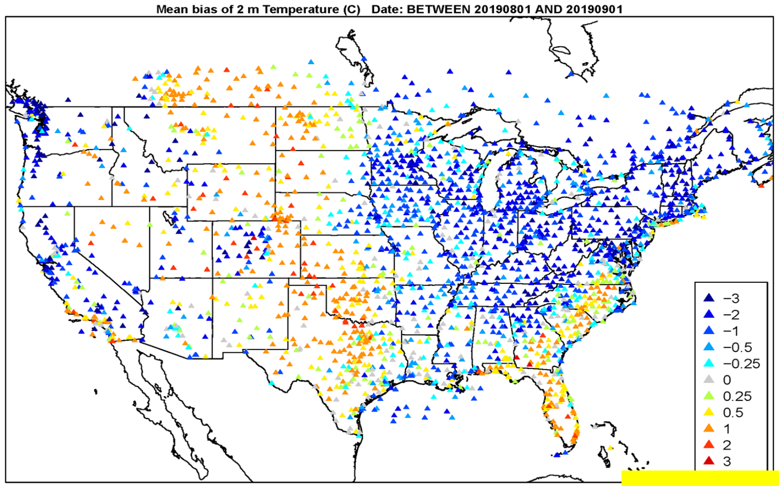
Nighttime

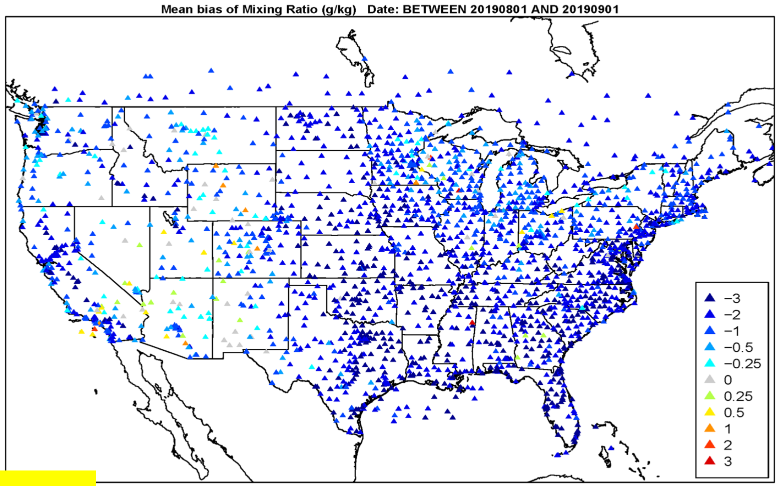


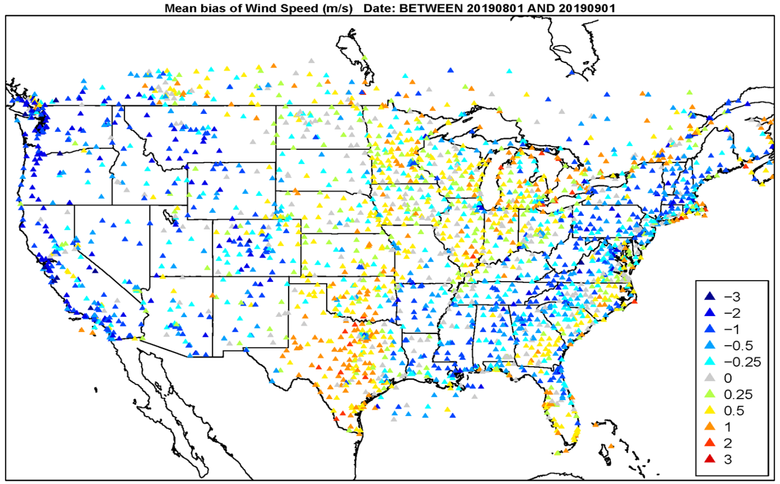


FV3GFSv16 vs. WRFv4.0.3 Surface Meteorology for METAR, August, 2019

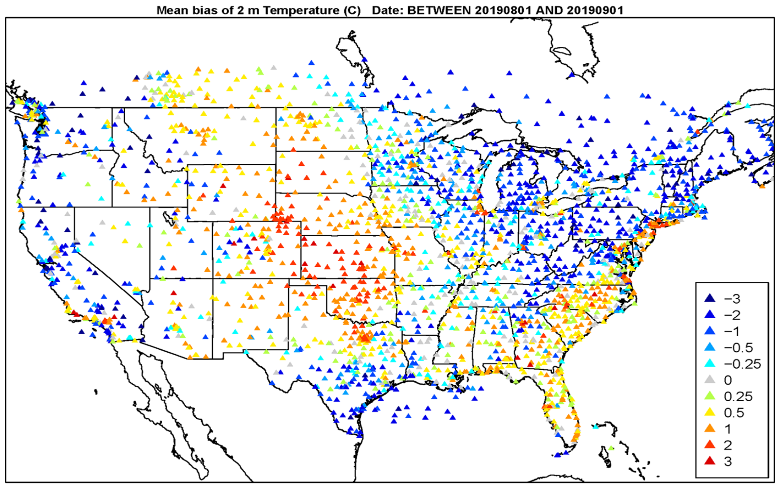
2-m Temperature (°C) | 2-m Mixing Ratio (g/kg) | 10-m Wind Speed (m/s)

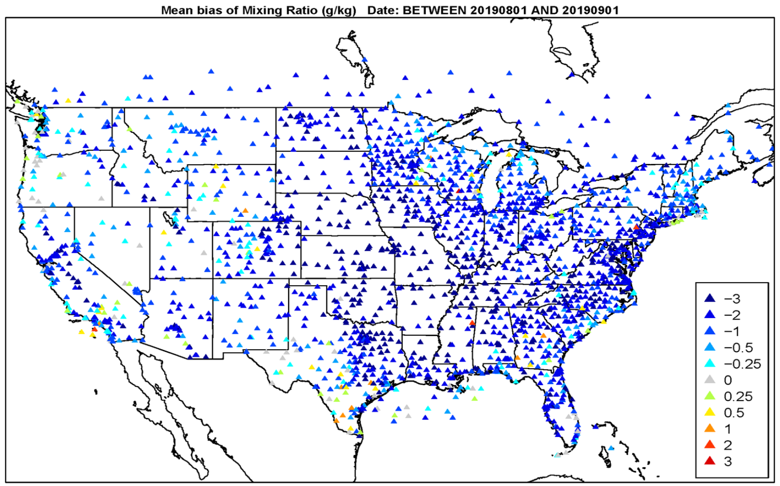


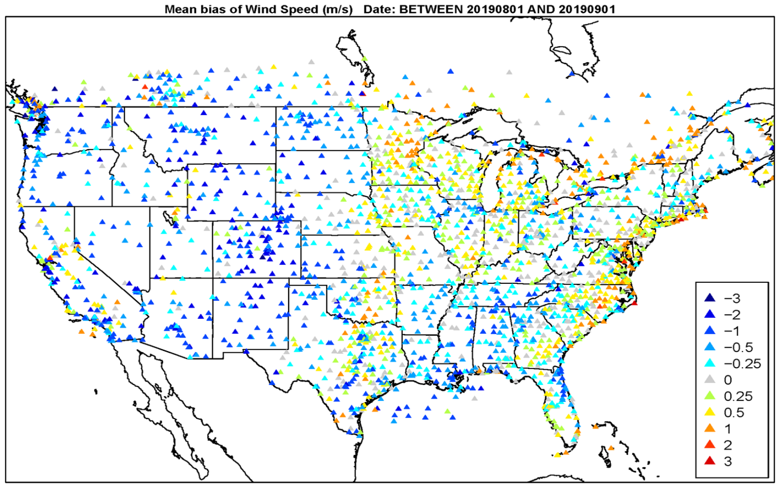




FV3GFSv16

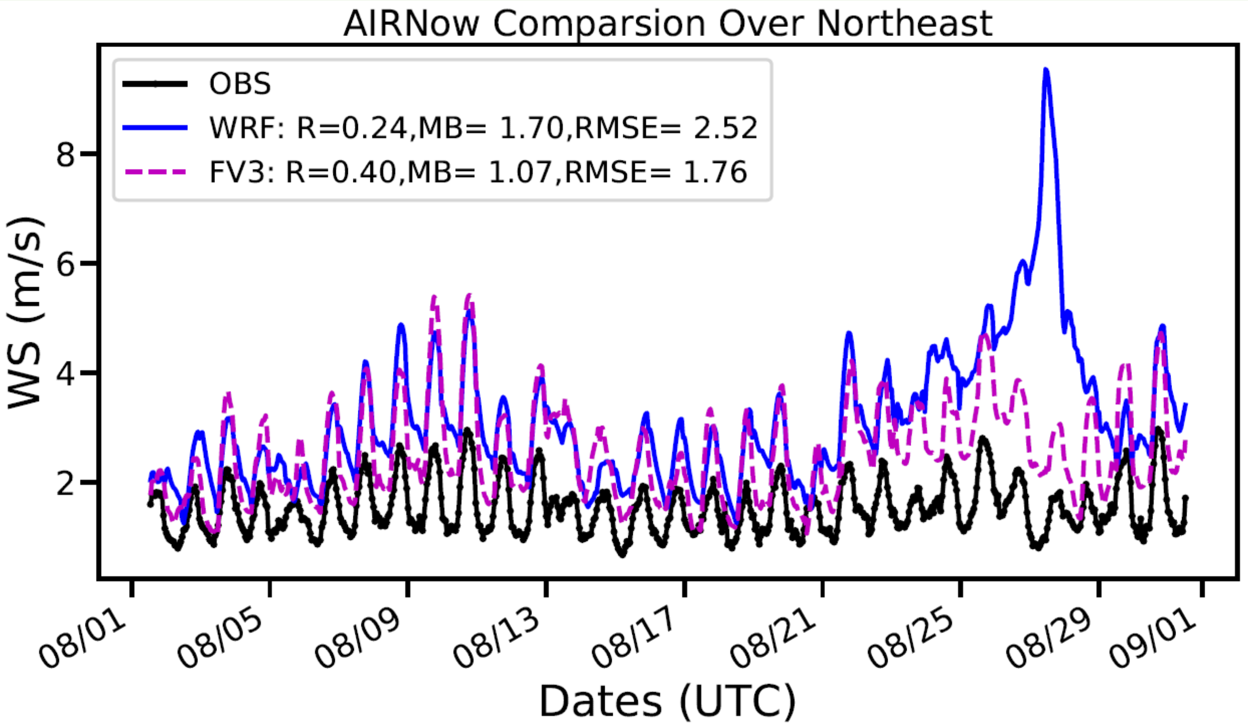


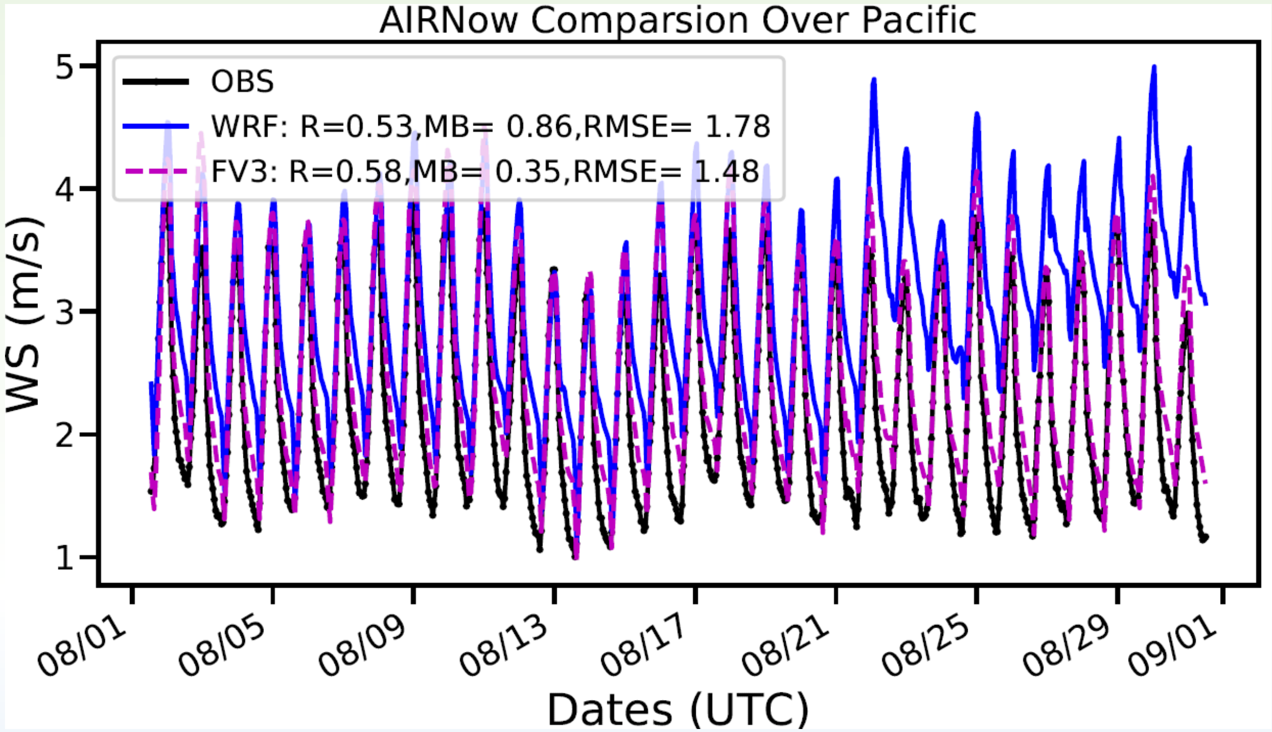




WRFv4.0.3

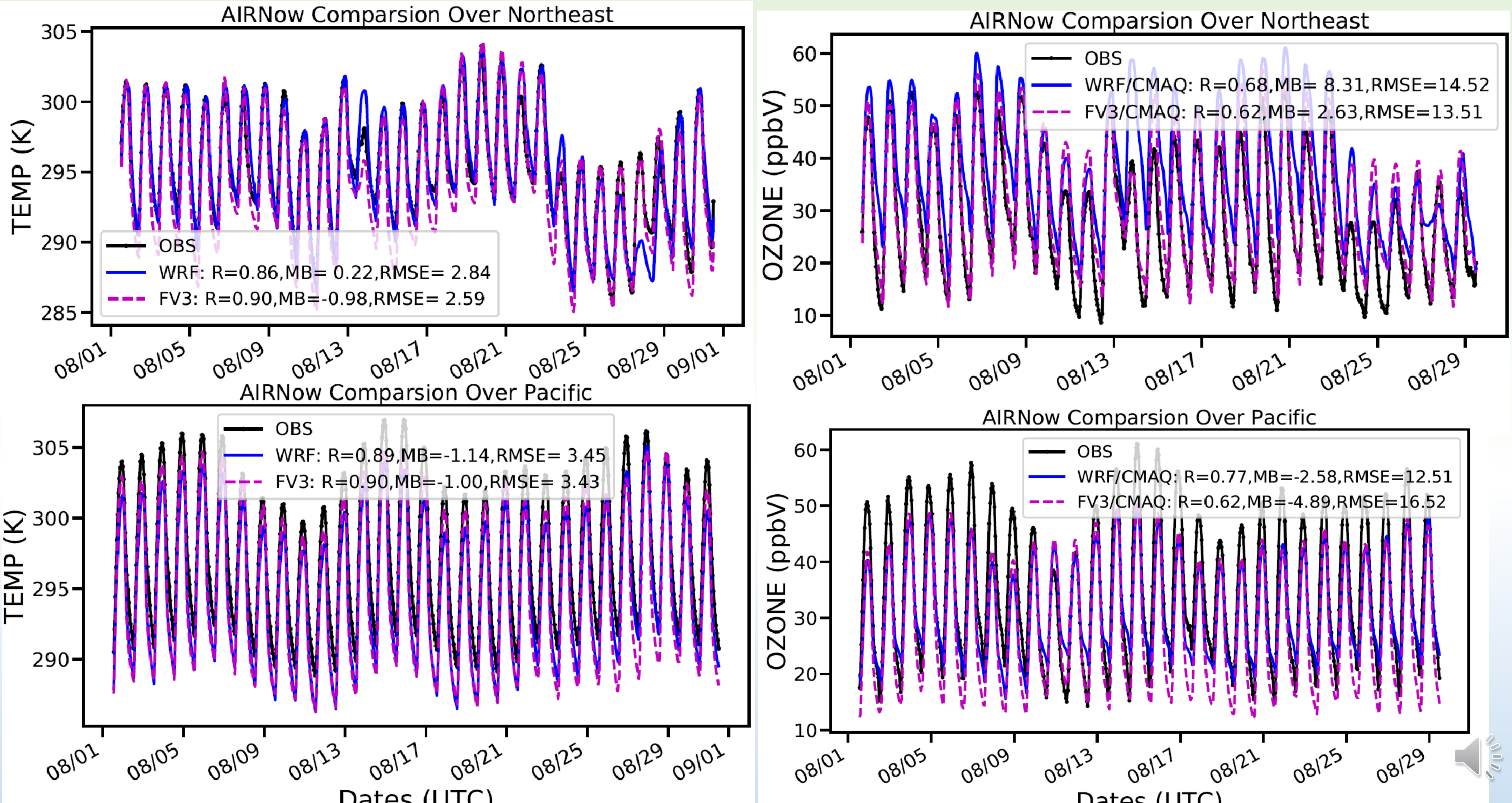
Surface 10-m wind speed comparison over AIRNow Stations



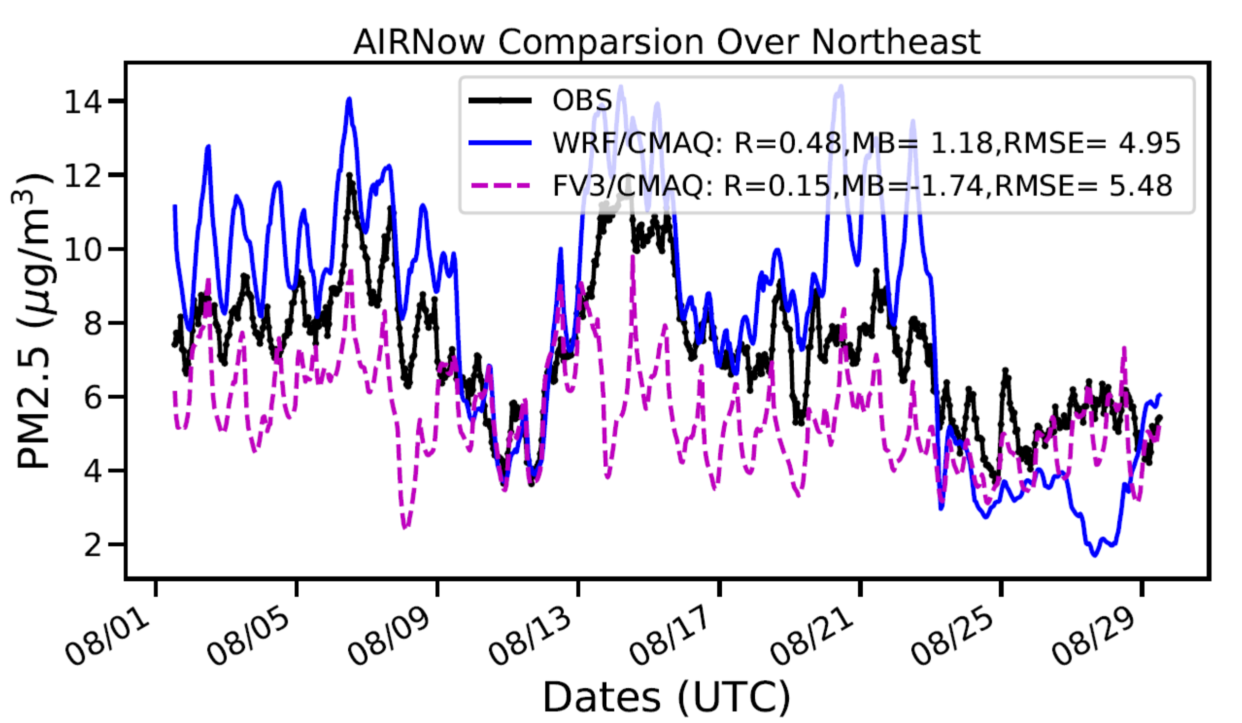


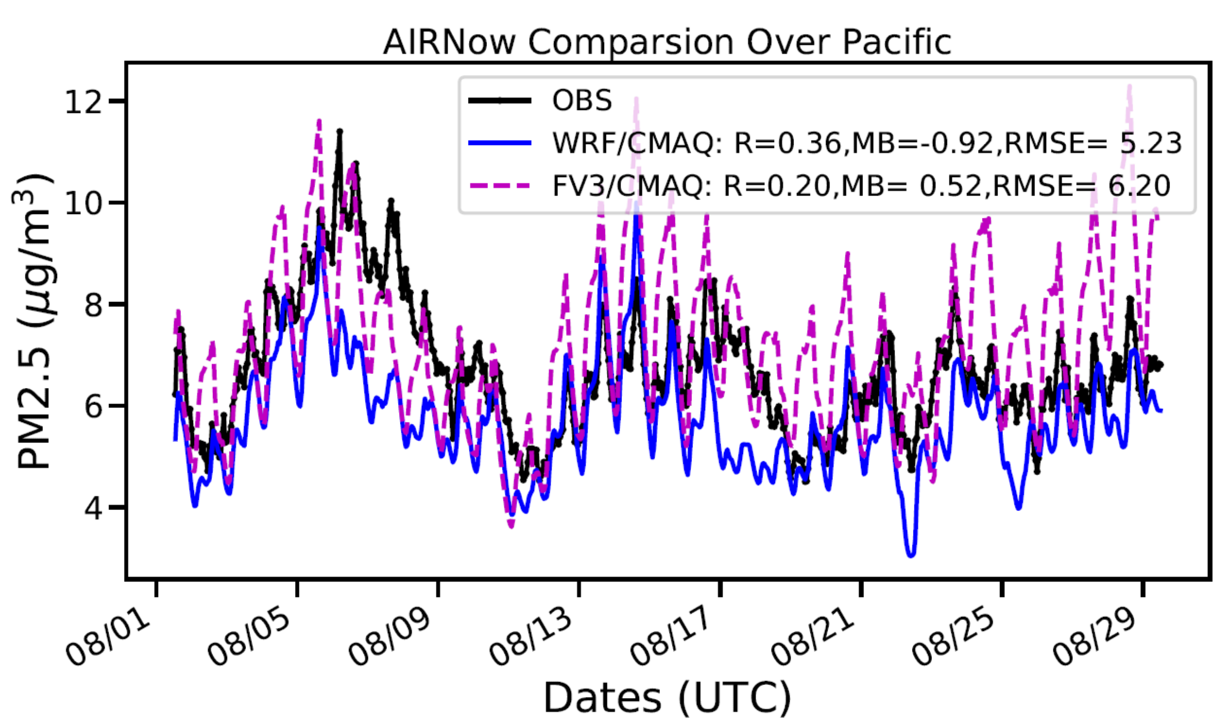
FV3 yields better 10-m wind over Northeast and Pacific coast region. The WRF run tends to overpredict surface wind, especially at night.

Surface ozone predictions show correlations to the 2-meter temperature predictions



Same as last slides but for PM2.5 predictions





Surface PM2.5 predictions have similar trends over Northeast states. Over the Pacific coast, FV3/CMAQ has higher PM2.5 than that of WRF/CMAQ. Both models have more variability compared to observations. WRF-CMAQ yields better correlations.

Summary

- An interpolation based meteorological preprocessor, NACC, is developed from the MCIPv5, and enable us to use global meteorological model FV3/GFS to drive CMAQ5.3.1.
- FIREX-AQ field data show that FV3/CMAQ and WRF/CMAQ have overall similar performance, and their difference were mainly driven by their meteorological model’s dynamics and physics.
- NEI2016v1 provided overall reasonable anthropogenic emissions except for SO2, Ethane etc. The GBBEPx wildfire emissions tended to underpredict some species even it captured the fire location and timing.
- Compared to the WRF run, FV3 have stronger PBL diurnal variation, lower 10m wind speed and 2m temperatures, which resulted in lower ozone and PM2.5 over the eastern USA.