Recent Performance of the NOAA Air Quality Forecasting Capability and the Impact of Driving Meteorology

http://www.emc.ncep.noaa.gov/mmb/aq

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September 27, 2017

Outline

- Overview CMAQ V5 & NAM V4 upgrades
- Evaluate ozone performance of V4.7 vs 5.0.2
- Experimental: Ozone Bias Correction
- Evaluate PM performance of V4.7 vs 5.0.2
- PM Bias Correction (Exp: use of V5 analogs)
- Experimental: HYSPLIT smoke emissions tests
- NEMS Global Aerosol Capability
- Future : FV3-Chem

CMAQ V4.x weaknesses Identified

- Overprediction of ozone in Eastern U.S. in Summer
  - Especially along coastal cities (NYC, DC, Cleveland)

    →Update National Emission Inventory point sources to 2011 (project to 2016)

    → *Evaluate NOx emissions based on OMI satellite trends (Deferred)*

    → *Evaluate Impact of NAM V4 and reduced SW radiation under clouds*

    → *Update CMAQ gas and aerosol chemistry/biogenic emissions to EPA V5.0.2*

- Underprediction of particulate matter (PM) in Summer and near wild-fires

  → *Update 10 year old USFS BlueSky smoke emission system*

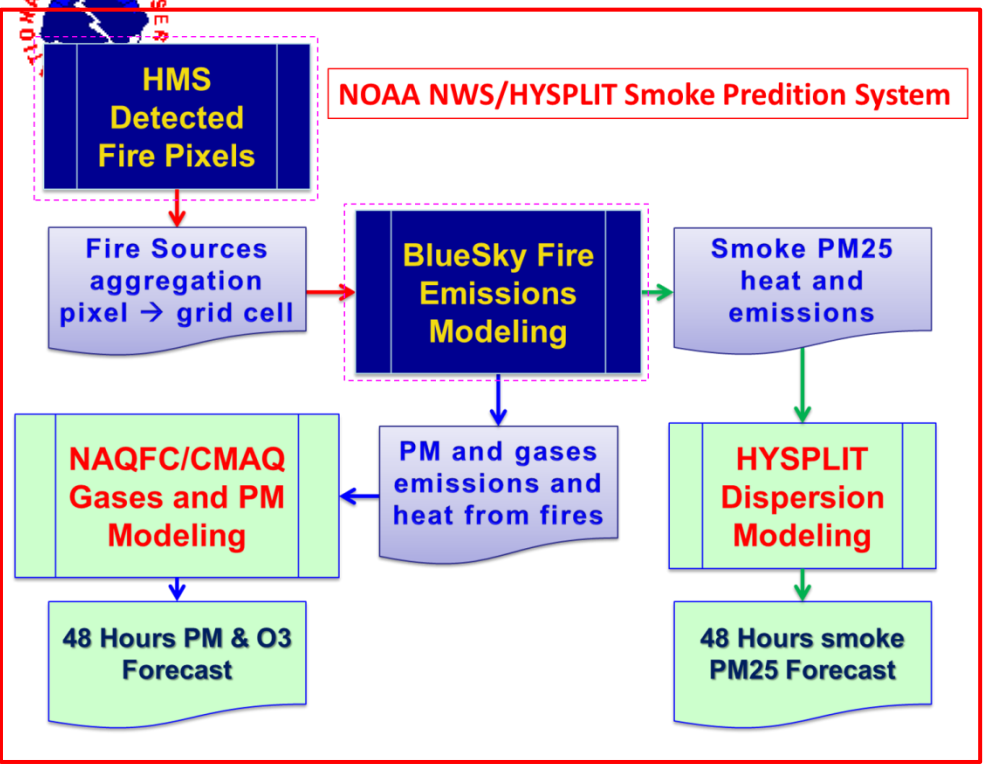
  → *Introduce 24 h pre-analysis cycle to correct fire time mismatch with CMAQ initial time*

- Underprediction of Ozone and PM when strong fires are present outside CMAQ domain

  → *Test NGAC full aerosol predictions for CMAQ lateral boundaries (deferred)*

- Overprediction of PM during winter-time stagnation episodes (cold, stable)

  → *update emissions/chemistry as in bullet 1*

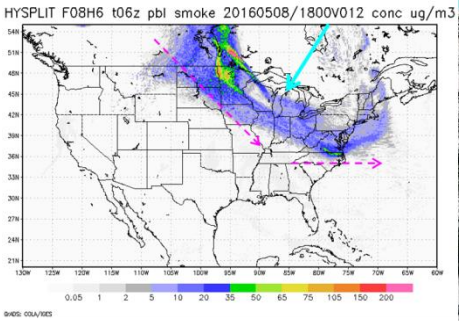


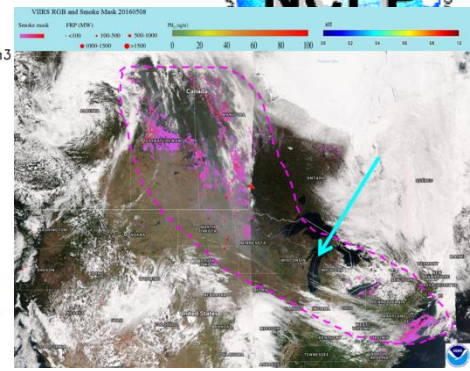
Updated USFS BlueSky smoke emissions:

- The Fuel Characteristic Classification System version 2 (FCCS2) which includes a *more detailed description of the fuel loadings with additional plant type categories*.
- Explicit fuel load map for Alaska
- improved fuel consumption model and fire emission production system (FEPS).

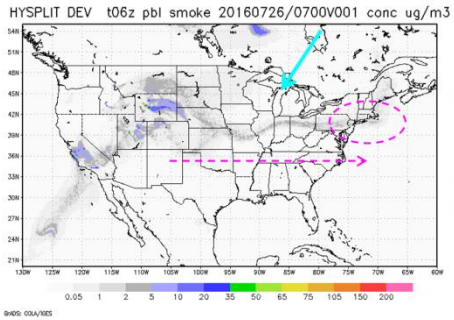
Courtesy Ho-Chun Huang, EMC

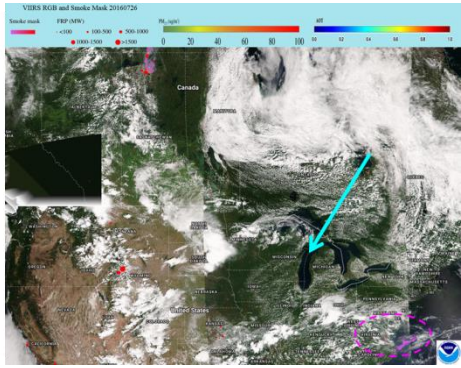
May 2016 Ft McMurry (Canada) Fires



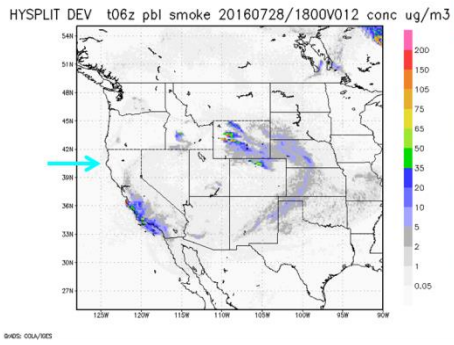


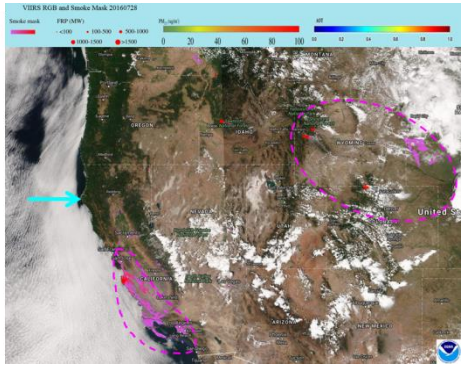
July 2016 Northern Wyoming Fires





July 2016 California Big Surf Fires





HYSPLIT/Smoke prediction

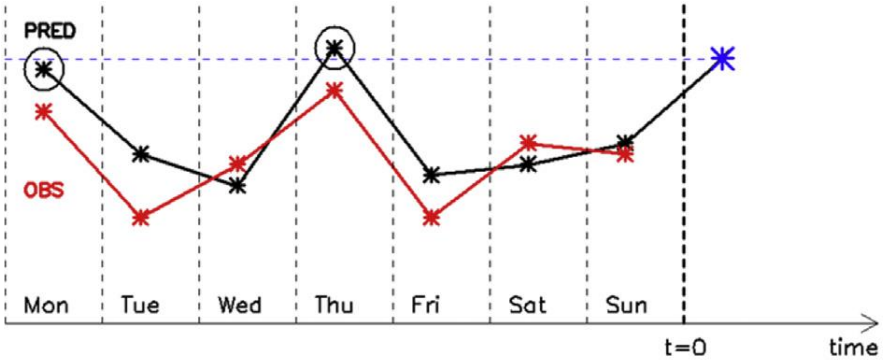
eIDEA Smoke Mask

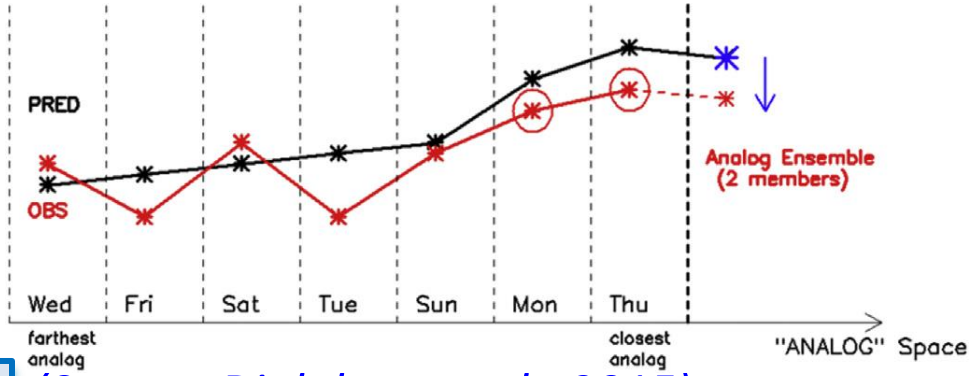
Analog Ensemble for $PM_{2.5}$ Bias Correction

- **Analog metric is determined by (Monache et al. 2011)**

$$\|F_t, A_{t'}\| = \sum_{i=1}^{N_v} \frac{w_i}{\sigma_{f_i}} \sqrt{\sum_{j=-\tilde{t}}^{\tilde{t}} (F_{i,t+j} - A_{i,t'+j})^2},$$

where F_t is current NWP forecast valid at future time t, $A_{t'}$ is analog at past time t', N_v is the number of variables , $\tilde{t}$ is half the number of additional computation time, w_i weight, σ_{f_i} standard deviation





(Source: Djalalova et al., 2015)

Implementation in NAQFC

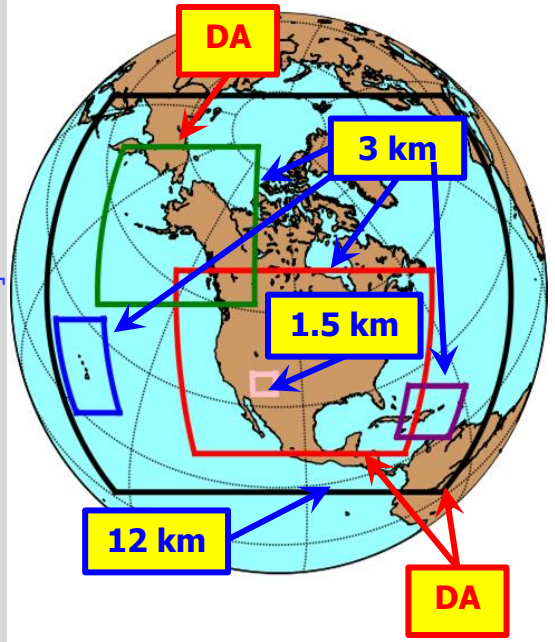
- **Variables for Analog search**: **$PM_{2.5}$, T_2, WS/WD**
- **Ensemble members: 5**
- **Training period**: **one year**

Kalman Filter: adds temporal changes

Courtesy Jianping Huang, EMC

NAM Forecast System - Version 4 (March 2017)

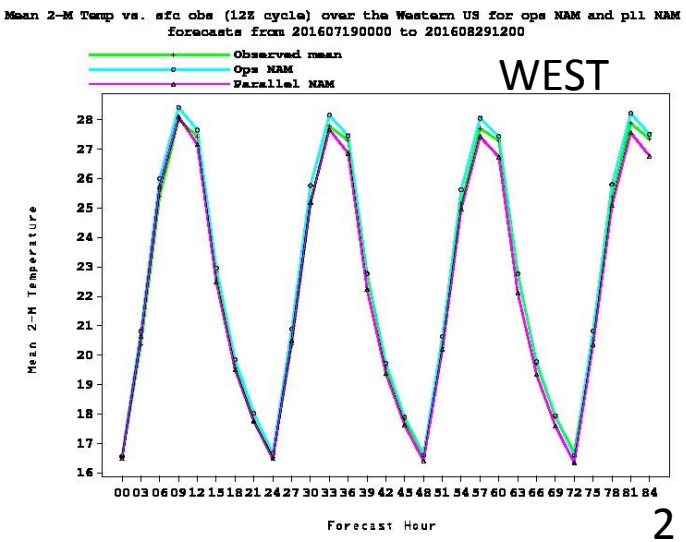
- **Resolution Changes**
  - CONUS (4 km) and Alaska (6 km) nests → **3 km**
  - Sync AK and CONUS On-Demand Fire Weather nests → **1.5 km**
- **Select Model Changes**
  - Updated microphysics → **Improved stratiform precip., better anvil reflectivity, lower peak dBZs, smaller areas of light/noisy reflectivity (rain treated as drizzle), improved nest QPF bias in warm season, Reduce incoming SW Rad under clouds; reduce warm season 2-m T warm bias**
  - More frequent calls to physics → **Physics/dynamics more in sync (e.g. improved upper air, improved nest QPF)**
  - **Improve effect of frozen soil on transpiration and soil evaporation → Improve cold season 2-m T/Td biases**
  - Adjustment to convection in 12 km NAM → **Improve QPF**
  - Modify latent heat flux treatment → **Improve visibility along CA coast**
- **Data Assimilation:**
  - DA cycles for 3 km CONUS and AK nests → **Much less 'spin-up' time**
  - Use of Lightning and Radar Refectivity-derived temperature tendencies in initialization
    - **Improved short-term forecasts of storms at 3 km**
    - **Improved 00-12 hr QPF**
  - New satellite radiances, satellite winds → **Improved Inital Conditions**



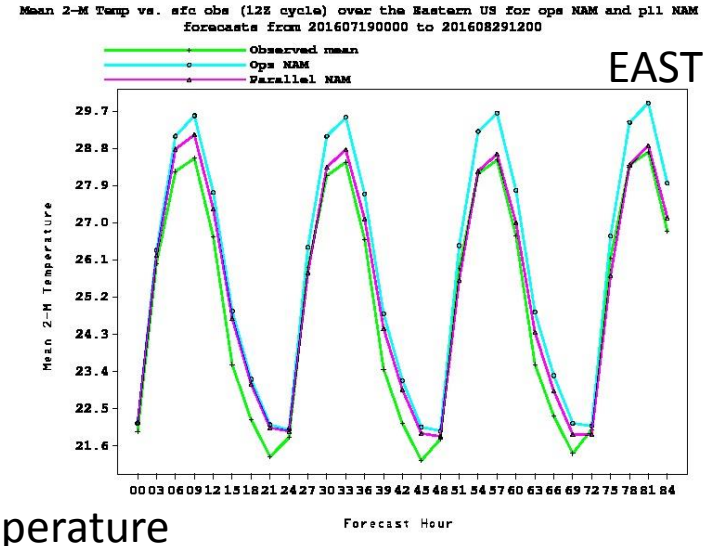
DA: Data Assimilation Cycle

Courtesy Eric Rogers, EMC

NAM March 21, 2017 Upgrade

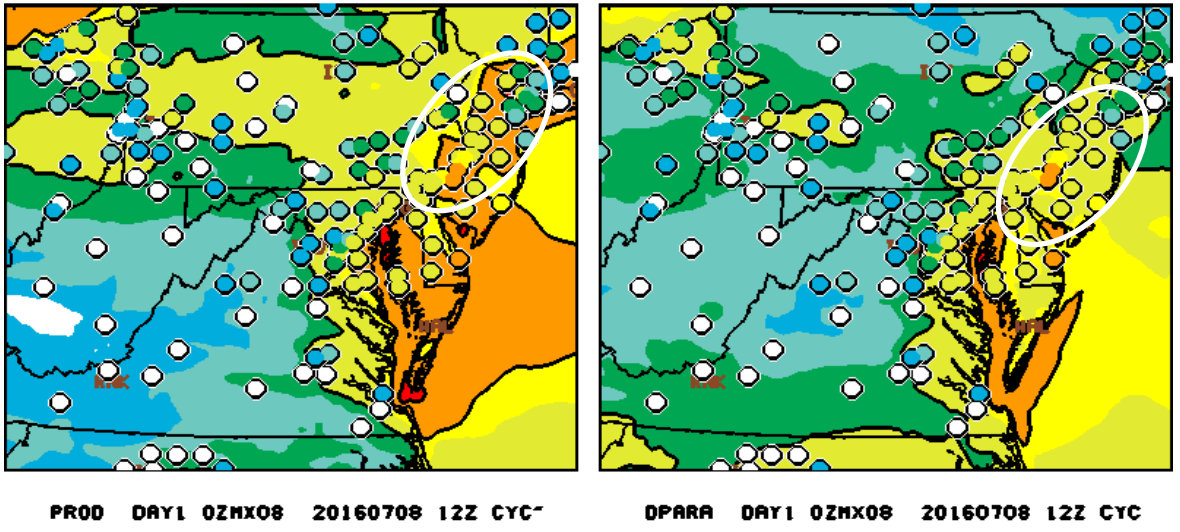


WEST



EAST

2 m Temperature

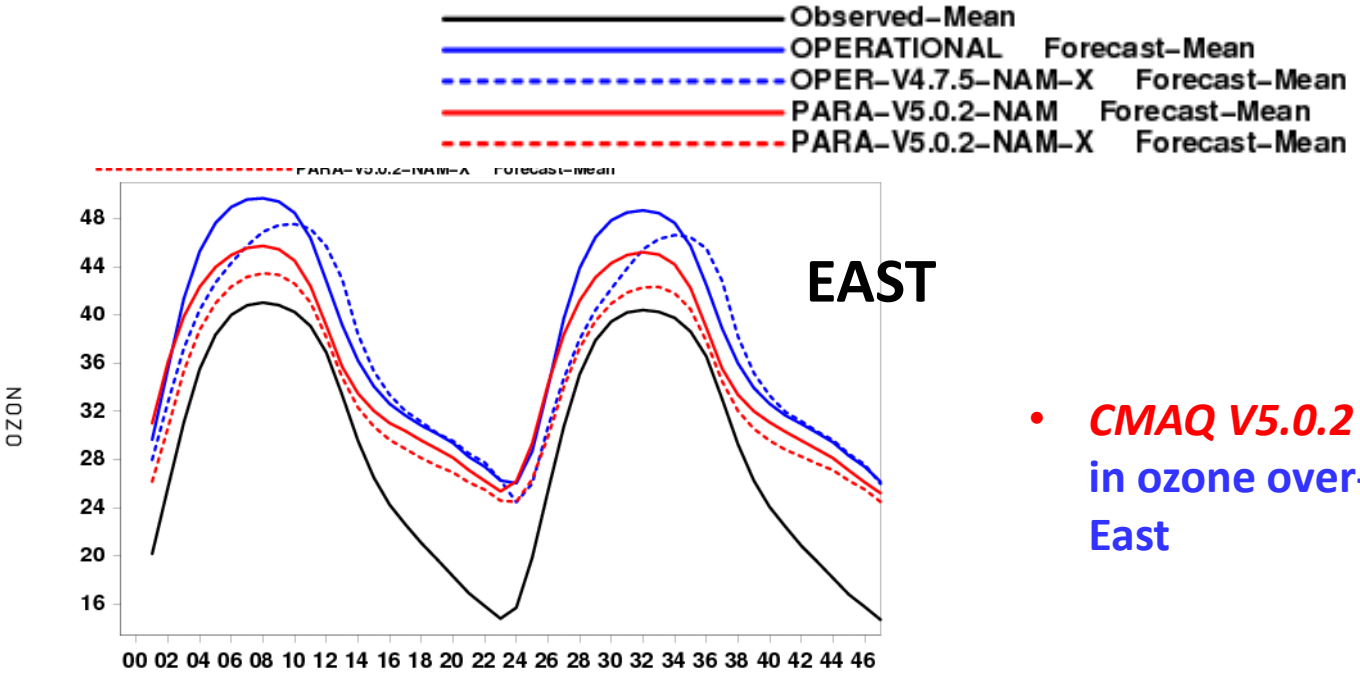


NAM - CMAQ V4.7

NAM-V4 - CMAQ V4.7

July 2016 NRT CMAQ Prod vs V5.0.2

1 h avg Diurnal Ozone



- ***CMAQ V5.0.2 NAM-V4***: improvement in ozone over-prediction over the East
- ***CMAQ V5.0.2 NAM-V4***: Strongest underestimate over West
- Meteorological impact nearly as large as CMAQ/Emissions upgrade

Experiments to address missed exceedences

➢No NOx Adjustment for Mobile Emissions (green line) NAMX

- Cross State Air Pollution Rule (CSAPR) 2011 Mobile Emission
- Should result in increased ozone product

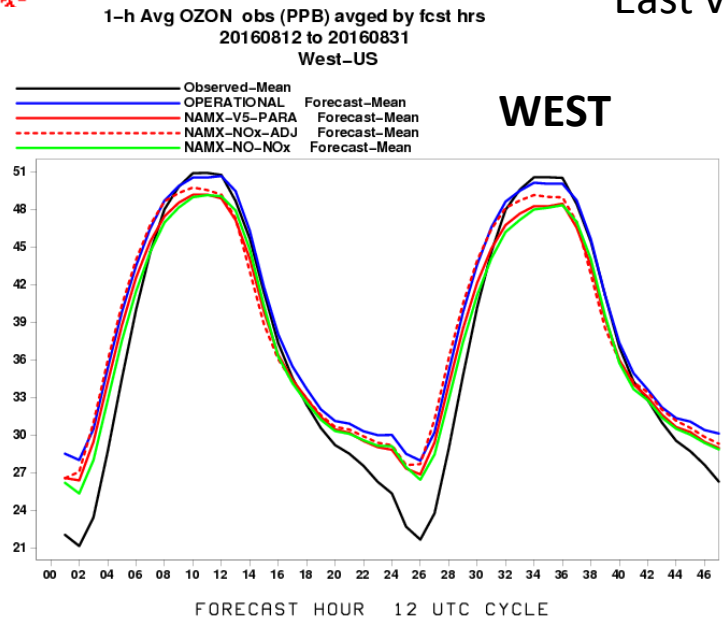
➢*Gridded NOx Mobile emission adjustment (red line) NAMX*

- Adjustment factor also considers fine-scale features by taking into account the12 x 12 km grid-by-grid satellite-observed NOx to NAQFC forecasted NOx ratio

➢ V5.0.2 Para：State wide NOx adjustment using NAM

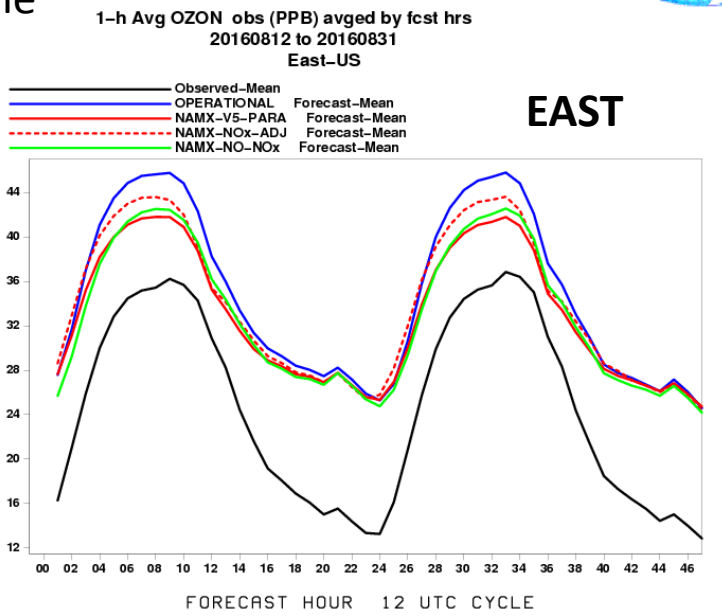
August 2016

East vs West Ozone



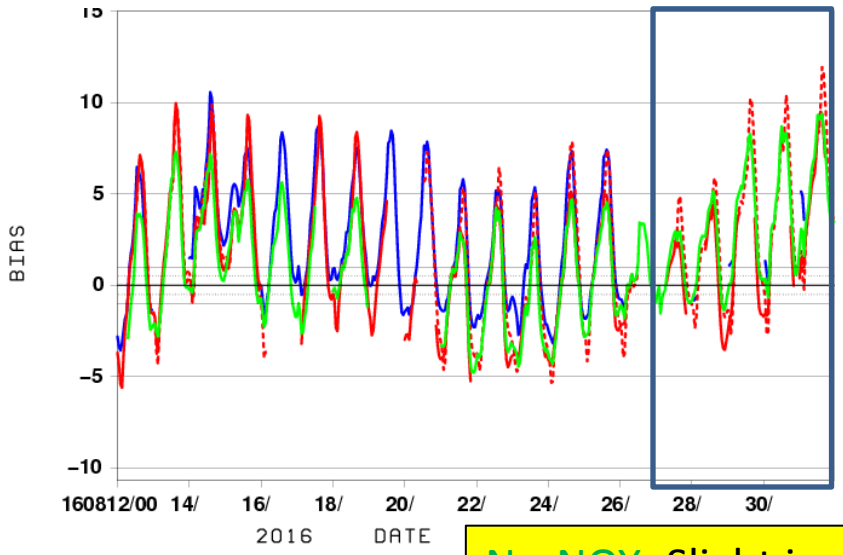
WEST

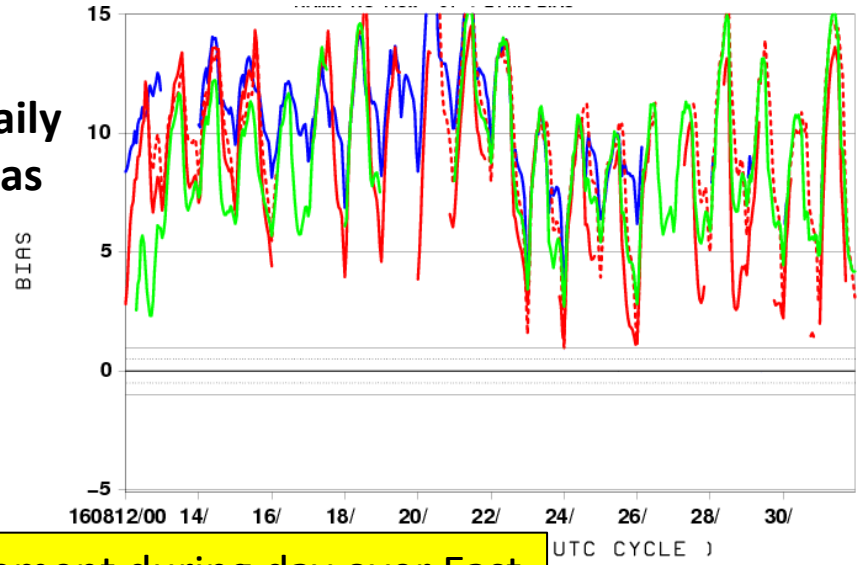
DIURNAL



EAST

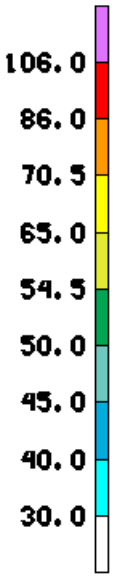
Daily Bias

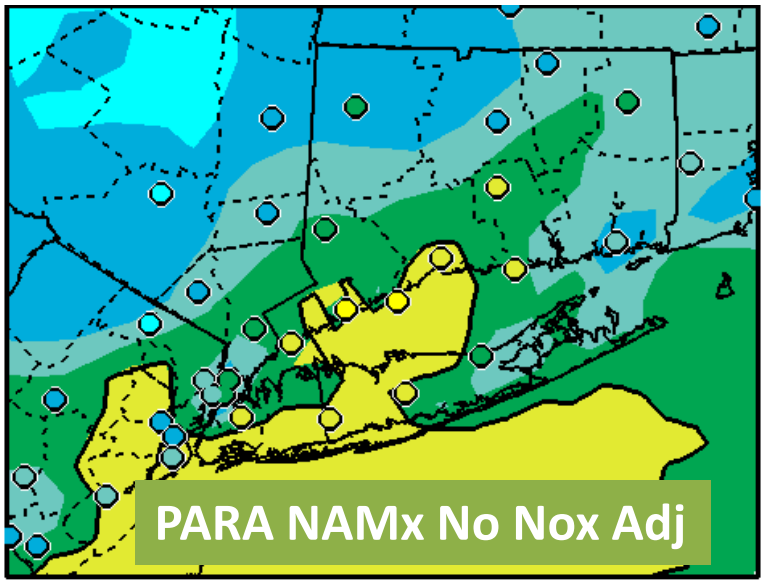




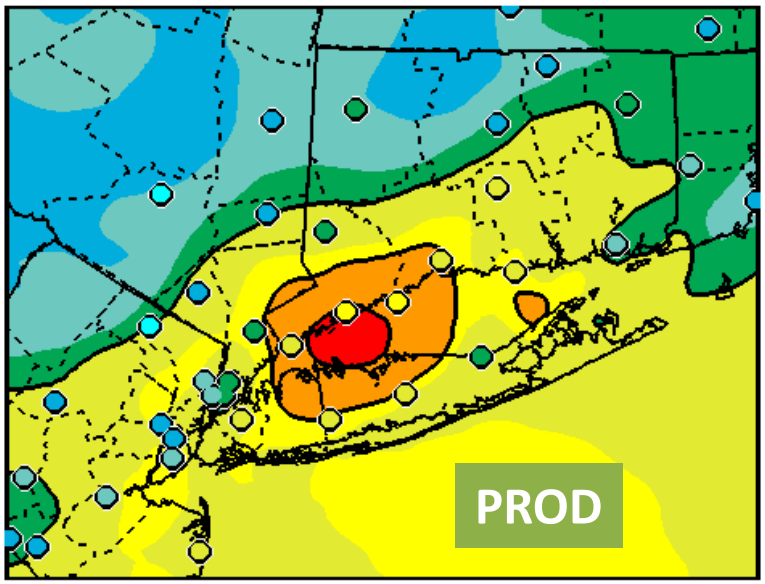
No-NOX: Slight improvement during day over East
Slightly better over West late August

August 18, 2016 Day 1





PARA 4X-DAY NAM-X NONOX DAY1 OZMX08 20160818 12Z CYC

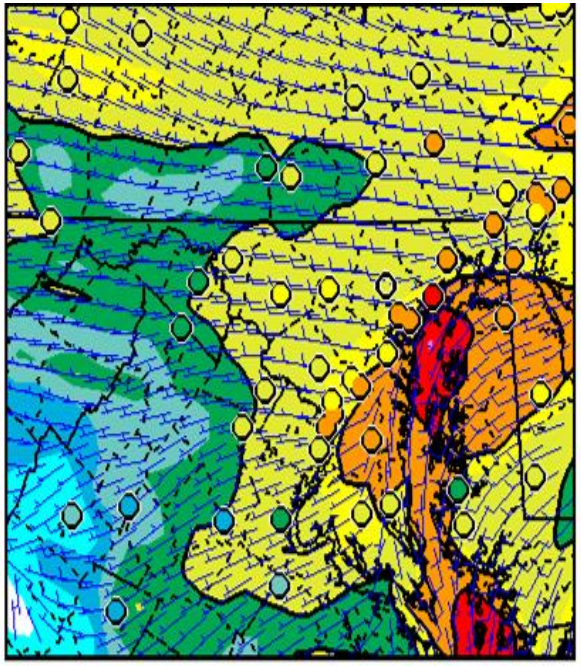


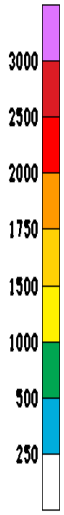
PROD AQM DAY1 OZMX08 20160818 12Z CYC

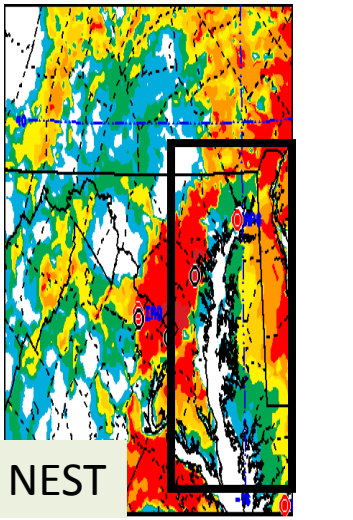
- NAMx showed a great improvement over PROD;
- NAMx eliminated the four false alarms.

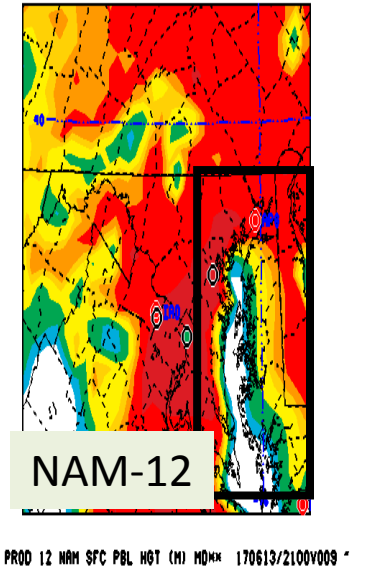
Courtesy Mike Geigart, CT DEP

June 2017 PBLH Evaluation

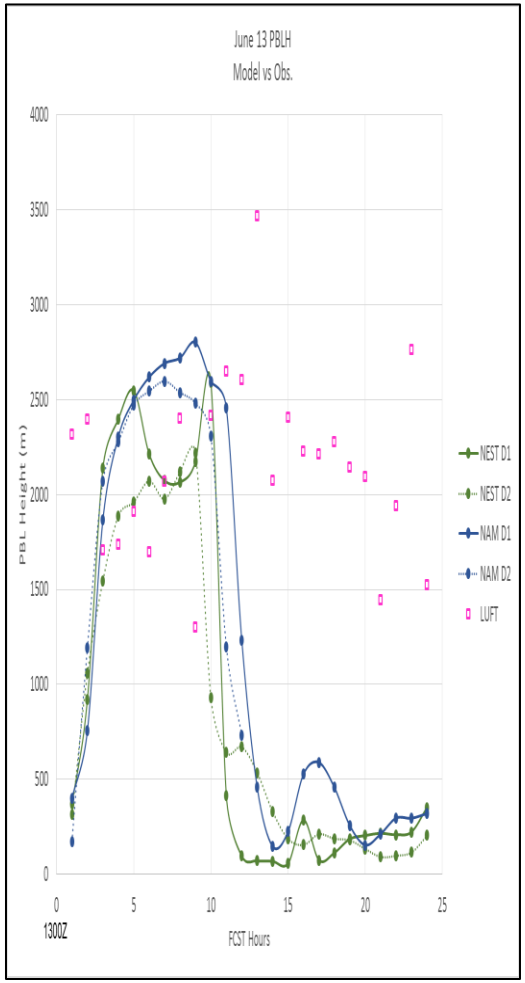








NAM vs Howard U. – Beltsville ceilometer PBLH

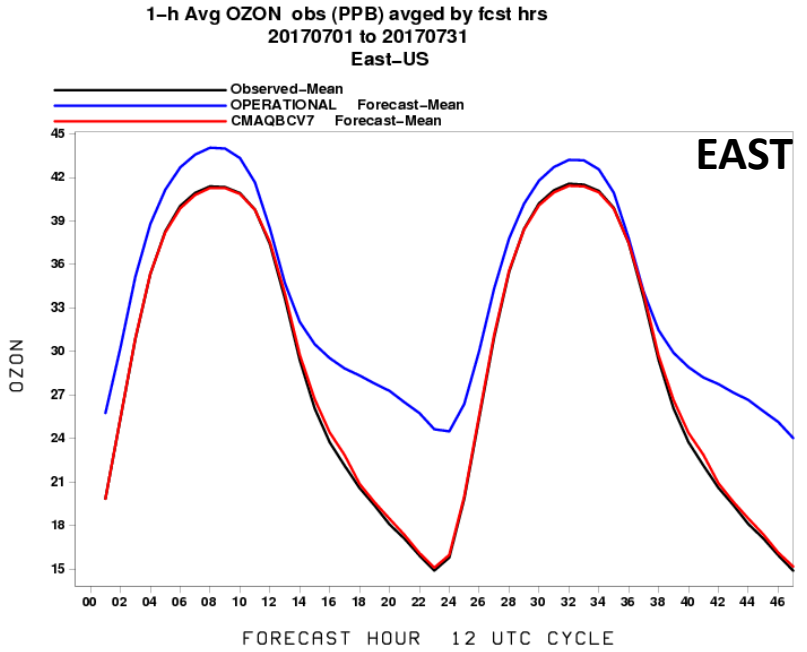


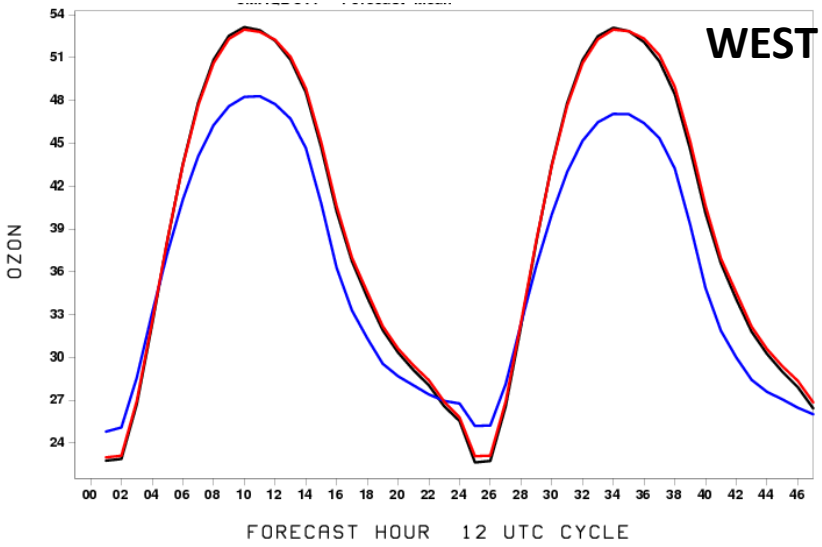
- Winds coming from the bay brought the marine air inland
- The NAM NEST 3km tended to bring the MBL further inland in the northern Chesapeake bay area, especially north of Baltimore

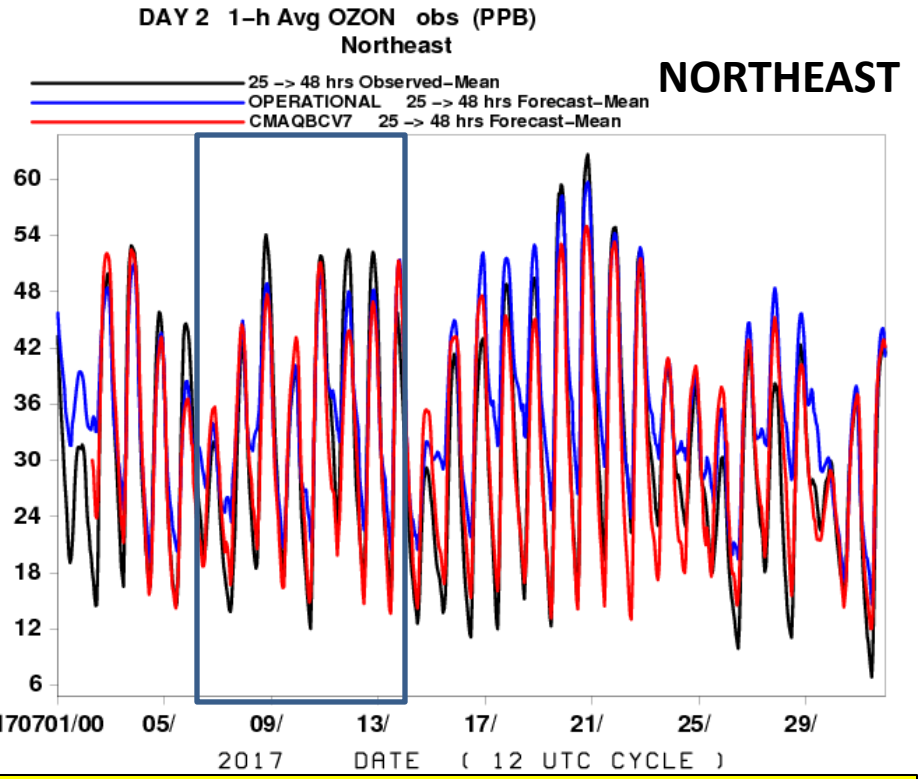
Courtesy: Amanda Sleinkofer

Ozone Errors: July 2017

Obs vs Raw vs Bias Corrected







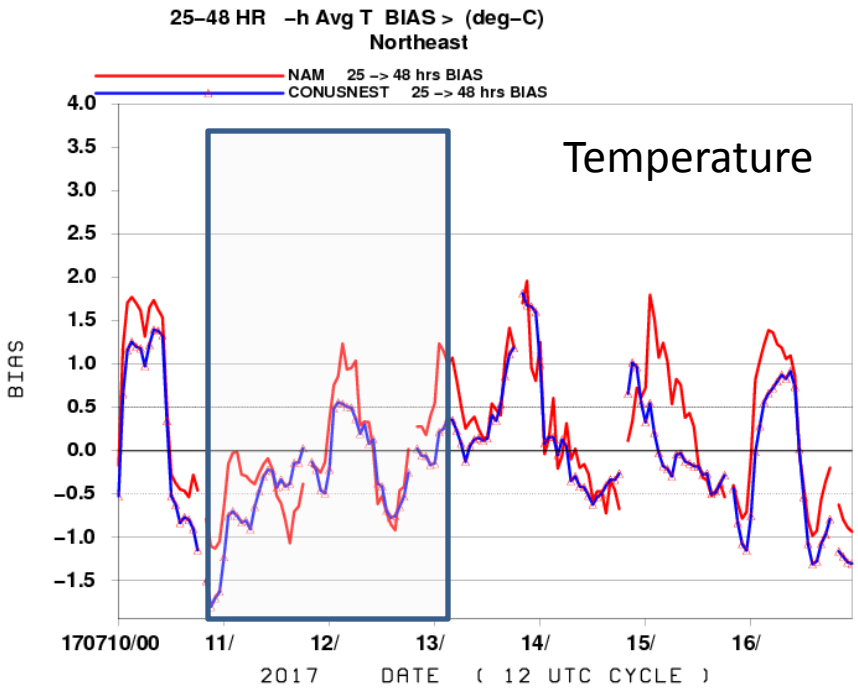
East : Overprediction overall but underprediction for July 10-12 exceedences

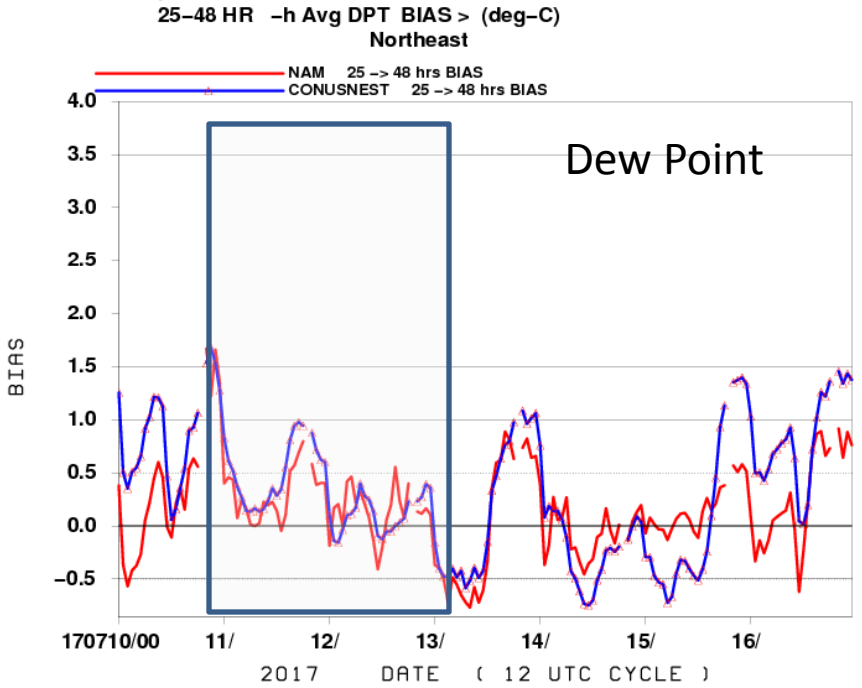
West: Continued underprediction

<u>O3 BIAS CORRECTION</u>:

→ Diurnal performance good, overcorrects some events (July 10-12, 18-21)

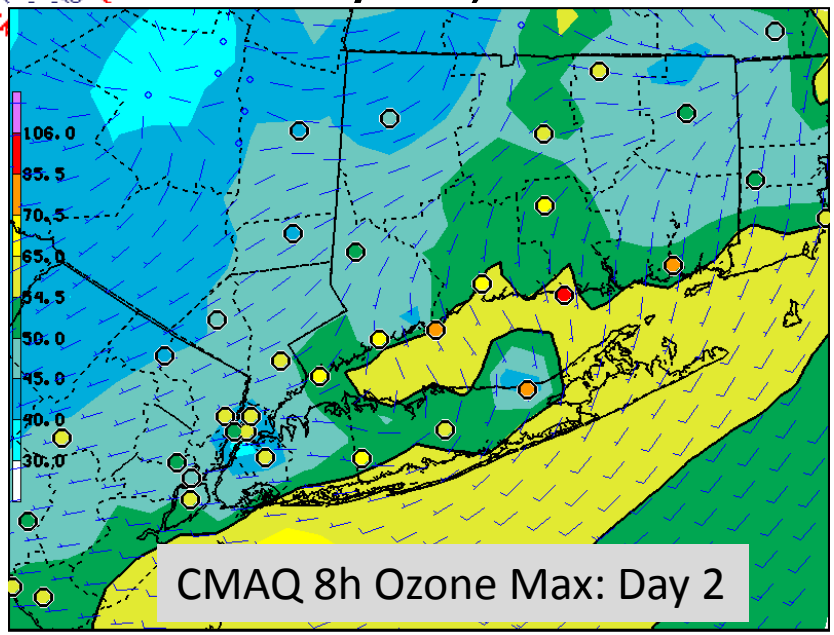
NE 25-48h T/Td Bias NE U.S.
July 10-16, 2017



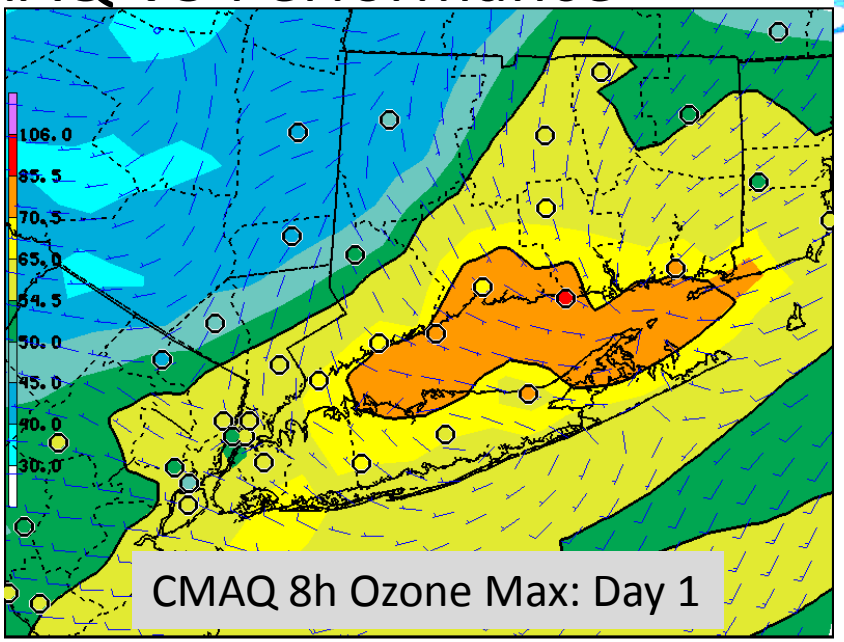


Cool, moist biases on 11th and 12th coincides with ozone underprediction

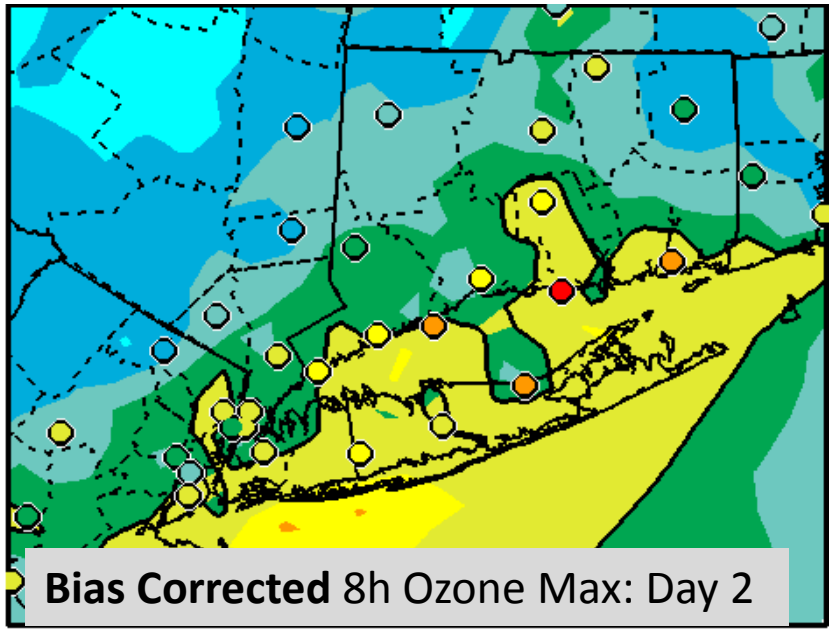
July 12, 2017 NAM-CMAQ V5 Performance



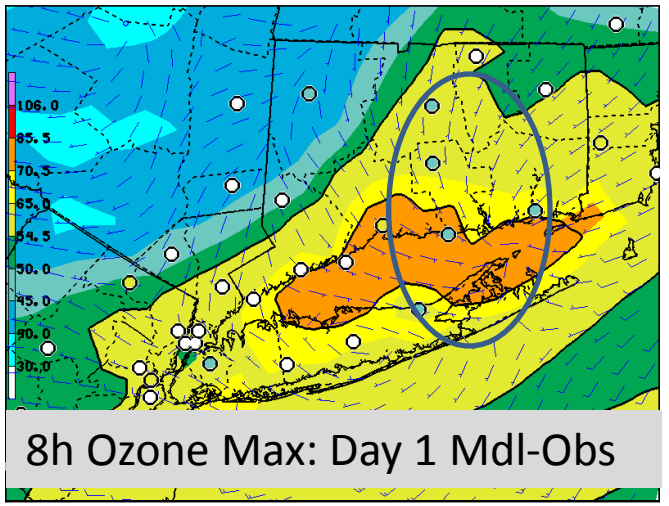
CMAQ 8h Ozone Max: Day 2



CMAQ 8h Ozone Max: Day 1



Bias Corrected 8h Ozone Max: Day 2

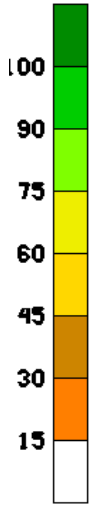


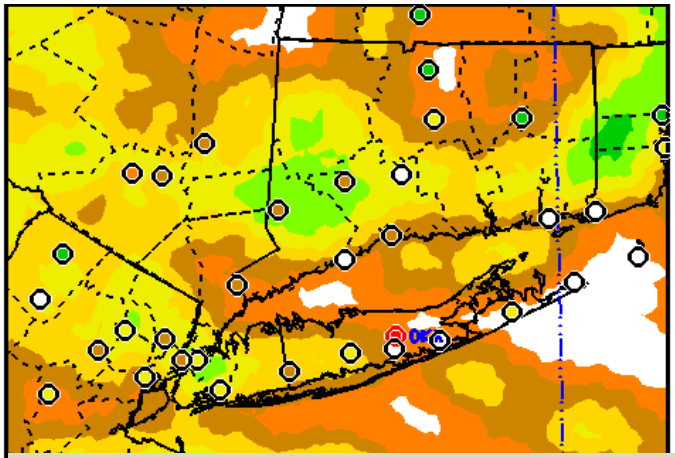
8h Ozone Max: Day 1 Mdl-Obs

- Continued less ozone predicted for day 2
- O3 Bias correction.improved over LI

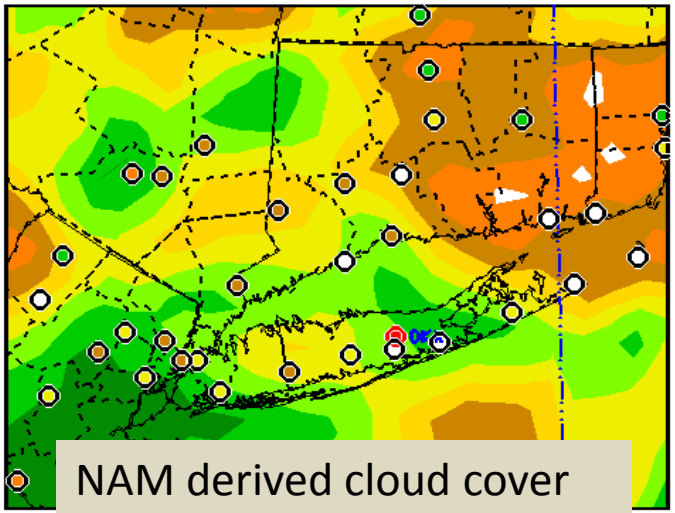
July 12, 2017 NAM-CMAQ V5 Performance

NE U.S. NAM,Nest, CMAQ 7/11/ 12Z 33 h Cloud Cover

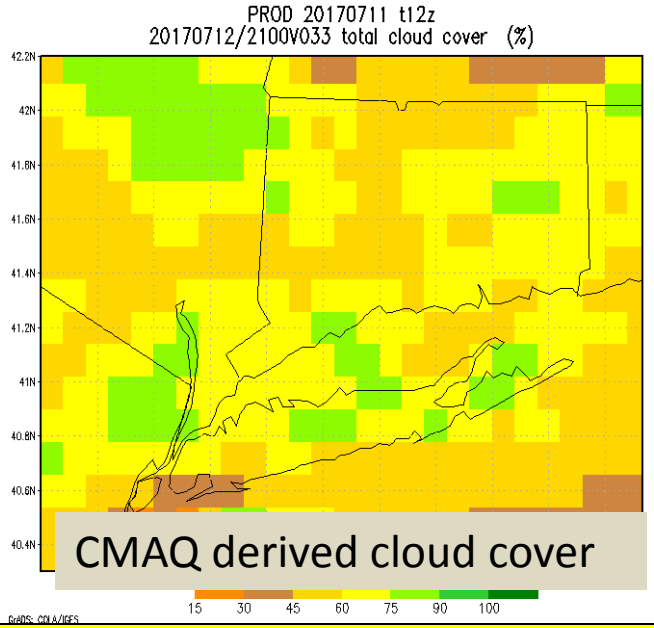




NAM Nest derived cloud cover



NAM derived cloud cover



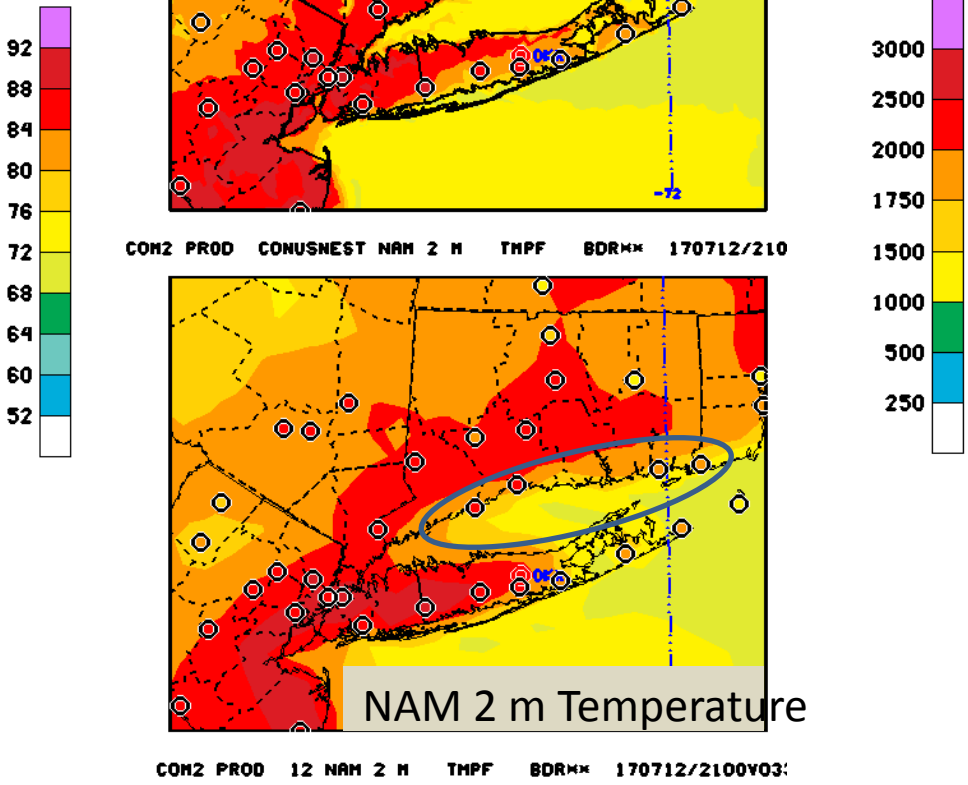
CMAQ derived cloud cover

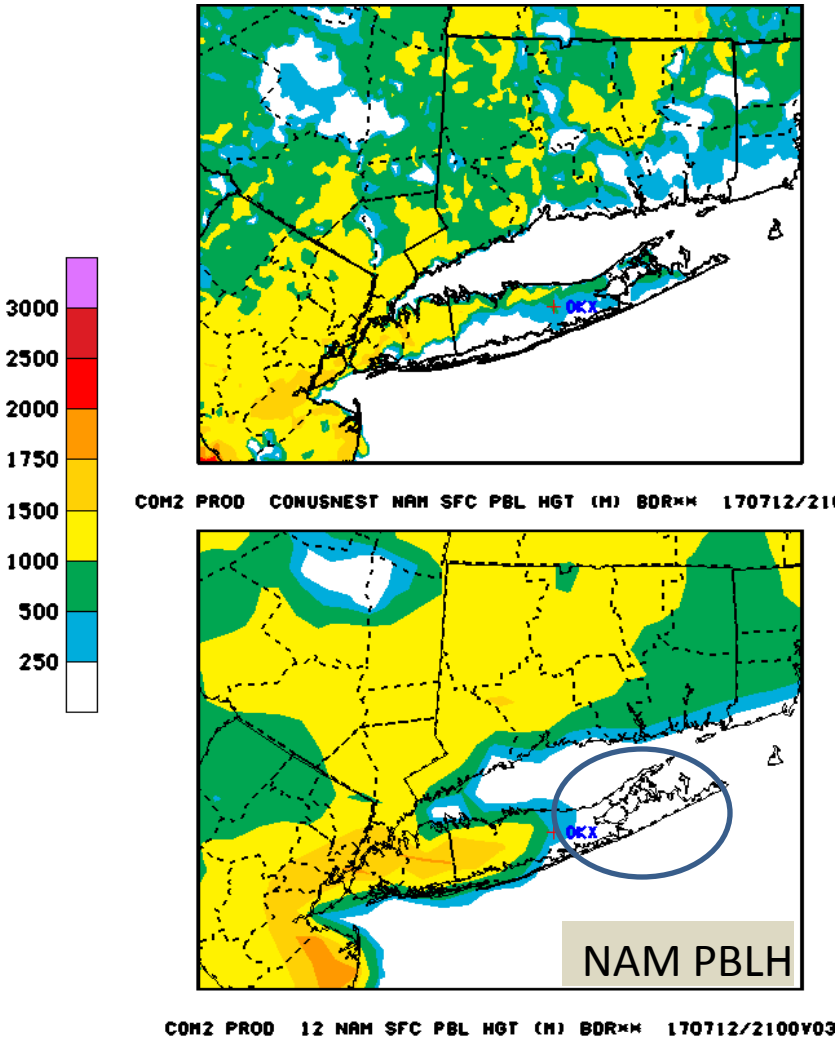
- NAM-12 cloud cover too high and extent too broad, CMAQ less
- NAM nest captures clearing along LIS and CT better

July 12, 2017 NAM-CMAQ V5 Performance

NE U.S. NAM vs Nest 7/11/ 12Z 33 h forecast

2m temperature, PBLH

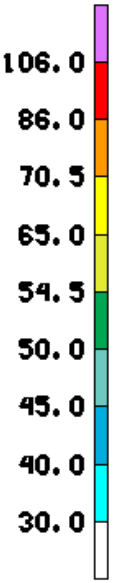


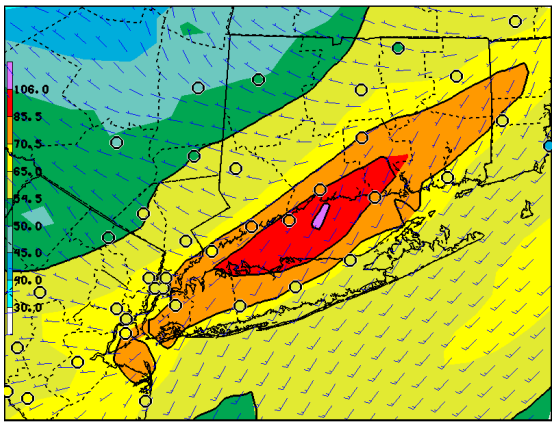


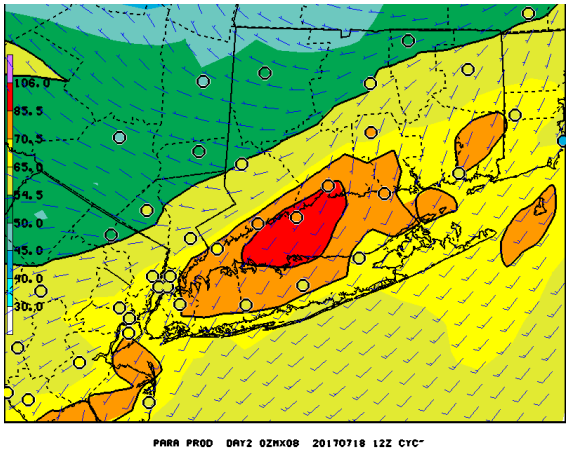
NAM: Temps too cool over CT coast, Nest better

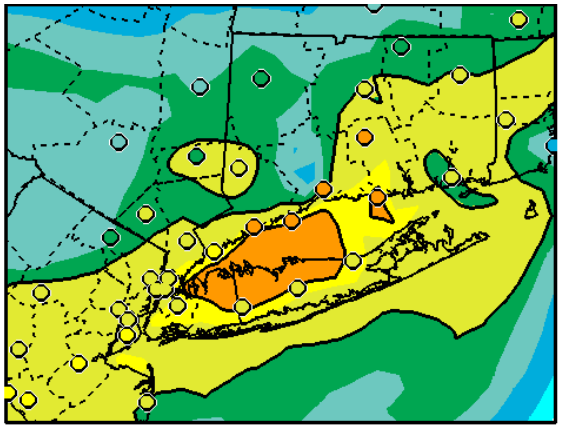
July 19, 2017

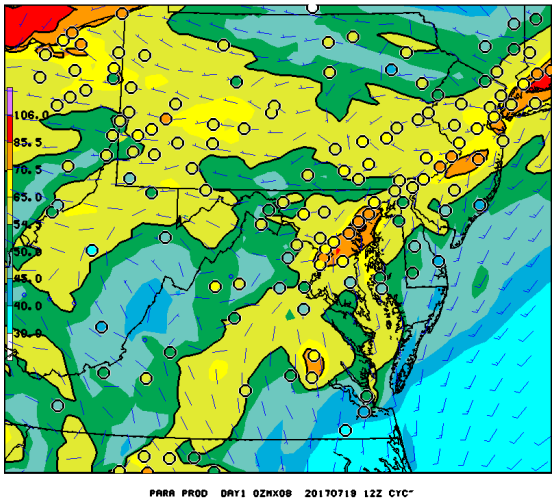
NAM-CMAQ V5 8h Daily max Ozone Performance

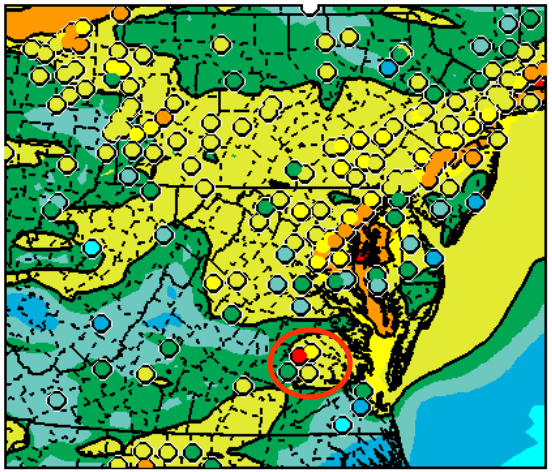


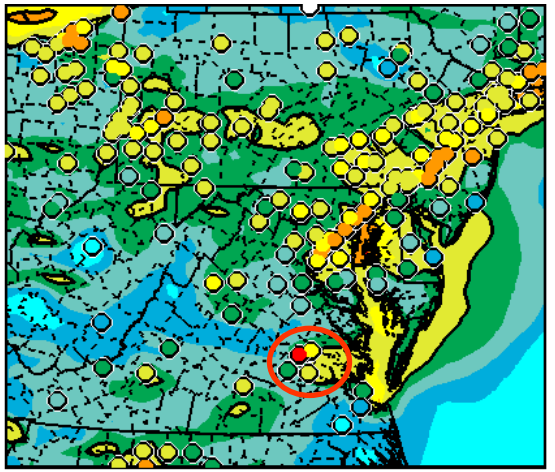












8h Ozone Max: Day 1

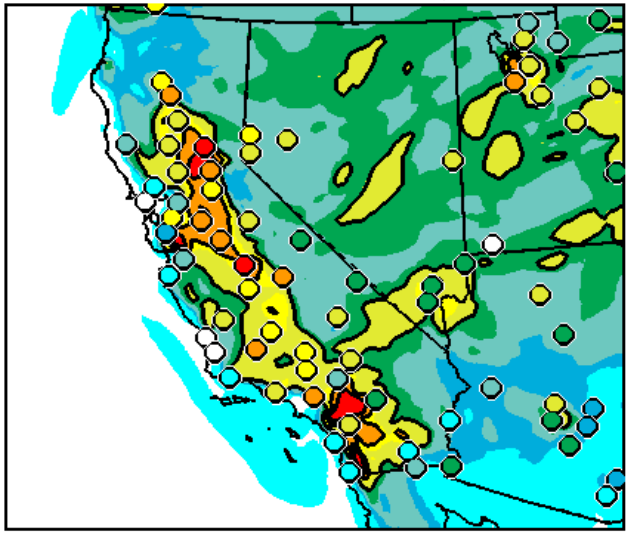
8h Ozone Max: Day 2

Bias corrected

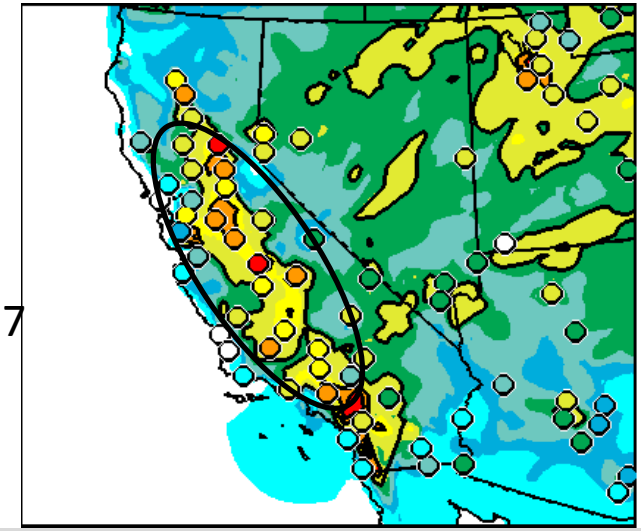
8h Ozone Max: Day 2

NE events captured albiet a bit overestimated by raw model
Underestimated in Western PA, DC day 2 made worse by BC

July NAM-CMAQ V5 Performance

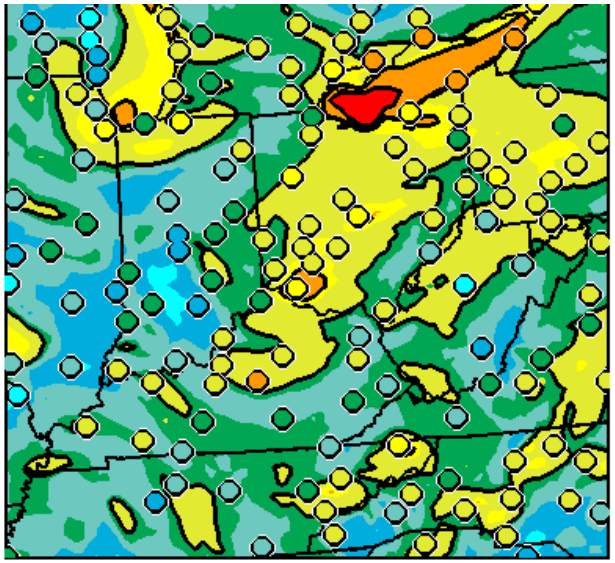


Southwest
July 31,2017

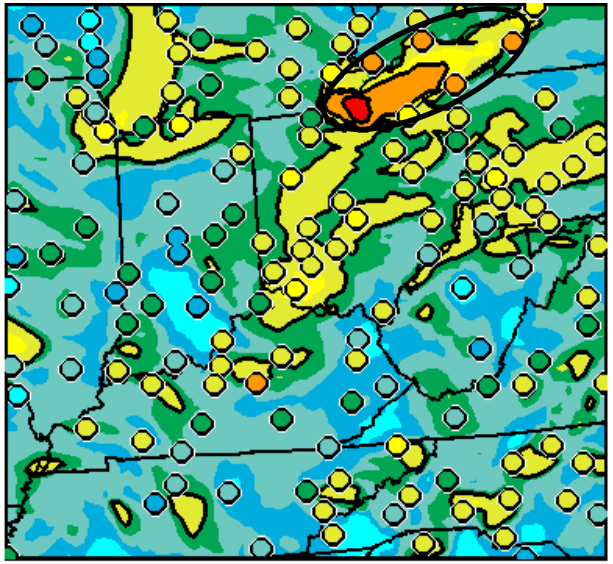


CMAQ 8h Ozone Max: Day 2

Bias Corrected 8h Ozone Max: Day 2



Ohio Valley
July 19, 2017



PROD 4X-DAY DAY1 OZMX08 2017

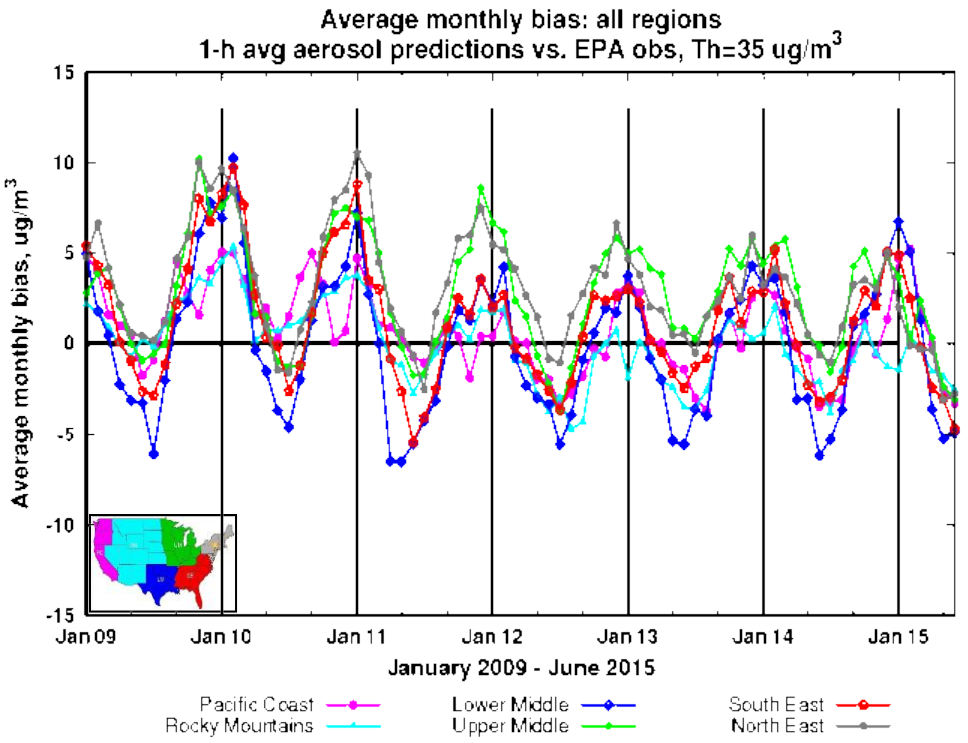
PARABC BIAS COR DAY1 OZMX08 20170719 122

- Continued less ozone predicted for day 2
- BC: Overcorrected in Sacramento & Ohio Valleys

Current issues of $PM_{2.5}$ predictions

- Significant seasonal bias
  - over-prediction in winter
  - Under/over in summer

- Sources of the bias
  - Emissions
  - Met (PBLH)
  - CMAQ chemistry
  - Deposition
  - LBCs

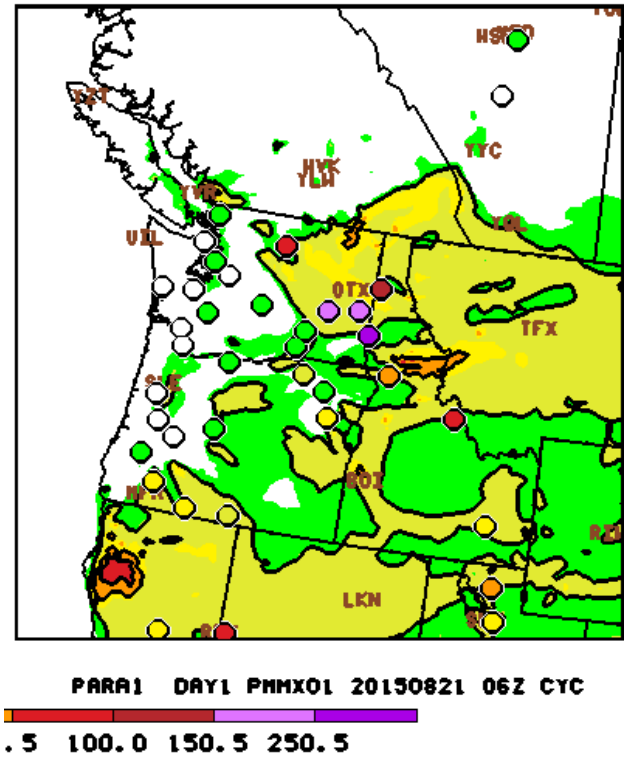


Over-prediction in winter is improving

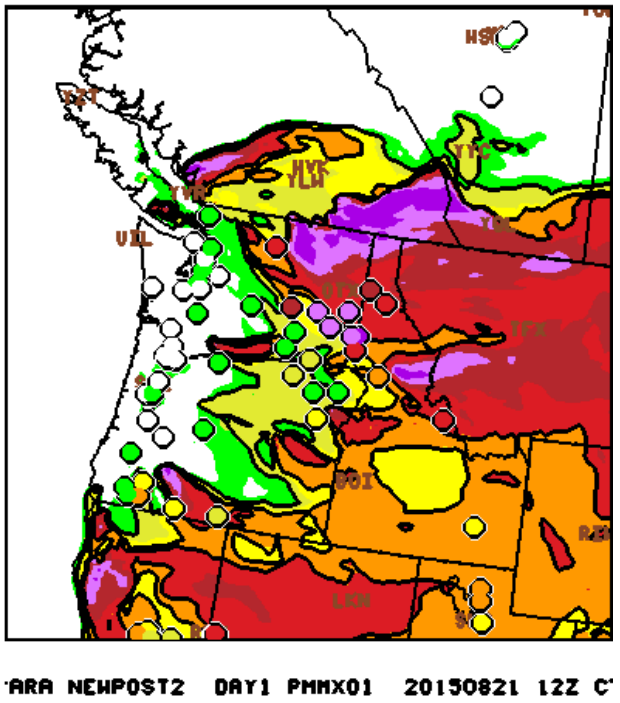
Western Fires

August 21, 2015 1hr PM2.5 Max

Operational V4.7

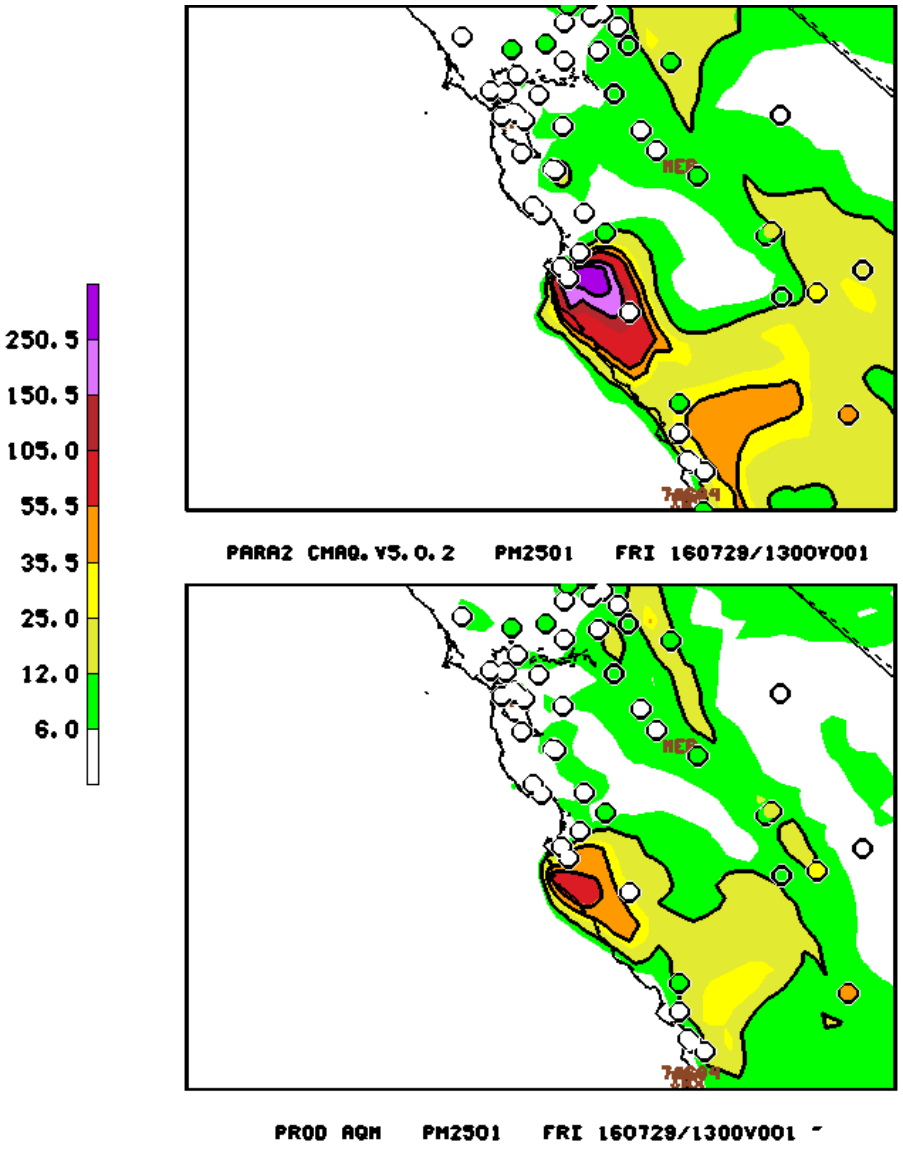


BlueSky v3.5.1 &
Current day locations



Operational runs: Most sites impacted by fire smoke are severely under-predicted.
Experimental tests: Updated BlueSky and use of current day fire info

July 29, 2016 Big Sur Fire forecast and comparison to **PM** measurements

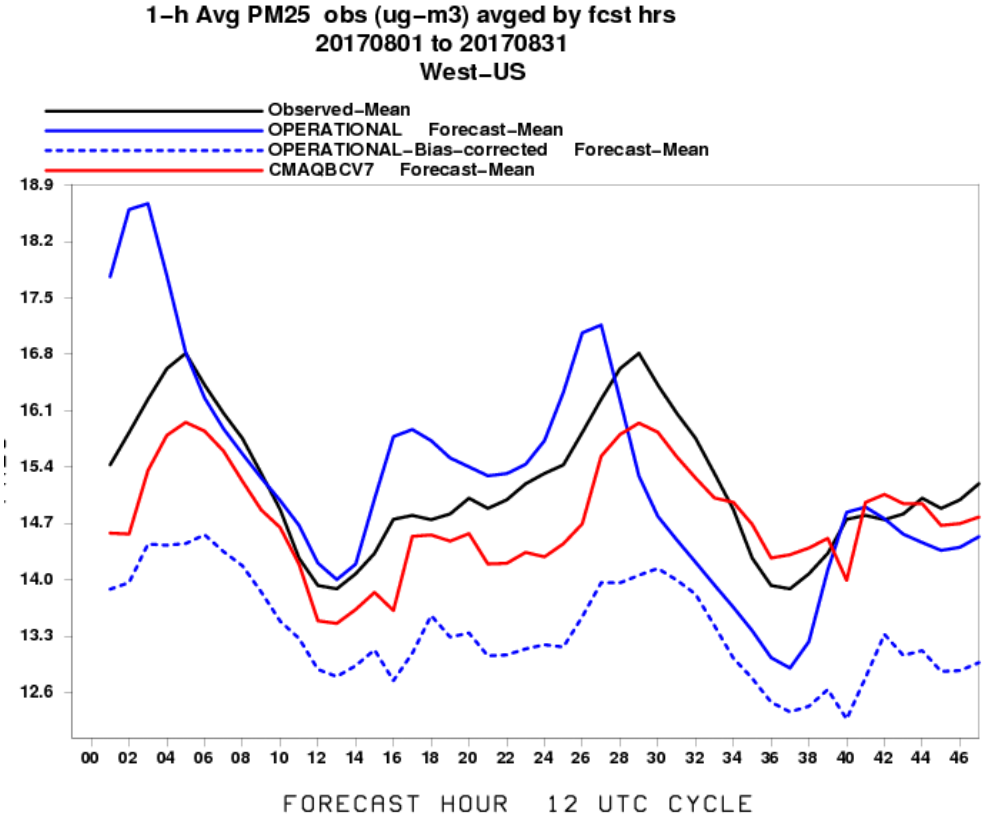


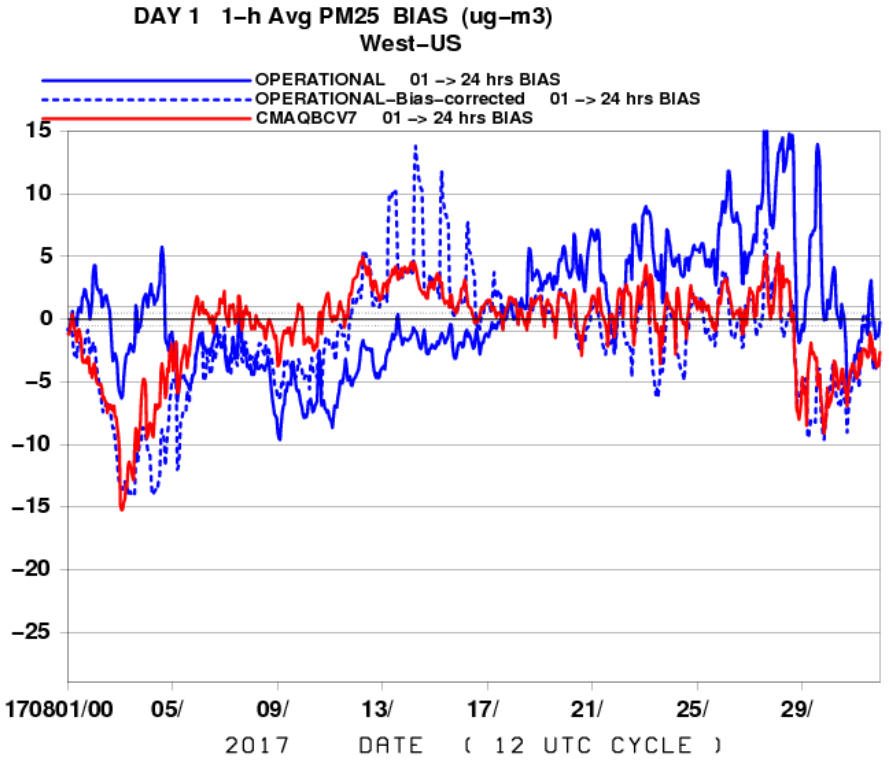
Smoke Emissions

- Location
- Magnitude
- Ejection height
- Diurnal evolution

August 2017 PM Predictions

1 h avg PM BIAS West

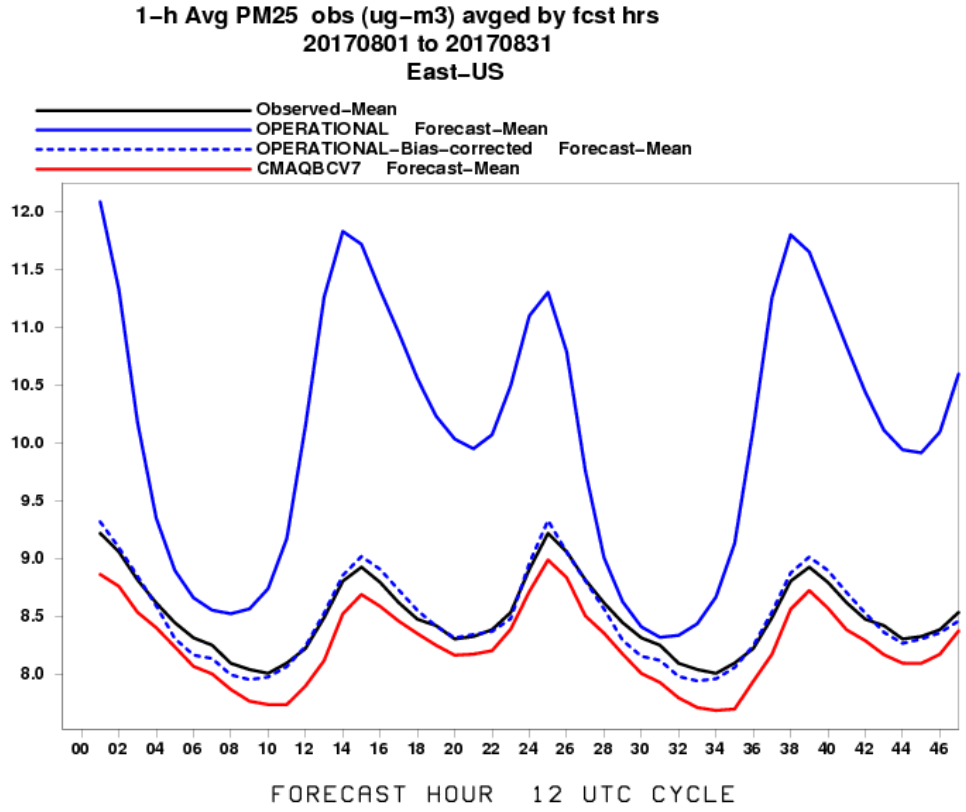


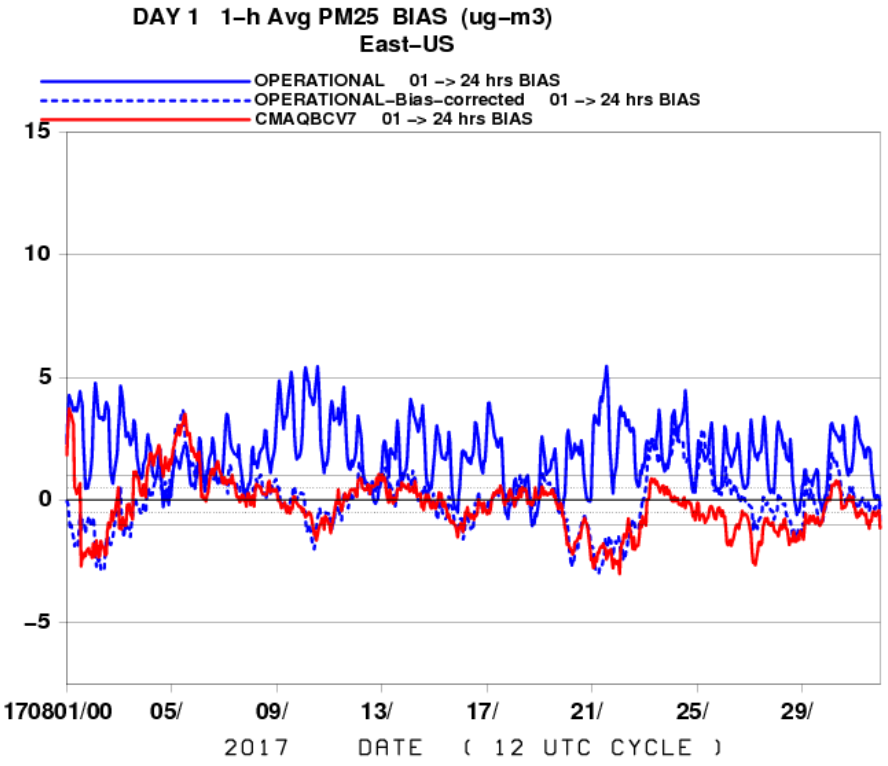


- WEST: Underpredict PM transitions to overprediction.
- *Bias Correction* w/ V5. analogs better than oper BC
- - More consistent smoke event analogs ?

August 2017 PM Predictions

1 h avg PM BIAS EAST

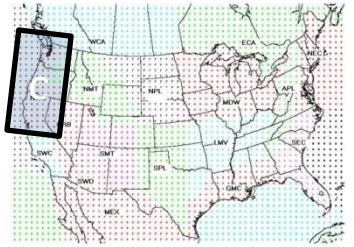


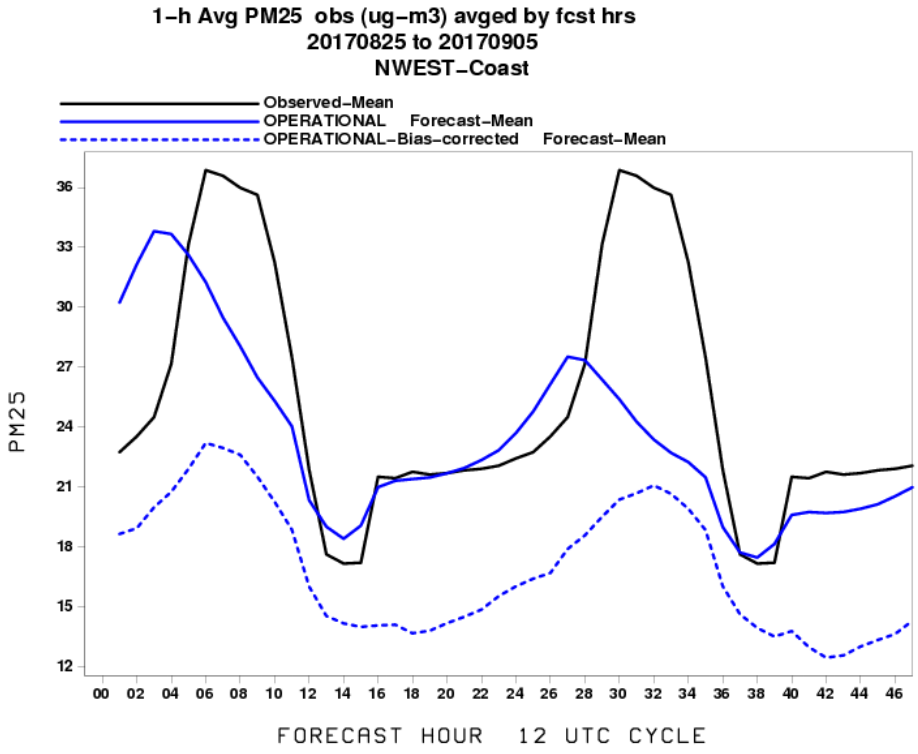


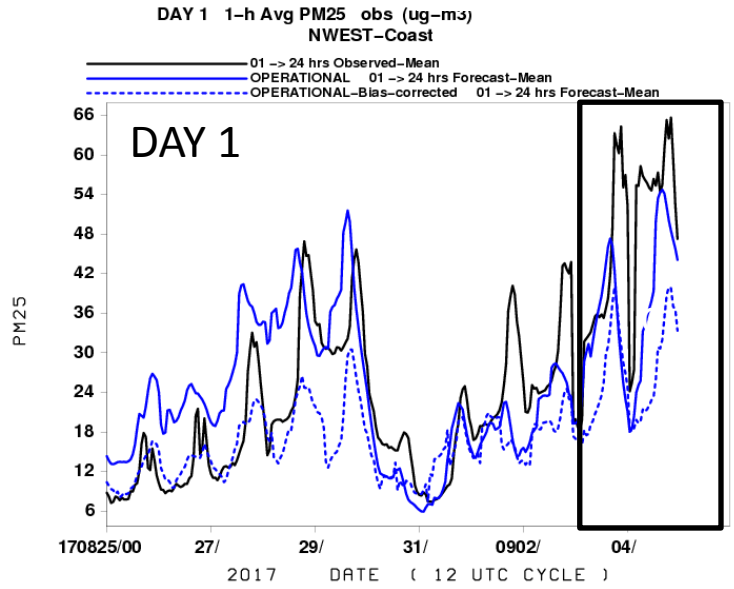
- East: PM overprediction
- *Bias Correction* w/ V5. analogs similar to oper BC

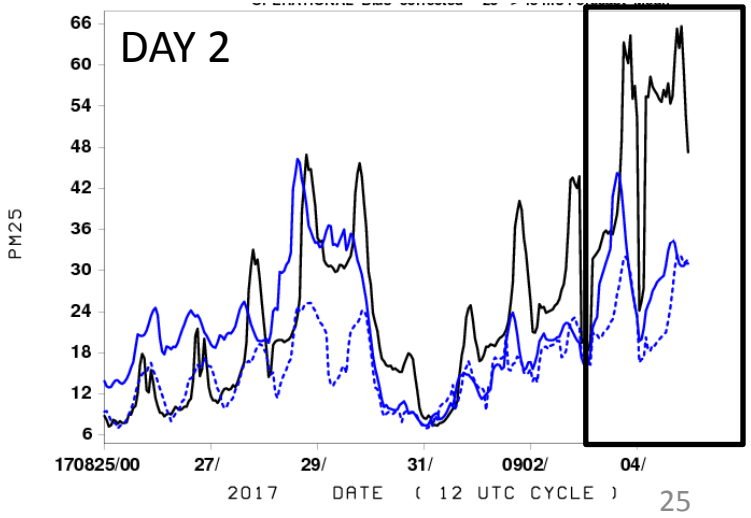
Aug 25-Sept 5 2017 PM Prediction

1 h avg PM : North West U.S. Fires





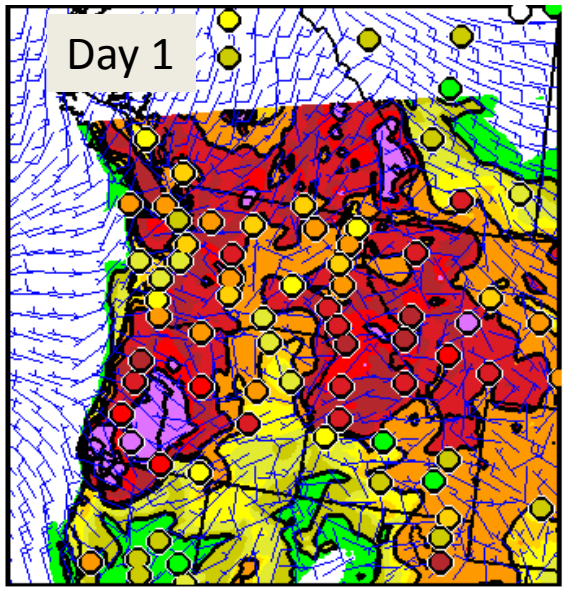


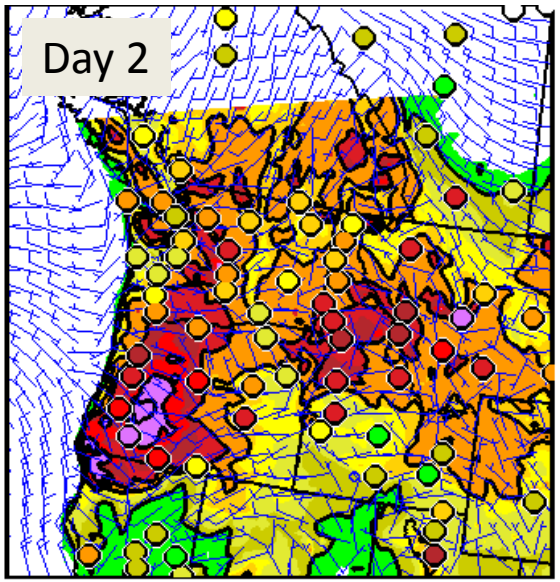


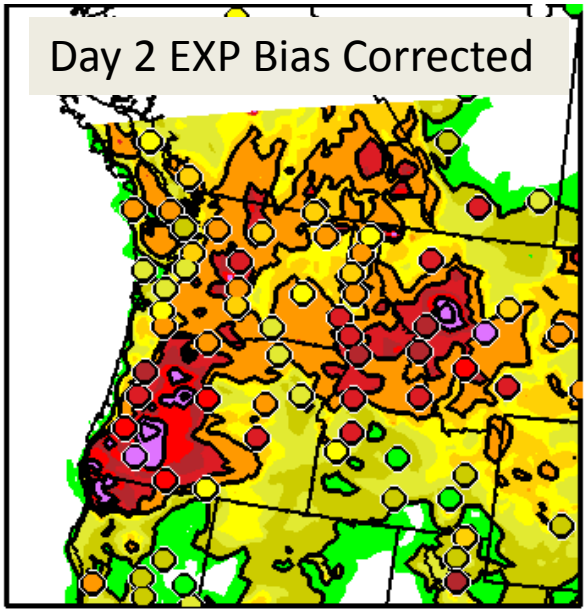
- Underprediction for Day 2 in general BUT :
- Day 1 Overprediction in early morning for smoke events
  - No diurnal emissions profile used
- Oper Bias correction performs poorly for smoke

August 29, 2017 PM Predictions

1 h avg Max PM : North West U.S. Fires



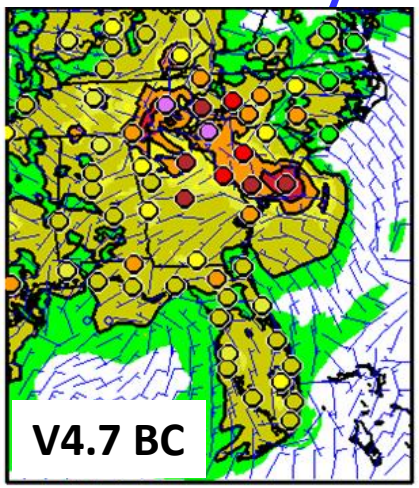


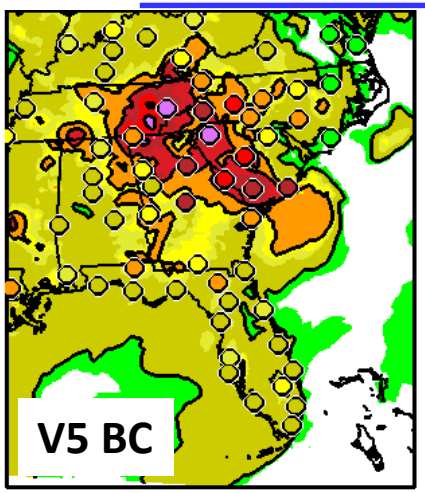


- Pyrocu lofting of smoke
- Less PM predicted for day 2
  - CMAQ :75% fire reduction after analysis responsible ?
- PM KFAN w/ V5 analogs overcorrects

November 15, 2016

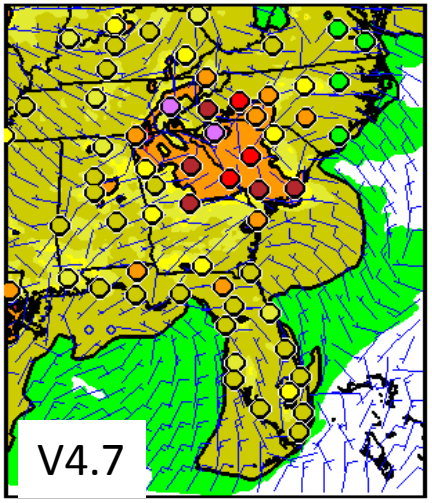
1 h Daily Max PM : South East U.S. Fires

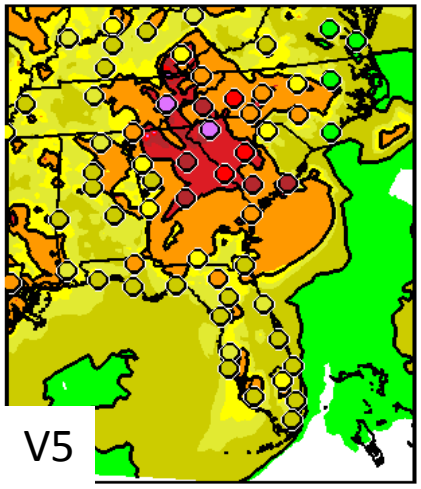




PROD BIAS COR DAY1 PMMX01 20161115 12Z

PARA BIAS BIAS COR DAY1 PMMX01 20161115





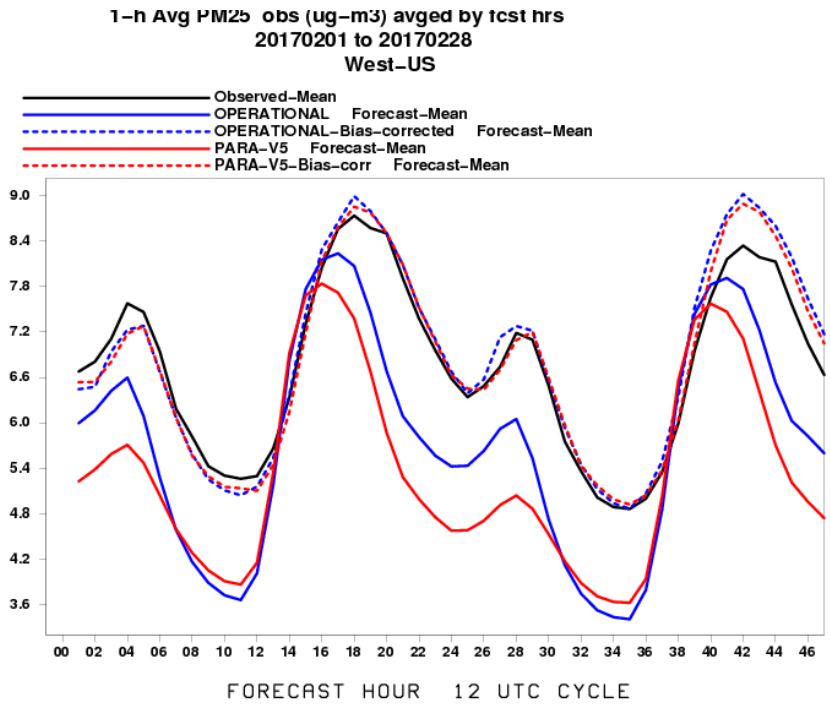
PROD DAY1 PMMX01 20161115 12Z CY

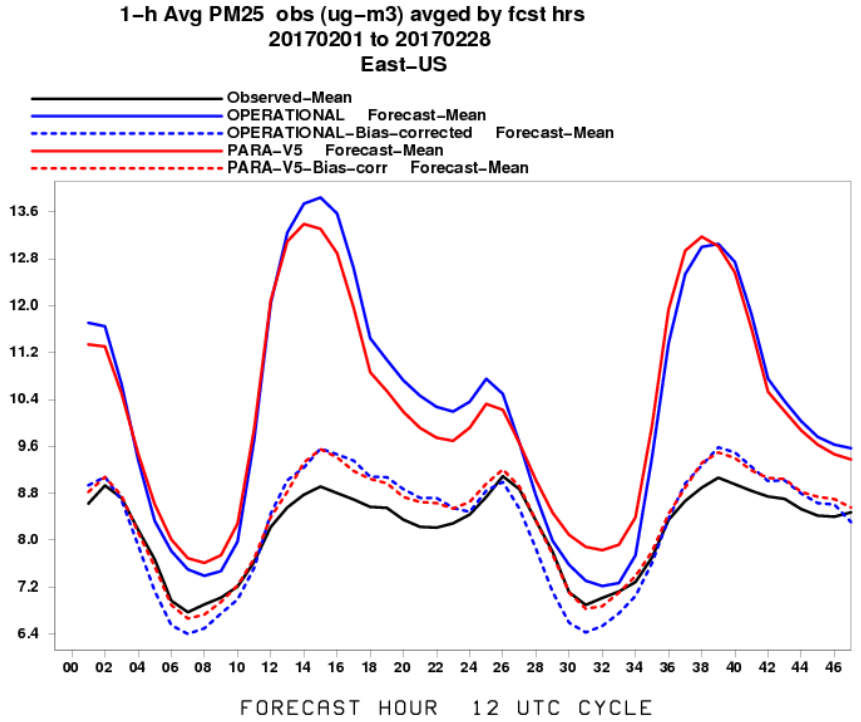
PARA 4X-DAY NAM-X DAY1 PMMX01 20161115

- BC underpredicts fire events, but still closer than other runs

February 2017

East vs West PM and Bias Corrected PM

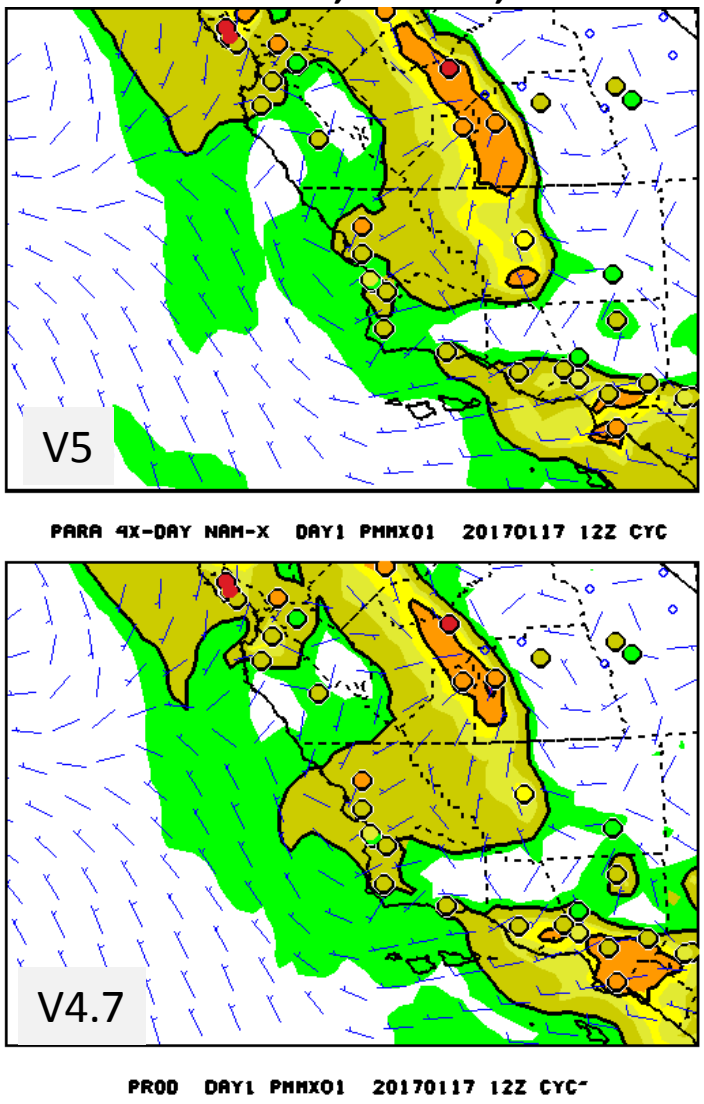




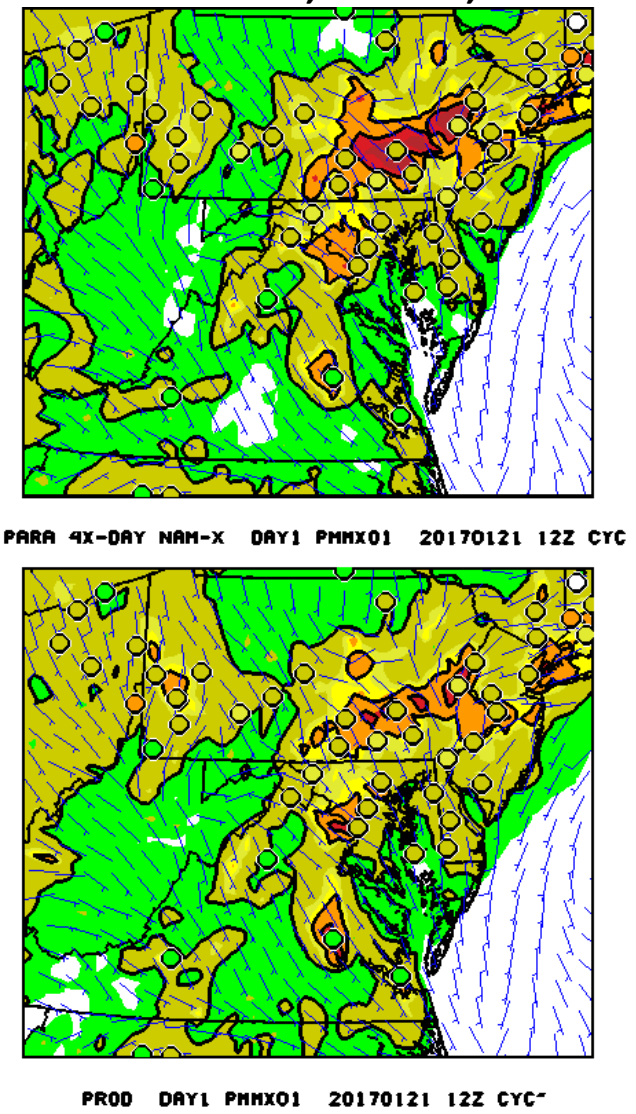
V5.0.2 (red) – Little improvement over CMAQ V4.7
East *Bias Correction* - corrects for strong PM overprediction

Winter Time PM

Southern CA, Jan. 17, 2017



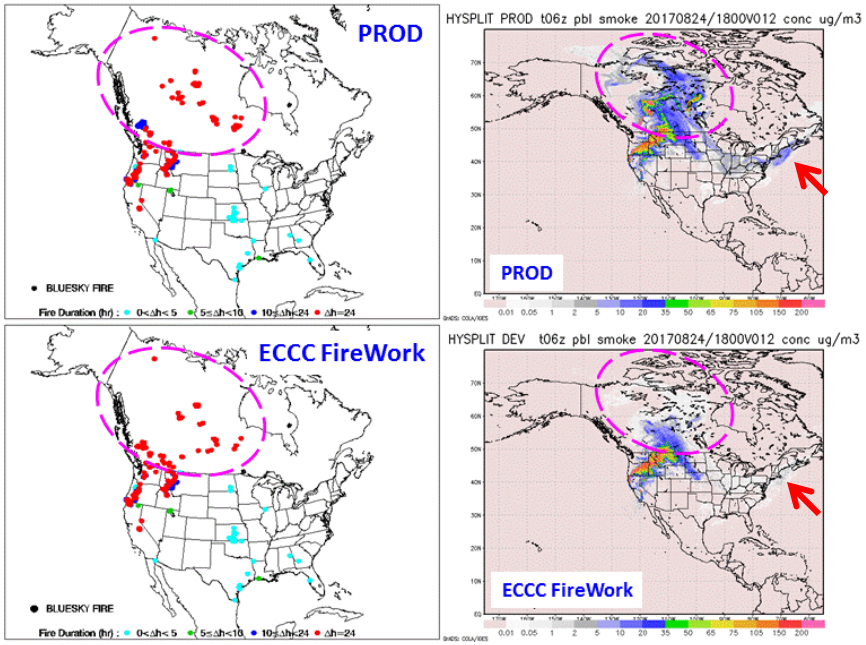
Mid Atlantic, Jan. 21,2017

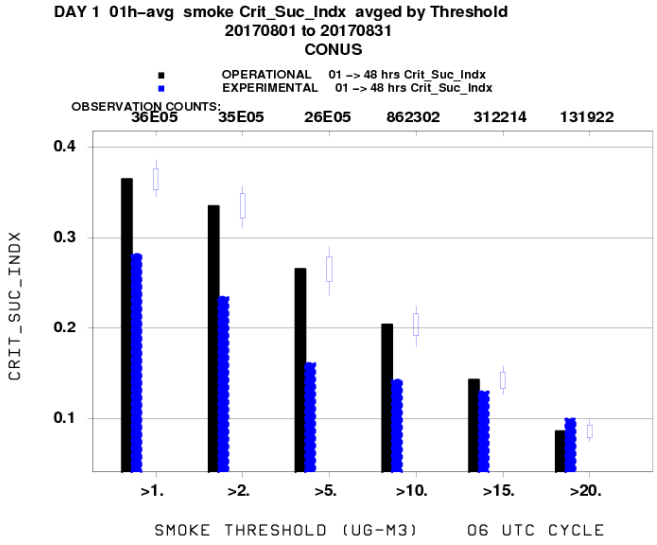


- Improved out west, but overprediction sometimes worsened over East

HYSPLIT : Environment and Climate Change Canada's (ECCC) FireWork Diurnal Hourly Smoke Emission in HYSPLIT/Smoke applications

- Replace NOAA HMS Canadian Fire Emission with ECCC Fire Work Emissions.
- In general, some of the wildland fire locations of ECCC FireWork are different from NOAA HMS.
- Daily fire smoke PM_{25} emissions of ECCC, in general, are less than that of NOAA HMS/BlueSky.
- The impact of different fire emission and diurnal emitted pattern can reach as far as the US East Coast.
- decreased performance w/ ECCC for August 2017 for concentration < 20 µg/m^3. Slightly better for that > 20 µg/m^3.
- **http://www.emc.ncep.noaa.gov/mmb/hchuang/web/html/hysplit_bluesky.html**





Courtesy Ho-Chun Huang

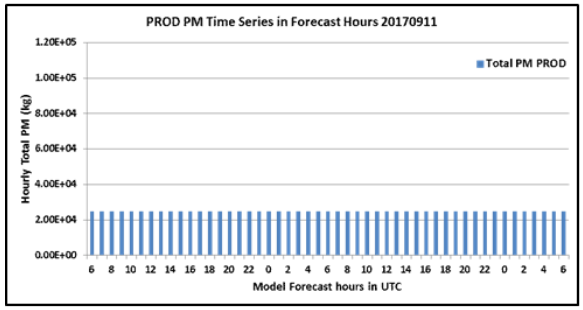
Fire behaviors difference between PROD, PARA, and PARA1 in Forecast Run

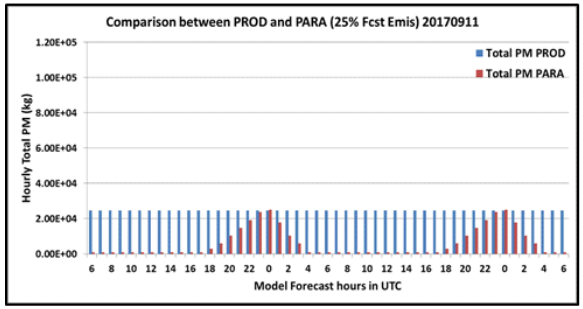
Diagnosis Date : September 11 2017. Selected fire.

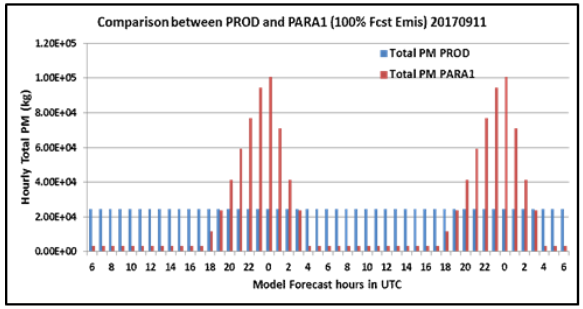
CMAQ : Forecast Runs (48 Hours; 24 Hour duration fires only)

- PROD reduces the PM_{25} emission and Heat in analysis run with 75 % reduction.
- EMC PARA reduces the PM_{25} emission and Heat in analysis run with 75 % reduction. (the summation of 24 hour PM_{25} emissions is 25% of PROD)
- EMC PARA1 uses the PM_{25} emission and Heat in analysis run without reduction. (the summation of 24 hour PM_{25} emissions is the same as that of PROD)
- Comparisons in next slides

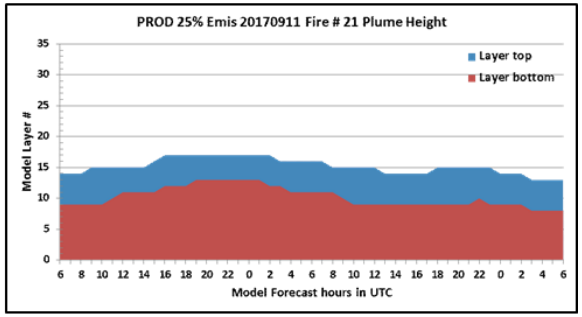
Hourly PM_{25} emission

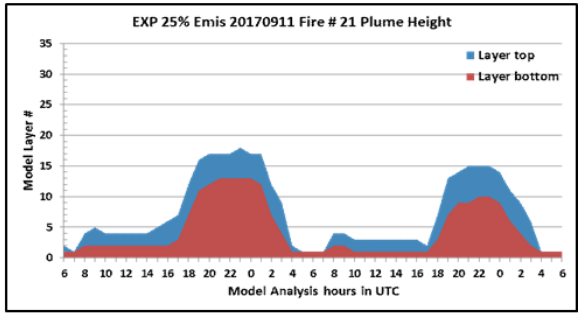


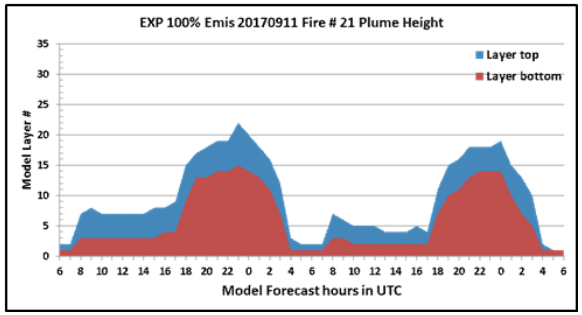




Hourly derived plume top and base

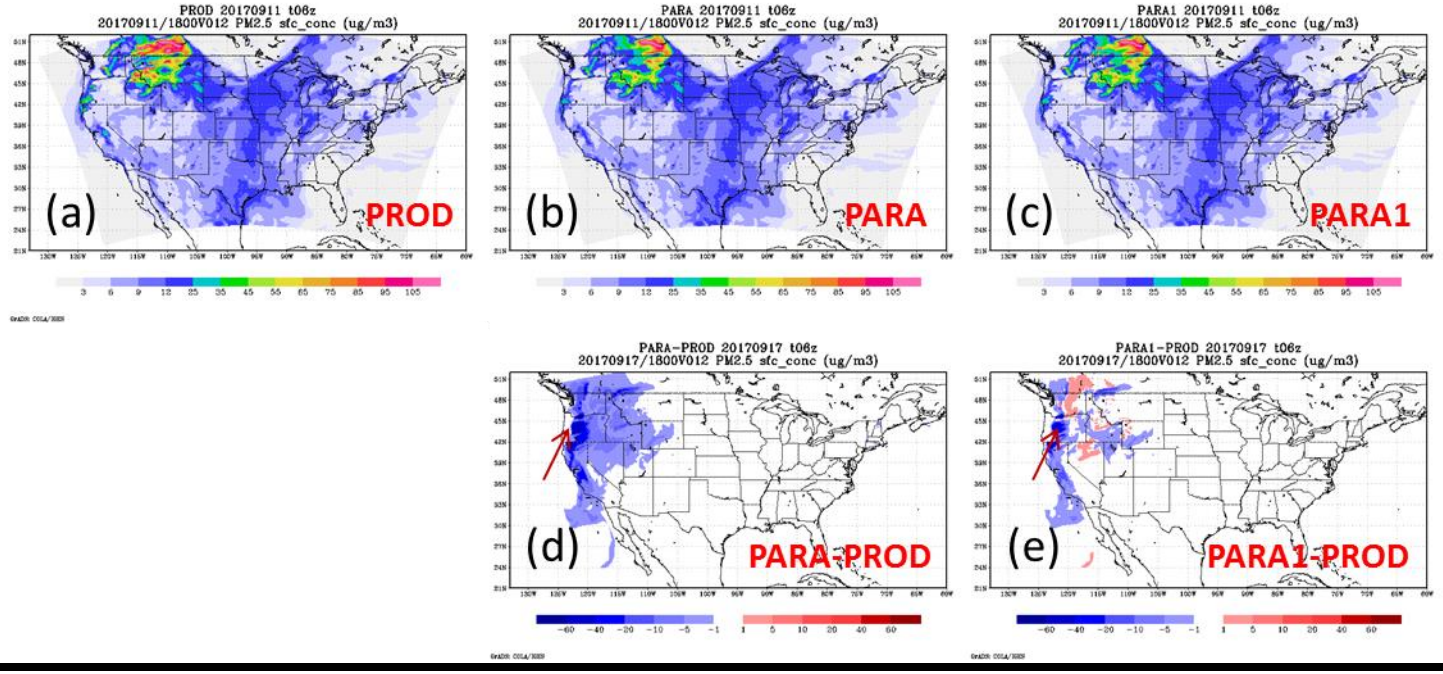




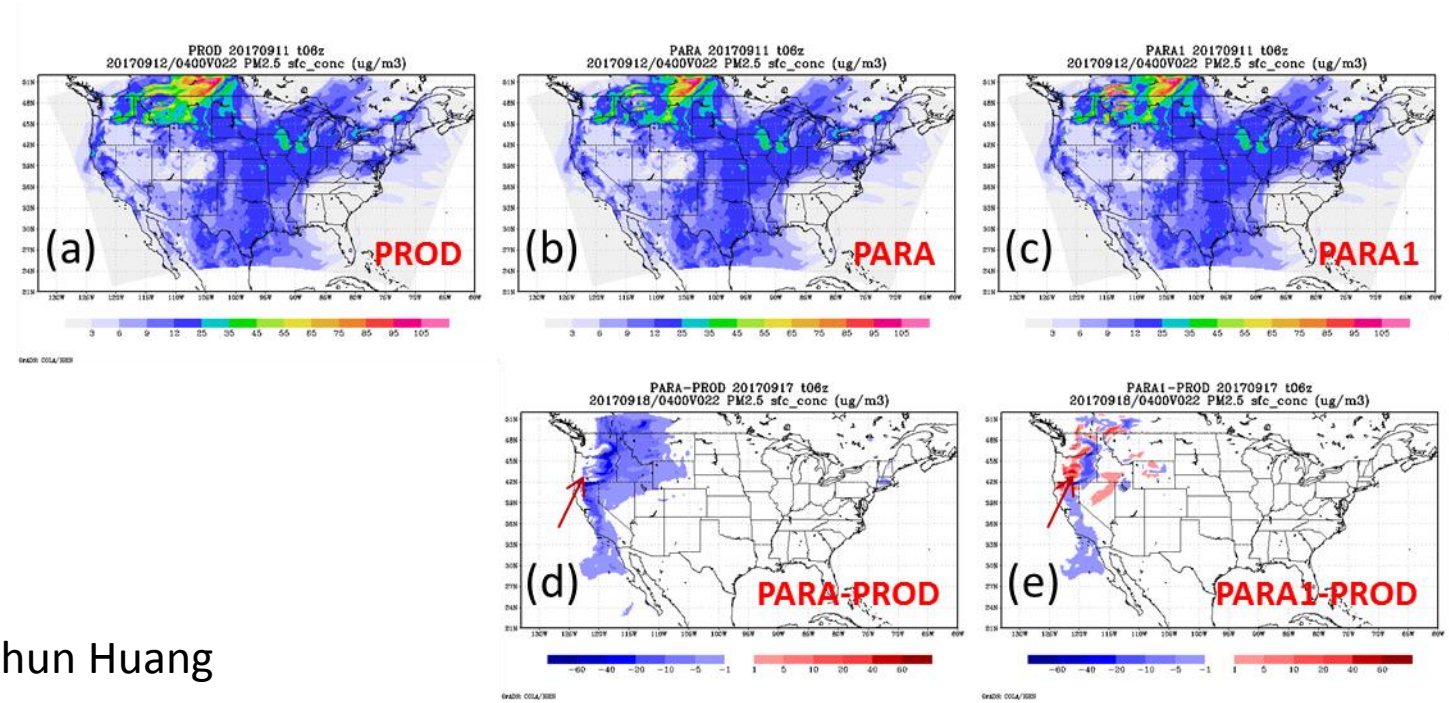


Courtesy Ho-Chun Huang

Over the ***night-time*** hours, both PARA (b) and PARA1 (c) emitted less PM_{25} as compared to PROD (a) near source area, (d) and (e).



Over the ***day-time*** hours, PARA (b) is slightly less that of PROD (a) and PARA1 (c) emitted more PM_{25} than PROD (a) near source area, (d) and (e).



Courtesy Ho-Chun Huang

Summary

- *V5.0.2 Ozone w/ NAM V4*
  - Improvement correcting over-prediction esp along coasts
    - Long Island Sound (CT DEP analysis), Lake Erie/Michigan and Ohio Coastline
  - Improved for marginal or non-events
  - Still Missed exceedences in NE with overprediction of cloudiness
  - *Remarkable overall improvement with KFAN ozone bias correction* overcorrects for episodes in East

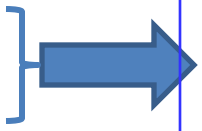
- *PM*
  - Large positive impact near forest fires :
    - Updated BlueSky and 24 h pre analysis run
    - Underprediction when external sources (Canadian fires) are impacting CONUS
    - Emission timing and ejection height uncertainties
  - Continued overprediction in Winter from raw predictions
  - Experimental PM bias correction w/ V5 analogs improves performance (Summer)

- HYSPLIT V7.4
  - Improvement for large fires with upgraded BlueSky
  - Experimental ECCC & temporal emissions produce mixed results

- Normally Updated NAM alone improves ozone overprediction forecast
  - Amount of incoming radiation under clouds critical

Future Emphasis

- Extend to 72 hours, update emissions to 2014 base
- Near real-time fire locations, strength, emissions
  - Canadian & external source impacts (testing)
  - Improved temporal profiles (testing) and plume rise algorithms
- NGAC full aerosol boundaries
- Unification of AQ systems
  - HYSPLIT smoke/dust → NGAC Aerosol
  - CMAQ ozone & total PM
  - HRRR-smoke



NGGPS ESRL/EPA FV3-CMAQ
- Inline allows for High Resolution

- Bias Correction:
  - Implement Ozone Kalman Filter bias correction
  - PM: Use CMAQ V5 predictions as analogs
- Improved Evaluations
  - Use of VIIRS/GOES-16/AERONET AOD, CALIPSO aerosols
  - Evaluate Operational models for field experiments (ESRL FireX 2019, FASMEE)

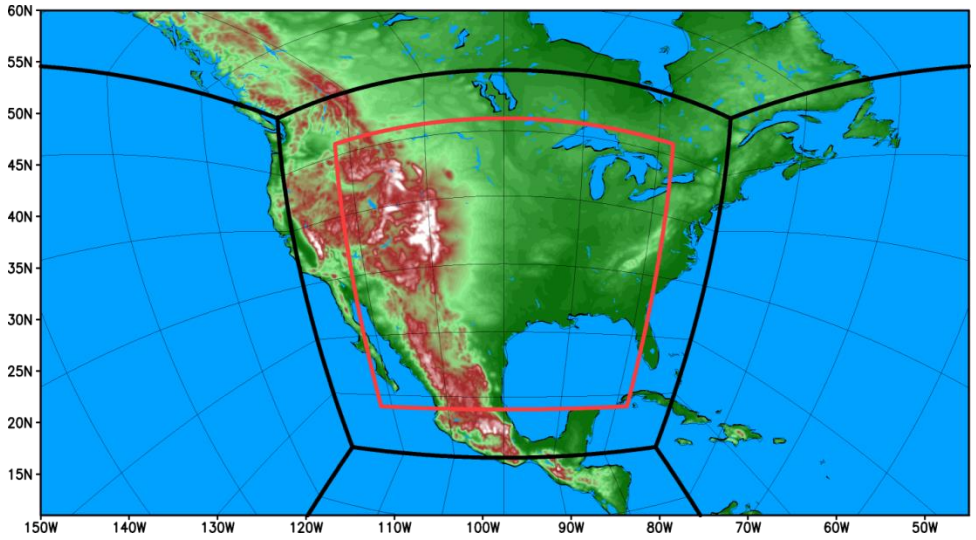
Thunderstorm-resolving resolution in a unified meso-global prediction system (FV3-GFS)

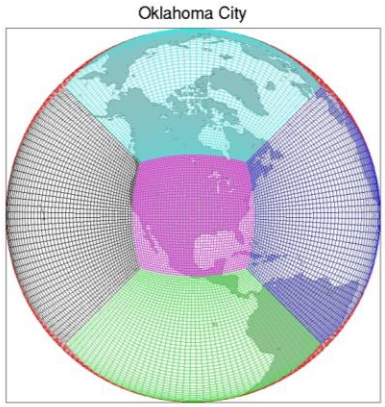
1) Grid stretching (smooth variation of grid spacing)

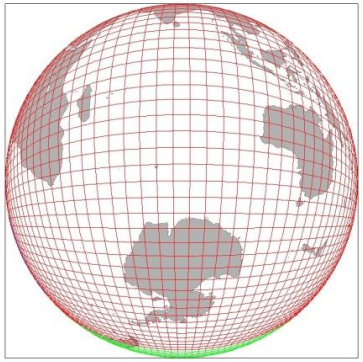
1) 2-way nesting (Harris and Lin 2014)

   FV3 is uniquely suitable for 2-way nesting, due to the application of two-time-level Finite-Volume transport scheme

2) Optimal combination of the “stretching” and “nesting”







FV3-GFS

→ **FY19 Global : 9 km L64**
→ **Regional: 3km nest or stand alone**
→ **aerosol aware microphysics/radiation option**

S.J. Lin, NOAA/GFDL

BACKUPS

Web pages
CMAQ V5.0.2

- Real-time parallel runs (July 2016-Present
  - http://www.emc.ncep.noaa.gov/mmb/aq/cmaq/web/html/max.html
- No NOx adj/NAM-X/4x-day cycling (Aug. 7-Sept 10)
  - http://www.emc.ncep.noaa.gov/mmb/aq/cmaqnox11/web/html/max.html
- Gridpoint NOx adj/NAM-X/1x-day cycling (Aug. 1-Sept 10)
  - http://www.emc.ncep.noaa.gov/mmb/aq/cmaqnox/web/html/max.html
- Verification statistics (prod,para, cmaqnox11, cmaqnox)
  - http://www.emc.ncep.noaa.gov/mmb/aq/fvs/web/html/regular.html