National Air Quality Forecast Capability program status and updates

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with contributions from the entire NAQFC Implementation Team

Air Quality Forecasters Focus Group

September 27, 2018

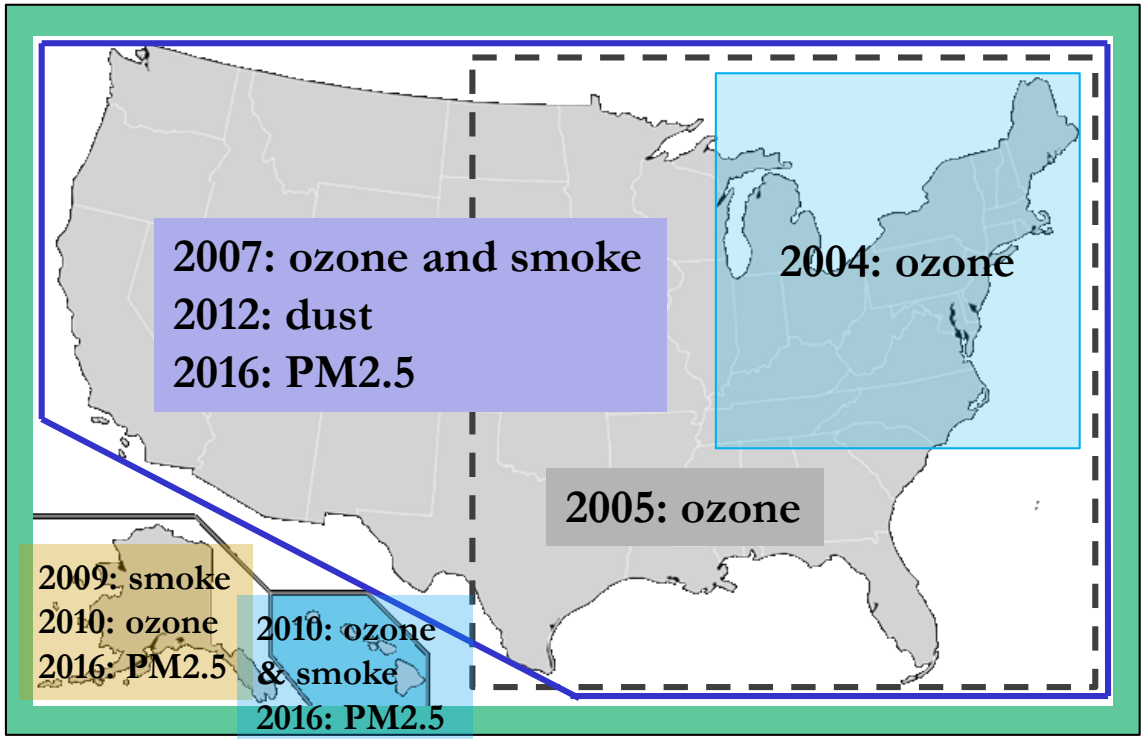
National Air Quality Forecast Capability
status in September 2018

- Improving the basis for air quality alerts
- Providing air quality information for people at risk

Prediction Capabilities:

- **Operations:**
  - *Ozone nationwide*
  - *Smoke nationwide*
  - *Dust over CONUS*
  - *Fine particulate matter (PM2.5) nationwide*

- **Testing of improvements:**
  - *Ozone*
  - *Smoke*
  - *PM2.5*
  - *Bias correction*



National Air Quality Forecast Capability
End-to-End Operational Capability

Model: Linked numerical prediction system

Operationally integrated on NCEP's supercomputer

- *NOAA NCEP mesoscale numerical weather prediction*
- *NOAA/EPA community model for air quality: CMAQ*
- *NOAA HYSPLIT model for smoke and dust prediction*

Observational Input:

- *NWS weather observations; NESDIS fire locations; climatology of regions with dust emission potential*
- *EPA emissions inventory*

Gridded forecast guidance products

- *On NWS servers: airquality.weather.gov and ftp-servers (12km resolution, hourly for 48 hours)*
- *On EPA servers*
- *Updated 2x daily*

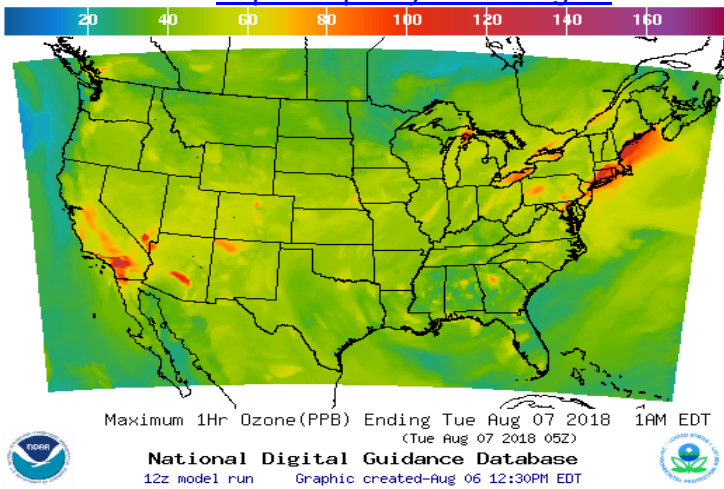
Verification basis, near-real time:

- *Ground-level AIRNow observations of surface ozone and PM2.5*
- *Satellite observations of smoke and dust*

Customer outreach/feedback

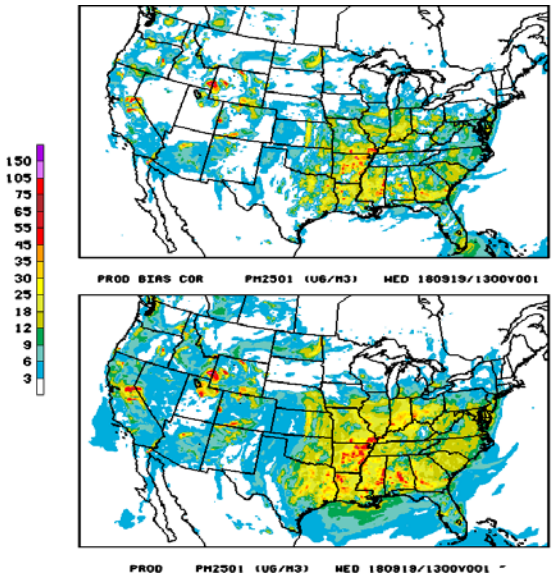
- *State & Local AQ forecasters coordinated with EPA*
- *Public and Private Sector AQ constituents*

http://airquality.weather.gov/



Ozone predictions

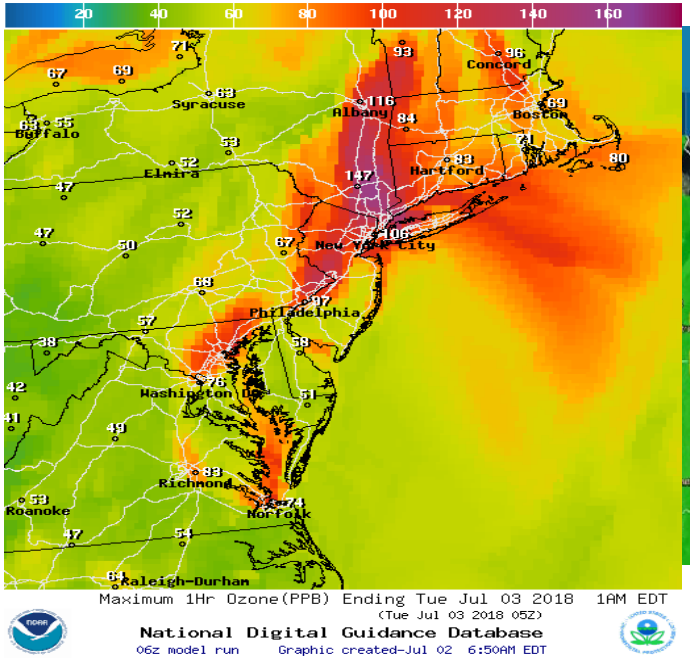
http://www.emc.ncep.noaa.gov/mmb/aq/cmaqbc/web/html/

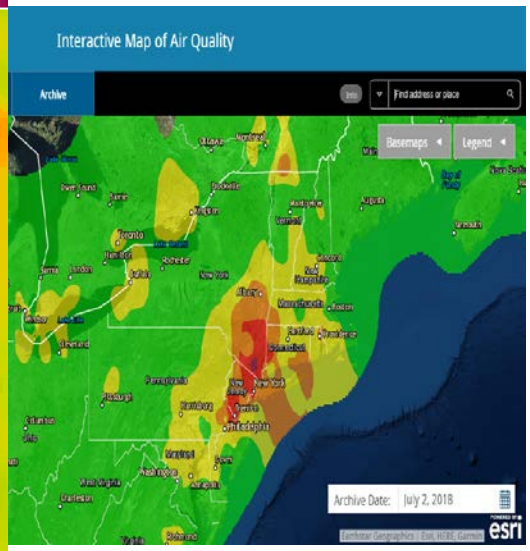


PM2.5 predictions

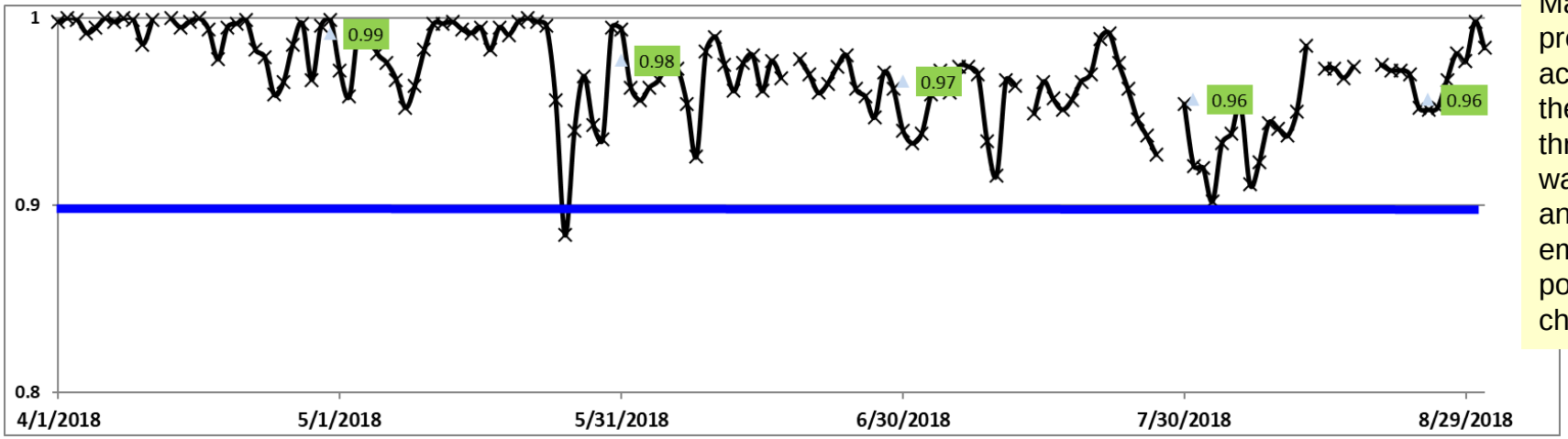
Ozone predictions

Verification for 2018



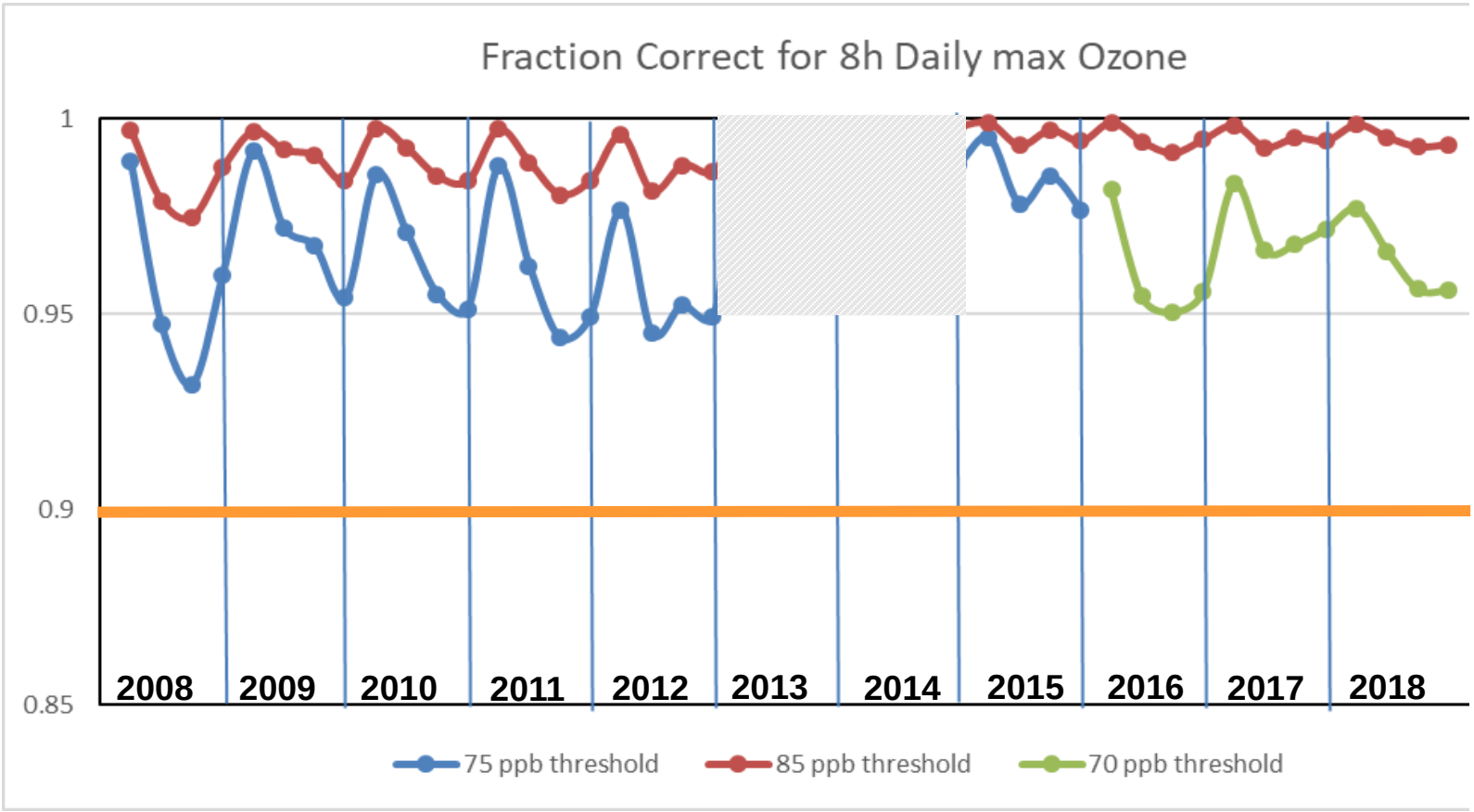


Operational daily maximum of 8h ozone predictions wrt 70 ppb threshold over CONUS



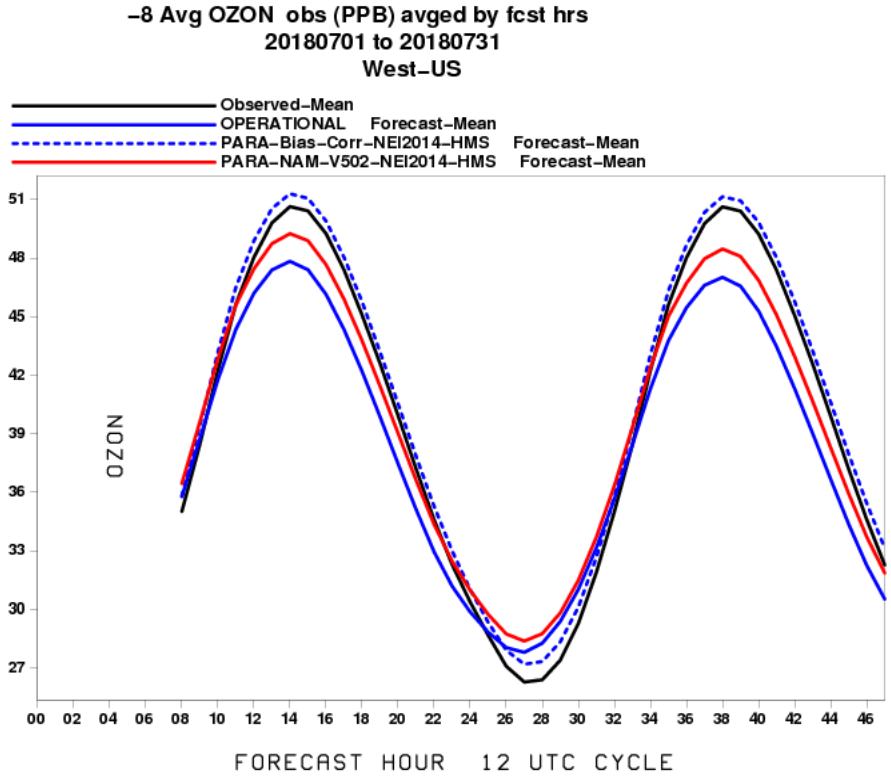
Maintaining prediction accuracy as the warning threshold was lowered and emissions of pollutants are changing

Performance of operational ozone predictions over CONUS

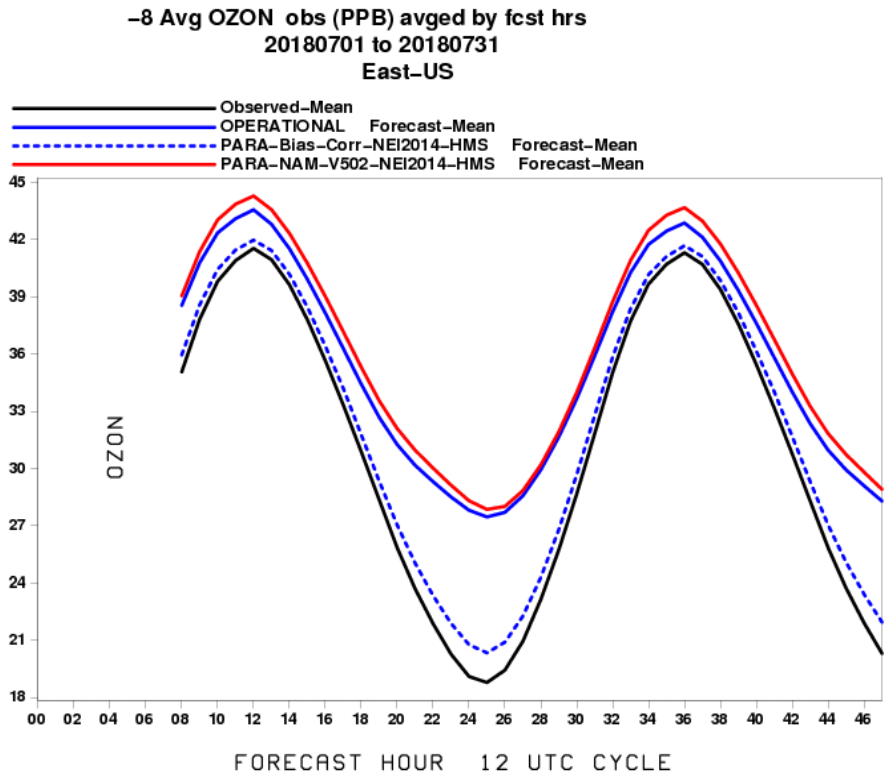


showing performance for May, June, July & August for each year

Performance of ozone predictions: diurnal variability in July 2018



Western U.S.

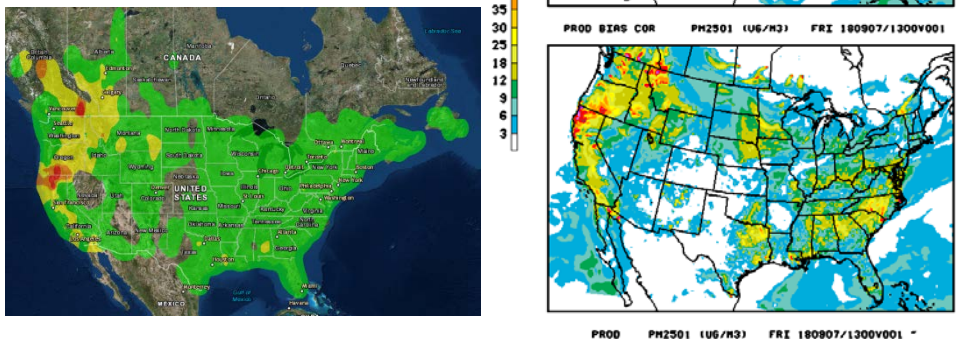


Eastern U.S.

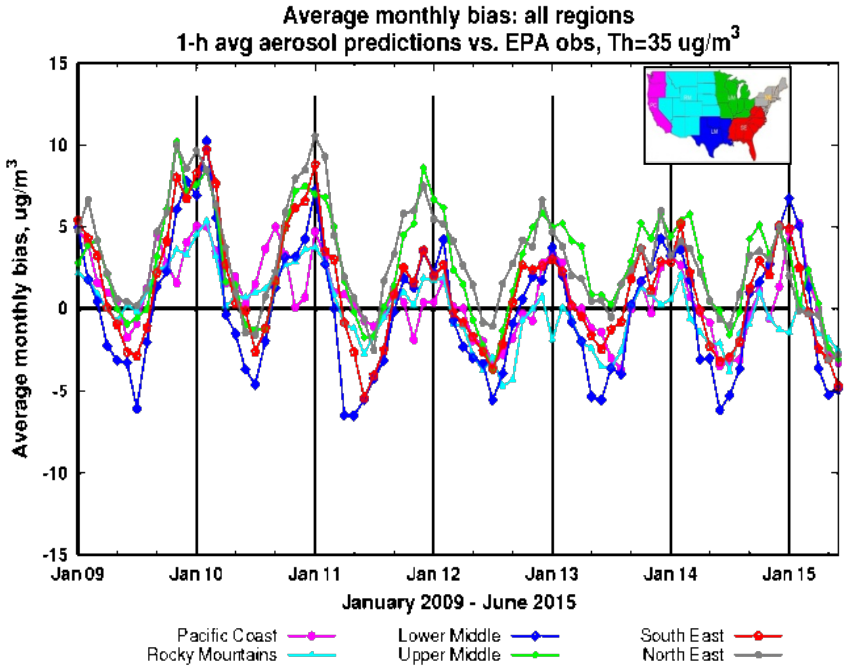
PM2.5 predictions
from the same CMAQ system

Predictions for 48h at 12km resolution over CONUS

- CMAQ 5.0.2: CB05 gases, AERO-6 aerosols since June 2017; CMAQ 4.7, CB05 with AERO-4 prior
- Sea salt emissions, wildfire and dust emissions and suppression of soil emissions from snow/ice covered terrain included since summer 2014 (Lee et al., Weather and Forecasting 2016); only NEI sources prior
- Model predictions exhibit seasonal prediction biases: overestimate in the winter; underestimate in summer.
- Additional observational input: AIRNow PM2.5 observations for bias correction and verification



NAQFC PM2.5 predictions



Forecast challenges

- *Improving sources for **wildfire smoke and dust***
- ***Chemical mechanisms eg. SOA***
- *Meteorology eg. PBL height*
- ***Chemical boundary conditions/trans-boundary inputs***

NEXT CMAQ SYSTEM UPGRADE

Updates to air quality predictions for the next implementation

Update fine particulate matter (PM2.5) bias correction system to use:

- Consistent model predictions for training of the unified KFAN bias correction system
- Increased number of observation sites for model bias correction to over 900 monitors
- Improvements to forecast extreme events by adding the difference between the current raw model forecast and historical analogs' mean to the KFAN bias-corrected predictions

New ozone bias correction with the same unified codes and configuration

- Uses ozone, wind direction, wind speed, temperature, solar radiation, NOx, NOy and PBL height as parameters to identify analogs

Updated anthropogenic emissions (oil and gas sector, point sources)

Updated fire emissions processing

- To accommodate NESDIS operational procedure changes

New fire emissions diurnal profile

Update Alaska and Hawaii domain CMAQ code to the same version used for CONUS :

- CB05 gas-phase and aero6 aerosol chemistry (155 species)
- Improved heterogeneous, aqueous, winter-time reactions
- Improved SOA and coarse mode PM

Wildfire smoke emissions and bias correction are not used on O-CONUS domains at this time.

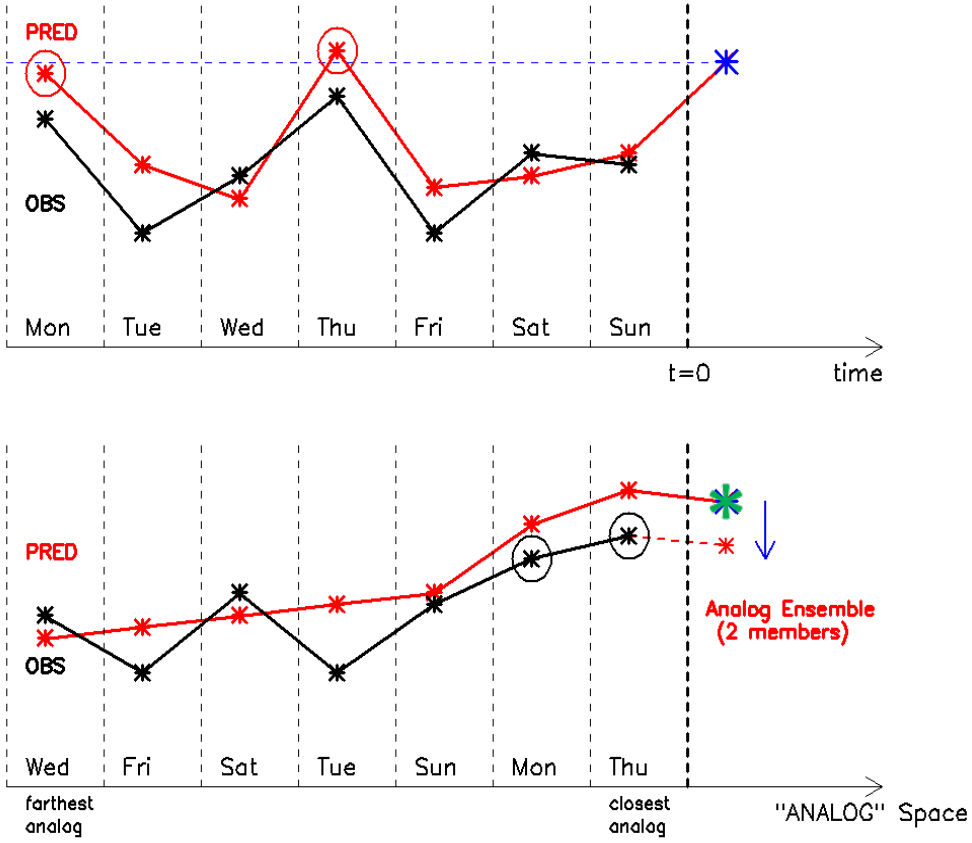
Tentative implementation date is December 26

Expected Benefits from this upgrade:

- Improved accuracy of bias-corrected fine particulate matter predictions.
- New bias-corrected predictions for ozone.
- Upgrade all NAQFC CMAQ domains to identical EPA version 5.0.2.
- Updated emissions inventories

Bias correction scheme

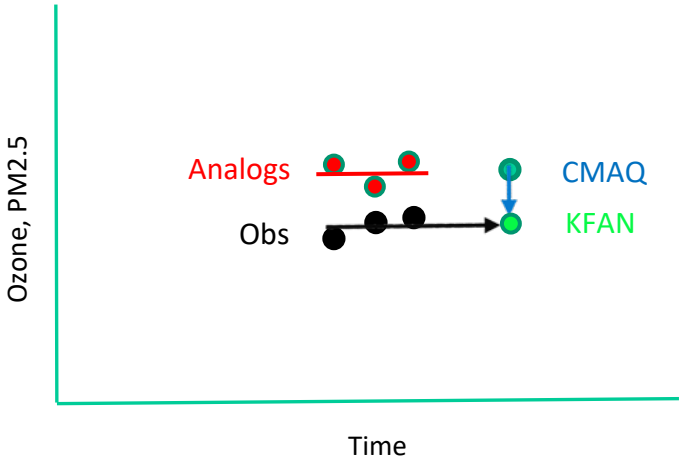
Schematic of the standard analog post-processing scheme.



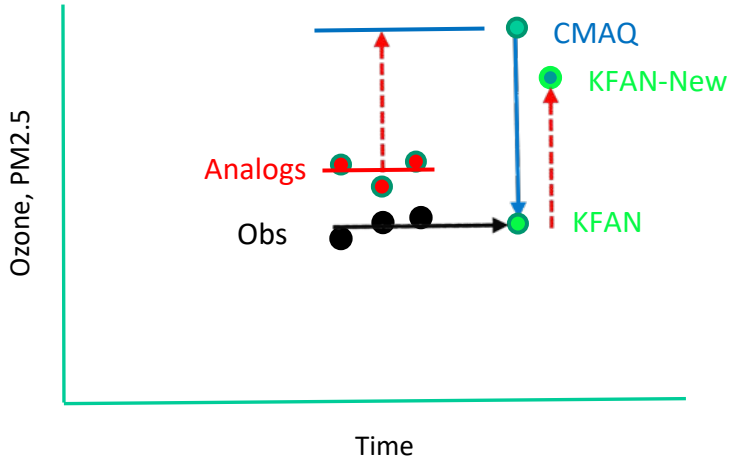
Red curve: time series predicted by a model
Black curve: observations
Data to the right of the dashed line at t=0: the new forecast

- The analog technique searches for previous forecasts similar to the current new forecast (blue star) – where the similar forecasts are circled in black, and re-orders the time series with the first closest analog directly preceding the new forecast, and the second closest forecast next (bottom panel)
- The observations (in black) corresponding to the two-best analog forecasts are then weighted by how closely they resemble the current forecast, and their weighted sum (the ensemble mean) provides the corrected forecast estimate (new green star on day eight)
- Once the bias correction is calculated at a given forecast hour for each AIRNow observation site, the bias is interpolated across the CMAQ grid, and then added to the CMAQ gridded forecast.

KFAN modification for extreme event correction



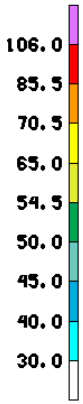
Standard KFAN bias correction with good analogs

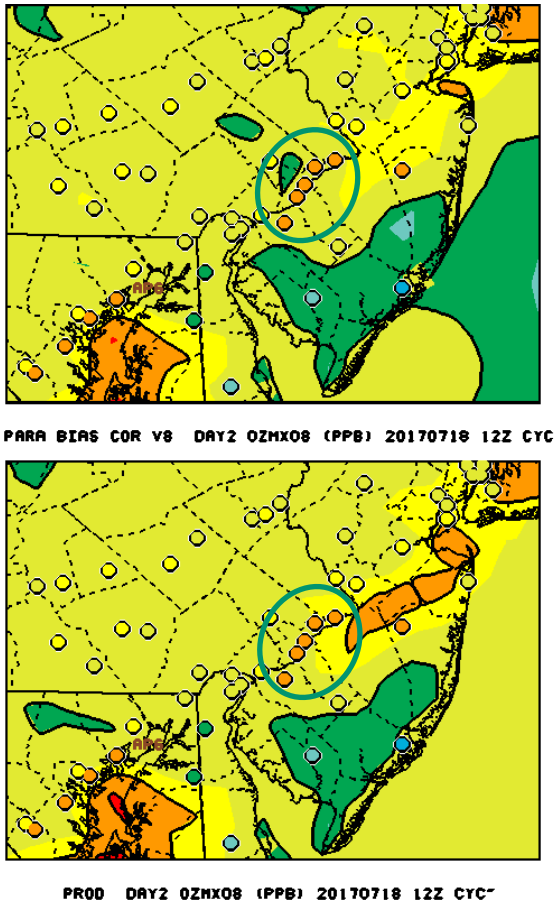


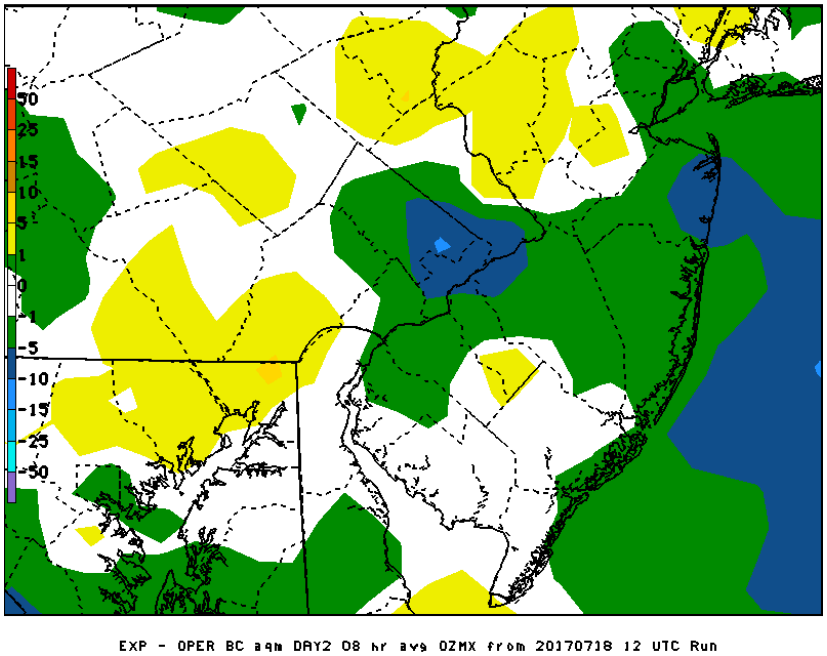
New KFAN bias correction with very poor analogs

- **The left panel is the typical case of having analogs that are similar to the current forecast, but the observations have a bias relative to those analogs, which is then corrected.**
- **If an extreme event occurs (right panel) that previously has not occurred in the training data set, the best analogs will have a different value than the current forecast (indicated by the dashed red line).**
- **The modification made to the KFAN technique is simply to add this difference (the dashed red line) to the standard KFAN value, resulting in the KFAN-new forecast.**

Day 2 8hr daily max O_3 Valid July 19,2017







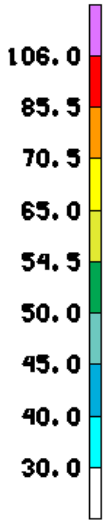
EXP BC - Production

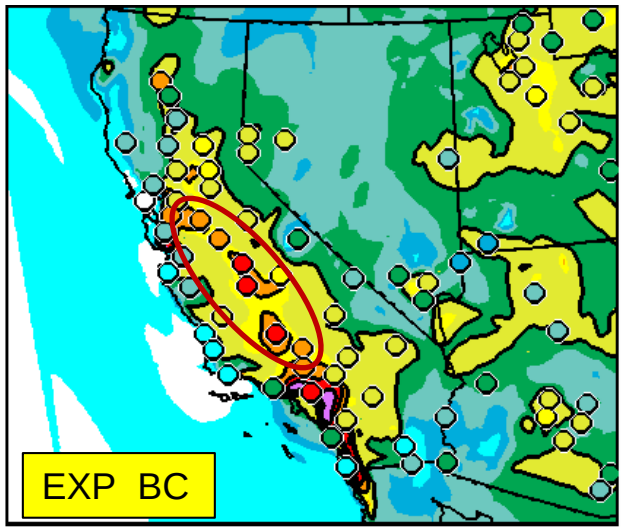
OBS: 77 ppb
Prod: 67
Exp BC: 61

Philadelphia experimental bias-corrected O_3 predictions degraded from Raw production predictions by 5-10 ppb

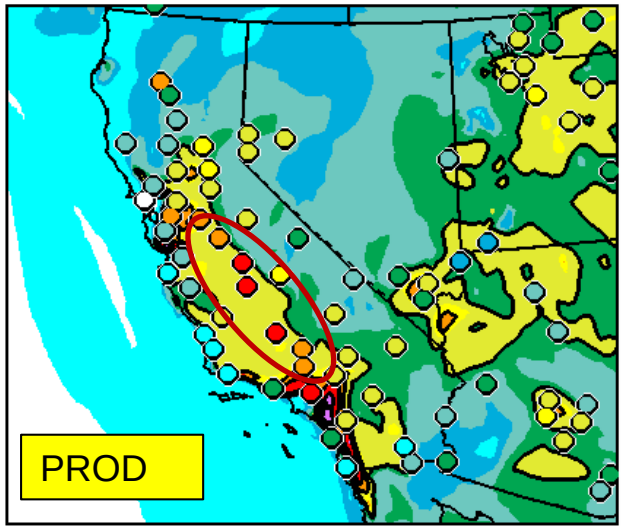
8 hr max O_3 for day 2

Valid Aug 28, 2017

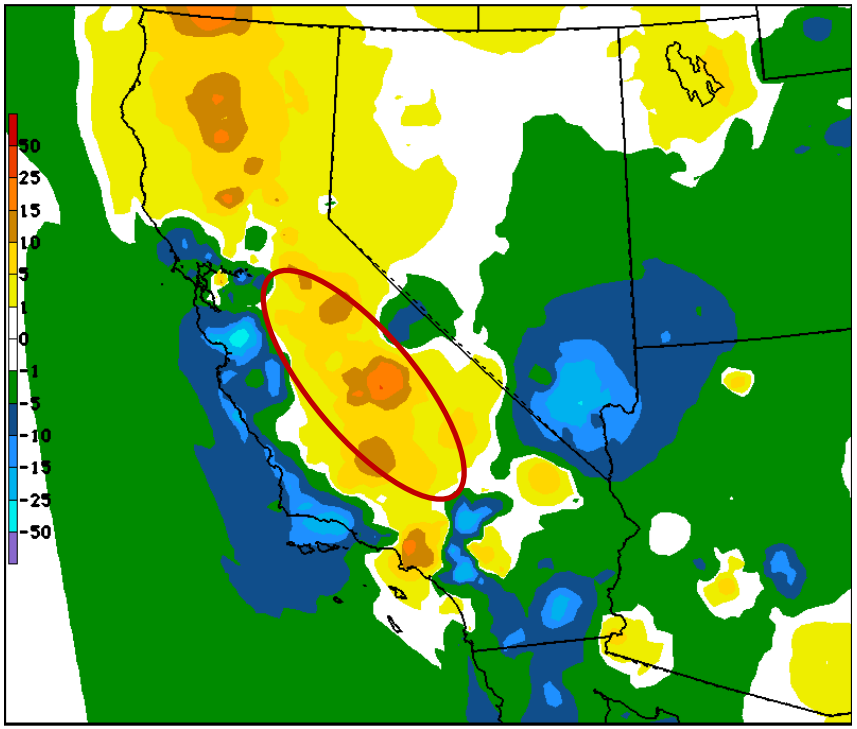




PARA BIAS COR V8 DAY2 OZMX08 (PPB) TUE 170829/12(



PROD DAY2 OZMX08 (PPB) TUE 170829/1200V048 *



EXP - OPER BC aqm DAY2 08 hr avg OZMX from 20170827 12 UTC Run

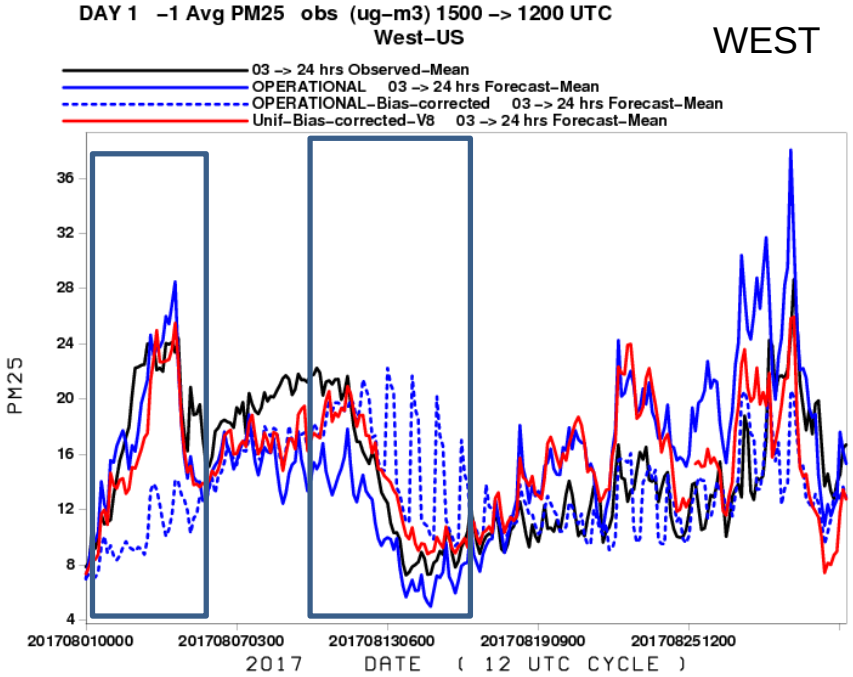
EXP BC - Production

BC: Helps correct underprediction over California valleys from fire influenced O_3 production

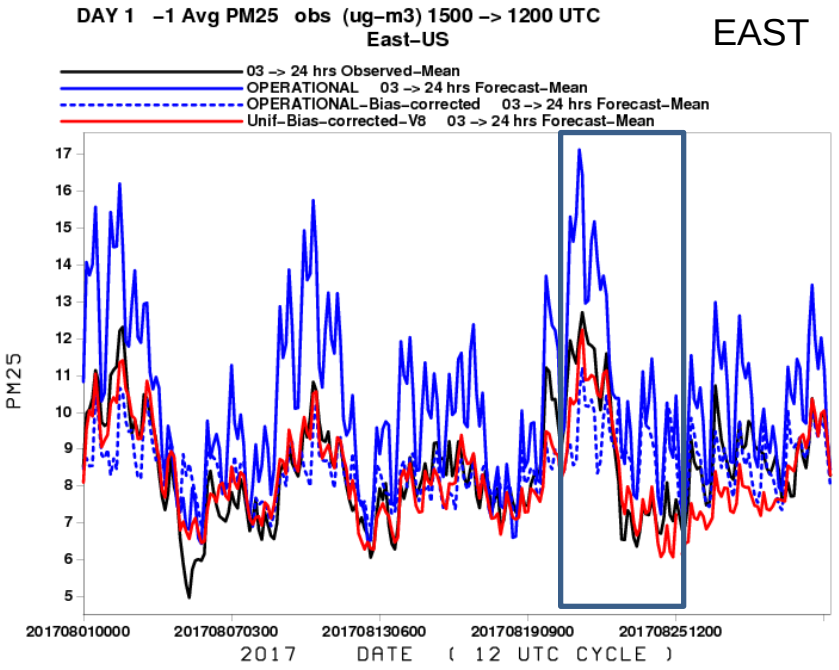
Prod, *Prod BC*, Exp BC PM2.5
Daily Time Series

August, 2017

WEST



EAST

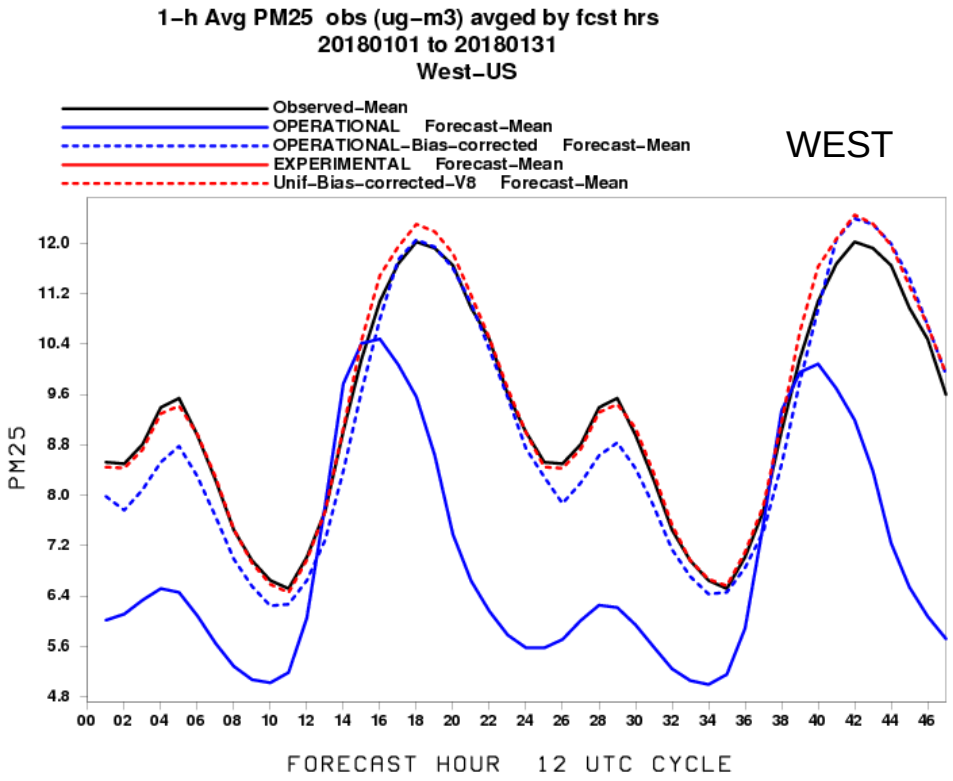


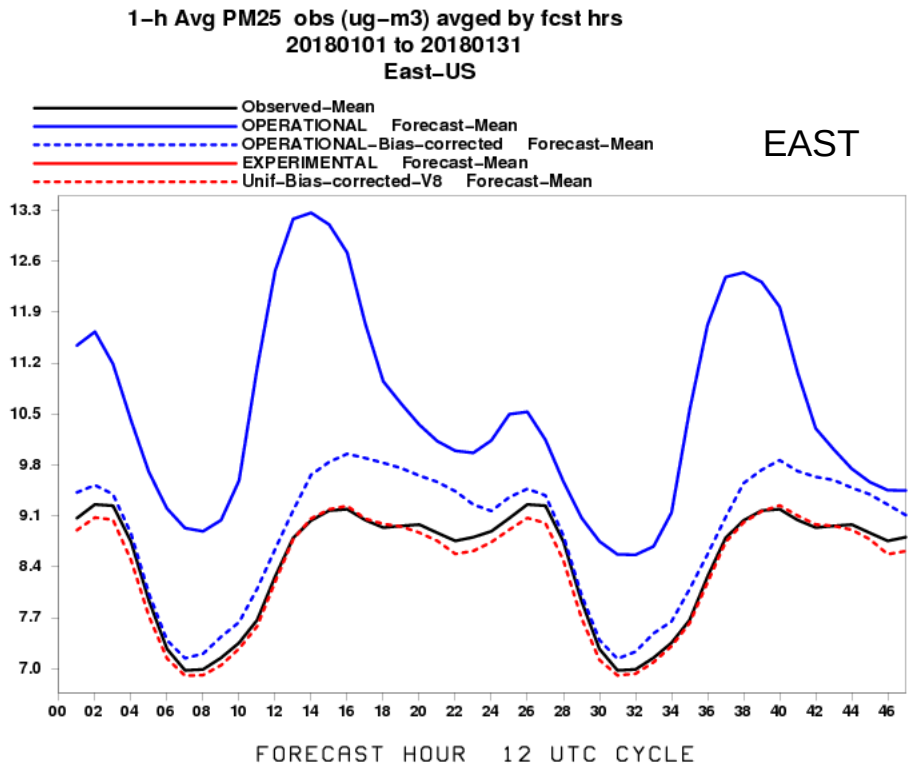
Exp Bias correction

- West: - Removes post wild-fire event noise
  - Captures wild-fire events esp. early Aug
- East: Similar to prod BC, some improvement around 8/21-8/25

Prod, *Prod BC*, Exp BC PM2.5 Diurnal Time Series

January 2018

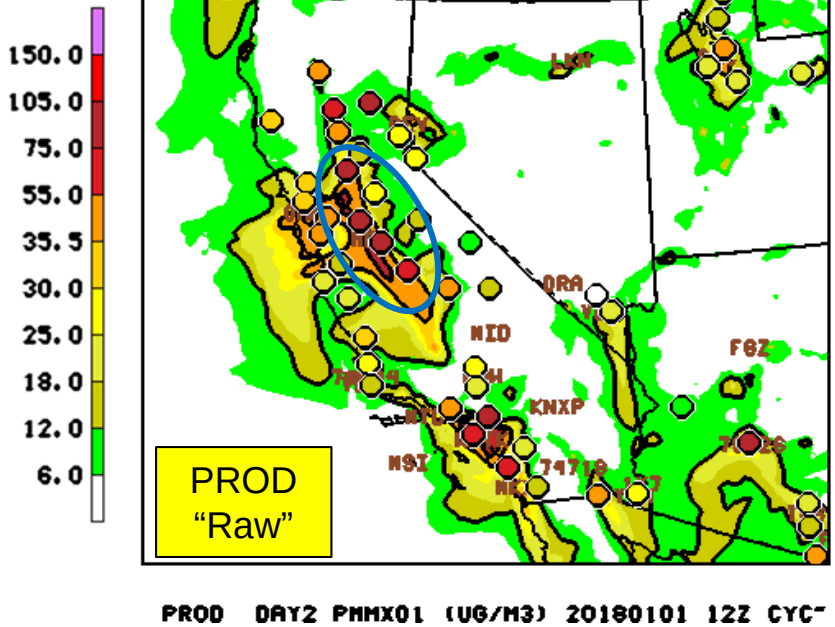


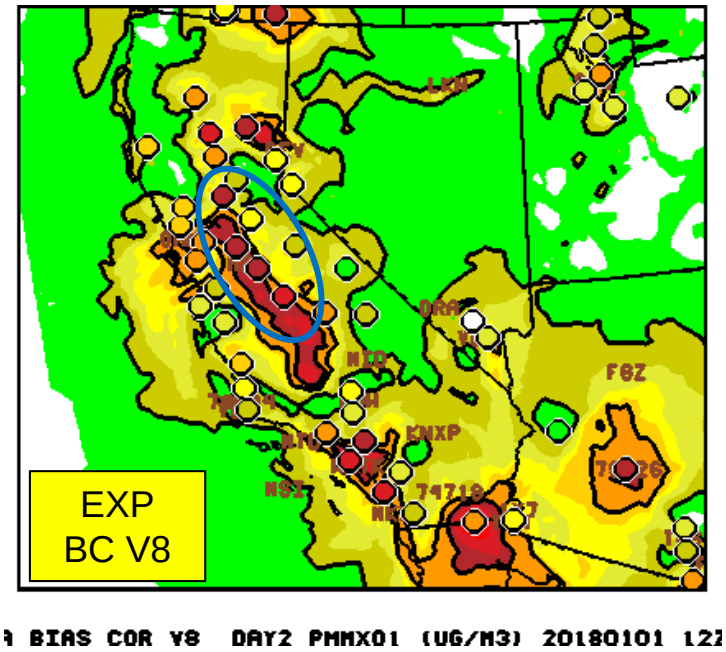


- Less PM (improved) over East with experimental bias correction processing

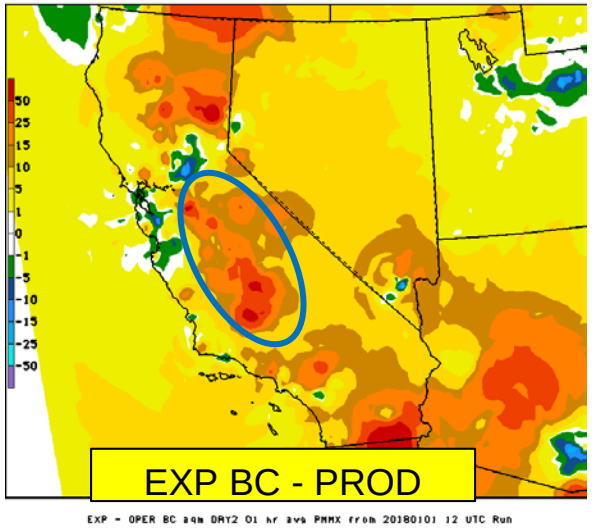
Note: Operational bias correction now using correct V5 training predictions

Day 2 daily 1hr Max PM2.5
Valid Jan.2, 2018





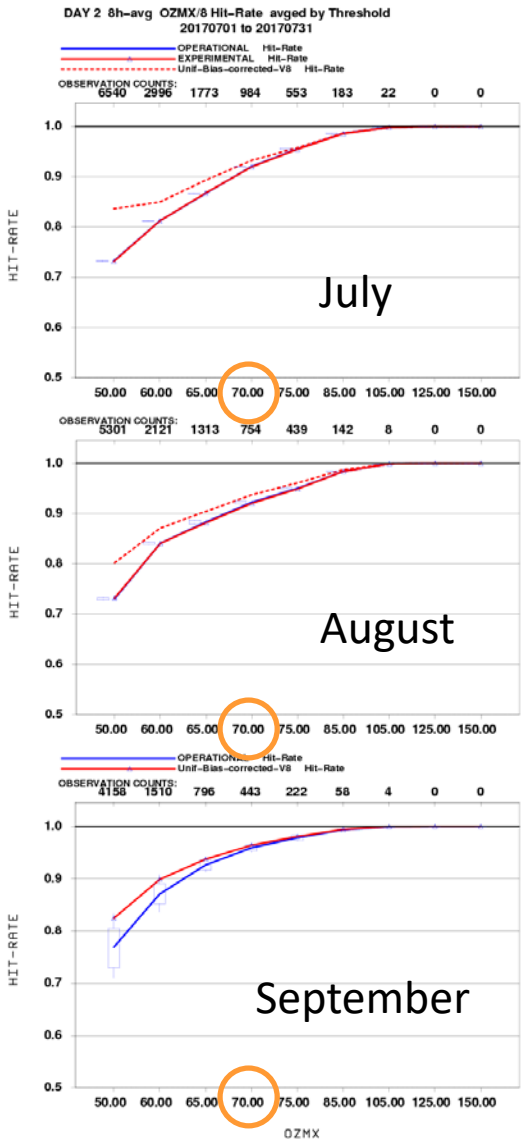
Bias correction better captures stagnation episode in Central Valley



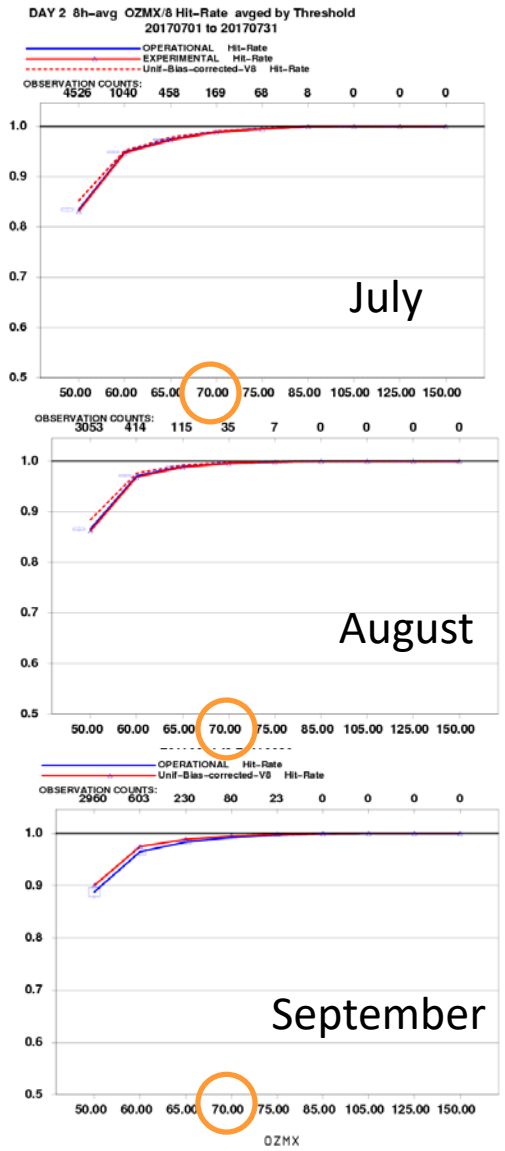
Performance of ozone predictions

Fraction correct for 8h ozone maximum (day 2)

Western US



Eastern US



BC compared to Raw	Exper. ozone 8h max BC	
Day 2	West	East
July	++	+
August	++	+
September	++	+

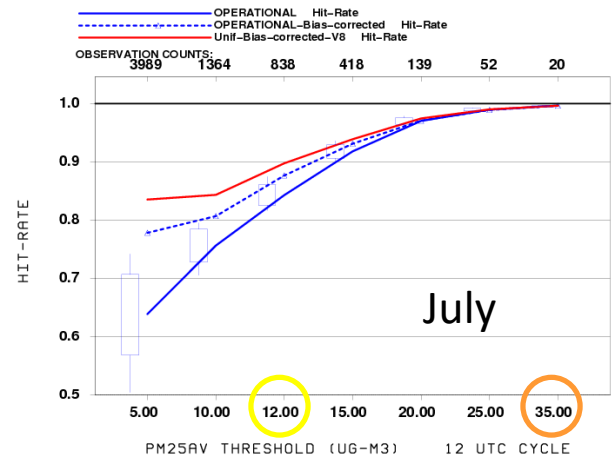
- Experimental bias correction for ozone is better than raw model, especially in the Western US

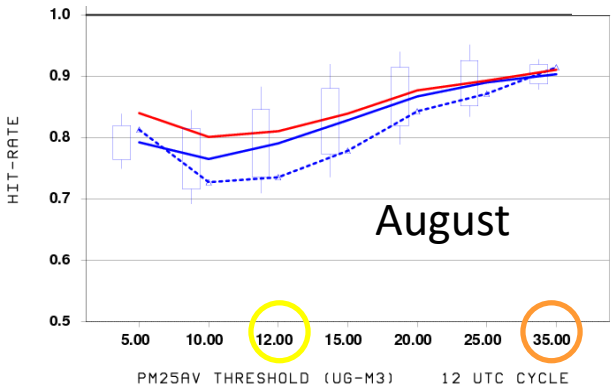
Performance of PM2.5 predictions
(July-Aug 2017)

Fraction correct for 24-hour average PM2.5 (day 2)

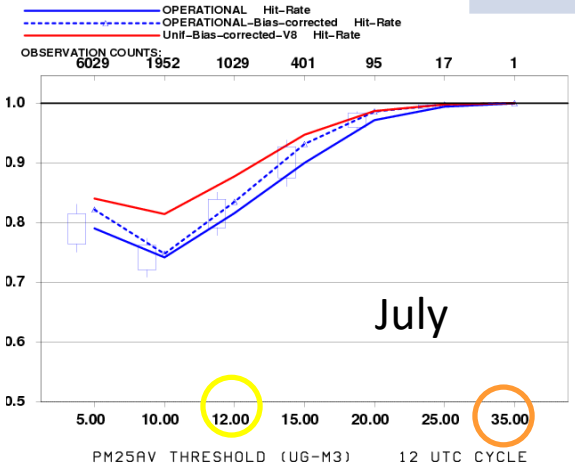
BC compared to Raw	Operational PM2.5 24h avg BC		Exper. PM2.5 24h avg BC	
Day 2	West	East	West	East
July	+	+	++	++
August	--	+	+	++

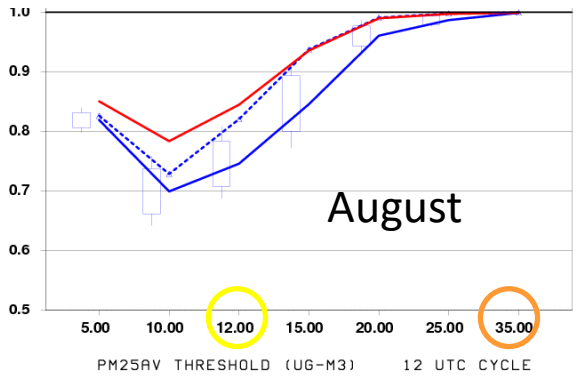
Western US





Eastern US





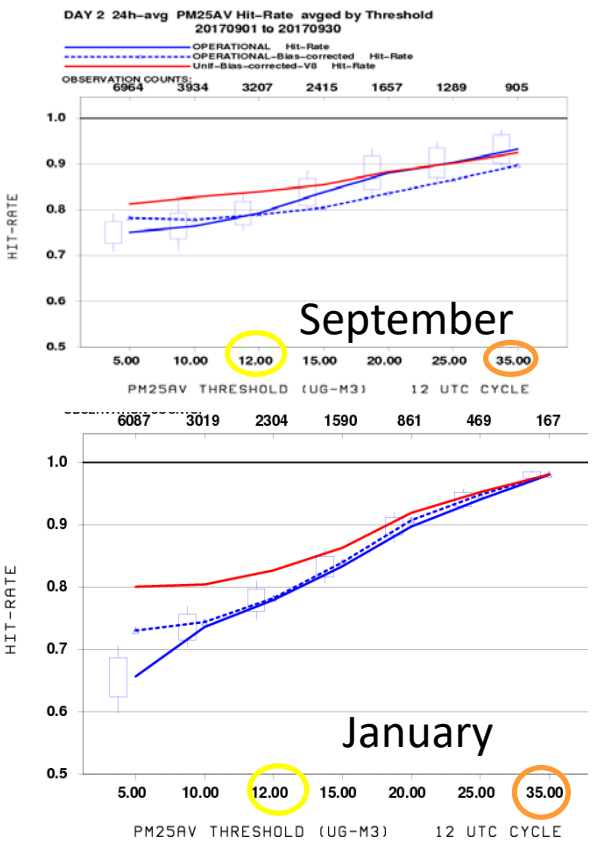
- Experimental bias correction is better than operational one
- Experimental bias correction is much better than raw model in July and in for Eastern US in August

Performance of PM2.5 predictions
(Sept 2017 & Jan 2018)

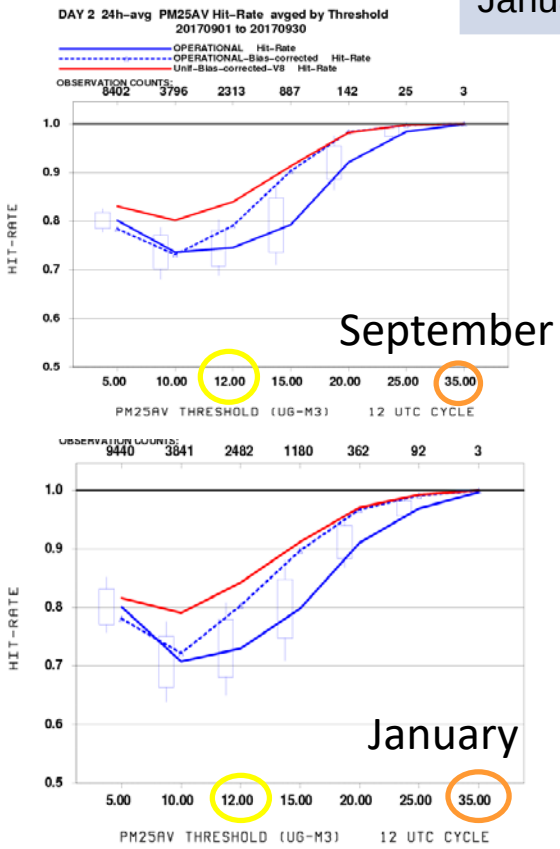
Fraction correct for 24-hour average PM2.5 (day 2)

BC compared to Raw	Operational PM2.5 24h avg BC		Exper. PM2.5 24h avg BC	
Day 2	West	East	West	East
September	-/+	+	+	++
January	+	+	++	++

Western US



Eastern US



- Experimental bias correction is better than operational one
- Experimental bias correction is much better than raw model in January and in for Eastern US in September

Summary evaluation of bias corrected predictions

BC compared to Raw	Operational PM2.5 24h avg BC		Exper. PM2.5 24h avg BC		Exper. ozone 8h max BC	
Day 2	West	East	West	East	West	East
July	+	+	++	++	++	+
August	--	+	+	++	++	+
September	-/+	+	+	++	++	+
January	+	+	++	++		

Fraction Correct for day 2 predictions indicates:

- New ozone bias corrected prediction is better than raw model prediction
- Updated PM2.5 bias correction is better than both raw model predictions and operational bias corrected predictions

EMISSIONS

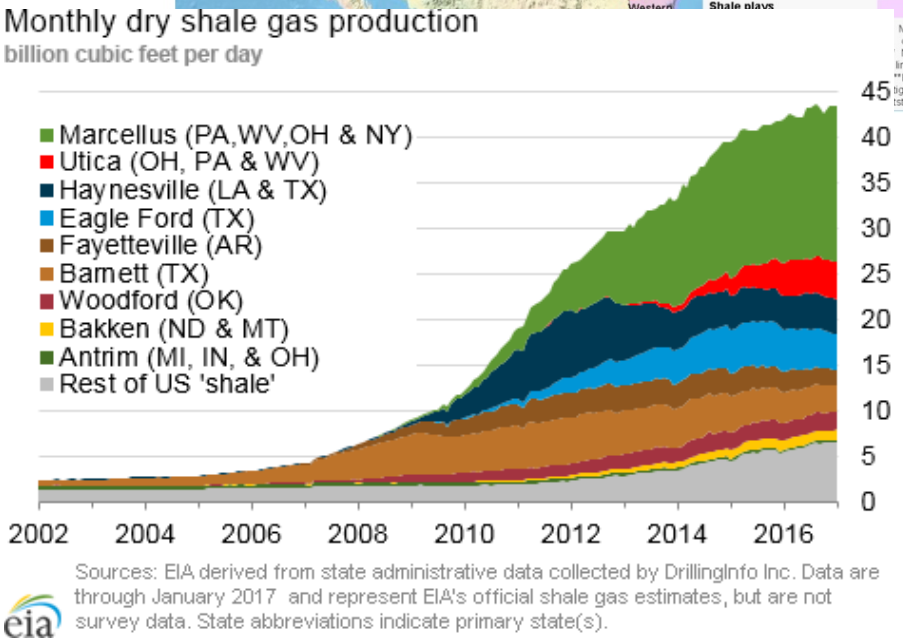
Emissions in the operational model

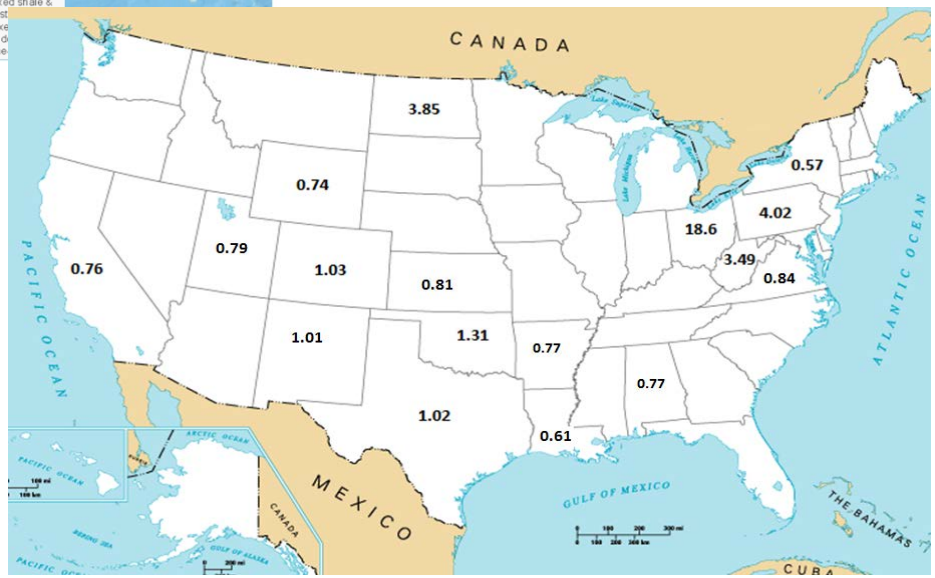
- Point sources: upgrade based on 2017 CEM and 2018 DoE Energy Outlook, Canada 2011 Environment Canada Emission Inventory (ECEI), Mexico inventory (MI) 2012 version2.2
- Area sources: NEI2011 with O_n_G adjustment for 2016 + FORM/NOx upgrade
- Non-road: for U.S. used NEI2011, ECEI 2006 for Canada; MI 2012 for Mexico
- Mobile sources: Cross State Air Pollution Rule (CSAPR) 2011 Emission Data
- Intermittent emissions: windblown dust – FENGSHA Model (Tong et al., 2016)
- Wild fires -- NESDIS Hazard Mapping System (HMS) & fuel from New USFS BlueSky v3.5.1
- Natural source: Biogenic with BEIS3 Version 3.14; Sea-salt based on 10m wind

Emissions updates: oil and gas sector

Testing of State-specific scaling for Oil_n_Gas area source

- July 11-21 sensitivity run confirmed that Marcellus area O3 increased
- Under-prediction in O3 in the Marcellus area was reduced
- However the over-prediction in O3 elsewhere was exacerbated

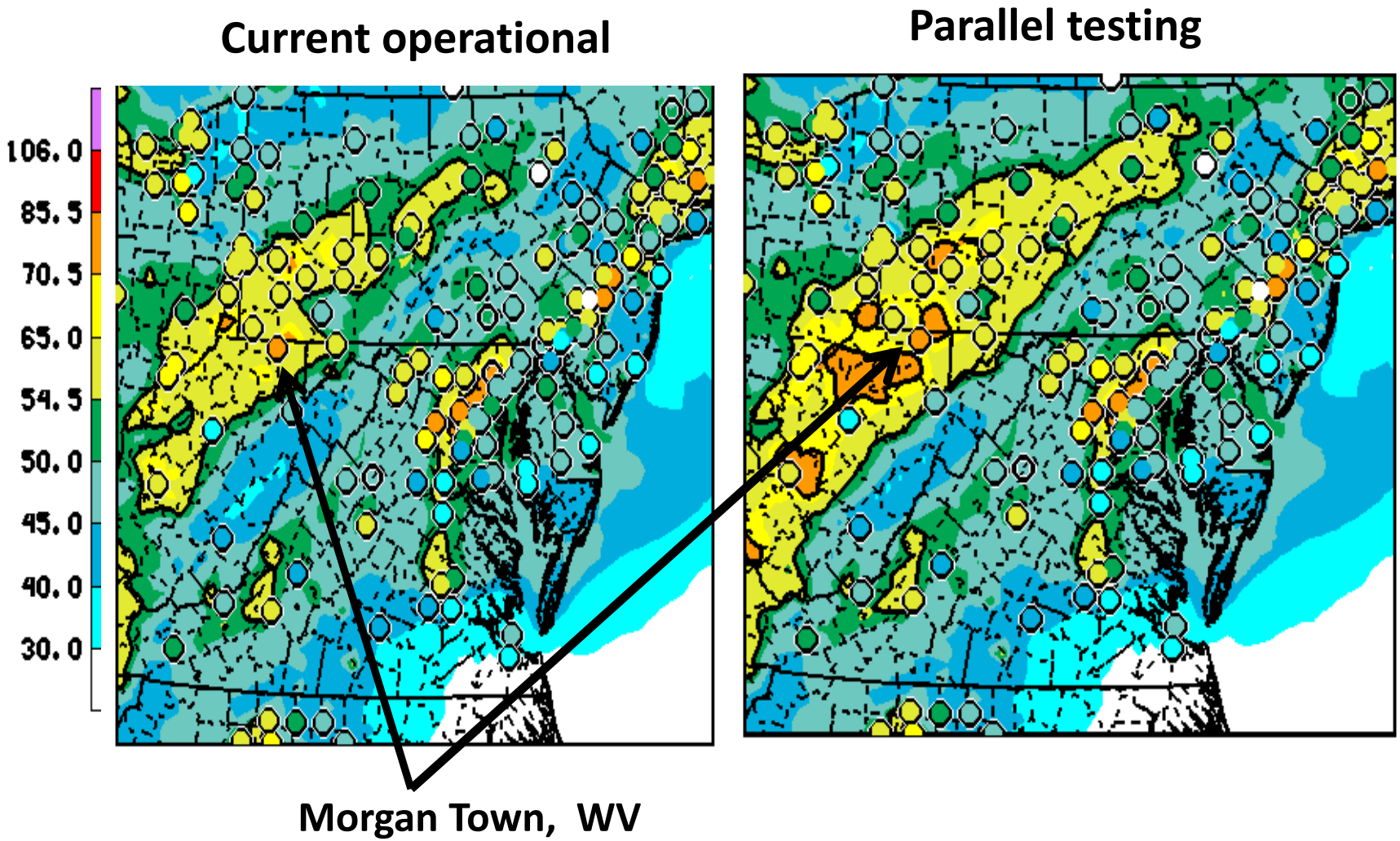




Adjustment factor applied to NEI2011 oil and gas area source sector

Area Source: Oil and gas activity upgrade

using activity data from 2016 production inventories

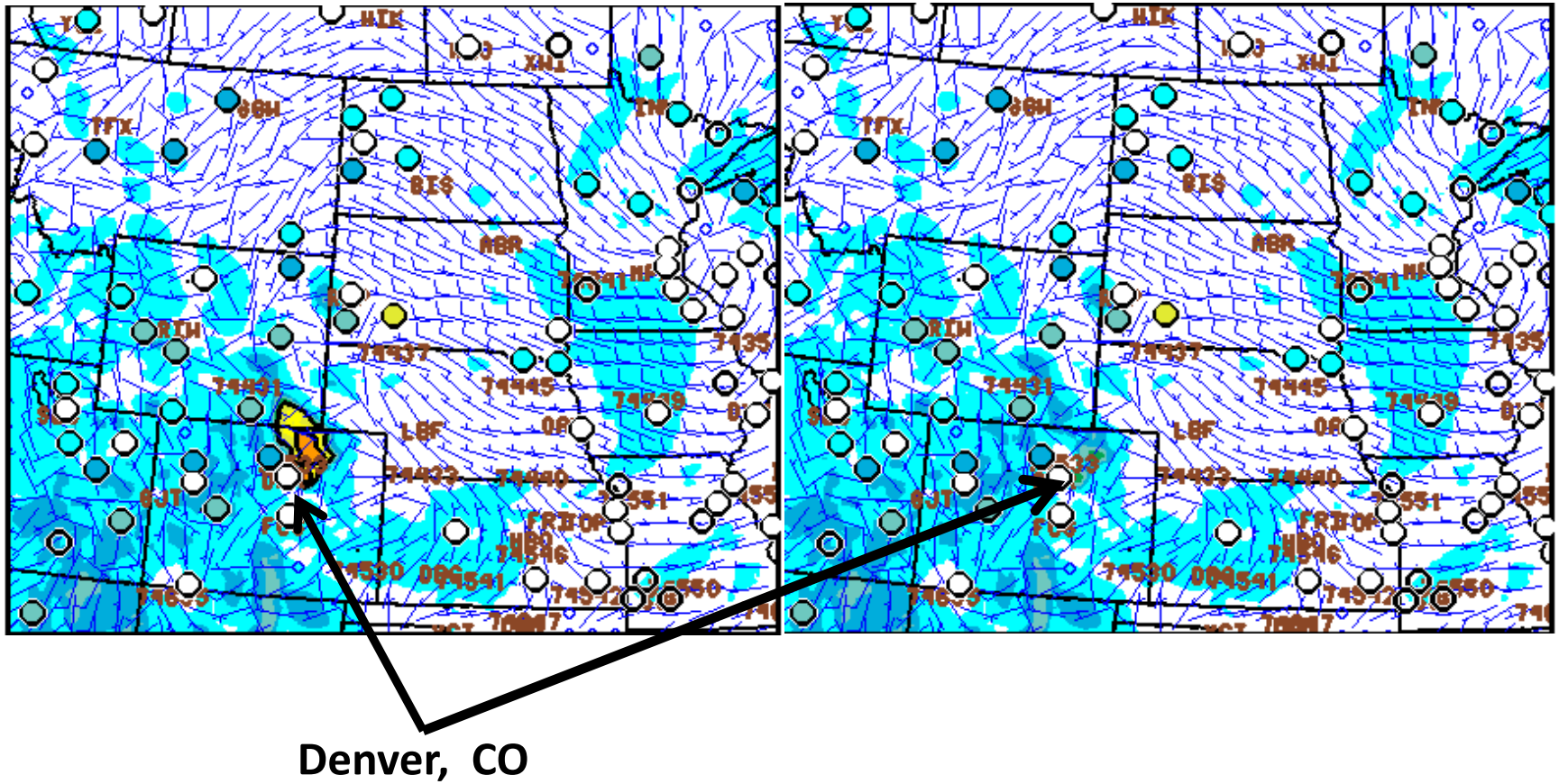


O_3 predictions at 18Z on July 18 2017 showing significant local impact

Area Source: Oil and gas activity upgrade

using latest formaldehyde to total VOC ratios

Current operational | **Parallel testing**

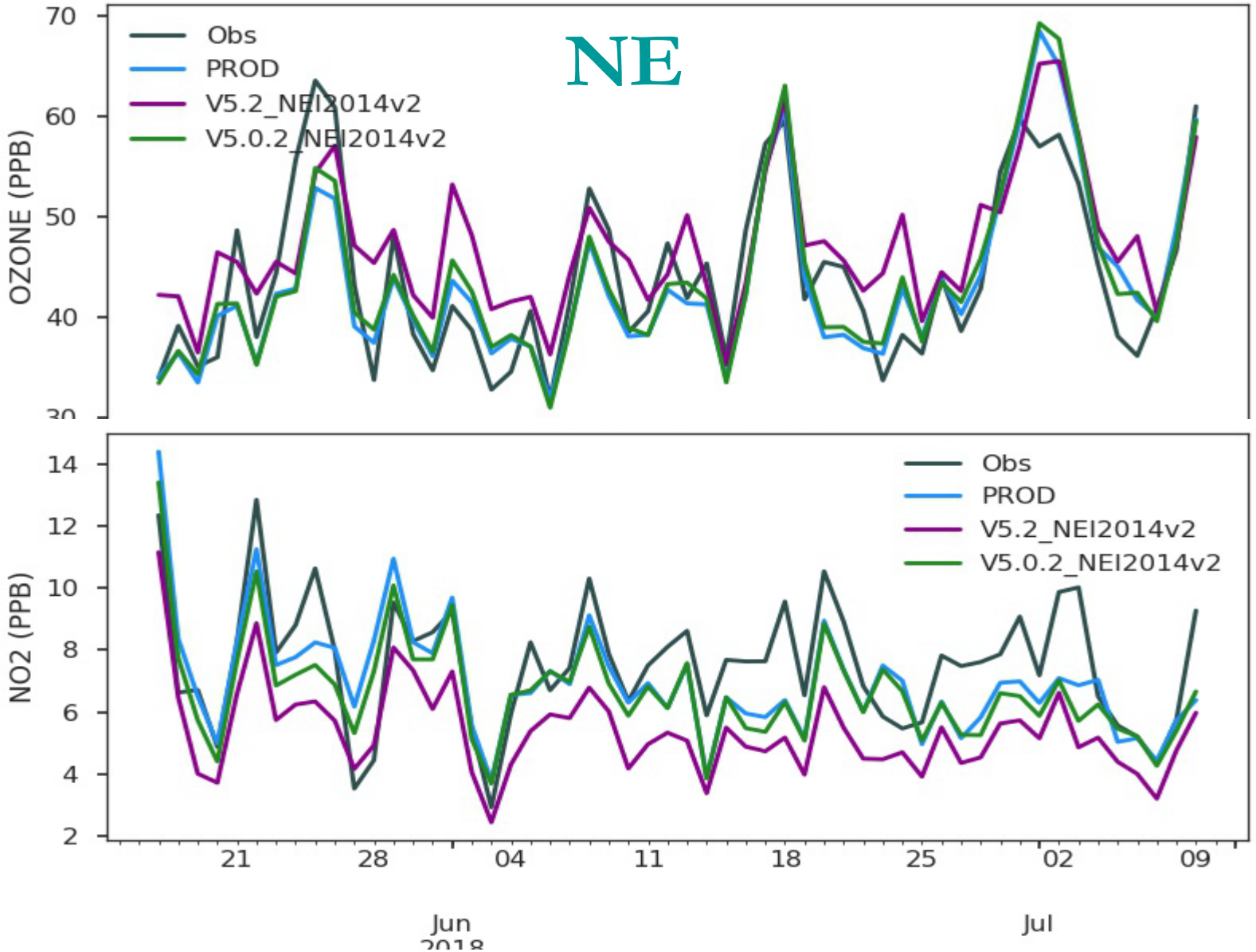


O_3 predictions at 13Z on Feb 23, 2018 showing significant local impact in Denver, CO

Next emission upgrade

- NEI2014v2 from EPA – significant activity data changes
- Differences from NEI2011: Oil and gas has point and area components & Biogenic uses BEIS3.6.1
- Area Agriculture: NH_3 expanded with all related species
- MOVES2014v2: 2014 Activities modulated by 2017 NAM
- Halogen chemistry related emission: for CMAQ5.2

Emissions testing Summer 2018

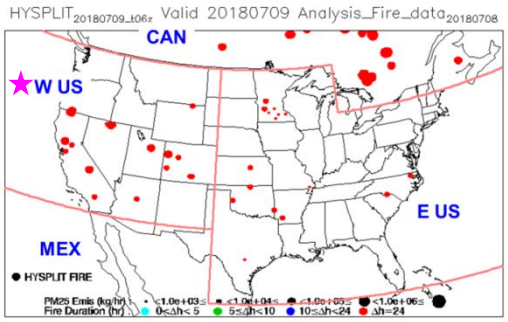


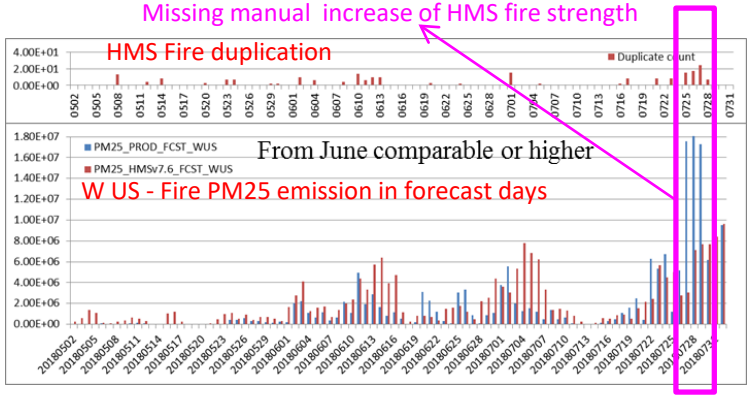
CHANGES TO SMOKE EMISSIONS

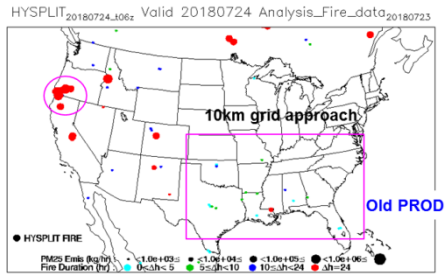
Updated HMS fire processing code in BlueSky for HYSPLIT and CMAQ applications

- **Interim NESDIS HMS processed fire information system (w/ GOES-16)**
  - NESDIS HMS group discontinues the manual inspection of HMS fire because of the increase number of fire detection from GOES-16 data.
  - All fires in a 10 km^2 gridded area are represented by one HMS fires information.
  - Interim solution only has manual inspection to remove false positive and add false negative west of 102W in the CONUS domain.
  - **Used operationally from April 11-July 31, 2018.**
- **New HYSPLIT/BlueSky fire processing based on HMS fire detections (w/ GOES-16)**
  - **New automated system is used operationally on August 01 2018.**
  - Aggregate all satellite fire detections, both geostationary and orbital, into a 0.01°x0.01° grid.
  - Identify HMS fire and starting time of each grids with more than one detection.

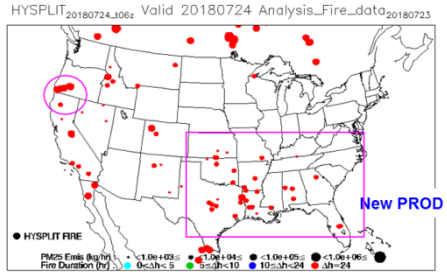
The comparison of the western US fire PM_{25} emission between using HMS provided fire information (w/ manual inspection; **blue bar**) and from automated system (**red bar**). Results from automated system lead to overestimate of small fires but underestimate of large fires with comparable results of medium fire.



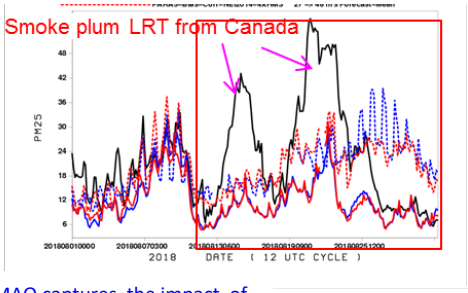




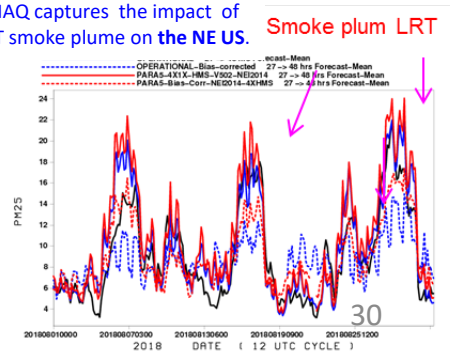
Impact of 24 hour fire duration assumption



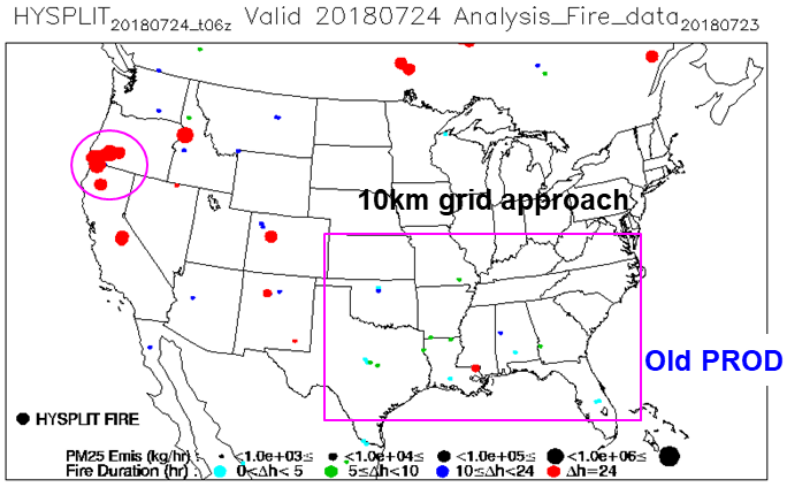
Without the Canadian smoke plume included in the LBC, CMAQ greatly underestimates **the NW US** PM_{25}.

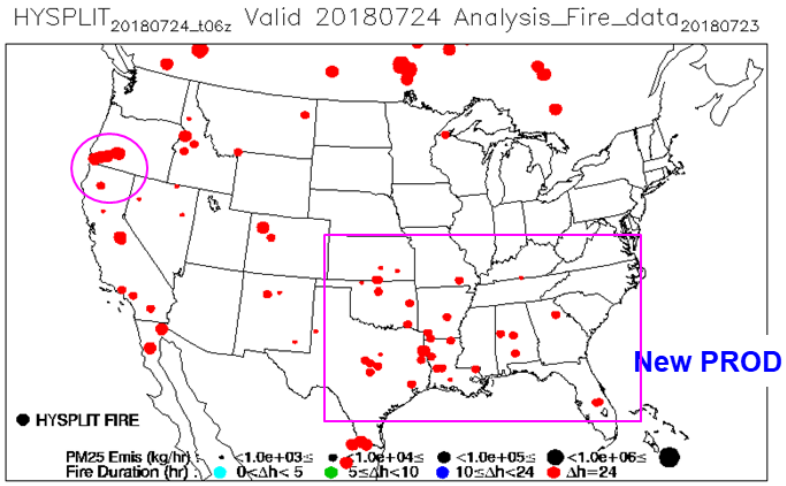


CMAQ captures the impact of LRT smoke plume on **the NE US**.

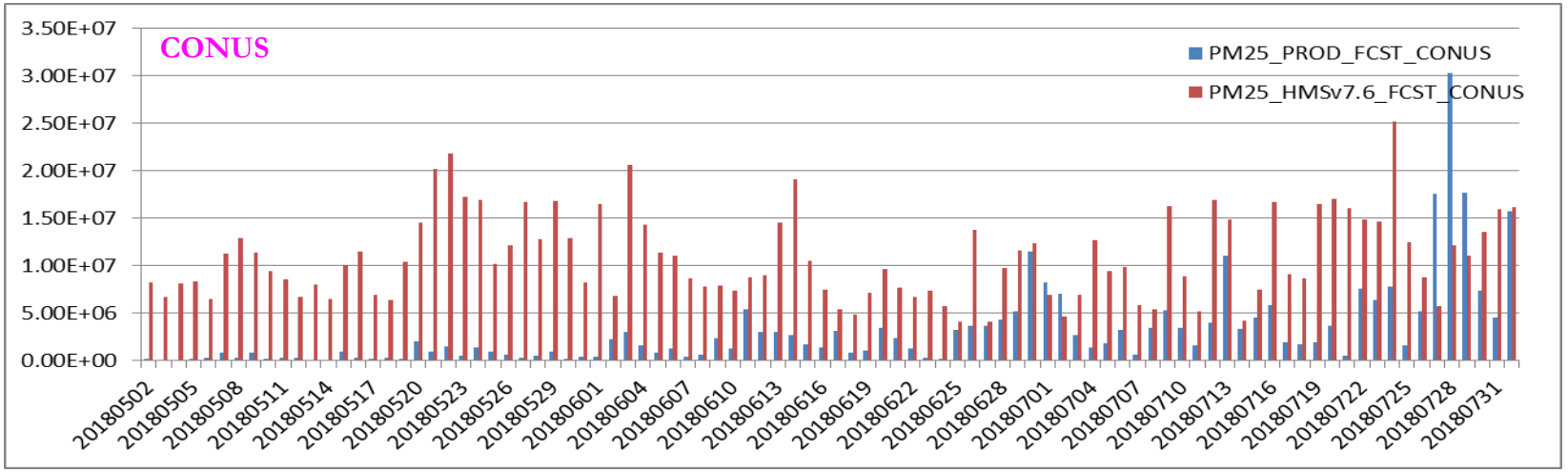


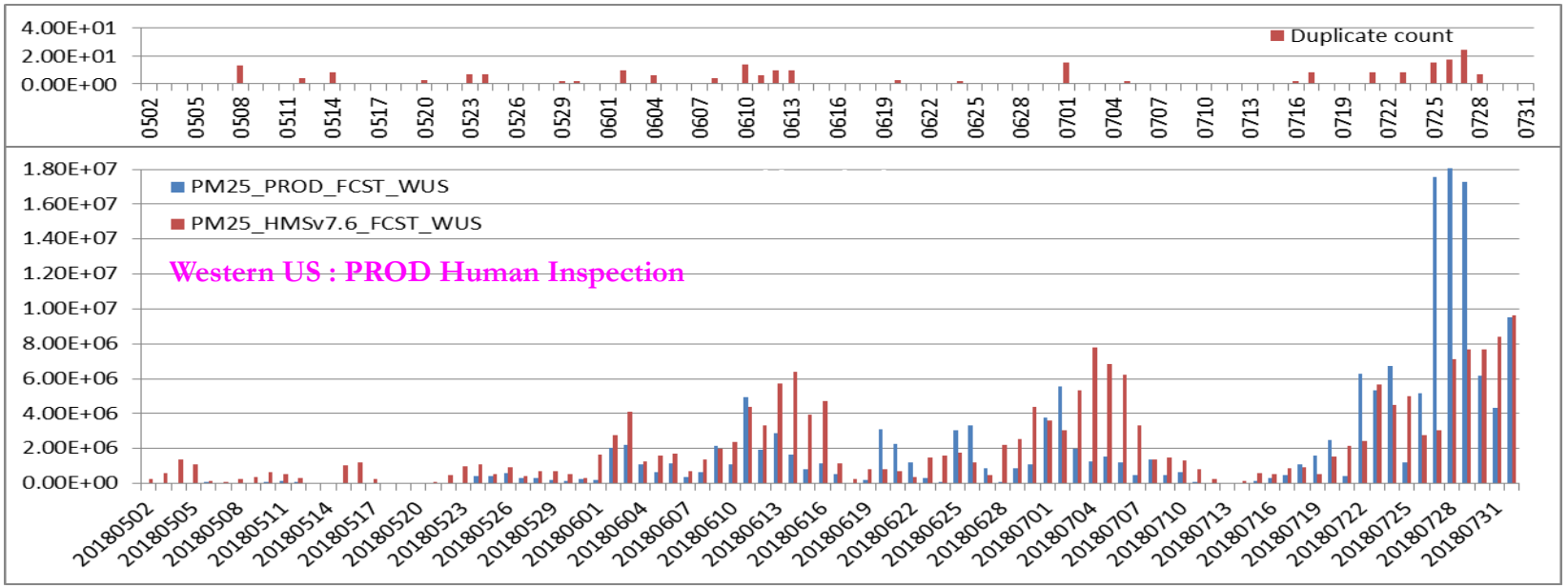
Fire point difference example





PM 2.5 emission comparisons

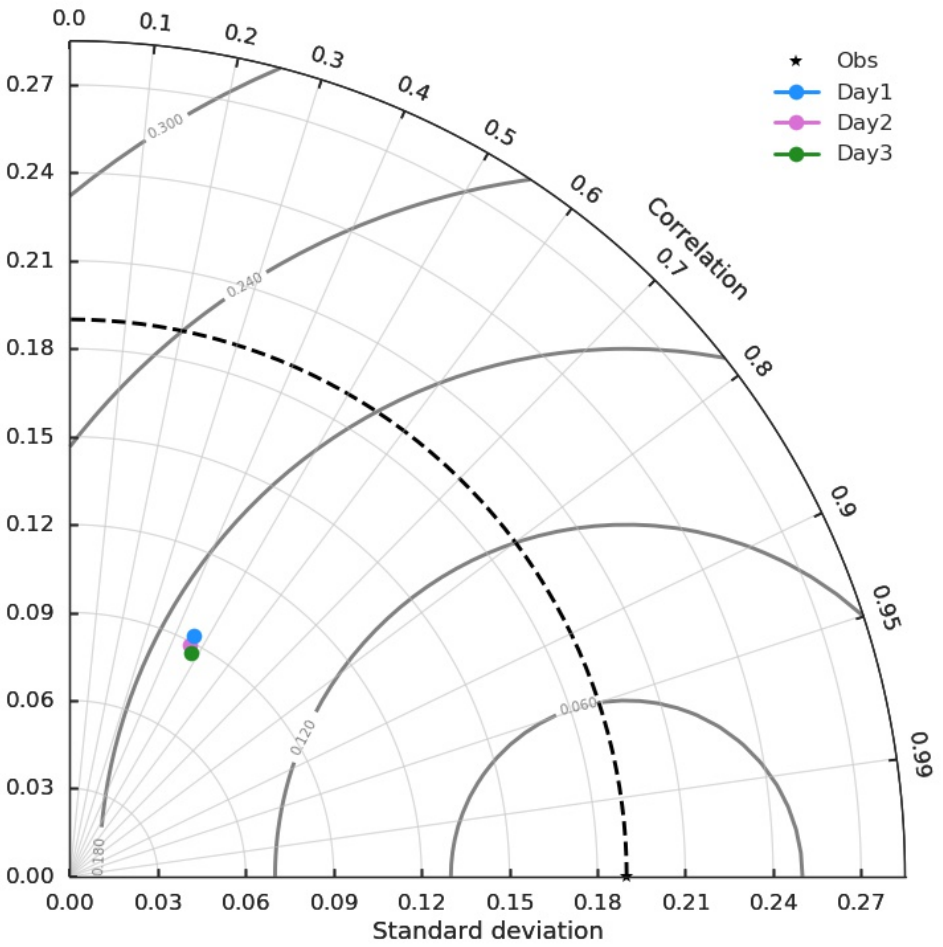




TESTING OF PREDICTIONS FOR DAY 3 (72 HOURS)

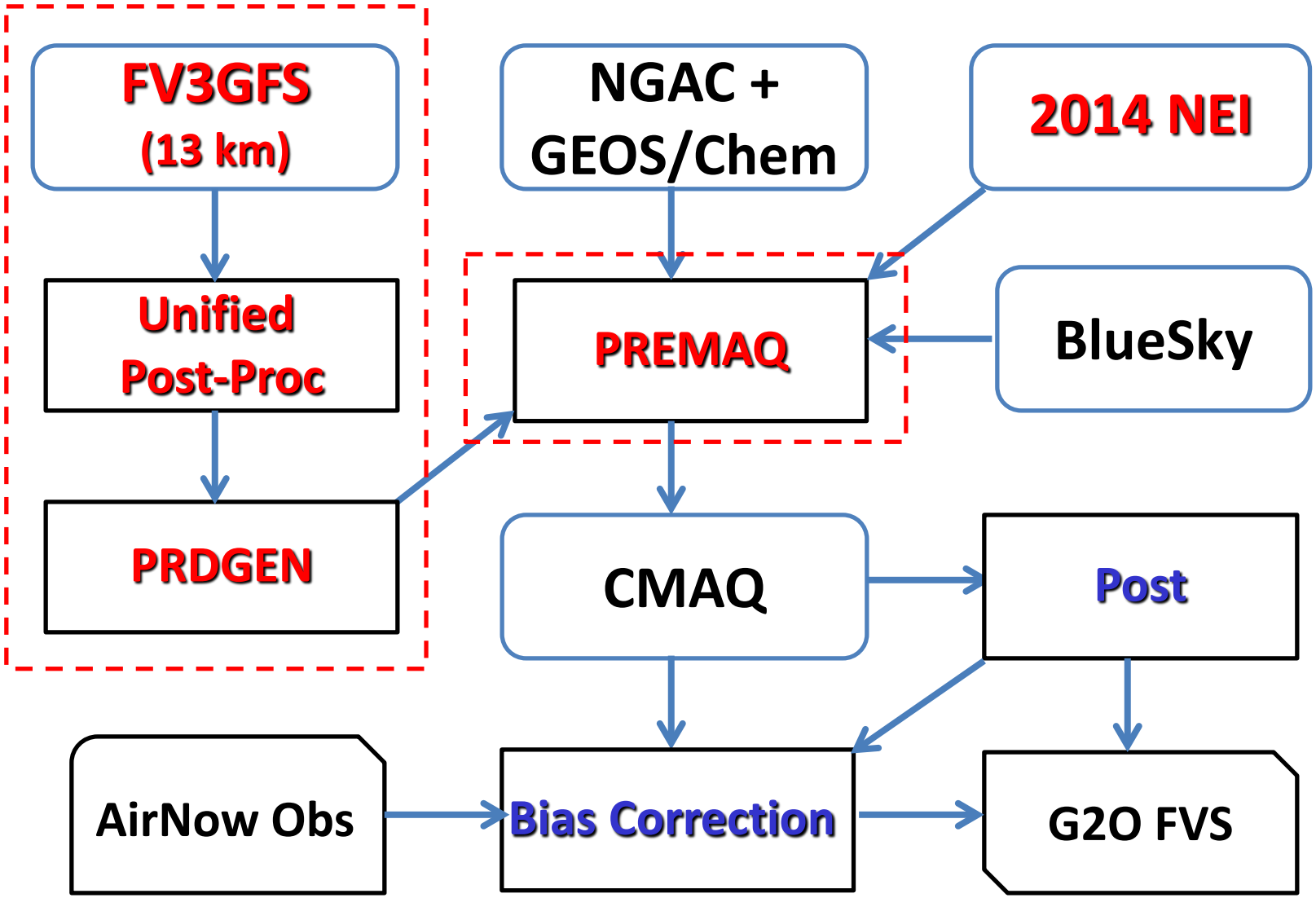
Ozone Day1,2,3 Performance for FV3-CMAQ5.0.2 20180911-20180921

MDA 8 hour O_3



TESTING WITH FV3GFS

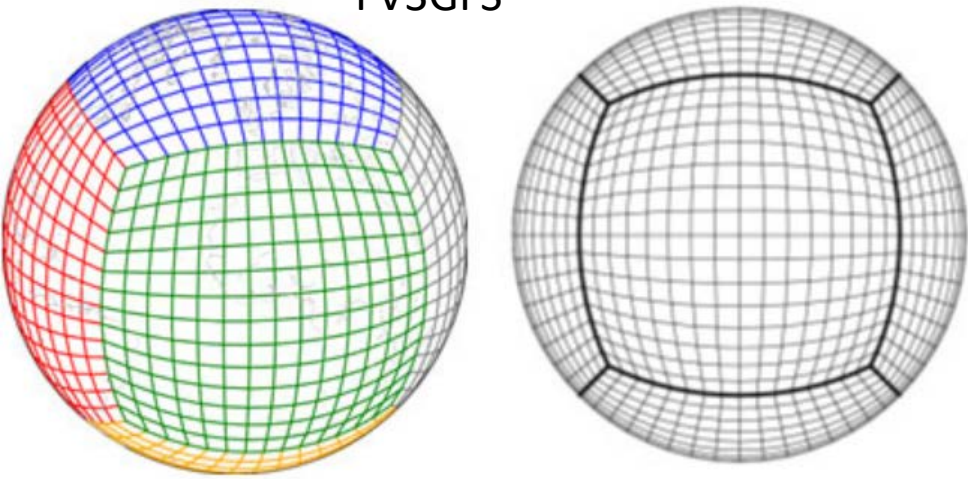
Transitioning to FV3

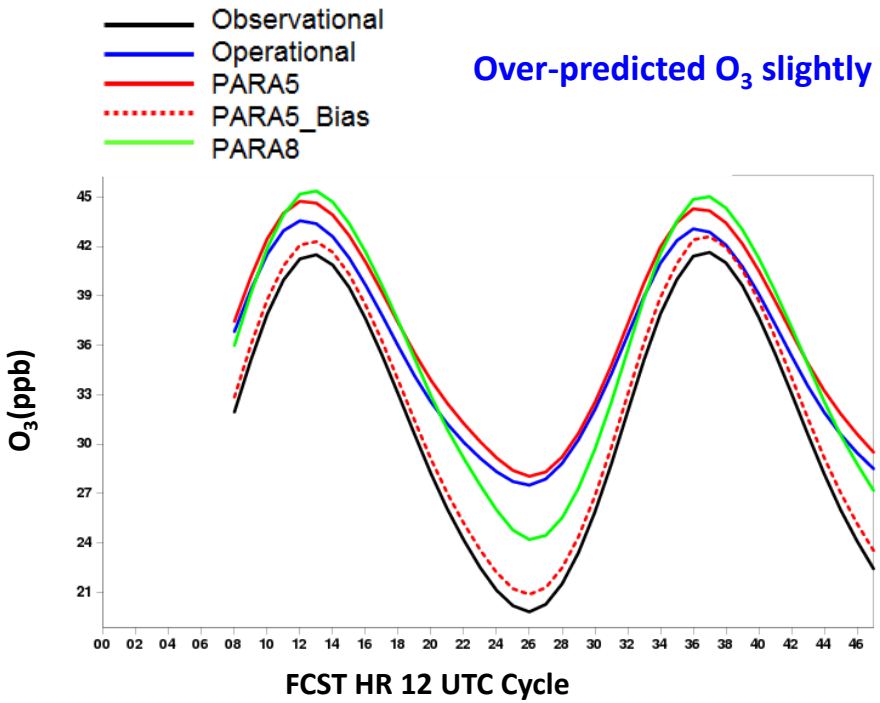


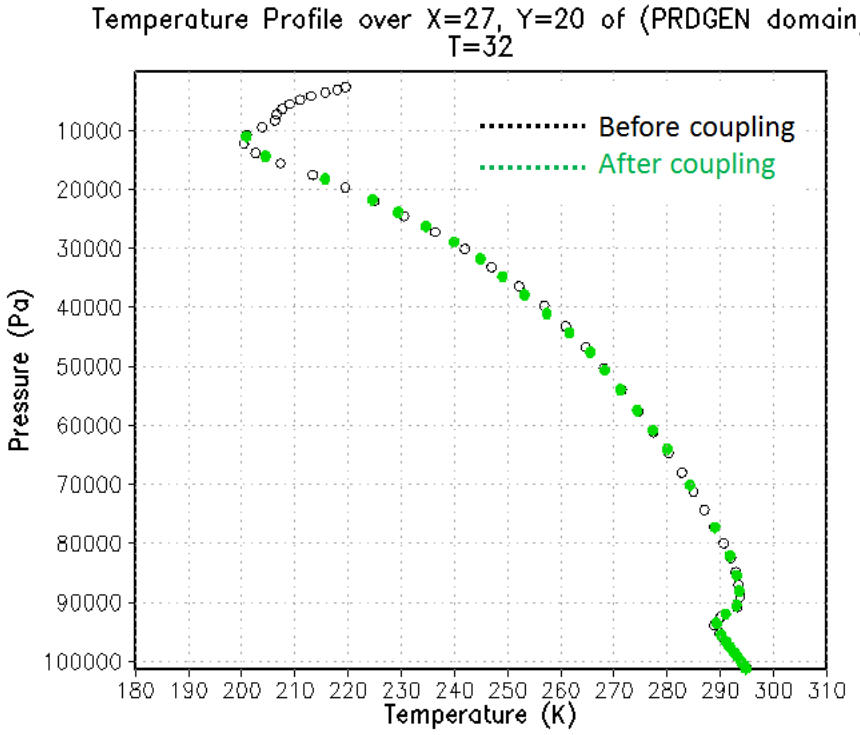
A flow-chart of the FV3GFS-CMAQ system

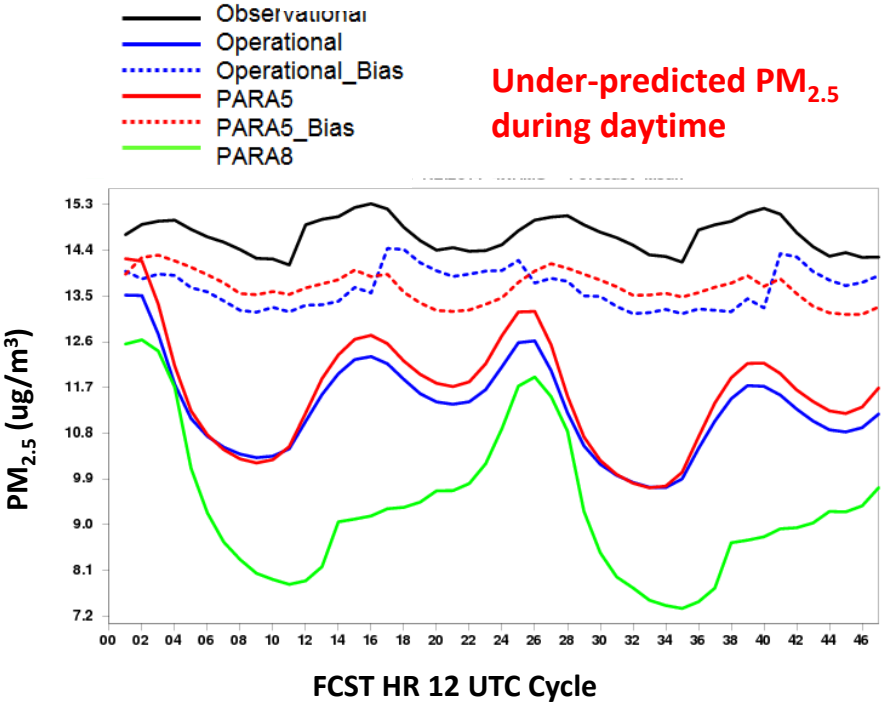
(new Changes as indicated by the red dashed boxes)

FV3GFS




Observational
Operational
PARA5
PARA5_Bias
PARA8
Over-predicted O_3 slightly
O_3(ppb)
FCST HR 12 UTC Cycle


Temperature Profile over X=27, Y=20 of (PRDGEN domain)
T=32
Before coupling
After coupling
Pressure (Pa)
Temperature (K)


Observational
Operational
Operational_Bias
PARA5
PARA5_Bias
PARA8
Under-predicted $PM_{2.5}$ during daytime
$PM_{2.5}$ (ug/m^3)
FCST HR 12 UTC Cycle

Summary

Next implementation:

- **Updated fine particulate matter (PM2.5) bias correction**
- **New ozone bias correction using the same unified bias correction code**
- **Updated anthropogenic emissions from NEI2014v2**
- **Updated wildfire smoke emissions diurnal profile**
- **Updated Alaska and Hawaii domain CMAQ code to the same version used for CONUS**

Work in progress:

- Transition to using Unified Forecast System based on FV3GFS to provide meteorology for off-line and in-line coupling with CMAQ
- Extension of predictions to 72 hours
- Emissions improvements
- Testing of updated CMAQ versions

Acknowledgments:
AQF implementation team members

Special thanks to previous NOAA and EPA team members who contributed to the system development

NOAA/NWS/STI	***Ivanka Stajner***	***NAQFC Manager***
NWS/AFSO	***Jannie Ferrell***	***Outreach, Feedback***
NWS/OD	***Cynthia Jones***	***Data Communications***
NWS/OSTI/MDL	***David Miller, Dave Ruth***	***Dev. Verification, NDGD Product Development***
NWS/STI	***Jose Tirado-Delgado***	***Program Support***
NESDIS/NCDC	***Alan Hall***	***Product Archiving***
NWS/NCEP		
Jeff McQueen, Jianping Huang, Ho-Chun Huang		**AQF model interface development, testing, & integration**
Jun Wang, Li Pan, *Sarah Lu		**Global dust aerosol and feedback testing**
***Brad Ferrier, *Eric Rogers,**		**NAM coordination**
***Hui-Ya Chuang, Perry Shafran, Boi Voung**		
Geoff Manikin		**Smoke and dust product testing and integration**
Rebecca Cosgrove, Steven Earle, Chris Magee		**NCO transition and systems testing**
Mike Bodner, Andrew Orrison		**HPC coordination and AQF webdrawer**
ESRL/PSD		
Jim Wilczak, Irina, Djalalova, Dave Allerud,		***bias correction development***
NOAA/OAR/ARL		
Pius Lee, Daniel Tong, Youhua Tang		**CMAQ development, adaptation of AQ simulations for AQF**
Barry Baker		
Ariel Stein		**HYSPLIT adaptations**
NESDIS/STAR	***Shobha Kondragunta***	***Smoke and dust verification product development***
NESDIS/OSDPD	***Liqun Ma***	***Production of smoke and dust verification products***
EPA/OAQPS partners:		
Chet Wayland, Phil Dickerson, Brad Johns, John White		***AIRNow development, coordination with NAQFC***

* Guest Contributors

Thank you

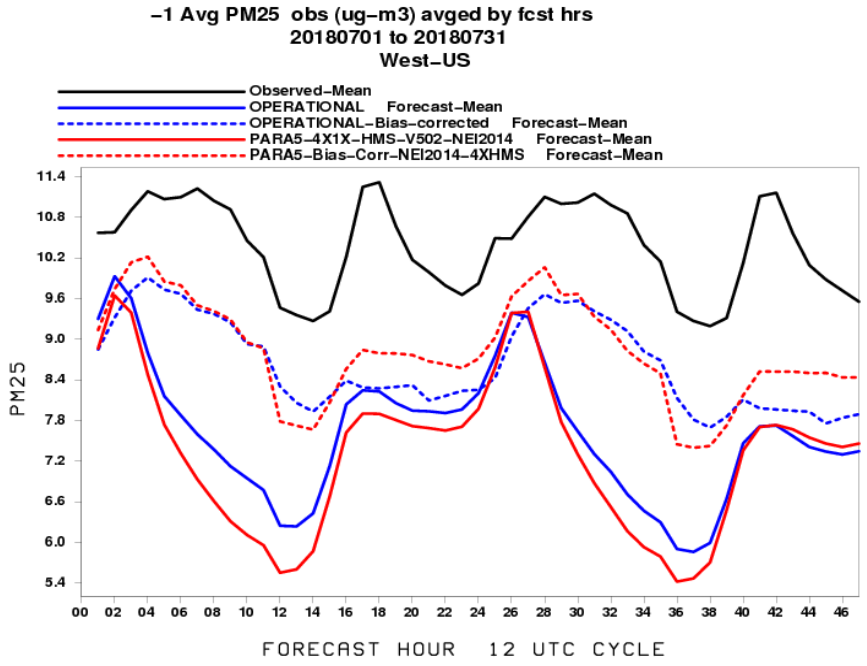
New smoke emissions processing code

- New BlueSky emissions code was implemented on August 1 2018.
- Necessary update as fire points are no longer manually inspected by an analyst.
- Significant effects on fire point quantity, duration and burn area inputs.
- Significant effects on smoke and PM 2.5 predictions

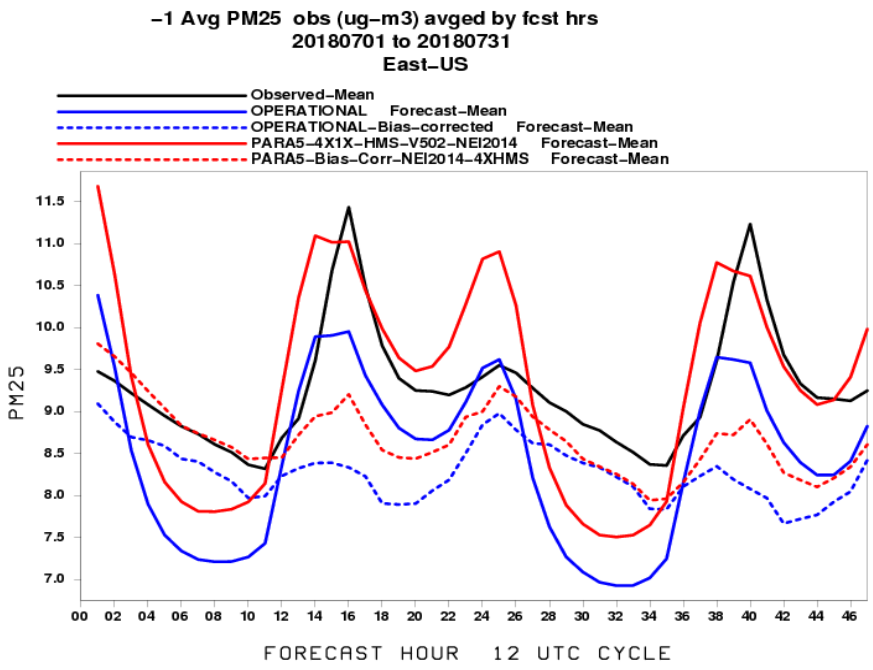
Testing in progress

- Transition to FV3 core and coupling of CMAQ with FV3
- Two versions of FV3 are being evaluated for air quality capabilities FV3GFS (12km) and FV3Meso (3km).
- Extension of predictions to 72 hours
- Emissions: Continuing testing of oil and gas and NEI 2014 emissions
- Wildfire emissions improvements still underway
- Updates and testing of Ozone and PM2.5 bias correction to account for changes in the HMS fire code

Performance of PM2.5 predictions: diurnal variability in July 2018



Western U.S.



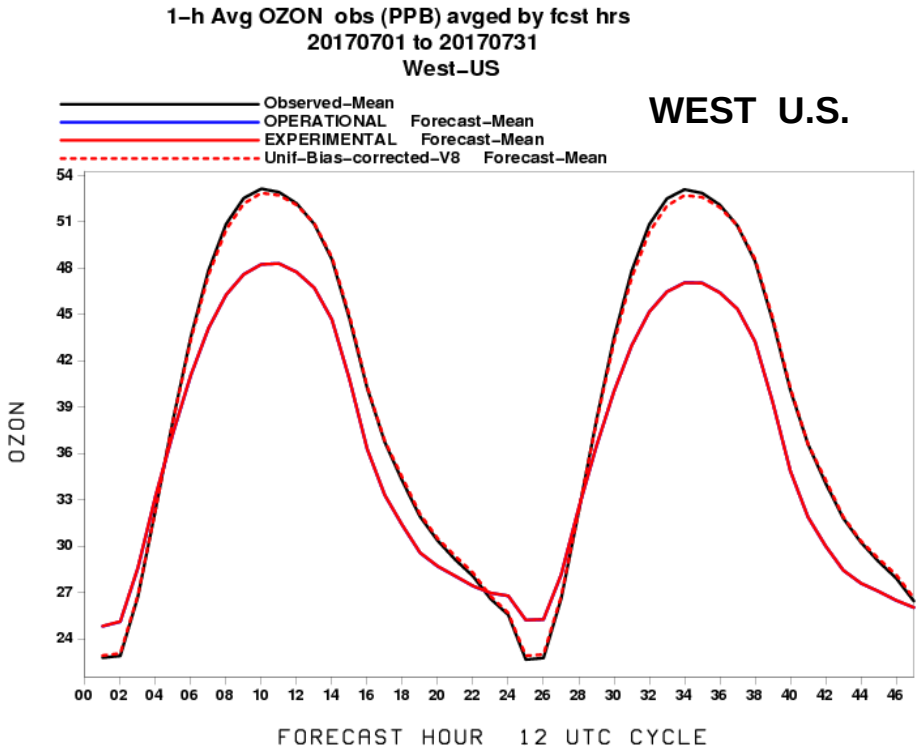
Eastern U.S.

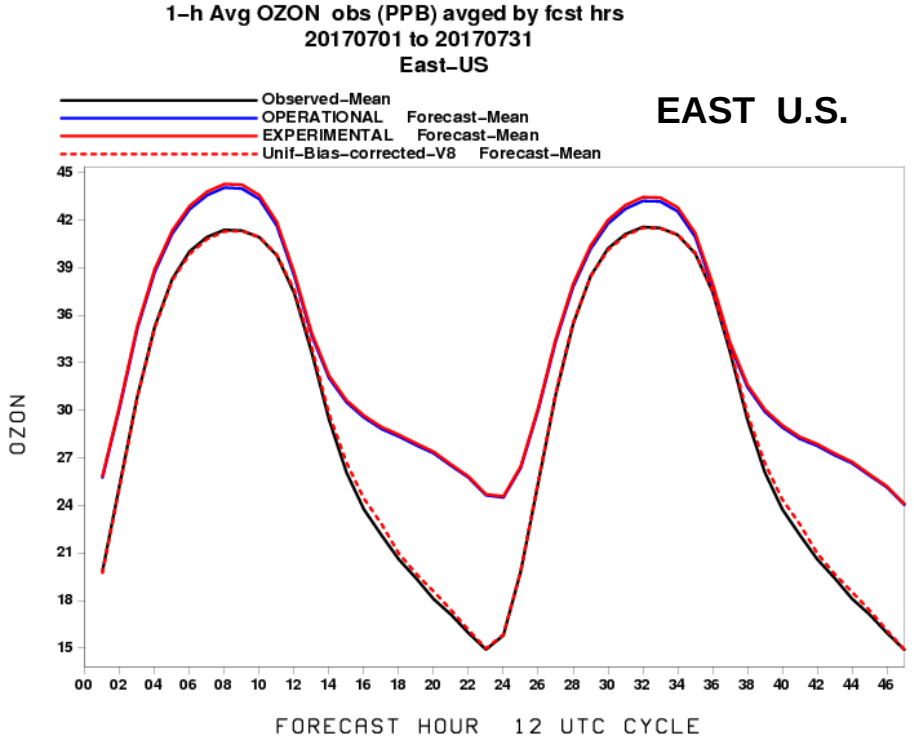
PARA 5 description:

- Uses NEI 2014V2 emissions for area and mobile sources
- Uses of HMS fire activity file for 06Z and 12Z cycle runs. All fires assumed continuous.
- Includes diurnal fire smoke emission profile
- Removes scaling of 4x larger smoke emissions during pre-analysis portion of run. Maintains emission strength during forecast.

Prod, EXP and *EXP bias corrected* O_3 Diurnal time-series

July 2017





Exp Unified Bias Correction near perfect
Prod & V5.1: - typical over-prediction East
- under-prediction West