National Air Quality Forecast Capability: Operational Fine Particulate matter (PM2.5) forecast guidance

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with contributions from the entire NAQFC Implementation Team

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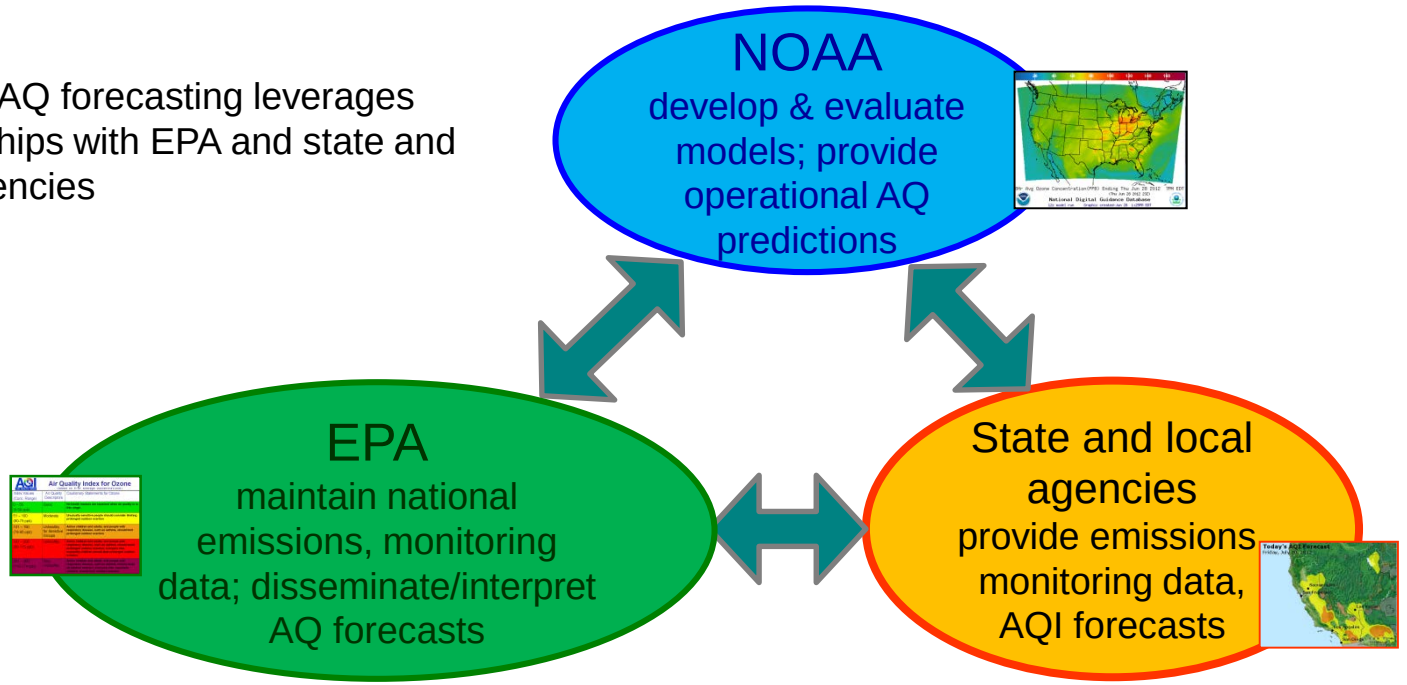
Background

- **Ongoing implementation of NOAA/NWS National Air Quality (AQ) Forecast Capability operationally to provide graphical and numerical guidance, as hourly gridded pollutant concentrations, to help prevent loss of life and adverse health impacts from exposure to poor AQ**
  - *Exposure to fine particulate matter and ozone pollution leads to premature deaths: 50,000+ annually in the US (Science, 2005; recently updated to 100,000 deaths; Fann, 2011, Risk Analysis)*
- **Direct impact on reducing loss of life: AQ forecasts have been shown to reduce hospital admissions due to poor air quality (Neidell, 2009, J. of Human Resources)**

- NOAA's AQ forecasting leverages partnerships with EPA and state and local agencies



National Air Quality Forecast Capability

Operational predictions at http://airquality.weather.gov

over expanding domains since 2004

Ozone and PM2.5

Linked numerical prediction system

Operationally integrated on NCEP's supercomputer

- NOAA/EPA Community Multiscale Air Quality (CMAQ) model
- NOAA/NCEP North American Mesoscale Forecast System (NAM) weather prediction

Observational Input:

- EPA emissions inventory, AirNow for bias correction
- NESDIS fire locations

Gridded forecast guidance products 2x daily nationwide

- At airquality.weather.gov and ftp-servers (12km resolution, hourly for 48 hours).
- On EPA servers

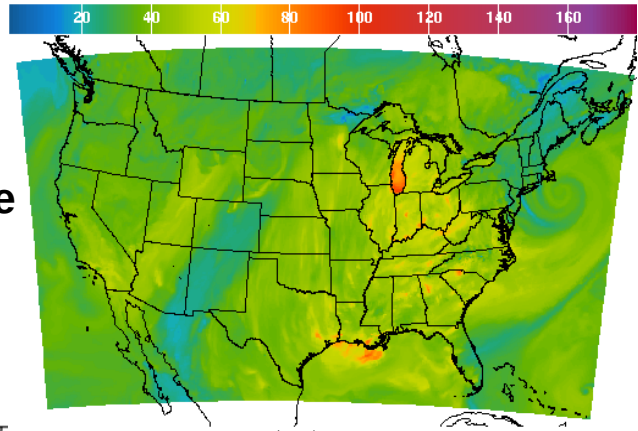
Verification, near-real time:

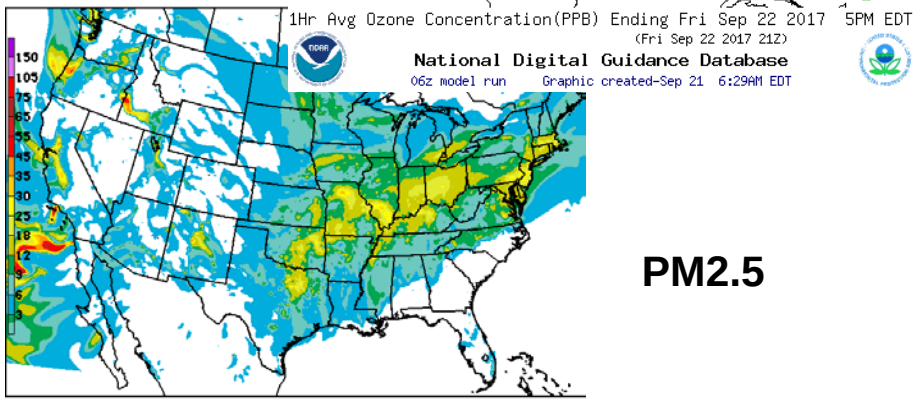
- Ground-level AirNow observations of surface ozone and PM2.5

Customer outreach/feedback

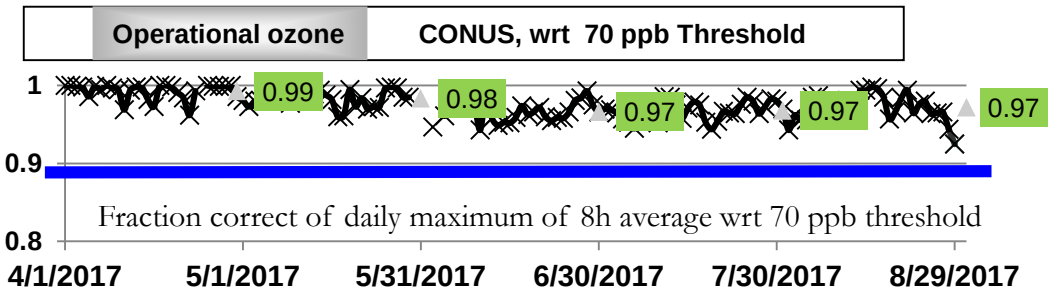
- State & Local AQ forecasters coordinated with EPA
- Public and Private Sector AQ constituents

Ozone





PM2.5



Maintaining prediction accuracy for lowered warning threshold and under changing pollutant emissions

National Air Quality Forecast Capability

Operational predictions at http://airquality.weather.gov

Smoke and dust

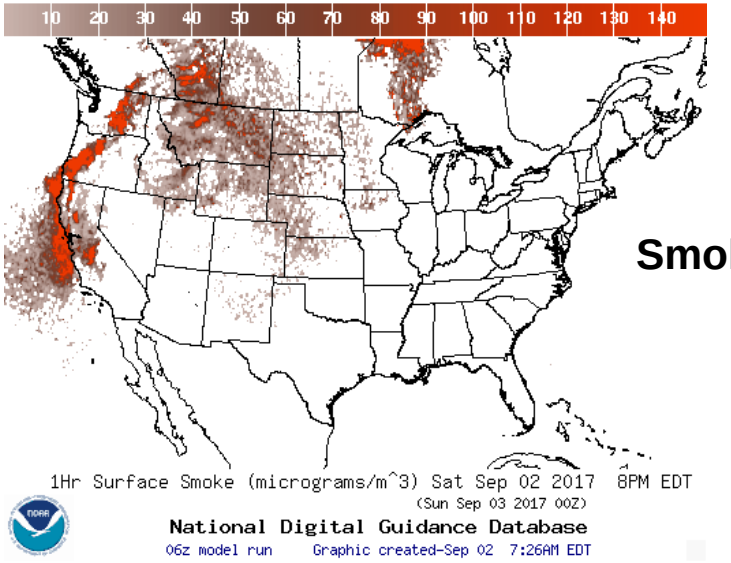
Emission sources

- **Smoke: NESDIS detects wildfire locations from satellite imagery. Emissions estimated by USFS BlueSky system.**
- **Dust: Source regions with emission potential are from MODIS deep blue climatology for 2003-2006. Emissions are modulated by wind and soil moisture.**

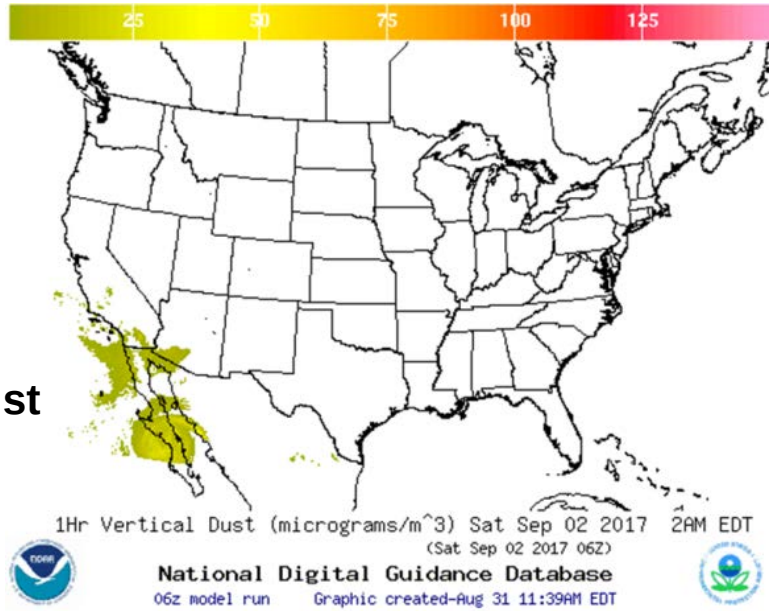
HYSPLIT model with NAM meteorology for transport, dispersion and deposition

- **Smoke: daily, nationwide**
- **Dust: 2x per day, CONUS**

Satellite products developed for verification



Smoke



Dust

Recent Updates

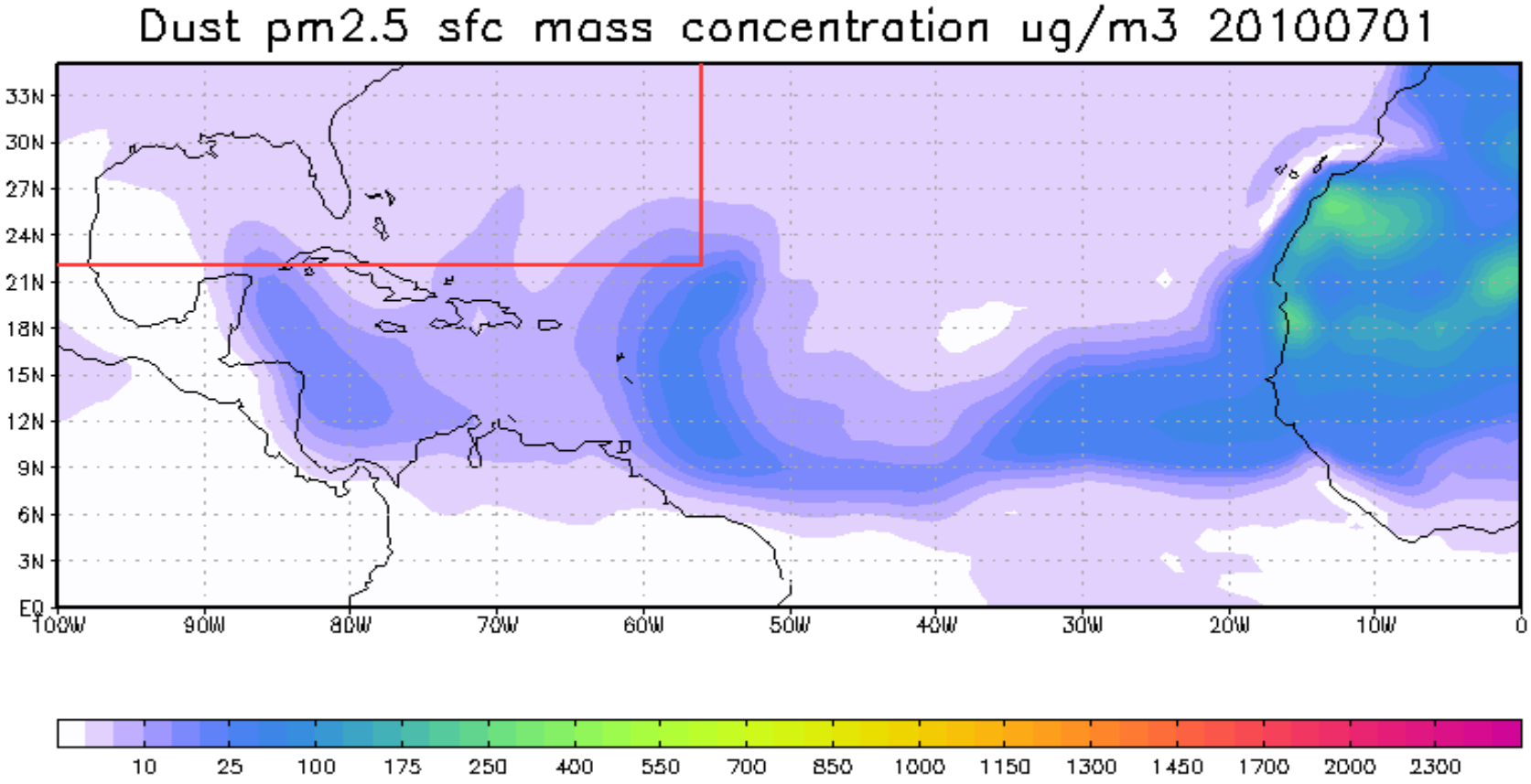
CMAQ system update in February 2016

First public release of raw model predictions and bias-corrected PM2.5 predictions

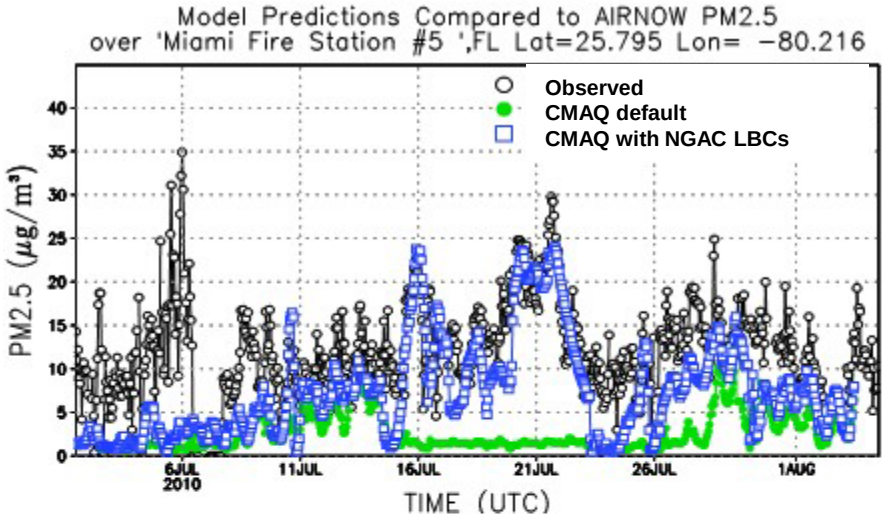
- Lateral boundary conditions from global dust predictions
- Increased vertical resolution from 22 to 35 layers in CMAQ v4.6
- Analog forecast technique for PM2.5 bias correction

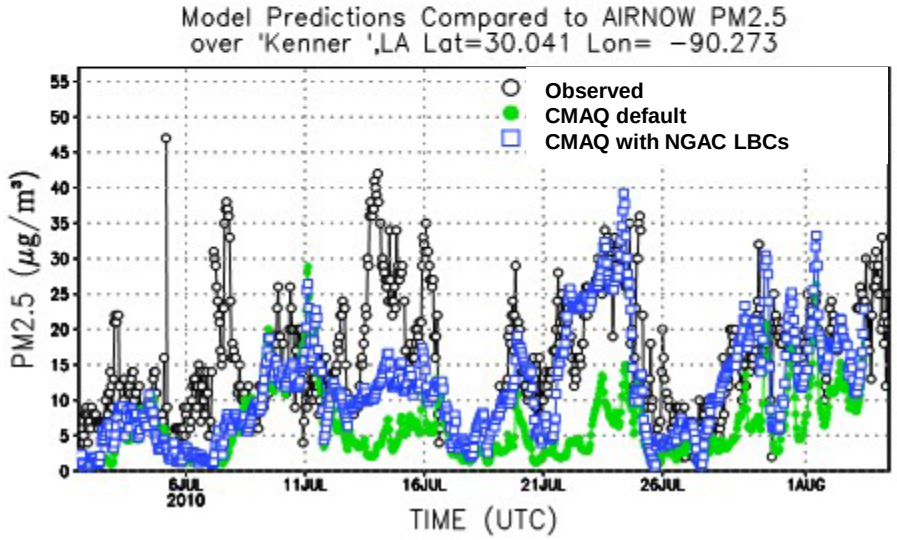
NGAC simulation of Saharan dust layer transport

- **Provides dust lateral boundary conditions for CMAQ**
- **Global-regional prediction linkage**
- **Increased number of model levels to better align CMAQ and global model levels**



Impact of NGAC LBCs on CMAQ predictions of PM2.5



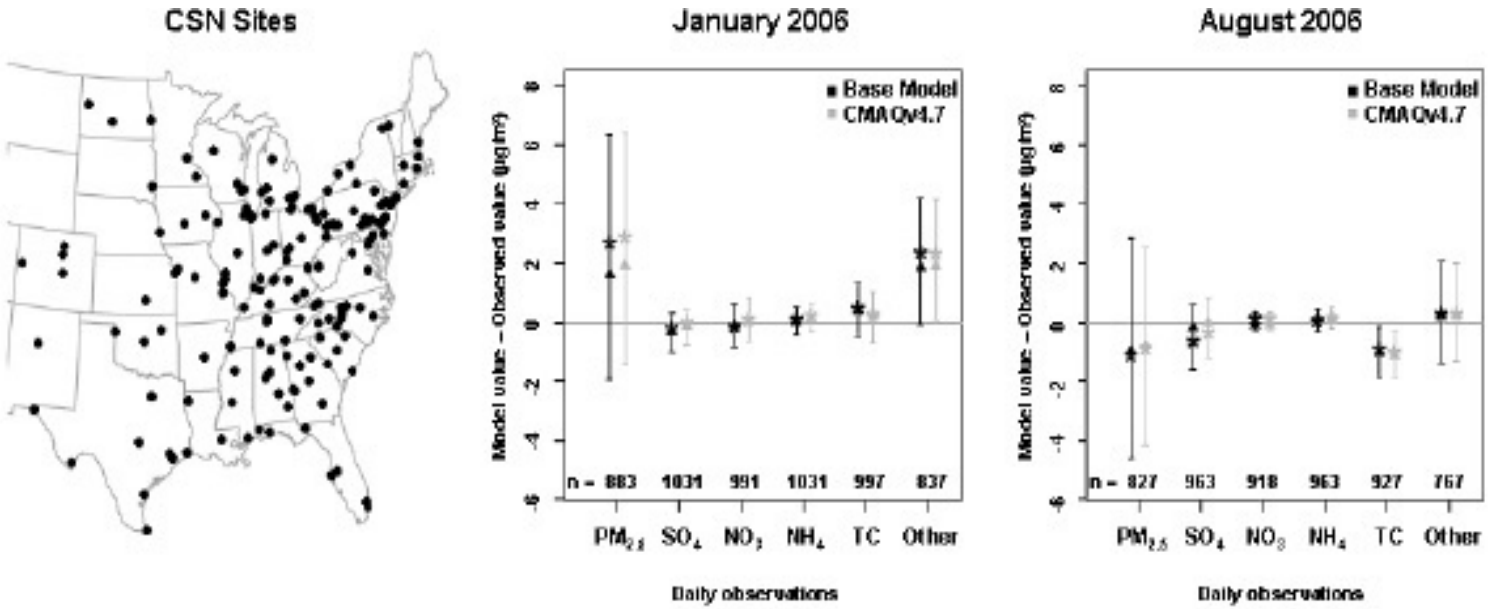


	CMAQ with default LBCs	CMAQ with NGAC LBCs
Whole domain July 1 – Aug 3	MB= -2.82 Y=1.627+0.583* X R=0.42	MB= -0.88 Y=3.365+0.600* X R=0.44
South of 38°N, East of -105°W July 1 – Aug 3	MB= -4.54 Y=2.169+.442*X R=0.37	MB= -1.76 Y=2.770+.617*X R=0.41
Whole domain July 18– July 30	MB= -2.79 Y=2.059+0.520* X R=0.31	MB= -0.33 Y=2.584+0.795* X R=0.37
South of 38°N, East of -105°W July 18– July 30	MB= -4.79 Y=2.804+.342*X R=0.27	MB= -0.46 Y=-0.415+.980*X R=0.41

Time series of PM2.5 from EPA AIRNOW observations (black dot), CMAQ baseline run using static Lateral Boundary Conditions (LBCs) (green dot) and CMAQ experimental run using NGAC LBCs (blue square) at Miami, FL (top panel) and Kenner, LA (bottom panel).

Credit: Youhua Tang

Seasonal Bias in PM2.5 prediction



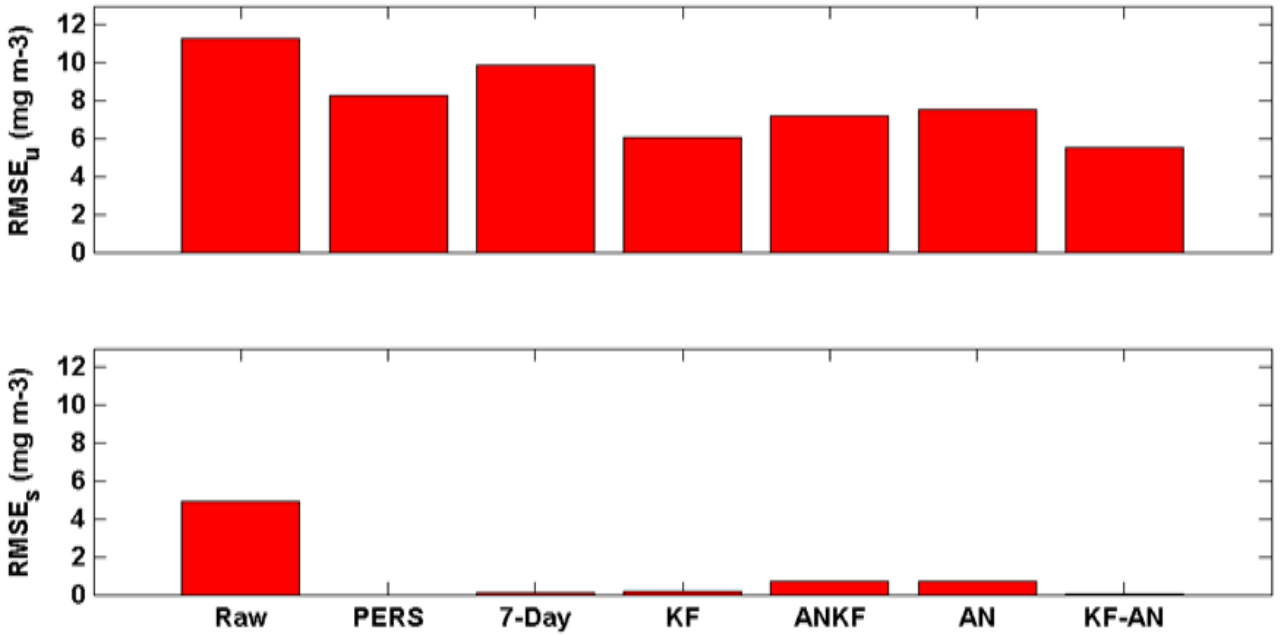
Mean (star), median (triangle), and inter-quartile ranges of model bias (model value – observed value) for multiple fine-particle species measured at CSN sites in the 12km domain. The number of model/observation pairs for each species is shown above the x-axis.

The bias in the total mass of PM2.5 is dominated by overpredictions of unspecified PM in the winter and by underpredictions of carbon aerosols in the summer. (*Foley et. al., Incremental testing of the Community Multiscale Air Quality (CMAQ) modeling system version 4.7, Geosci. Model Dev., 3, 205-226, 2010)*

Saylor et. al. found same type of seasonal speciation biases in the CMAQ v4.6 for IMPROVE sites.

Bias correction for PM2.5 predictions

- Quality control of the observations is essential
- Five different post-processing techniques were tested



Raw: Hourly AIRNow data available in real-time

PERS: Persistence forecast

7-day: 7-day running mean subtraction

KF: Kalman-filter approach

ANKF: Analog forecast technique followed by Kalman filter approach

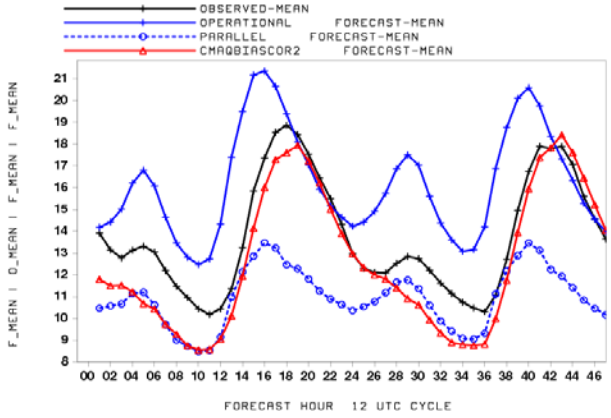
AN: Analog Forecast technique

KF-AN: Kalman-filter approach followed by Analog forecast technique

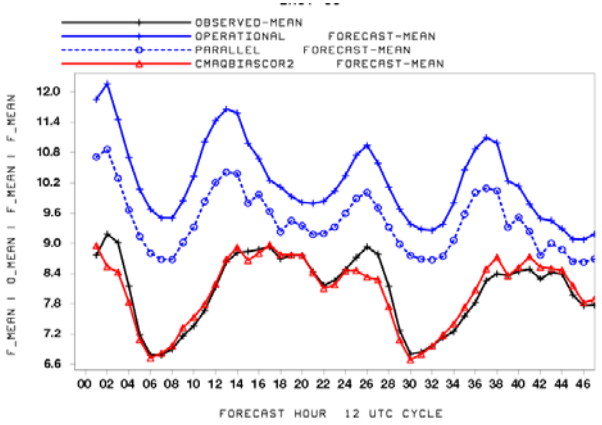
Unsystematic component of the RMSE (top panel) and systematic component of RMSE (bottom panel) using hourly values for the month of November evaluated at the 518 AIRNow PM2.5 sites.

I. Djalalova, L. Delle Monache, and J. Wilczak: PM2.5 analog forecast and Kalman filter post-processing for the Community Multiscale Air Quality (CMAQ) model, Atmospheric Environment, Volume 108, May 2015, pp.76–87.

2016 Update: Raw and bias-corrected PM2.5 predictions



Western US

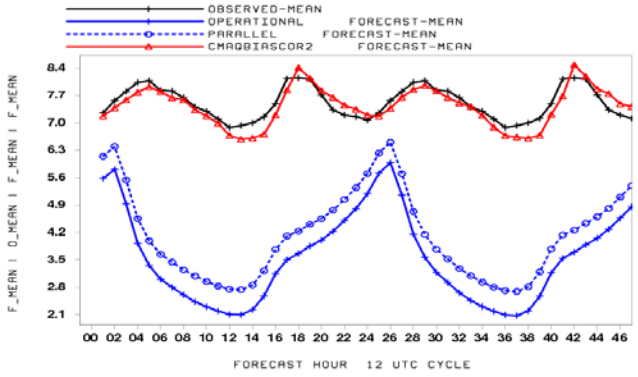


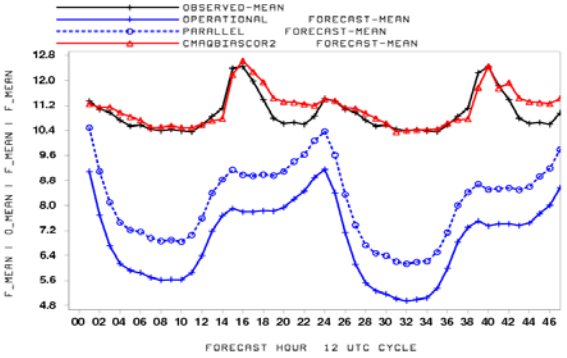
Eastern US

Winter (Jan 2015)

Regional mean for each of 48 prediction hours

- **Observations**
- **Previous model**
- **2016 model update**
- **AN Bias correction of 2016 updated model**





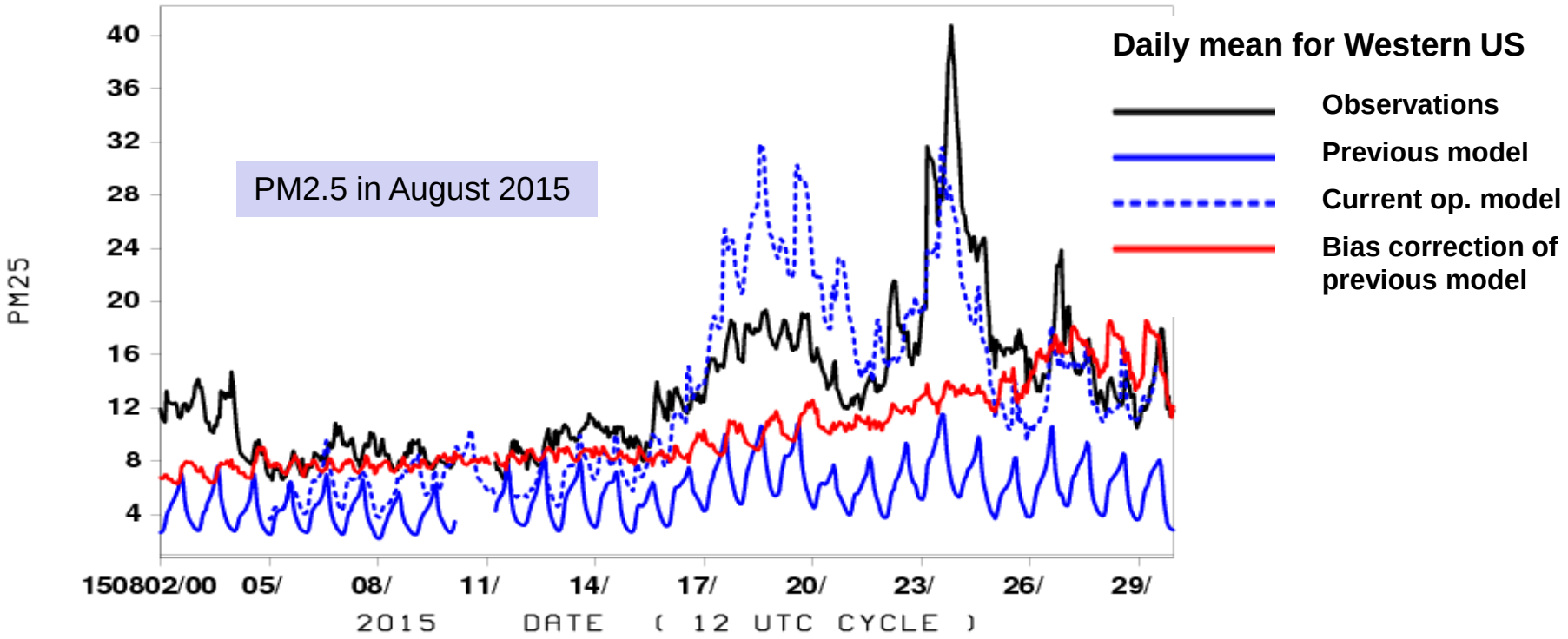
Summer (July 2015)

Updates to air quality predictions implemented in June 2017

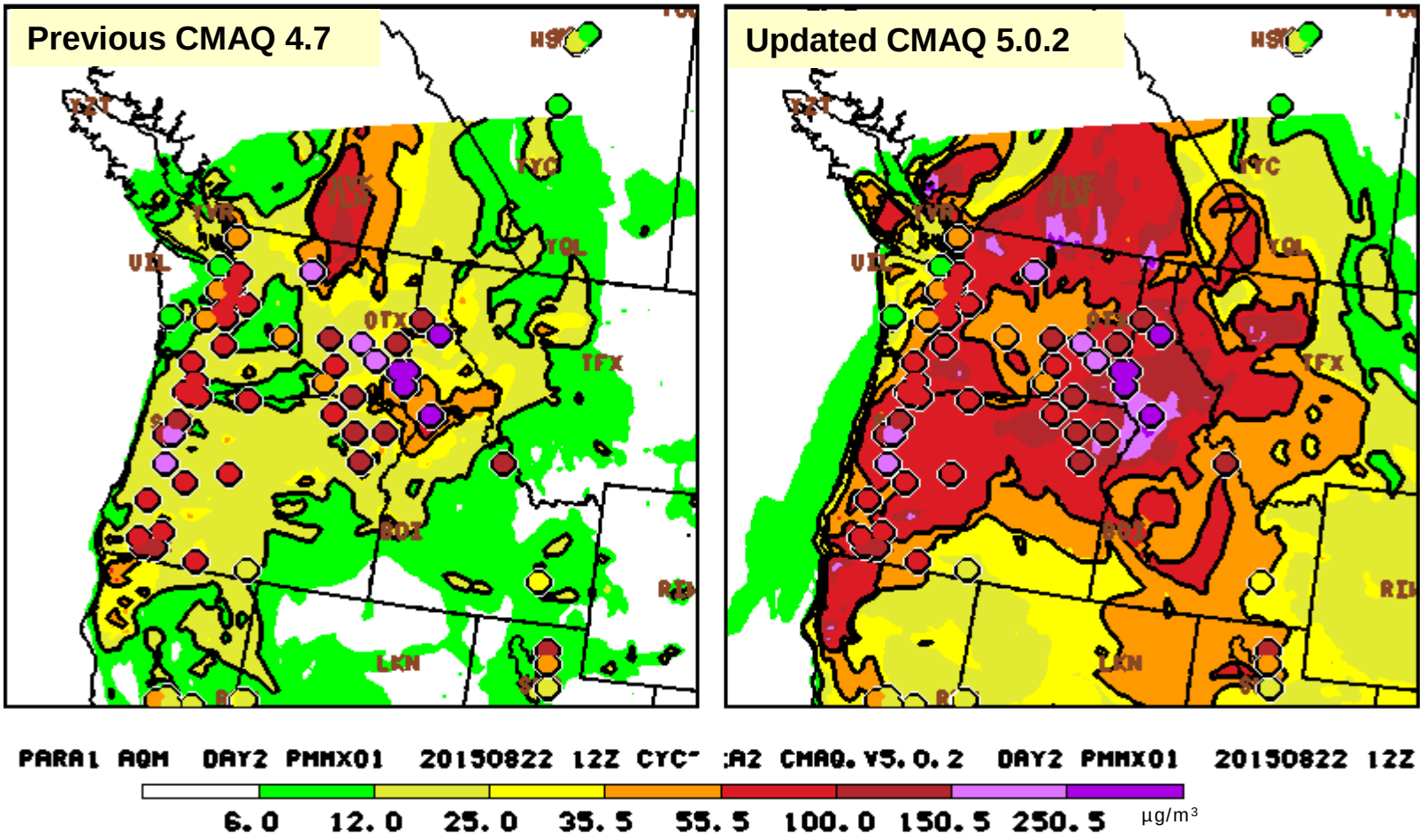
- Community Multi-scale Air Quality (**CMAQ**) model **v5.0.2**
- US Forecast Service **BlueSky** smoke emissions system **v3.5.1**
  - *Fuel Characteristic Classification System version 2 (FCCS2), which includes a more detailed description of the fuel loadings with additional plant type categories.*
  - *Improved fuel consumption model and fire emission production system (FEPS).*
  - *Explicit fuel load map for Alaska (HYSPLIT only)*
- Addition of **24-hour analysis cycle** to include **wildfire emissions** at the time when they are observed
- **Bias-correction** post-processing for PM2.5 forecast guidance updated to use the Kalman Filter Analog (**KFAN**) technique
- **Point source emissions** to projections for 2017
- **Dust** related aerosol species at the CMAQ **lateral boundaries** to use the NEMS Global Aerosol Component (**NGAC**) **v2** forecasts
- Meteorology from **NAM version 4** since March 2017

PM2.5 from wildfires in CMAQ

- Better representation of wildfire smoke emissions based on detections of wildfire locations from satellite imagery, BlueSky system emissions, included over previous 24 hours when fires were detected and projected with reduced intensity into the 48 hour forecast period



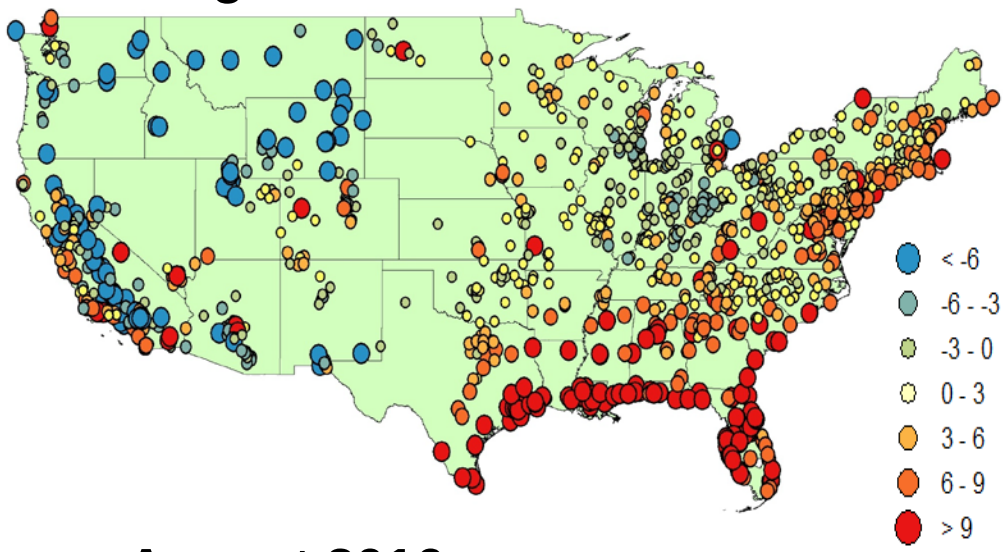
Representation of wildfires – NW U.S. example on August 23, 2015



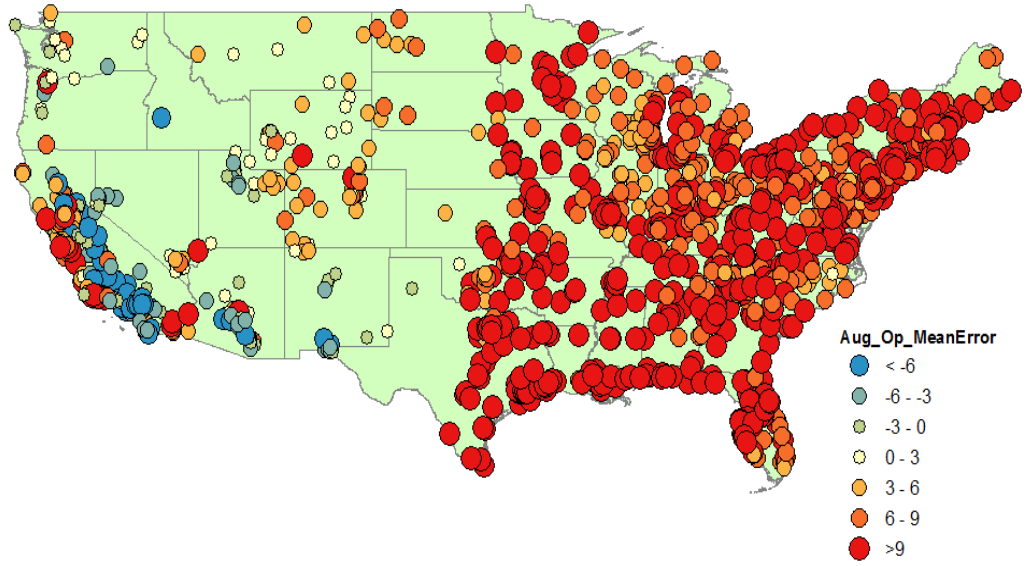
- Wildfires are strongly impacting air quality in the region
- Observed daily maximum of hourly PM2.5 exceeds 55 µg/m^{3}and even 100 µg/m^3
- Operational system predicts values below 25 µg/m^3 for many of these monitors
- Updated system in testing predicts values much closer observed

Daily maximum 8 hour ozone bias

August 2017



August 2016



Ozone bias has decreased substantially with CMAQ 5.0.2 implemented in June 2017 and NAM version 4 implemented in March 2017

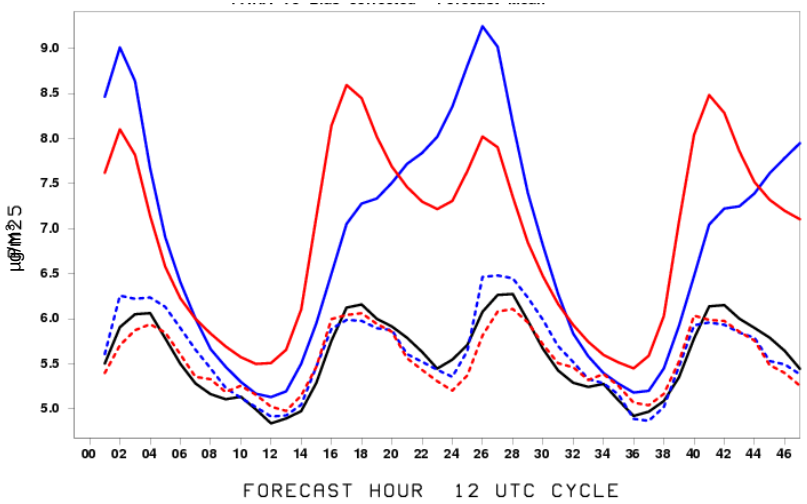
+ = Model Over-Predicted
- = Model Under-Predicted

Courtesy: Joel Dreessen & James Boyle, MD DOE

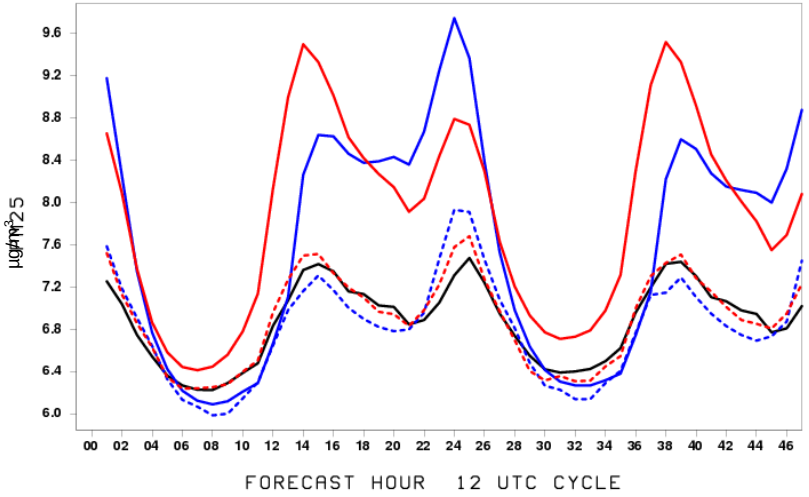
Statistical performance of PM2.5 for May 2017

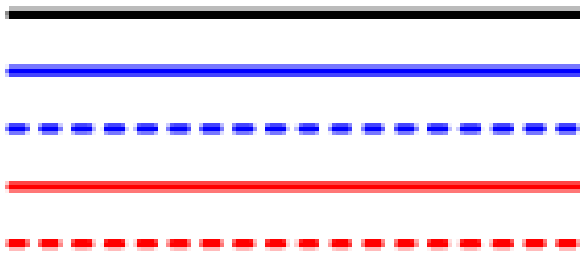
Mean PM2.5 by forecast hour

Western U.S.



Eastern U.S.





Observations

Previous operational model

Bias correction for previous model

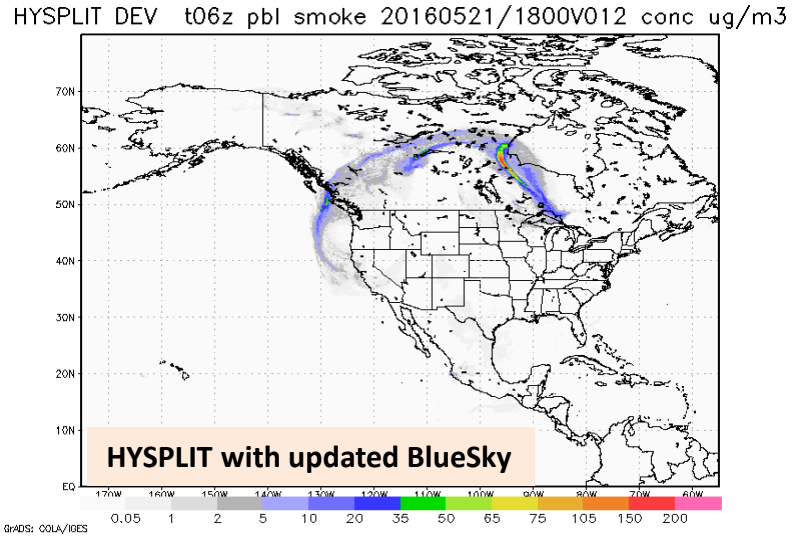
Current operational model

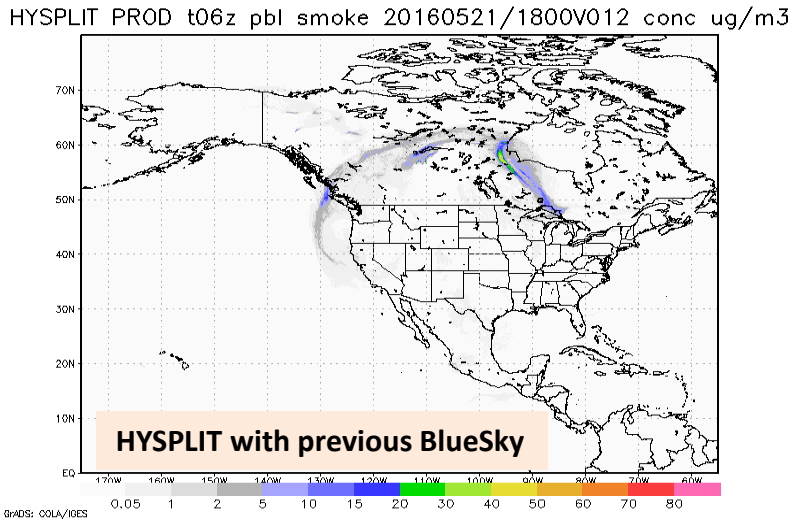
Bias correction for current model

I. Djalalova, L. Delle Monache, and J. Wilczak: PM2.5 analog forecast and Kalman filter post-processing for the Community Multiscale Air Quality (CMAQ) model, Atmospheric Environment, Volume 108, May 2015, pp.76–87.

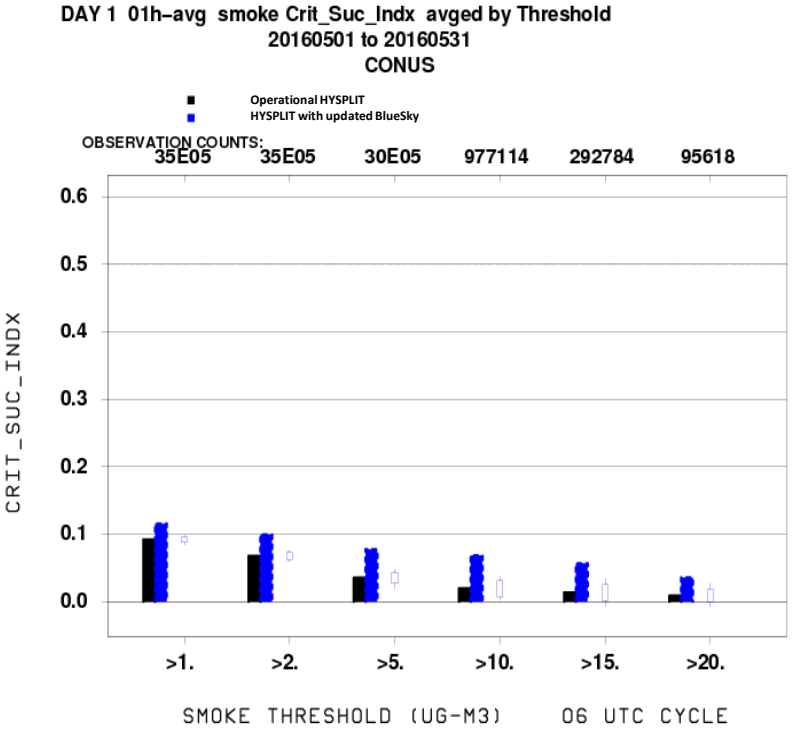
Huang et al., Improving NOAA NAQFC PM2.5 predictions with a bias correction approach, Weather and Forecasting, 2016.

BlueSky Evaluation





Comparing previous operational smoke predictions with those using updated BlueSky for May 2016

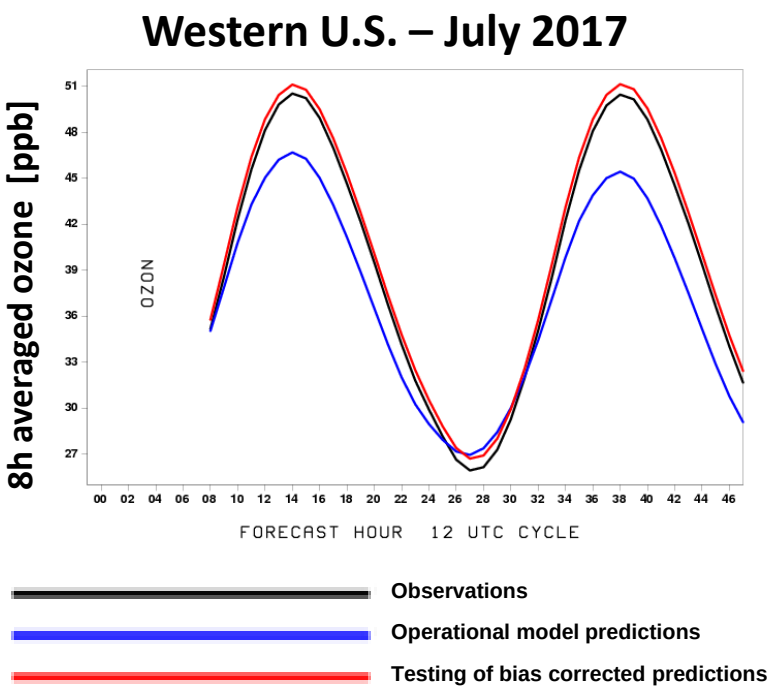


Improved skill scores in May from large Ft. McMurray fires for currently operational HYSPLIT with updated BlueSky

Testing in Progress

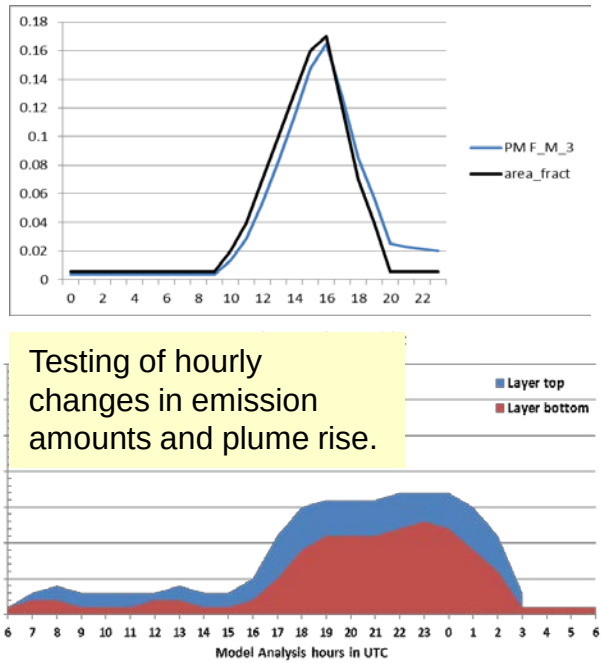
Testing in progress

- Emissions updates: testing of oil and gas updates, testing of NEI 2014
- Ozone bias correction



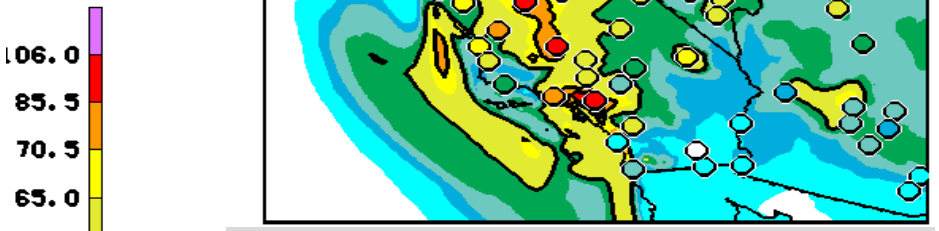
- Extension of predictions to 72 hours
- Wildfire emissions: hourly from BlueSky, ECCC emissions

Example PM diurnal profile for mixed forest

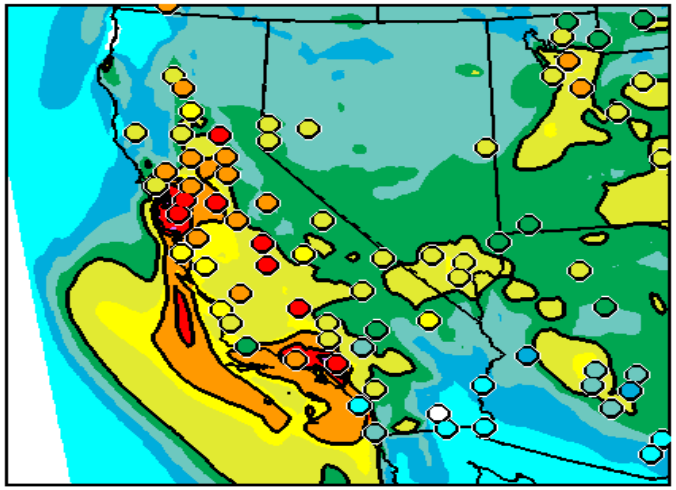


Ozone bias correction performance

Sept 2, 2017



CMAQ 8h Ozone Max

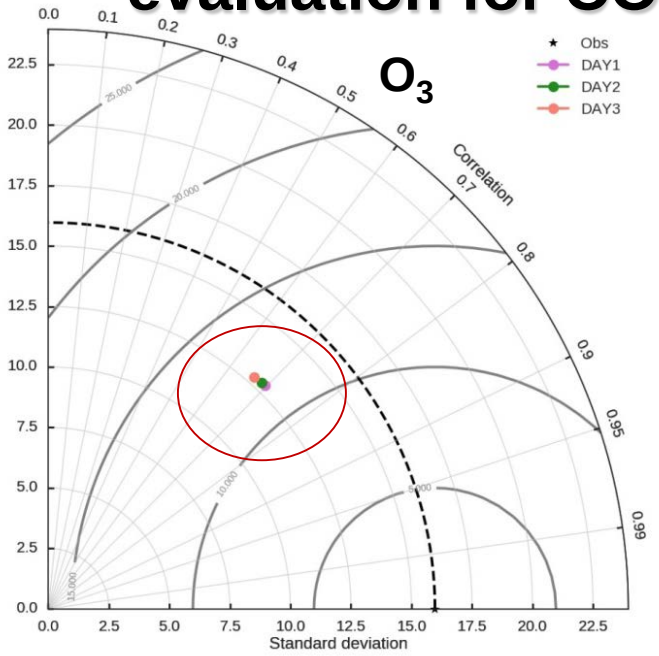


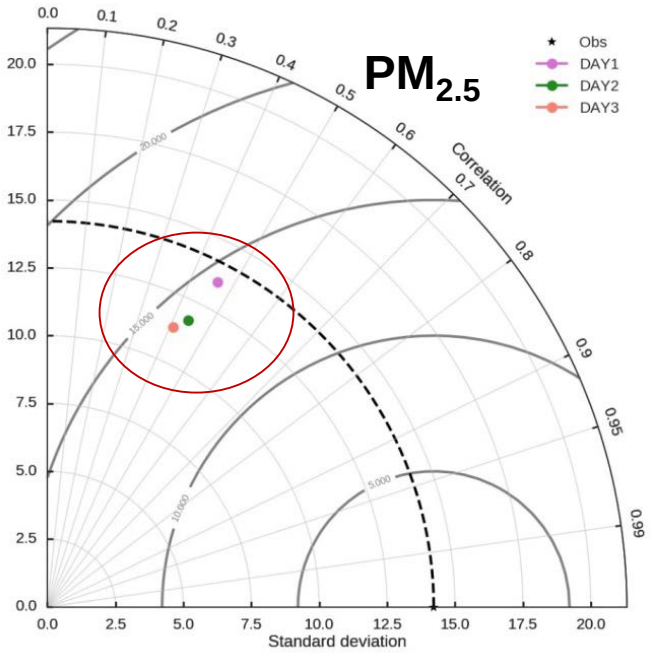
Bias Corrected 8h Ozone Max

Corrects under-prediction over California valleys but reduced ozone near fires East of San Francisco

Testing of predictions for 72 hours
evaluation for CONUS

Statistics for all hours

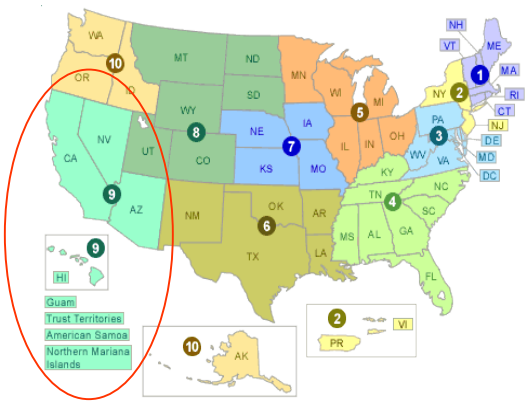


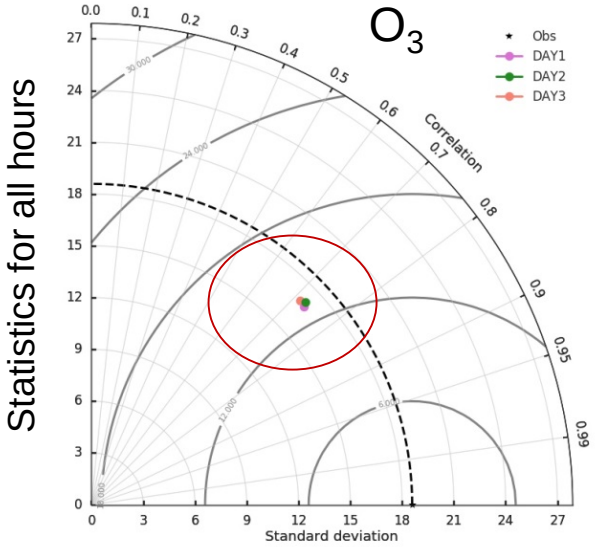


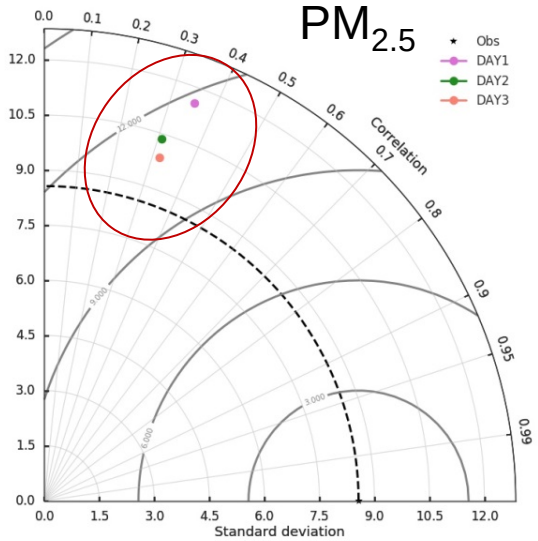
Performance of predictions for days 1, 2 & 3 over **CONUS** for August 10-19, 2017

Pollutant	Prediction day	obs	Bias	RMSE	corr, r
Daily max. of 8h average ozone [ppb] (N=27300)	D1	39.0	2.58	9.65	0.75
	D2		2.23	9.78	0.74
	D3		1.76	10.14	0.71
Daily average PM2.5 [ug/m^3] (N=18560)	D1	10.61	1.55	10.32	0.59
	D2		0.92	9.88	0.58
	D3		0.76	10.28	0.53

Testing predictions for 72 hours evaluation for Pacific Southwest







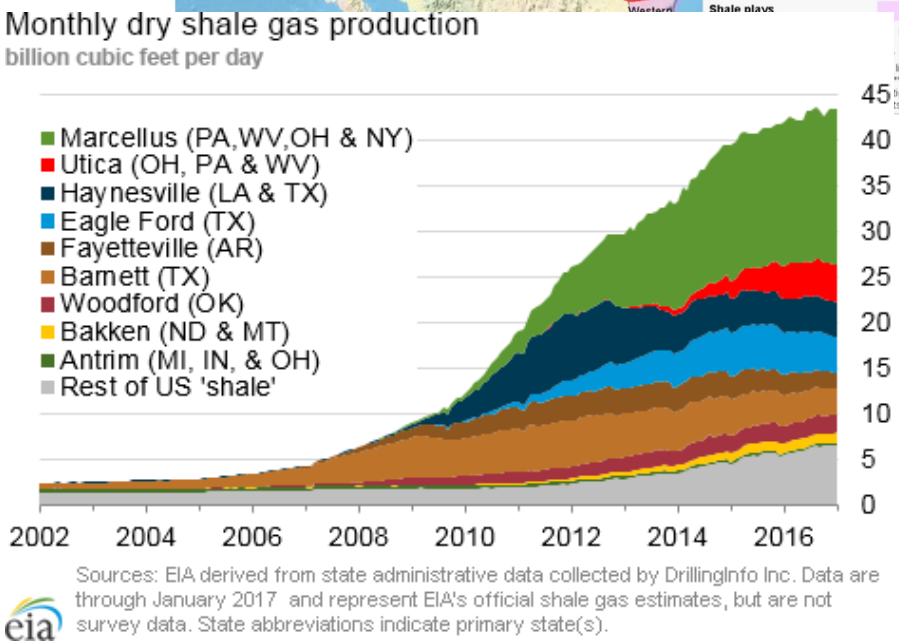
Day1,2,3 Performance over Pacific Southwest (region 9) for August 10-19, 2017

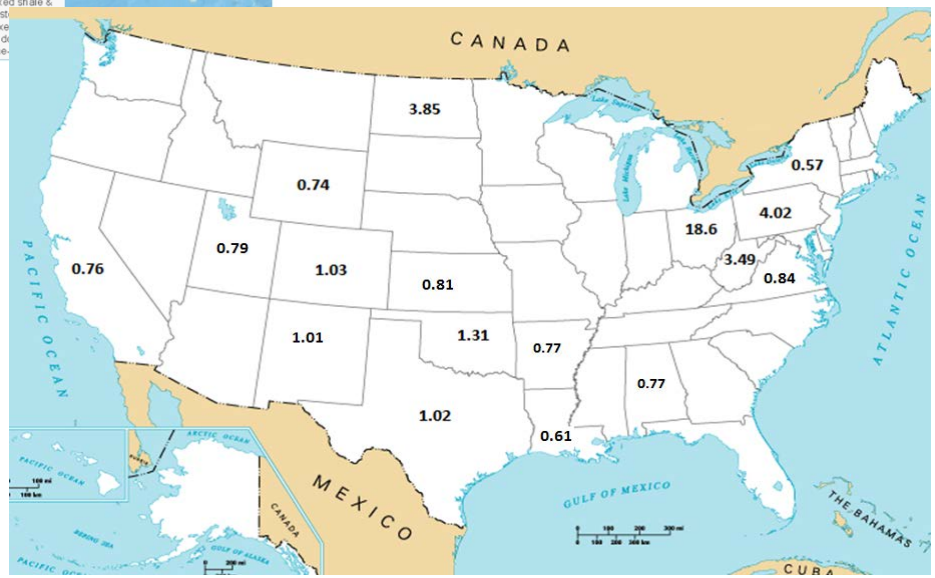
Pollutant	Obs	Bias	RMSE	corr, r
Daily max of 8h ozone (N= 4620) D1	49.7	-0.30	11.15	0.77
D2		-0.72	11.40	0.77
D3		-1.53	11.91	0.75
Daily average of PM2.5 (N= 2875) D1	11.6	1.98	10.52	0.46
D2		0.03	8.65	0.40
D3		0.53	9.59	0.38

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

Partnering with AQ Forecasters

Focus group, State/local AQ forecasters:

- Participate in real-time developmental testing of new capabilities, e.g. aerosol predictions
- Provide feedback on reliability, utility of test products
- Local episodes/case studies emphasis
- Regular meetings; working together with EPA's AIRNow and NOAA
- ***Feedback is essential for refining/improving coordination***

Examples of AQ forecaster feedback after emissions update in 2012:

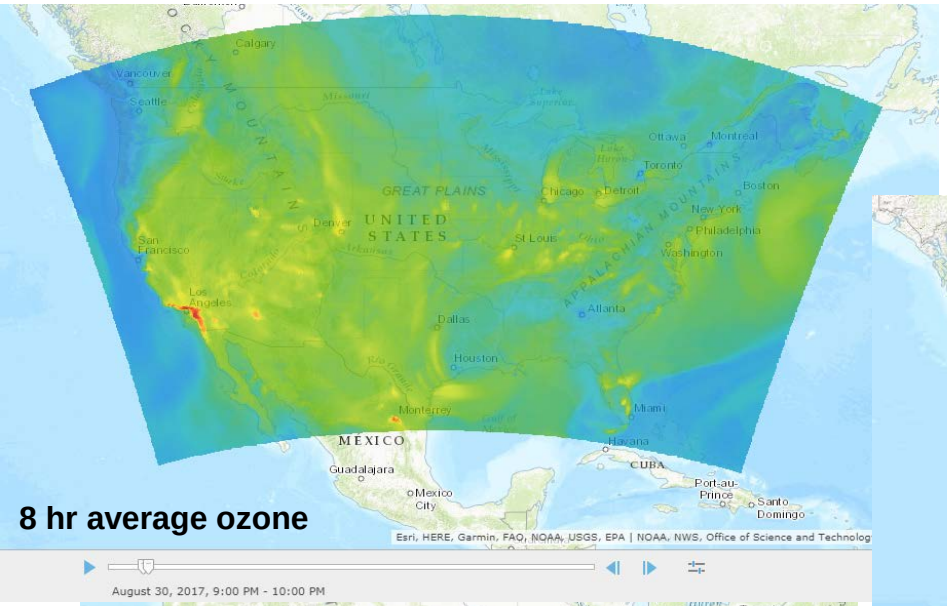
- In Maryland, NOAA ozone predictions have improved since 2011: significant improvement in false alarm ratio (FAR) with some decrease in probability of detection (POD). *(Laura Landry, Maryland Department of the Environment)*

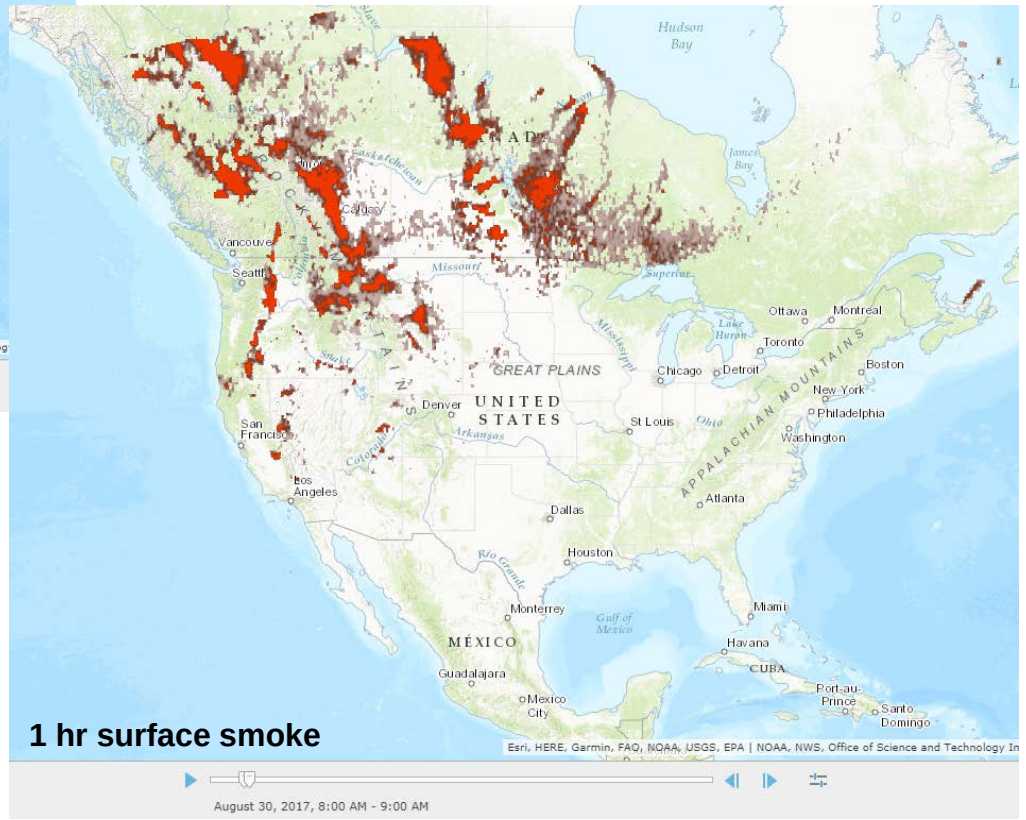
Evaluation in June 2017:

- Received recommendation to implement system upgrade as proposed from AQ forecasters from Virginia, Connecticut, North Carolina, Texas, Washington and Maryland.

Based on forecaster needs currently testing extension of ozone and PM2.5 predictions from 48h to 72h

Web services





Examples of ozone, smoke and dust predictions in web enabled map service

https://idpgis.ncep.noaa.gov/arcgis/rest/services/NWS_Forecasts_Guidance_Warnings

Summary and plans

US national AQ forecasting capability:

- **Ozone** prediction nationwide; updated to CMAQ version 5.0.2 and new Bluesky
- **Smoke** prediction nationwide; updated with newer BlueSky system
- **Dust** prediction for CONUS sources
- **PM2.5** predictions; include wildfire and dust emissions, dust LBCs from global predictions; refinement of bias correction using KFAN approach

Current testing and plans:

- Extension of CMAQ predictions to 72 hours
- Emissions updates (NEI 2014 including oil and gas sources)
- Ozone bias correction
- Wildfire smoke inputs: hourly evolution from BlueSky for CONUS and ECCC for Canada
- Update display, dissemination and web presence for PM2.5 predictions
- Finer resolution and inline with meteorology (longer term)

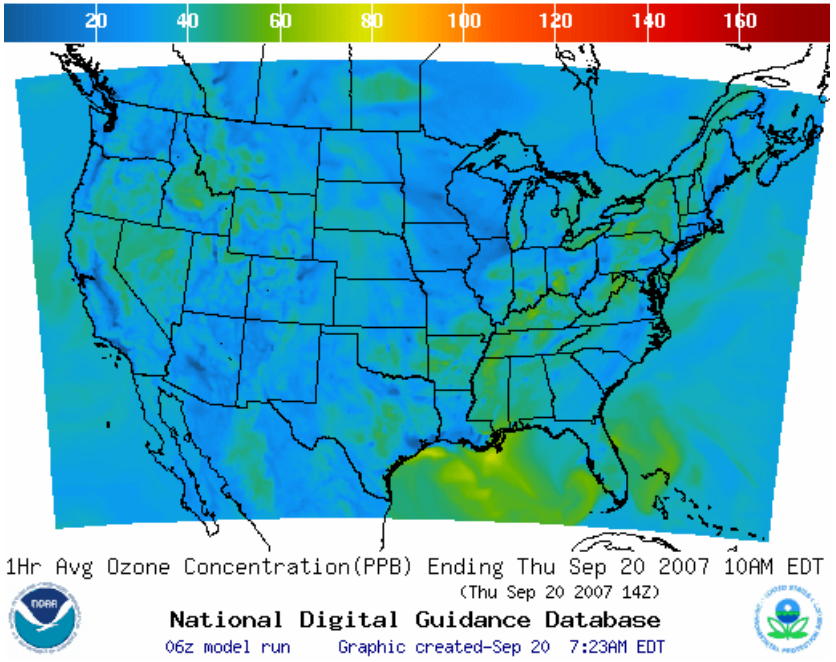
Acknowledgments:
AQF implementation team members

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

NOAA/NWS/OSTI	***Ivanka Stajner***	***NAQFC Manager***
NWS/AFSO	***Jannie Ferrell***	***Outreach, Feedback***
NWS/OD	***Cynthia Jones***	***Data Communications***
NWS/OSTI/MDL	***David Ruth***	***NDGD Product Development***
NWS/OSTI	***Sikchya Upadhayay***	***Program Support***
NESDIS/NCDC	***Alan Hall***	***Product Archiving***
NWS/NCEP		
Jeff McQueen, Jianping Huang,		**AQF model interface development, testing, & integration**
Jun Wang, *Sarah Lu		**Global dust aerosol and feedback testing**
***Jack Kain, *Eric Rogers,**		**NAM coordination**
***Hui-Ya Chuang**		
Ho-Chun Huang		**Smoke and dust product testing and integration**
Rebecca Cosgrove, Steven Earle		**NCO transition and systems testing**
Andrew Orrison		**HPC coordination and AQF webdrawer**
NOAA/OAR/ARL		
Pius Lee, Daniel Tong, Tianfeng Chai		**CMAQ development, adaptation of AQ simulations for AQF**
Li Pan, Hyun-Cheol Kim, Youhua Tang		
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,***
Mark Ruminski , John Simko		***HMS product integration with smoke forecast tool***
EPA/OAQPS ***partners:***		
Chet Wayland, Phil Dickerson, Brad Johns, John White		***AIRNow development, coordination with NAQFC***

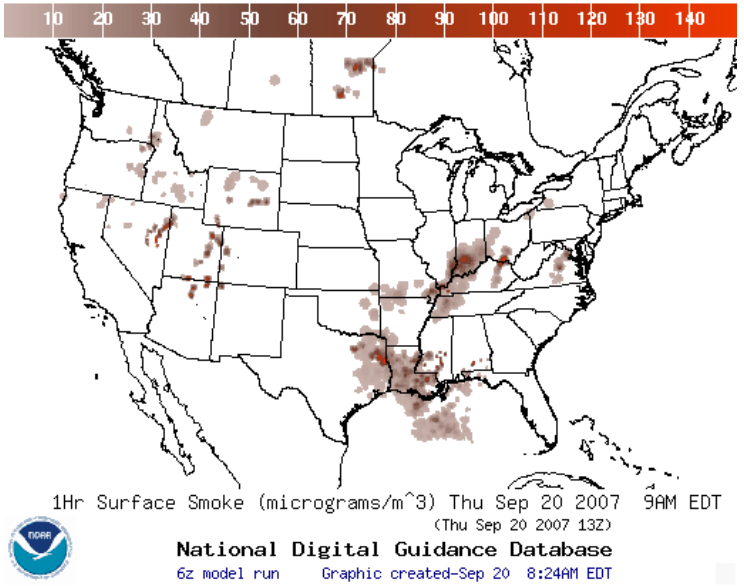
* Guest Contributors

Operational AQ forecast guidance at airquality.weather.gov



Ozone products
Nationwide since 2010

Smoke Products
Nationwide since 2010



Dust Products
Implemented 2012

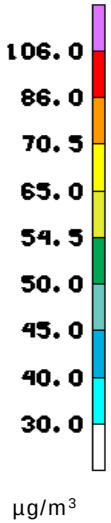
PM2.5 products
Implemented 2016

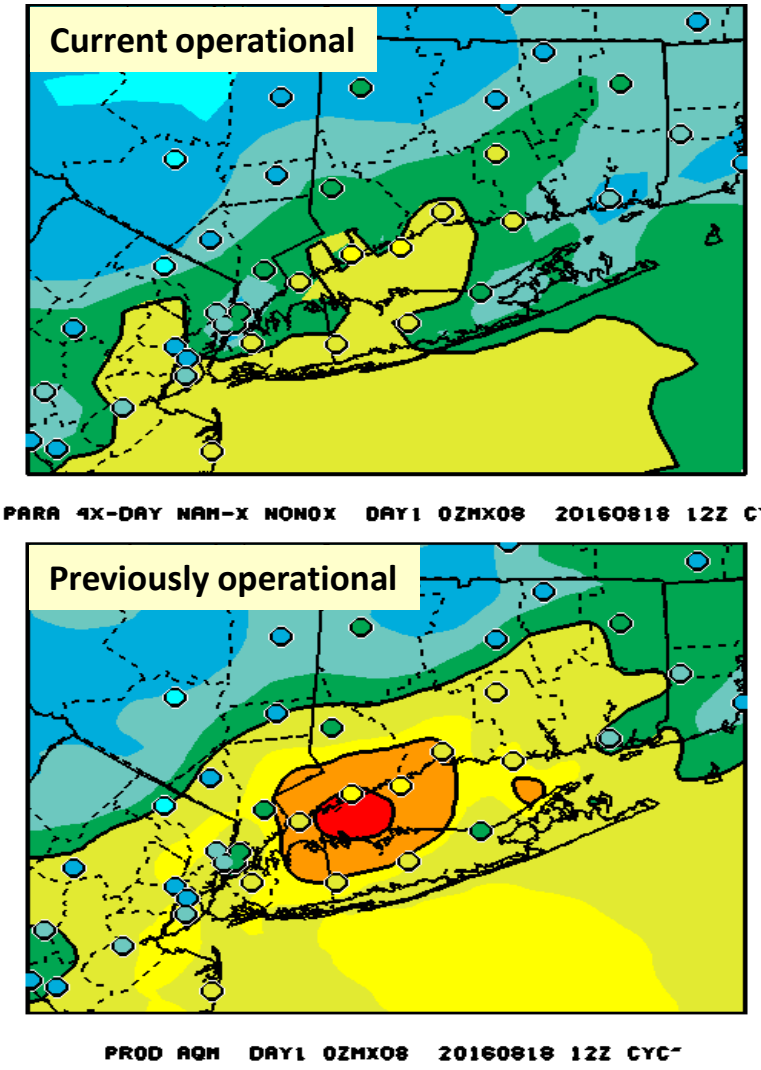
New web site:

https://www.weather.gov/sti/stimodeling_airquality

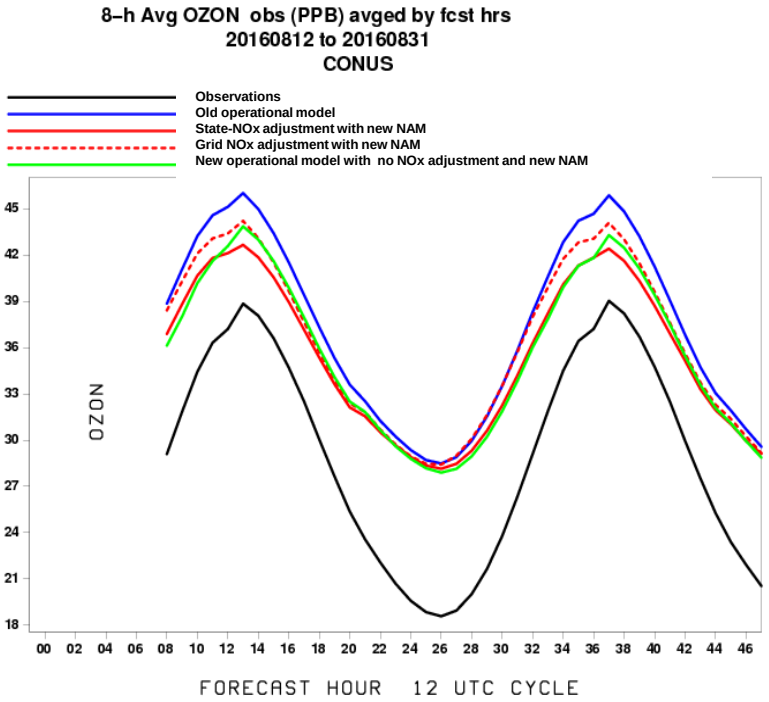
Backup

Improvements in ozone predictions in Eastern U.S.





Current operational CMAQ V5.0.2 showed a great improvement over previously operational model for August 18, 2016 case

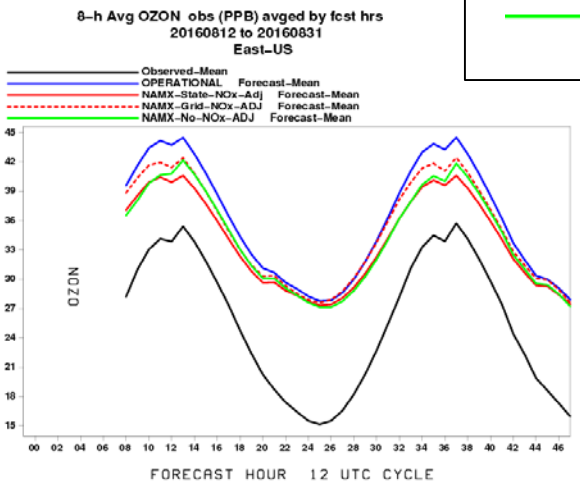


Statistical performance for Ozone

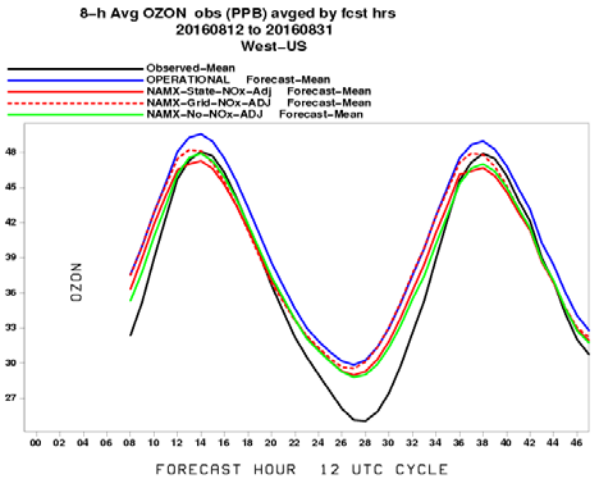
(Aug 2016)

Observations
Old operational model
State-NOx adjustment with new NAM
Grid NOx adjustment with new NAM
New operational model with no NOx adjustment and new NAM

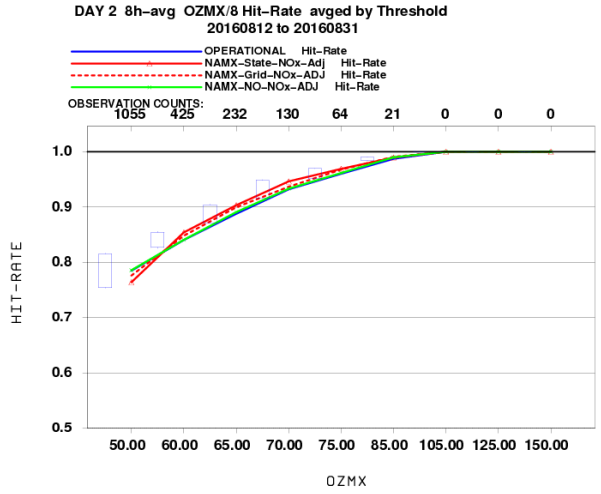
Western U.S.



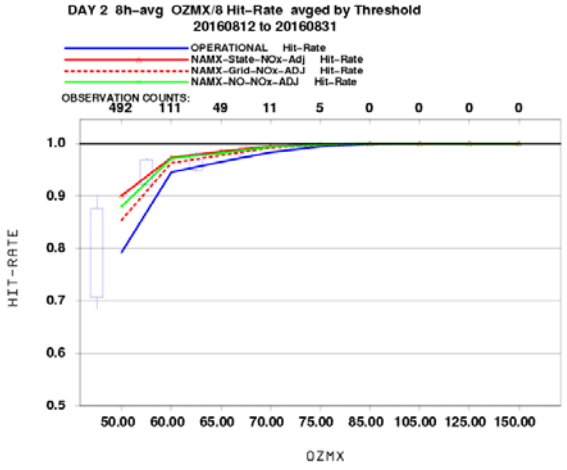
Eastern U.S.



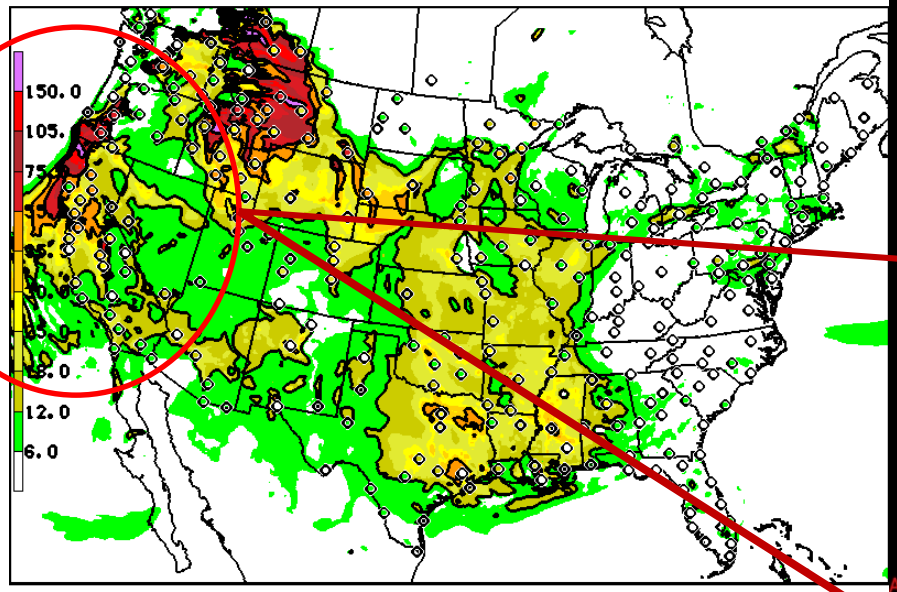
Mean

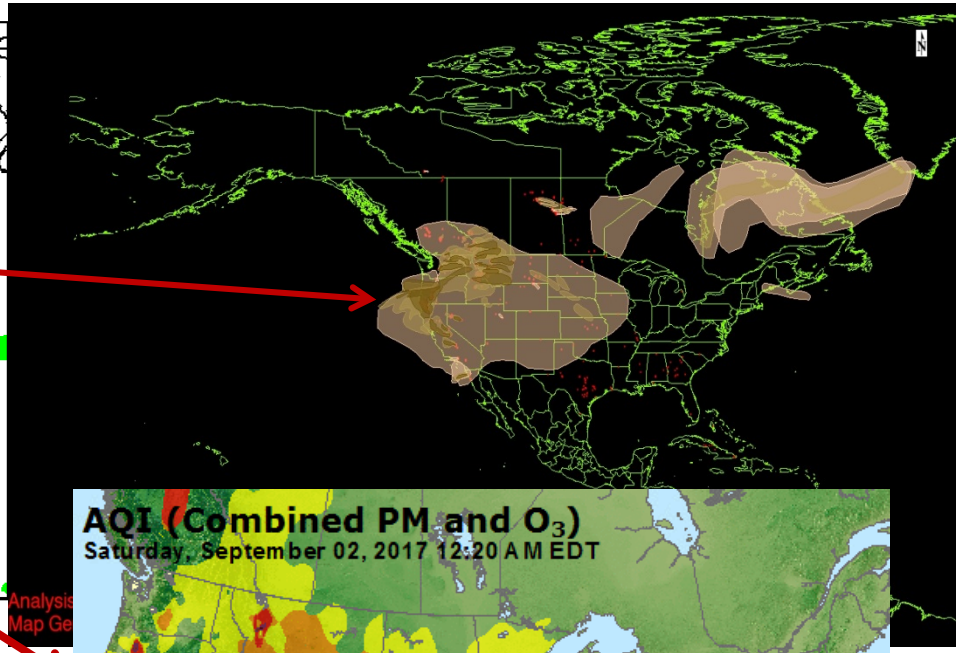


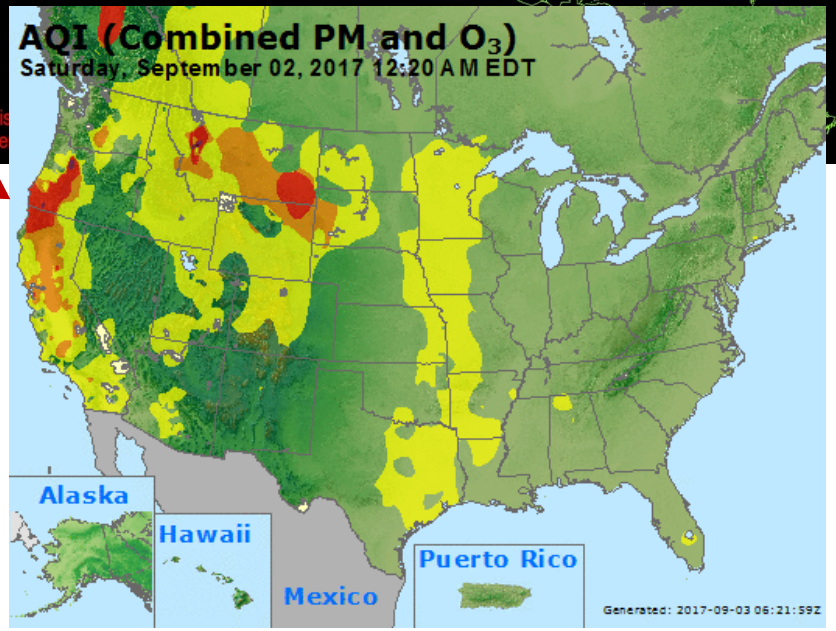
Fraction correct



La Tuna Fire in California (September 2017)

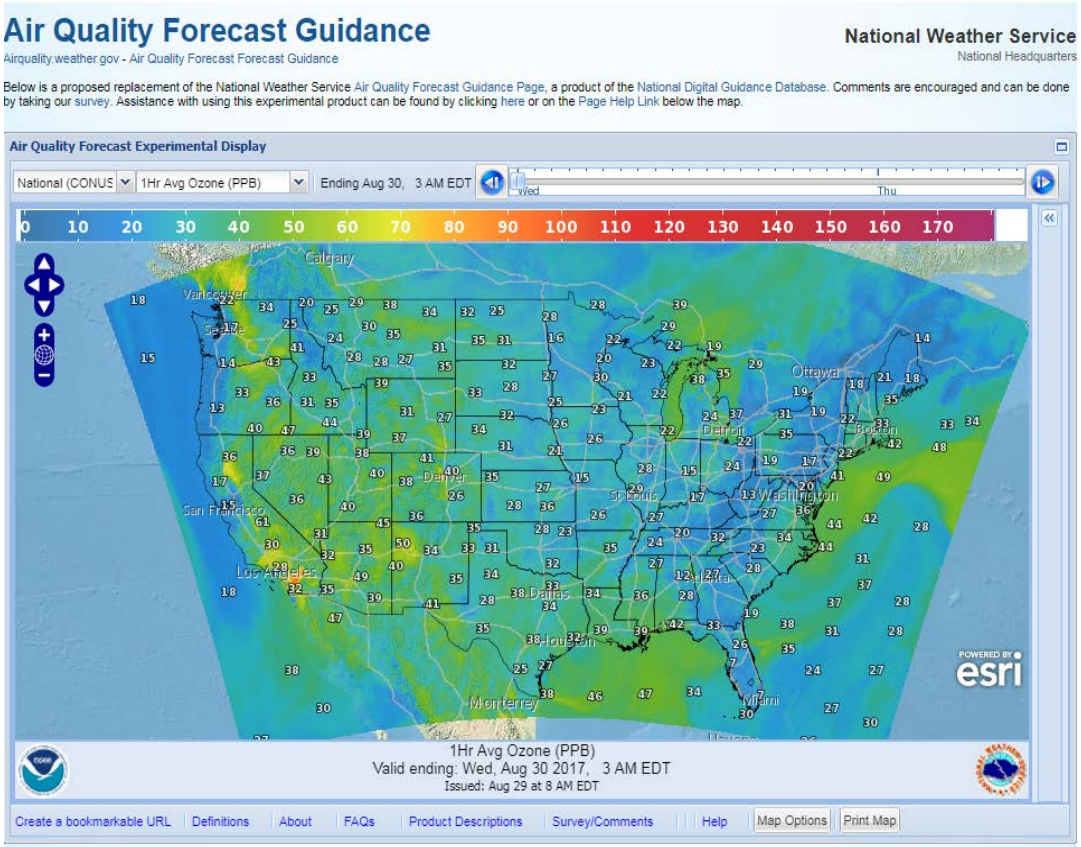






Current operational PM2.5 captured the La Tuna fire in Verdugo Mountains in Los Angeles, California which caused more than 300 homes to be evacuated.

Next Generation of AQ display/distribution on the Web



- Uses a PostgreSQL Database with PostGIS extensions to manage data
- Open Geospatial Consortium (OGC) Web Mapping Service (WMS)
- Possible expansion of NWS XML/SOAP Services to include Air Quality Data
- Uses Open Layers with a ESRI Map Background
- Very Interactive – zoom and roam/data interrogation
- Faster data refresh
- Mobile device support