National Air Quality Forecast Capability

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with contributions from the entire NAQFC Implementation Team

Outline:

Background on NAQFC

Recent progress and updates for AQ predictions:

- Ozone, smoke, dust, PM2.5
- CMAQ upgrade in February 2016
- CMAQ upgrade proposed fro FY 2017
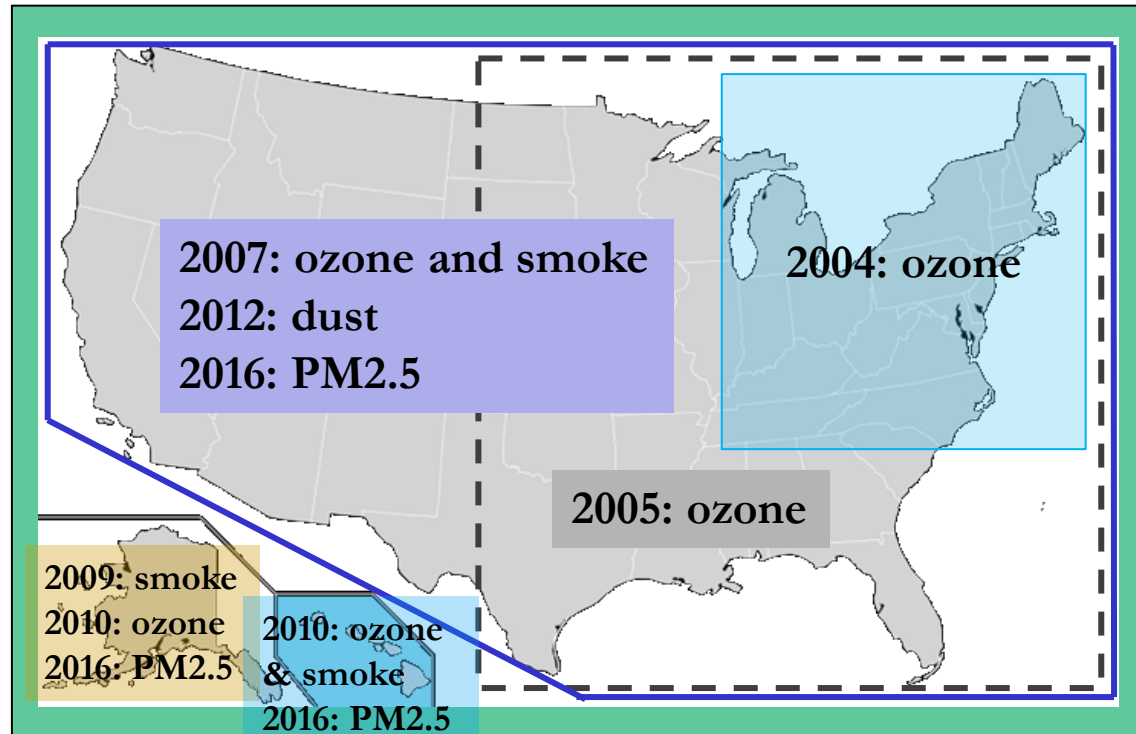- Display, dissemination and web presence
- Outreach and feedback

Summary and plans

National Air Quality Forecast Capability
status in September 2016

- 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) predictions

- **Testing of improvements:**

  Ozone

  Smoke

  PM2.5

2007: ozone and smoke
2012: dust
2016: PM2.5

2004: ozone

2005: ozone

2009: smoke
2010: ozone
2016: PM2.5

2010: ozone & smoke
2016: PM2.5

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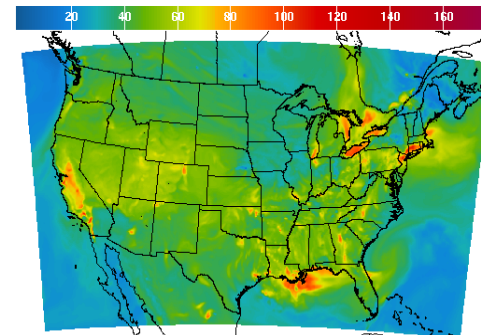## *End-to-End Operational Capability*

Model: Linked numerical prediction system

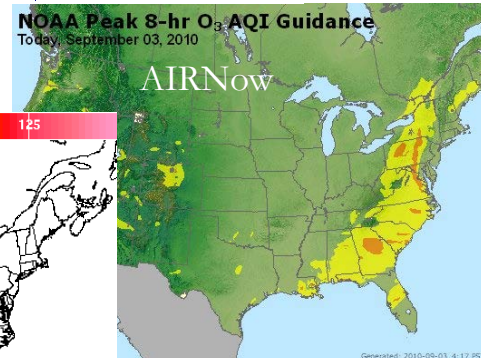**Operationally integrated on NCEP's supercomputer**

- *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*
- *Satellite observations of smoke and dust*

Customer outreach/feedback

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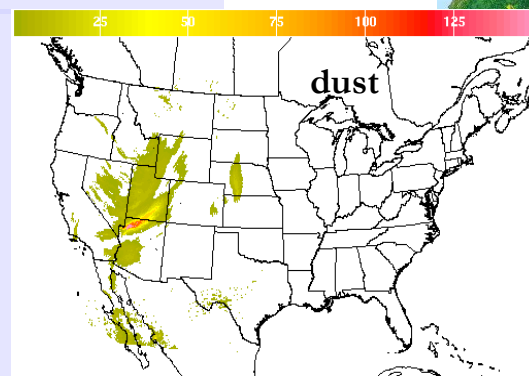- *Public and Private Sector AQ constituents*

1Hr Avg Ozone Concentration(PPB) Ending Wed Jul 29 2015 7PM EDT
(Wed Jul 29 2015 23Z)
National Digital Guidance Database
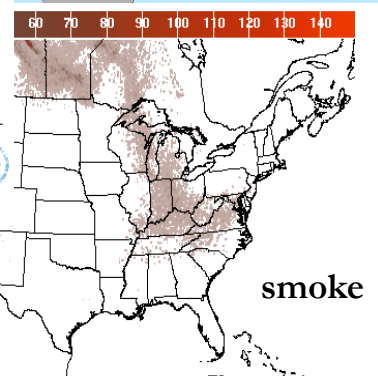12z model run   Graphic created-Jul 29 12:23PM EDT

NOAA Peak 8-hr O$_3$ AQI Guidance
Today, September 03, 2010
AIRNow
Generated: 2010-09-03 4:17 PST

dust

1Hr Vertical Dust (micrograms/m^3) Tue Apr 14 2015 7PM EDT
(Tue Apr 14 2015 23Z)
National Digital Guidance Database
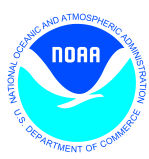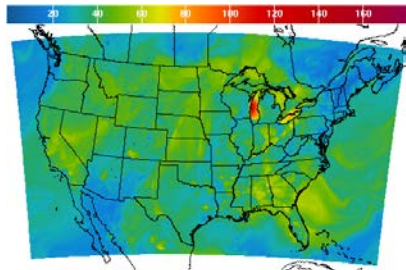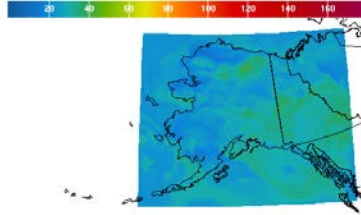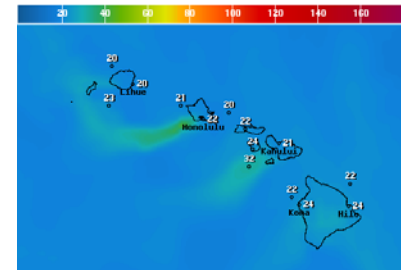12z model run   Graphic created-Apr 14 12:24PM EDT

smoke

1Hr Surface Smoke (micrograms/m^3) Tue Jun 09 2015 6PM EDT
(Tue Jun 09 2015 22Z)
National Digital Guidance Database
06z model run   Graphic created-Jun 08 7:20AM EDT

Ozone predictions

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

over expanding domains since 2004

1-Hr Average Ozone

8-Hr Average Ozone

1-Hr Average Ozone

8-Hr Average Ozone

1-Hr Average Ozone

8-Hr Average Ozone

Fraction correct of daily maximum of 8h average wrt 70 ppb threshold

| Operational |
| CONUS, wrt 70 ppb Threshold |

Maintaining prediction accuracy as the warning threshold was lowered and emissions of pollutants are changing
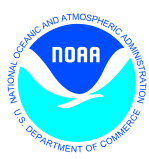
Performance of operational ozone predictions

Fraction correct for 8h daily maximum of NOAA's operational ozone predictions for CONUS with respect to three thresholds

Legend:
- 75 ppb threshold
- 85 ppb threshold
- 70 ppb threshold
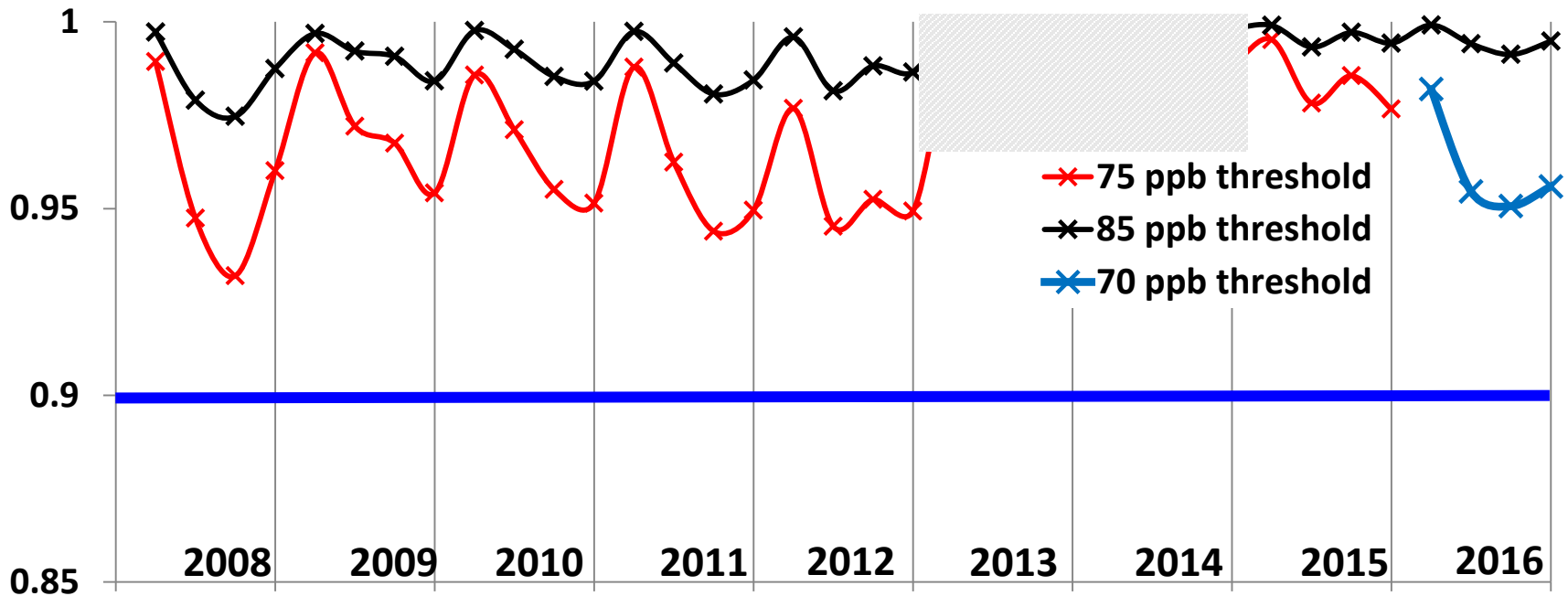
showing performance for May, June, July & August for each year

Smoke predictions

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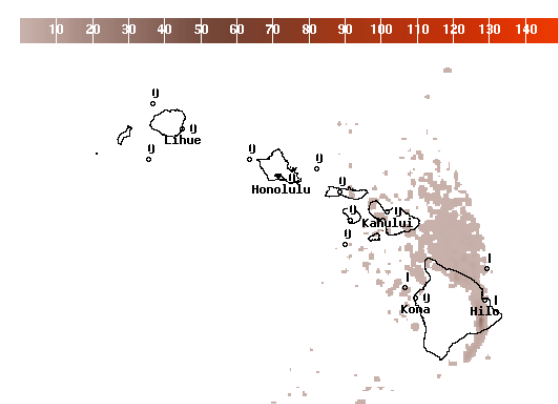
Surface Smoke

Vertical Smoke

Surface Smoke

Vertical Smoke

Surface Smoke

Vertical Smoke
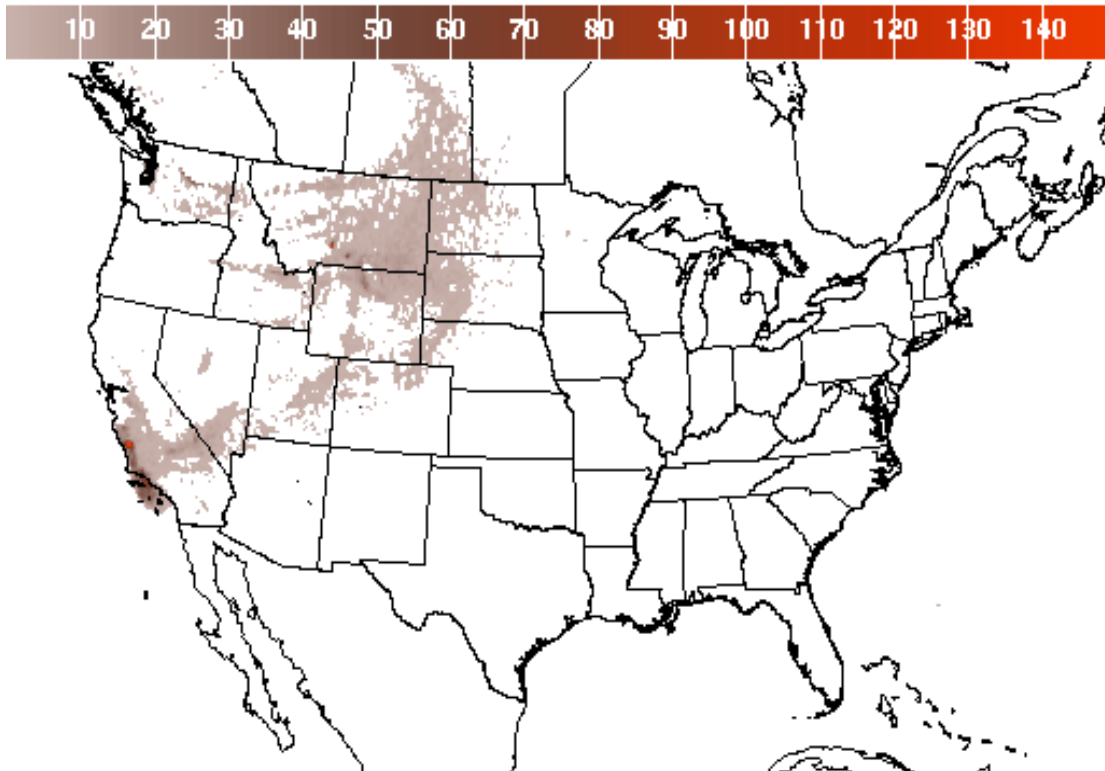
Smoke predictions

1Hr Surface Smoke (micrograms/m^3) Mon Aug 22 2016 7PM EDT
(Mon Aug 22 2016 23Z)

National Digital Guidance Database

06z model run   Graphic created-Aug 22 7:40AM EDT

- Smoke predictions for CONUS (continental US), Alaska and Hawaii

- NESDIS provides wildfire locations detected from satellite imagery

- Bluesky provides emissions estimates

- HYSPLIT model for transport, dispersion and deposition (Rolph et. al., W&F, 2009)

- Increased plume rise, decreased wet deposition, changes in daily emissions cycling

- Developed satellite product for verification (Kondragunta et.al. AMS 2008)

Current testing includes

- Updated BlueSky System v3.5.1 for smoke emissions (first update since predictions became operational in 2007)

Verification of smoke predictions for CONUS

Daily time series of FMS for smoke concentrations larger than 1um/m3
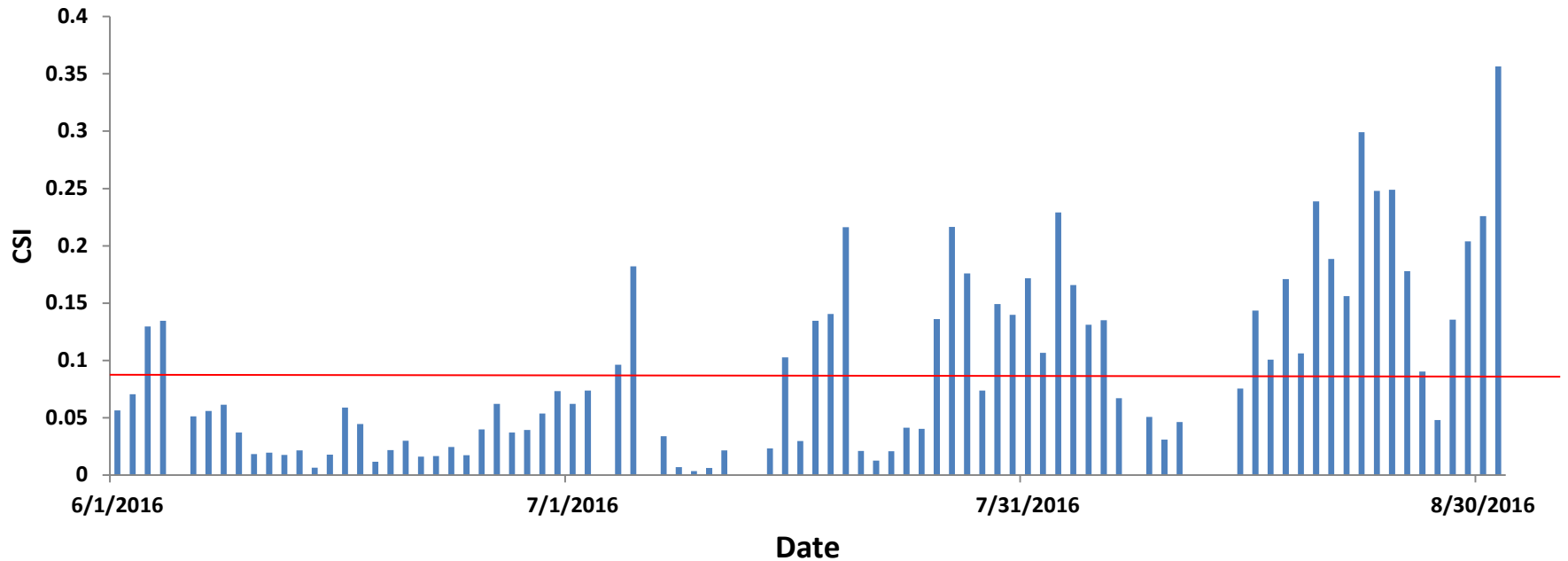
- Figure of merit in space (FMS), which is a fraction of overlap between predicted and observed smoke plumes, threshold is 0.08 marked by red line
- NESDIS GOES Aerosol/Smoke Product is used for verification

CONUS dust predictions

Operational Predictions at http://airquality.weather.gov/
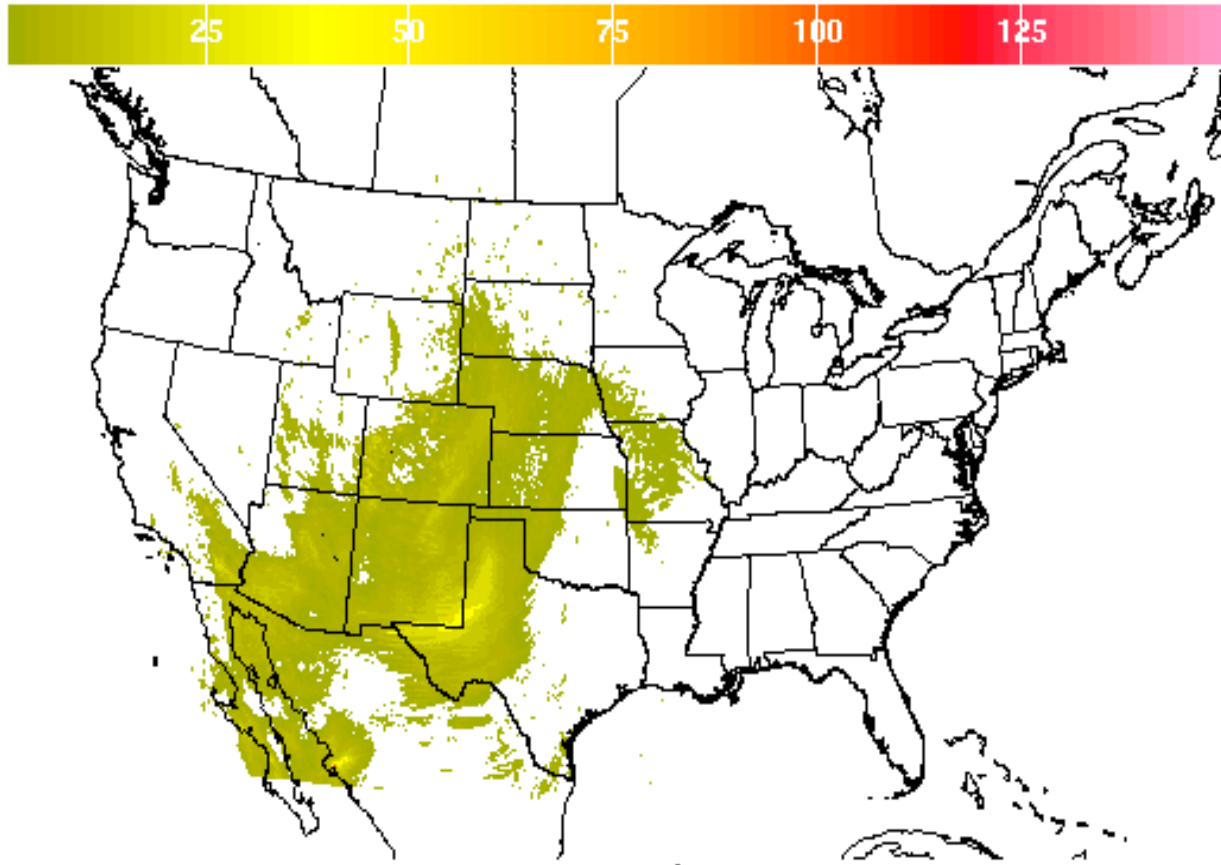
1Hr Vertical Dust (micrograms/m^3) Tue Apr 26 2016 7PM EDT
(Tue Apr 26 2016 23Z)

National Digital Guidance Database

12z model run   Graphic created–Apr 26 12:28PM EDT

No updates in 2016

Standalone prediction of airborne dust from dust storms:

• Wind-driven dust emitted where surface winds exceed thresholds over source regions

• Source regions with emission potential estimated from MODIS deep blue climatology for 2003-2006 (Ginoux et. al. 2010).

• Emissions modulated by real-time soil moisture.

• HYSPLIT model for transport, dispersion and deposition (Draxler et al., JGR, 2010)

• Wet deposition updates in July 2013

• Developed satellite product for verification (Ciren et.al., JGR 2014)

9

PM2.5 predictions – development and testing

Predictions for 48h at 12km resolution over CONUS

From NEI sources only before summer 2014

- CMAQ:
  CB05 gases, AERO-4 aerosols
- Sea salt emissions
- Wildfire and dust emissions and suppression of soil emissions from snow/ice covered terrain included since summer 2014 *(Lee et al., submitted manuscript)*
- Model predictions exhibit **seasonal prediction biases**:

  overestimate in the winter; underestimate in summer

Average monthly bias: all regions
1-h avg aerosol predictions vs. EPA obs, Th=35 ug/m³

January 2009 - June 2015

Pacific Coast — Lower Middle — South East —
Rocky Mountains — Upper Middle — North East —

Daily Average PM AQI
Saturday, January 03, 2015

(Dev) 0-24h Averaging Surface PM2.5 (µg/m³)
Starting at 12Z UTC, JAN-03-2015
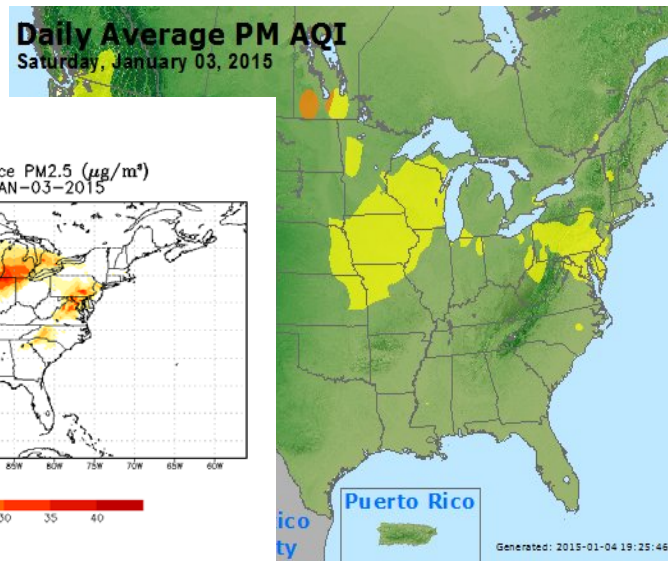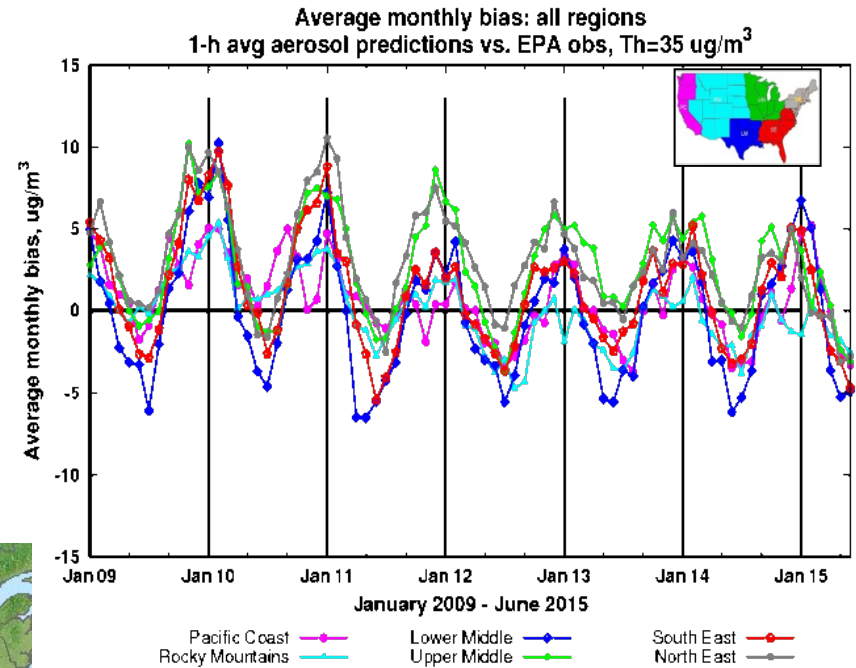
Forecast challenges

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

10
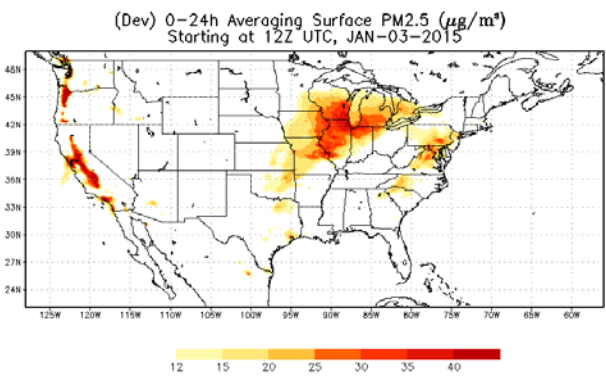
Seasonal Bias in PM2.5 prediction
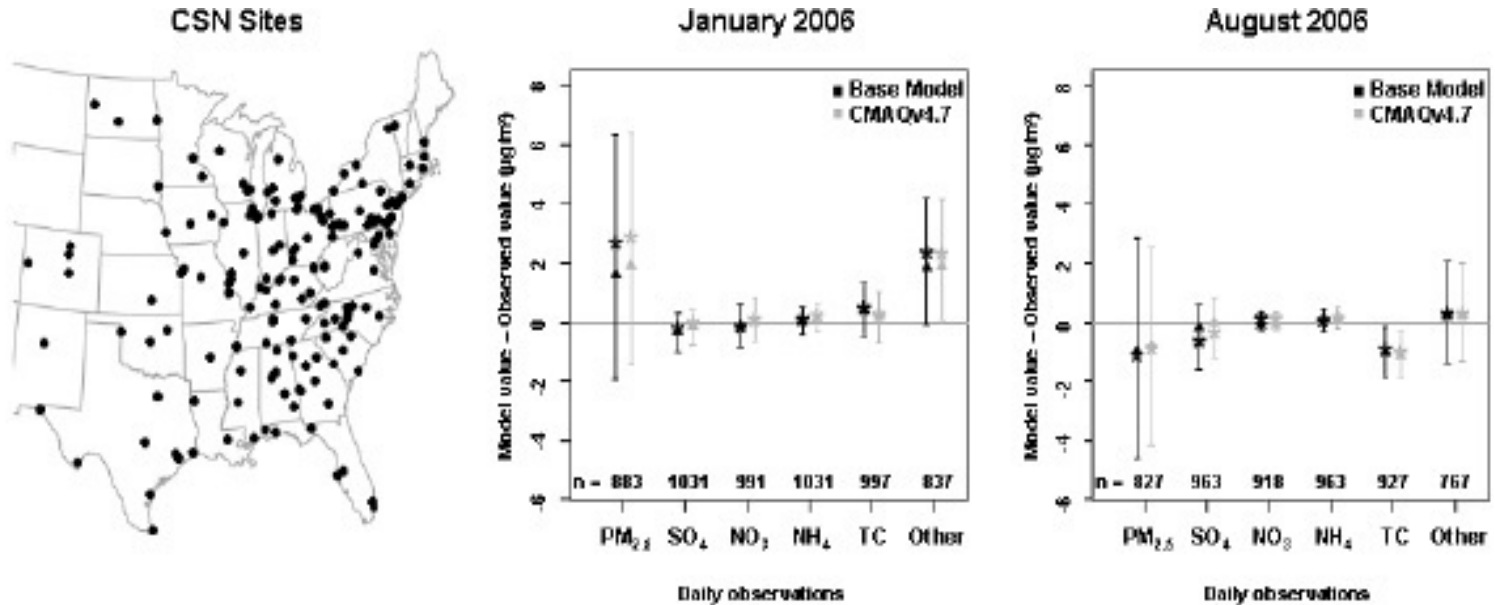
Mean (star), median (triangle), and inter-quartile ranges of model bias (model value – observed value) for multiple fine-particle species measured at CSN sites in the 12km domain. The number of model/observation pairs for each species is shown above the x-axis.

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.

11
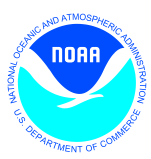
CMAQ UPDATE IN FEBRUARY 2016

CMAQ system update
in February 2016

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**

Dust pm2.5 sfc mass concentration ug/m3 20100701
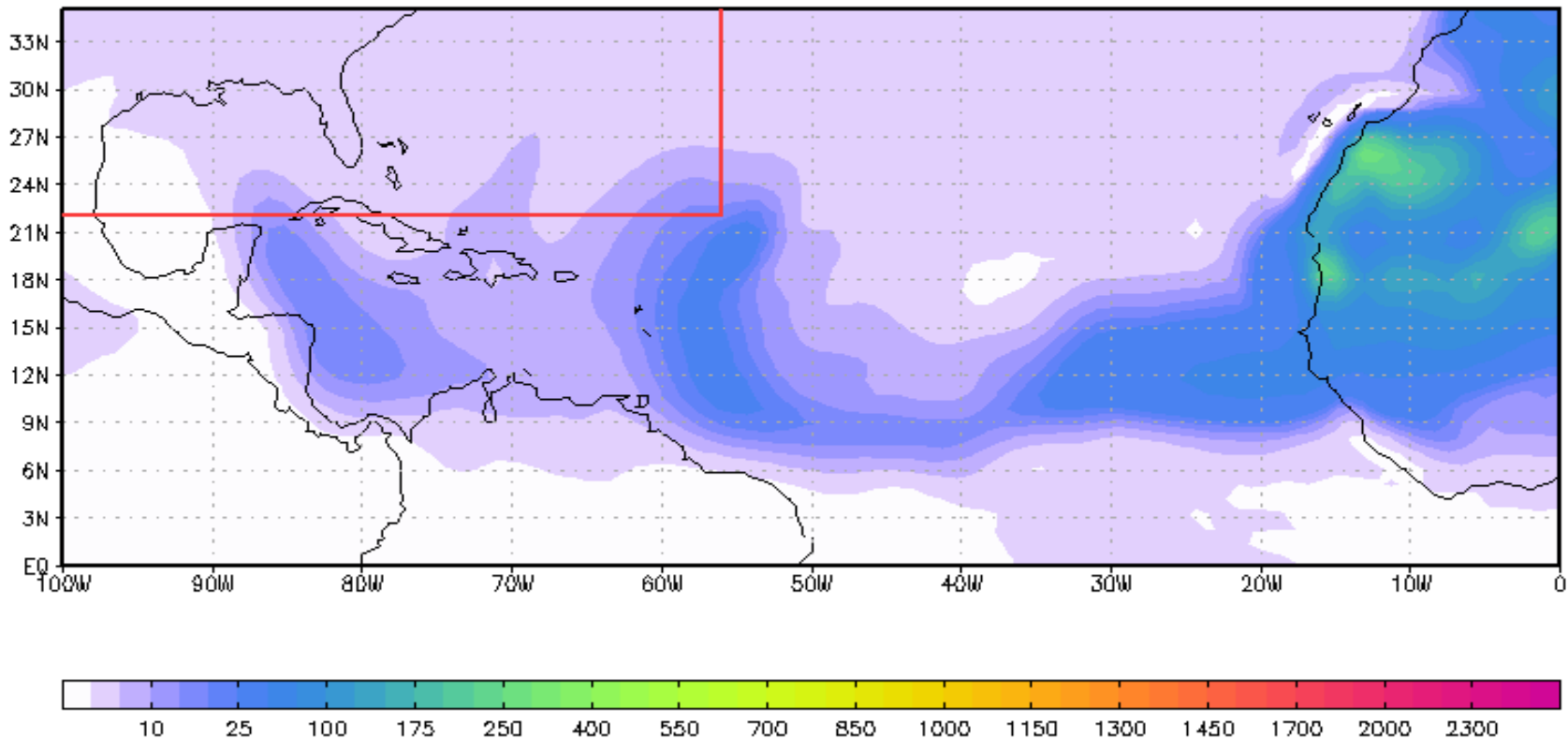
Impact of NGAC LBCs on CMAQ predictions of PM2.5

Model Predictions Compared to AIRNOW PM2.5 over 'Miami Fire Station #5 ',FL Lat=25.795 Lon= −80.216

- ○ Observed
- ● CMAQ default
- □ CMAQ with NGAC LBCs

Model Predictions Compared to AIRNOW PM2.5 over 'Kenner ',LA Lat=30.041 Lon= −90.273

- ○ Observed
- ● CMAQ default
- □ CMAQ with NGAC LBCs

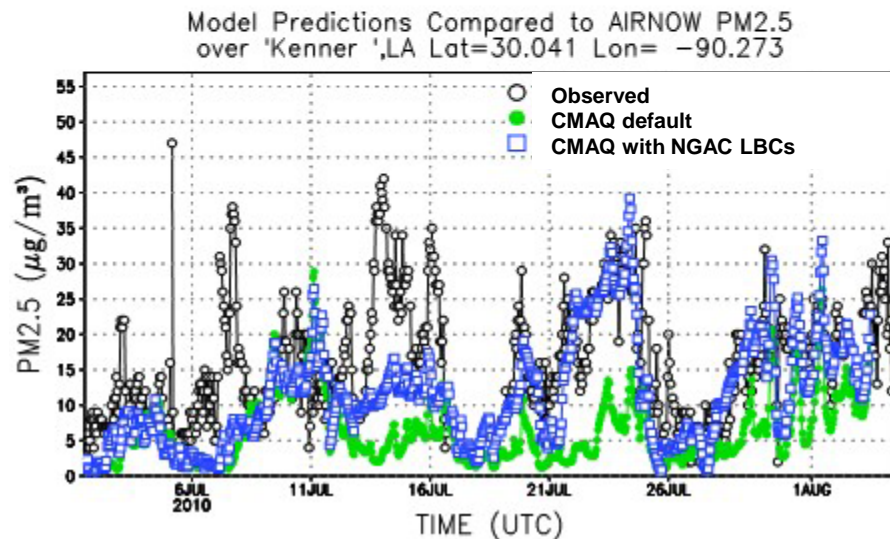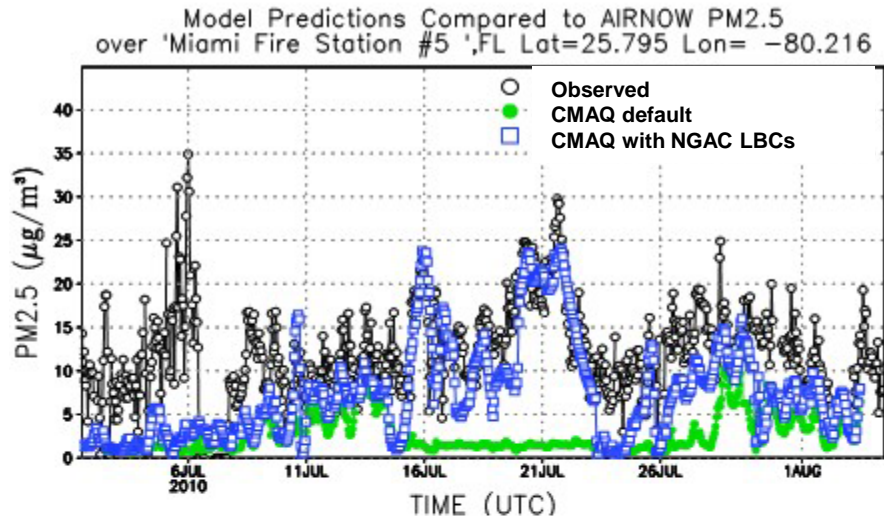|	CMAQ with default LBCs	CMAQ with NGAC LBCs
Whole domain July 1 – Aug 3	MB= -2.82 Y=1.627+0.583*X R=0.42	MB= -0.88 Y=3.365+0.600*X R=0.44
South of 38°N, East of -105°W July 1 – Aug 3	MB= -4.54 Y=2.169+.442*X R=0.37	MB= -1.76 Y=2.770+.617*X R=0.41
Whole domain July 18– July 30	MB= -2.79 Y=2.059+0.520*X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

Bias correction for PM2.5 predictions

- Quality control of the observations is essential
- Five different post-processing techniques were tested
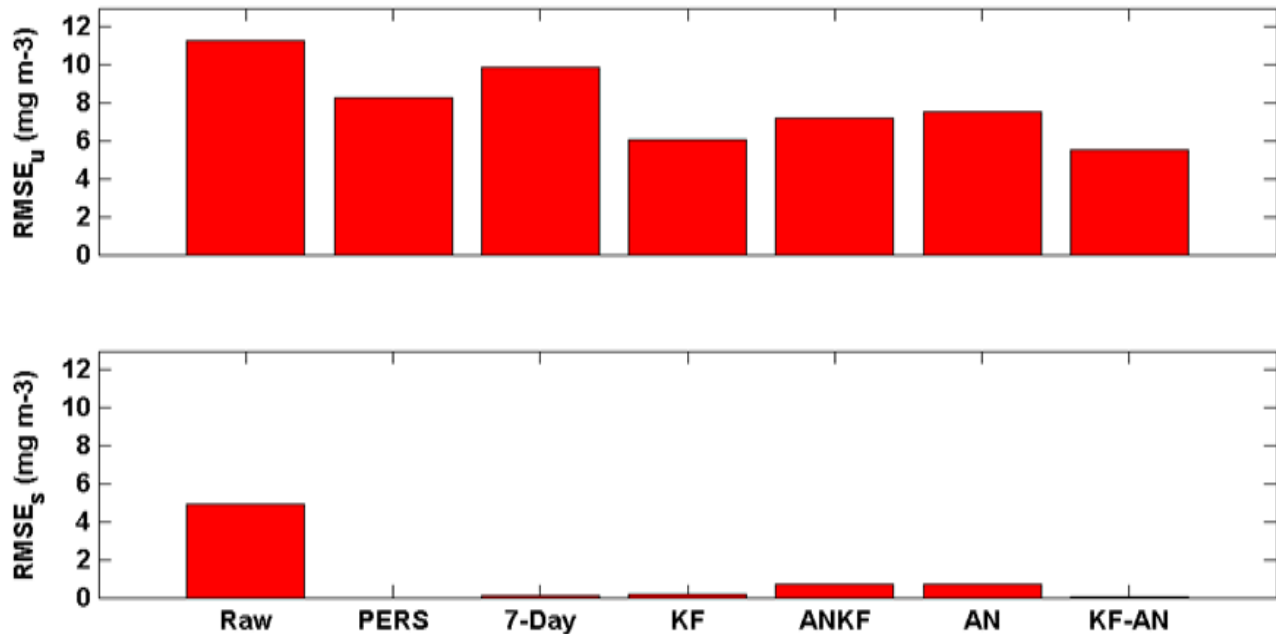
Raw: Hourly AIRNow data available in real-time

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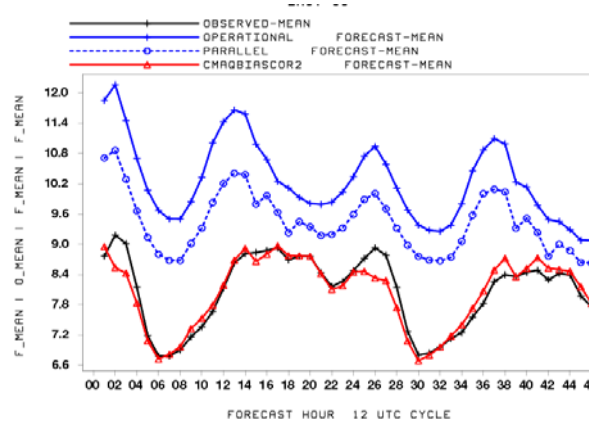
I. Djalalova, L. Delle Monache, and J. Wilczak: PM2.5 analog forecast and Kalman filter post-processing for the Community Multiscale Air Quality (CMAQ) model, Atmospheric Environment, Volume 108, May 2015, pp.76–87.

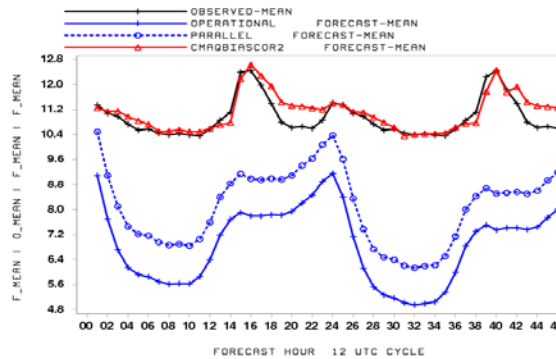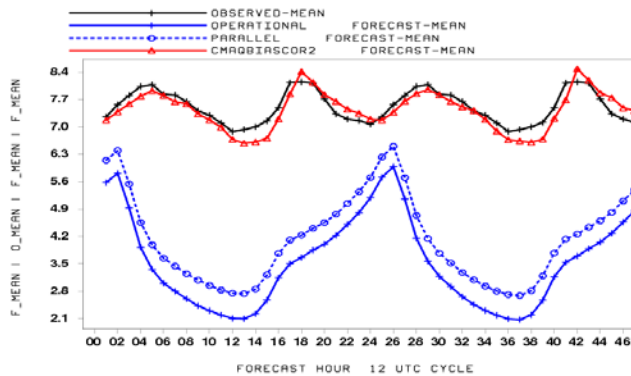# Raw and bias-corrected PM2.5 predictions
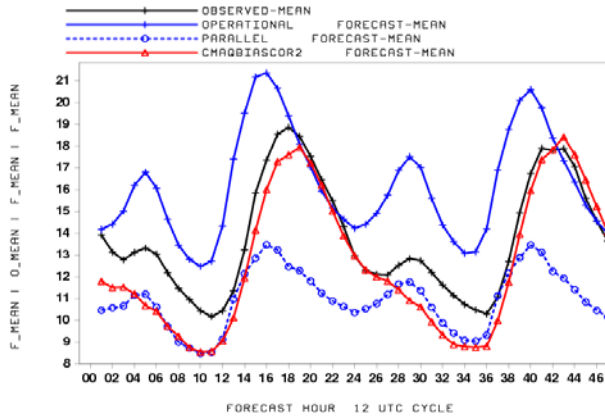
Winter (Jan 2015)

Western US

Eastern US

Summer (July 2015)

Regional mean for each of 48 prediction hours

Observations
Previous model
Updated model
Bias correction of new model
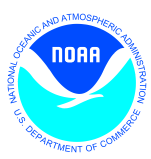
CMAQ UPDATE PROPOSED FOR FY 2017
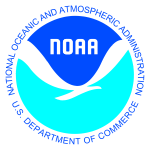
Testing of the CMAQ system update proposed for FY 17

- Update to CMAQ v5.0.2

- Better representation of wildfire smoke emissions (updated BlueSky system and 24-hour "analysis cycle" to include emissions when they were observed)

- Updated mobile NOx emissions: NEI 2005 projected to 2011 using Cross-State Air Pollution Rule (CSAPR) projection for US sources and then adjusted further to the forecast year using trends from surface and satellite observations from 2011 to 2014

- Update of bias correction method to KFAN
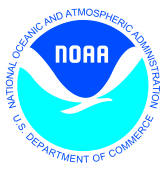
Summary of Emission Data Sources for CMAQ 5.0.2 testing

- ❖ **Area Sources**
  - ➢ **US EPA 2011 NEIs;**
  - ➢ **Canada 2006 Emission Inventories (in NEI2011 package);**
  - ➢ **Mexico 2012 EI for six border states (in NEI2011 package);**
  - ➢ **New US residential wood combustion and oil and gas sectors;**
  - ➢ **Snow/Ice effect on fugitive dust emissions;**
- ❖ **Mobile Sources (onroad)**
  - ➢ **NEI 2005 projected to 2011 using Cross-State Air Pollution Rule (CSAPR) projection for US sources and then adjusted further to the forecast year using trends from surface and satellite observations from 2011 to 2014;**
  - ➢ **Canada 2006 Emission Inventories;**
  - ➢ **Mexico 2012 EIs;**
- ❖ **Point Sources (EGUs and non-EGUs)**
  - ➢ **Baseline emissions from NEI2011;**
  - ➢ **US EGU sources updated with 2014 Continuous Emission Monitoring (CEM);**
  - ➢ **Projected into forecast year using DOE Annual Energy Outlook projection factors;**
- ❖ **Natural Sources**
  - ➢ *Terrestrial biogenic emission:* **BEIS model v3.14;**
  - ➢ *Sea-salt emission:* **CMAQ online Sea-salt emission model based on 10m wind;**
  - ➢ **Fire emissions based on HMS fire detection and BlueSky emission model;**
  - ➢ **Windblown dust emission: FENGSHA model;**

20

NOx emission update

Emission inventory (NEI) lags 4+ years behind the forecast year

Apply emission adjustment using fused satellite and ground observations to represent recent trends

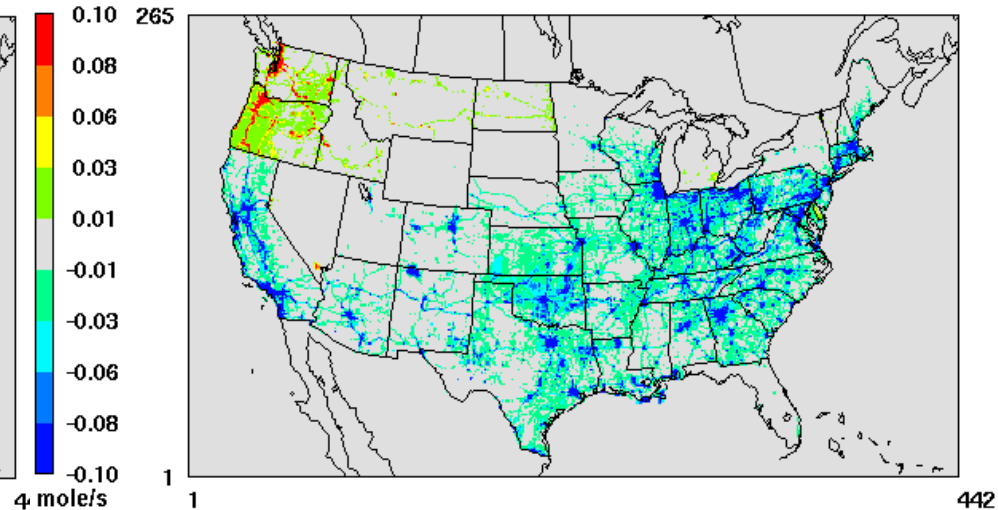**Adjustment Factors**
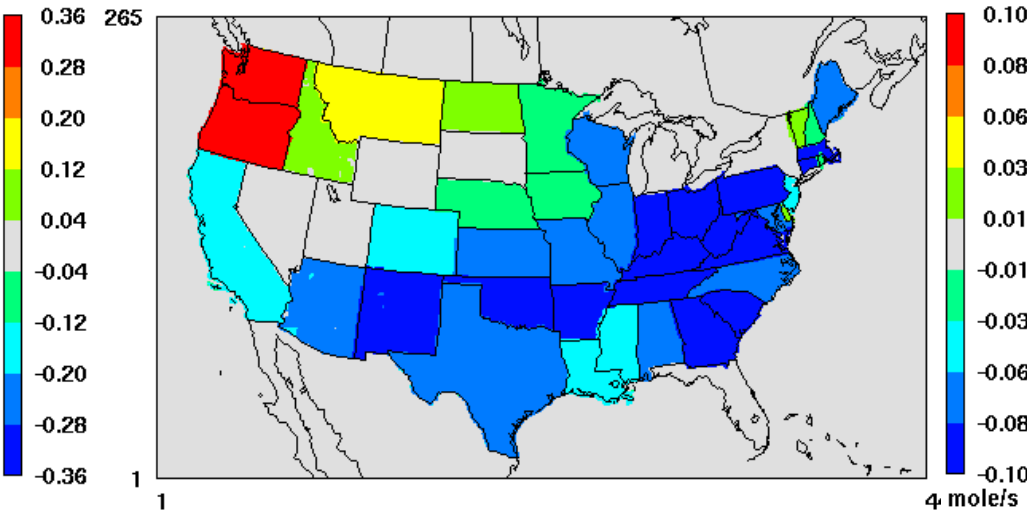
Min= -0.41 at (291,132), Max= 0.43 at (44,218)

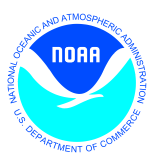**Ground: Air Quality System (6-9 LST)**
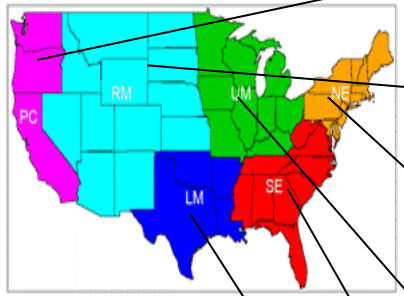**Satellite: GOME-2 (10:30AM)**

NOx Emission Changes

Min= -2.30 at (94,93), Max= 3.22 at (45,218)

(2011-2014)

Tong et al., submitted manuscript

21

Retrospective testing for 2015

Daily maximum 8h average ozone regional statistics for August 2015

[ppb]		Obs.	Mean	Bias	RMSE	Corr. coef.
CONUS	**PROD**	44.1	49.45	5.35	11.17	0.70
	502 test		45.89	1.79	10.00	0.70
PC	**PROD**	50.3	50.22	-0.08	12.11	0.64
	502 test		49.78	-0.52	10.94	0.73
RM	**PROD**	51.9	53.35	1.45	9.04	0.60
	502 test		49.39	-2.51	9.53	0.49
NE	**PROD**	45.0	51.54	6.54	10.45	0.76
	502 test		47.12	2.12	9.38	0.71
UM	**PROD**	41.0	45.42	4.42	8.44	0.70
	502 test		41.75	0.75	6.83	0.72
SE	**PROD**	42.0	50.53	8.53	12.15	0.68
	502 test		45.33	3.33	9.78	0.61
LM	**PROD**	47.0	55.30	8.30	14.02	0.71
	502 test		51.65	4.65	13.50	0.64

- CONUS-wide statistics are all improved
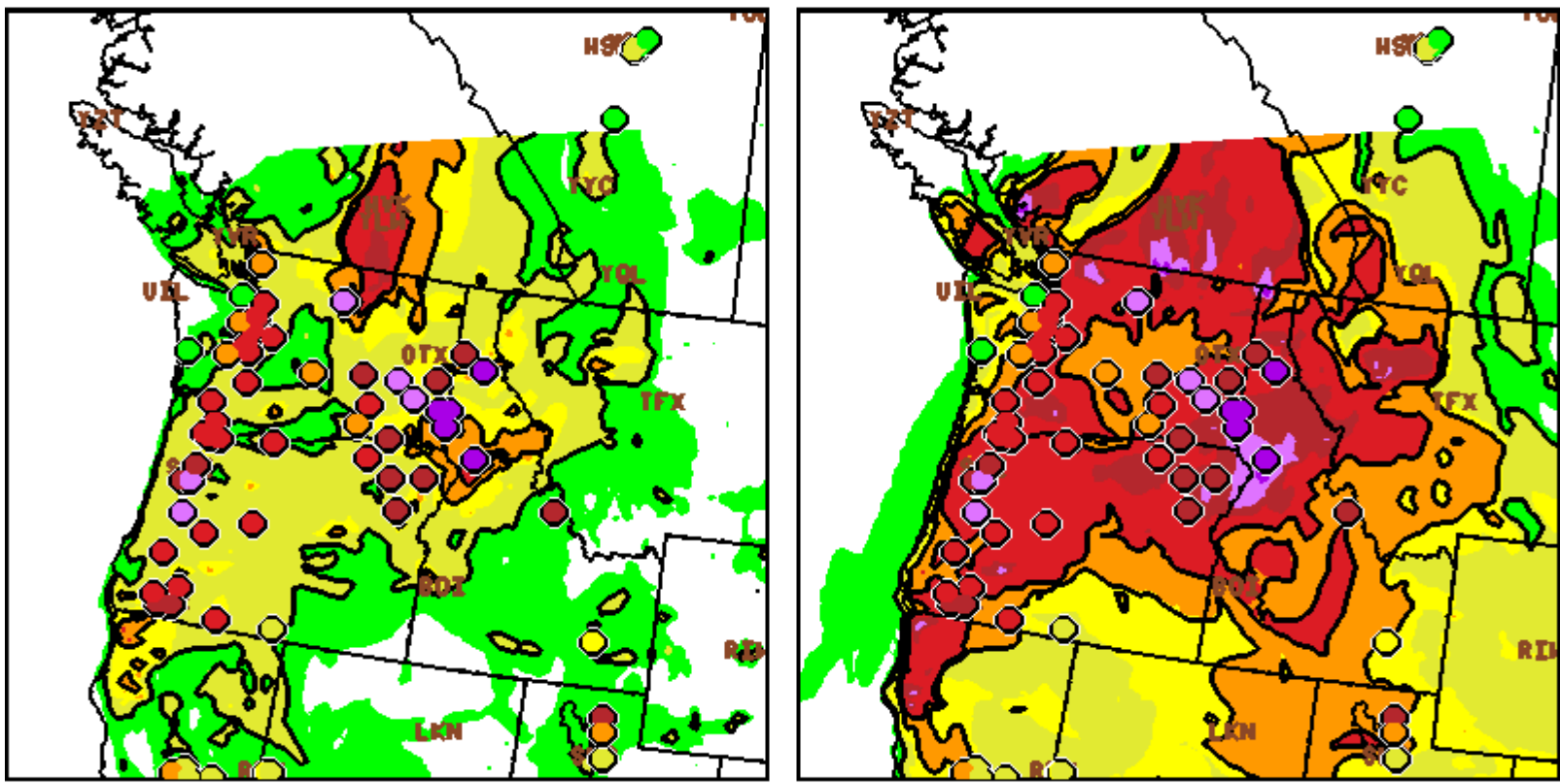- Bias and RMSE are improved in four regions in the eastern part of the US

Representation of wildfires

- 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

Daily mean for Western US

- Observations
- Current model
- New model
- Bias correction of current model

PM2.5 in August 2015
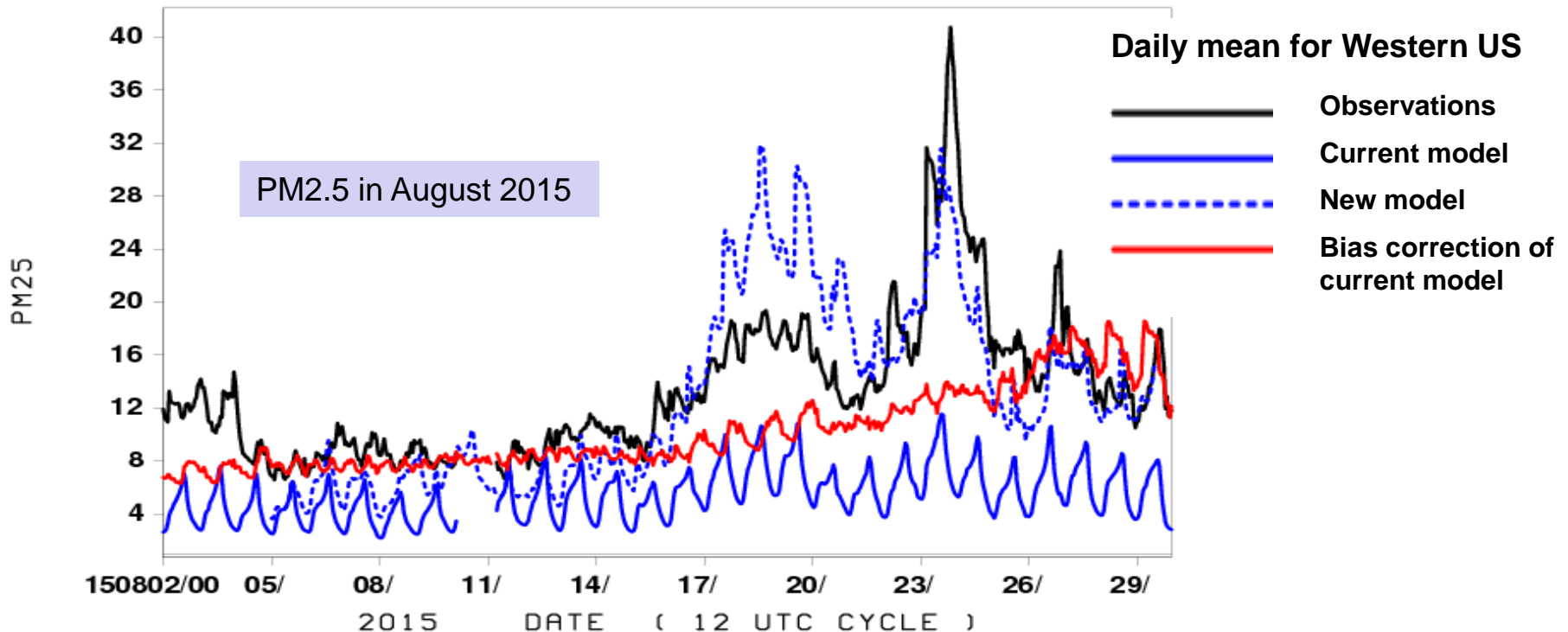
# Representation of wildfires – NW U.S. example on August 23, 2015

PARA1 AQM DAY2 PMMX01 20150822 12Z CYC⁻ :A2 CMAQ.V5.0.2 DAY2 PMMX01 20150822 12Z

6.0   12.0   25.0   35.5   55.5   100.0 150.5 250.5

- Wildfires are strongly impacting air quality in the region
- Observed daily maximum of hourly PM2.5 exceeds 55 μg/m³ and even 100 μg/m³
- Operational system predicts values below 25 μg/m³ for many of these monitors
- Updated system in testing predicts values much closer observed

24 hour average PM2.5 concentrations regional statistics for August 2015

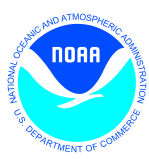| [μg/m³]	Sample size		Obs.	Mean	Bias	RMSE	Corr. coeff.
CONUS	13100	PROD	10.0	6.78	-3.22	10.12	0.34
		502 test		9.08	-0.92	8.40	0.66
PC	3000	PROD	14.0	5.67	-8.33	14.98	0.57
		502 test		12.22	-1.78	12.14	0.63
RM	1235	PROD	12.9	5.56	-7.46	19.46	0.61
		502 test		12.91	0.01	15.77	0.70
NE	1850	PROD	7.8	7.91	0.11	3.78	0.56
		502 test		7.74	-0.06	3.87	0.52
UM	2400	PROD	7.7	8.08	0.38	4.02	0.54
		502 test		8.05	0.35	3.98	0.53
SE	2050	PROD	9.2	6.85	-2.35	5.35	0.29
		502 test		6.72	-2.48	4.61	0.38
LM	1550	PROD	10.2	6.70	-3.30	5.79	0.25
		502 test		7.70	-2.30	5.28	0.31
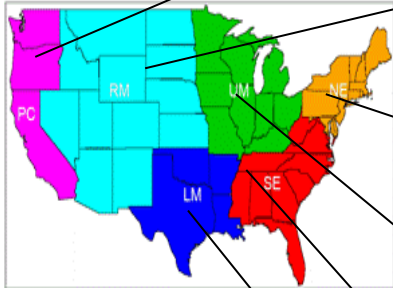
- **CONUS-wide statistics are improved.**
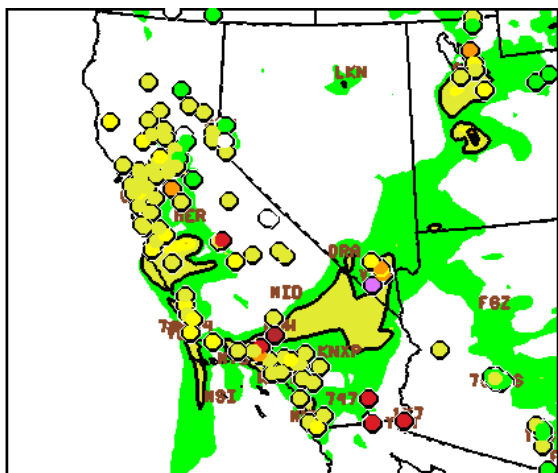- **Largest improvements are for wildfire-impacted western US regions**
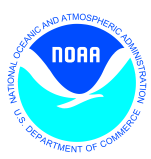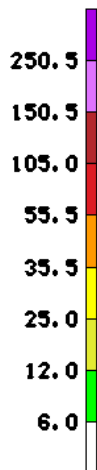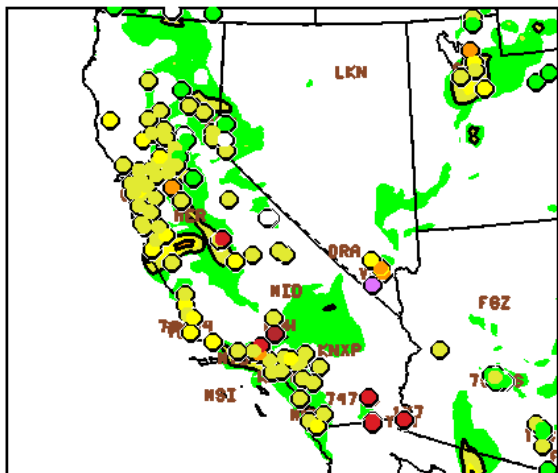
Real-time testing

California Fires (July 2016)

July 24, 2016 12Z run Day 1 1hr max PM2.5

PARA2 CMAQ.V5.0.2 DAY1 PMMX01 20160724 12Z CYC

PROD DAY1 PMMX01 20160724 12Z CYC

NESDIS HMS Fire smoke graphic

VIIRS high res (375 m) imagery

Some signature from fires in V5.02
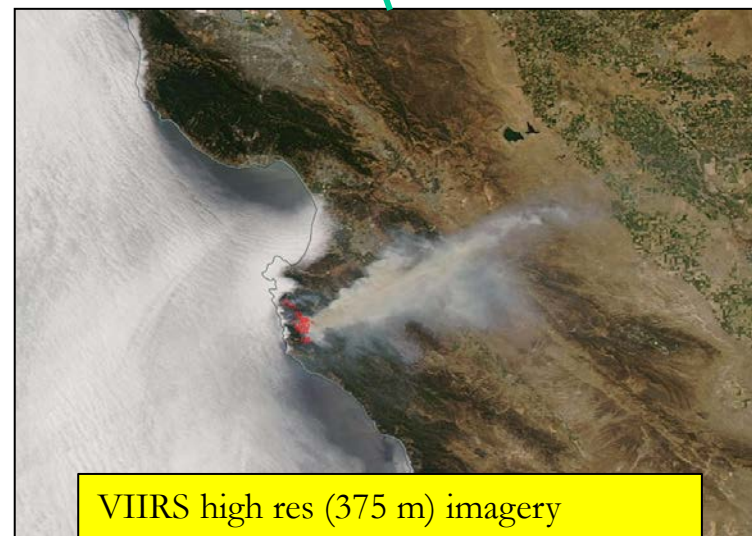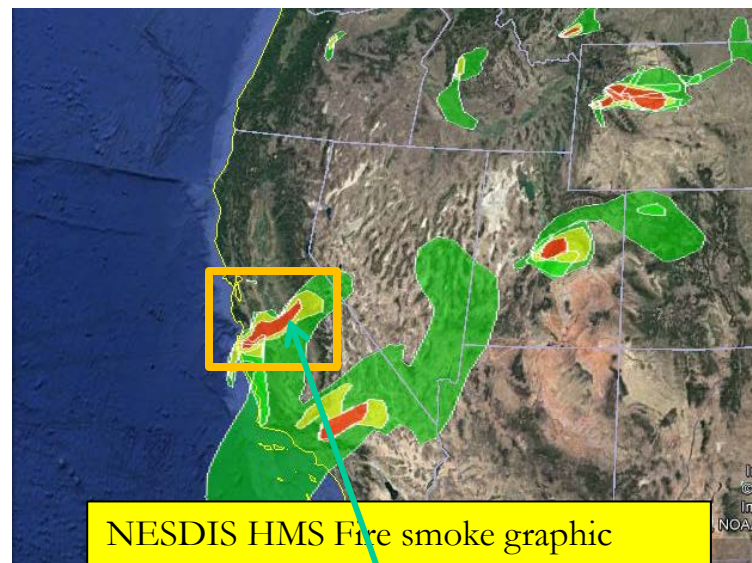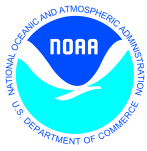
8-h Avg OZON obs (PPB) avged by fcst hrs
20160801 to 20160905
CONUS
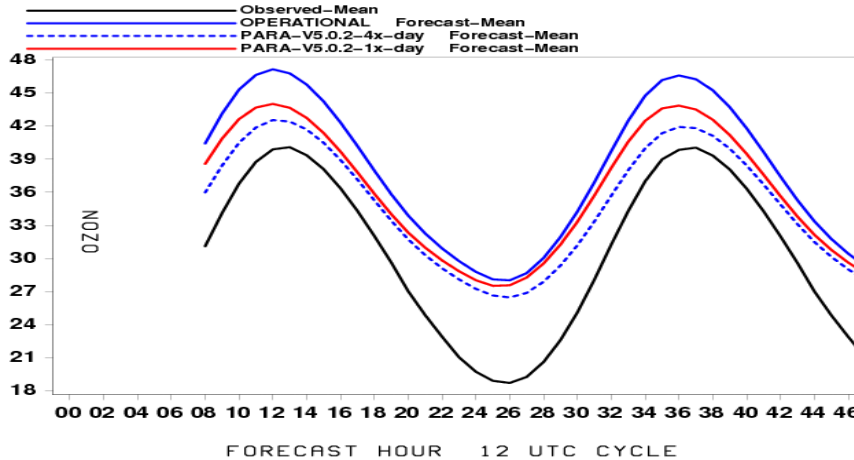
Mean

New model:
CMAQ 5.0.2
Updated NOx emissions
Updated wildfire emission specification

Statistics for 48 contiguous States (CONUS)

DAY 2 8h-avg OZMX/8 Hit-Rate avged by Threshold
20160701 to 20160824
CONUS

Fraction correct wrt threshold

Observations

Operational model

New model 4x/day

New model 1x/day

1-h Avg PM25 obs (ug-m3) avged by fcst hrs
20160801 to 20160824
CONUS

DAY 2 01h-avg PM25MX Hit-Rate avged by Threshold
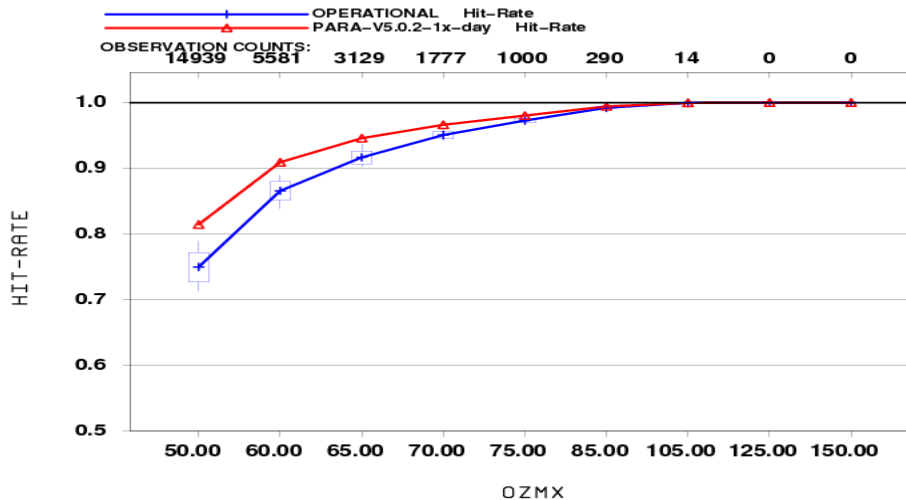20160801 to 20160905
CONUS

New model:
CMAQ 5.0.2
Updated NOx emissions
Updated wildfire emission
specification

Statistics for 48 contiguous
States (CONUS)
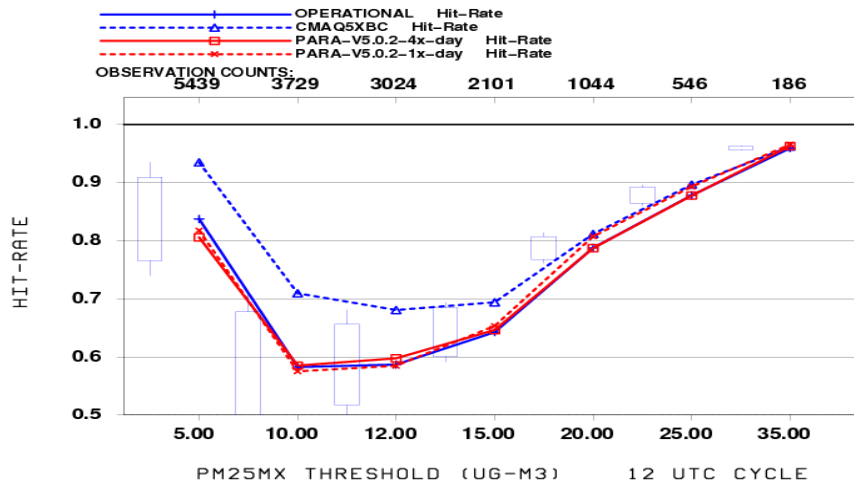
Observations

Operational model

Bias-corrected ops model

New model 1x/day

New model 4x/day
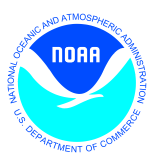
DISPLAY, DISSEMINATION AND WEB PRESENCE UPDATES
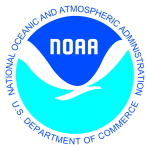
Next Generation of AQ display/distribution on the Web
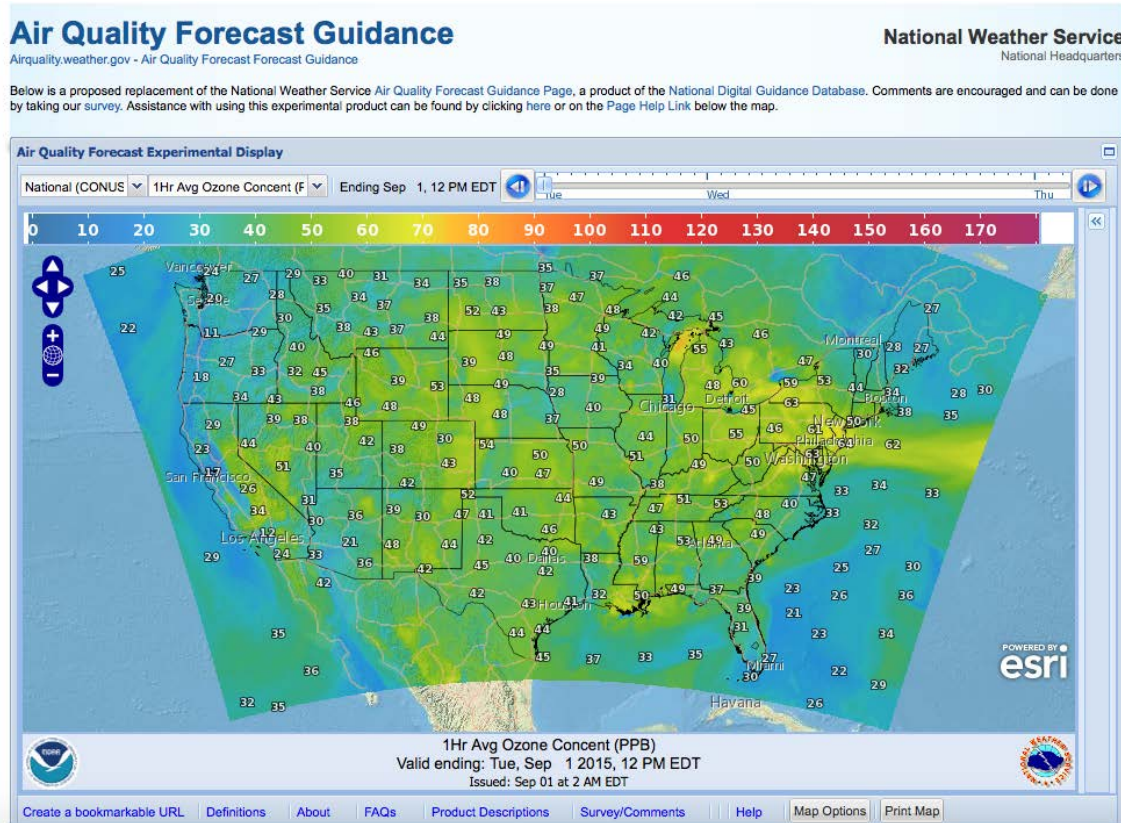
- Uses a PostgreSQL Database with PostGIS extensions to manage data

- 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

Webservices
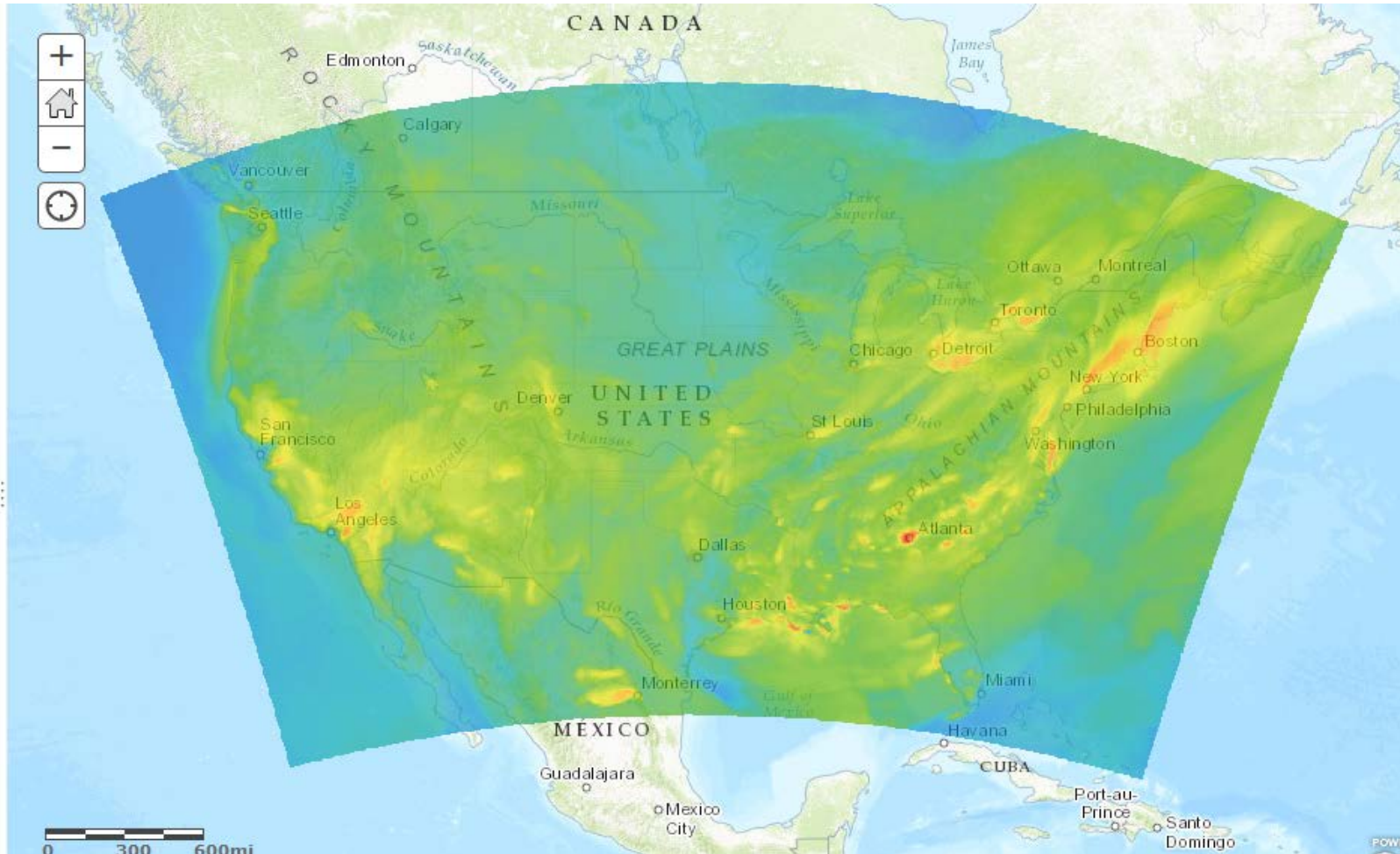
Example of ozone predictions in web enabled map service currently in development based on GIS application

Operational AQ forecast guidance at
airquality.weather.gov
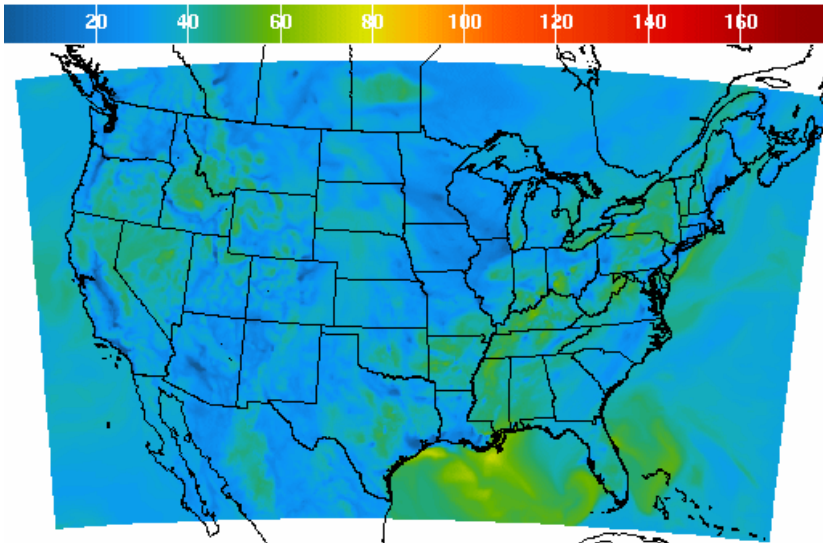
1Hr Avg Ozone Concentration(PPB) Ending Thu Sep 20 2007 10AM EDT
(Thu Sep 20 2007 14Z)
National Digital Guidance Database
06z model run   Graphic created-Sep 20 7:23AM EDT

Ozone products
Nationwide since 2010
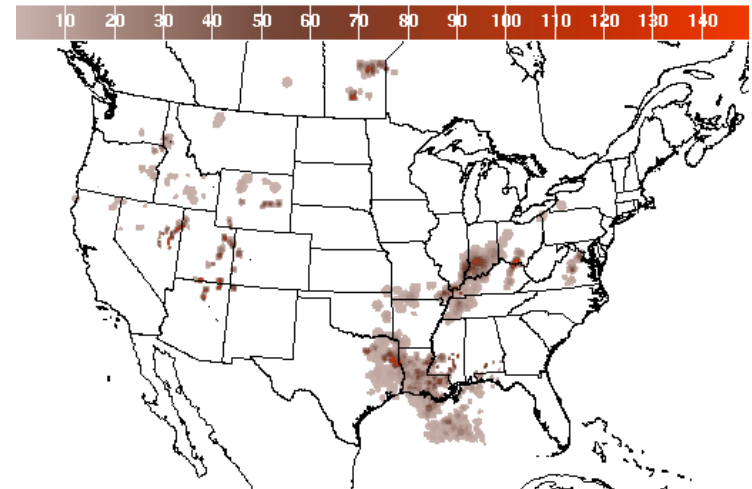
1Hr Surface Smoke (micrograms/m^3) Thu Sep 20 2007   9AM EDT
(Thu Sep 20 2007 13Z)
National Digital Guidance Database
6z model run   Graphic created-Sep 20 8:24AM EDT

Smoke Products
Nationwide since 2010
Dust Products
Implemented 2012

New web site:
https://www.weather.gov/sti/stimodeling_airquality

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***
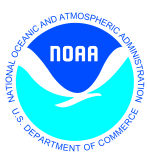
Examples of AQ forecaster feedback after emissions update in 2012:

- 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 Feb. 2016:

- Received recommendation to implement system upgrade as proposed from AQ forecasters from Virginia, Texas, Maryland, South Carolina, Maine, Pennsylvania, Connecticut, Washington with some caveats.

Currently evaluating updates for ozone, PM2.5 and smoke predictions
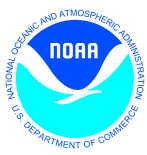
Acknowledgments:
AQF implementation team members

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	**Marc Saccucci,**	**Dev. Verification, NDGD Product Development**
	Dave Ruth	
NWS/OSTI	**Sikchya Upadhayay**	**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, *Sarah Lu — Global dust aerosol and feedback testing
*Brad Ferrier, *Eric Rogers, — NAM coordination
*Hui-Ya Chuang
Geoff Manikin — Smoke and dust product testing and integration
Rebecca Cosgrove, Chris Magee — NCO transition and systems testing
Mike Bodner, 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*

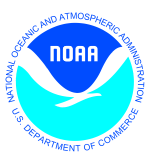**NESDIS/OSDPD** Liqun Ma, Mark Ruminski — *Production of smoke and dust verification products,*

HMS product integration with smoke forecast tool

EPA/OAQPS partners:

Chet Wayland, Phil Dickerson, Brad Johns, John White — *AIRNow development, coordination with NAQFC*
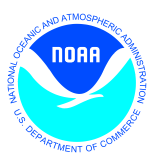
* Guest Contributors

# Summary and plans

US national AQ forecasting capability:

• **Ozone** prediction nationwide; CMAQ with CB05 mechanism

• **Smoke** prediction nationwide

• **Dust** prediction for CONUS sources

• **PM2.5** predictions; CMAQ with NEI, wildfire and dust emissions, dust LBCs from

  global predictions - new since February 2016

Current testing and plans to improve O3 and PM2.5 accuracy and utility:

• Updating to newer CMAQ version 5.0.2

• Updated wildfire smoke emissions with a newer Bluesky system and Canadian sources

• Update NOx emissions using recent observed trends

• Refinement of bias correction for PM2.5 using KFAN approach

• Linkage with additional aerosols from global predictions

• Extend predictions to 72 hours

• Update display, dissemination and web presence

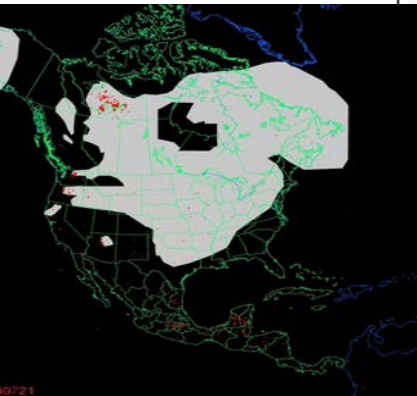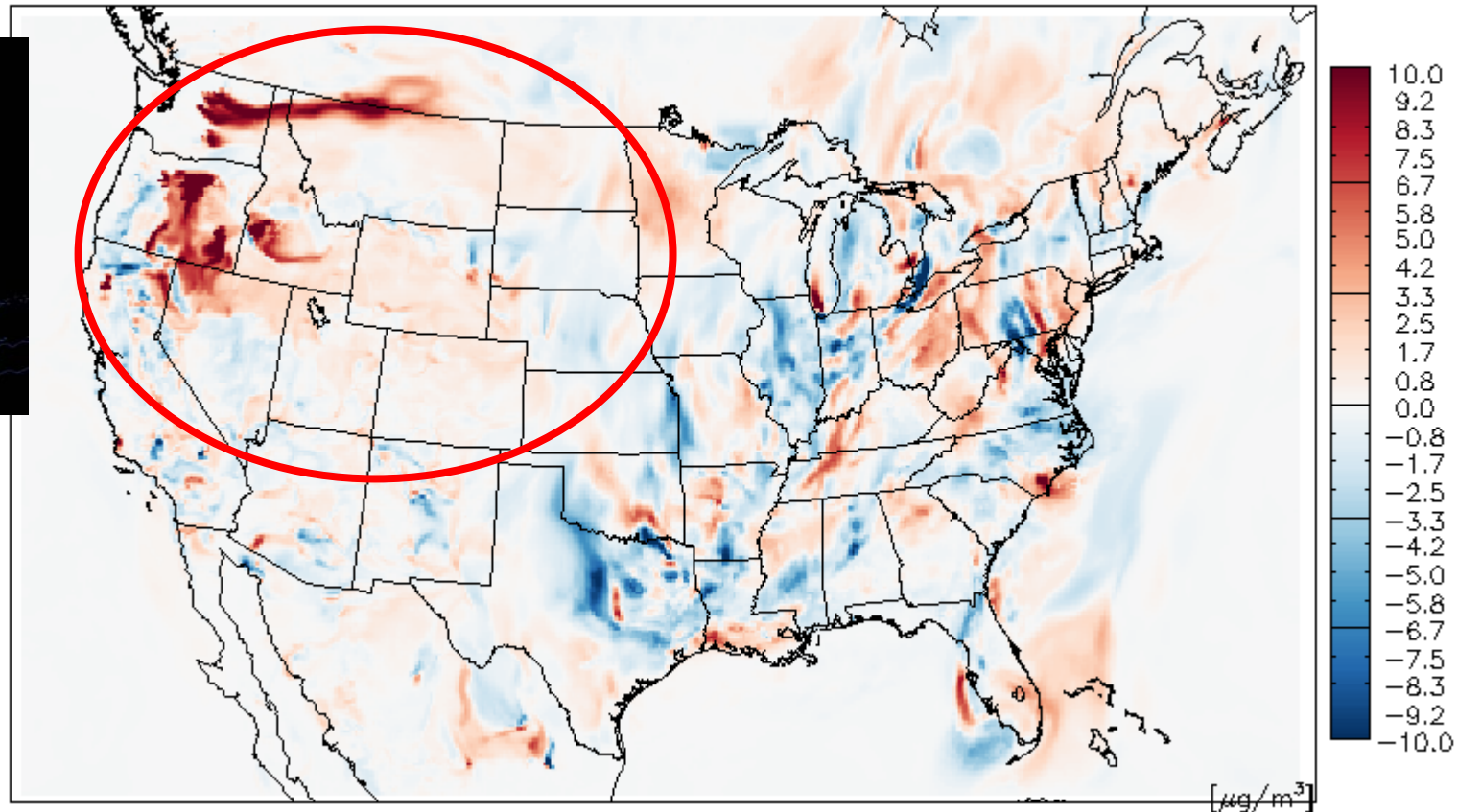• Finer resolution (longer term)

Backup
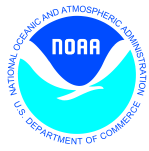
Impact of forest fires in testing of PM2.5 predictions

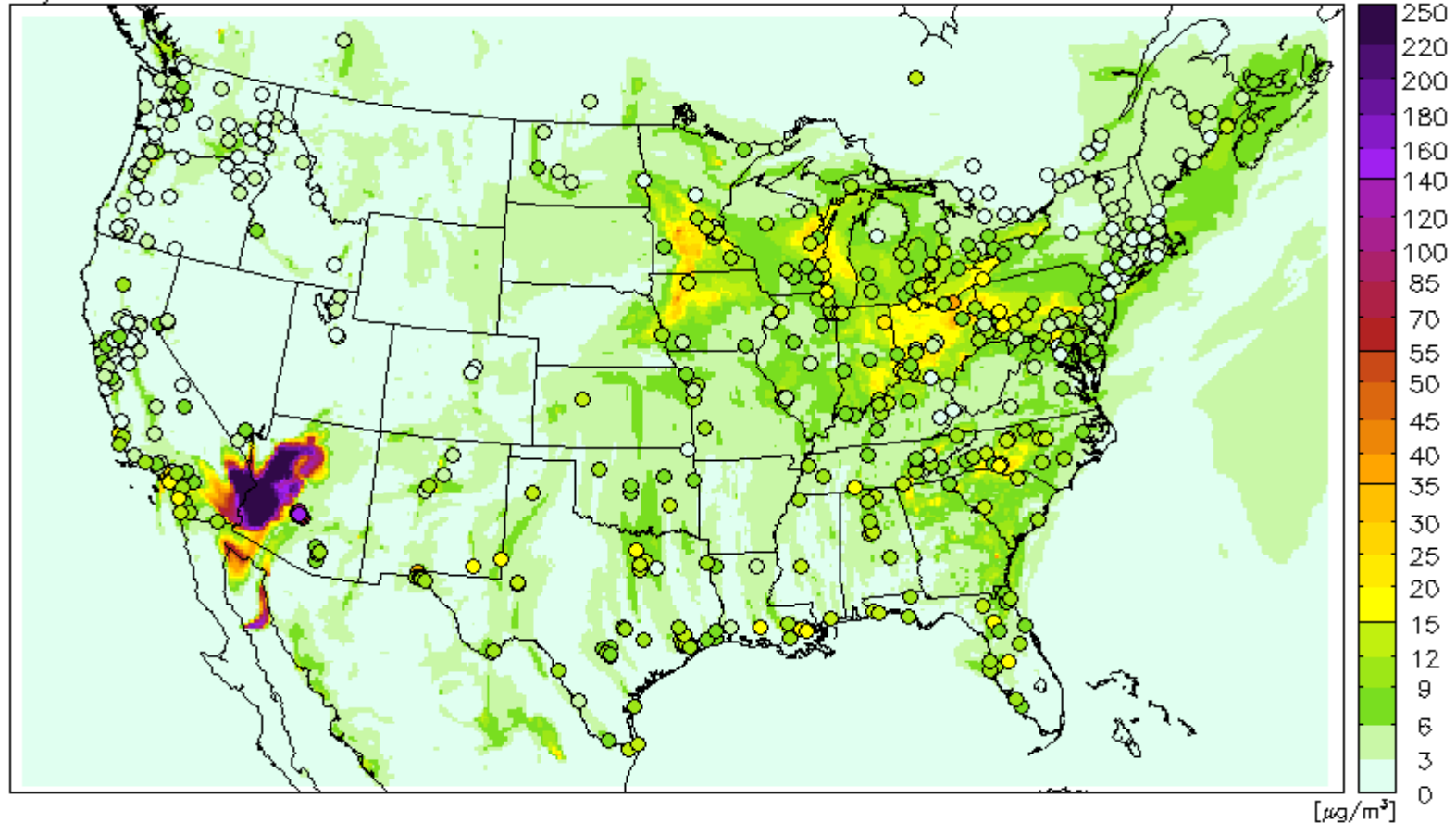Difference between two PM2.5 predictions: with-minus-without fire emissions

NOAA NESDIS Hazard Mapping System Fire and Smoke Analysis

Detection of wildfire locations from satellite imagery

Blowing dust event in testing of PM2.5 predictions

May 11 2014 12:00 UTC

Independent NOAA/NESDIS analysis narrative based on satellite imagery:

BLOWING DUST

California/Arizona: An area of moderately dense blowing dust was visible sweeping across northern Baja California/Arizona into western New Mexico behind a strong cold frontal boundary. This remnant dust originated from multiple areas in southern California last evening.

40