Operational Predictions of Air Quality for the United States: Applications of Satellite Observations

Ivanka Stajner[1], Pius Lee[2], Daniel Tong[2,4], Li Pan[2,4], Jeff McQueen[3], Jianping Huang[3,5], Ho-Chun Huang[3,5], Roland Draxler[2], Shobha Kondragunta[6], Sikchya Upadhayay[1,4]

1 NOAA NWS/OST
2 NOAA ARL
3 NOAA NWS/NCEP
4 CICS, University of Maryland
5 I.M. Systems Group, Inc.
6 NOAA/NESDIS
7 Syneren Technologies

with contributions from the entire NAQFC Implementation Team

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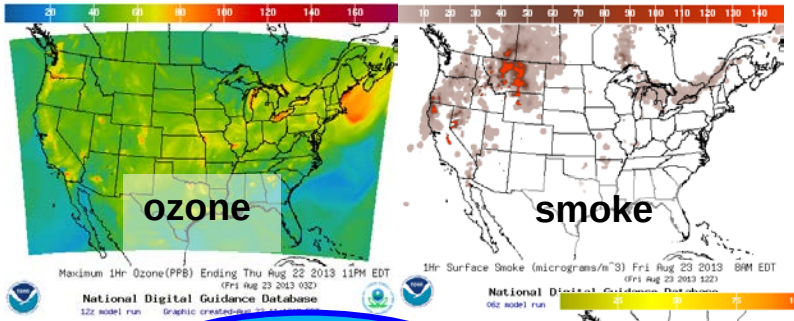
Air Quality Forecasting in the US

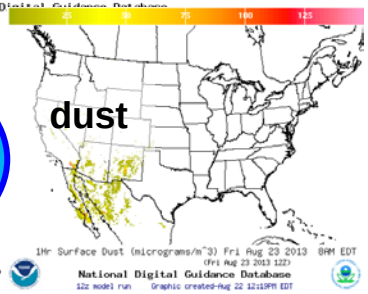
Exposure to fine particulate matter and ozone pollution leads to premature deaths of more than 50,000 annually in the US (Science, 2005; recently updated to 100,000 deaths; Fann, 2011, Risk Analysis)

Air quality forecasting in the US relies on a partnership among NOAA, EPA, state and local agencies

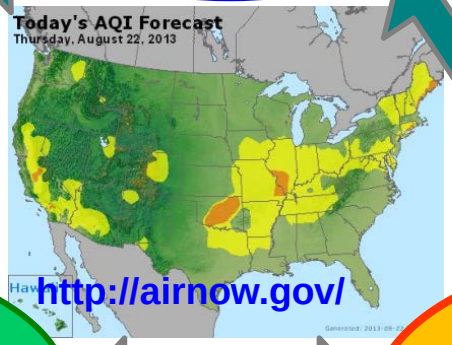
NOAA air quality forecasting team includes NWS, OAR and NESDIS

http://airquality.weather.gov/

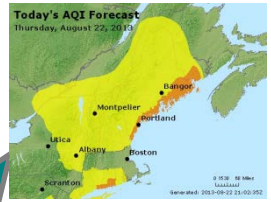




NOAA
develop & evaluate models; provide operational AQ predictions



http://airnow.gov/



EPA
maintain national emissions, monitoring data; disseminate/interpret AQ forecasts

State and local agencies
provide emissions, monitoring data AQI forecasts

Ozone predictions

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

over expanding domains since 2004

Model: Linked numerical prediction system

Operationally integrated on NCEP's supercomputer

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

Observational Input:

- *NWS compilation weather observations*
- *EPA emissions inventory*

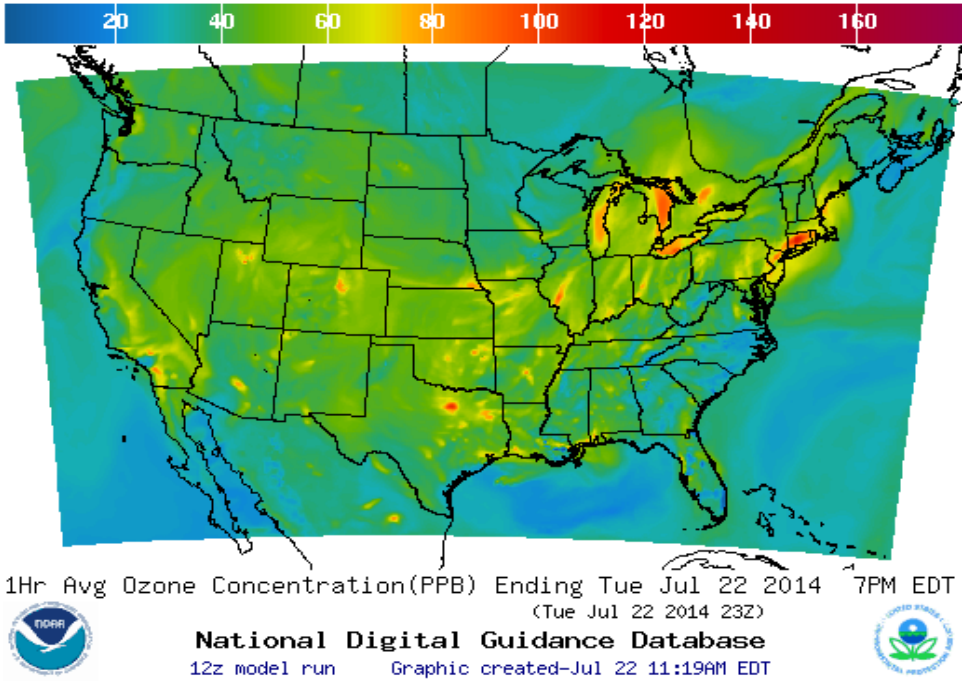
Gridded forecast guidance products

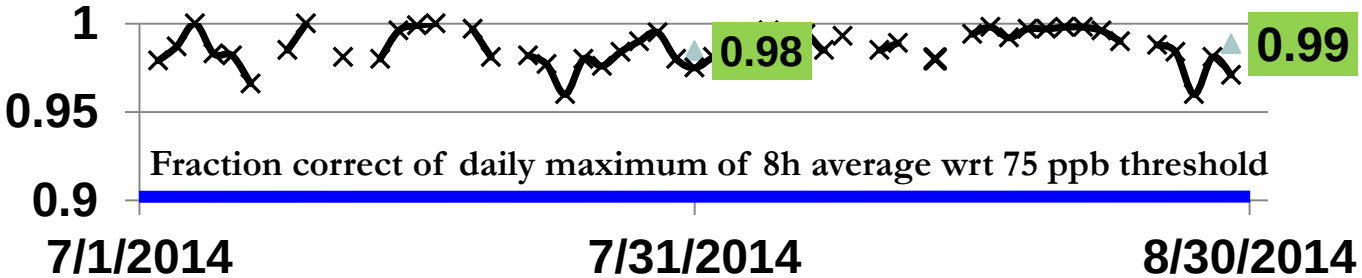
- *On NWS servers: airquality.weather.gov and ftp-servers (12km resolution, hourly for 48 hours)*
- *On EPA servers*
- *Updated 2x daily*

Verification basis, near-real time: *Ground-level AIRNow observations of surface ozone*

Customer outreach/feedback

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



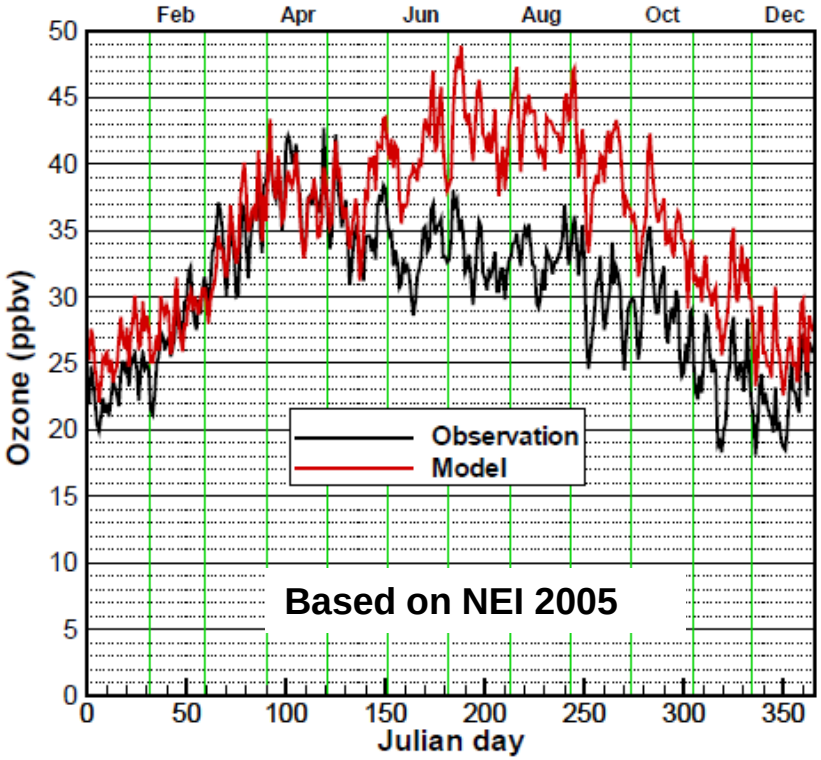


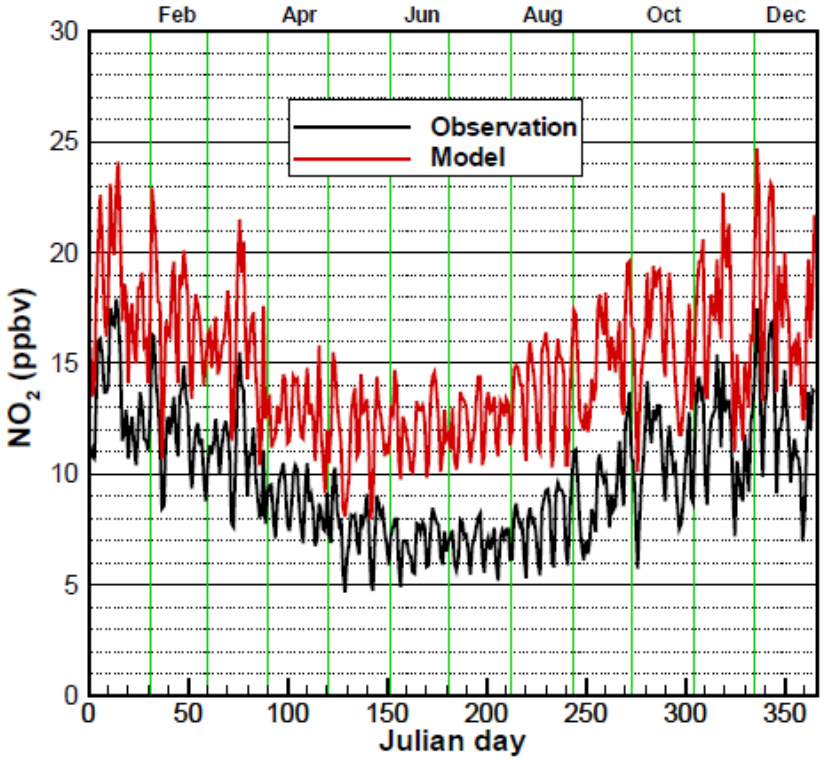
Operational

CONUS, wrt 75 ppb Threshold

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

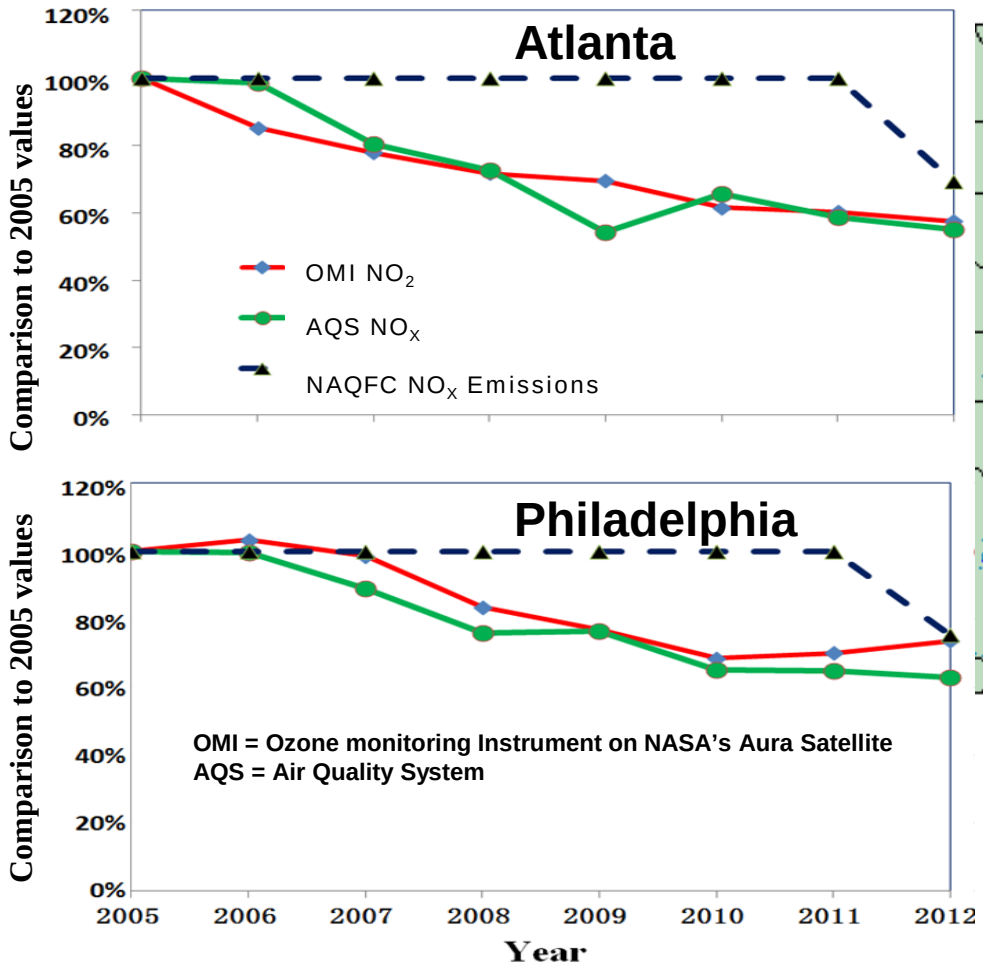
Evaluation of experimental CB05 NAQFC ozone predictions for 2010, prior to emissions update





- *T. Chai et al., Geosci. Model Dev., 2013* *(http://www.geosci-model-dev.net/6/1831/2013/gmd-6-1831-2013.html)*
- *Ozone overestimation in August is larger in rural areas, during morning hours, and in the southeast US*
- *NO2 overestimation in August is larger at night time*
- *Ozone biases higher on weekends, but NO2 biases higher on weekdays*

NOx Changes

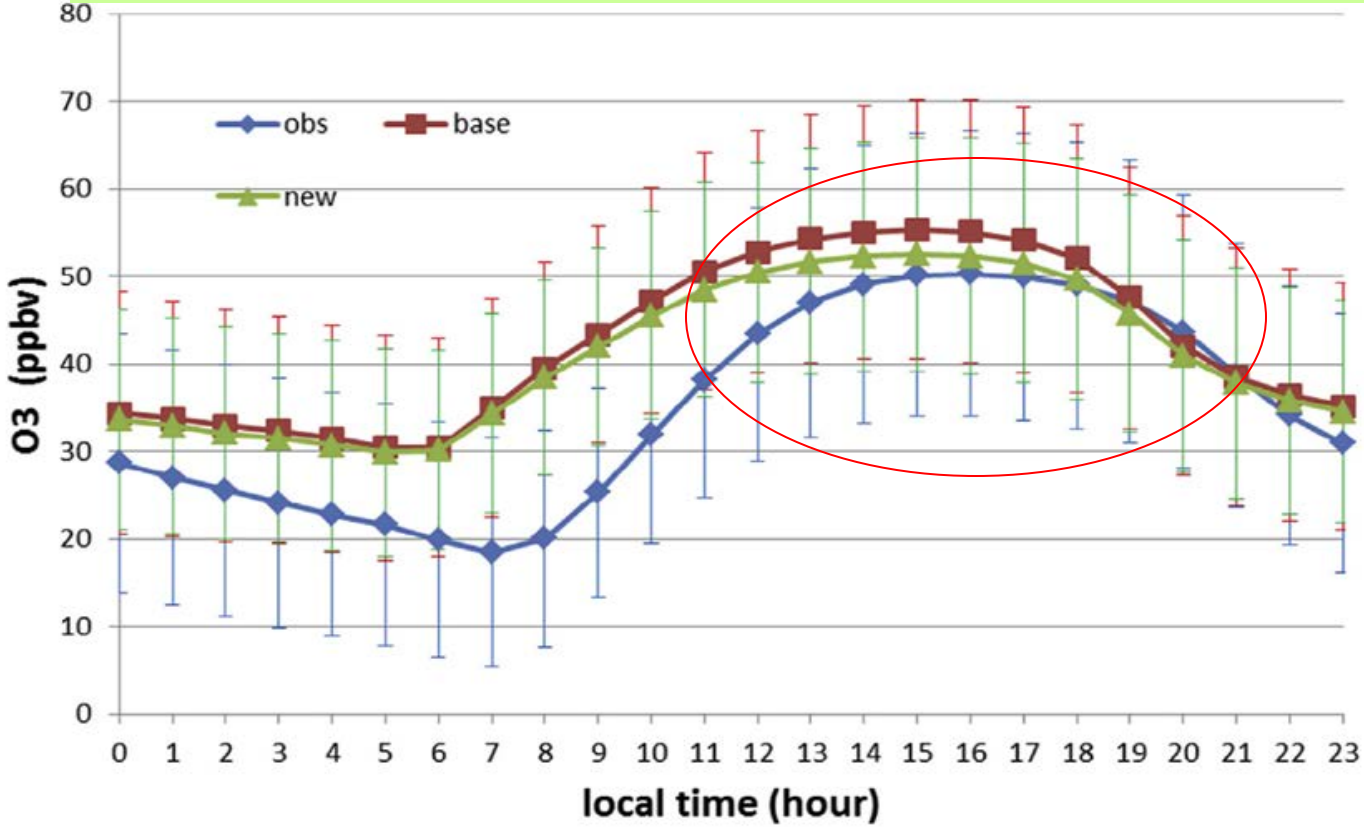


- Difference between NOx emissions used in 2012 and 2011 (blue indicates decrease in 2012).
- Mobile and nonroad emissions were updated based on projections for 2012.

Comparison of projected emissions with surface and satellite observations shows that projected reductions from 2005 to 2012 are similar to observed (*Tong et. al. Long-term NOx trends over large cities in US, Atm. Env. 2015*).

Impact of NOx emissions update on ozone predictions

NOx emission used in July 2012 are 17.2% lower than those used in July 2011



Peak Ozone bias in summertime is reduced with updated emissions

(Pan et. al., Assessment of NOx and Ozone forecasting performance in the US NAQFC before and after the 2012 major emissions updates, Atmospheric Environment, 2014).

NOx and Ozone biases over CONUS (*in July 2011*)

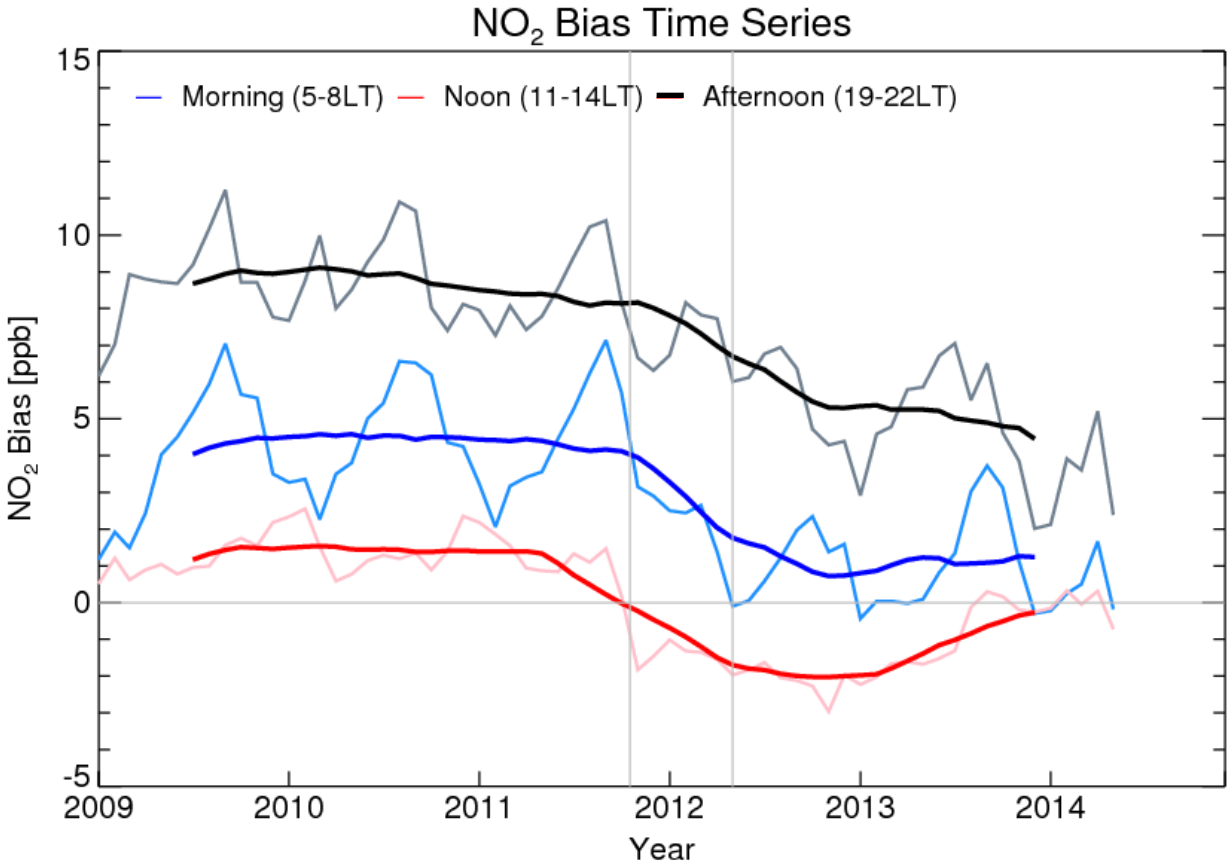
Land use	NO_x_Bias[a] (ppbv)		ΔNOx (New-base)	O3_Bias[b] (ppbv)		ΔO3 (New-base)
	Base	New		Base	New	
Urban	2.8	0.46	-2.34	7.08	6.16	-0.92
Suburban	4.62	2.53	-2.09	7.48	6.22	-1.26
Rural	0.75	0.18	-0.57	7.8	5.93	-1.87

a The total number of NO_x AQS sites is 295 including urban (101), suburban (111) and rural (83).

b The total number of ozone AQS sites is 1144 including urban (201), suburban (438) and rural (505).

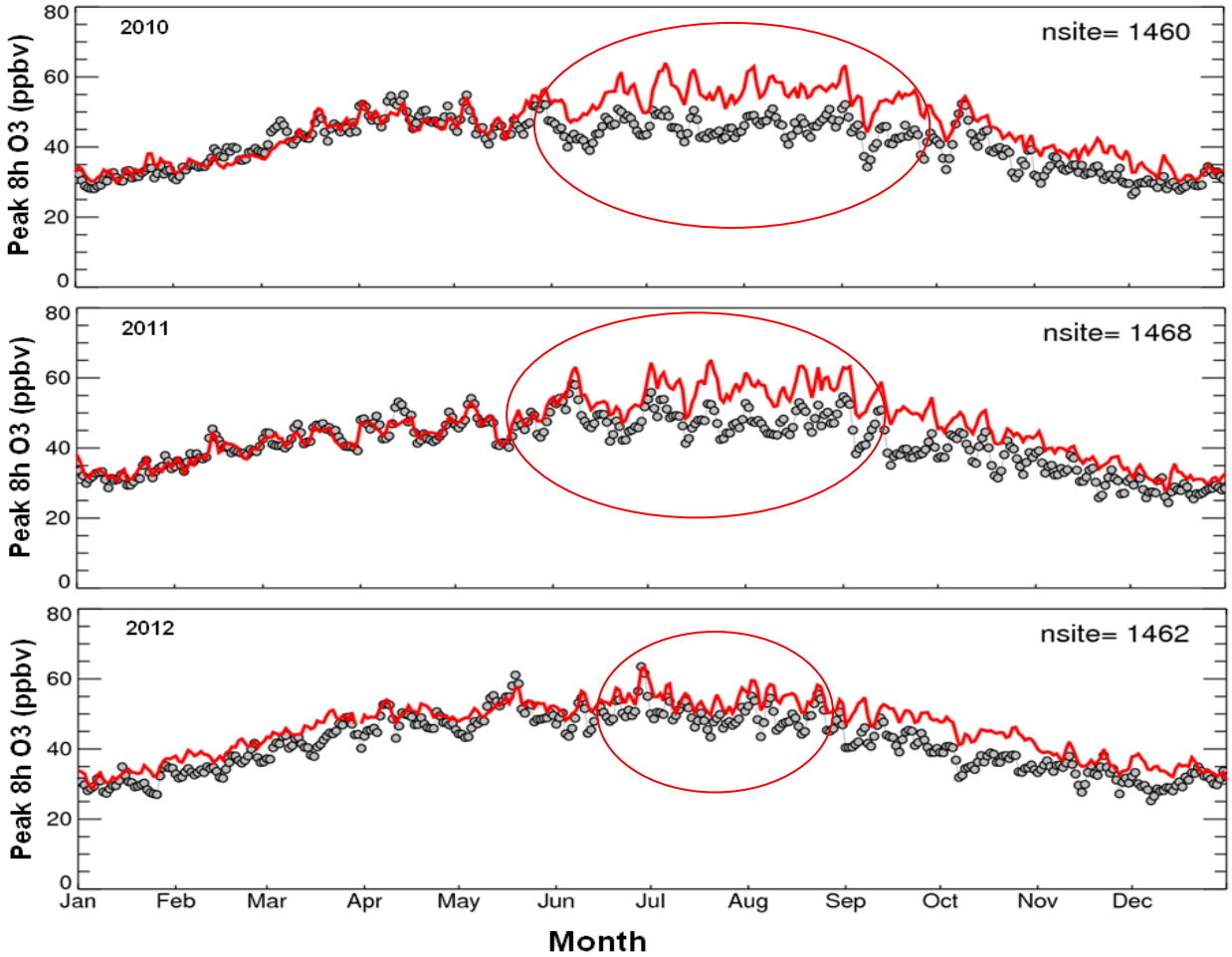
- **Positive biases reduced for all urbanization types for NOx and ozone.**
- **Largest improvements for NOx are in urban areas.**
- **Largest improvements for ozone in rural areas.**

Impacts of model and emission updates on other species



NO_2 bias by time of the day was reduced following experimental model update in 2011 and emission update in 2012 *(Courtesy: Hyun-Cheol Kim)*

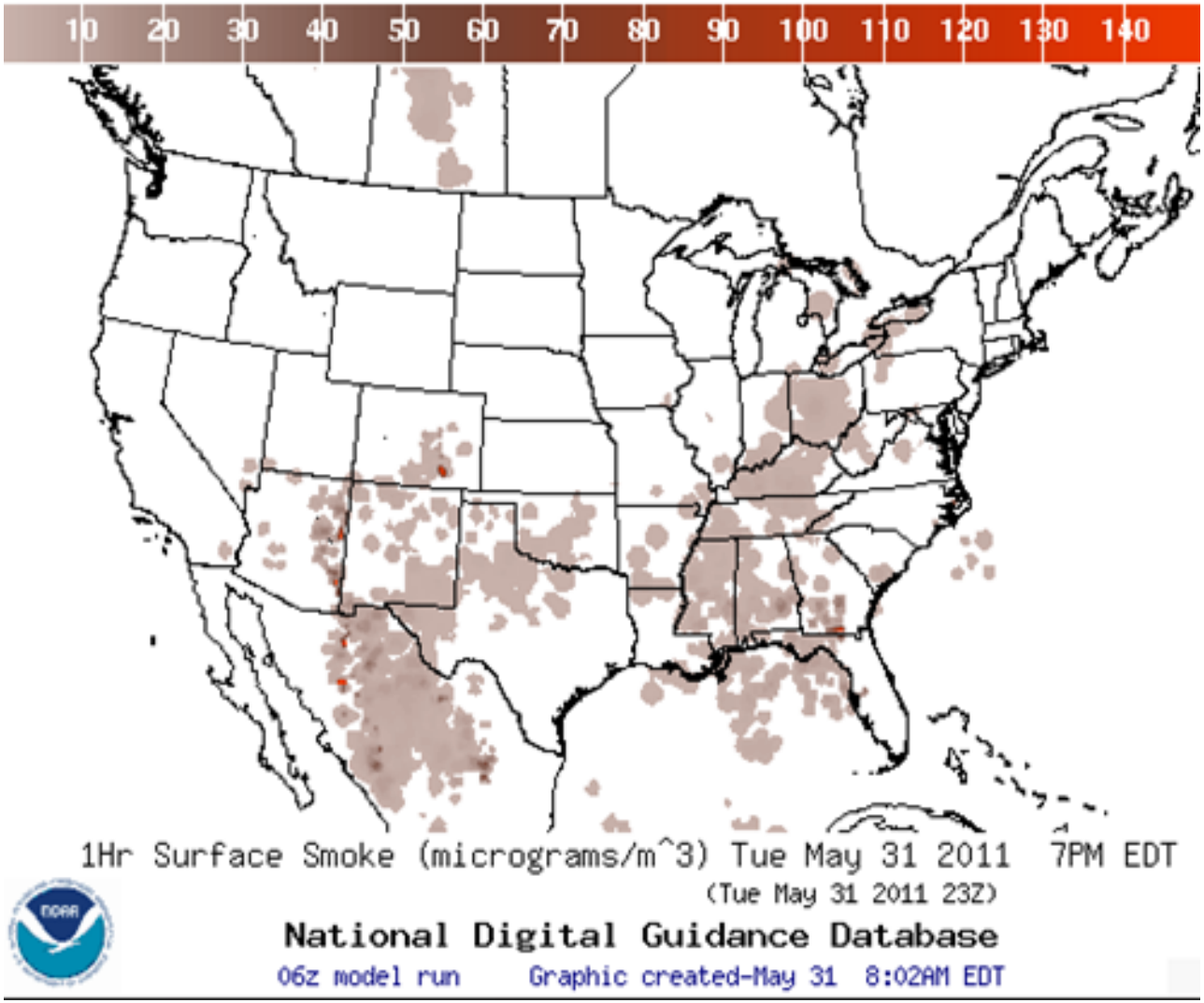
Impact of emission update on ozone



Comparison of mean values over the continental US of daily maximum 8-hr Ozone concentrations from surface monitor observations (circles) and collocated NAQFC predictions (red line) for years 2010, 2011 and 2012.

Smoke Predictions

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



- Smoke predictions for CONUS (continental US), Alaska and Hawaii
- NESDIS provides wildfire locations
- Emissions estimates from USFS Bluesky system (Testing updated version)
- HYSPLIT model for transport, dispersion and deposition (Rolph et. al., W&F, 2009)
- Recent updates include increased plume rise, decreased wet deposition, changes in daily emissions cycling
- Developed satellite product for verification (Kondragunta et.al. AMS 2008)

Smoke Verification using Satellite Data

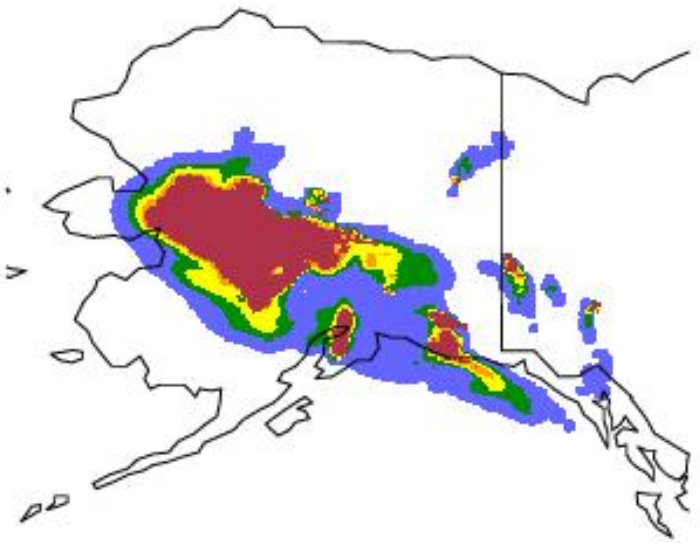
July 13, 2009 example

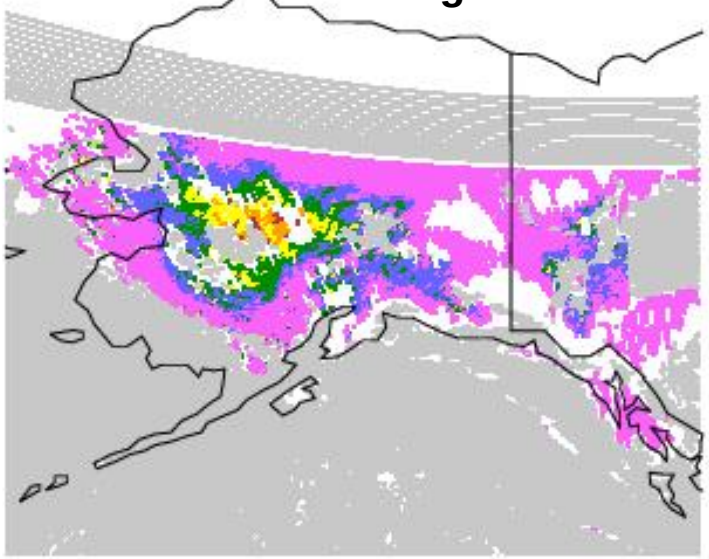
7/13/09, 17-18Z, Prediction:

7/13/09, 17-18Z, Observation:

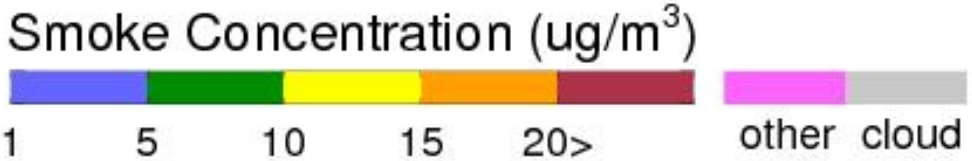
GOES smoke product: Confirms areal extent of peak concentrations

FMS = 30%, for column-averaged smoke > 1 ug/m³





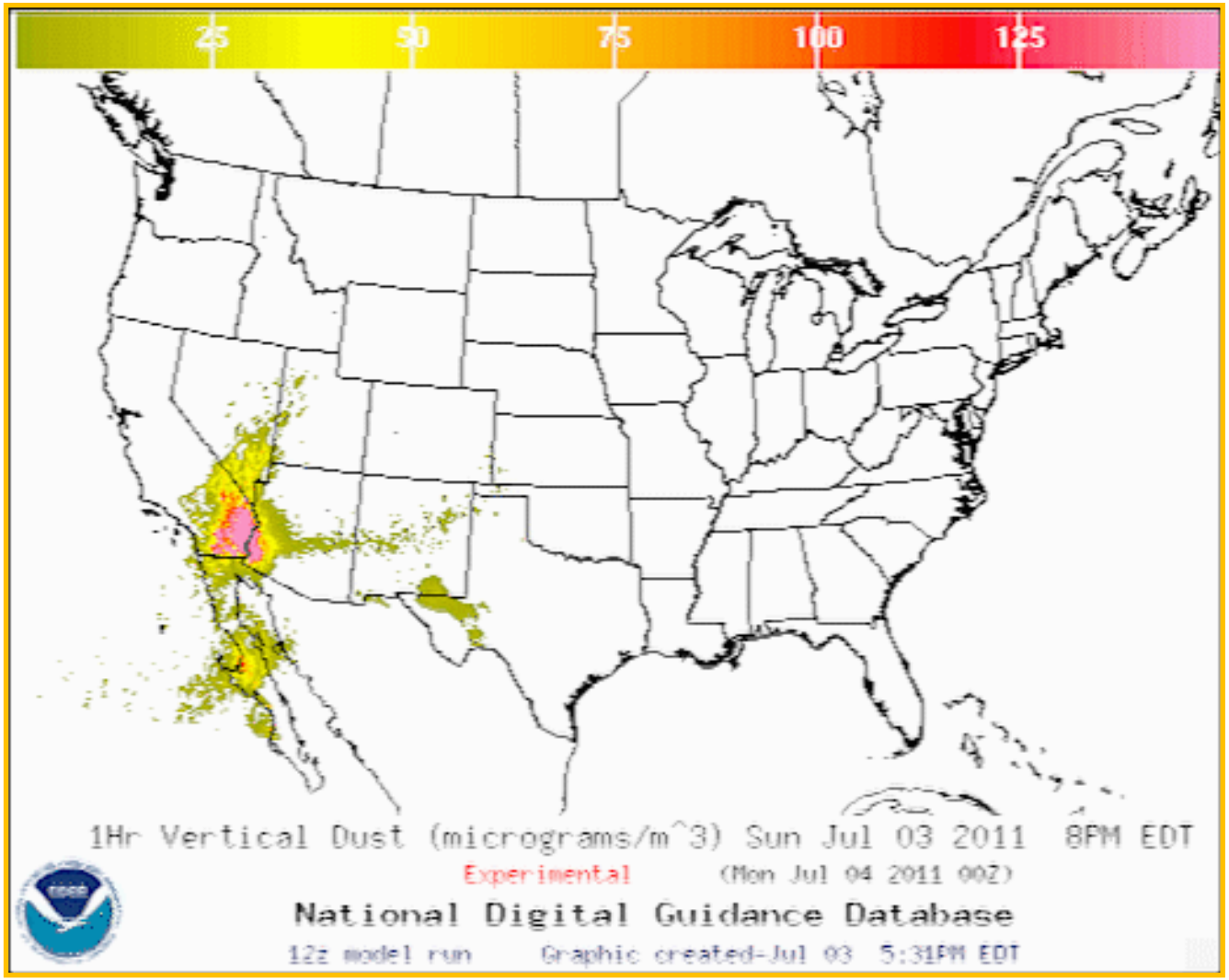
Levels:	1ug/m³	5ug/m³
FMS (%):	29.74	22.65



Manuscript about smoke verification product is in preparation

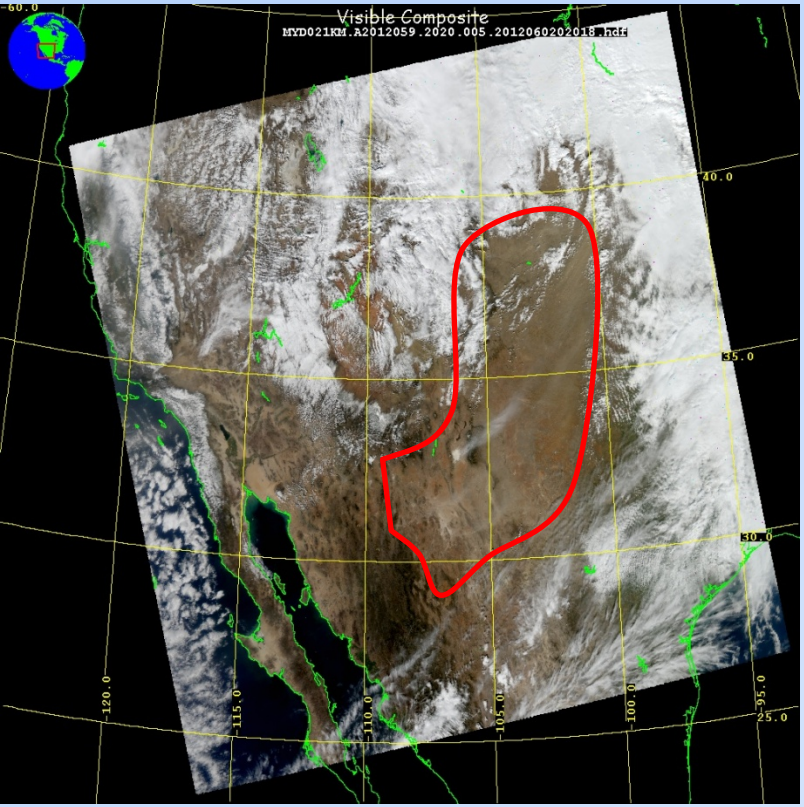
CONUS Dust Predictions

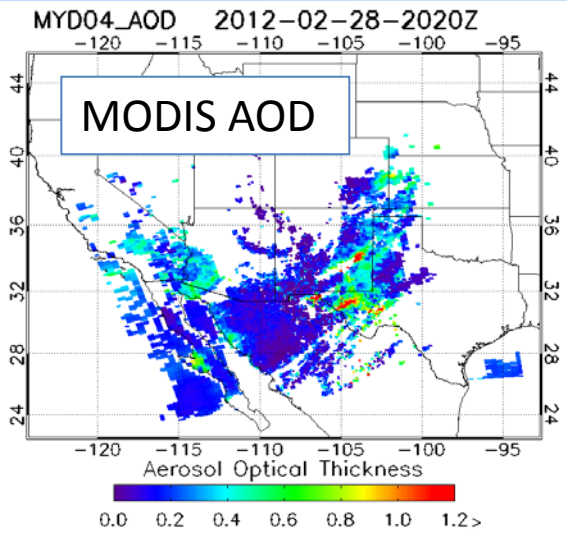
Operational Predictions at http://airquality.weather.gov/



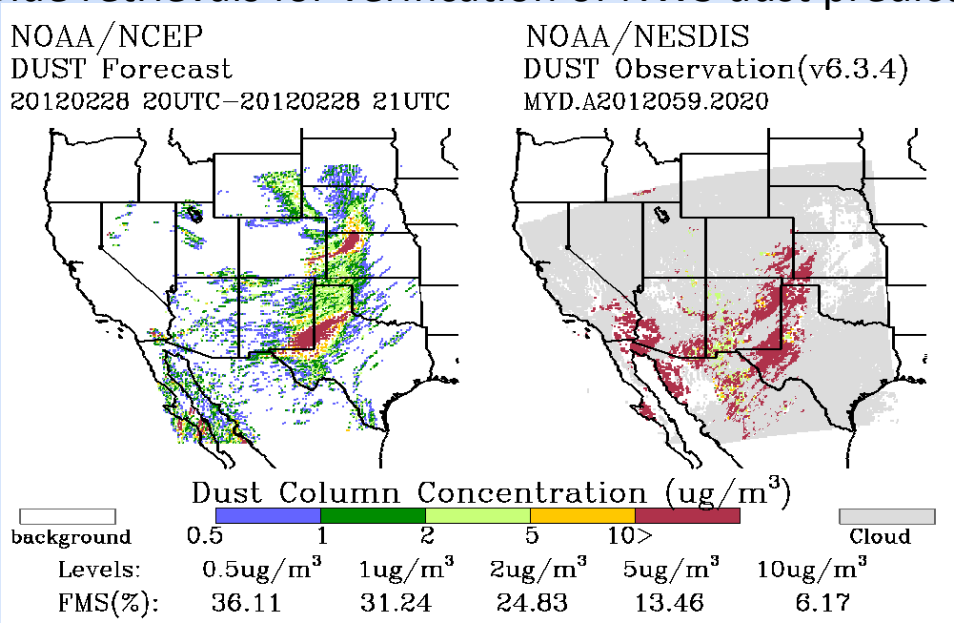
- Standalone prediction of airborne dust from dust storms:
- Wind-driven dust emitted where surface winds exceed thresholds over source regions
- Source regions with emission potential estimated from MODIS deep blue climatology for 2003-2006 (Ginoux et al. JGR 2010)
- Emissions modulated by real-time 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)

Dust Event and Verification on 02/28/2012





NESDIS developed dust retrieval using MODIS Deep Blue retrievals for verification of NWS dust predictions

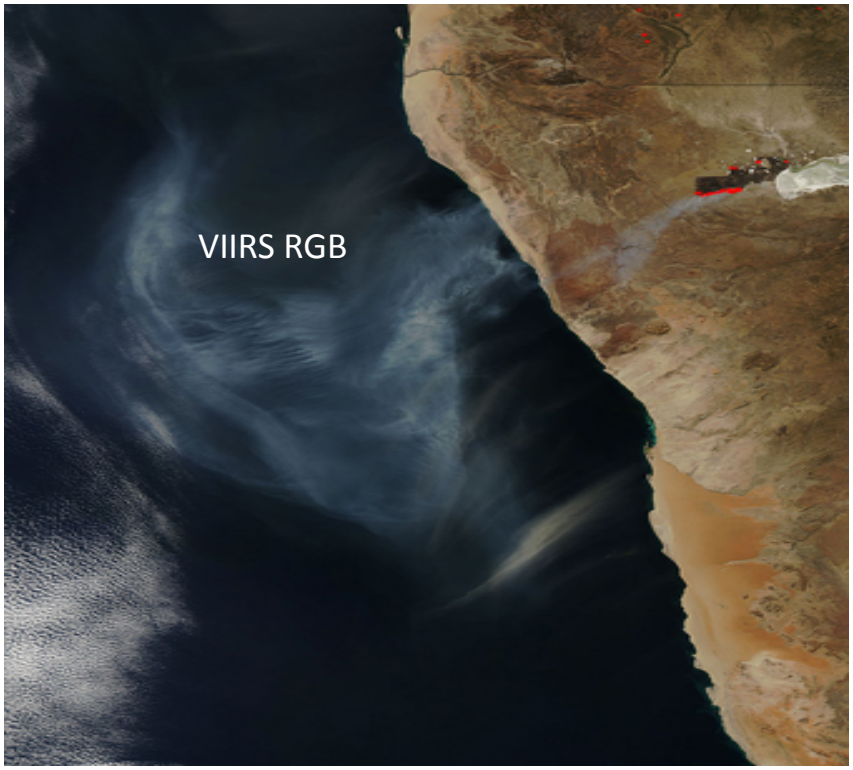


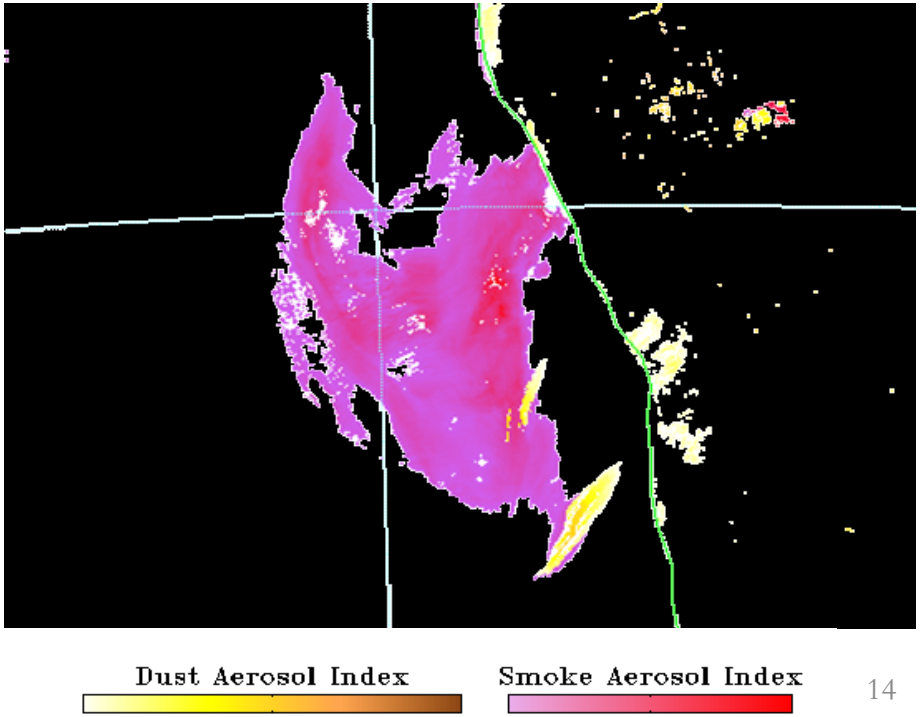
- Large dust storm occurred in Central Plains resulting in large swath of blowing dust
- Generated from eastern New Mexico, Western Texas, Texas Panhandle, southeast Colorado, Oklahoma Panhandle, and Western Kansas

VIIRS Dust and Smoke Detection for Air Quality Forecast Applications

$$DAI = -100*[\log_{10}(R_{412nm}/R_{445nm})-\log_{10}(R'_{412nm}/R'_{445nm})]$$
$$NDAI = -10*[\log_{10}(R_{412nm}/R_{2.25um})]$$

Dust Aerosol Index and
Non Dust (smoke) Aerosol Index
in preoperational real time testing
at NOAA/NESDIS/STAR





Testing of PM2.5 Predictions

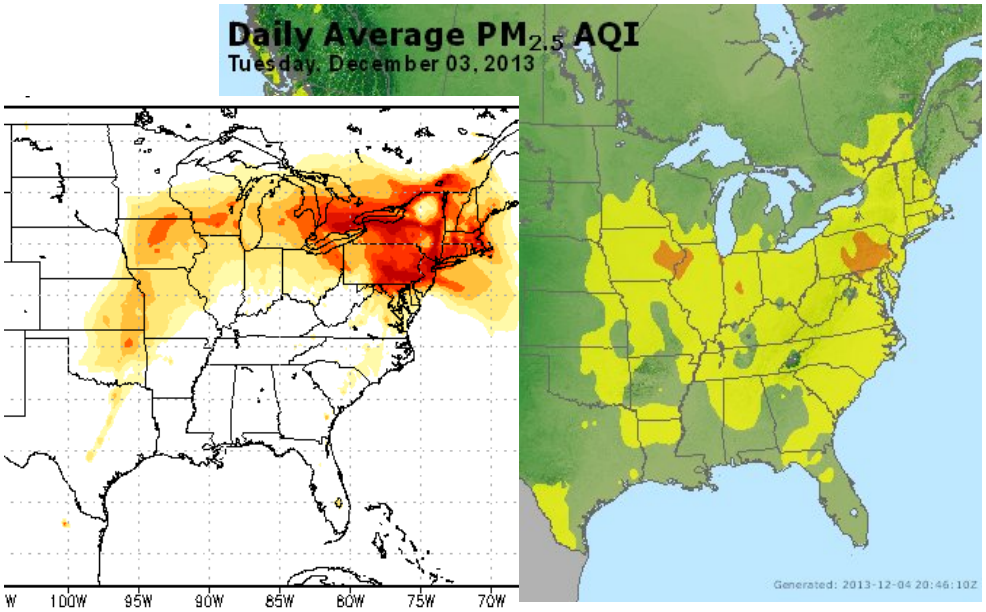
AQ Forecaster Focus group access only, real-time as resources permit

Aerosols over CONUS

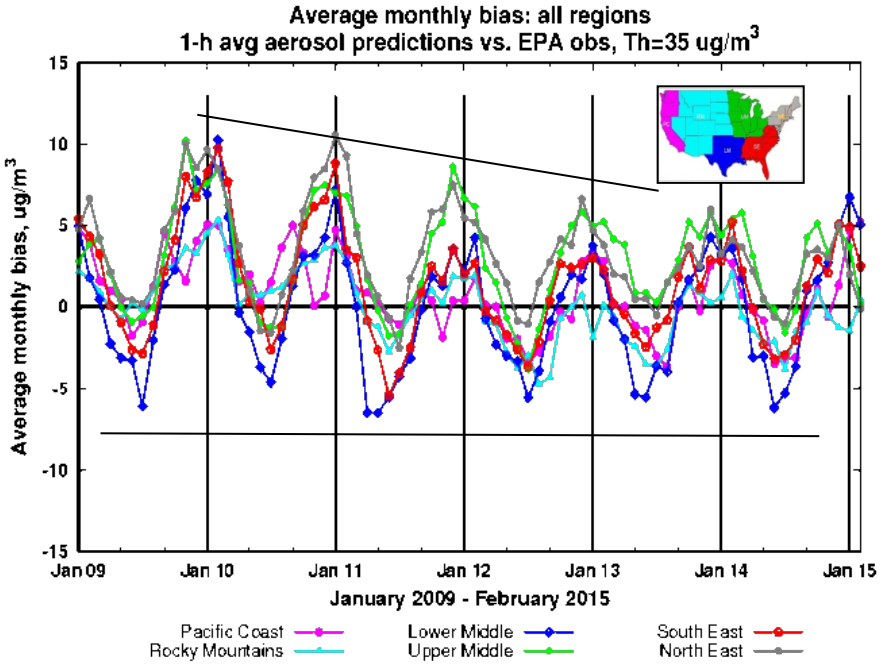
From NEI sources only before summer 2014

- CMAQ:
  CB05 gases, AERO-4 aerosols
- Sea salt emissions

- Show seasonal bias-- winter, overprediction; summer, underprediction



NAQFC PM2.5 test predictions

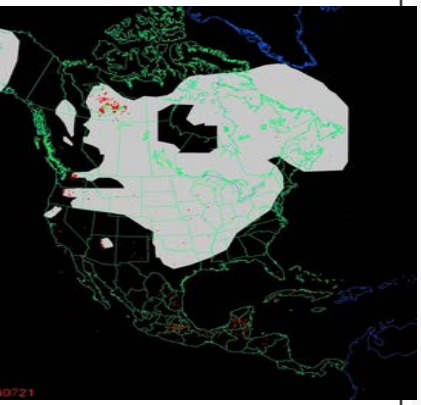


Forecast challenges

- *Including **wildfire smoke and dust** emissions – in testing since summer 2014*
- *Chemical mechanisms eg. SOA*
- *Meteorology eg. PBL height*
- *Chemical boundary conditions/trans-boundary inputs*

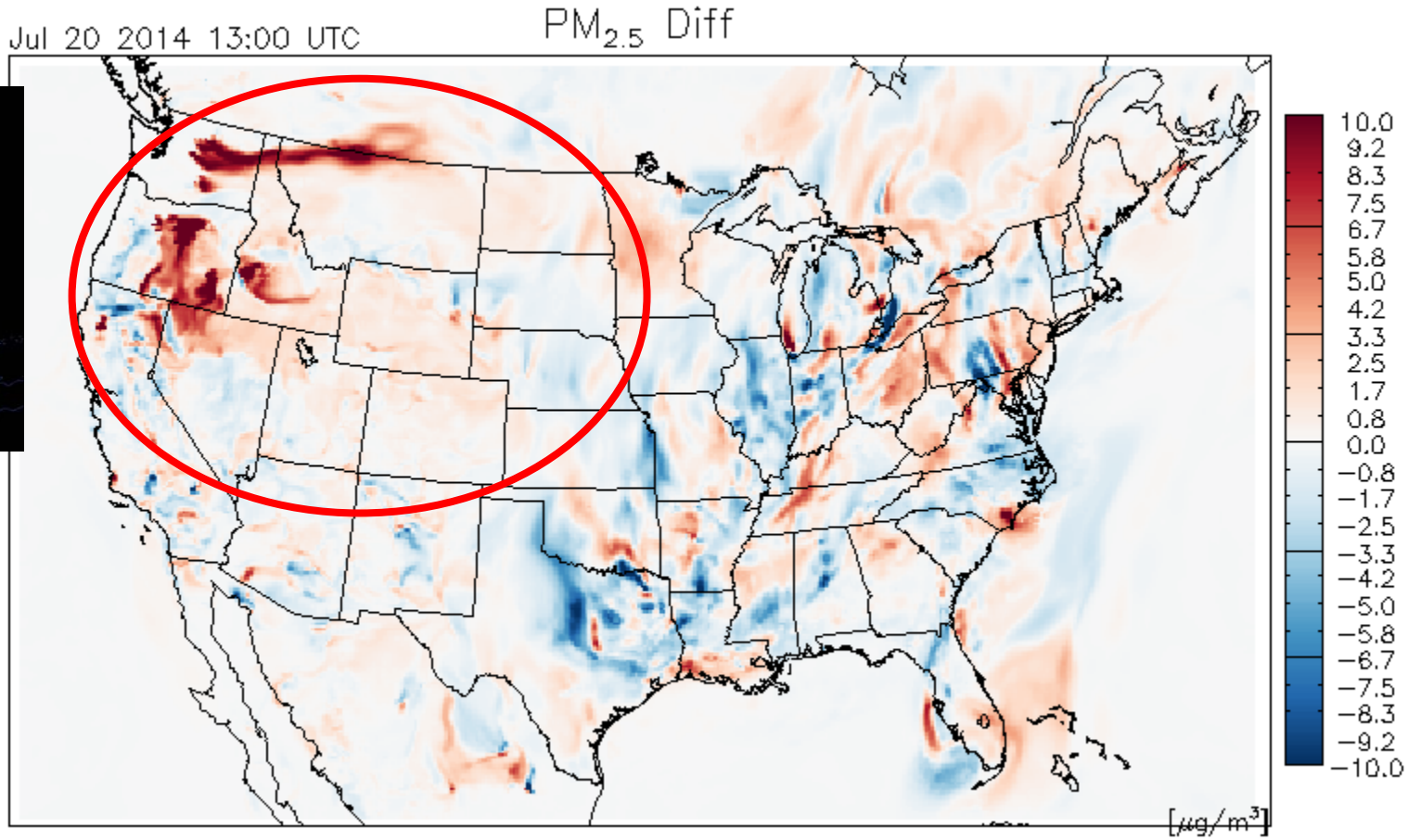
Impact of forest fires in testing of PM2.5 predictions

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

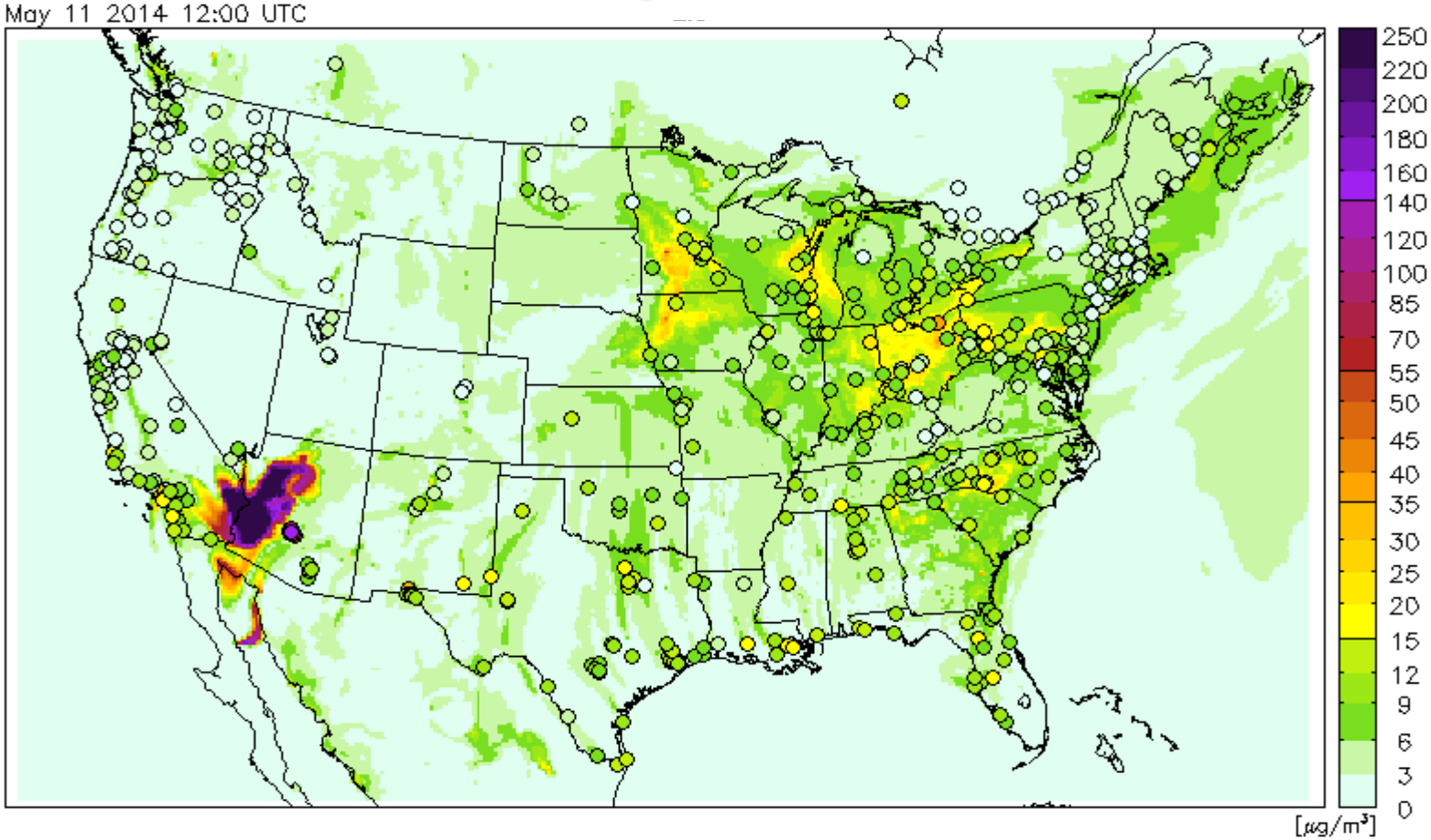


NOAA NESDIS Hazard Mapping System Fire and Smoke Analysis

Detection of wildfire locations with visible smoke plumes from satellite imagery



Blowing Dust Event in testing of PM2.5 predictions



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.

Summary and Plans

US national AQ forecasting capability:

- Operational **ozone** prediction nationwide; CMAQ with CB05 mechanism
- Operational **smoke** prediction nationwide
- Operational **dust** prediction for CONUS sources
- Prototype CMAQ **PM2.5** predictions with NEI, wildfire and dust emissions
- Satellite data used for detection of wildfire locations to specify smoke emissions, verification of smoke and dust predictions, and in evaluation of NO_x emission projection.

Ongoing testing:

- Linking national AQ predictions with global model predictions: using increased vertical resolution and lateral boundary conditions from global dust predictions in prototype PM2.5 predictions
- Bias correction for PM2.5 and partial update of emissions using NEI2011
- Bluesky smoke emission updates

Acknowledgments:
AQF Implementation Team Members

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NOAA/NWS/OST	***Ivanka Stajner***	***NAQFC Manager***
NWS/OCWWS	***Jannie Ferrell***	***Outreach, Feedback***
NWS/OPS/TOC	***Cynthia Jones***	***Data Communications***
NWS/OST/MDL	***Jerry Gorline, Marc Saccucci, Dave Ruth***	***Dev. Verification, NDGD Product Development***
NWS/OST	***Sikchya Upadhayay***	***Program Support***
NESDIS/NCDC	***Alan Hall***	***Product Archiving***
NWS/NCEP		
Jeff McQueen, Jianping Huang,		**AQF model interface development, testing, & integration**
***Jun Wang**		**Global dust aerosol and feedback testing**
***Brad Ferrier, *Eric Rogers, *Hui-Ya Chuang**		**NAM coordination**
Ho-Chun Huang		**Smoke and dust product testing and integration**
Becky Cosgrove, Chris Magee		**NCO transition and systems testing**
Mike Bodner, Andrew Orrison		**HPC coordination and AQF webdrawer**
NOAA/OAR/ARL		
Pius Lee, Daniel Tong,		**CMAQ development, adaptation of AQ simulations for AQF**
Li Pan, Hyun-Cheol Kim,		
Roland Draxler, 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