On the Assimilation of Satellite Retrievals of Aerosol Optical Depth to Improve 0-48 h Air Quality Predictions Over the U.S.

Luca Delle Monache
National Center for Atmospheric Research
Boulder, Colorado, USA
lucadm@ucar.edu

Acknowledgments
THIS RESEARCH IS FUNDED BY NASA EARTH SCIENCE APPLICATIONS: HEALTH AND AIR QUALITY (A.44)

Project Team

Principal Investigator: Luca Delle Monache (NCAR/RAL, Boulder, CO)

Co-Principal Investigator: Gabriele Pfister (NCAR/ACOM, Boulder, CO)

Co-Investigators:
Stefano Alessandrini (NCAR/RAL, Boulder, CO)
Barry Baker (UMD, College Park, MD)
Jamie Bresh (NCAR/MMM, Boulder, CO)
Irina Djalalova (CU Boulder, Boulder, CO)
David Edwards (NCAR/ACOM, Boulder, CO)
Rajesh Kumar (NCAR/RAL, Boulder, CO)
Zhiquan Liu (NCAR/MMM, Boulder, CO)
Youhua Tang (UMD, College Park, MD)

Collaborators:
Pius Lee (NOAA/ARL, College Park, MD)
Pablo Saide (NCAR/RAL, Boulder, CO)
James Wilczak (NOAA/ESRL, Boulder, CO)

Outline

- Project goal and objectives
- Tasks:
  - Chemical data assimilation (Rajesh Kumar, NCAR)
  - Uncertainty quantification (Stefano Alessandrini, NCAR)
  - "Spreading technique" to generate 2D Maps (Irina Djalalova, NOAA/ESRL)
  - Transition to operations (Pius Lee, NOAA/ARL)
  - Socio-economic impact study (Jeff Lazo, NCAR)
- Summary

Outline

- Project goal and objectives
- Tasks:
  - Chemical data assimilation (Rajesh Kumar, NCAR)
  - Uncertainty quantification (Stefano Alessandrini, NCAR)
  - "Spreading technique" to generate 2D Maps (Irina Djalalova, NOAA/ESRL)
  - Transition to operations (Pius Lee, NOAA/ARL)
  - Socio-economic impact study (Jeff Lazo, NCAR; not started, yet)
- Summary

Project Goal & Objectives

Goal:

- National Oceanic and Atmospheric Administration (NOAA) / National Centers for Environmental Prediction (NCEP) air quality (AQ) forecasting system is a key tool for decision makers across the U.S. to protect the public from poor AQ
- To enhance this decision-making activity this project aims to improve the accuracy of NOAA/NCEP short-term predictions of ground-level ozone (O_3) and particulate matter less than 2.5 μm in diameter ($PM_{2.5}$) and to provide reliable quantification of their uncertainty

Objectives:

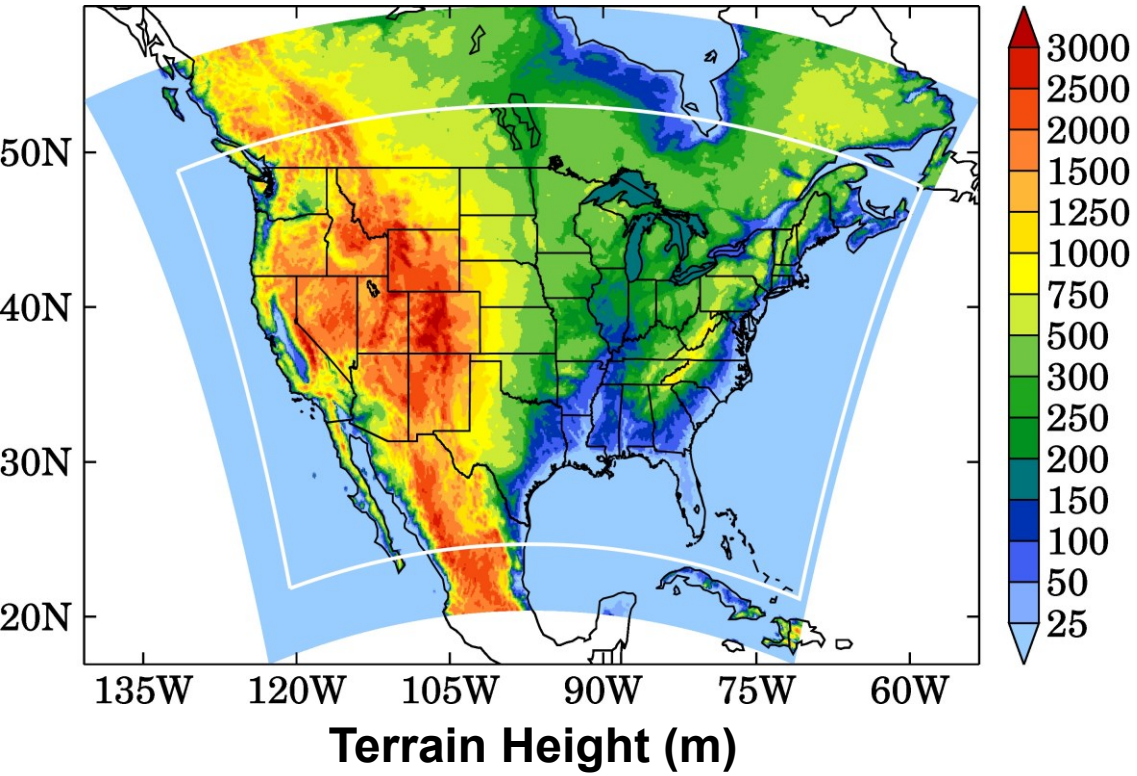
① Improve initialization of NOAA/NCEP Environmental Protection Agency (EPA) Community Multiscale AQ (CMAQ) model through chemical data assimilation of satellite retrieval products and in-situ observations with the Community Gridpoint Statistical Interpolation (GSI) system

① Improve CMAQ prediction accuracy and reliably quantify its uncertainty with analog-based post-processing methods

Air Quality Prediction System

NOAA/NCEP National Air Quality Forecast Capability (NAQFC) is based on the EPA Community Multiscale Air Quality (CMAQ) model

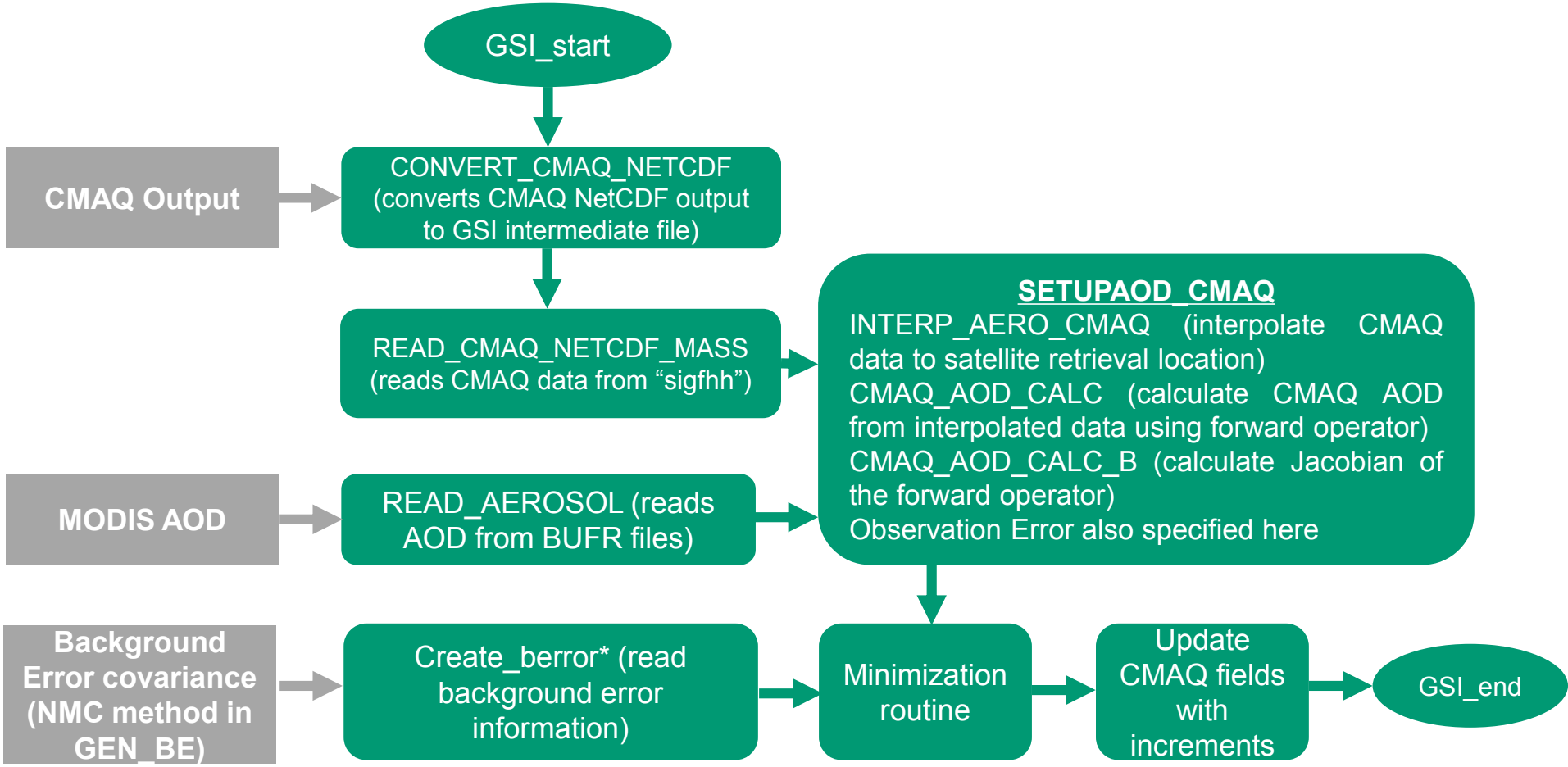
WRF and CMAQ Domains



Present-study CMAQ set-up:

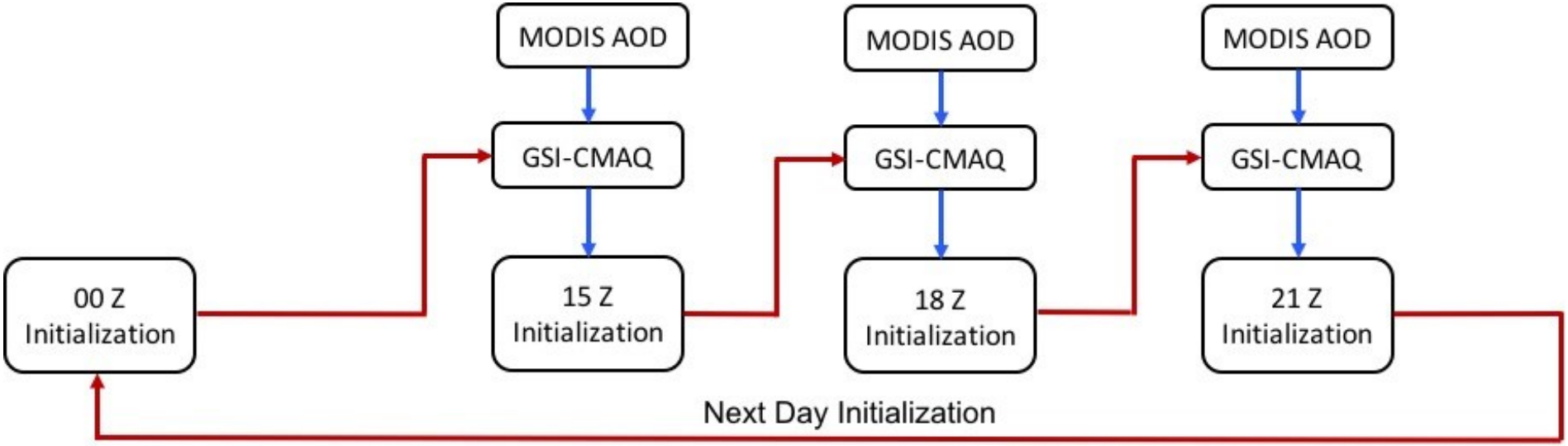
- CMAQ version: 5.1
- Resolution: 12 km^2
- Emissions:
  - ✧Anthropogenic: NEI 2011
  - ✧Biogenic: Online (BEIS)
  - ✧Fires: U.S. forest service
- IC: previous CMAQ run
- BC: Static
- Other configuration options are consistent with NAQFC
- Run period:
  15 Jul – 14 Aug 2014

GSI/CMAQ Code Development



Note: this code will be shared with the community as part of the GSI software

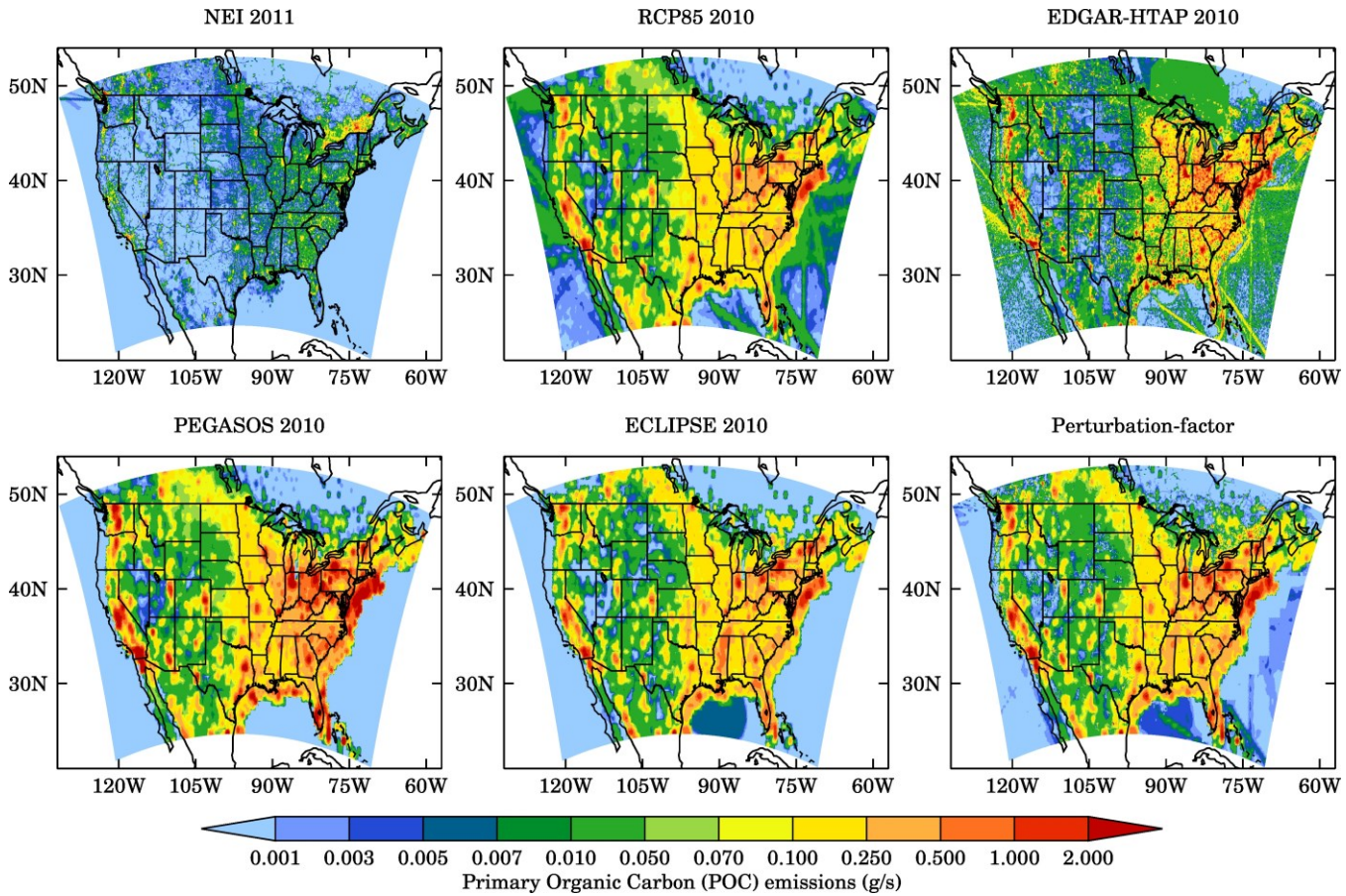
24-h Assimilation Cycle



Tropospheric Emissions Monitoring of Pollution (TEMPO): NASA geostationary satellite that will provide high-spatial and temporal resolution of AOD retrievals. Launch in 2019 timeframe.

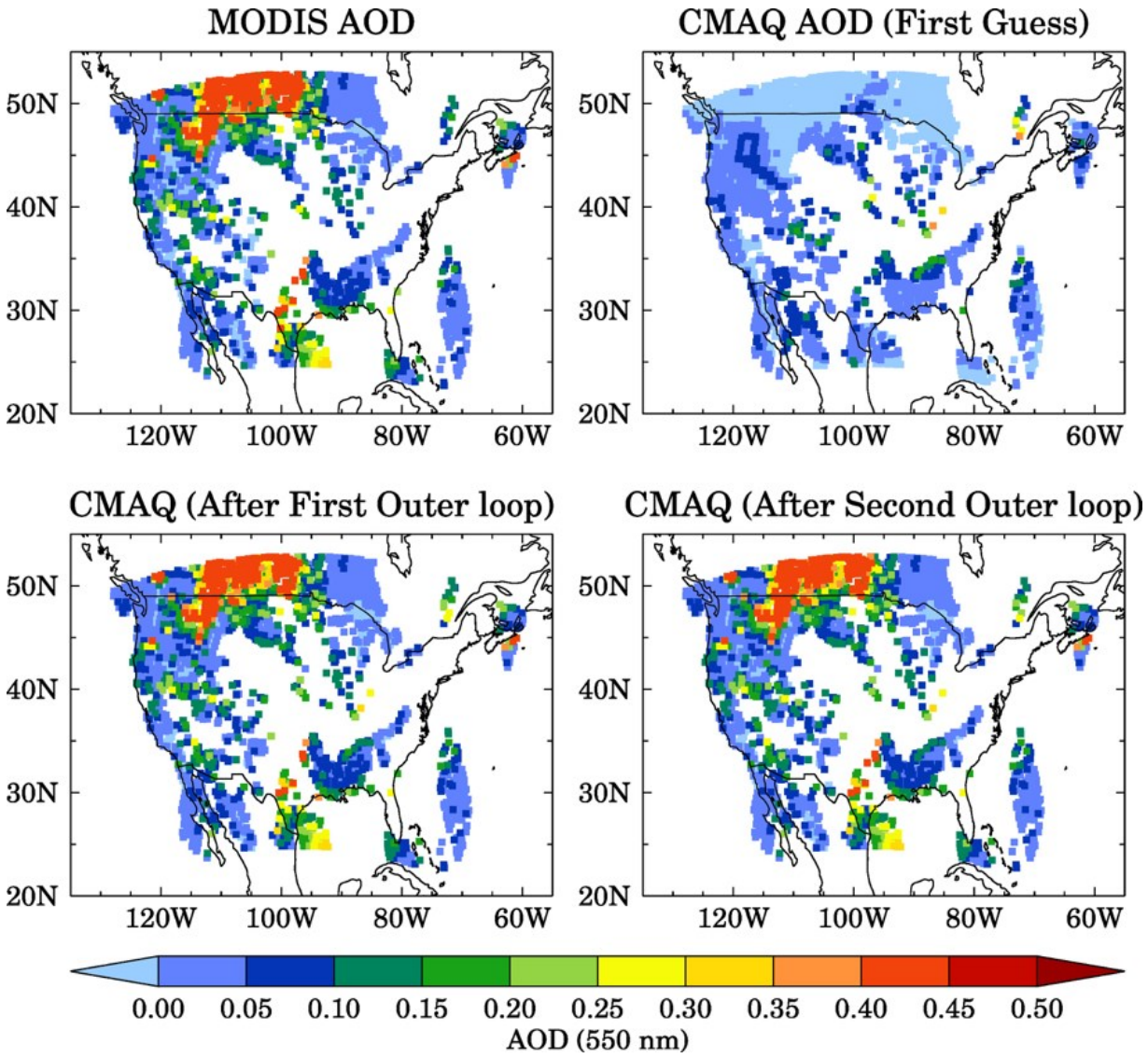
Background Error (BE) Statistics

- GEN_BE is used to calculate BE statistics
  - Different meteorology (i.e., forecasts initialized at 00z and 06z)
  - Different emissions

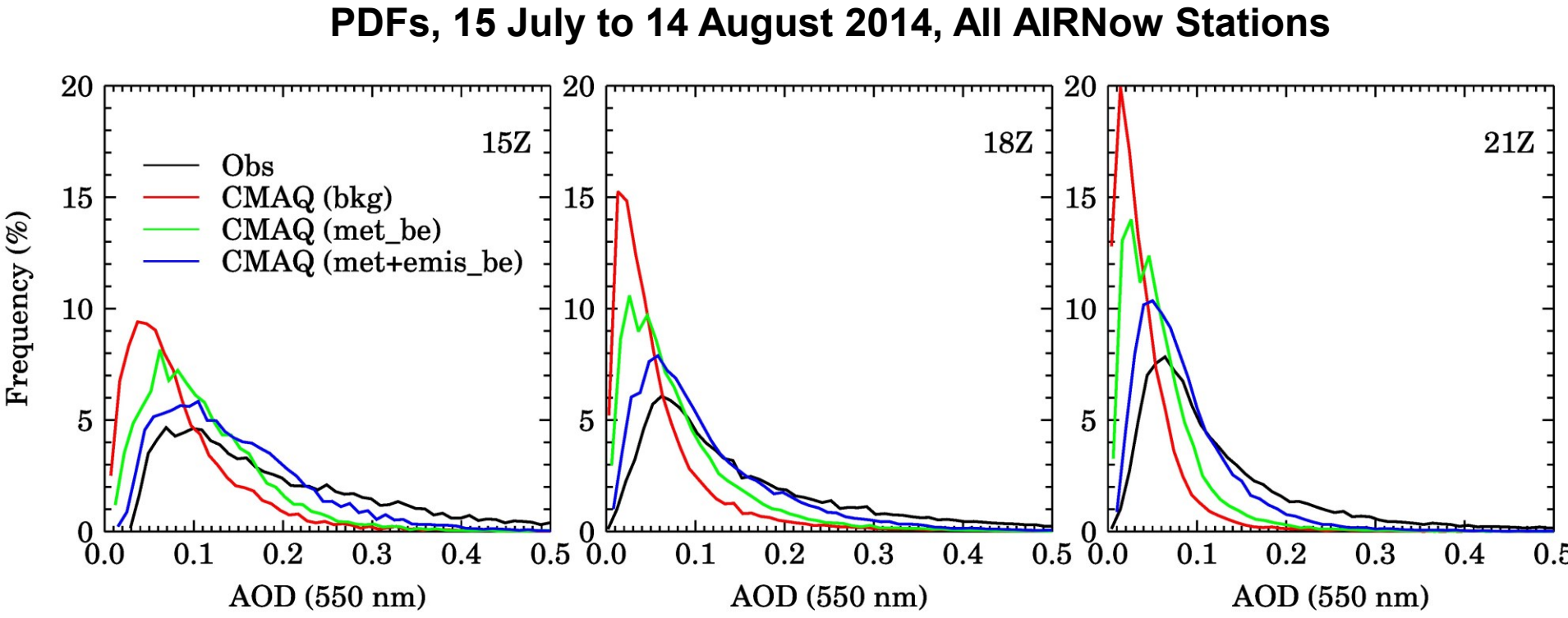


Perturbed emissions = NEI - Mean(NEI – E_i); i = 1, 2, 3, 4

AOD Results

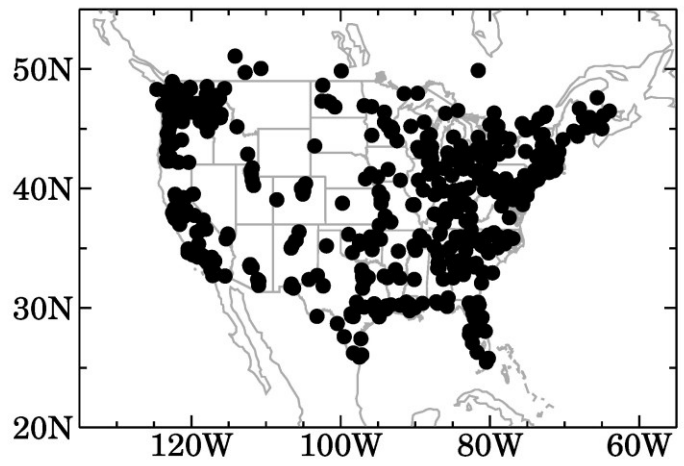

MODIS AOD
CMAQ AOD (First Guess)
CMAQ (After First Outer loop)
CMAQ (After Second Outer loop)
50N
40N
30N
20N
120W
100W
80W
60W
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
AOD (550 nm)

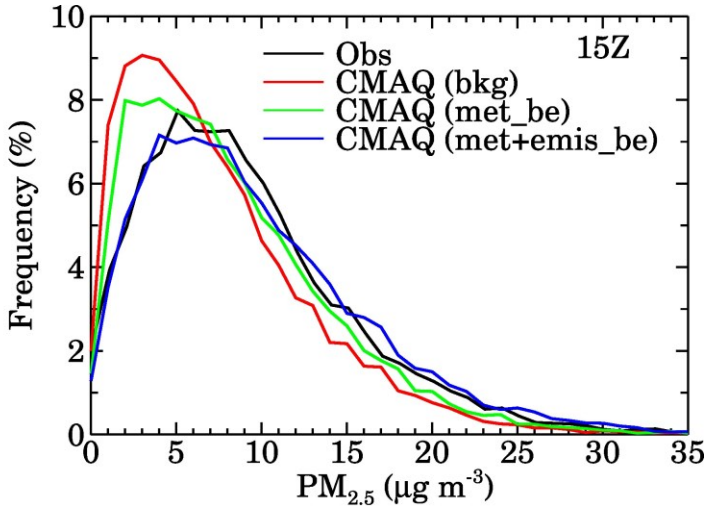
Effect of AOD Assimilation on AOD Initialization

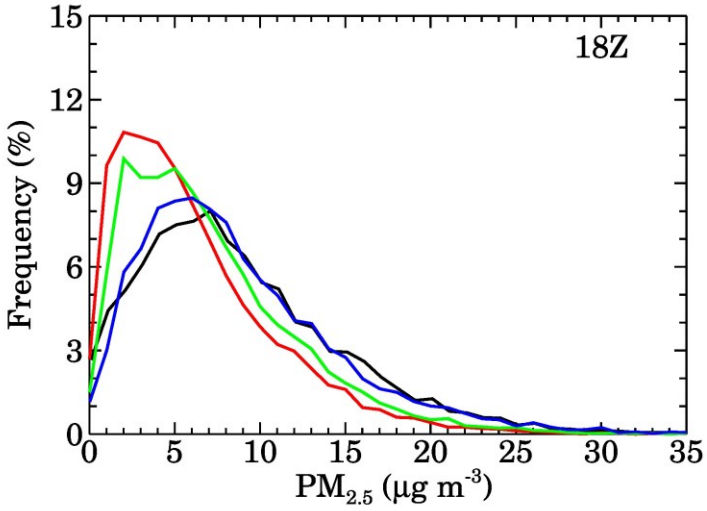


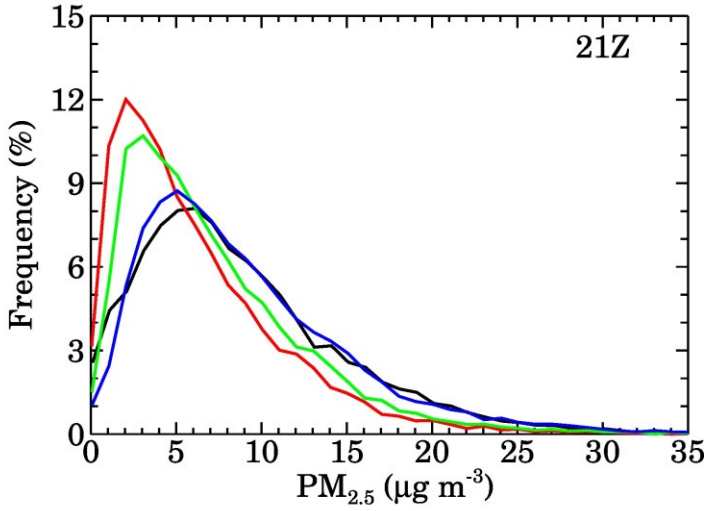
Obs **CMAQ bkg** **CMAQ met_be** **CMAQ met+emis_be**

Effect of AOD Assimilation on $PM_{2.5}$ Initialization



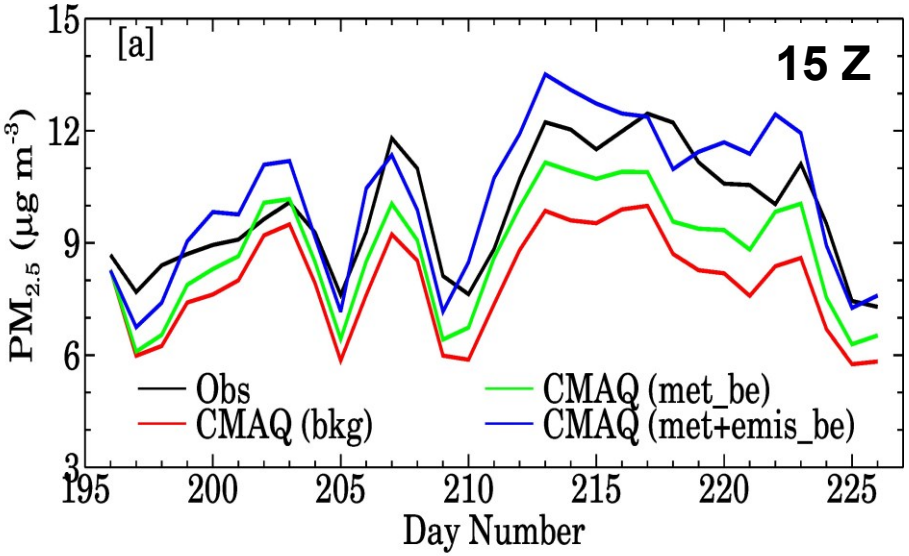


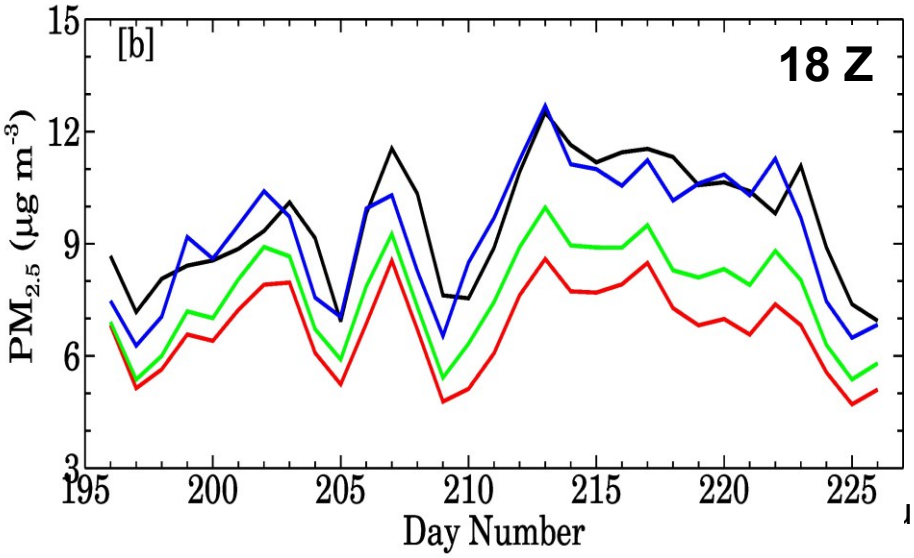




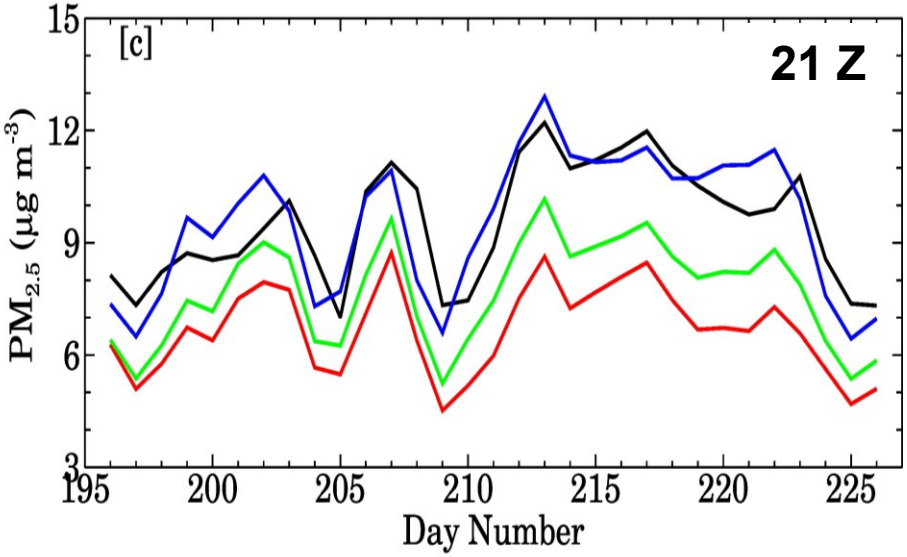
MODIS AOD is assimilated in CMAQ at 15, 18, and 21Z − The assimilation pushes the modeled state towards observed state at all the three times

$PM_{2.5}$ Time Series at Assimilation Time





15 July to 14 August 2014
Averaged over all AIRNow stations

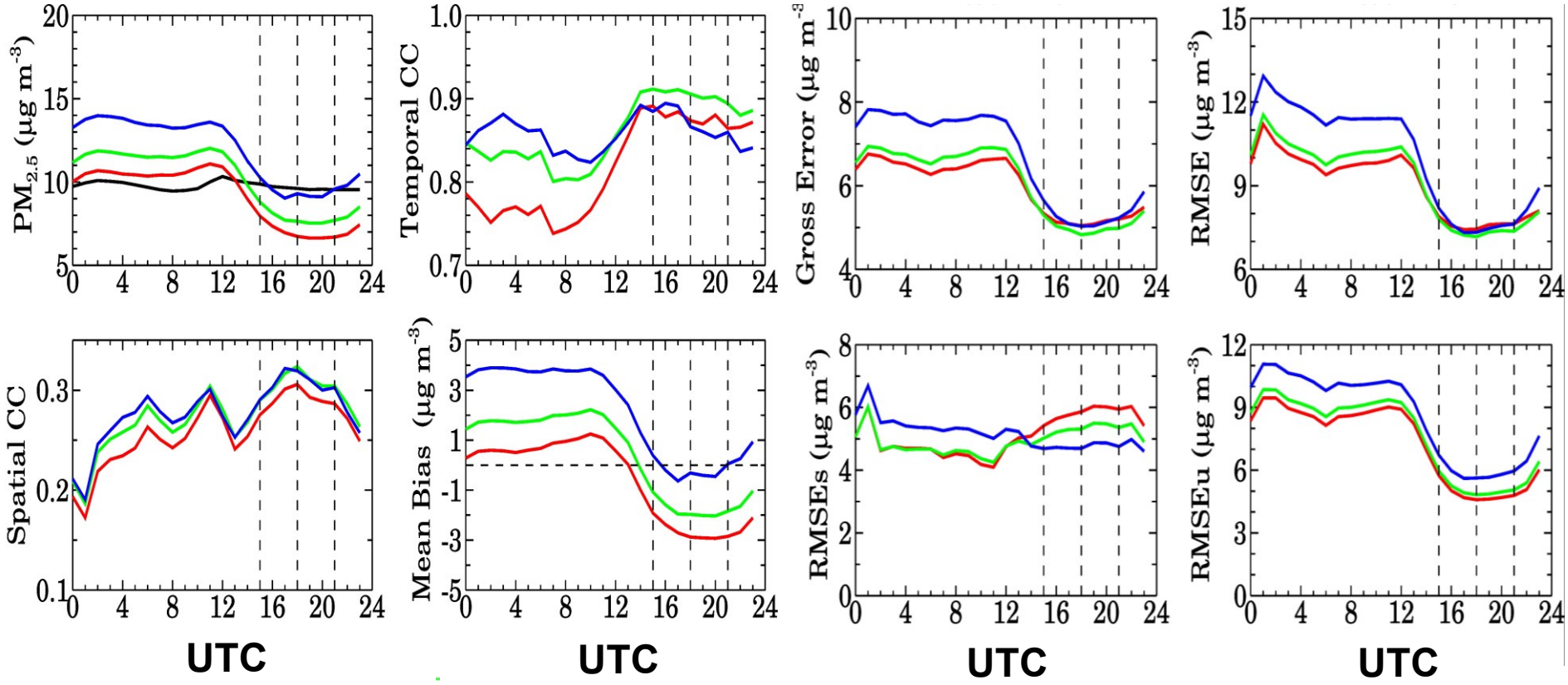


Obs **CMAQ met_be**
CMAQ bkg **CMAQ met+emis_be**

urity Applications Program

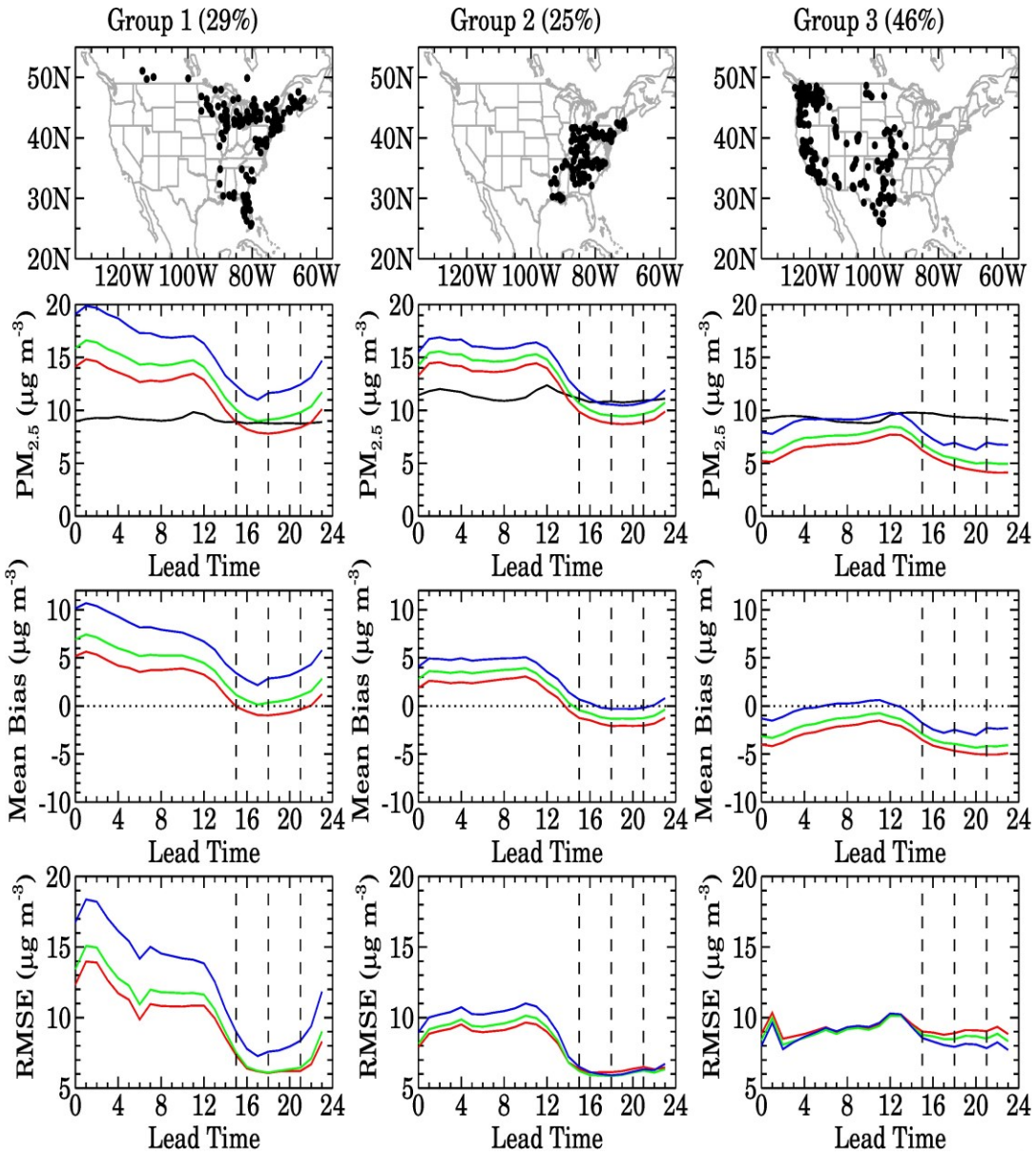
Effect on Predictions

15 July to 14 August 2014
Averaged over all AIRNow stations



Obs **CMAQ bkg** **CMAQ met_be** **CMAQ met+emis_be**

Spatial differences in $PM_{2.5}$ Response to DA



Obs **CMAQ met_be**
CMAQ bkg **CMAQ met+emis_be**

- Nighttime overestimation in Group 1 and Group 2 even in the "bkg" run without assimilation
- Discrepancies in CMAQ relative to MODIS AOD are likely not representative of the discrepancies in CMAQ surface $PM_{2.5}$ at 29% of the AIRNow sites (Group 1)
- DA improves the initialization at 25% sites (Group 2) in the eastern US but then the model has a tendency to overestimate nighttime $PM_{2.5}$ levels
- The current DA system works very well to the western U.S. (Group 3)

Summary

We are improving NOAA/NCEP operational AQ predictions, by:

- Chemical data assimilation
  - ✧ Improvements in AOD and $PM_{2.5}$ estimates
  - ✧ However, forecast at times is degraded (e.g., eastern U.S.)
- Analog-based methods
- Ongoing socio-economic impact study to assess the value of improvements on end-user decision making process