Simultaneous Three-dimensional Variational Assimilation of Surface Fine Particulate Matter and MODIS Aerosol Optical Depth

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Introduction

- Improve WRF-Chem aerosol forecasts by assimilating aerosol-related observations

- Assimilated 550 nm *aerosol optical depth (AOD)* from MODIS sensors onboard Aqua and Terra satellites

- Assimilated *surface $PM_{2.5}$ observations* from the AIRNow network

- Assimilated these observations both individually and concurrently

GOCART aerosol module

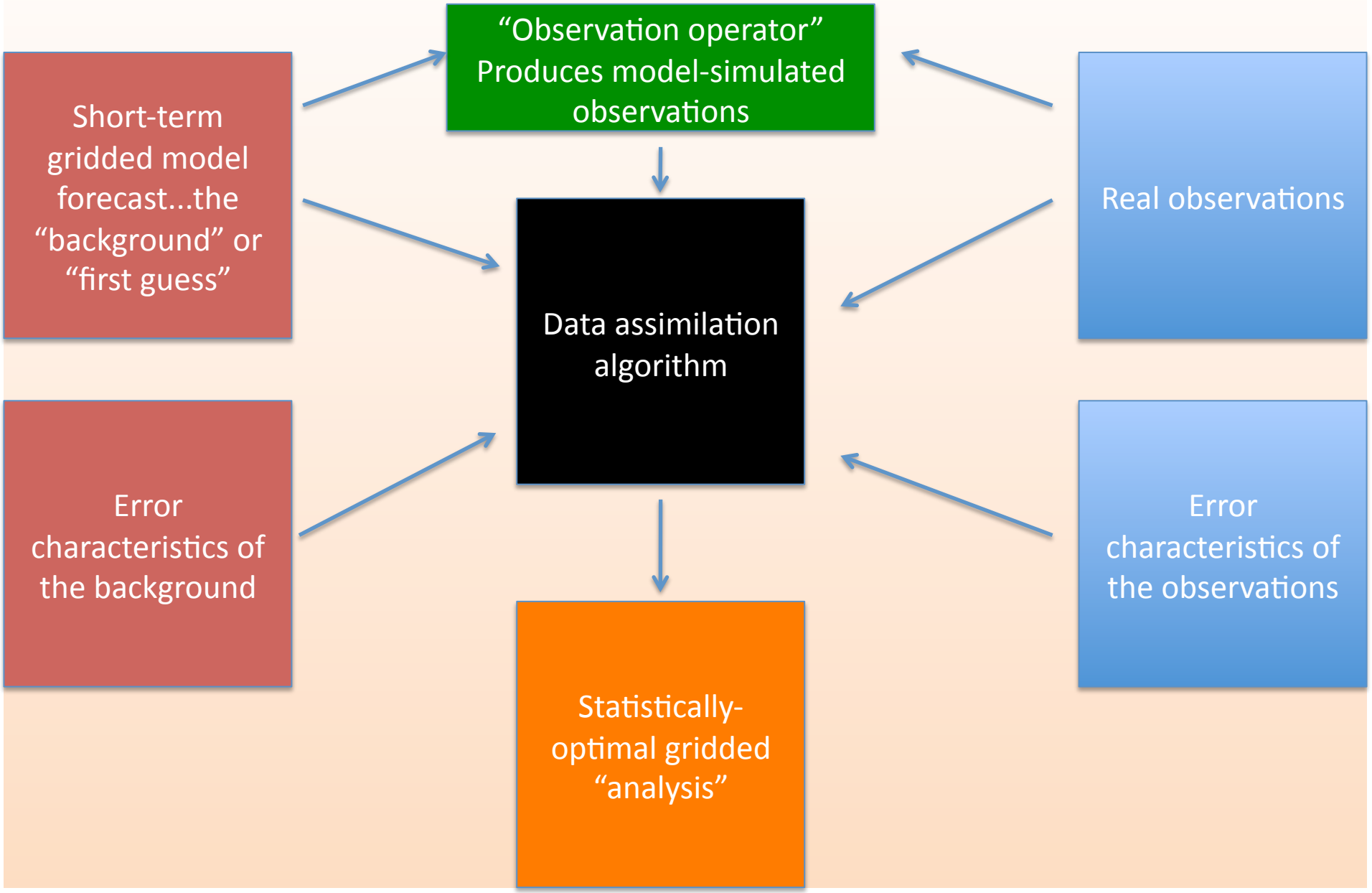
•The GOCART aerosol module is available within the WRF-Chem model and produces forecasts for 14 aerosol species:

- •Hydrophobic and hydrophilic organic carbon
- •Hydrophobic and hydrophilic black carbon
- •Sulfate
- •Dust in 5 particle-size bins
- •Sea salt in 4 particle-size bins

•Also produces forecasts of unspeciated contributions to $PM_{2.5}$ when run within WRF-Chem

•<u>The 3D GOCART fields can be used in data assimilation</u>

What is data assimilation?



Assimilation concept

- Direct AOD and surface $PM_{2.5}$ data assimilation with one-step procedure using NCEP's Gridpoint Statistical Interpolation (GSI) 3DVAR system

- Use the GOCART variables to derive model-simulated AOD and $PM_{2.5}$ observations (at the observation locations)

  - The community radiative transfer model (CRTM) was used to produce model-simulated observations of AOD

Experimental design

- Four experiments
  1) No data assimilation (continuous WRF-Chem forecast)
  2) Assimilated surface $PM_{2.5}$ observations
  3) Assimilated 550 nm MODIS AOD observations
  4) Assimilated both 550 nm MODIS AOD and surface $PM_{2.5}$ observations

- Cyclic data assimilation with 6-hr cycles beginning 0000 UTC 01 June, ending 1800 UTC 14 July 2010 (~45 days)
  - All 1800 UTC analyses initialized 48-hr WRF-Chem forecasts

- Meteorological initial and boundary conditions updated each cycle for all experiments from the 20-km NAM

- $PM_{2.5}$ observations assimilated each cycle, but 550 nm AOD observations primarily available at 1800 UTC

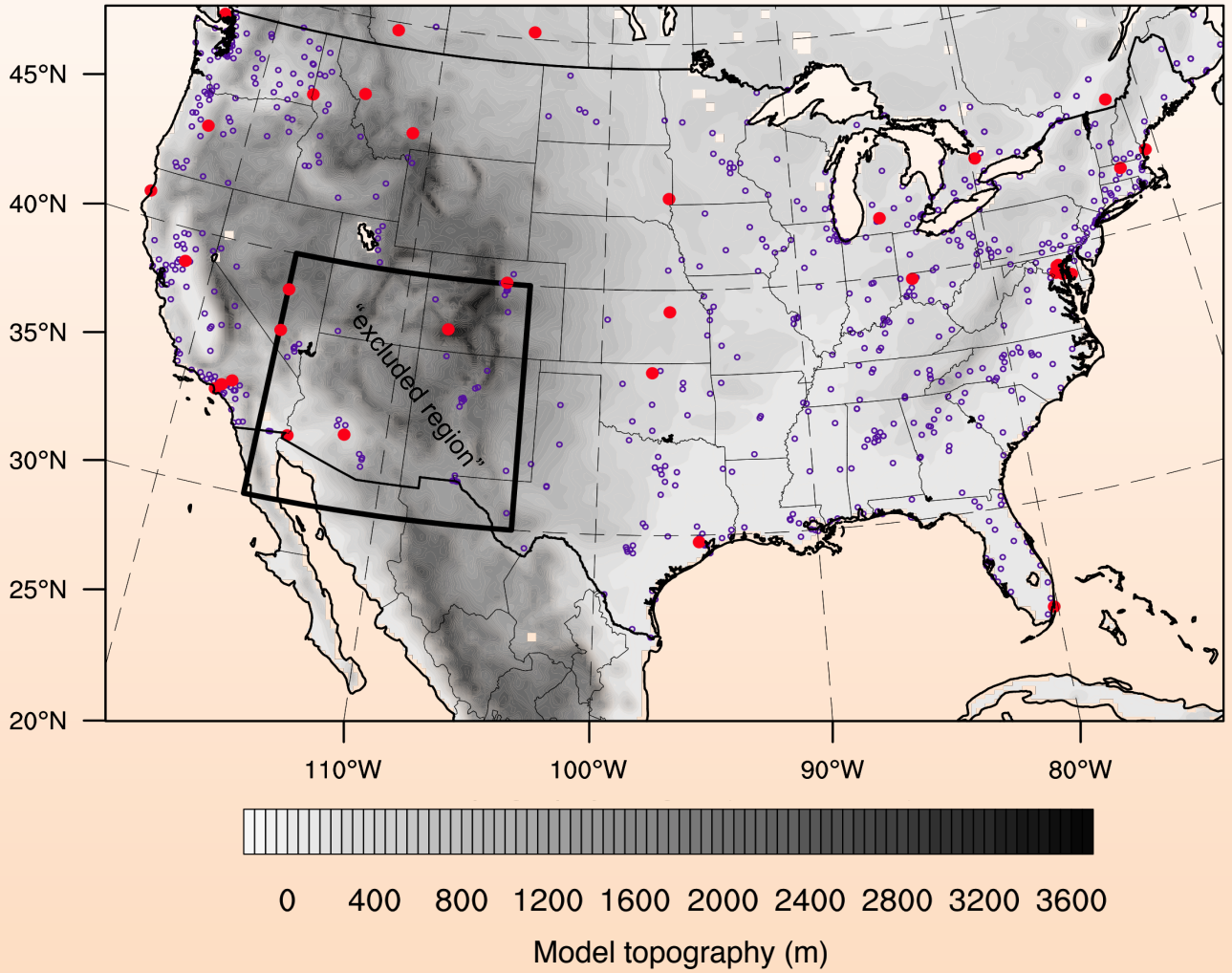
Model configurations

- Version 3.3 of WRF-Chem
- 20-km horizontal grid spacing, 41 vertical levels, 50 hPa top
- Simple GOCART chemistry (chem_opt = 300)
- U.S. EPA NEI-2005 anthropogenic emissions
- Full set of meteorological parameterizations:
  - YSU PBL
  - WSM5 microphysics
  - RRTM longwave radiation
  - Goddard shortwave radiation
  - Noah land surface model
  - Grell-3D cumulus parameterization

"Worf" from Star Trek

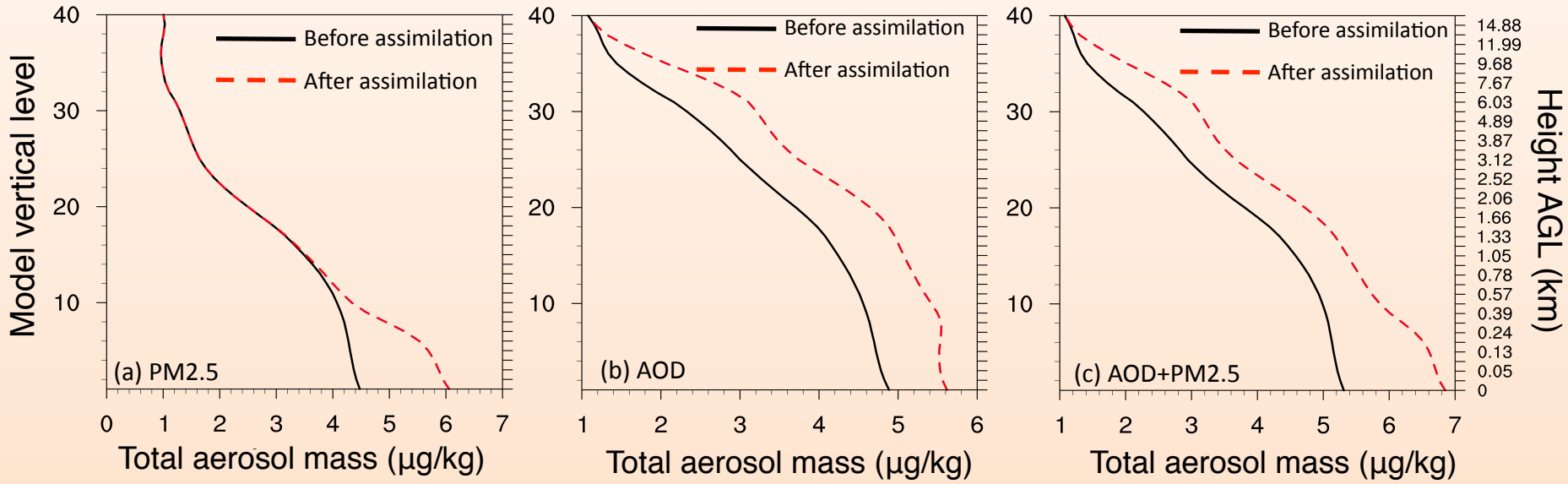
Computational domain

- Purple dots: AIRNow sites with $PM_{2.5}$ measurements
- Red dots: AERONET sites with AOD measurements



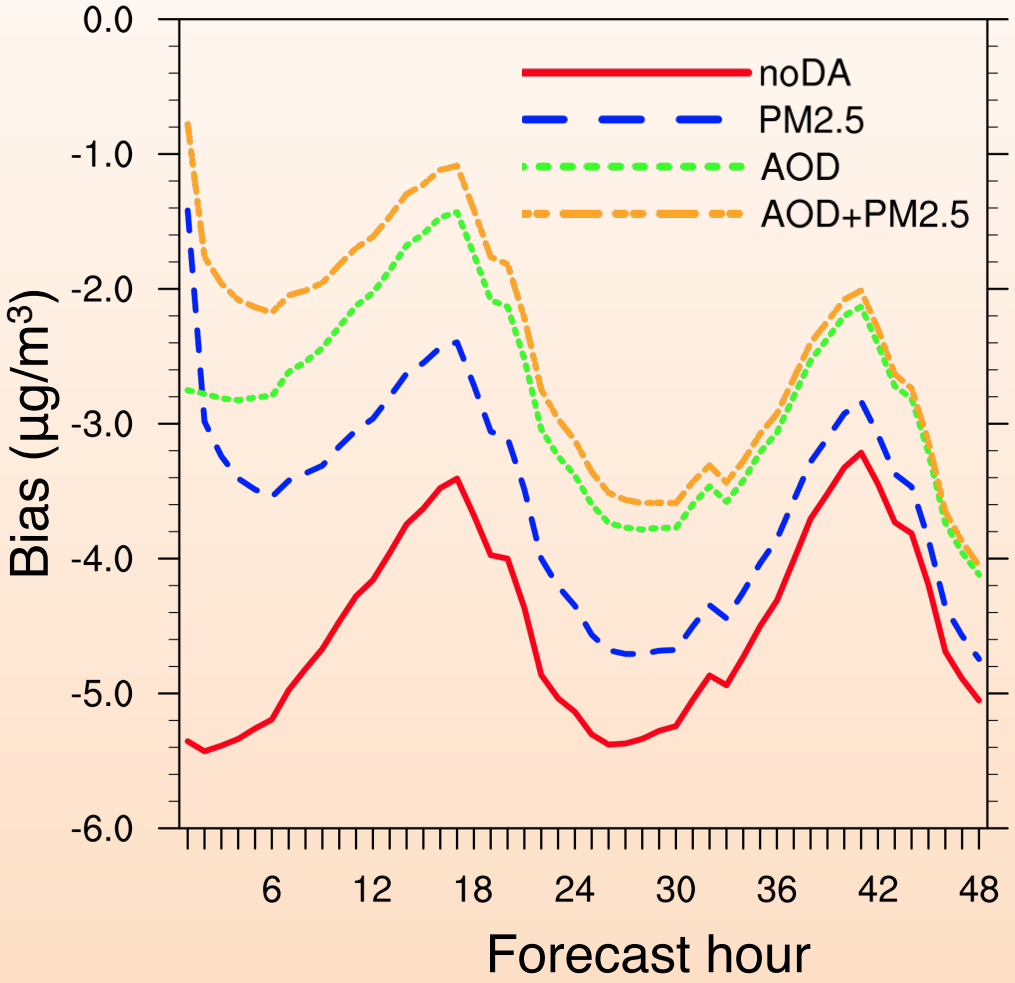
Mean $PM_{2.5}$ concentrations

- Domain average $PM_{2.5}$ concentrations, averaged over all 1800 UTC analyses



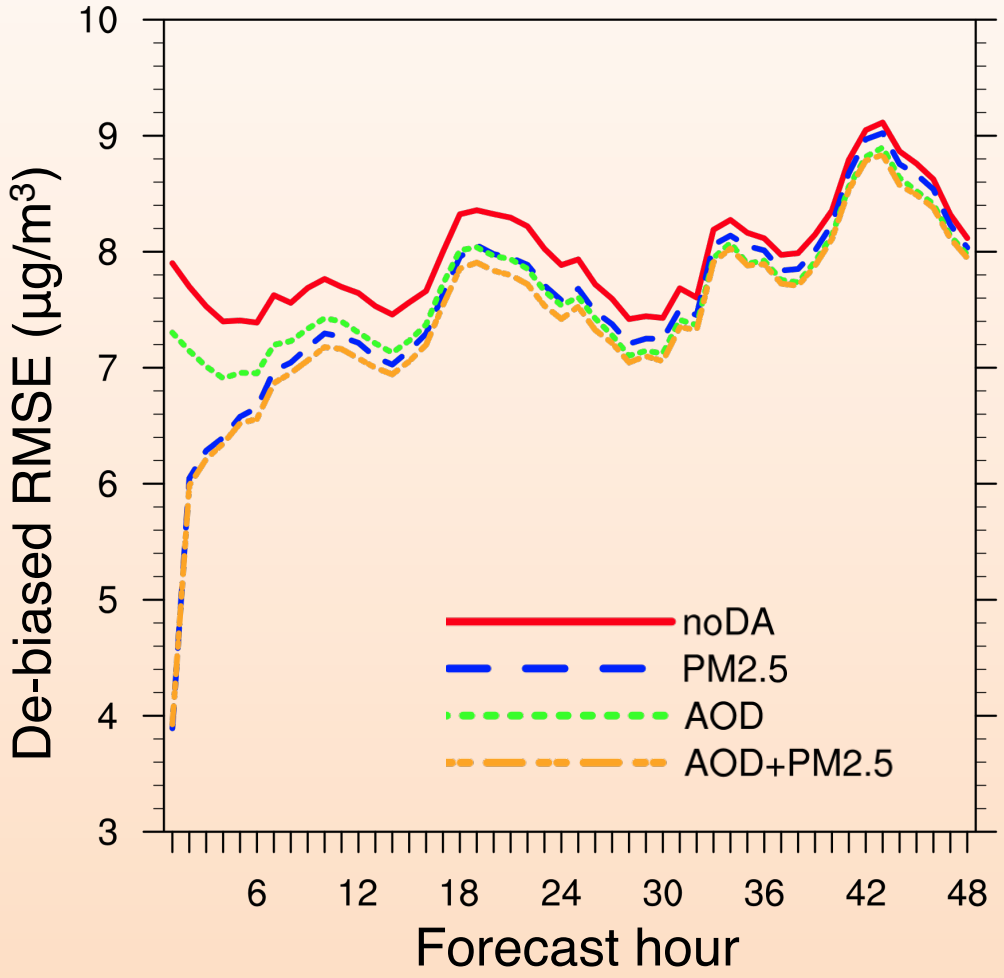
Aggregate bias for $PM_{2.5}$

- Domain averaged and aggregated over all 1800 UTC forecasts



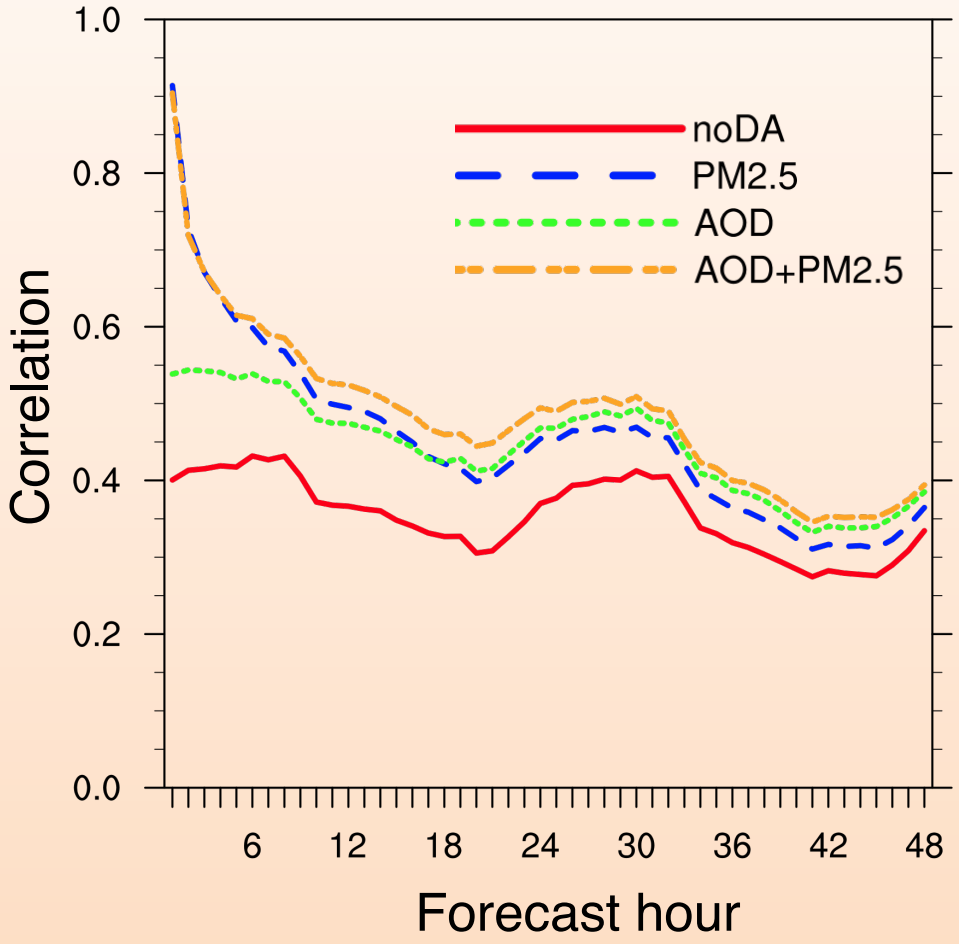
Aggregate de-biased RMSE for $PM_{2.5}$

- Domain averaged and aggregated over all 1800 UTC forecasts



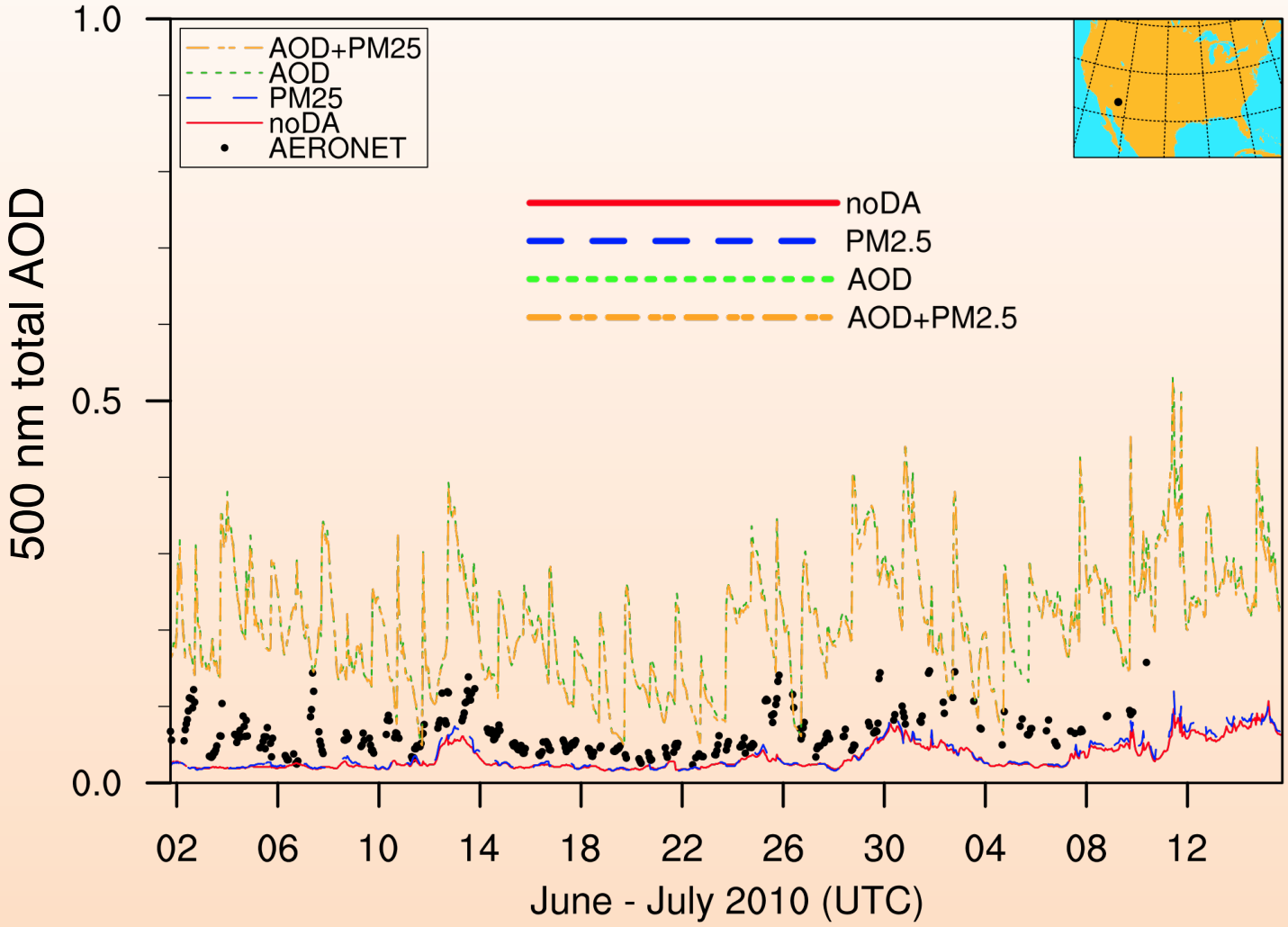
Aggregate correlation for $PM_{2.5}$

- Domain averaged and aggregated over all 1800 UTC forecasts



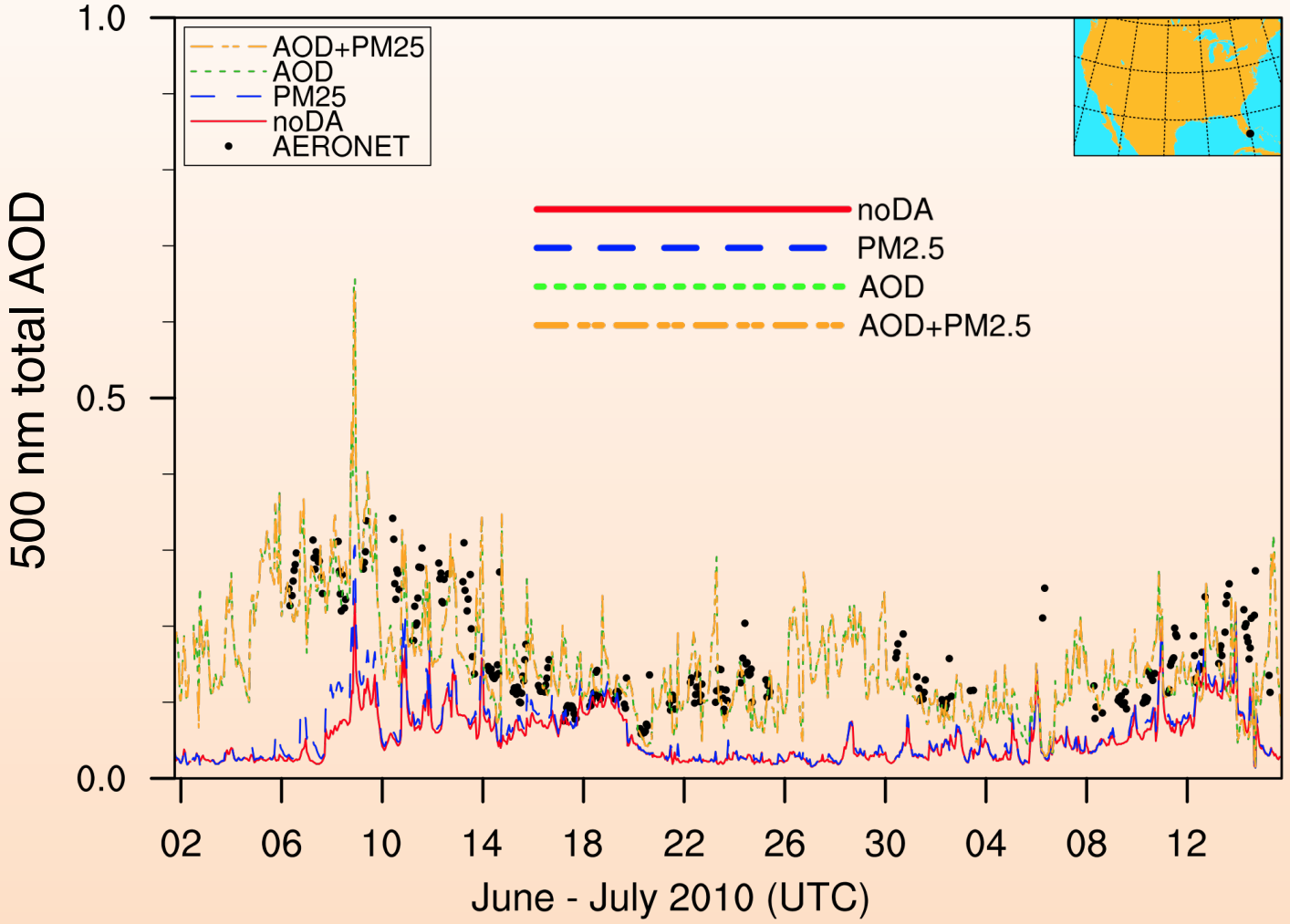
AOD—Maricopa AERONET site

- Model curves are 0-23 hr forecasts initialized at 1800 UTC



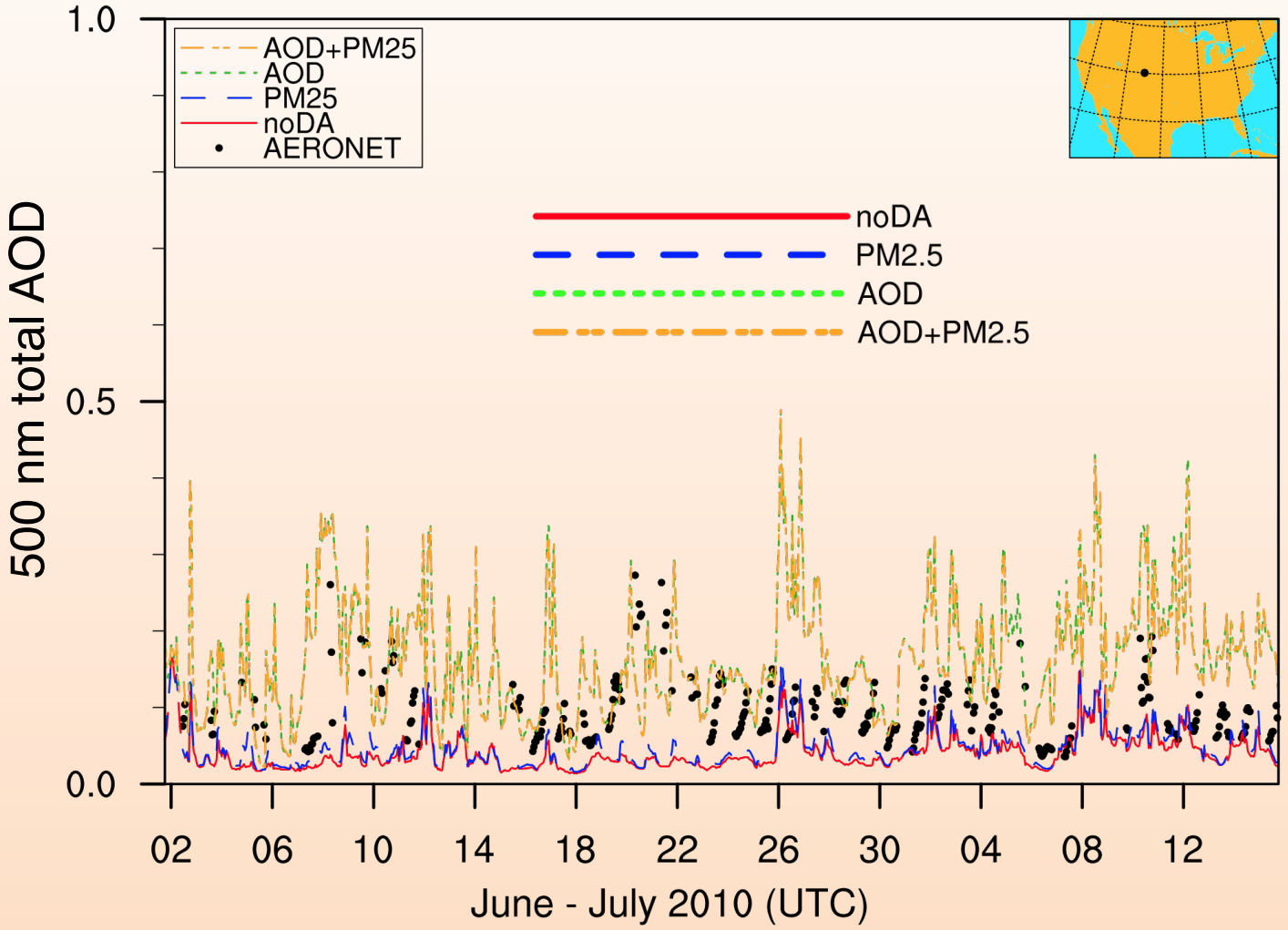
AOD—Key Biscayne AERONET site

- Model curves are 0-23 hr forecasts initialized at 1800 UTC



AOD—Boulder AERONET site

- Model curves are 0-23 hr forecasts initialized at 1800 UTC



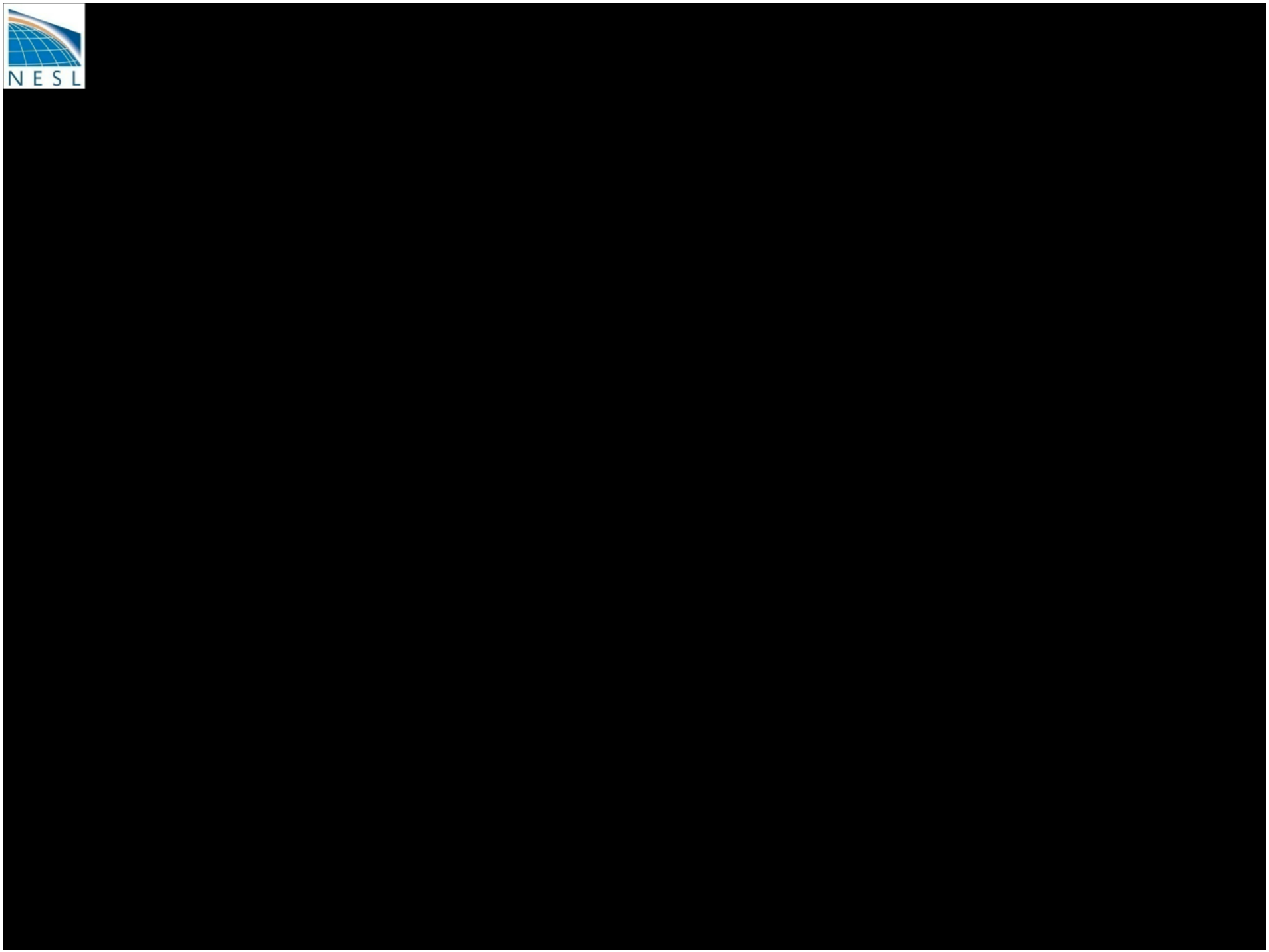
Conclusions

- Both individual and simultaneous assimilation of AOD and $PM_{2.5}$ observations improved surface $PM_{2.5}$ forecasts

- Assimilating AOD improved AOD forecasts

- Considering the overall aerosol forecasts, concurrent assimilation of both AOD and $PM_{2.5}$ unequivocally produced the best results

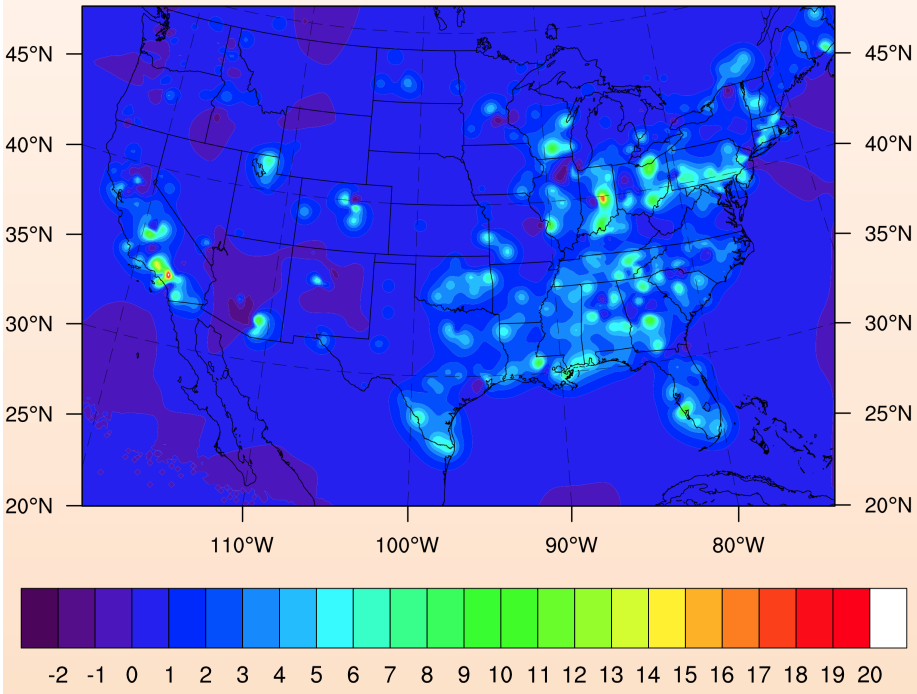
- See Schwartz et al. (2012) in JGR for more information



Mean $PM_{2.5}$ analysis increments

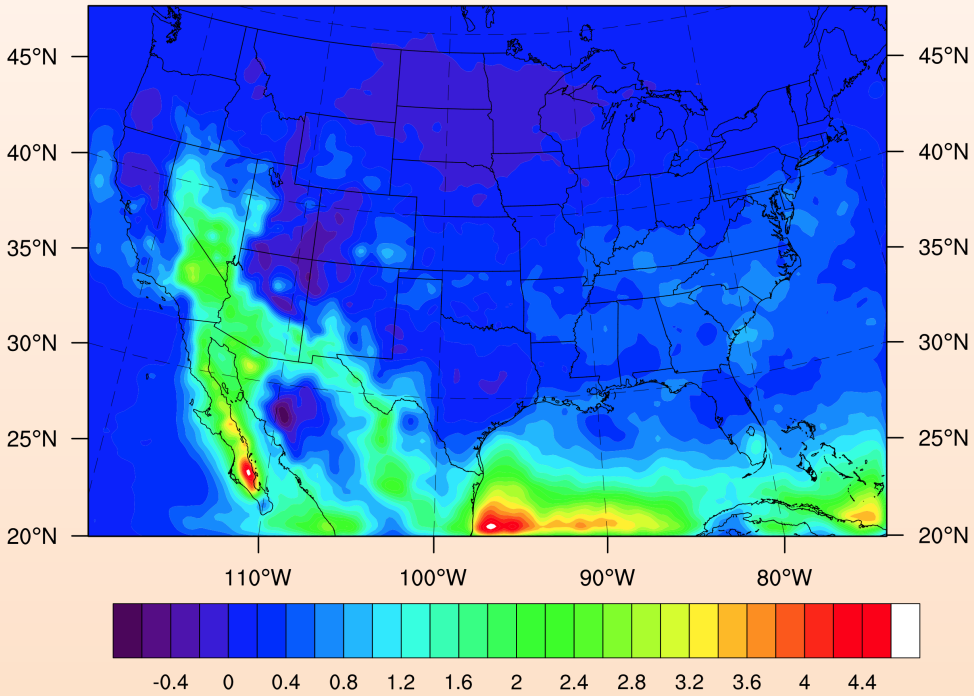
- $PM_{2.5}$ analysis increments averaged over all 1800 UTC analyses
- Lowest model level

$PM_{2.5}$ assimilation



Mean $PM_{2.5}$ increment ($\mu g/m^3$)

AOD assimilation



Mean $PM_{2.5}$ increment ($\mu g/m^3$)

Mean AOD Bias

- 0-24-hr forecasts averaged over the entire period