Relative Merit of MODIS AOD and Surface PM2.5 for Aerosol Analysis and Forecast

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GOCART and WRF/Chem

- The GOCART aerosol module is available within the WRF/Chem model and produces forecasts for 14 aerosol species:
  - Hydrophobic and hydrophilic organic carbon (OC1, OC2)
  - Hydrophobic and hydrophilic black carbon (BC1, BC2)
  - Sulfate
  - Dust in 5 particle-size bins [dust{1,2,3,4,5]
  - Sea salt in 4 particle-size bins [seas{1,2,3,4}]

- WRF-Chem "P25" aerosol variable also an analysis variable
  - P25 is unspeciated aerosols contributing to $PM_{2.5}$

15 aerosol variables (mass concentration) to be analyzed

3DVAR aerosol data assimilation

(Liu et al., 2011, JGR)

- 3DVAR is to minimize a cost function (in a least square sense)

$$J(x)=\frac{1}{2}(x-x_b)^{\mathrm{T}}\mathrm{B}^{-1}(x-x_b)+\frac{1}{2}[H(x)-y]^{\mathrm{T}}\mathrm{R}^{-1}[H(x)-y]$$

which measures the weighted distance of the model state x to the model "background" x_b and the observations y.

In our case for aerosol data assimilation:

X are 15 aerosol species mass concentration in 3D space.

X_b the "background" of X, short-term forecast from WRF/Chem.

Y can be any aerosol-related observations (in our case, MODIS AOD and surface PM2.5).

H is "observation operator", which transforms the model state to observation space.

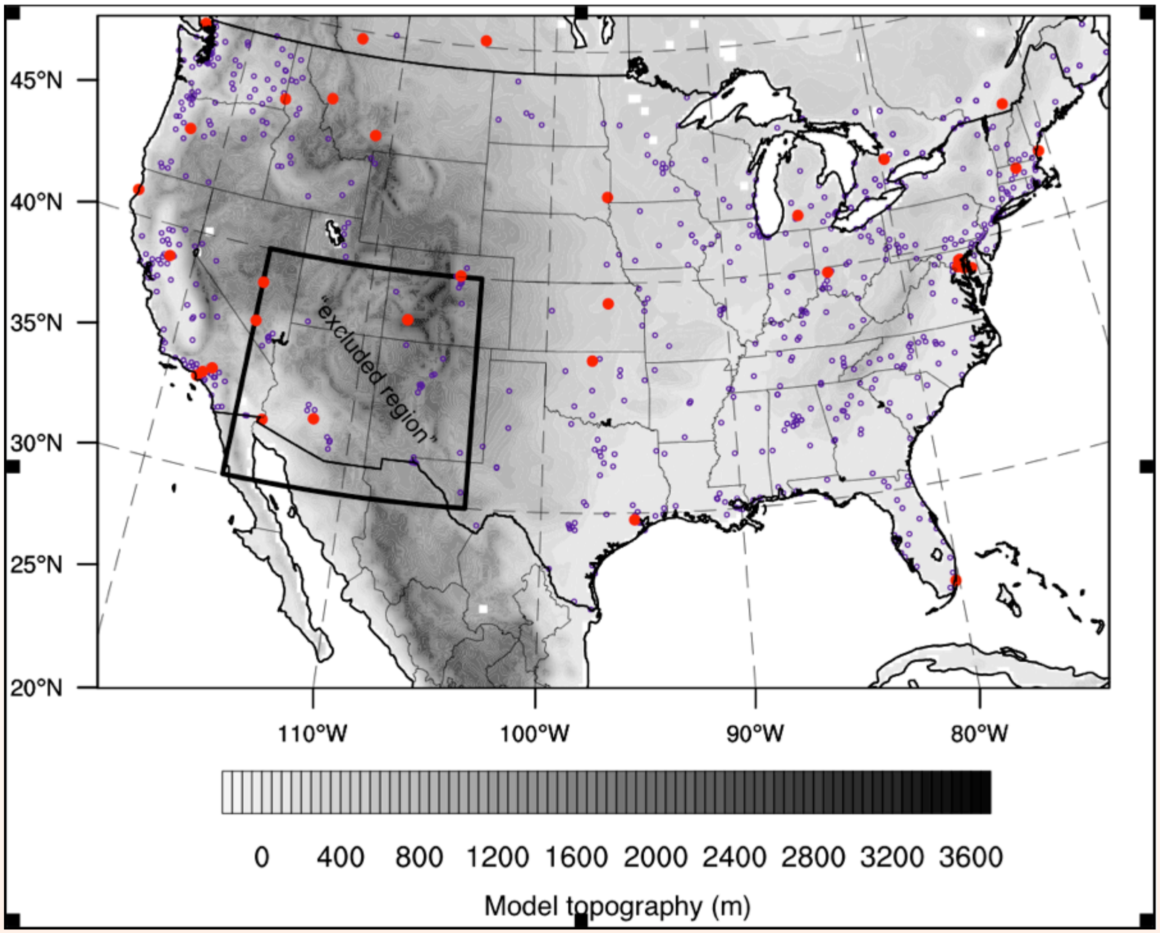
The background error covariance B (having spatial correlation) and observation error covariance R (no spatial correlation).

Observation Operators

- MODIS AOD:
  - Use Community Radiative Transfer Model (CRTM) of Joint Center for Satellite Data Assimilation (JCSDA) as the observation operator, including both forward and Jacobian models to calculate the gradient of cost function.

- Linear formula for model-simulated $PM_{2.5}$ (from WRF-Chem)
  - $PM_{2.5} = \rho[p25 + bc1 + bc2 + 1.8(oc1 + oc2) + dust1 + 0.286*dust2 + seas1 + 0.942*seas2 + 1.375*sulf]$

North America domain



246x164 @20 km
41L with top @50 hPa

Observation coverage:

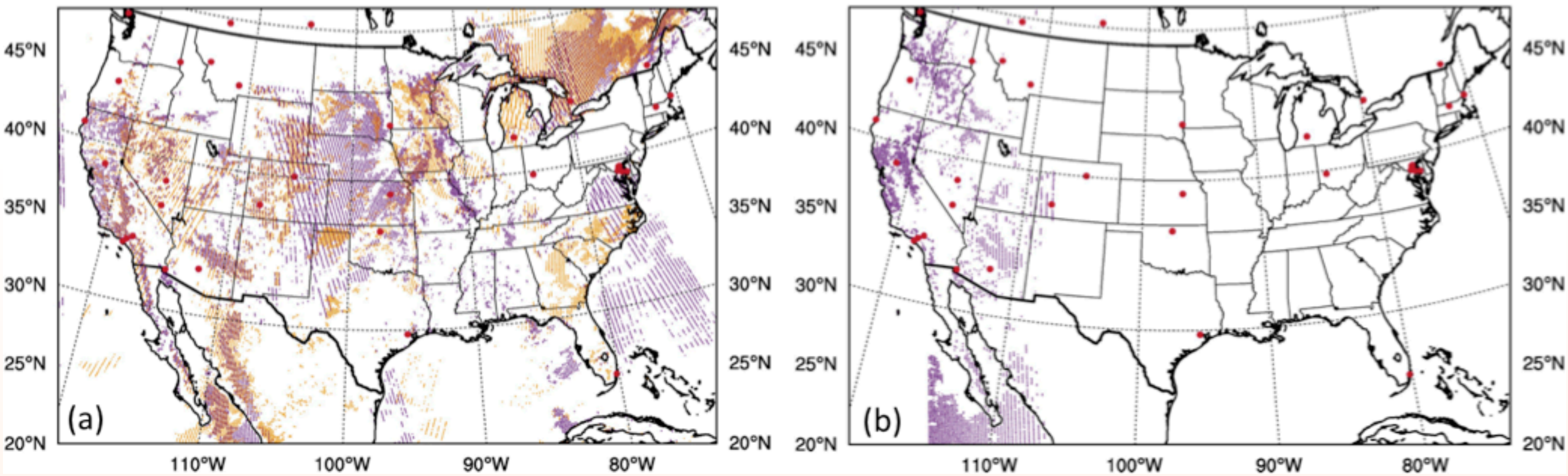
AERONET sites (not assimilated)
AIRNow PM2.5 sites (assimilated)

chem_opt=300:
GOCART w/o chemistry

Area within the box excluded for PM2.5 verification score calculation: desert area, bad MODIS AOD data

MODIS AOD coverage (only day time)

15Z – 21Z, 17 June 2010 | 21Z 22 ~ 03Z 23, June 2010



NASA Level 2 10km x 10km ocean & land total AOD @ 550 nm from Aqua and Terra. Deep blue product not used in this study.

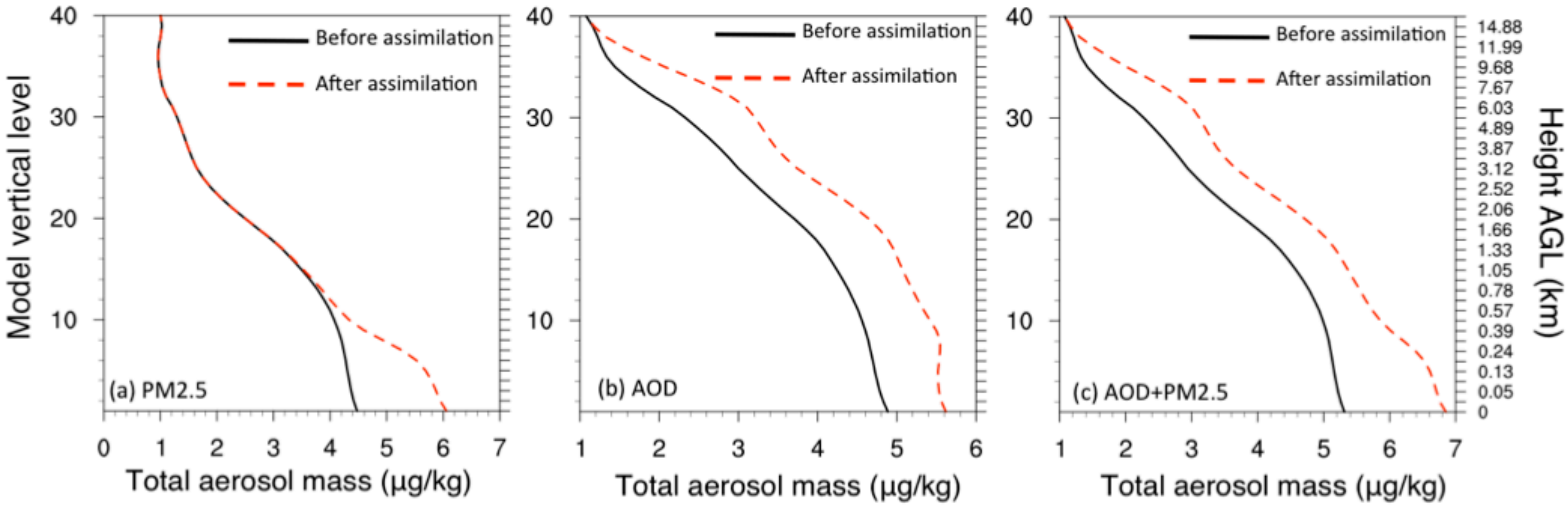
Experimental design

- Four experiments
  1) No data assimilation (continuous WRF-Chem forecast)
  2) $PM_{2.5}$ DA
  3) AOD DA
  4) AOD+$PM_{2.5}$ DA

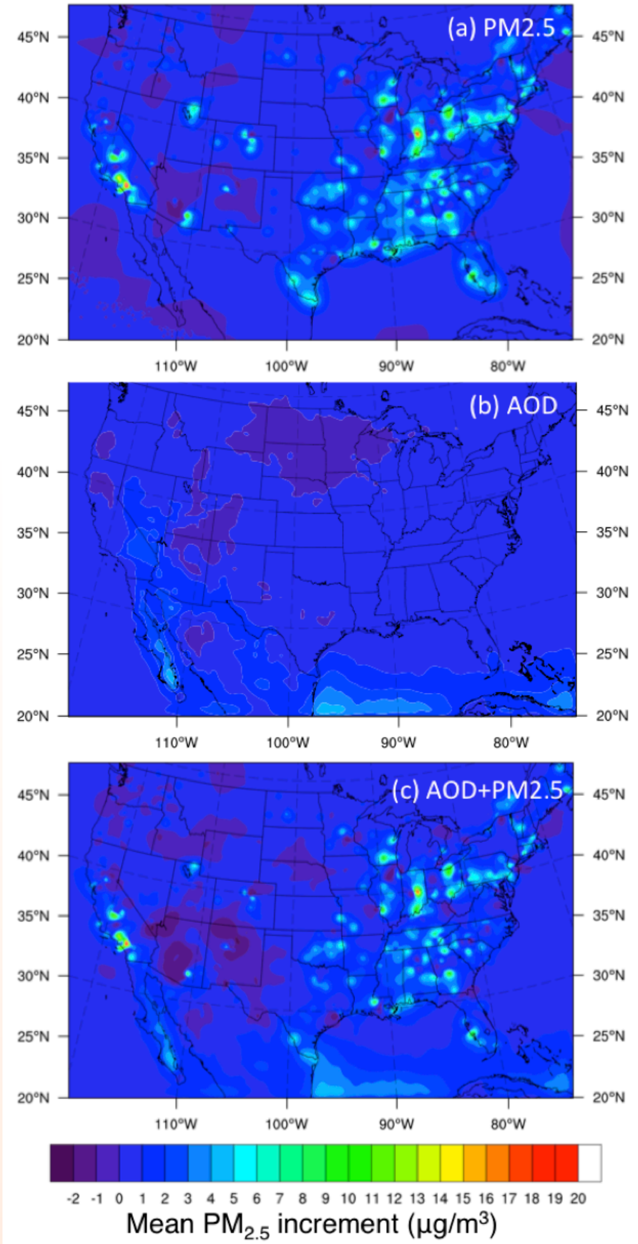
- Cyclic data assimilation with 6-hr cycles beginning 0000 UTC 01 June, ending 1800 UTC 14 July, 2010. (~45 days)
  - $PM_{2.5}$ observations assimilated each cycle, but AOD observations primarily available only at 1800 UTC
  - All 1800 UTC analyses initialized 48-hr forecasts

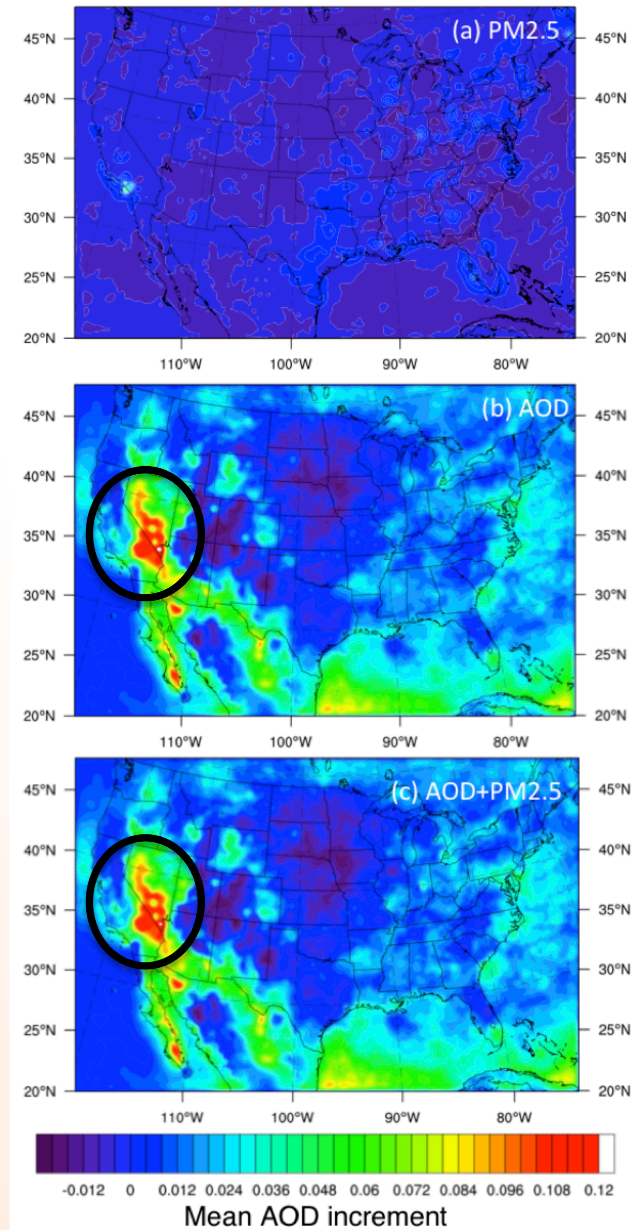
- Meteorological fields updated every 6-hrs from 20-km NAM grids

Domain-averaged total aerosol mass concentration @ 1800 UTC before/after data assimilation



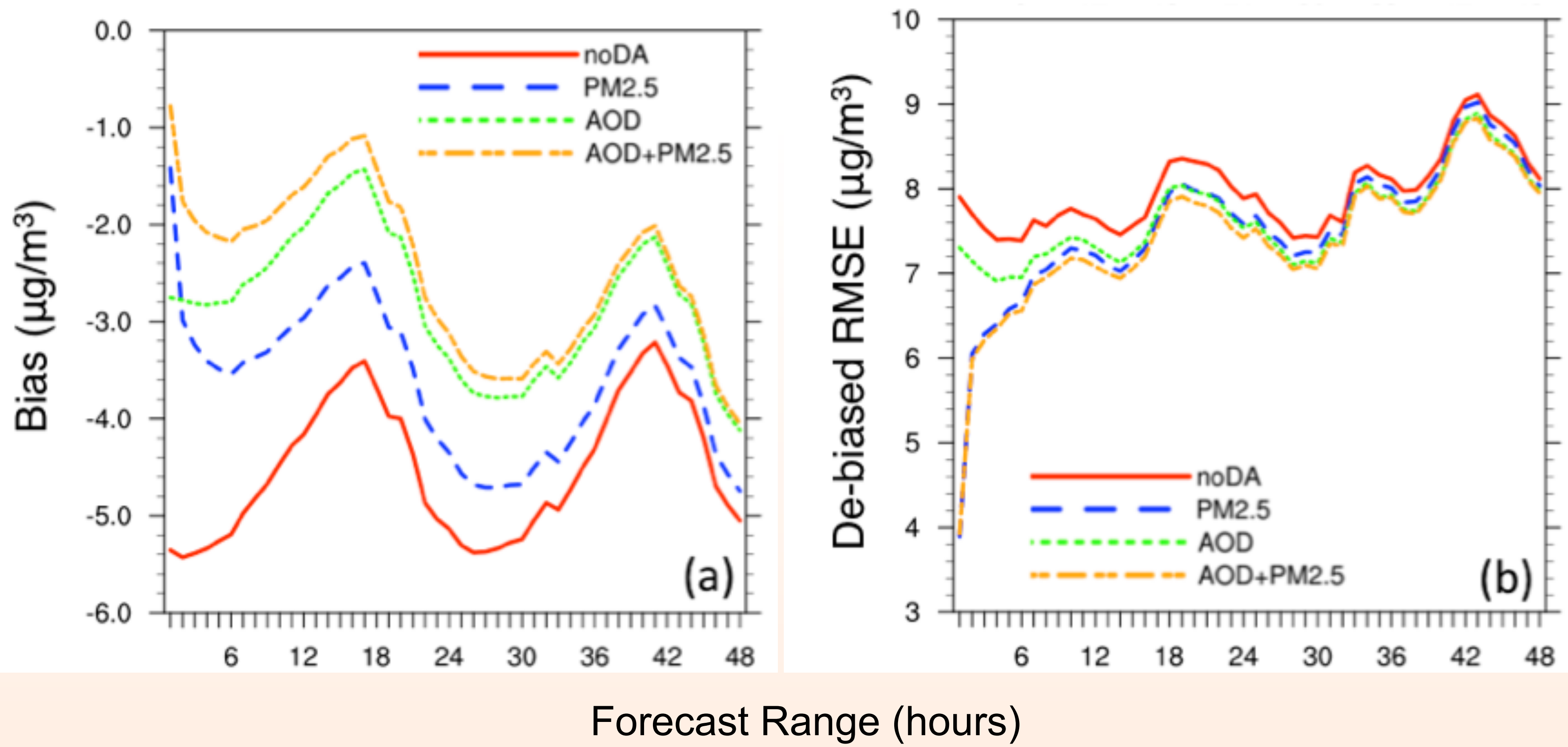
Mean surface $PM_{2.5}$ and AOD analysis increments (1800 UTC)





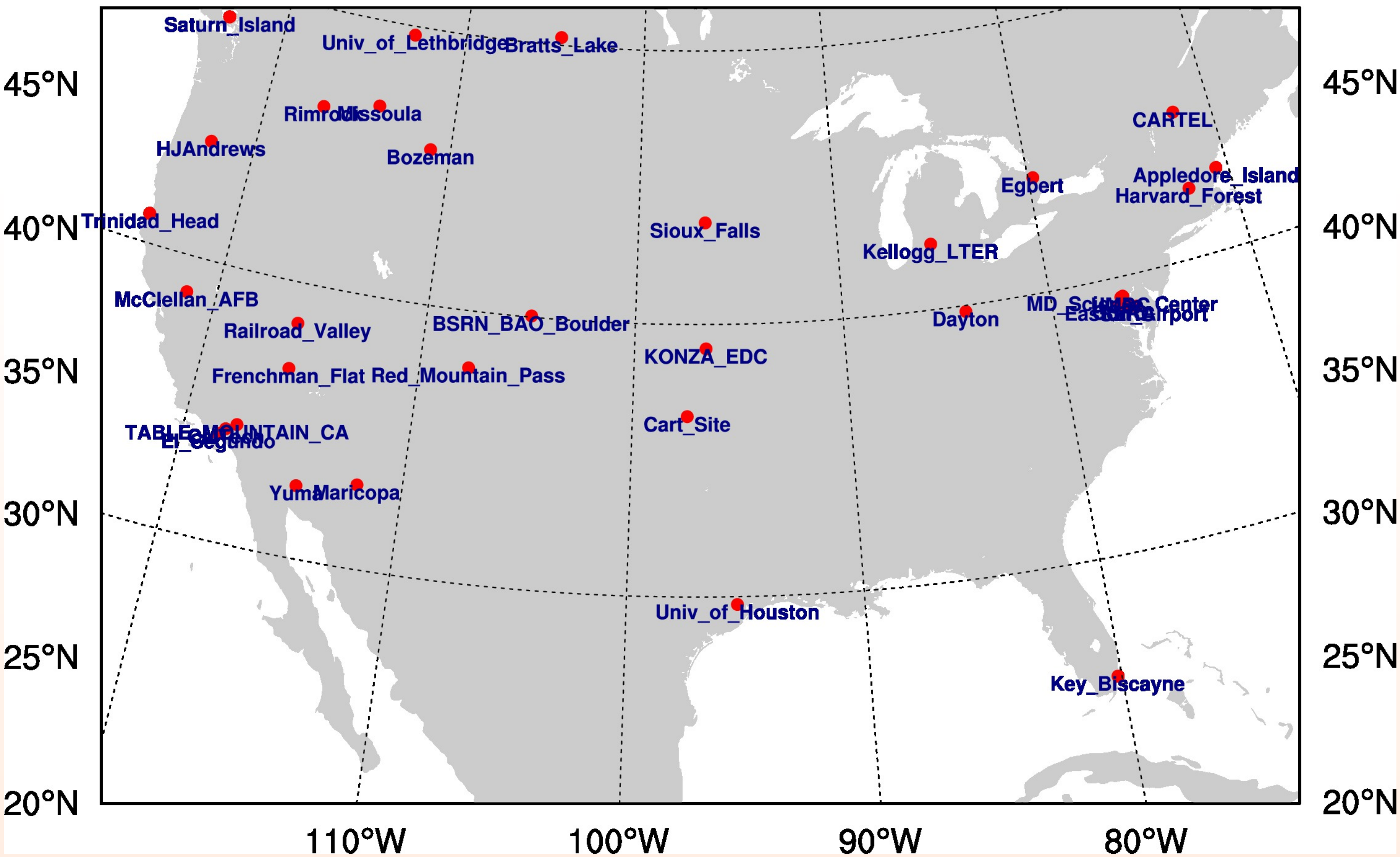
$PM_{2.5}$ forecast verification

- PM2.5 obs impact quickly decreased in the first 1-hour.
- MODIS AOD is more efficient than PM2.5 data to correct low model bias.



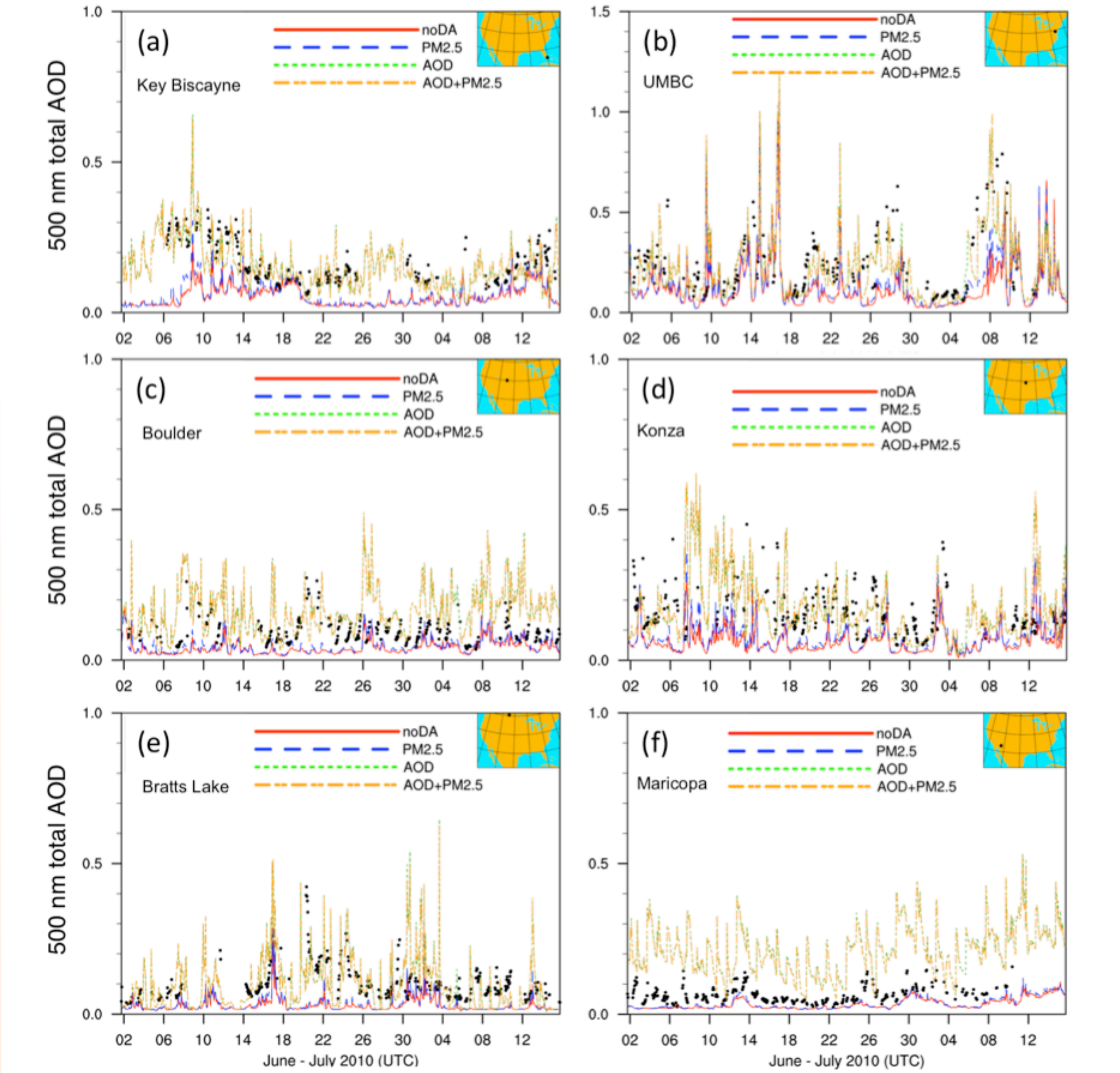
Verification vs. AERONET AOD

- 34 AERONET sites within the domain

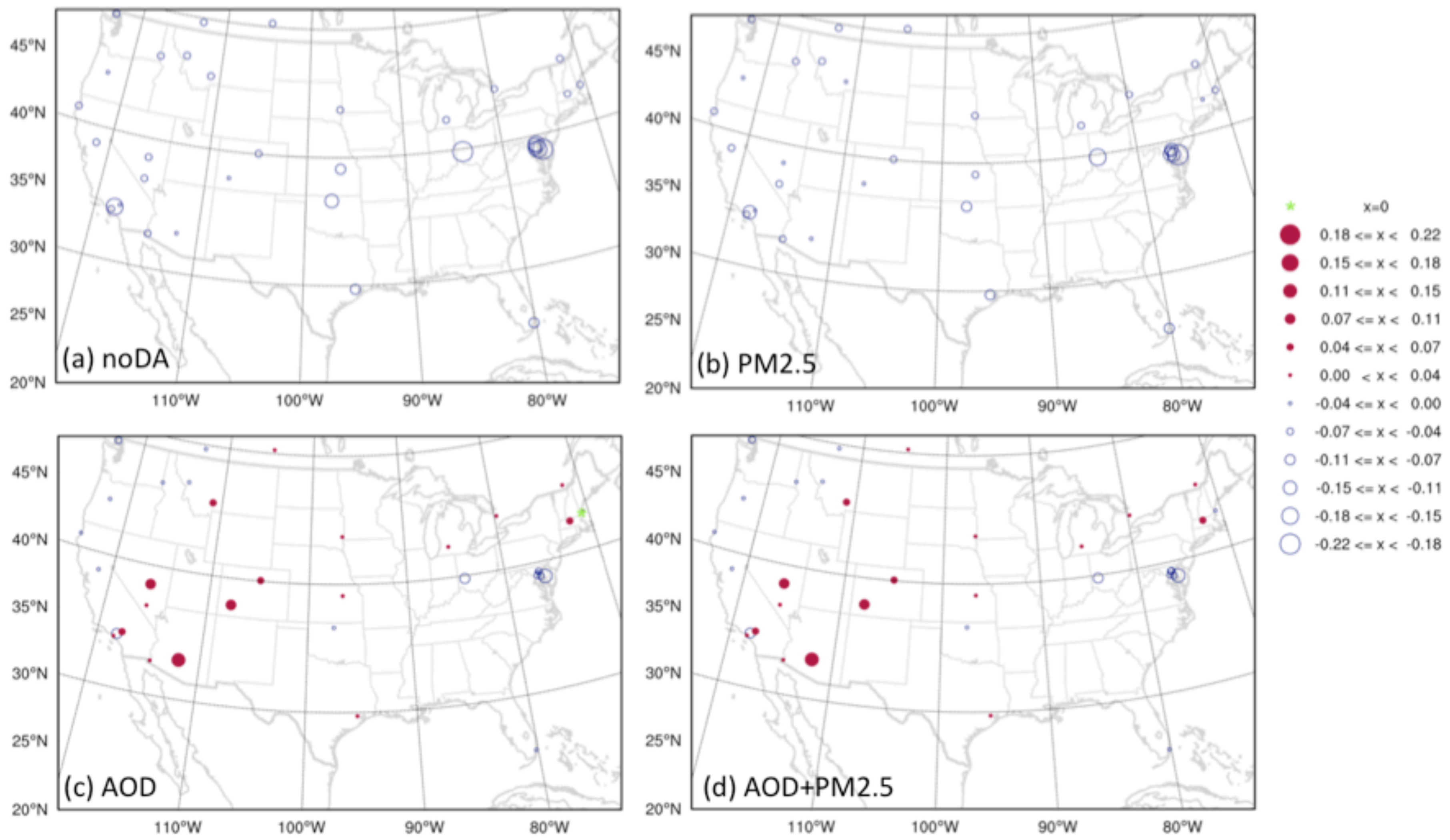


AERONET AOD time-series @ 500 nm

Model curves: 0-23 hr forecasts each 1800 UTC initialization



Mean AOD bias vs. AERONET



Summary

- A 3DVAR aerosol DA framework allows simultaneous assimilation of aerosol-related observations from multiple sources (both space-borne and ground-based).

- Assimilating AOD observations is more efficient than PM2.5 data to reduce model low PM2.5 bias

- Simultaneous assimilation of surface PM2.5 and MODIS AOD produced the best analysis and forecast of PM2.5 and AOD.

References:

Liu, Z., Q. Liu, H.-C. Lin, C. S. Schwartz, Y.-H. Lee, and T. Wang, 2011: Three-dimensional variational assimilation of MODIS aerosol optical depth: Implementation and application to a dust storm over East Asia. *J. Geophys. Res.,* 116 , D23206, doi:10.1029/2011JD016159.

Schwartz, C. S., Z. Liu, H.-C. Lin, and S. McKeen, 2012: Simultaneous three-dimensional variational assimilation of surface fine particulate matter and MODIS aerosol optical depth. *J. Geophys. Res., Submitted.*