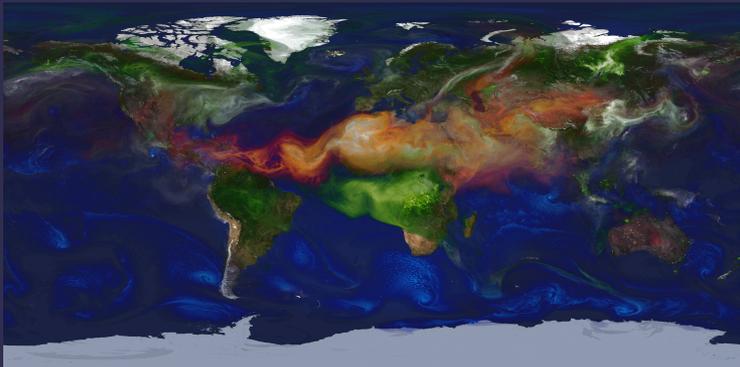




Evaluation of MERRAero (MERRA Aerosol Reanalysis)

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Arlindo da Silva, Cynthia Randles, Peter Colarco, Anton Darmenov, Ravi Govindaraju



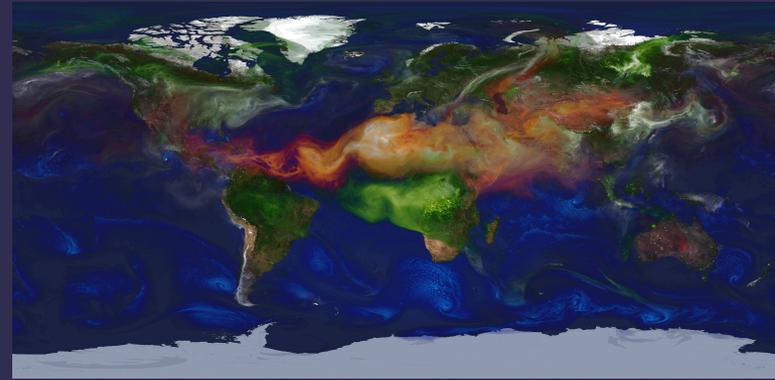
JCSDA workshop, 14 May 2015

Introduction

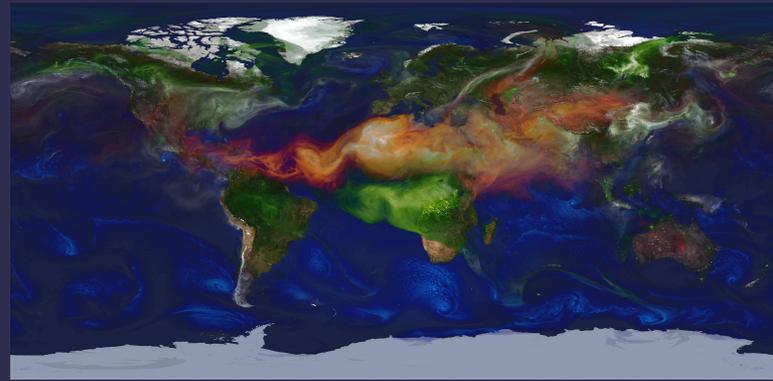
- **MERRA Aerosol Reanalysis (MERRAero)**

is the first aerosol reanalysis produced at GMAO :

- based on a version of the GEOS-5 model radiatively coupled to GOCART aerosols,
- assimilation of bias corrected Aerosol Optical Depth (AOD) from the MODIS sensor on both Terra and Aqua satellites.



Introduction



- **MERRA Aerosol Reanalysis (MERRAero)**

is the first aerosol reanalysis produced at GMAO :

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- assimilation of bias corrected Aerosol Optical Depth (AOD) from the MODIS sensor on both Terra and Aqua satellites.

- **Two different ways of validating MERRAero:**

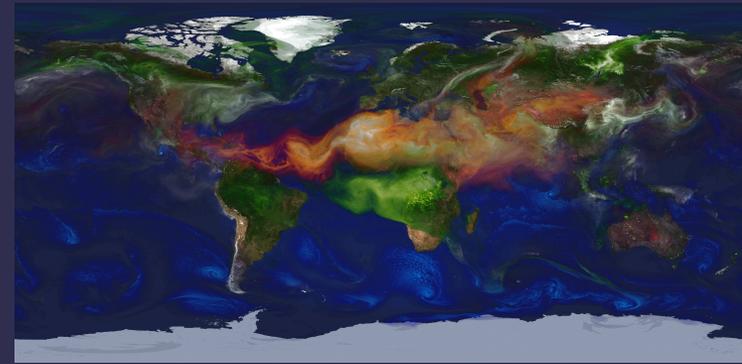
- 1) Absorption:**

- Effect of aerosols on climate system depends :
 - on the total aerosol concentration,
 - on the radiative or optical properties of the particles.

In MERRAero : absorption is not constrained by observations.

- We used OMI/AURA AI measurements and AAOD retrieval as independent validation for MERRAero absorption.

Introduction



2) Surface concentration:

- $PM_{2.5}$ fine particulate matter with diameter less than 2.5 μm :
 - Negative effects on regional air quality and on human health,
 - Ways to monitor:
 - Global monitoring networks -> but offer sparse geographic coverage,
 - Satellite measurements, especially AOD -> large spatial coverage but limited to cloud free conditions, uncertainties on AOD retrievals and how do you relate $PM_{2.5}$ to AOD,
 - Combination of satellites retrievals and model,
 - Data assimilation of AOD in model → **MERRAero**.

➤ We used EPA-AQS and IMPROVE surface $PM_{2.5}$ measurements to assess the quality of simulated surface $PM_{2.5}$ in MERRAero.

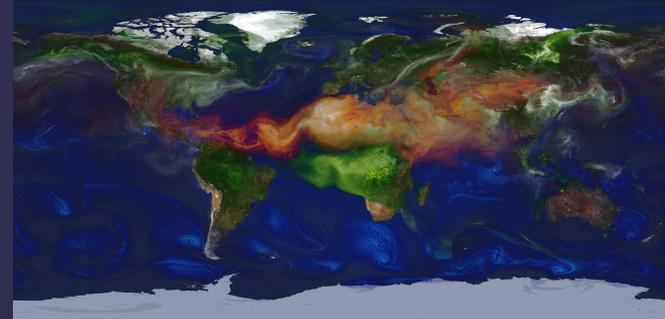
Outline

- MERRAero overview
- Evaluation of MERRAero absorption
- Evaluation of MERRAero surface $PM_{2.5}$
- Conclusions

Summary of GEOS-5 Reanalysis Activities

Name	Nominal Resolution	Period	Aerosol Data	Available
MERRA-1	50 km	1979-present	NONE	now
MERRAero	50 km	2002-present	MODIS C ₅	now
FP for Inst. Teams	50 km	1997-	MODIS C ₅	In progress
NCA	25 km	2010-11	MODIS C ₅ , MISR	Now
MERRA-2 Not discussed here	50 km	1979-present	AVHRR, MODIS C ₅ , MISR, AERONET	Summer 2015
MERRA-2 Dynamical Downscaling	12.5 km	2000-2015	AVHRR, MODIS C ₅ /C ₆ , MISR, AERONET	Q4 2015

MERRAero Overview (1)



Feature	Description
Model	GEOS-5 Earth Modeling System (w/ GOCART) Constrained by MERRA Meteorology (Replay) Land sees observed precipitation (like MERRALand) Driven by QFED daily Biomass Emissions
Aerosol Data Assimilation	Local Displacement Ensembles (LDE) NNR AOD: Neural Net Retrievals <ul style="list-style-type: none">• Based on MODIS “Level 2” reflectances• Trained on AERONET Retrievals Stringent cloud screening
Period	mid 2002-present (Aqua + Terra)
Resolution	Horizontal: nominally 50 km Vertical: 72 layers, top ~85 km
Aerosol Species	Dust, sea-salt, sulfates, organic & black carbon

MERRAero Overview (2)

Analysis Splitting

3D Aerosol Concentration Analysis

$$x^a = x^f + P^f H^T (HP^f H^T + R)^{-1} (y^o - Hx^f) \equiv x^f + \delta x^a$$

where y is AOD, and x is aerosol concentration.

2D AOD Analysis

Since the AOD observable is 2D is common to solve the AOD analysis equation:

$$y^a \equiv Hx^a = y^f + HP^f H^T (HP^f H^T + R)^{-1} (y^o - Hx^f) \equiv y^f + \delta y^a$$

Projecting AOD into Concentration Increments

The 3D concentration increments is related to the 2D AOD increments by:

$$\delta x^a = P^f H^T (HP^f H^T)^{-1} \delta y^a$$

For efficiency, this last equation can be solved in 1D (vertical).

MERRAero Overview (3)

Analysis Splitting with Ensembles

If the background error covariance P^f is parameterized in terms of ensemble perturbations, say

$$\begin{aligned} X &= (x_1 \quad x_2 \quad \cdots \quad x_E) \\ Y &= HX \\ &= (Hx_1 \quad Hx_2 \quad \cdots \quad Hx_E) \\ &= (y_1 \quad y_2 \quad \cdots \quad y_E) \end{aligned}$$

so that

$$P^f \sim XX^T$$

it follows that

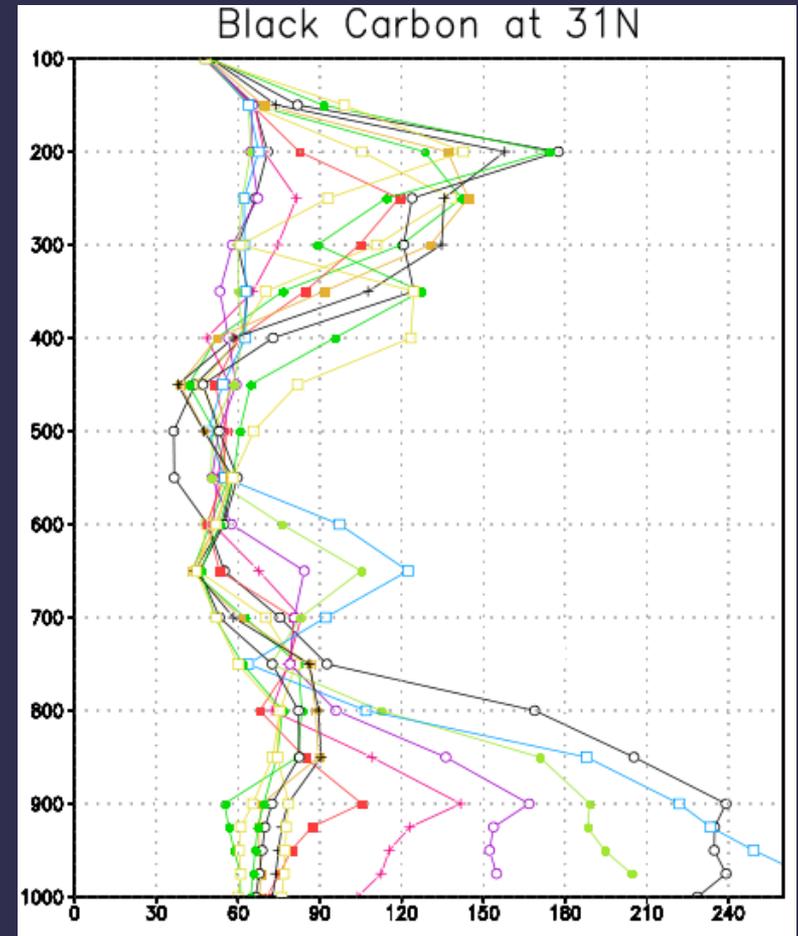
$$\delta x^a = XY^T (YY^T)^{-1} \delta y^a$$

This is the well known (unbiased) linear regression equation.

MERRAero Overview (4)

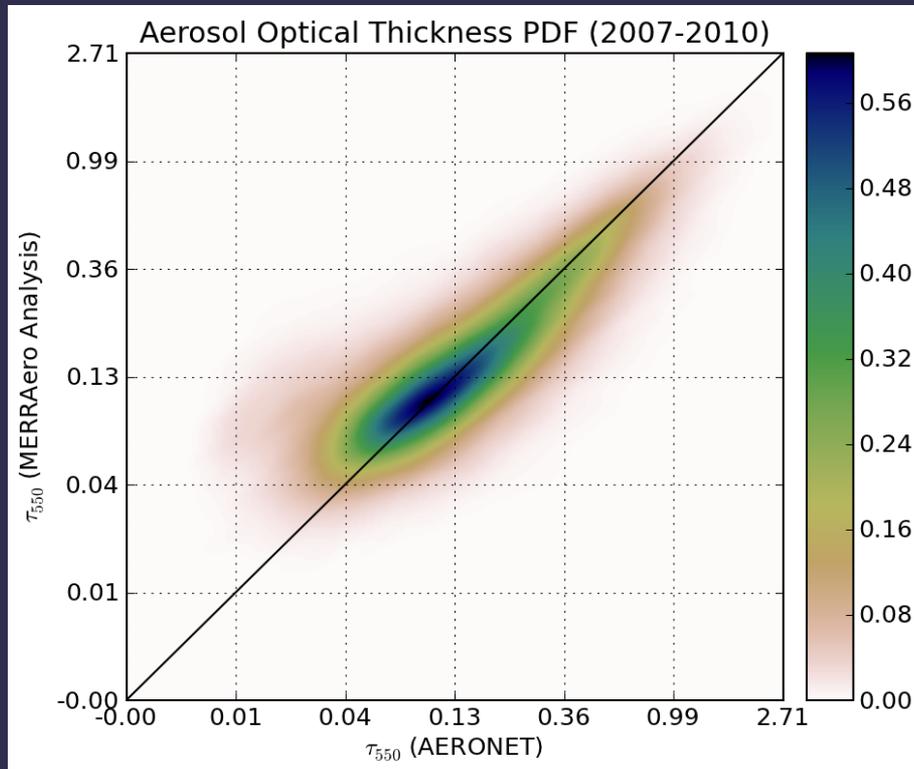
Local Displacement Ensembles (LDE)

- Construct perturbation ensembles by means of isotropic displacements around gridbox
- Weigh each ensemble member by its fit to 2D AOD analysis
- For efficiency, perform the AOD-to-mixing ratio calculation in 1D



MERRAero Overview (5)

Independent AERONET AOD evaluation



Evaluation of MERRAero Absorption

AI observed/simulated comparison (1)

AI: Qualitative indicator of the presence of absorbing aerosol ($AI > 0$)

AI is derived from the change in the spectral dependence of the back-scattered UV radiances induced by aerosols relative to the Rayleigh scattering between 354 and 388 nm [Torres et al., 1998, 2007].

$$AI = -100 \left[\log_{10} \left(\frac{I_{354}^{Obs}}{I_{354}^{calc(Ray)} (R_{388}^{Obs})} \right) \right]$$

AI depends on :

- aerosol concentration
- aerosol layer height
- aerosol optical properties

MERRAero simulated radiances and AI: Radiative transfer code **VLIDORT**

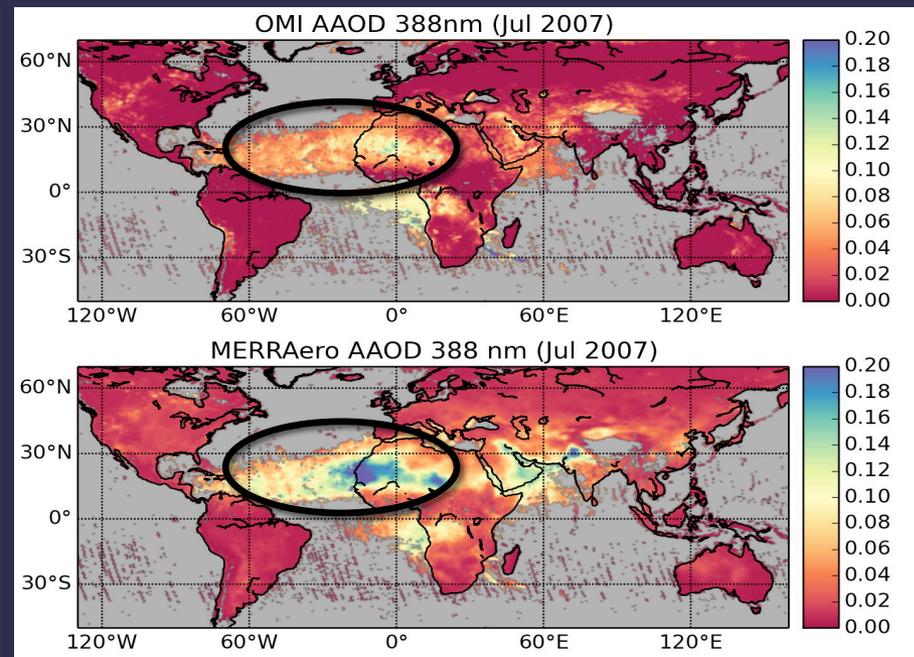
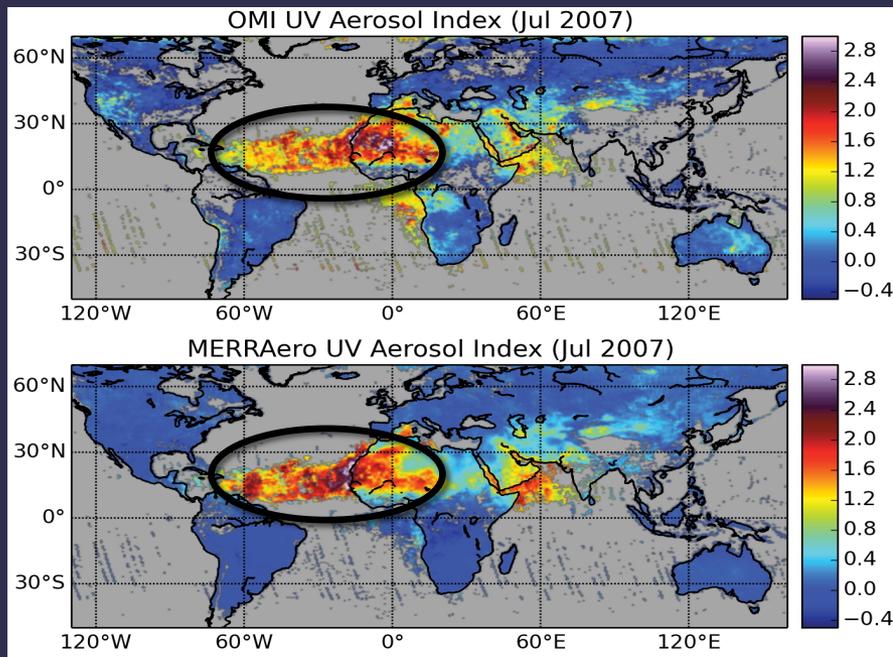
[Spurr et al., 2002, 2006].

AI observed/simulated comparison (2)

RESULTS (baseline simulation)

AI

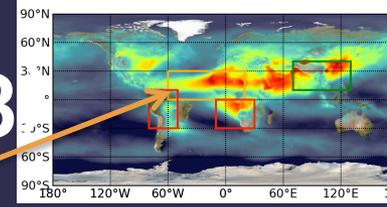
AAOD



OMAERUV product [Torres et al., 2007]

- Globally MERRAero AI captures major features but :
 - Tend to underestimate over North America, South America and more importantly in the Southern Africa Biomass burning region.
- MERRAero AAOD greater than OMI AAOD at 388 nm:
 - Saharan dust region → conflicted diagnosis

AI observed/simulated comparison (3)

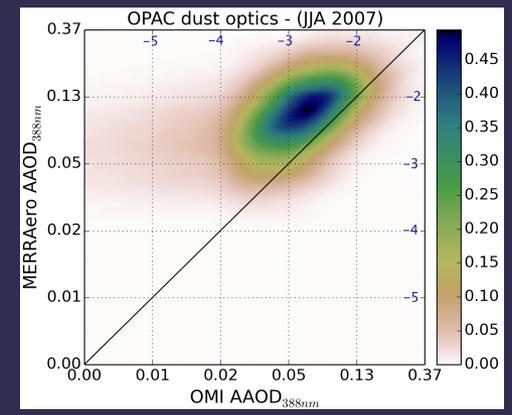
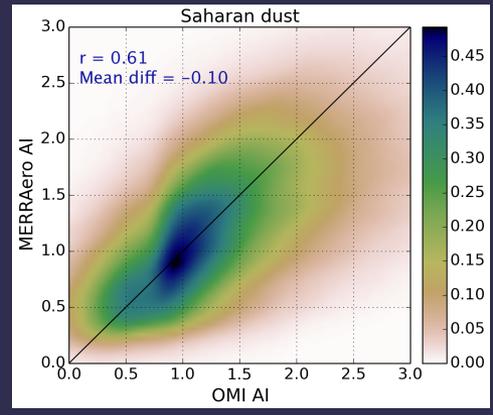


Saharan dust

AI

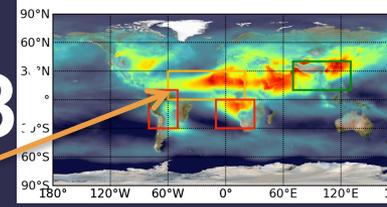
AAOD

Baseline simulation :



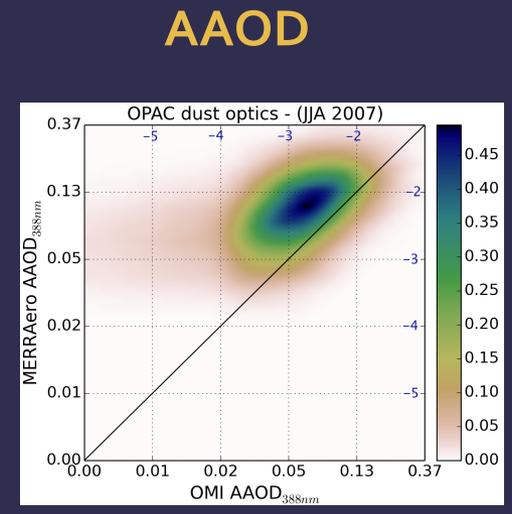
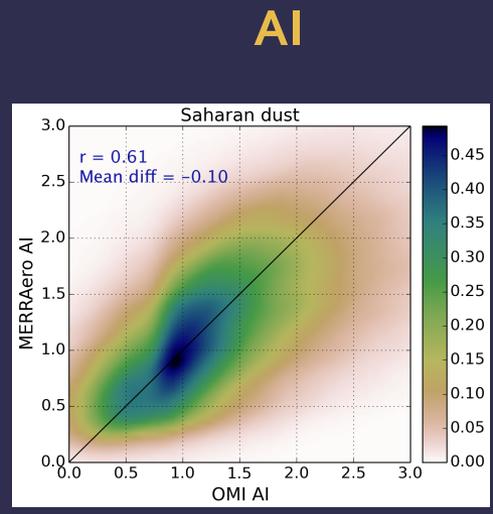
OMAERUV product
[Torres et al., 2007]

AI observed/simulated comparison (3)

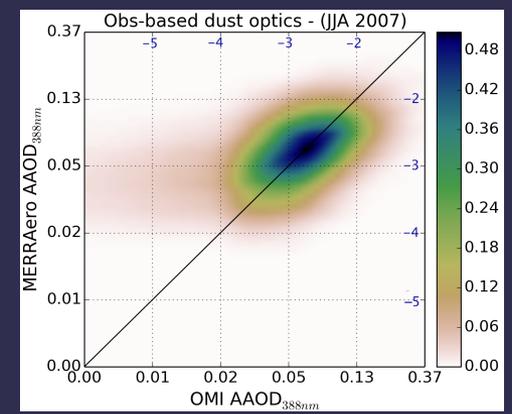
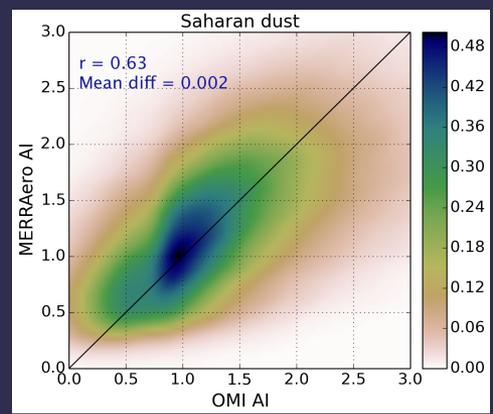


Saharan dust

Baseline simulation :



Updated simulation :



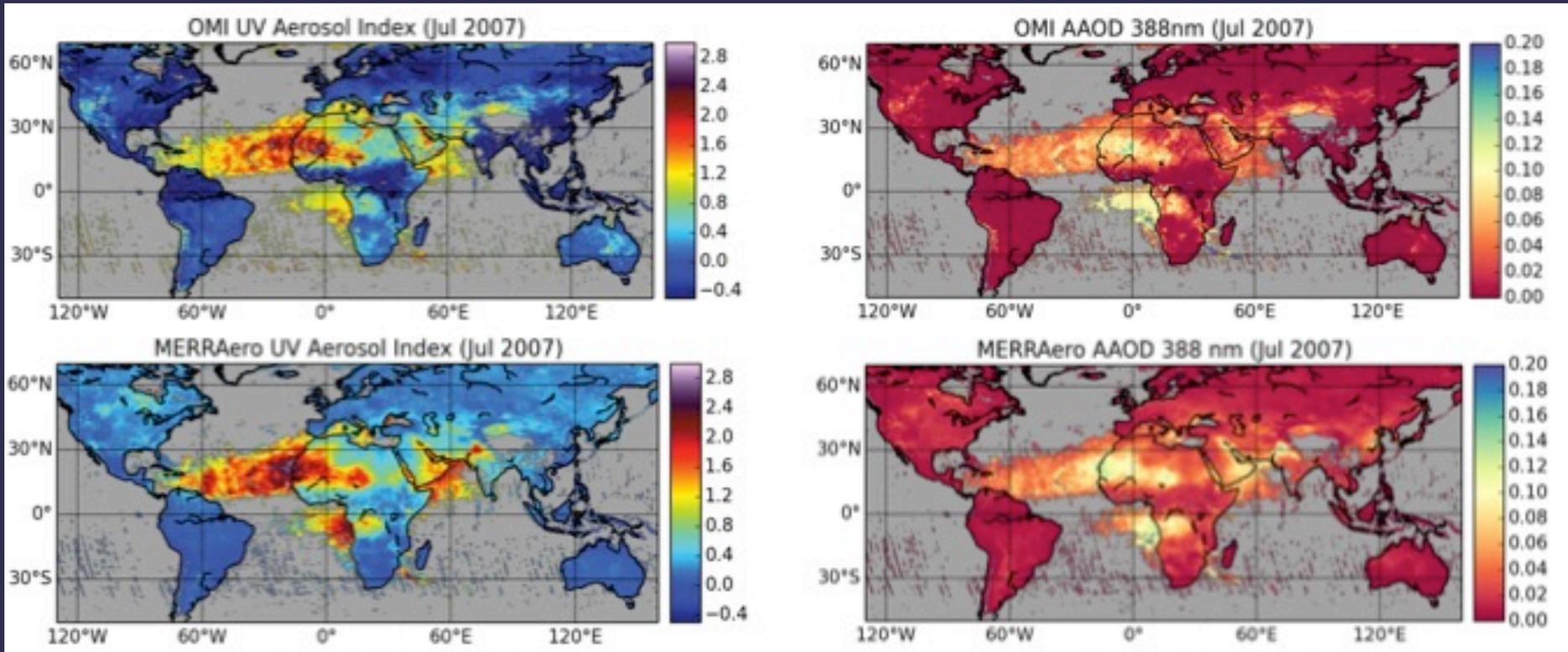
Fraction of MERRAero AAOD from DUST aerosol > 0.7

AI observed/simulated comparison (4)

RESULTS (updated simulation)

AI

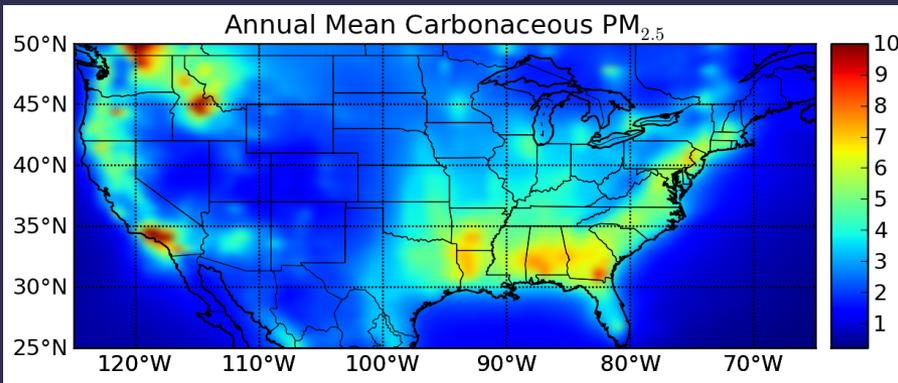
AAOD



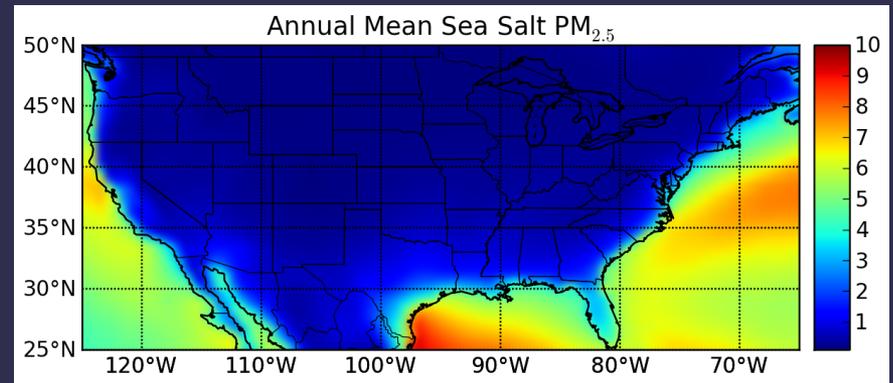
Evaluation of MERRAero Surface PM_{2.5}

Evaluation of Surface PM_{2.5} (1)

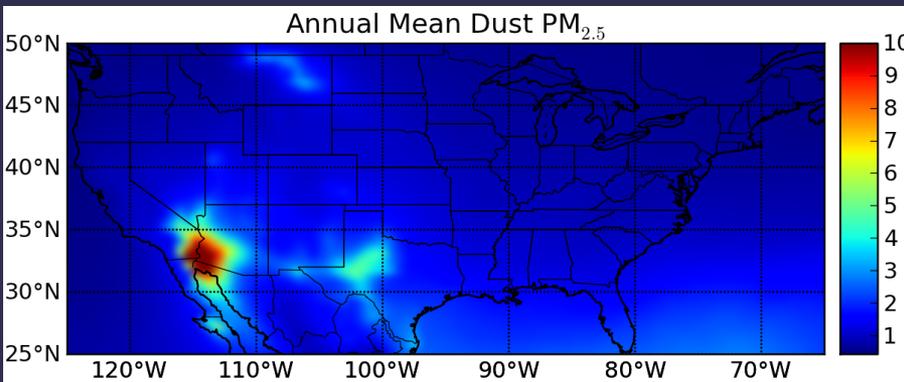
MERRAero Annual mean PM_{2.5} (ug/m³)



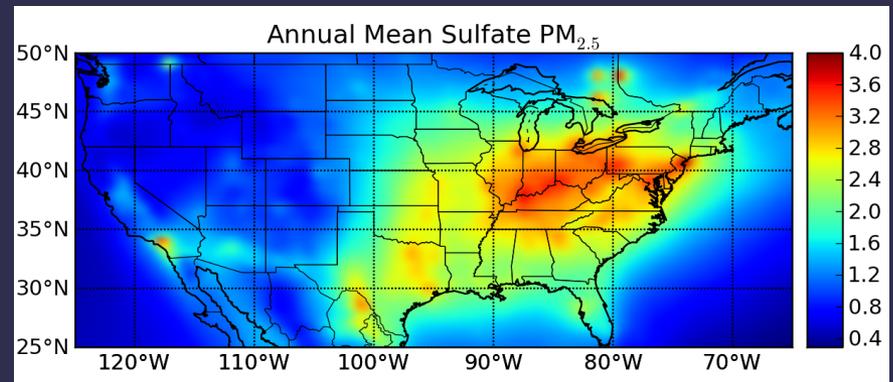
→ Carbonaceous from anthropogenic and biomass burning sources



→ Too much penetration in land



→ Dust from local sources

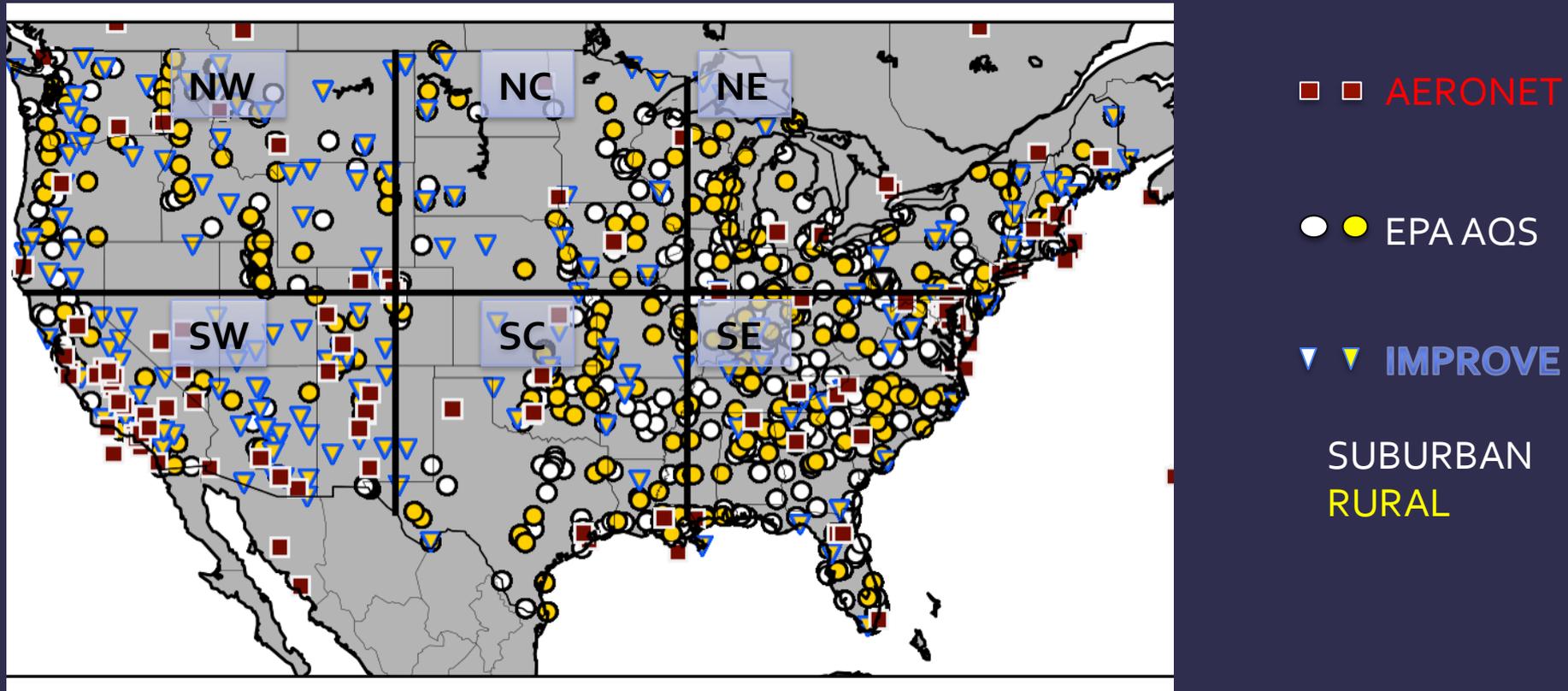


→ High values of sulfate in the Ohio River Valley due to abundance of SO₂ emitted by several power plants

Nitrate is also a component of PM_{2.5}: nitrate particle formation is not considered in MERRAero.

Evaluation of Surface PM_{2.5} (2)

AOD (AERONET) & PM_{2.5} measurements (IMPROVE and EPA networks)



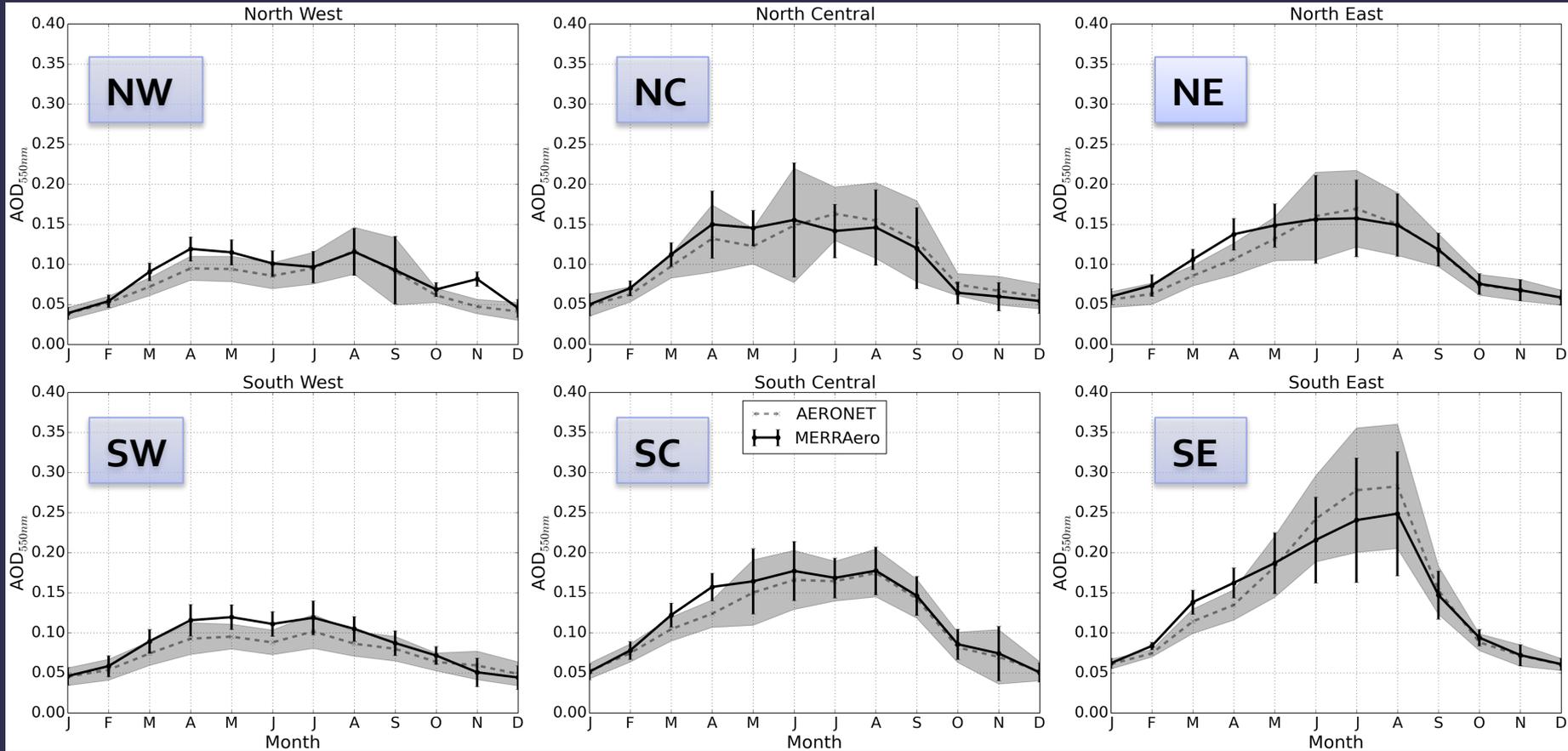
IMPROVE stations → mainly RURAL & more spread across the country.
EPA AQS stations → Eastern region

-> Comparisons by regions

Evaluation of Surface PM_{2.5} (3)

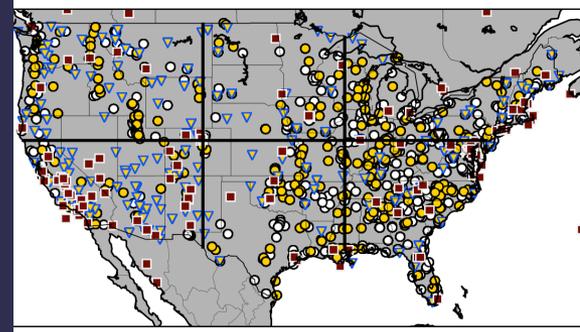
AERONET comparisons:

AOD 550 nm Seasonal variability

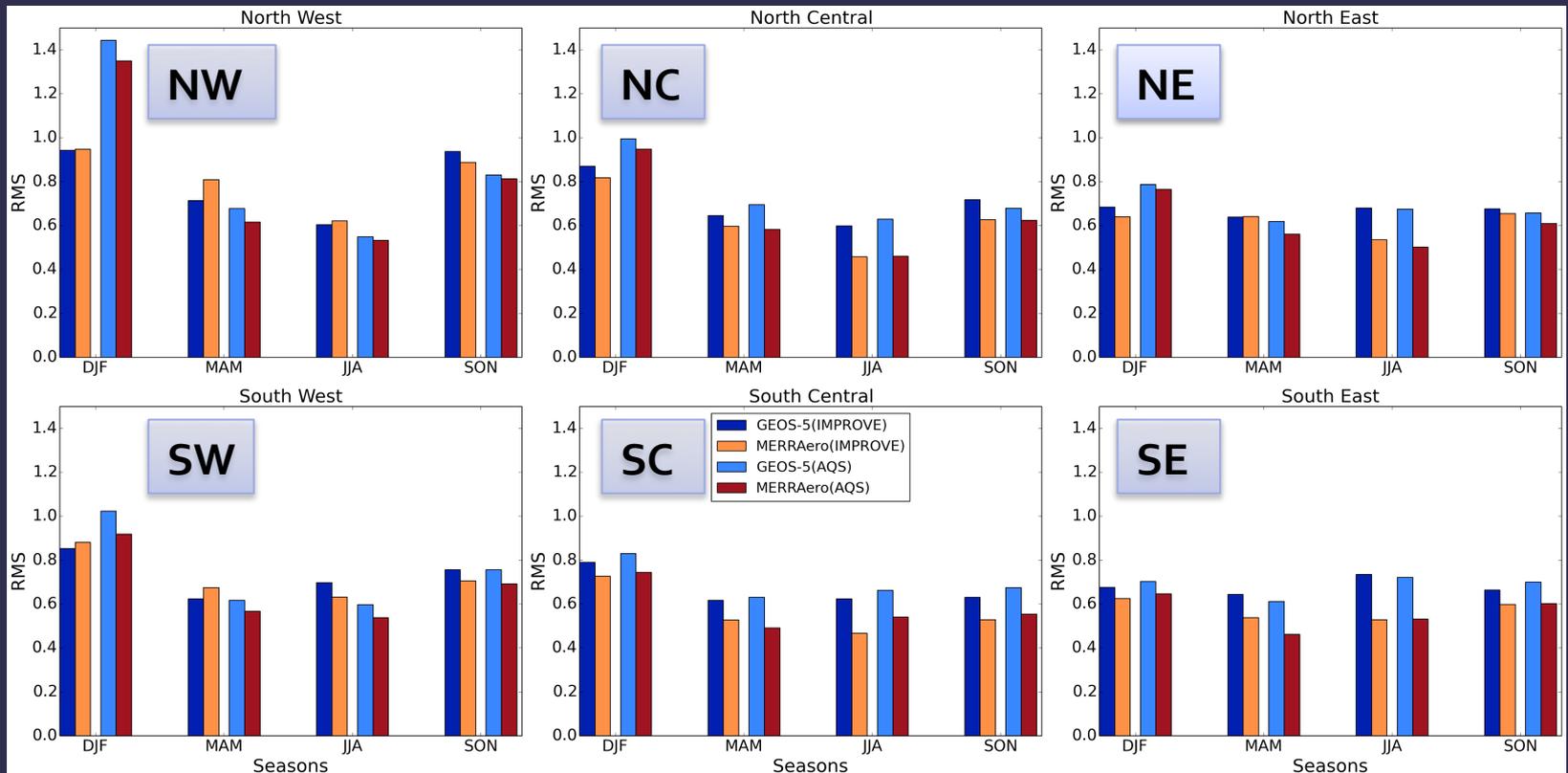


→ MERRAero AOD seasonal cycles follows AERONET seasonal cycles

Evaluation of Surface PM_{2.5} (4)



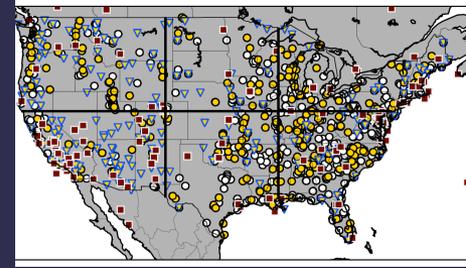
PM_{2.5} - Impact of AOD assimilation



Seasonal and regional RMS of the differences (model - observation) for MERRAero and the GEOS-5 model without AOD assimilation. MERRAero and GEOS-5 sampled at IMPROVE and EPA-AQS stations.

→ Positive impact on surface PM_{2.5} with RMS generally lower for MERRAero.

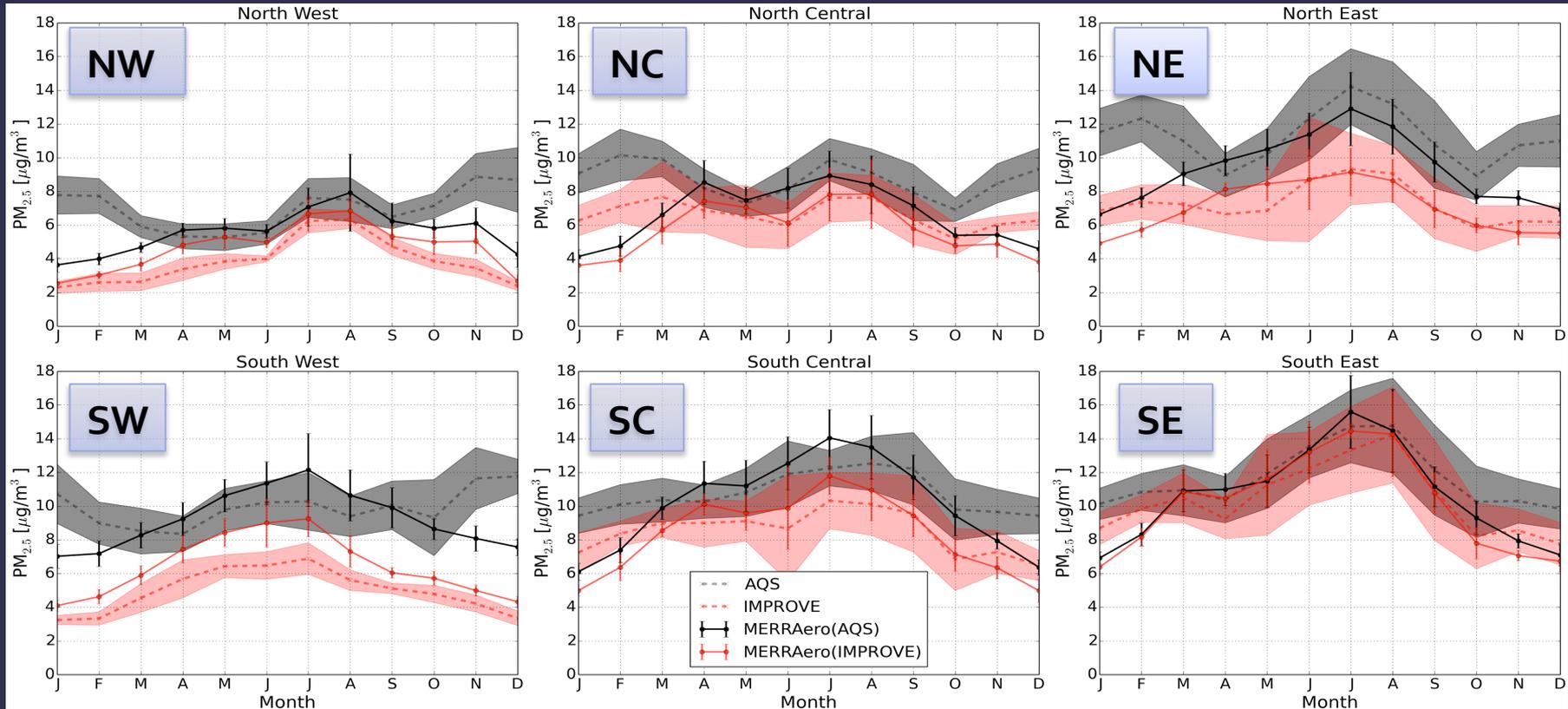
Evaluation of Surface PM_{2.5} (5)



PM_{2.5} Seasonal variability

Total PM_{2.5}

For quality control: buddy check of Dee et al. (2001)

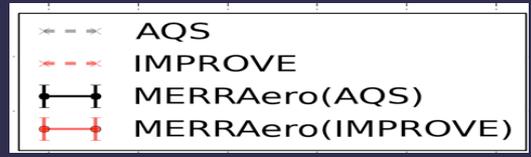
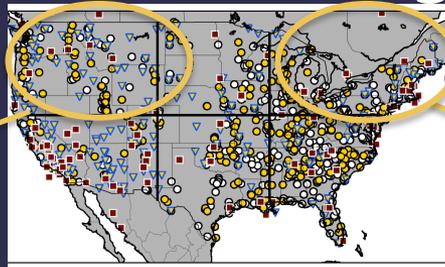


- IMPROVE and EPA PM_{2.5} highly correlated, except in the Western regions.
- IMPROVE → lower values of PM_{2.5} → mostly rural stations.
- MERRAero PM_{2.5} better correlated with IMPROVE stations.
- Compared to EPA: better agreement during the summer; bias during the winter.



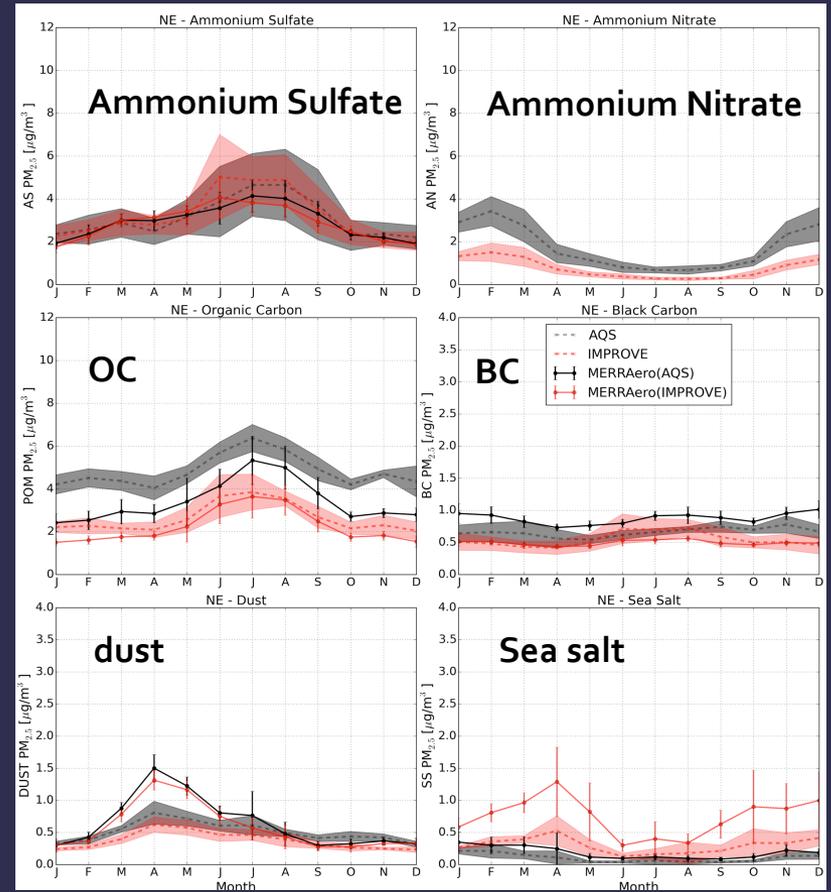
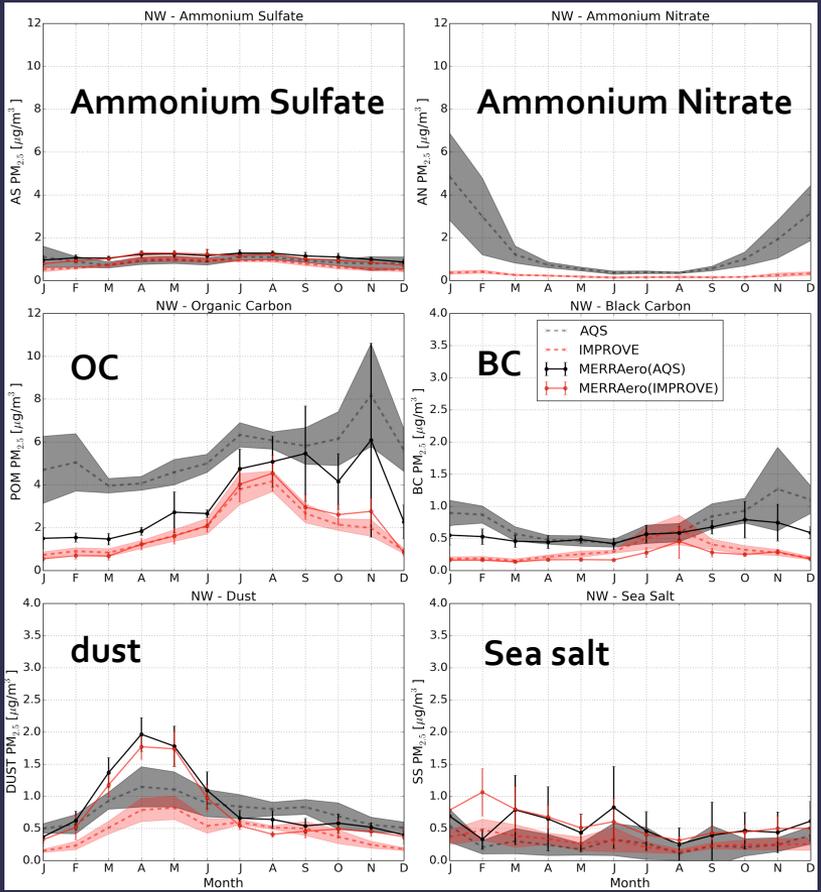
Evaluation of Surface PM_{2.5} (6)

PM_{2.5} – per species



NW

NE



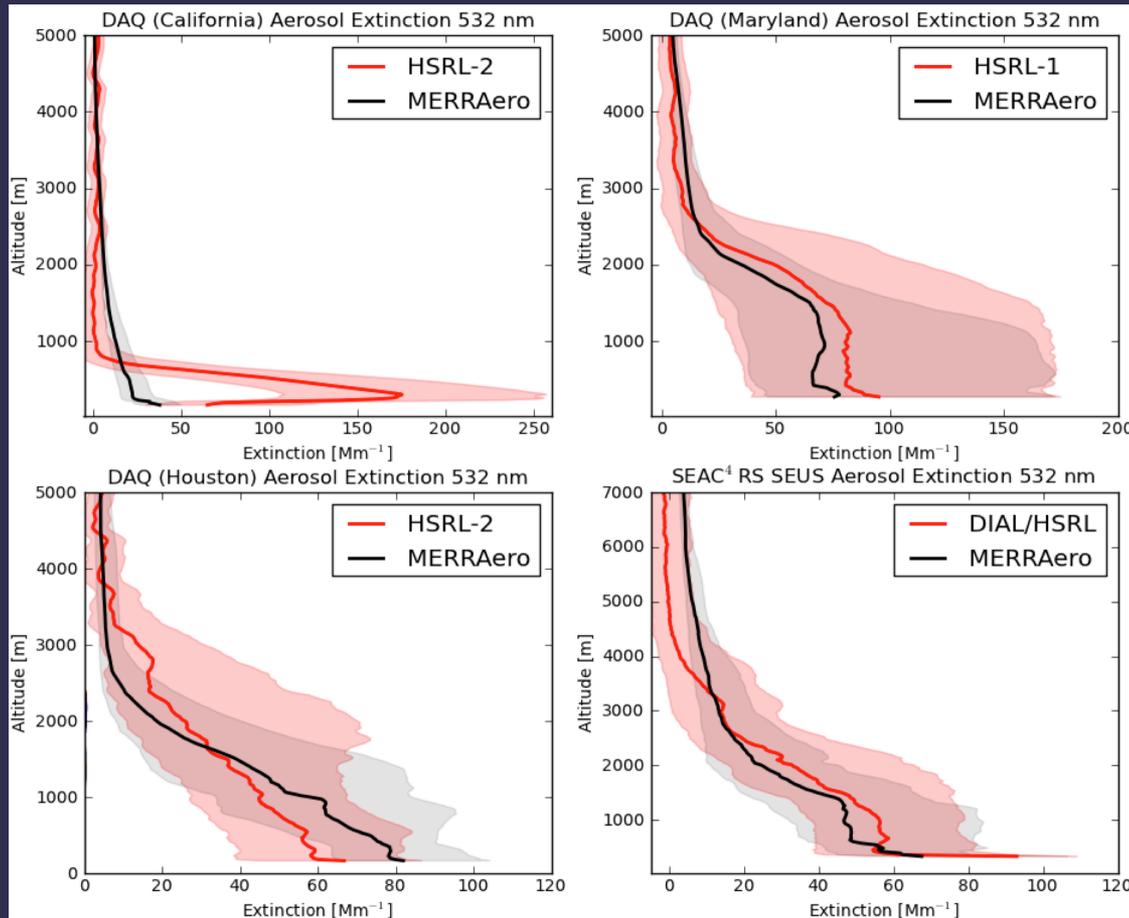
→ Lack of nitrate and underestimation of source emissions of OC over suburban areas.

Conclusions

- **MERRAero** : Assimilation of bias corrected MODIS AOD. It does not assimilate any data capable of directly constraining its vertical placement or composition.
- **Evaluation of Absorption:**
 - Absorption AOD is not assimilated,
 - Good agreement for dust after tuning of optical properties.
- **Evaluation of PM_{2.5}:**
 - Comparisons with independent AERONET AOD:
 - Seasonal AOD variability captured
 - Comparisons with PM_{2.5} observations:
 - Better agreement with IMPROVE (mostly rural stations), magnitude and seasonal cycle are generally in good agreement, particularly for the summer.
 - Some discrepancies during the winter are species dependent, in particular lack of nitrate and underestimation of OC. MERRAero vertical structure might also be part of these discrepancies.
- **Future work:**
 - Development of an Ensemble Kalman Filter based scheme for the aerosol data assimilation.

Evaluation of Surface PM_{2.5} (7)

MERRAero Vertical structure



Houston (August-September 2013),
California (January-February 2013),
Baltimore-Washington, D.C. (July 2011)
SEAC₄RS (August-September 2013)

HSRL and modeled extinction profiles during DISCOVER-AQ and SEAC₄RS field campaigns.