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Using Models and Satellite Data for Air Quality Studies: Challenges and Needs

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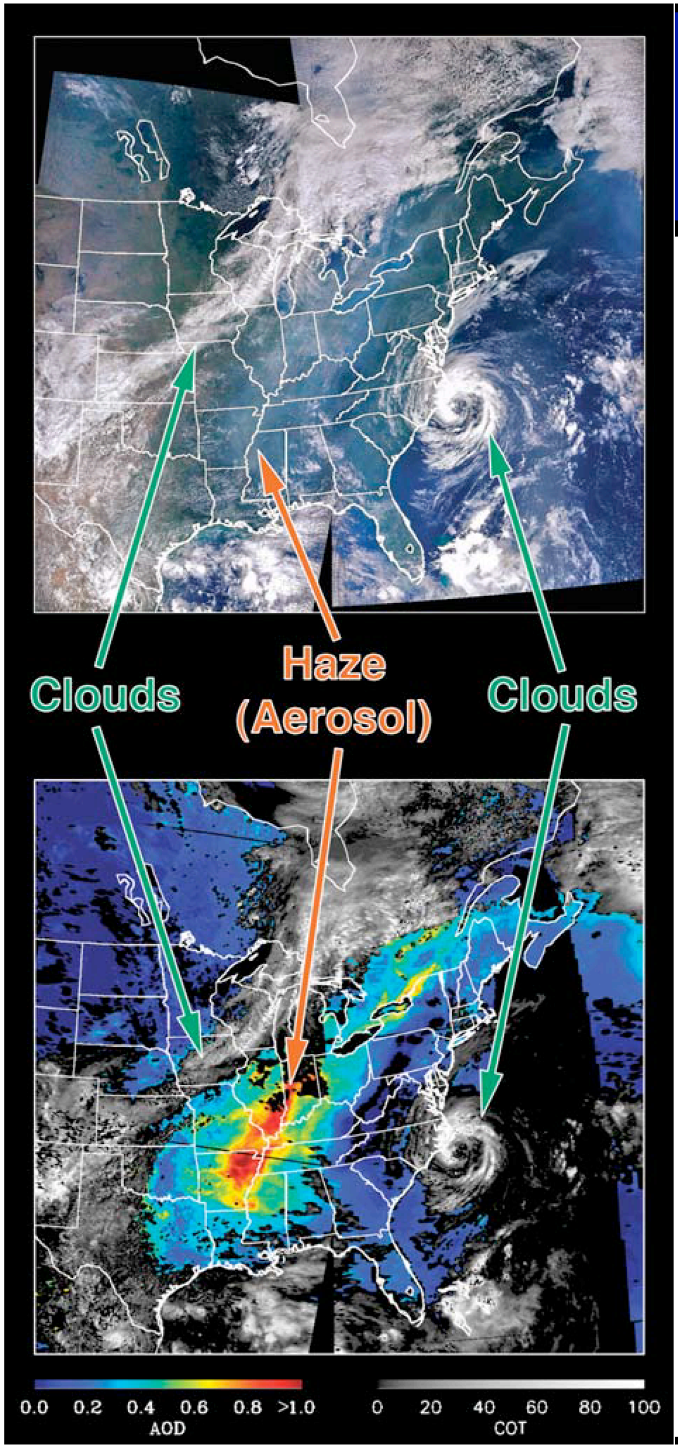
Introduction

- PM2.5 (particulate matter, or aerosol particles, with diameter less than 2.5 μm) is a key component determining air quality
- Remote sensing capability of atmospheric aerosol optical depth (AOD) could lead to a quantum leap in our ability of air quality monitoring and prediction, especially for regions where surface monitoring network does not exist
- I will discuss:
  - What are the advantages and limitations of using the current satellite data for regional AQ (PM2.5) studies?
  - Can we use data assimilation to improve PM2.5 prediction?
  - What are the critical data needs?

Q1. What are the advantages and limitations of using the current satellite data for regional AQ (PM2.5) studies?

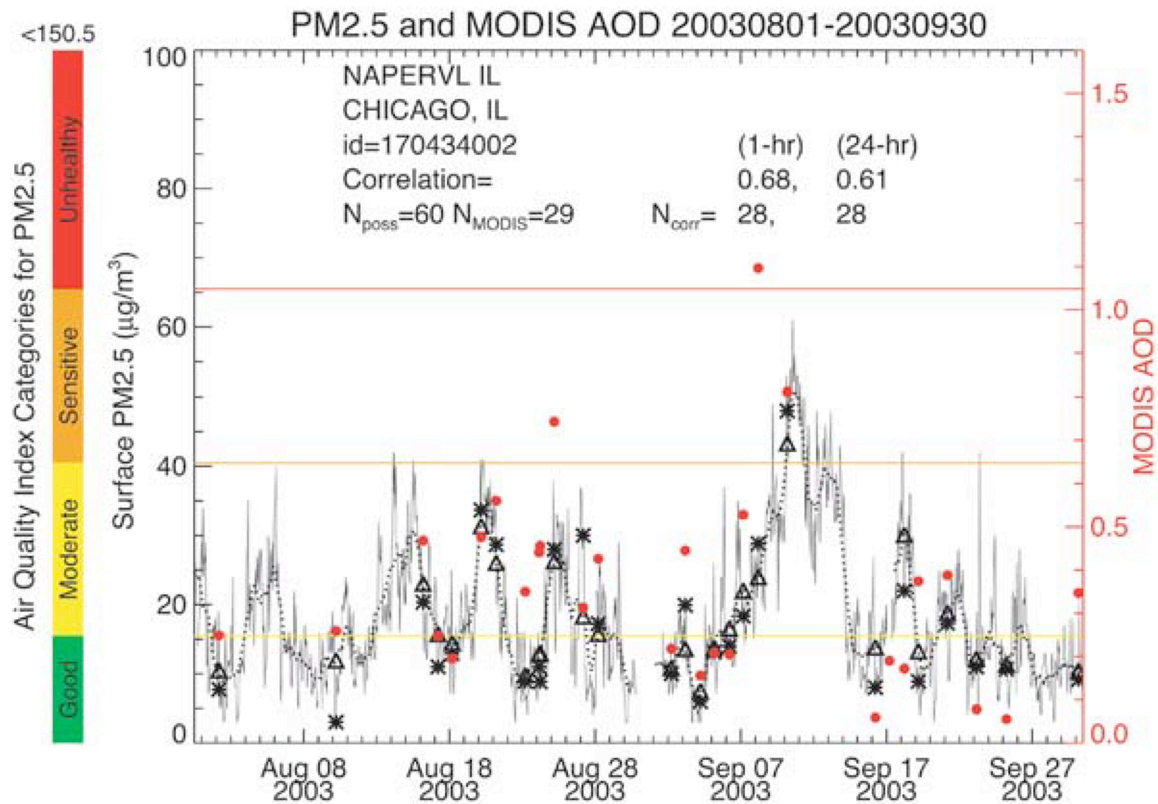
Current US involved satellite aerosol products

Sat.	Instr.	Pros	Cons
Terra & Aqua	**MODIS** (0.47 – 2.13 µm)	• Daily near global coverage • Morning and afternoon observations • Size information (fine/coarse) • High spatial resolution (1 – 10 km)	• Large uncertainties or not data over bright surfaces • No vertical information • No speciation • No data when cloudy
Terra	**MISR** (0.45 – 0.87 µm)	• High accuracy over land • Size information • Air mass differentiation • Plume height information in some cases • (Particle shape information)	• Limited area coverage (global coverage every ~7 days) • Hit or miss – difficult for daily AQ monitoring • Almost no vertical information • No speciation • No data when cloudy
Aura	**OMI** (0.27 – 0.50 µm)	• Daily near global coverage • Detecting aerosol over bright land surface • Aerosol absorption (thus information of BC or dust) • Aerosol Index detecting aerosol in clouds • Precursor measurements (SO_2, NO_2)	• No vertical information • No speciation • ???
IceSat	**GLAS** (0.532 & 1.064 µm)	• Vertical distributions • Cloud information	• Very limited space and time coverage • Uncertainties in retrieving extinction profiles
Calipso (not launched)	**CALIOP** (0.532 & 1.064 µm)	• Vertical distributions • Cloud information	• Limited space and time coverage • Uncertainties in retrieving extinction profiles



MODIS AOD tracks PM2.5, providing guidance for PM2.5 forecasts

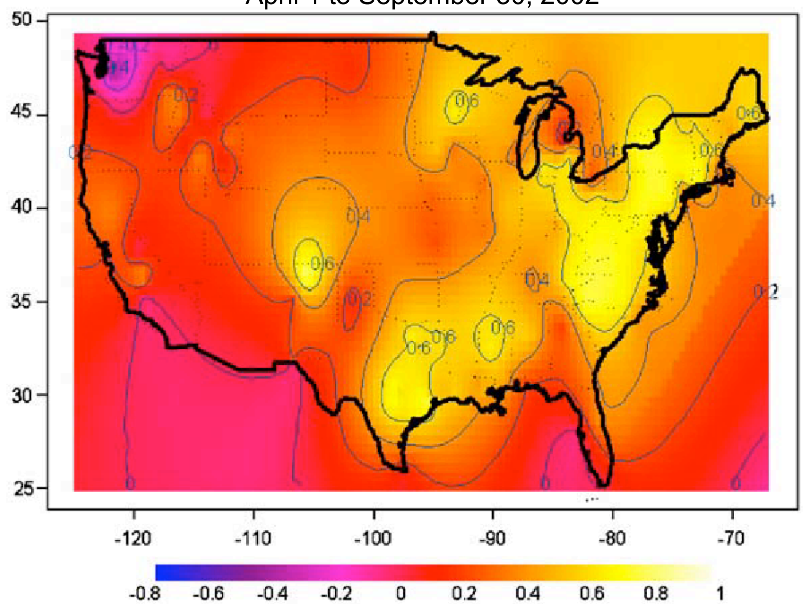
(Figures from Al-Saadi et al., BAMS 2005)



Can satellite AOD data be quantitatively used to predict surface PM2.5?

- Yes, if aerosol composition and vertical distribution do not vary much
- No, if aerosol composition and vertical distribution vary a lot
- Maybe so, if the AOD are supplemented with vertical data or a reliable chemistry-transport model

Correlations between AOD and PM2.5(hourly)
April 1 to September 30, 2002



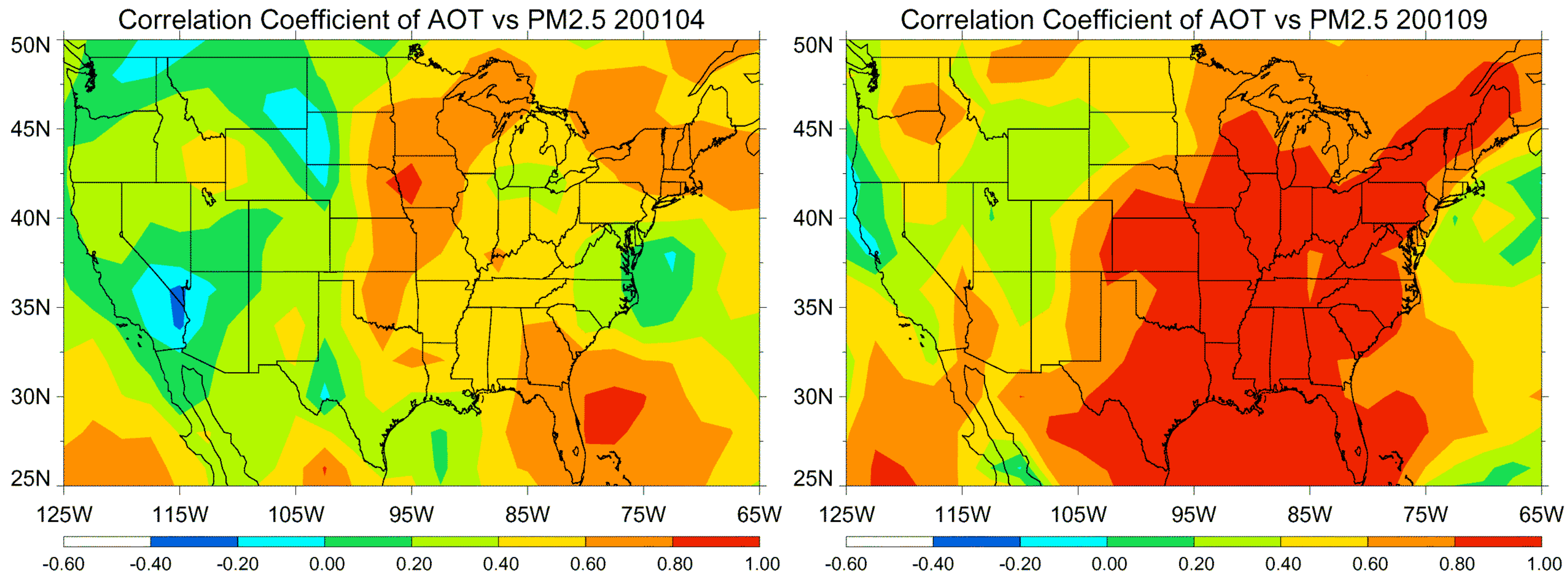
AOD from Terra-MODIS
PM2.5 from STN and IMPROVE networks

Engel-Cox et al. (2004) show that the correlation coefficients between the MODIS AOD and surface PM2.5 measurements vary with locations: better correlated in the eastern US than in the western US for the period of 4/1 – 9/30/2002.

GOCART model shows a similar relationship between AOD and PM2.5

GOCART: global model

Aerosols from the GOCART model include: Sulfate, OC, BC, dust, & sea-salt

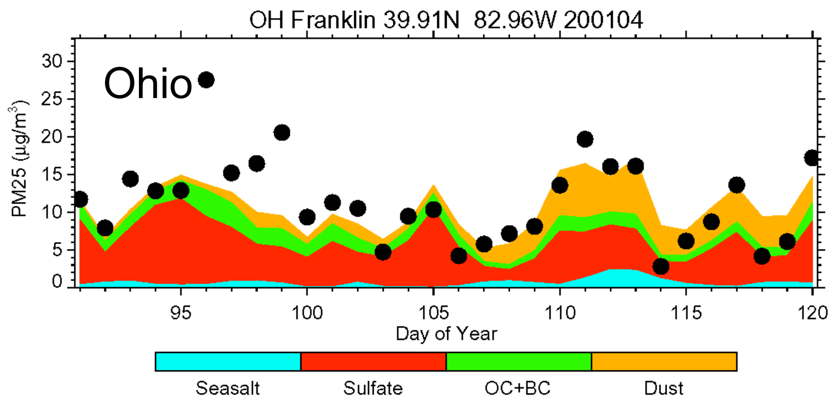


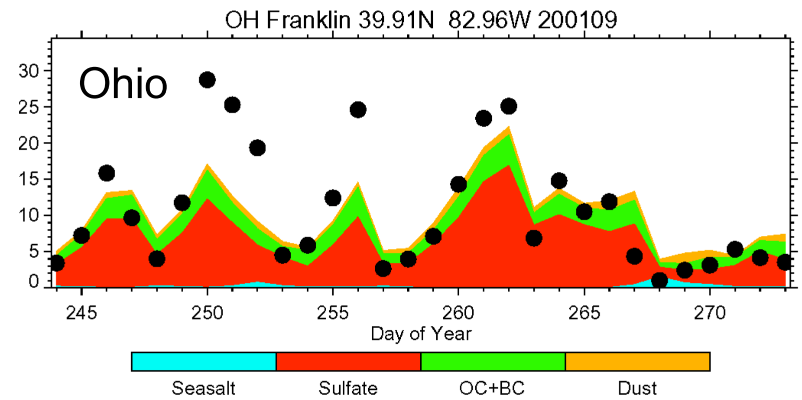
- AOD and PM2.5 is better correlated in the eastern half of the U.S. than in the western
- AOD and PM2.5 is better correlated in September than in April
- This is mainly because the change in composition and/or vertical structure

Eastern U.S. –

Composition and vertical distribution

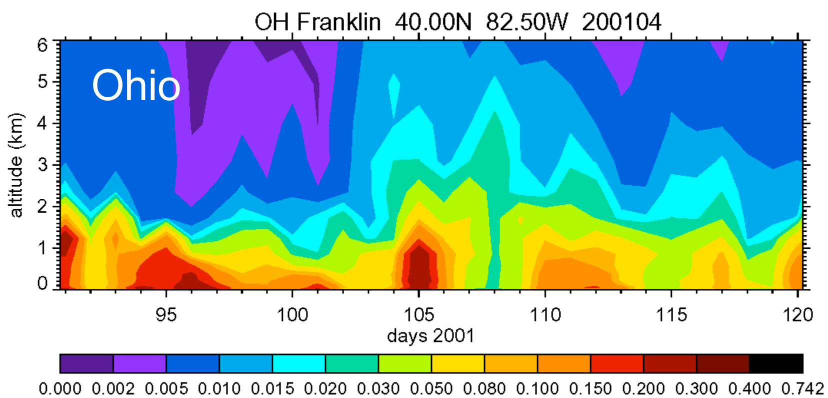
Surface PM2.5

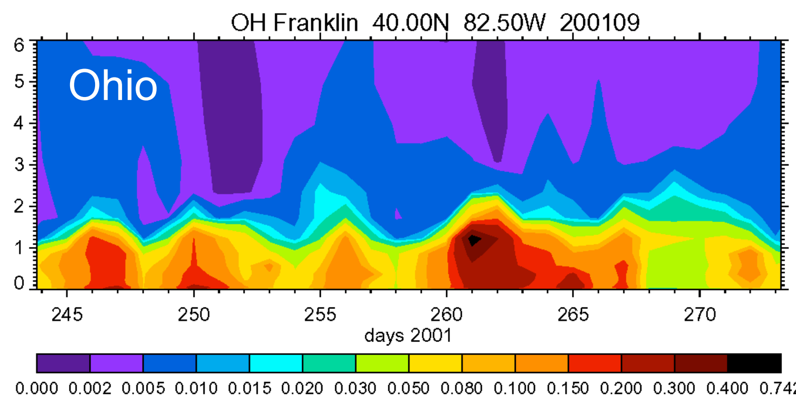




Sulfate is the major aerosol type for both seasons

Vertical Ext.





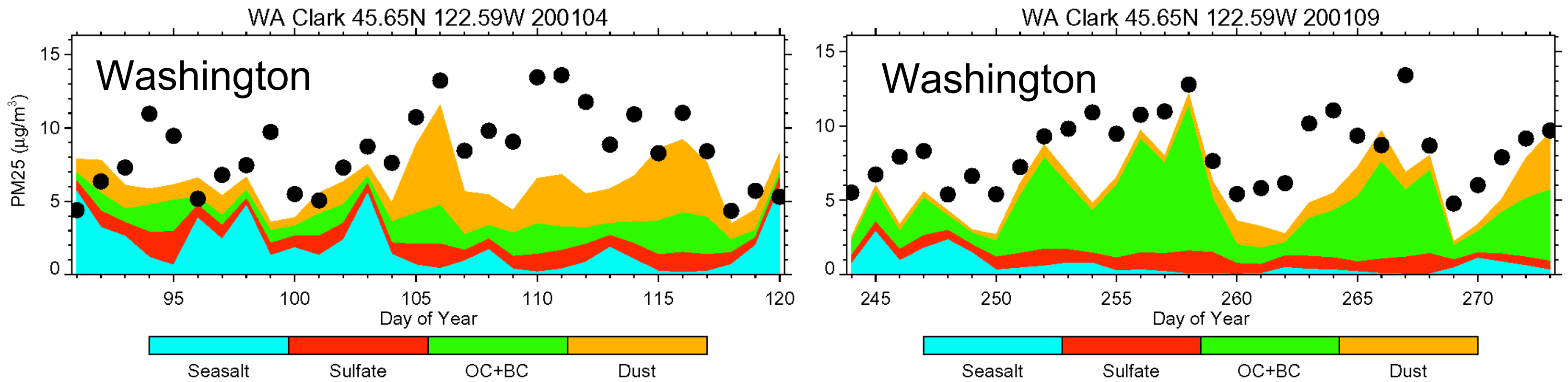
Aerosols are mostly located within the boundary layer for both seasons

Western U.S. –

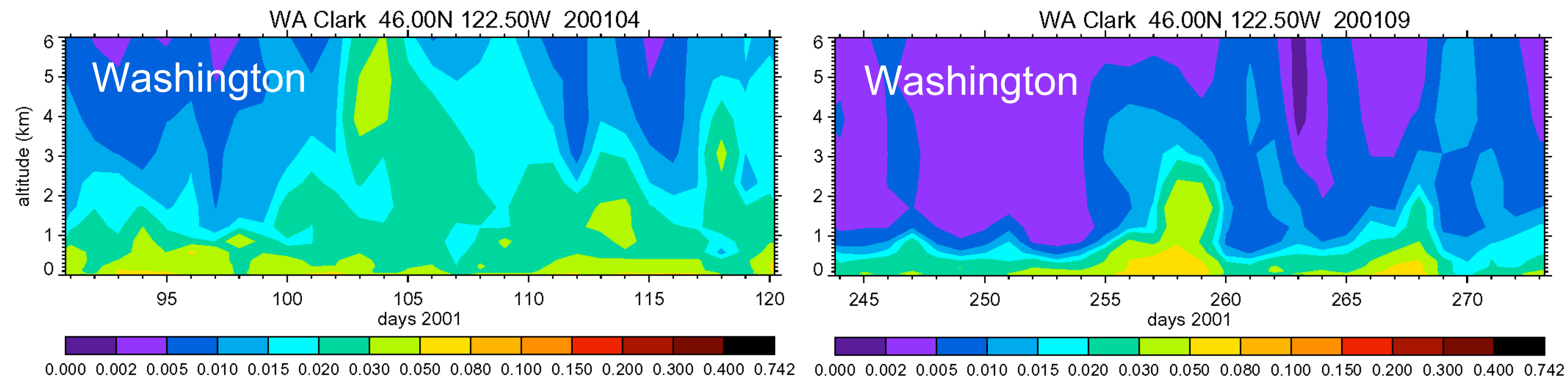
Composition and vertical distribution: Example: Western U.S.

Surface PM2.5

Vertical Ext.



Aerosol composition changes with seasons

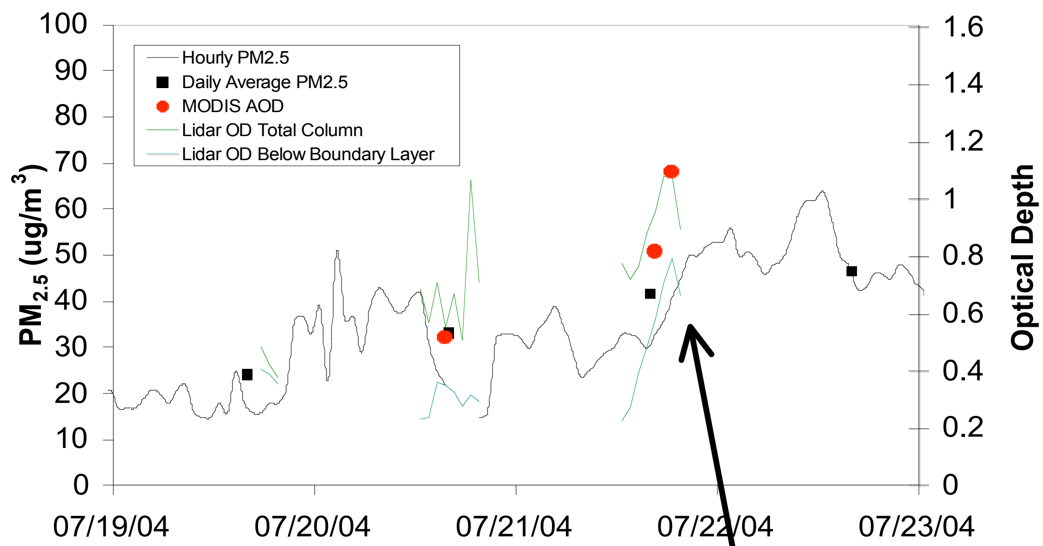


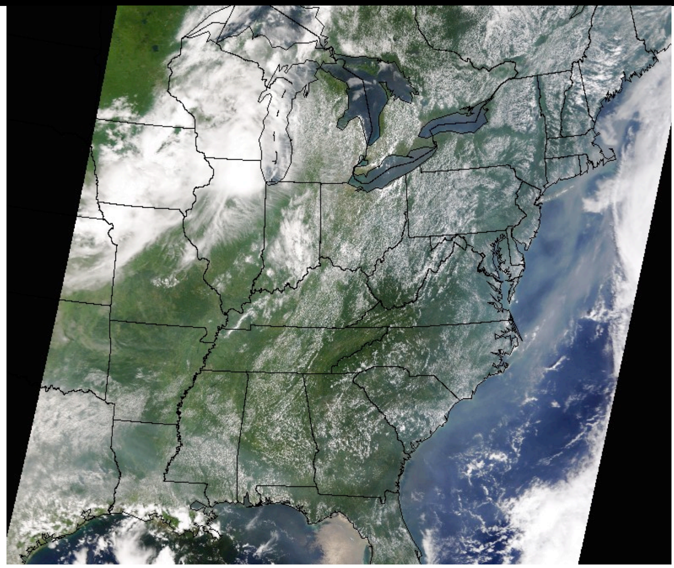
Aerosols vertical distribution changes with seasons

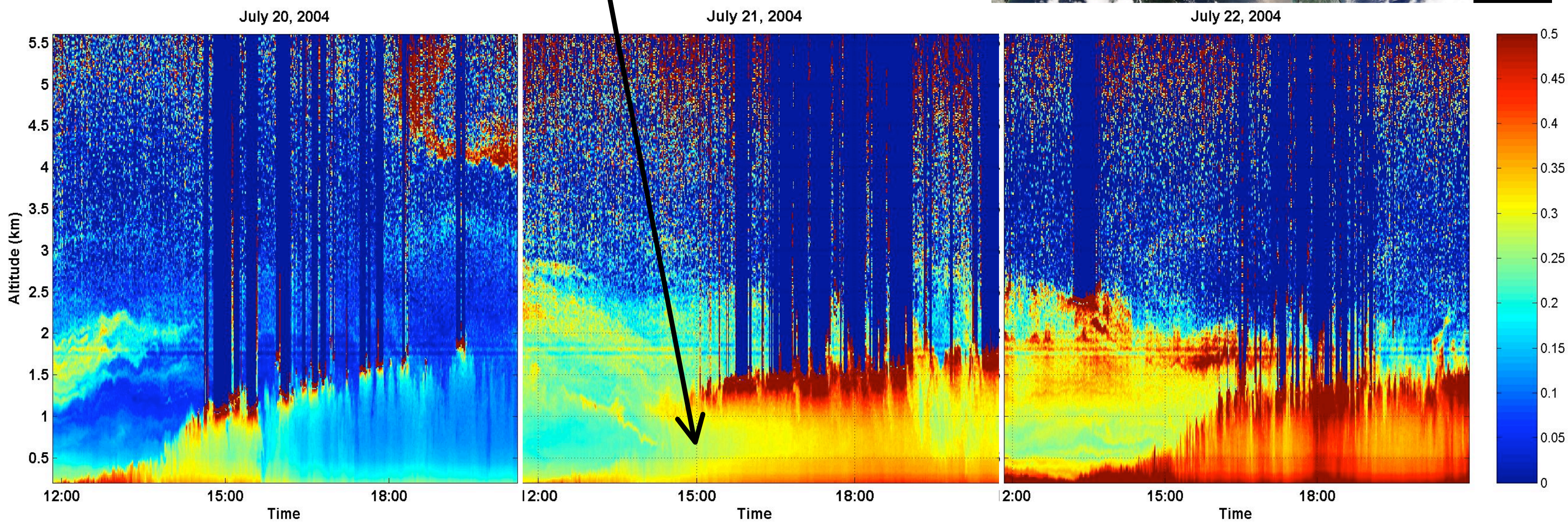
Figures from:
Ray Hoff,
Ray Rodgers,
Jill Engel-Cox
(UMBC)

Smoke mixing in Maryland 20-22 July 2004

(Engel-Cox et al., *Atmos. Environ.*, 2006)







Q1.

What are the advantages and limitations of using the current satellite data for regional AQ (PM2.5) studies?

R1.

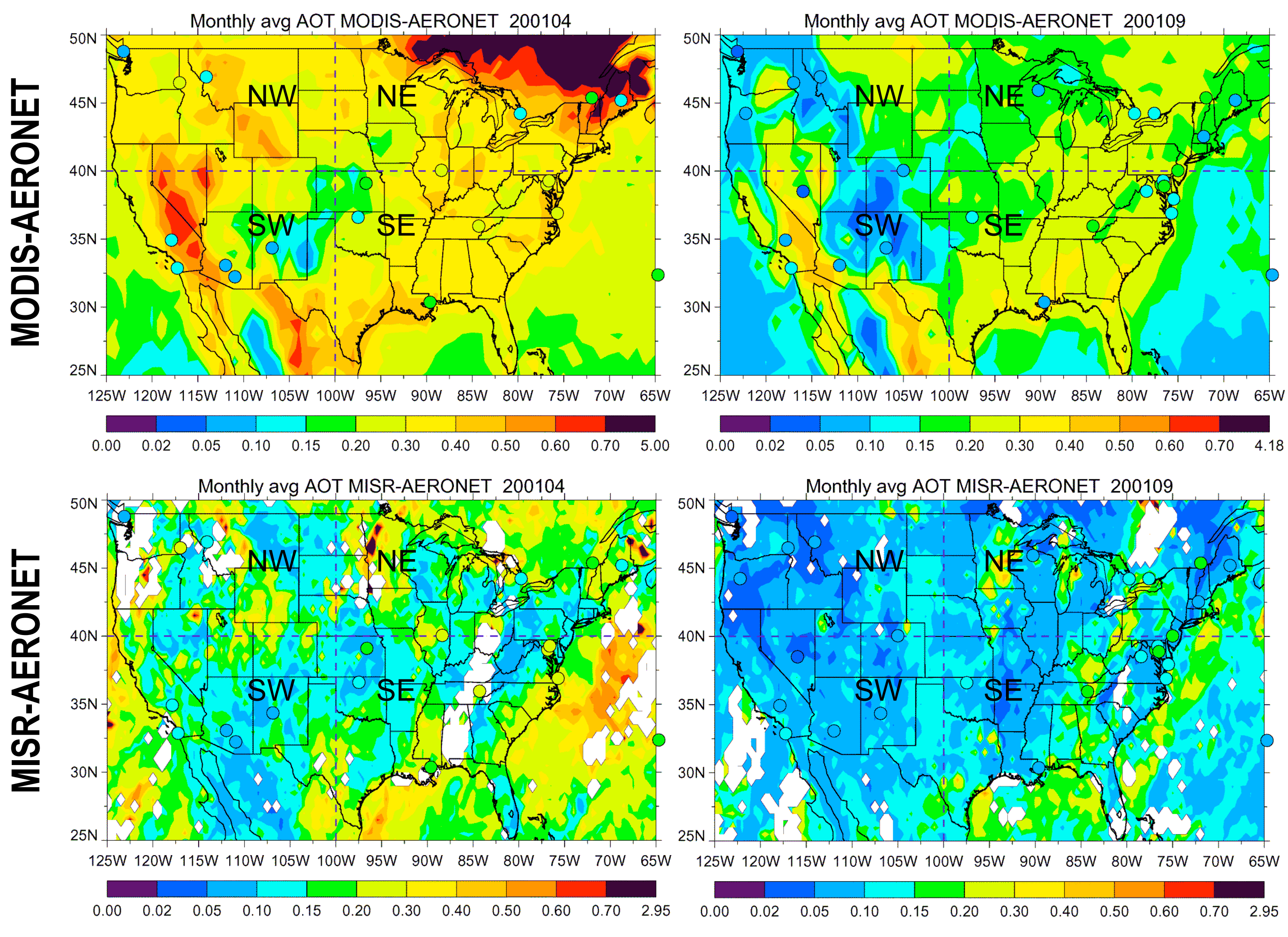
- Advantages:
  - Providing very useful guidance – "big picture"
  - When aerosol composition and vertical profiles are relatively stable (e.g., eastern US in summer/fall), AOD is proportional to PM2.5
  - Profiling data (e.g. GLAS) can provide vertical information
- Limitations:
  - Quantitative use is not always possible, especially at places (e.g. western US) where aerosol composition and vertical profile have large variations
  - Satellite data are not always available (e.g., no data when cloudy, sparse temporal/spatial coverage)
  - Retrieval uncertainties
- Best use:
  - MODIS (and OMI):
    - Daily guidance for PM2.5 prediction
    - Scaling to PM2.5 for selected time and locations
  - MISR:
    - Gathering long-term data (e.g. monthly average for multiple years) for research
    - Selecting specific time/location for specific case studies
  - GLAS (and CALIOP):
    - Interpreting AOD-PM2.5 relationships (including plume height)

Q2. Can we use data assimilation to improve PM2.5 prediction?

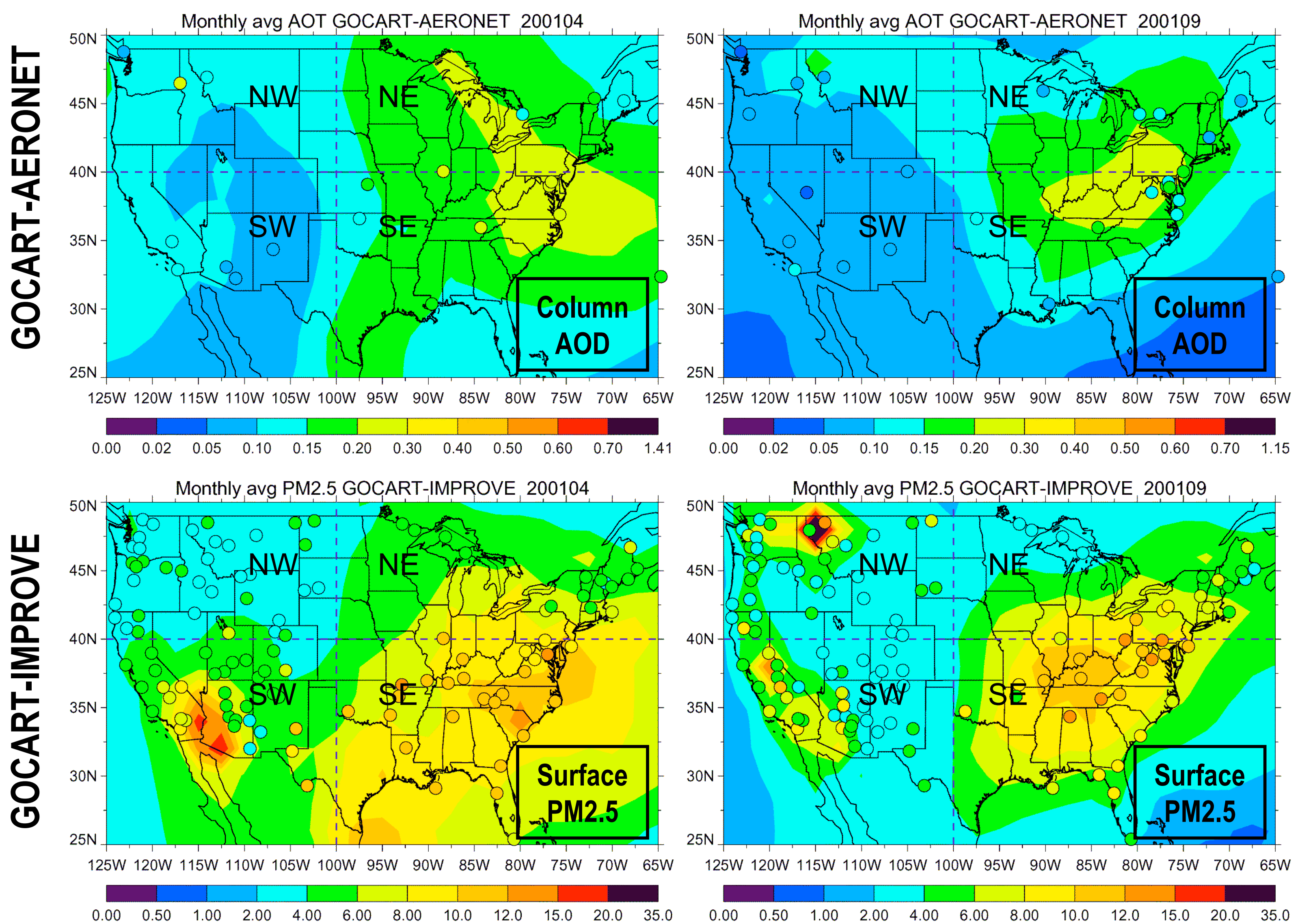
What to assimilate? That is the question

- Assimilating AOD alone is not sufficient
  - What type of aerosols? Different aerosol types have different mass extinction efficiency
  - Where is the aerosol located? Aerosol aloft does not affect surface AQ
  - What about those gaps and bias?
- Assimilating surface PM2.5 and chemical composition may not be consistent with column AOD
- Assimilating radiance (directly measured by satellite) is very challenging
  - Particle shape
  - Surface albedo
  - Mixing state
  - Satellite viewing geometry, etc etc etc
- Multi-dimensional (3-D plus information on composition) assimilation may be the best, but currently has little data

AOD from MODIS, MISR, AERONET:



GOCART vs. AERONET & IMPROVE:



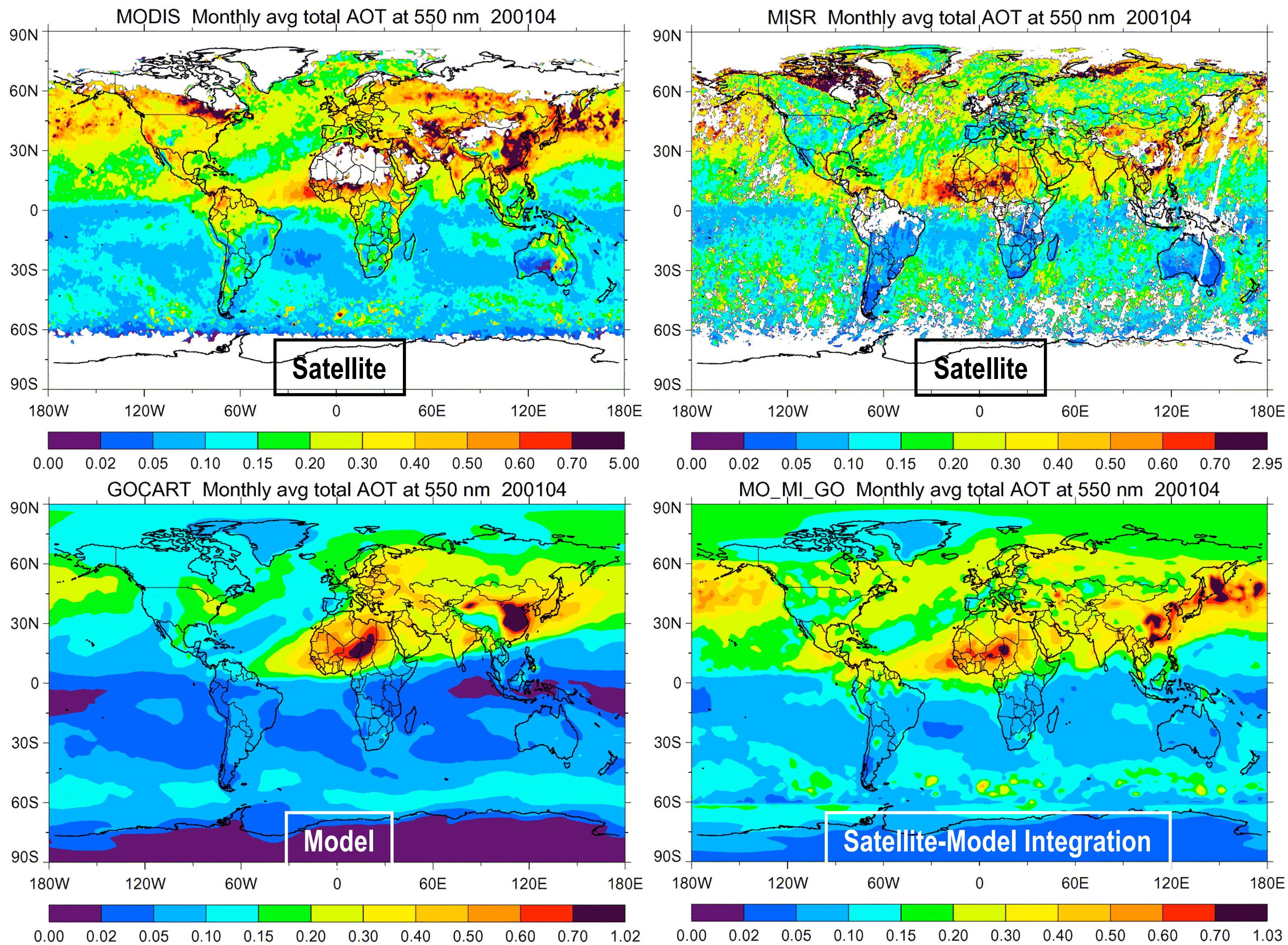
Example

Optimal integration ("fake" assimilation) of MODIS, MISR, and GOCART

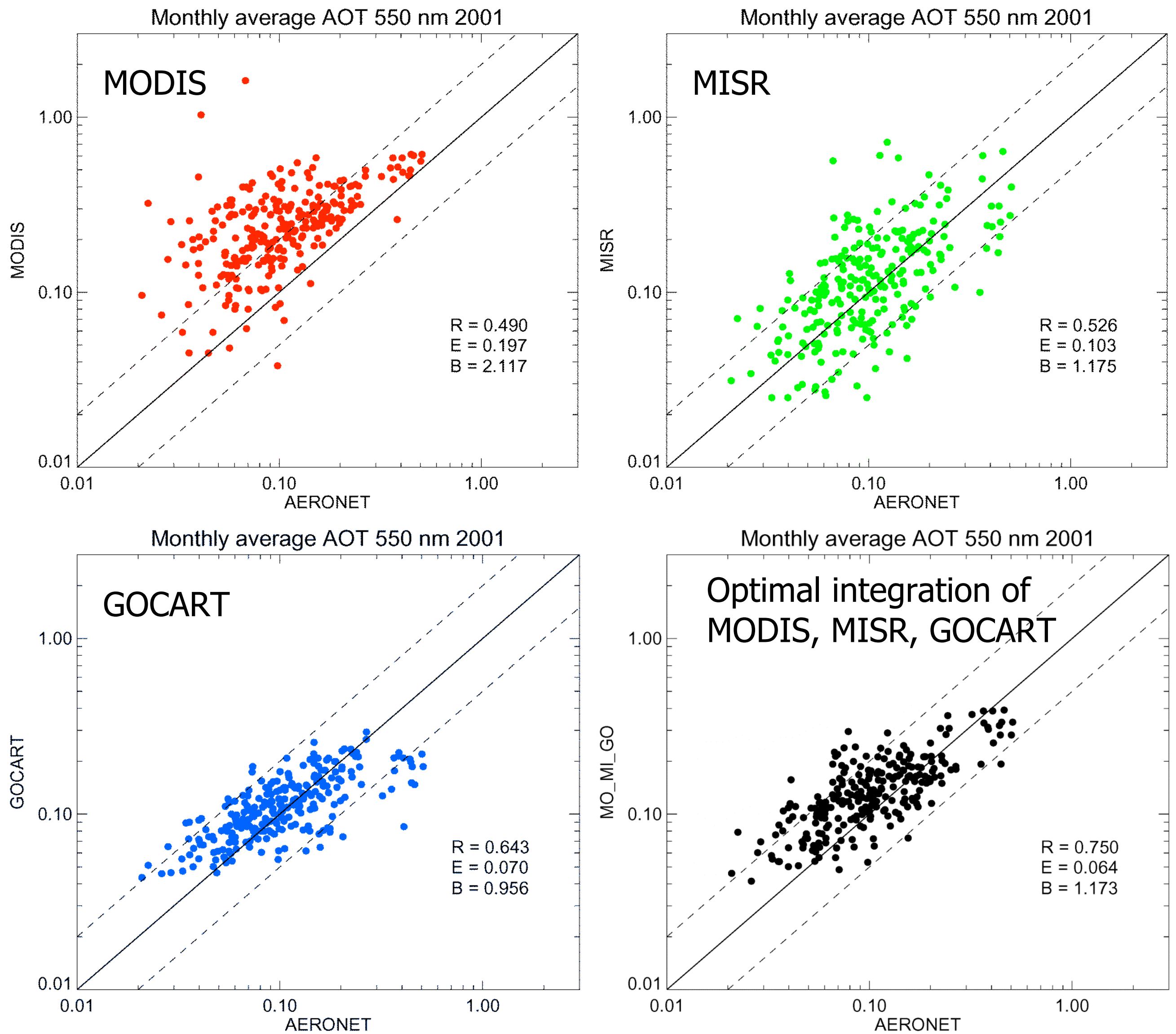
- Weighing uncertainties in both satellite and model to obtain a best and complete description of AOD distributions (Yu et al., 2003)
  - Over land: mostly MISR-GOCART integration
  - Over ocean: mostly MODIS-GOCART integration
- Using aerosol compositions and vertical profiles from the model to "retrieve" PM2.5 from the integrated AOD product:

$$PM2.5_{corrected} = PM2.5_{model} \frac{AOD_{assim}}{AOD_{model}}$$

MODIS, MISR, GOCART, and MO_MI_GO, 200104

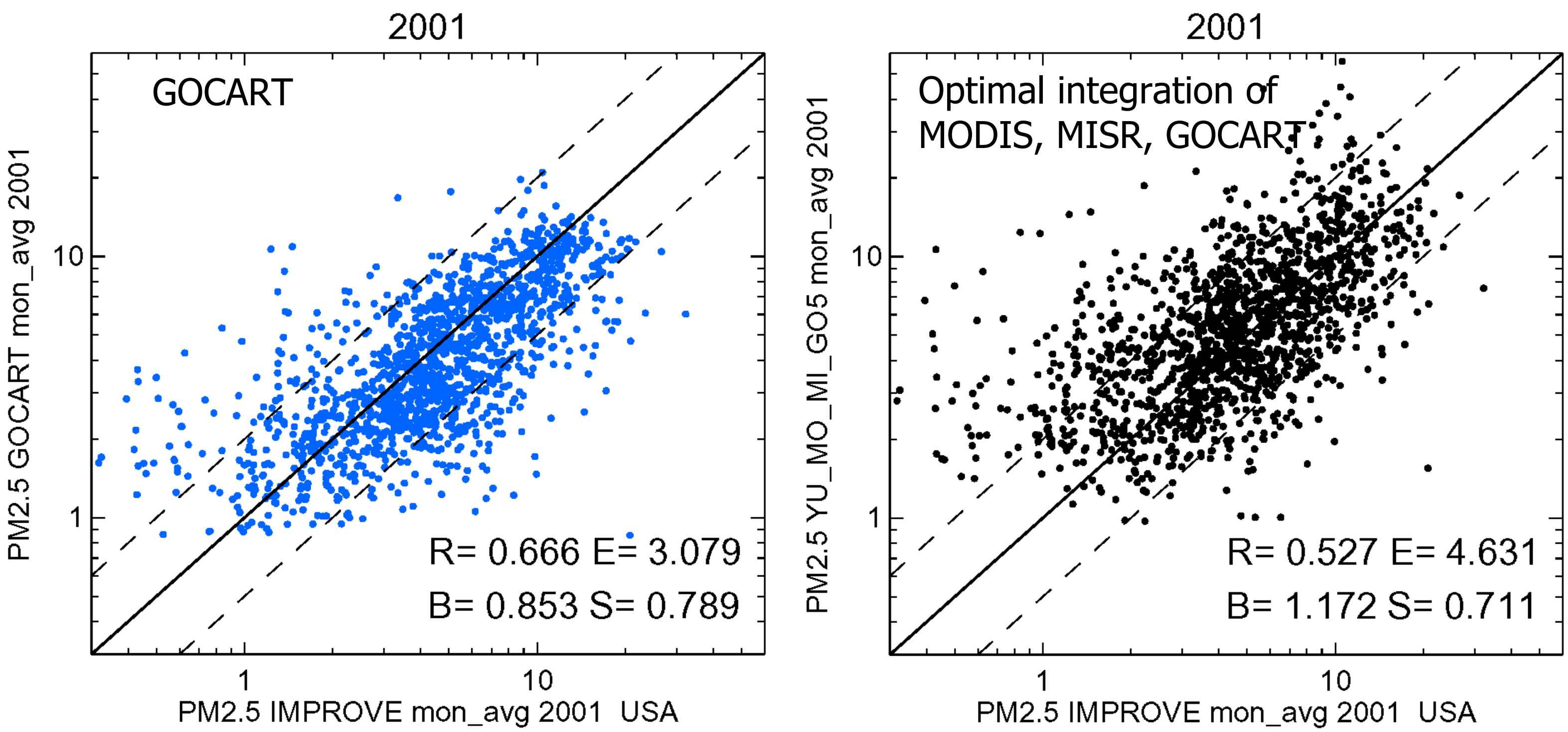


MO_MI_GO improves the agreement with AERONET measurements of column AOT…



CONUS

…but does not translate to a better agreement with IMRPOVE PM2.5



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Q2.	Can we use data assimilation to improve PM2.5 prediction?
R2.	• Using aerosol assimilation of satellite data may not improve PM2.5 prediction compared with using model only, due to lack of constraints of vertical profile and composition • 3-D assimilation (e.g. AOD+lidar) is likely to significantly enhance the PM2.5 estimation but may not be practical for daily forecasts • Without (a) high quality model(s) the quality of assimilation cannot sustain • Model development and improvement is the key to integrate the knowledge and data for forecasts, assessments, analyses, and observation designing

Q3.

What are the critical needs?

R3.

- Space sensor for global or near global coverage:
  - Vertical profile measurement to resolve BL
  - Composition
  - Daily revisit (minimum)
- Ground-based networks for diurnal variation, detailed composition, and for satellite validation (mostly likely over North America and Europe):
  - AERONET type + lidar
  - Chemical composition (IMPROVE type)
- In-situ measurements (once in a while) in key areas
- These data provide critical information for model evaluation, improvement, and development

Combination of model and data can:

min

more

- Fill the gaps of observations
- Provide "inside" information of unmeasurable quantities
- Link data from different plateforms (space, ground, aircraft)
- Derive relationships between remote-sensed data (AOD, extinction etc) to surface concentrations and apply these relationships to regions where AQ measurement is none (e.g. developing countries)
- Provide AQ forecast, assessment, and management strategy