Possibilities and Challenges in Using Satellite Aerosol data for Surface PM air quality studies

Mian Chin

NASA Goddard Space Flight Center

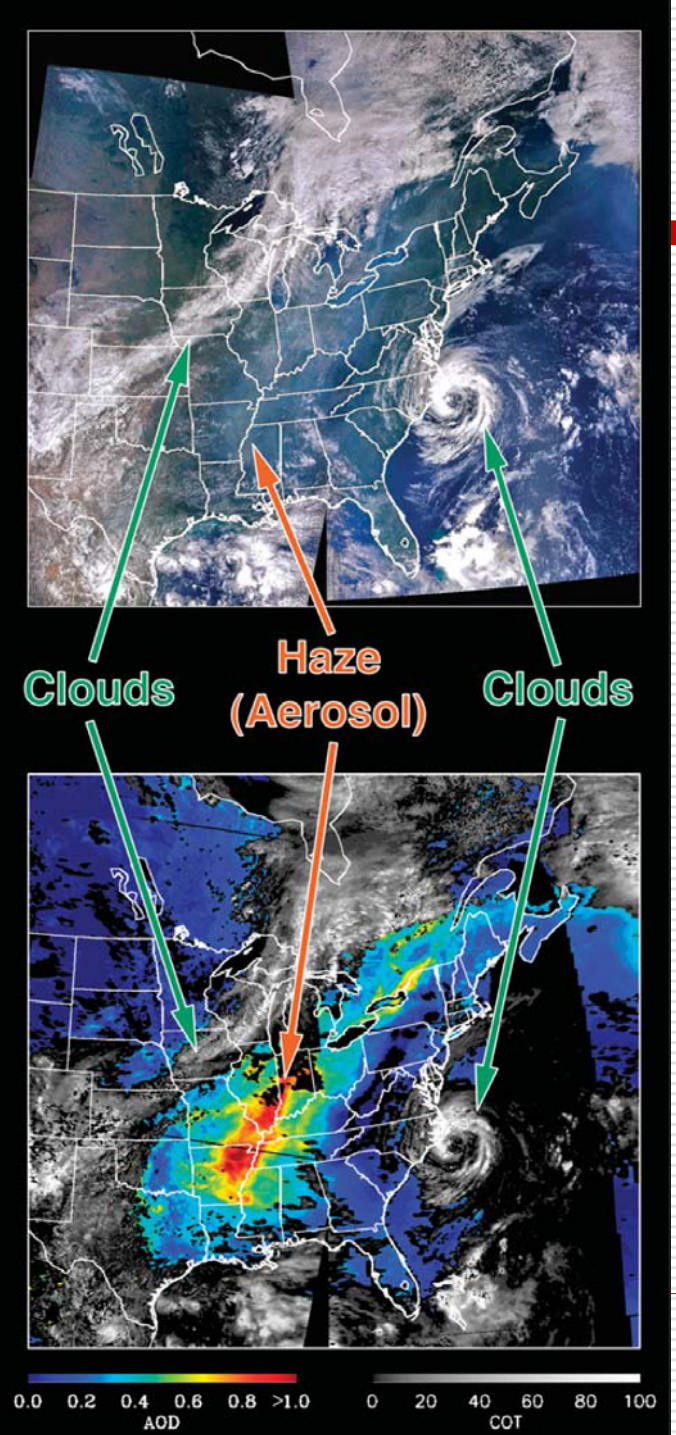
Introduction

- PM2.5 is a key component determining air quality
- Local emission and long-range transport can both contribute to the PM2.5 levels at the surface
- Over many places in the world, there are no existence of systematic air quality monitoring networks
- Satellite observations capability of atmospheric aerosol optical depth (AOD) could lead to a quantum leap in our ability of air quality monitoring and prediction
  - They show large scale pictures to track plume transport
  - They provide indication of possible surface PM2.5 levels
  - They may serve as “air quality index” for those places where no in-situ measurements are available

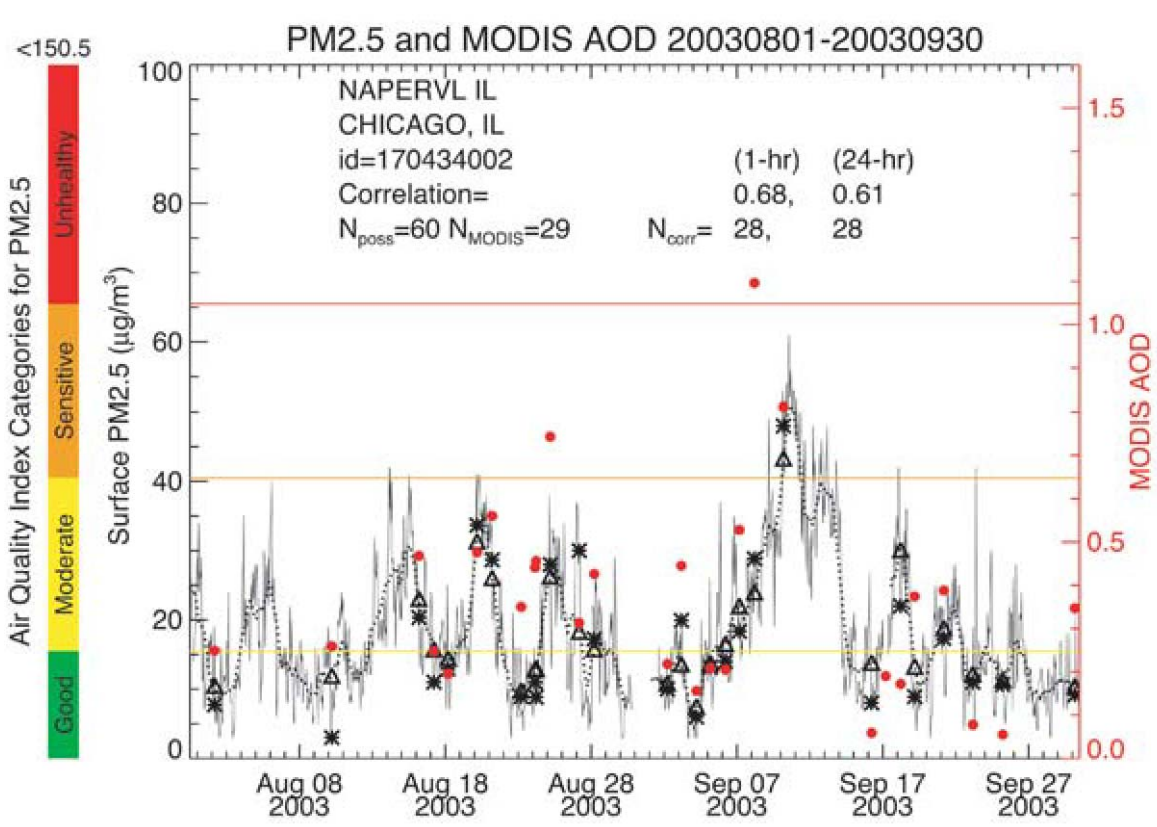
What have been done?

- Analyzing relationships between satellite optical depth (AOD) and surface PM:
  - Satellite data includes MODIS, MISR, SeaWiFS, and sometimes AERONET (ground-based "satellite")
    - Chu et al., 2003; Engel-Cox et al., 2004; Liu et al., 2004, 2005; Al-Saadi et al., 2005; van Donkelaar et al., 2006; Pelletier et al., 2007; Vidot et al., 2007; etc.
- IDEA (infusing satellite data into environmental applications) prototype study in September 2003:
  - Provide MODIS daily AOD and other data (e.g. fire) to local forecasters through a web interface
    - Al-Saadi et al., 2005

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



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



Two questions for discussion:

- Can satellite AOD be used to obtain surface PM2.5?
- Can a CTM be used to “retrieve” PM2.5 from satellite AOD?

Q1: Can satellite AOD be used to obtain surface PM2.5?

- Possible, because studies over the eastern U.S. and Europe have shown high correlations
- Difficult, because AOD and PM2.5 are not always correlated

Corr. Coef. of MODIS AOD and EPA PM2.5, Aug-Sep 2003

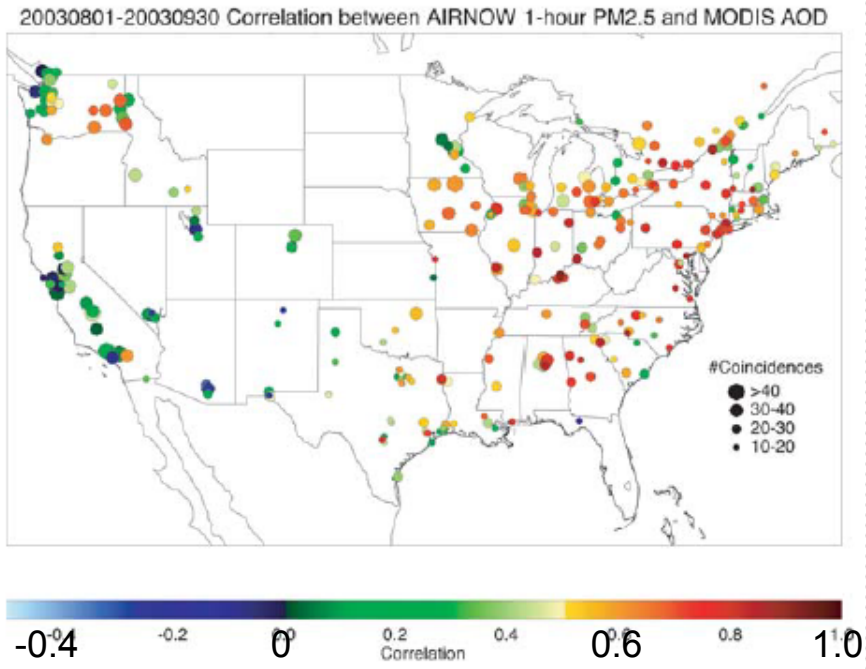
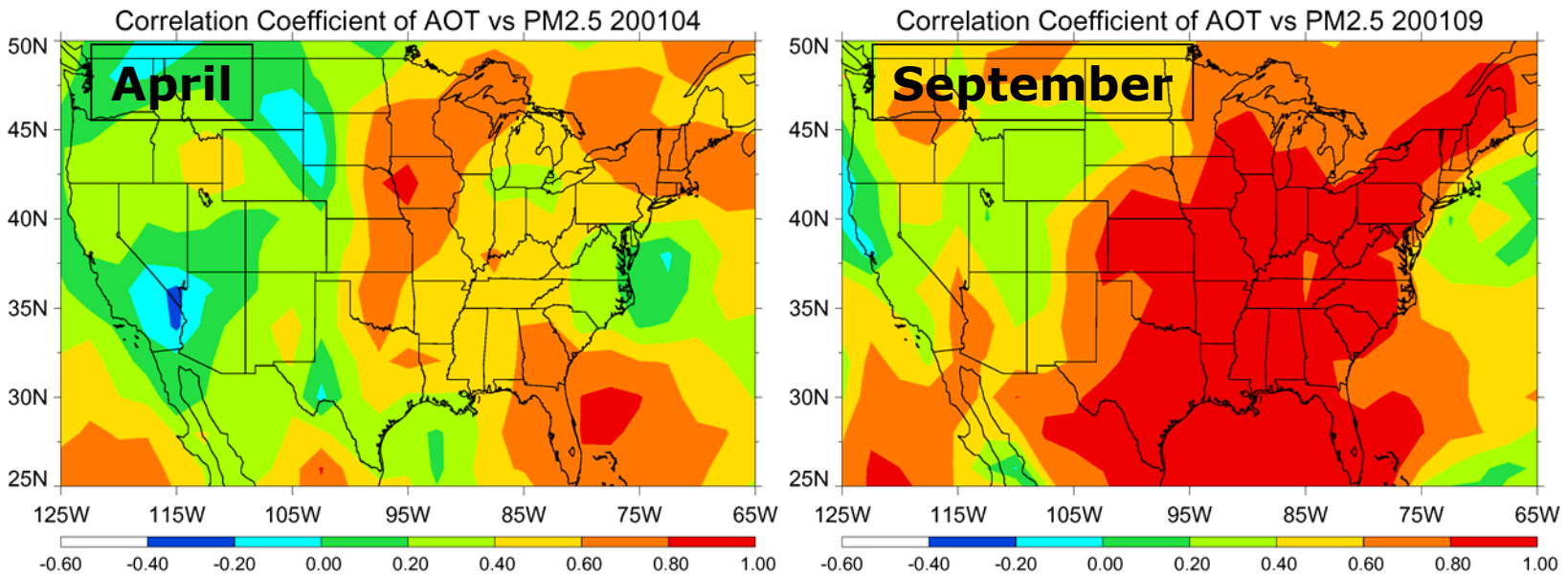


Figure from Al-Saadi et al., 2005

Can we explain the AOD-PM2.5 relationships?

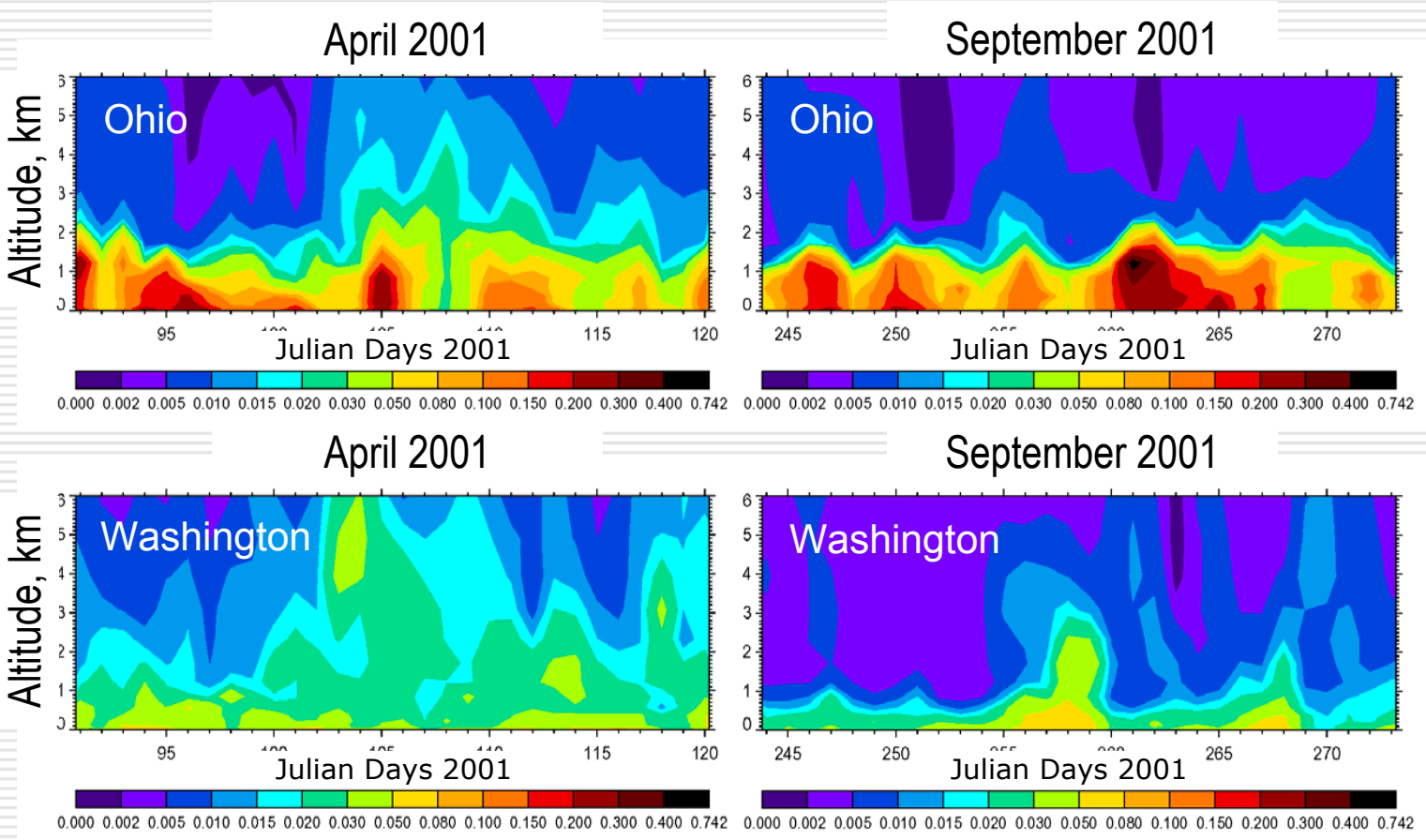
The AOD-PM2.5 correlations from GOCART model:



- AOD and PM2.5 are better correlated in the eastern half of the U.S. than in the western half
- AOD and PM2.5 are better correlated in September than in April
- In addition, slope changes too even at good correlated area (eastern US)

Why does the relationship between AOD and PM2.5 change with location and time?

- Vertical profile, vertical profile, vertical profile:



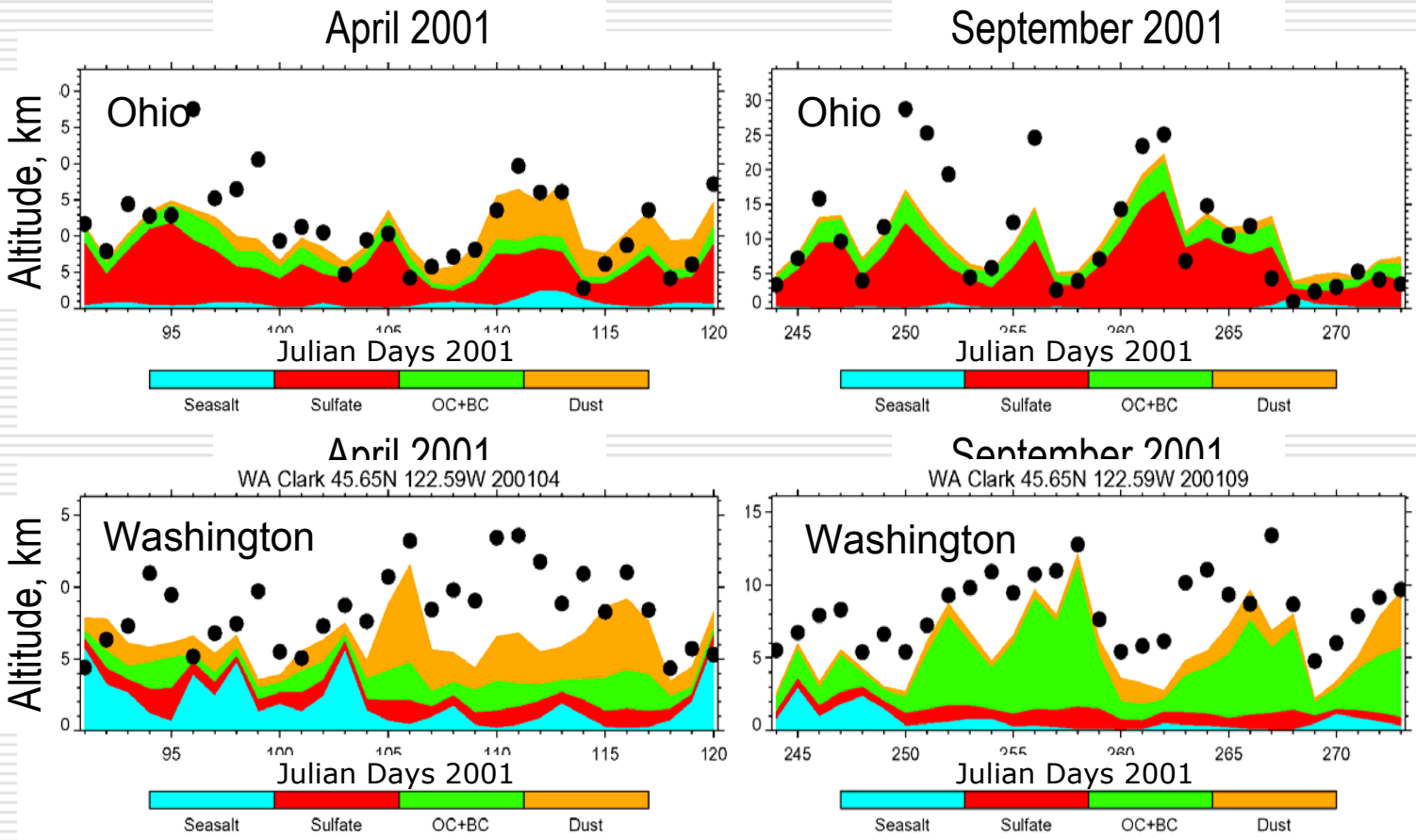
Eastern US: Aerosol is concentrated in boundary layer in both seasons

Western US: Aerosol vertical profile varies significantly with season

Aerosol extinction (km^{-1}) from GOCART

Why the relationship between AOD and PM2.5 changes with location and time?

- Composition, composition, composition:



Eastern US: Sulfate (pollution) is the major PM type for both seasons

Western US: PM composition varies significantly with season

Color shads: PM2.5 from GOCART Circles: EPA data

Summary for part 1:

- Satellite AOD data provide “big picture” for AQ guidance, but quantitative use is not always possible
- This is because AOD does not provide information of aerosol vertical distribution and composition, therefore a robust AOD-PM relationship only exists over some places or certain seasons, even in a “model-perfect” world
- Additional limitations of satellite data:
  - Bias, especially over land
  - Spatial/temporal coverage issues (e.g., clear sky only, narrow swath)
  - Inconsistency among different satellite datasets

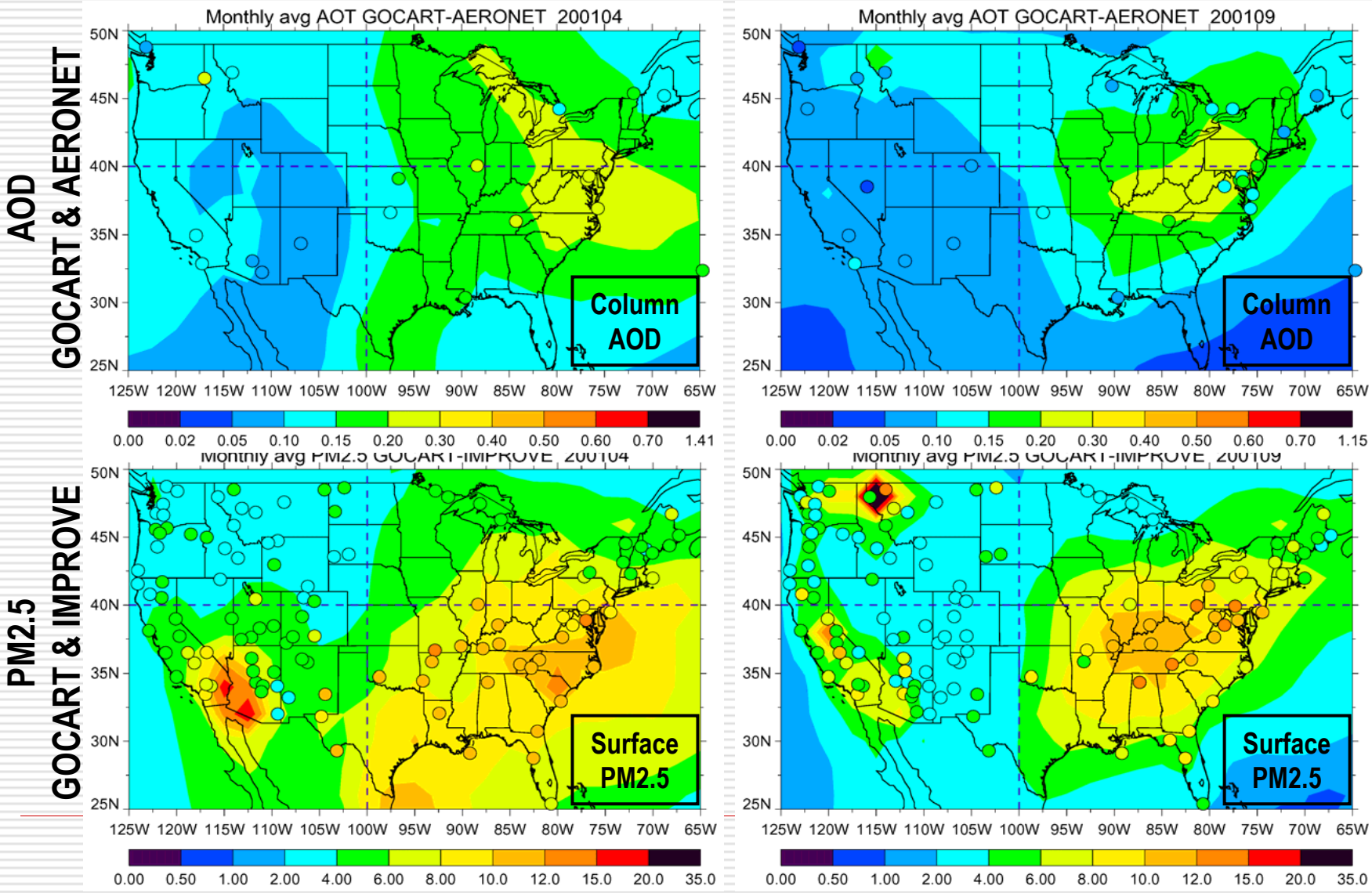
Q2: Can a CTM be used to "retrieve" PM2.5 from satellite AOD?

- Possible, if (1) the model bias on AOD is mostly due to the bias on mass, (2) the model vertical profile and composition are correct, and (3) satellite AOD has small error, such that

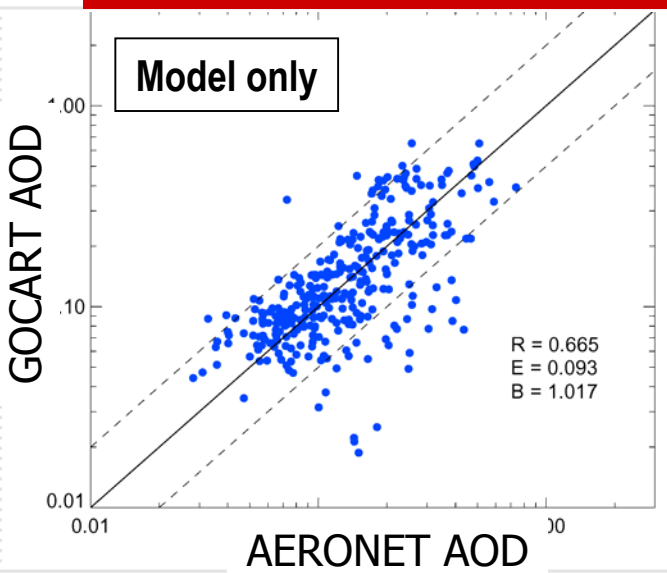
$$PM_{retriev} = \frac{AOD_{sat}}{AOD_{mdl}} \times PM_{mdl}$$

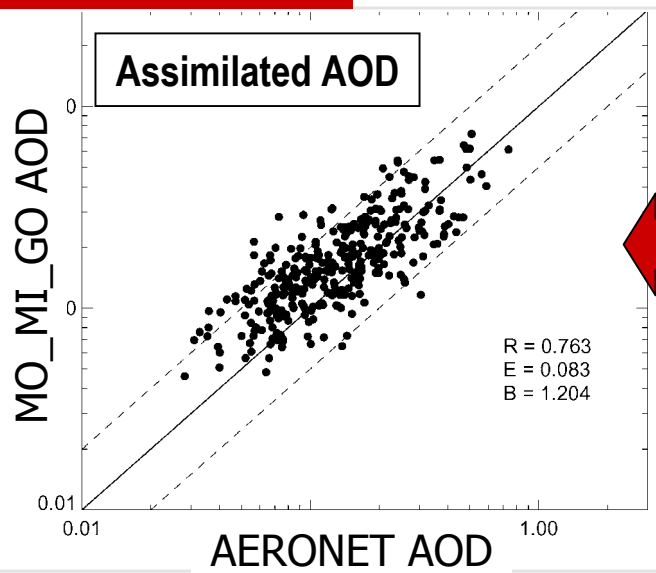
- Difficult, because of the opposite of the above

GOCART vs. AERONET & IMPROVE:

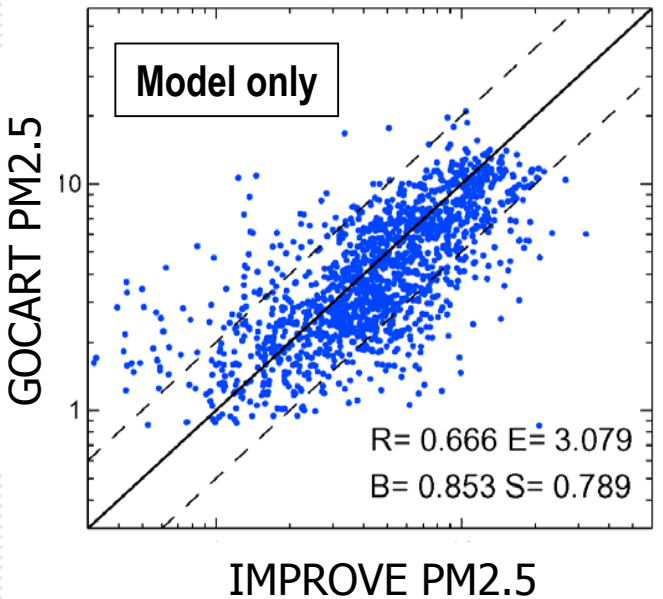


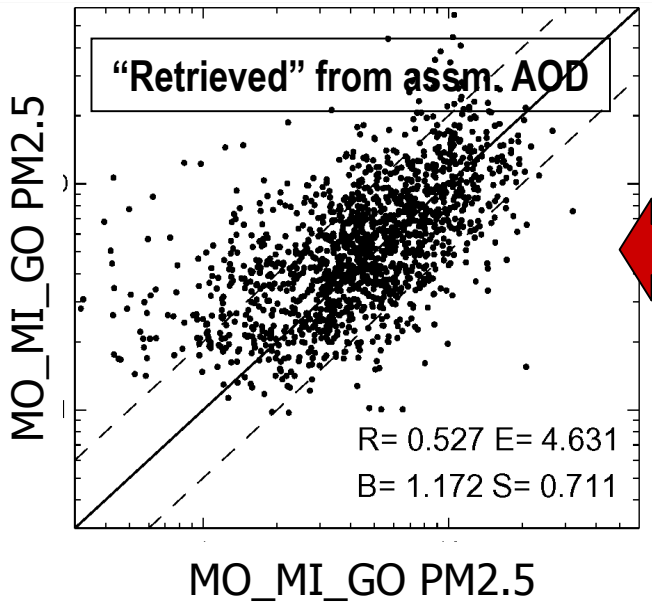
This is an example…





Assimilation of satellite AOD better agrees with AERONET AOD than model does





However the better AOD does not translate to better PM2.5

Summary for part 2:

- Compared with CTM simulations, PM "retrieved" from satellite or other AOD products may not be of better quality, because
  - The magnitude of difference between AOD_{mdl} and AOD_{sat} may not be the same as that between $PM2.5_{mdl}$ and $PM2.5_{obs}$, so a simple scaling of AOD may not work
  - There is little information of aerosol vertical profile and composition from column AOD so that the model errors in these quantities cannot be "corrected" by AOD data
  - Remote sensing of AOD has its own issues (bias, clouds, etc.)

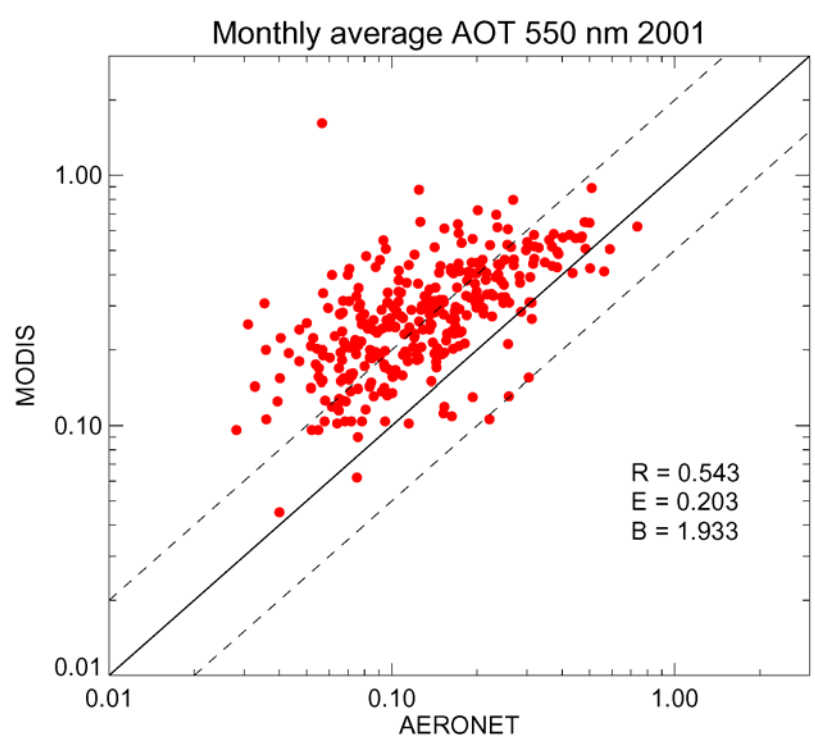
What should be done?

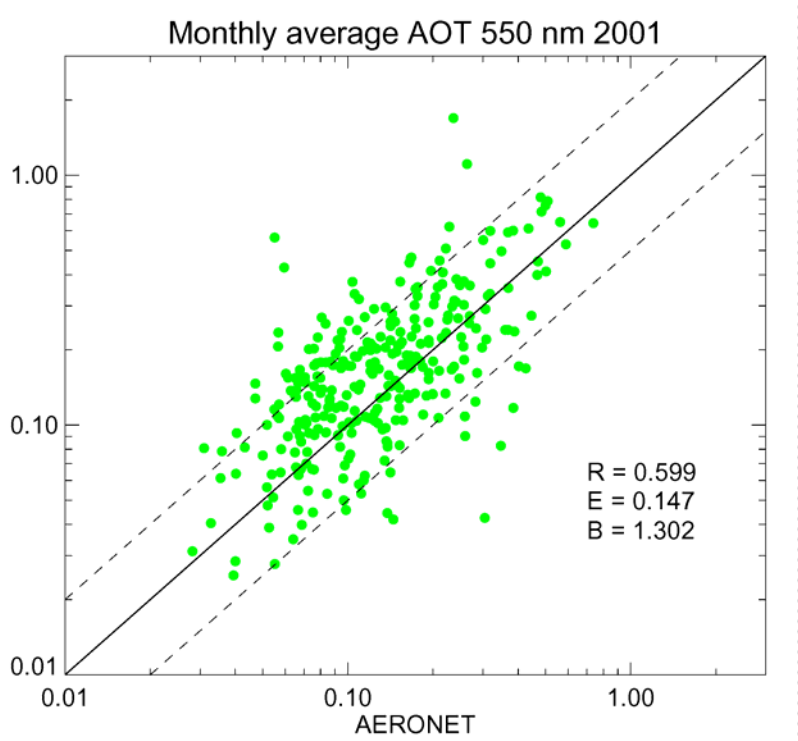
- There is no question that satellite AOD data provide a large scale, dynamic change of aerosol distributions and transport. It is the QUANTITATIVE USE for PM that is challenging
- Despite some success stories in using satellite AOD for estimating PM air quality, a lot of work need to be done to objectively evaluate when and where and to what extent such an application is valid
- A thorough assessment of advantages and limitations of current satellite sensors for AQ application is needed
- Until new satellite sensors are developed that are designed for AQ study, CTMs that incorporate current data (e.g. anthrop. emissions, fire detection and volcanic eruptions) remain a critical role in AQ forecasts

Some current satellite aerosol products

Satellite	*Instrument*	*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)	Uncertainties over land No vertical information No speciation No data when cloudy
Terra	MISR (0.45 – 0.87 μm)	Higher 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) 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 Aerosol Index detecting aerosol in clouds Precursor measurements (SO_2, NO_2)	Biased high No vertical information No speciation No data when cloudy
Calipso	CALIOP (532 & 1064 nm)	Vertical distributions Cloud information	Limited space and time coverage (16-day repeating cycle) Uncertainties in retrieving extinction profiles

Backups


Monthly average AOT 550 nm 2001
MODIS
AERONET
1.00
0.10
0.01
0.01
0.10
1.00
R = 0.543
E = 0.203
B = 1.933


Monthly average AOT 550 nm 2001
AERONET
1.00
0.10
0.01
0.01
0.10
1.00
R = 0.599
E = 0.147
B = 1.302