



# Variational Assimilation of MODIS AOD over East Asia

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# Outline

- Scientific/Technical background
- Results for a dust storm event over East Asia
- Future work



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## AOD DA: previous work

- Collins et al. (2001), Adhikary et al. (2008), Zhang et al. (2008, NAAPS)
  - Two-step procedure:
    - first use 2D-OI or 2D-VAR to analyze 2D AOD field
    - then adjust 3D aerosol concentration profiles from updated AOD fields.
  - Usually do a scaling in the second step by assuming constant weight of each species to total aerosol mass concentration.
- Benedetti et al. (2009, ECMWF): 4DVAR, but use total aerosol mass as analysis variable





# Our approach for AOD DA: 3DVAR

- Directly analyze 3D aerosol mass concentration with a one-step procedure of variational minimization within the GSI
  - Do NOT apply any assumption about vertical shape and relative weight of individual species.
- 14 WRF/Chem-GOCART 3D aerosol mass concentration as analysis variables
  - need background error covariance statistics for each aerosol species
- Use CRTM as the AOD observation operator, including both forward and Jacobian models.

*Liu Z. et al., (2011): Three-dimensional variational assimilation of MODIS aerosol optical depth: Implementation and application to a dust storm over East Asia. Accepted by JGR.*



# Advantages of our 3DVAR approach

- Straightforward to add more AOD data from multi-sensor/angle products and also other aerosol related observations (e.g., PM<sub>10</sub>/PM<sub>2.5</sub>, Lidar ext. profiles).
- Allow simultaneous assimilation of aerosol and meteor. observations (e.g., humidity and hydrophilic aerosols).
  - though NOT for the results shown here



<http://modis-atmos.gsfc.nasa.gov/index.html>

## MODIS Aerosol Products

MOD - Terra

MYD - Aqua

**MOD04\_L2: MODIS Level 2 Aerosol Product at 10 km spatial resolution**

MOD08\_D3: MODIS Level 3 Daily Atmosphere Gridded (1°X1°) Product

MOD08\_E3: MODIS Level 3 Eight Day Atmosphere Gridded (1°X1°) Product

MOD08\_M3: MODIS Level 3 Monthly Atmosphere Gridded (1°X1°) Product

## Index of [ftp://ladsweb.nascom.nasa.gov/allData/51/MYD04\\_L2/2010/045/](ftp://ladsweb.nascom.nasa.gov/allData/51/MYD04_L2/2010/045/)

Collection 51 ←

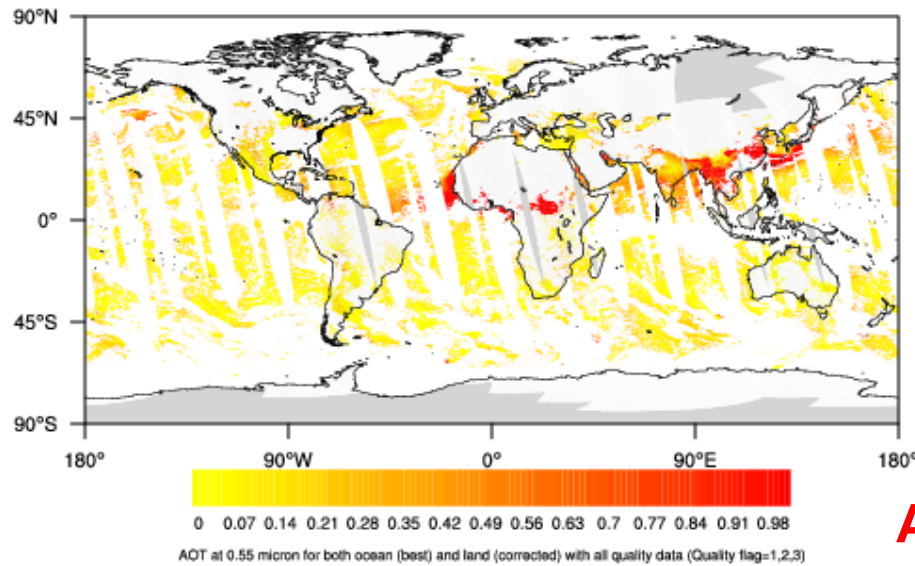
[Up to higher level directory](#)

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Start time HHMM	<a href="#">MYD04_L2.A2010045.0100.051.2010047000052.hdf</a>		2/15/10 7:07:00 PM
	<a href="#">MYD04_L2.A2010045.0105.051.2010046235927.hdf</a>		2/15/10 7:05:00 PM
	<a href="#">MYD04_L2.A2010045.0110.051.2010047000041.hdf</a>		2/15/10 7:07:00 PM
Collection version	<a href="#">MYD04_L2.A2010045.0115.051.2010047000409.hdf</a>		2/15/10 7:12:00 PM
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	<a href="#">MYD04_L2.A2010045.0125.051.2010047000238.hdf</a>		2/15/10 7:07:00 PM

One HDF file consists of 5 min data (“Granule”)

9th Adjoint Workshop, 10/10/2011

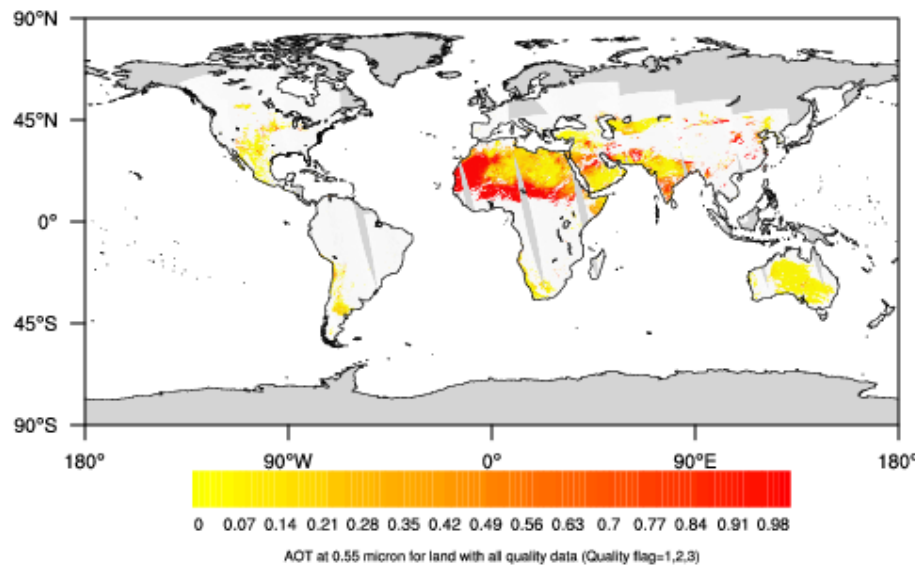
137 MODIS swaths: 20100321000008 - 20100321233508



Standard AOD product over ocean & land

**Assimilate only 0.55  $\mu\text{m}$  band from both Terra and Aqua.**

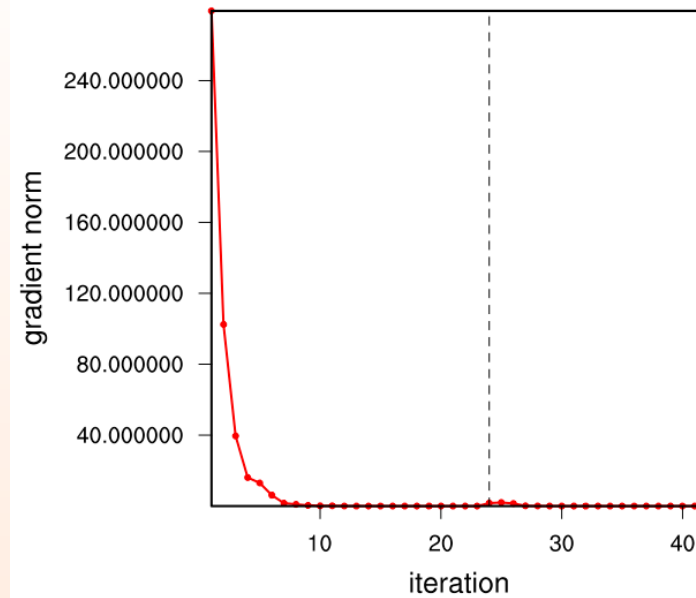
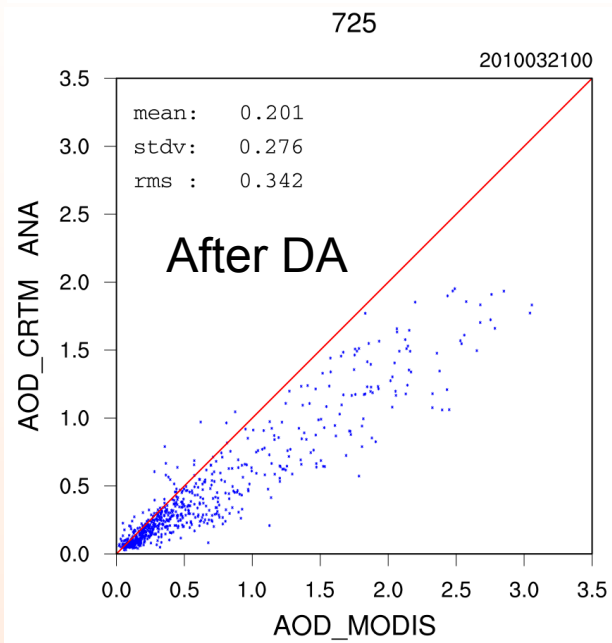
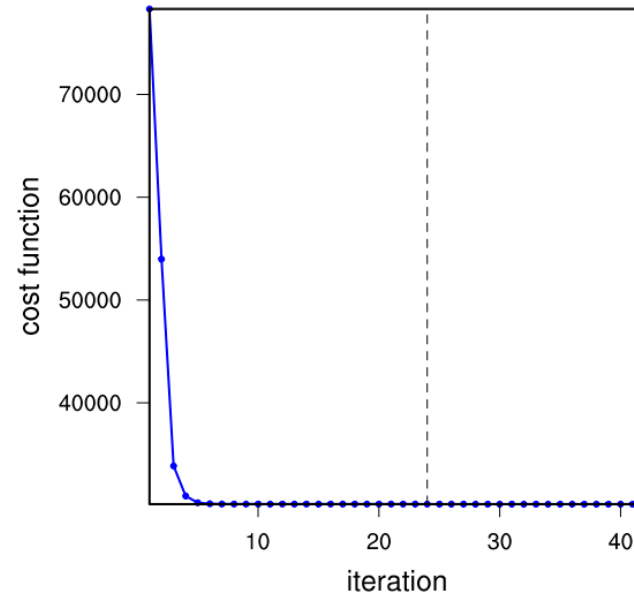
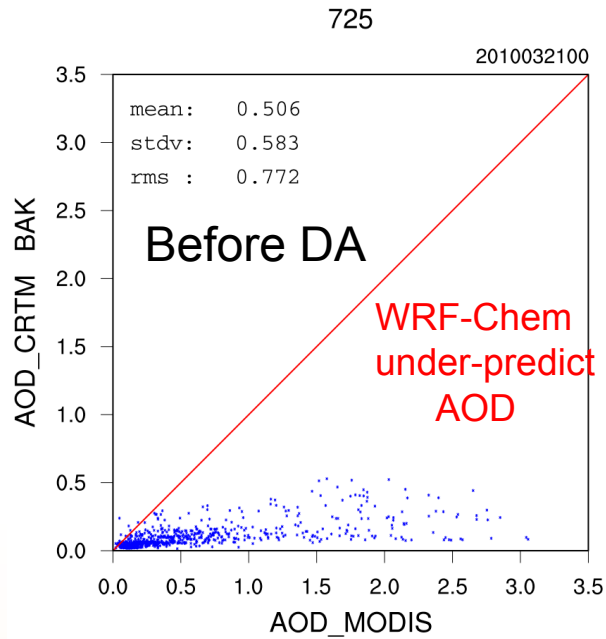
137 MODIS swaths: 20100321000008 - 20100321233508



“Deep Blue” AOD product over bright land surface



# Minimization





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# Dust storm affected Nanjing on Mar. 21, 2010



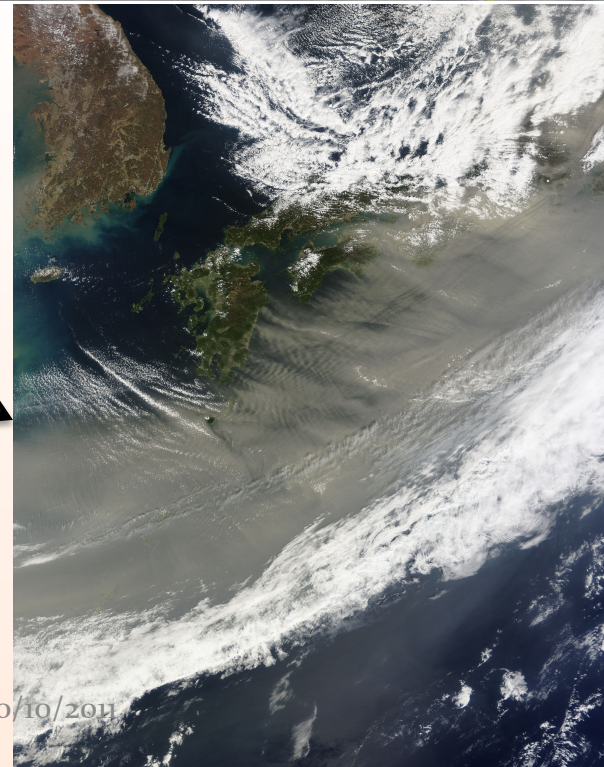
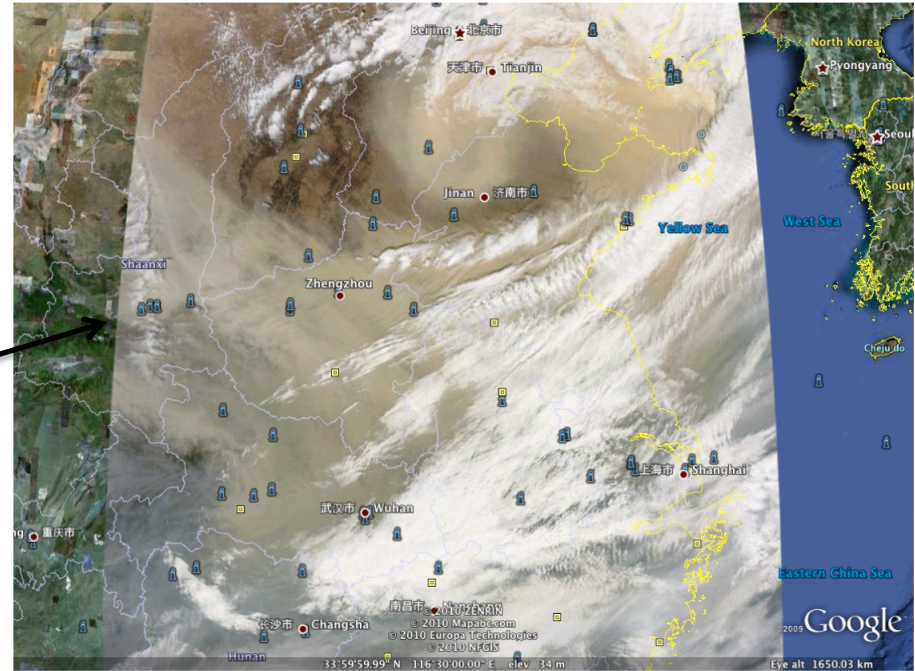
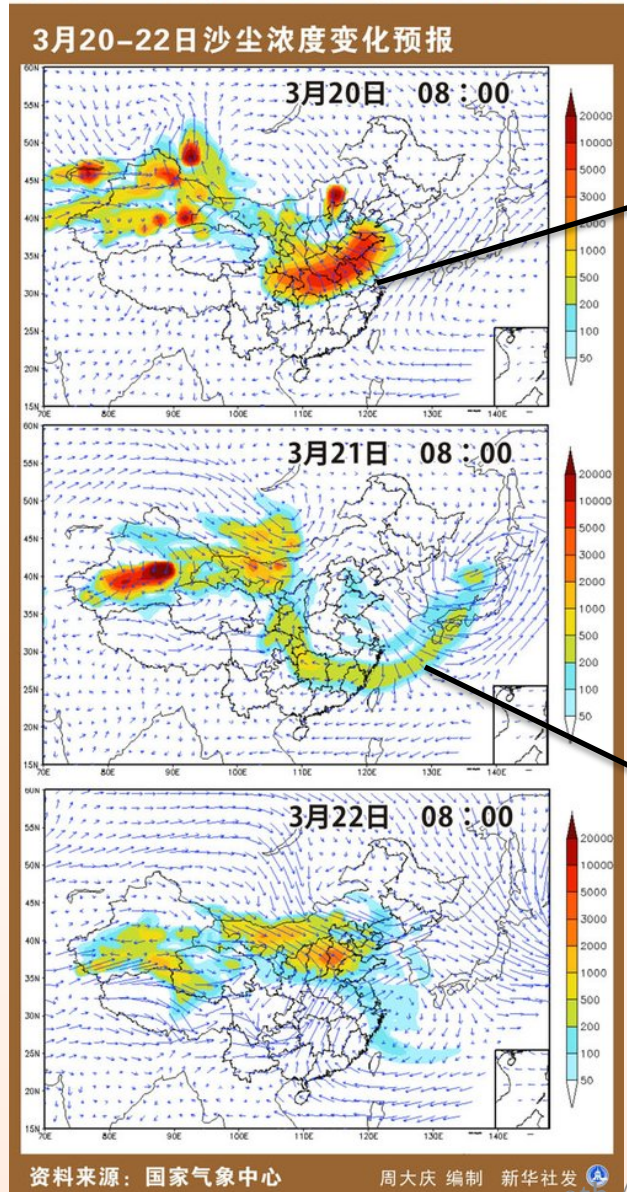
昨天北方沙尘来到南京,使南京蒙上灰蒙蒙的“沙帐”。张筠 摄





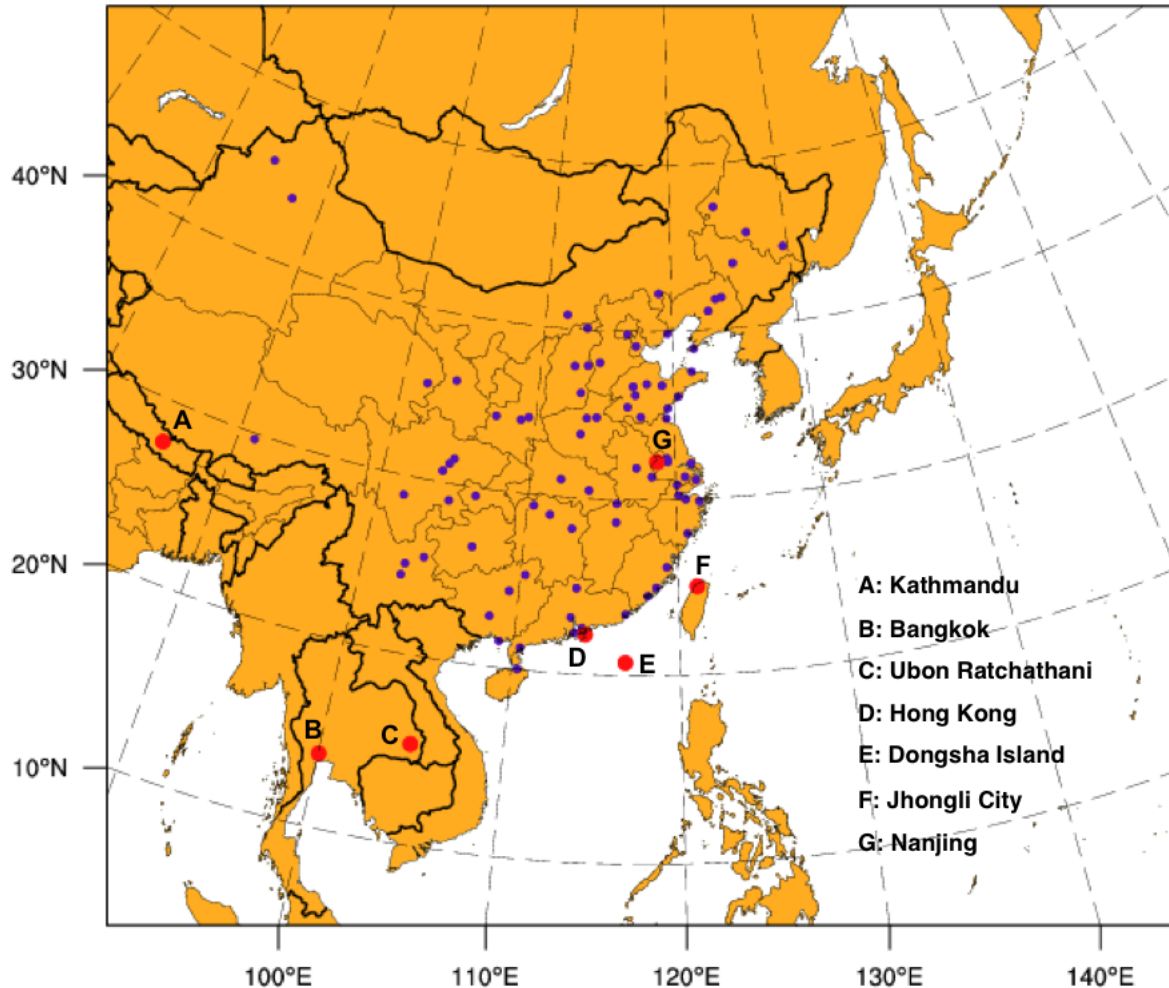
# CMA dust model forecast

## 未来三天沙尘天气过程示意图





# East Asia domain



261x222 @27 km  
45L with top @50 hPa

Validation observations:

7 AERONET sites  
83 PM10 sites

chem\_opt=301:  
GOCART+RACM

Emissions:

Online biogenic  
RETRO+"Streets" anthropogenic  
GOCART dust emission

LBC: NCAR CAM-Chem

6-hr cycling DA/FC experiment:  
17~24 March, 2010.

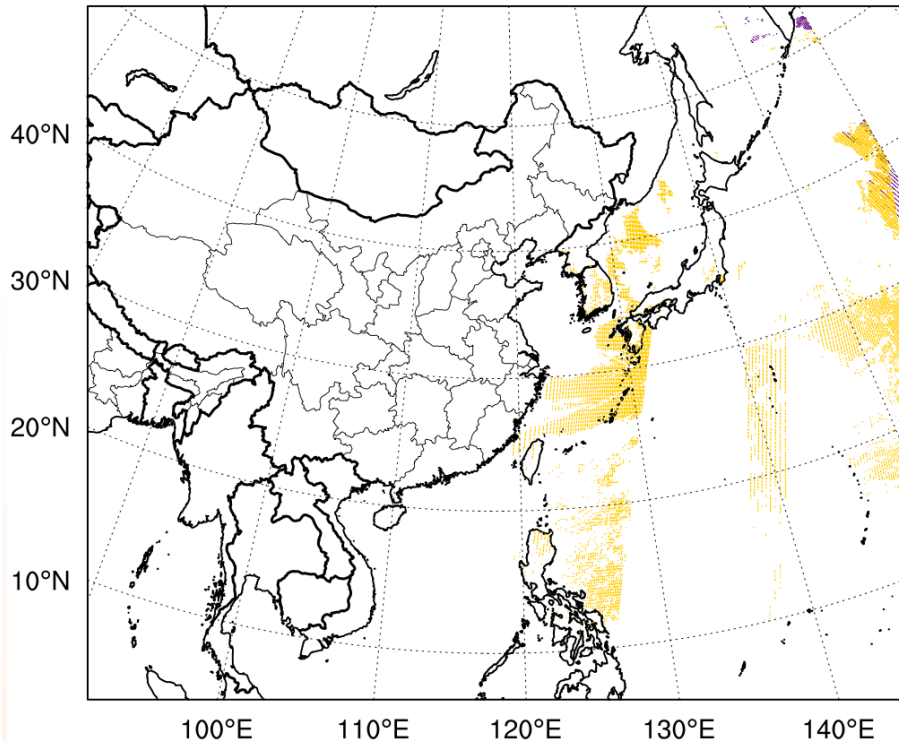
MET fields updated from GFS.  
Aerosol fields updated from AOD DA.

# L2 MODIS AOD@0.55 $\mu$ m coverage

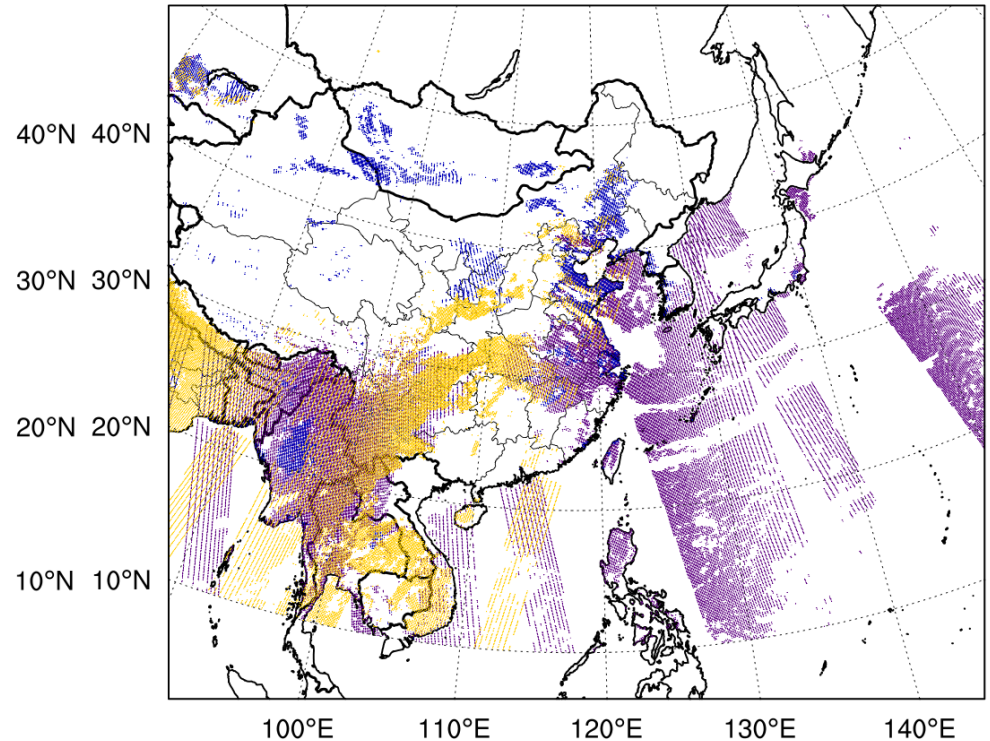
0000 UTC, 21 March 2010

Terra/Aqua

2010032100



0600 UTC, 21 March 2010



Data only available at day time  
(00Z and 06Z), visible band.

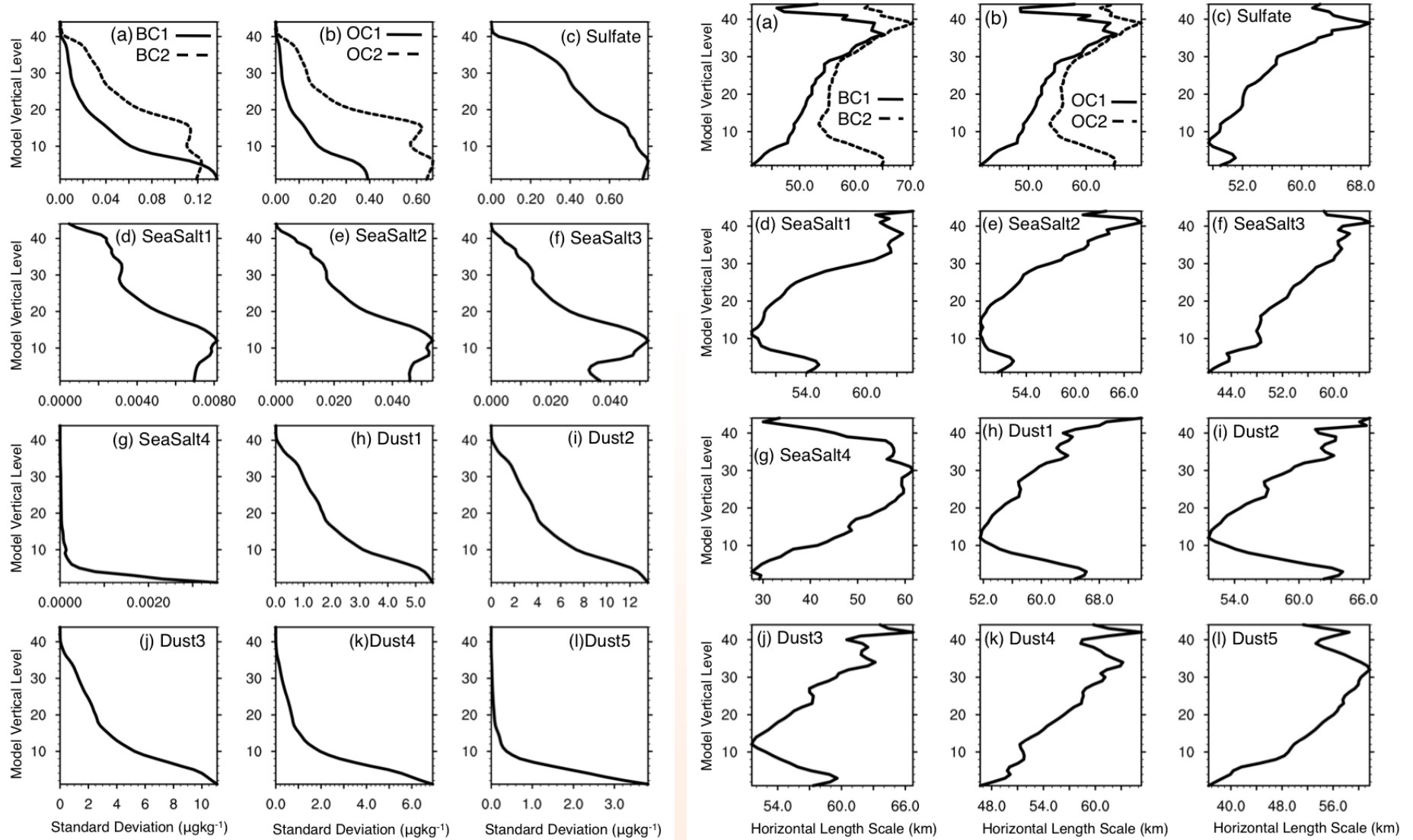
**purple: dark-surface retrievals from Aqua;**  
**gold: dark surface from Terra;**  
**blue: deep-blue produced from Aqua.**



# Estimate B for Aerosol Species

- “NMC” method was used to compute aerosol background error covariance (B) statistics using WRF-Chem model forecasts (at 00Z and 12Z) in March.
  - Uses differences between 24- and 12-hr forecasts valid at the same time
  - Compute standard deviation, vertical and horizontal length-scale for 14 GOCART aerosol variables
  - No multivariate correlation

# Matrix B: Standard deviation & horizontal length-scale





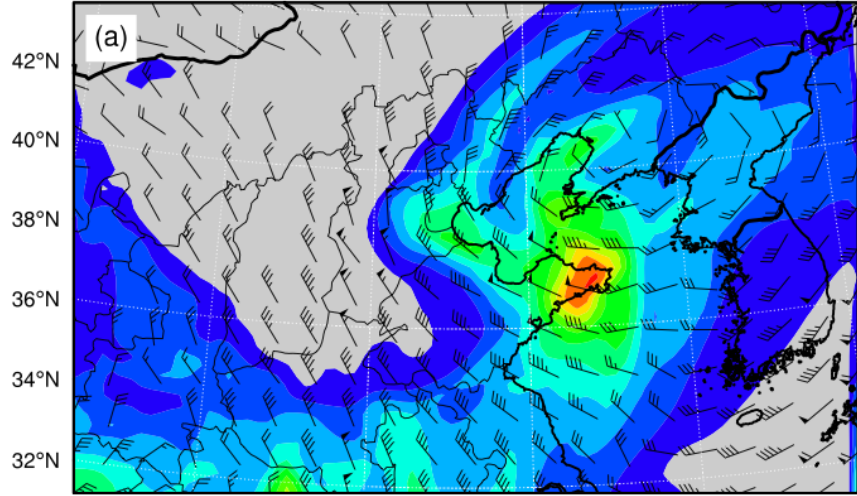


# DUST

## Column dust vs. MODIS true color image. 2010032003

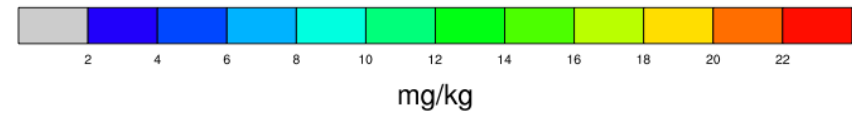
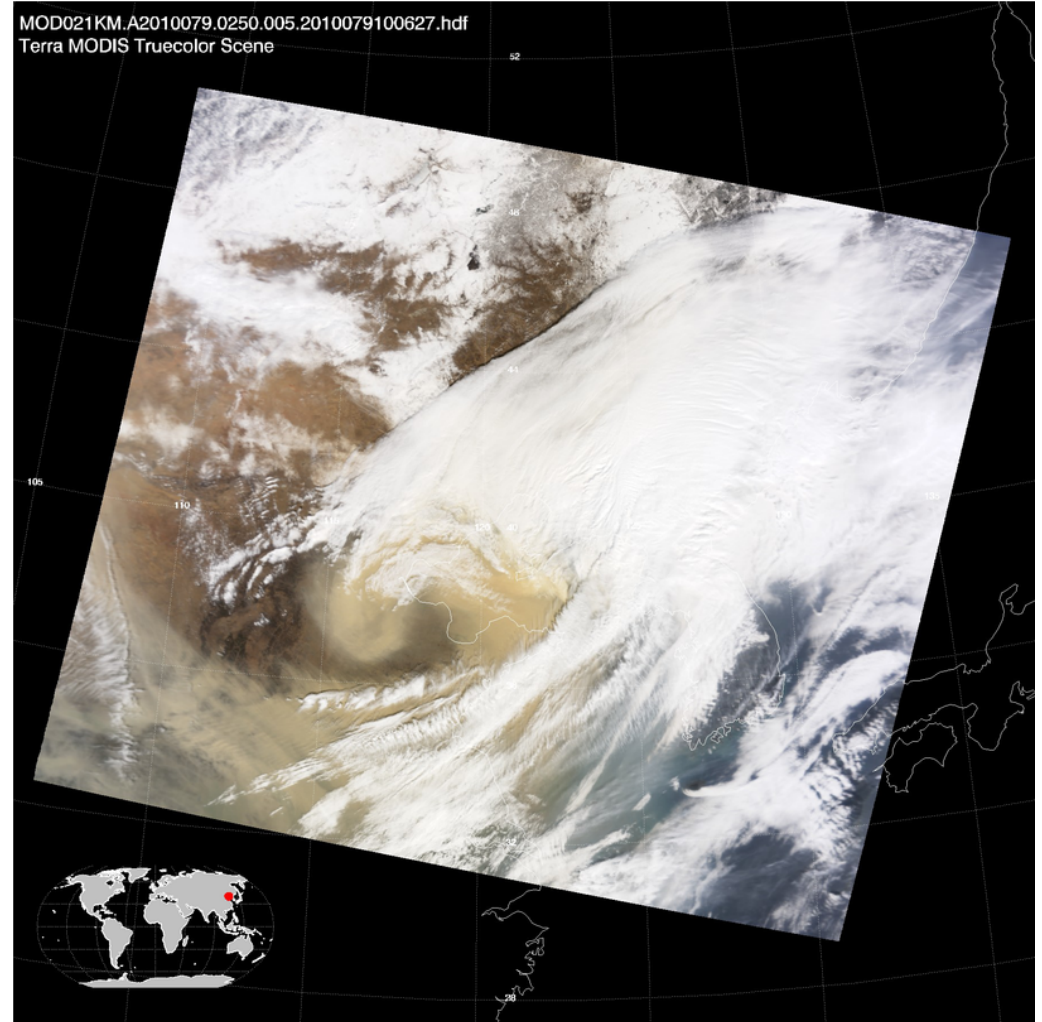
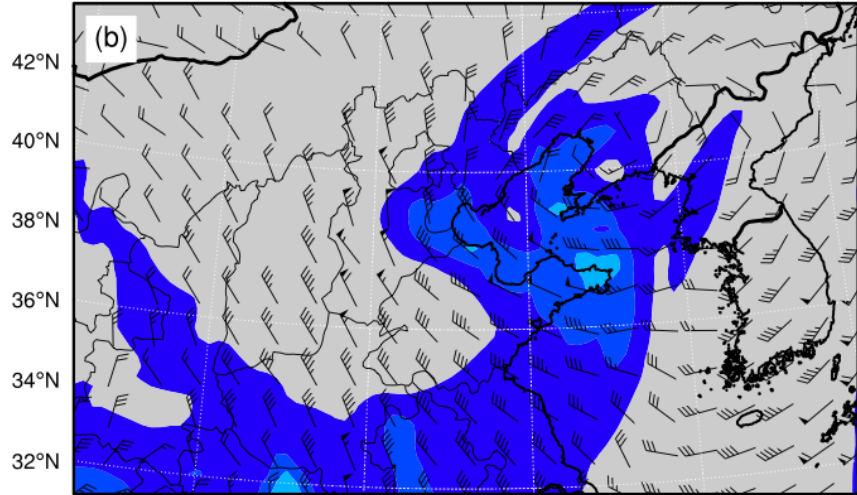
init:2010032000\_valid:2010032003

DA



init:2010032000\_valid:2010032003

noDA

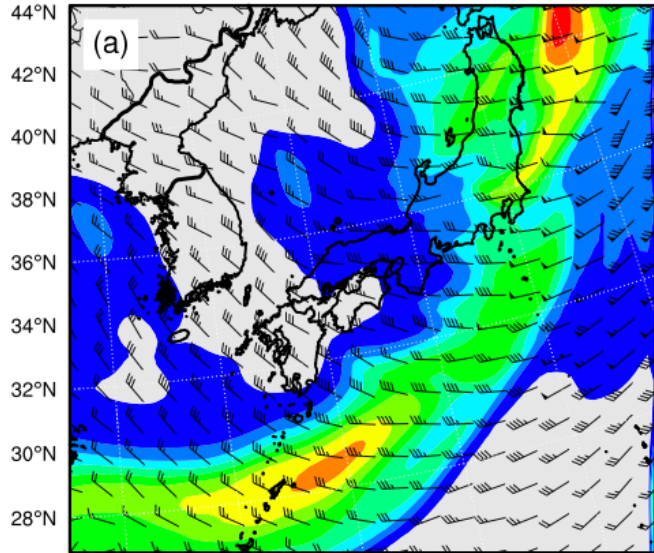


# DUST



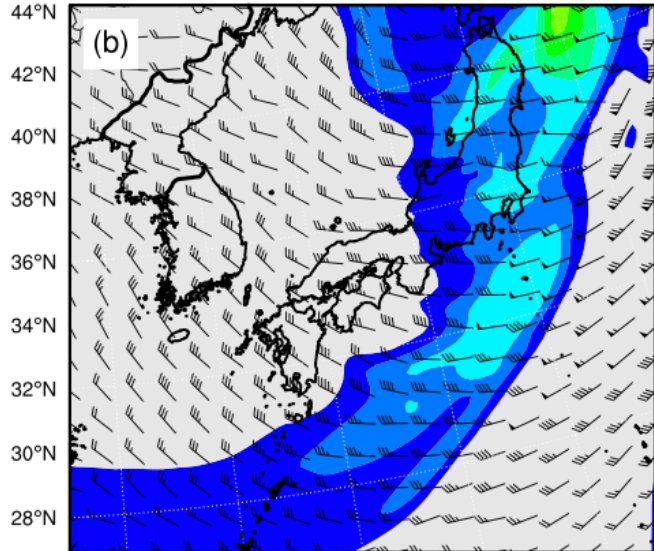
init:2010032100\_valid:2010032103

DA



init:2010032100\_valid:2010032103

noDA

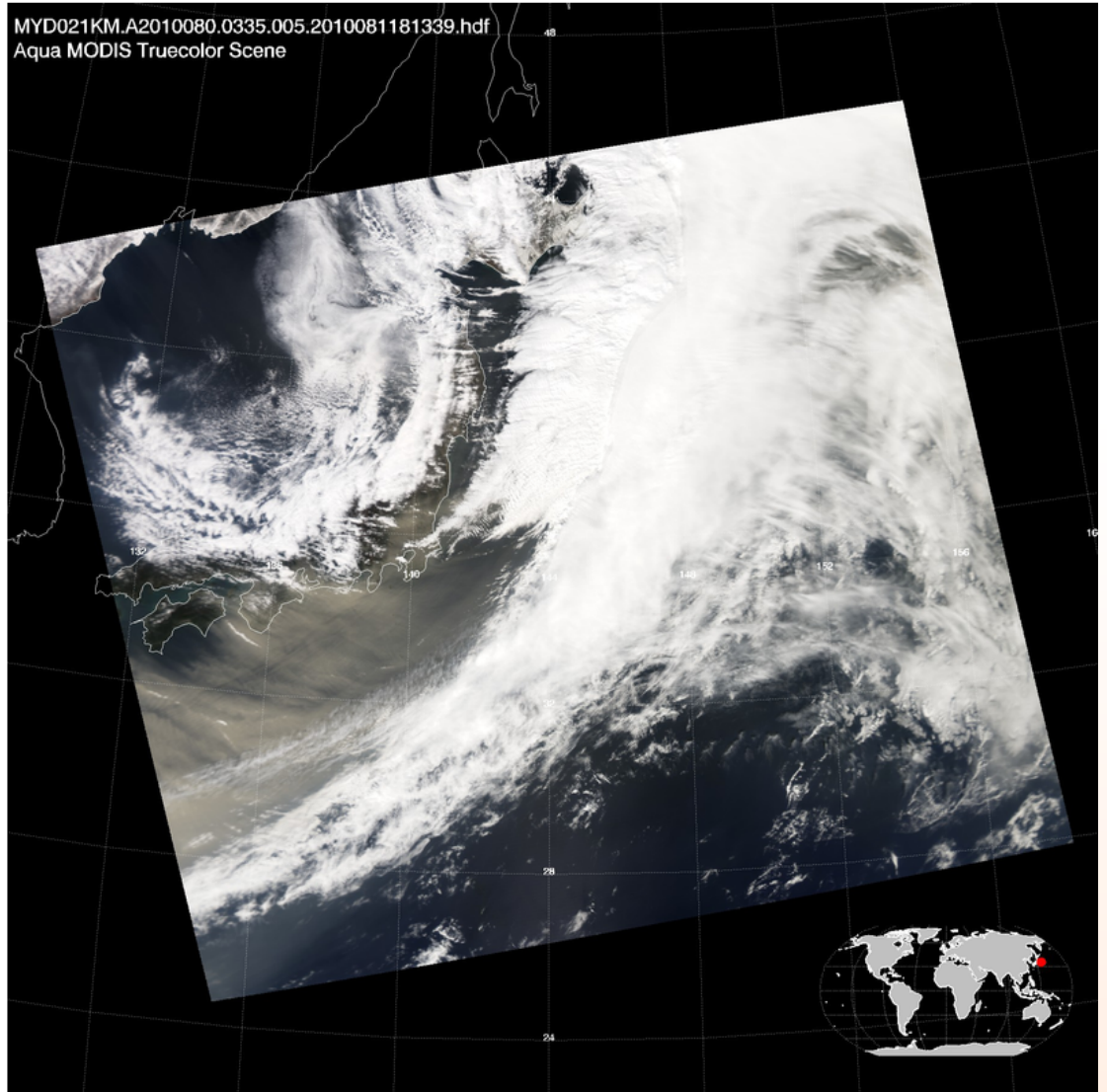


126°E 130°E 134°E 138°E



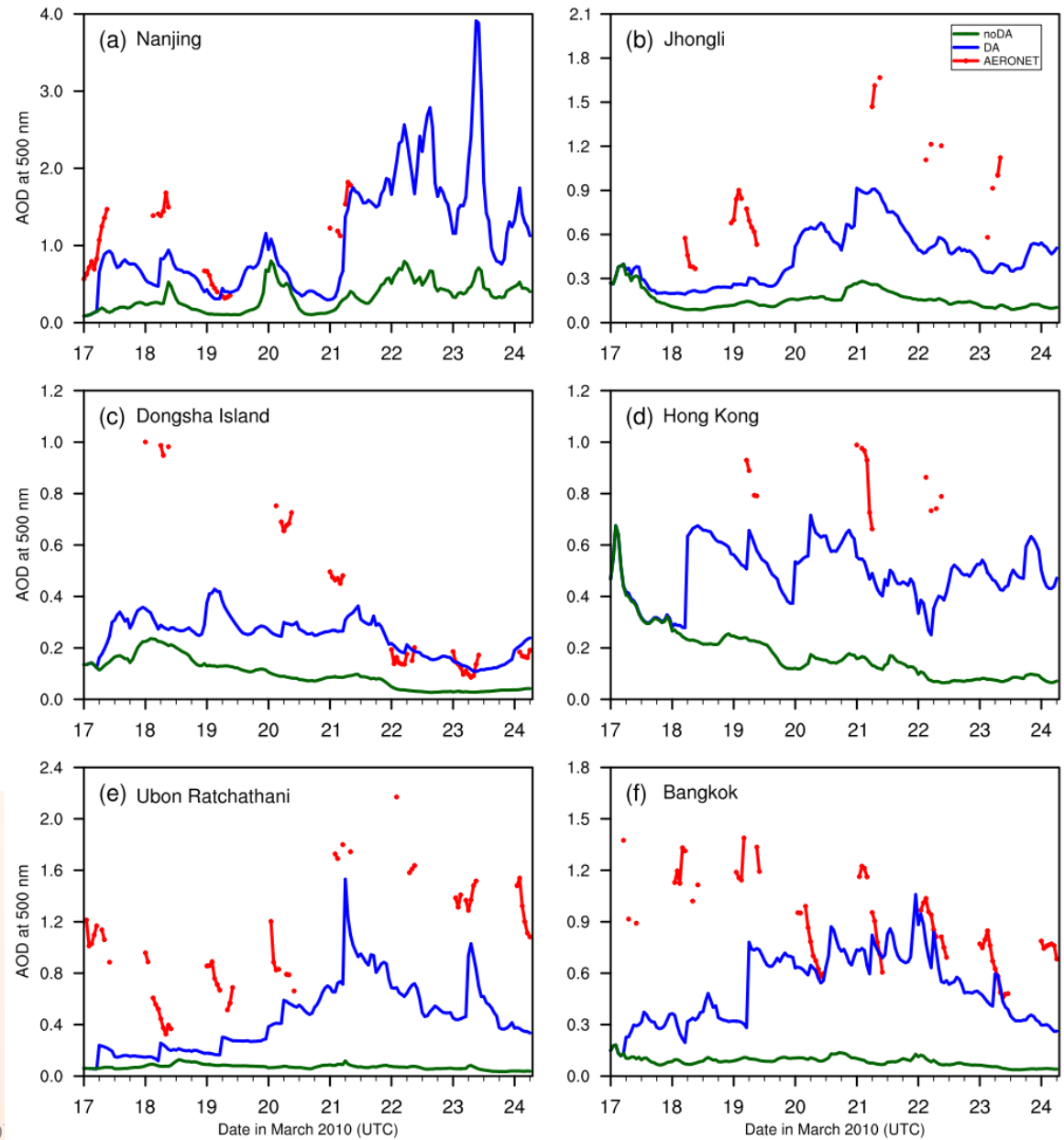
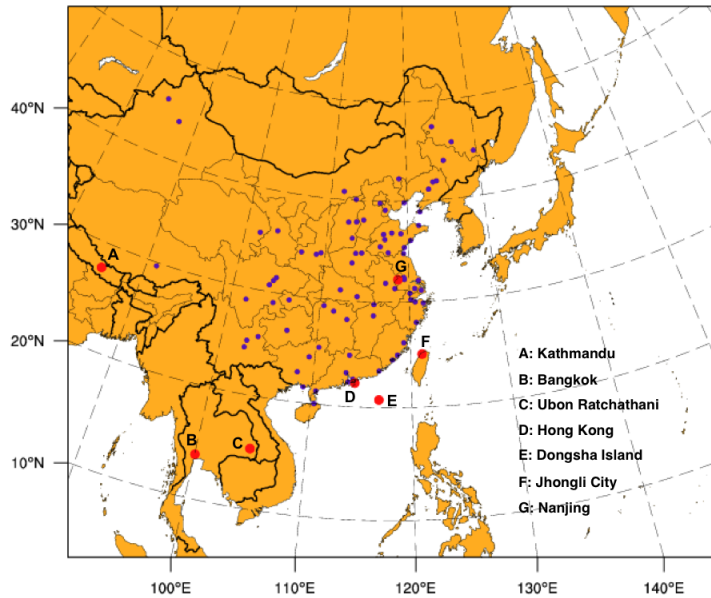
mg/kg

## Column dust vs. MODIS true color image. 2010032103



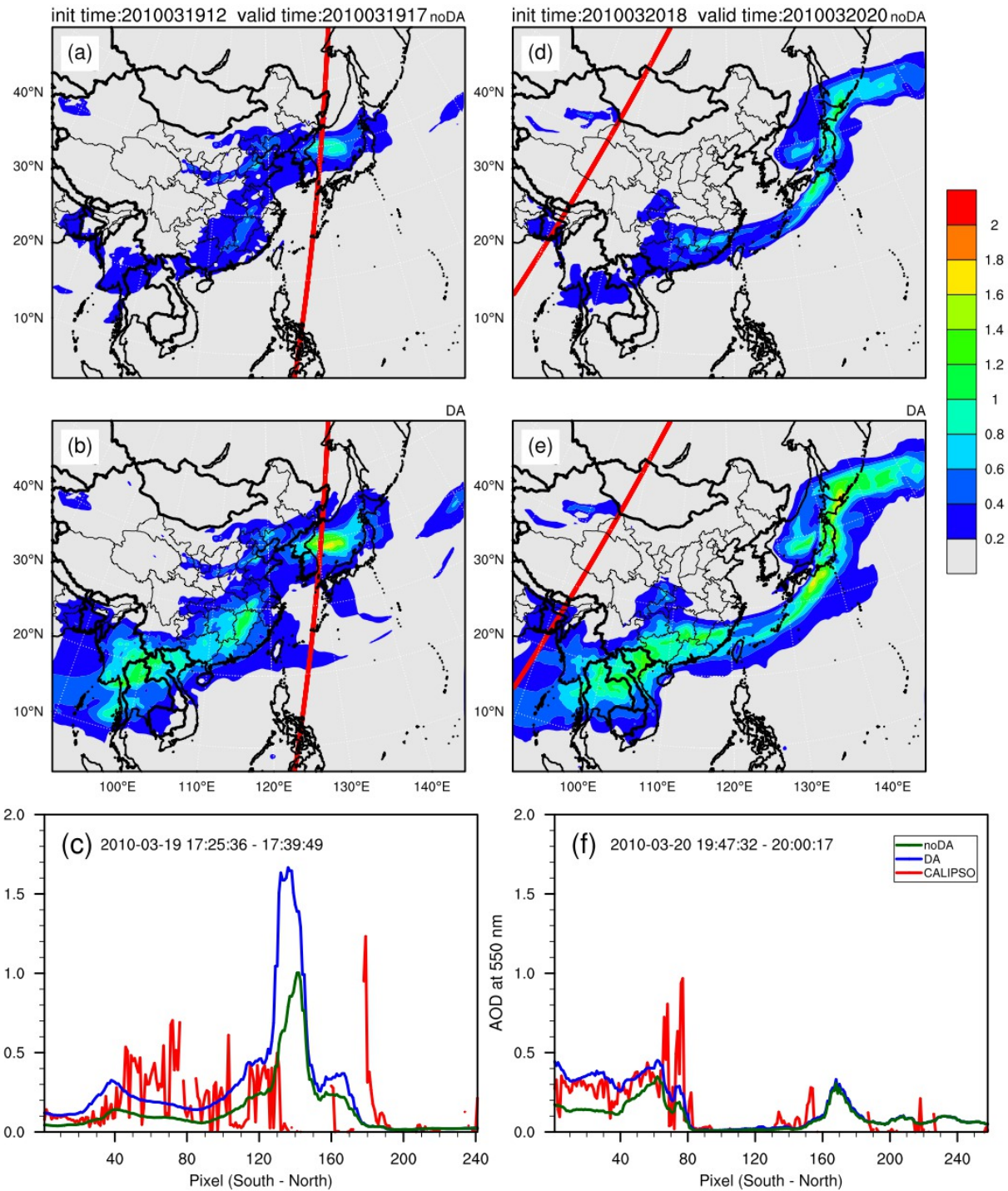


# Verify @550nm at other 6 AERONET sites





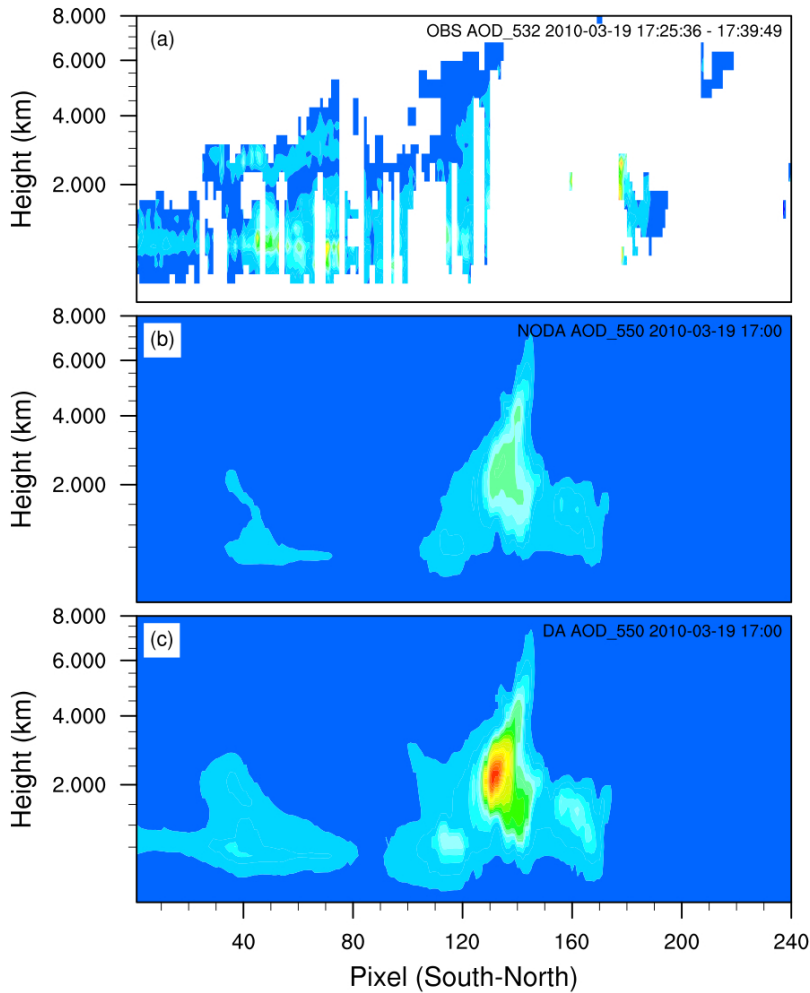
# Verify vs. CALIPSO AOD



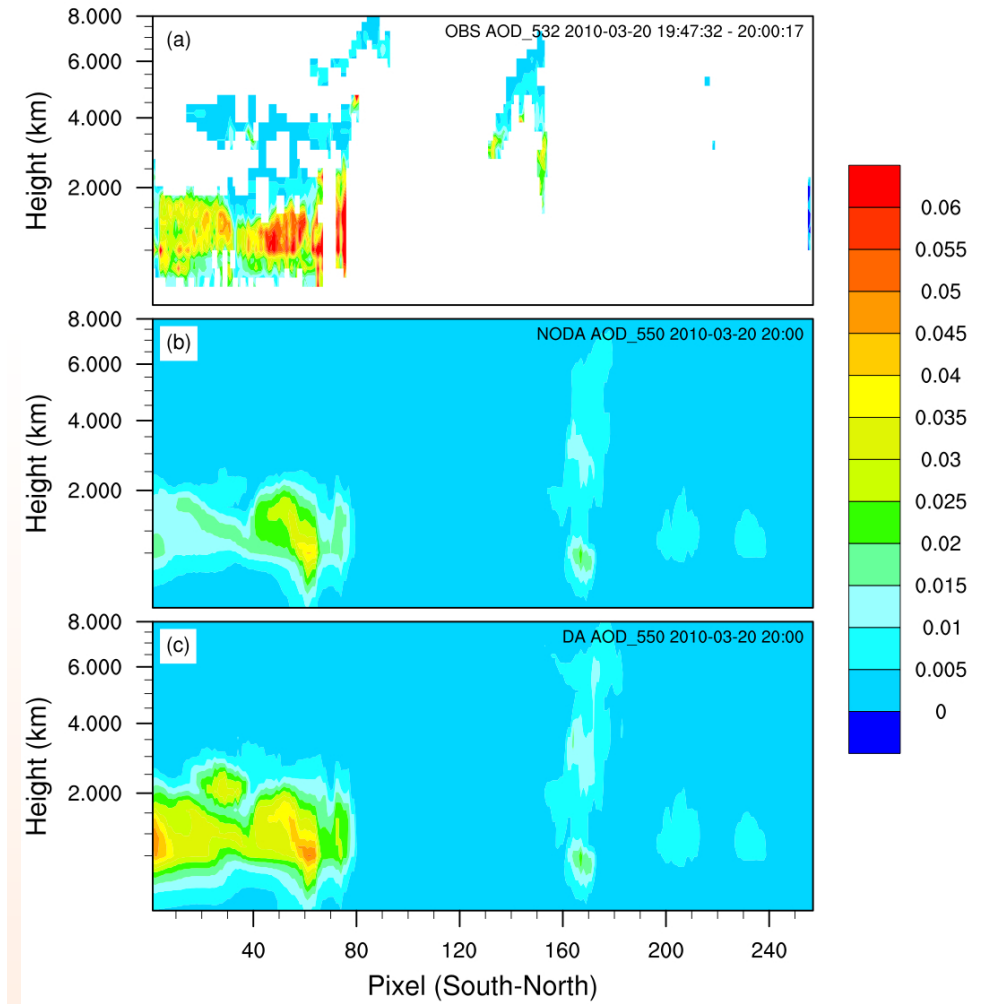


# Vertical distribution of AOD

2010-03-19 17:00

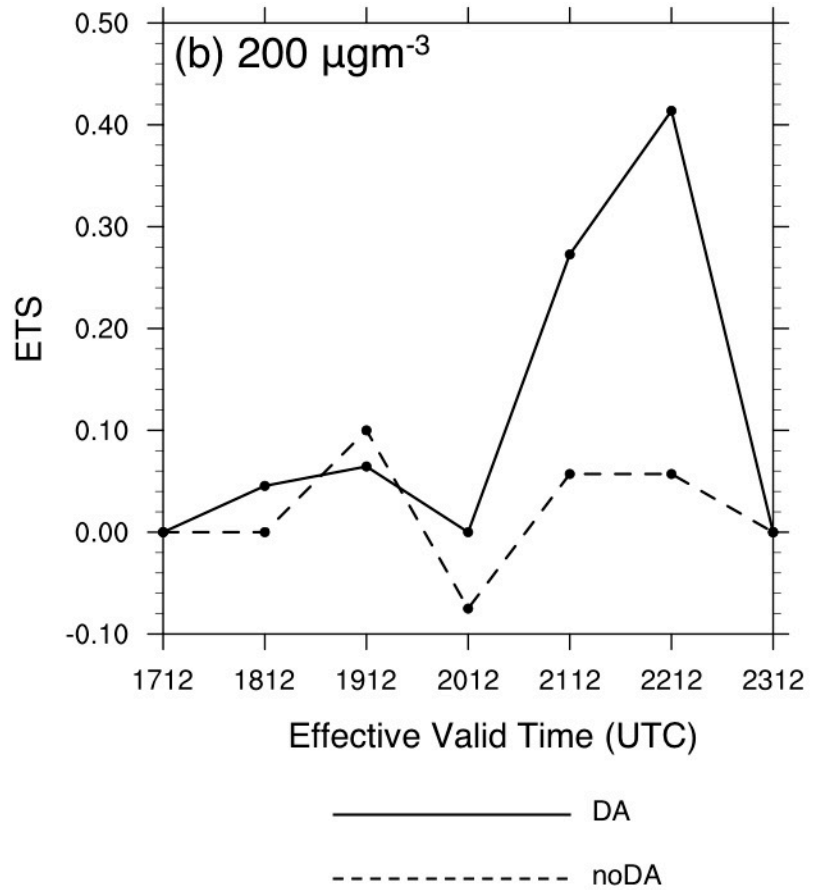
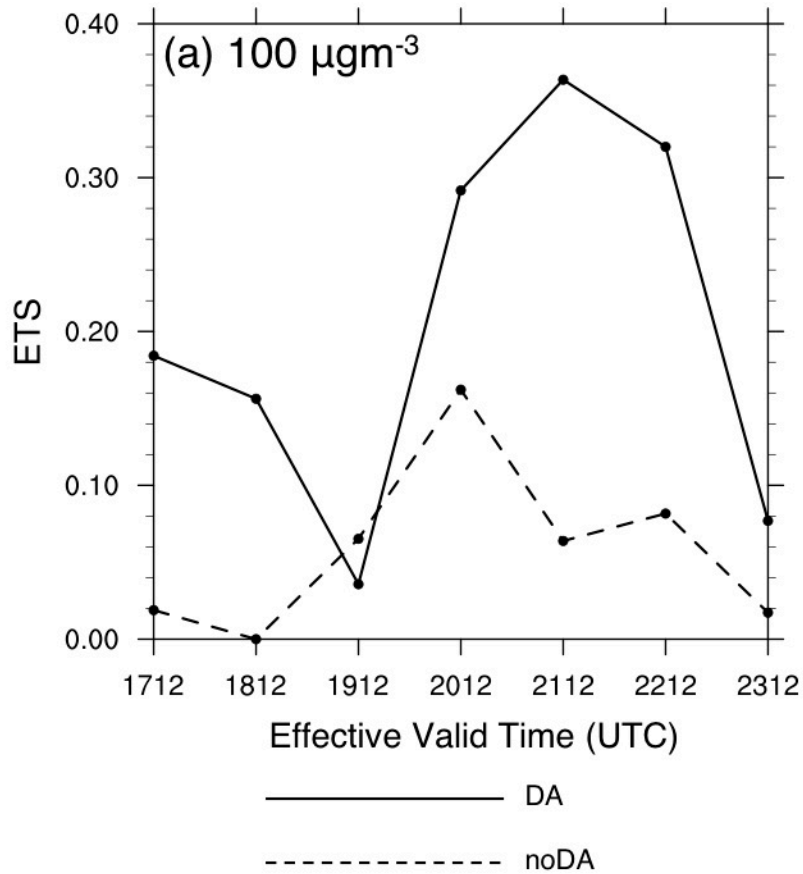


2010-03-20 20:00





# Verify vs. Surface PM10 (83 sites)



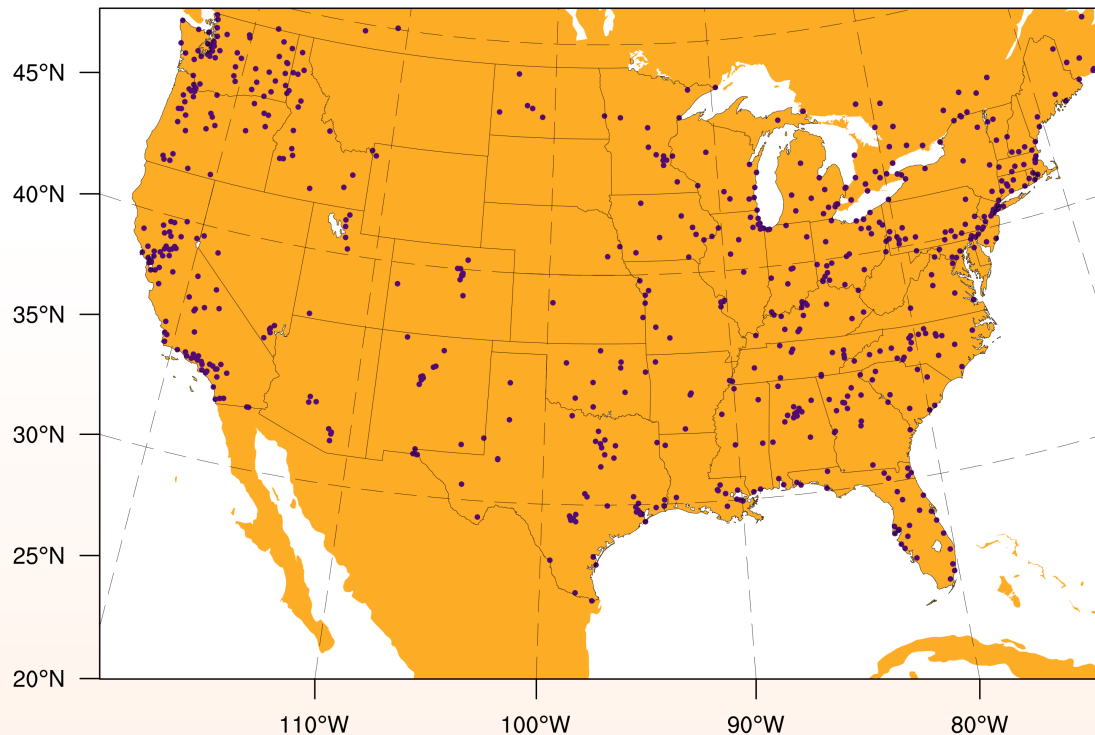


# Future work

- Assimilate multi-spectral/sensor/angle AOD products
  - Improve QC and observation error modeling
  - GOES, AVHRR, SeaWiFS, MISR, future GOES-R/VIIRS ...
- Assimilate other aerosol related observations
  - e.g., PM<sub>2.5</sub>/PM<sub>10</sub>, Visibility, Lidar ext. coeffs. profiles (both ground- and satellite-based)
- Explore direct radiance DA for aerosol analysis
- Develop 4DVAR and EnDA approaches for aerosol analysis
- Extend to general chemical DA
- More applications
  - air-quality, biomass burning, volcanic ash, weather-aerosol interaction ...



# CONUS domain (AOD+PM2.5 assimilation)



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

Validation observations:

23 AERONET sites  
PM2.5 sites

chem\_opt=300:  
GOCART w/o chemistry

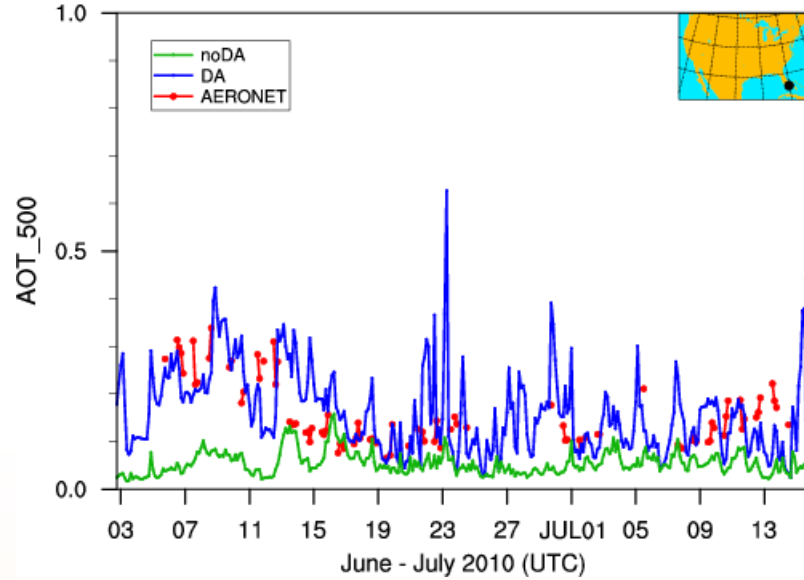
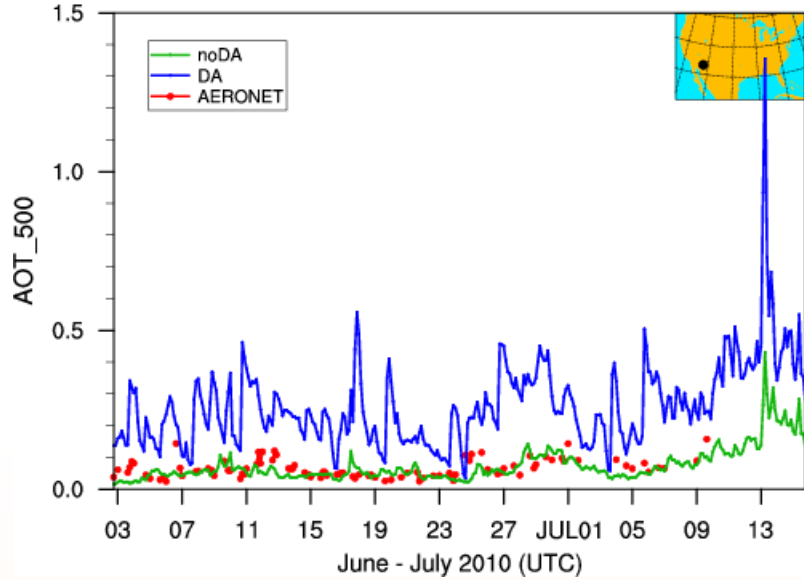
6-hr cycling DA/FC experiment:  
MET fields updated from GFS.  
Aerosol fields updated from AOD+PM2.5  
DA (2 June – 14 July, 2010).



# Verify vs. AERONET @500nm

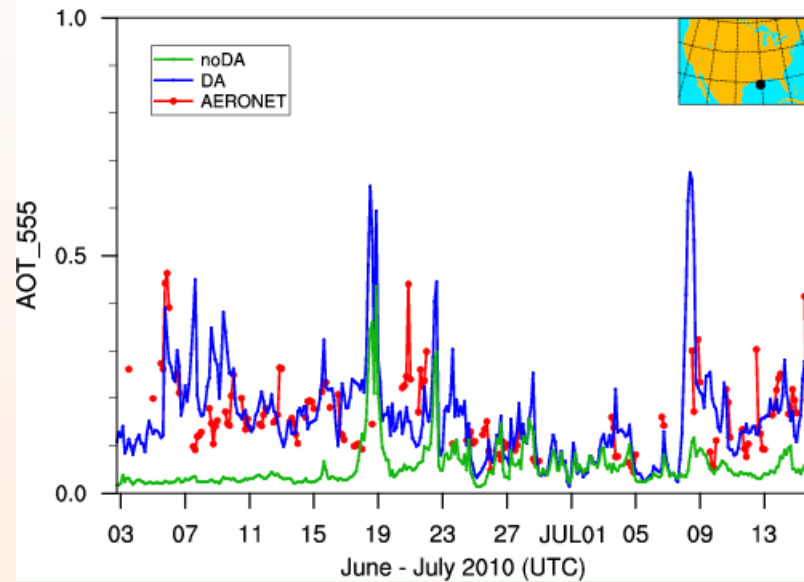
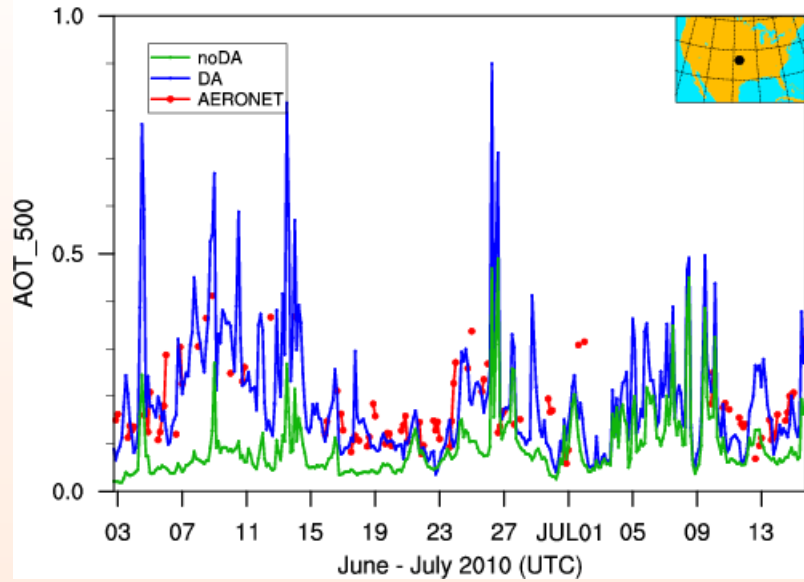
Maricopa (33.069N, -111.972E)

Key\_Biscayne (25.732N, -80.163E)



Cart\_Site (36.607N, -97.486E)

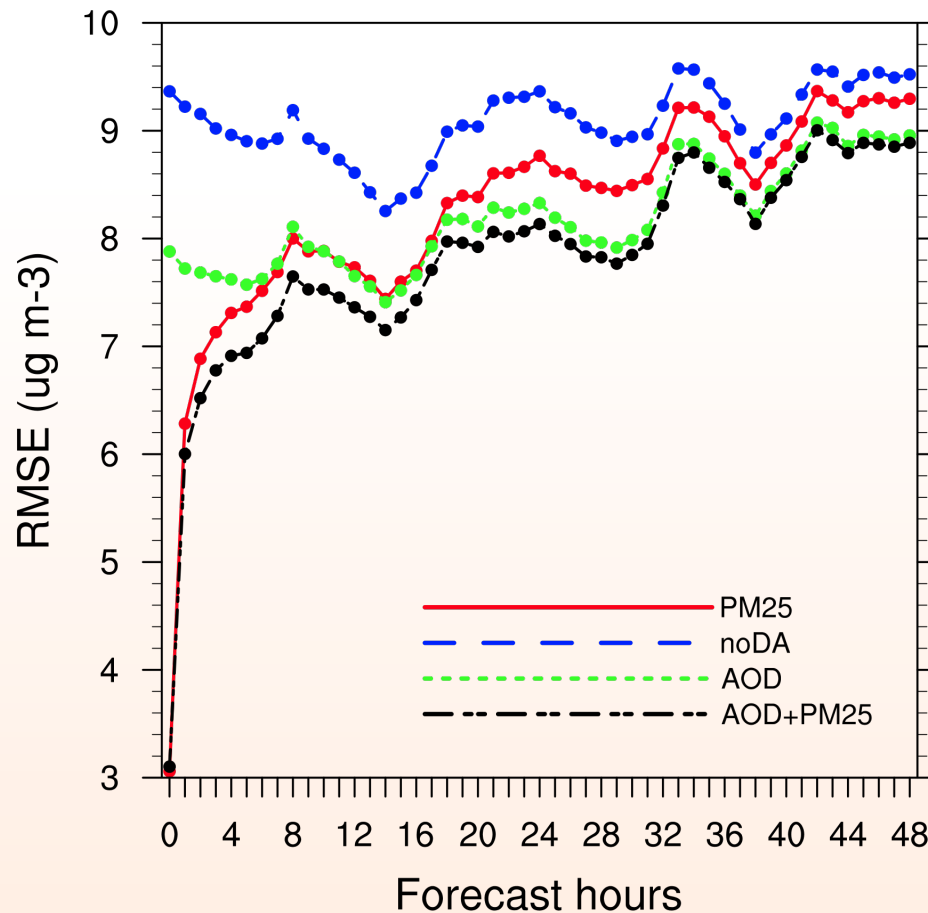
WaveCIS\_Site\_CSI\_6 (28.867N, -90.483E)





# RMSE for PM<sub>2.5</sub> forecasts

- Domain-averaged and aggregated RMSE over the 1800 UTC initializations (44 forecasts):





# Questions?

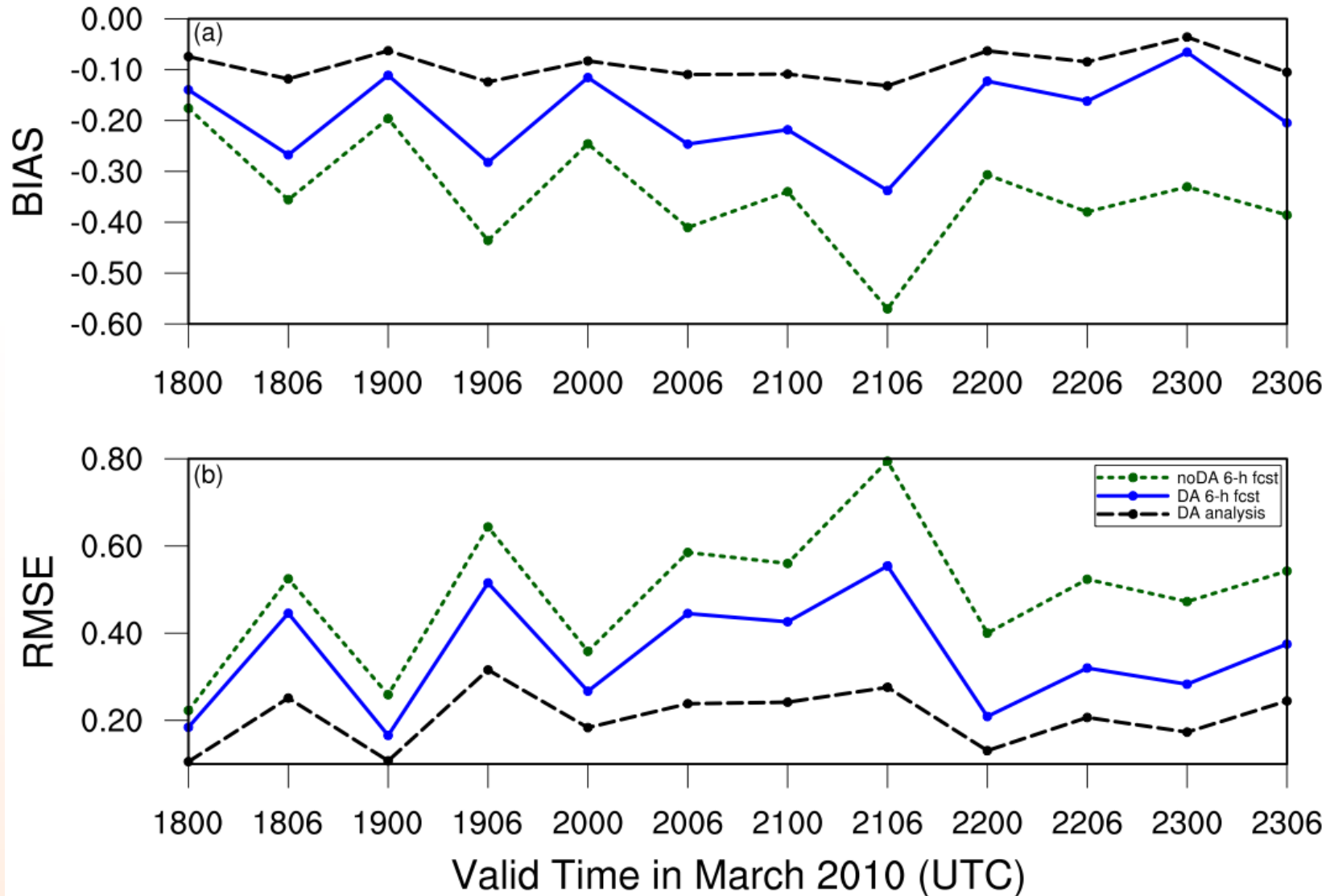
**The NESL Mission is:**

**To advance understanding of weather, climate, atmospheric composition and processes;  
To provide facility support to the wider community; and,  
To apply the results to benefit society.**

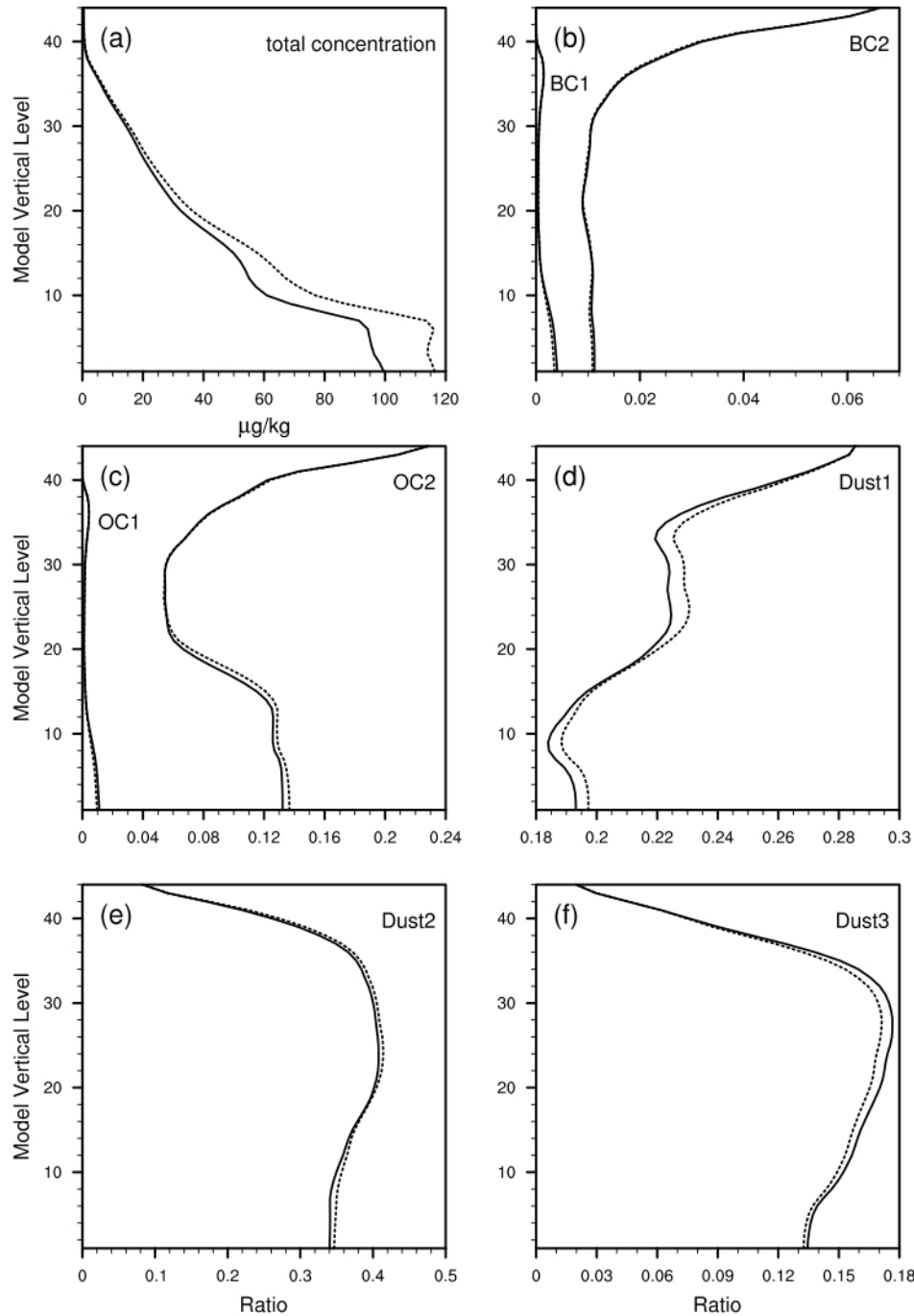
**NCAR is sponsored by the National Science Foundation**

9th Adjoint Workshop, 10/10/2011

# OMB/OMA of MODIS AOD



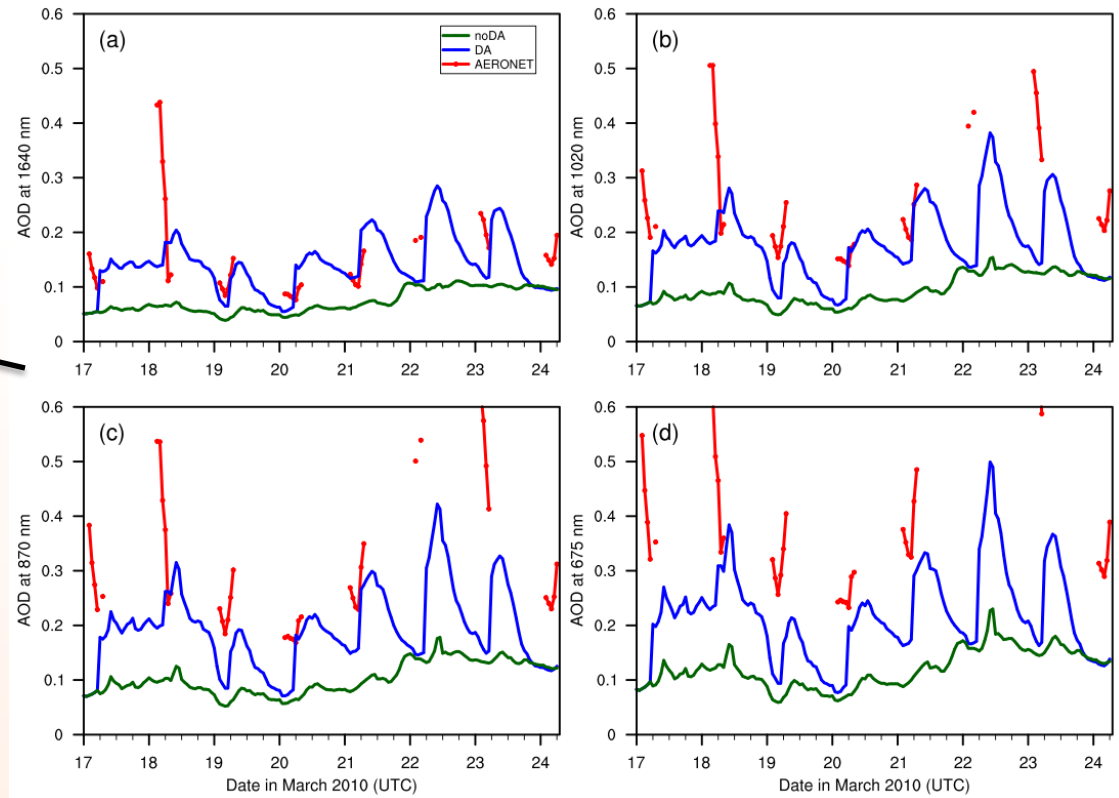
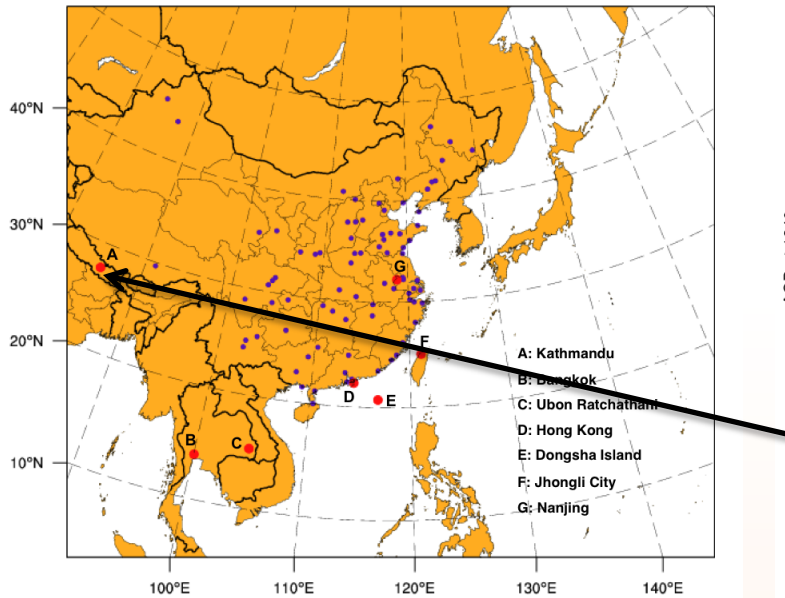




Domain-averaged  
vertical distribution of  
aerosol species  
before/after AOD DA

# Verify vs. AERONET AOD @1640, 1020, 870, 675 nm

## Kathmandu of Nepal



AERONET obs and DA likely reflect air-pollution variation due to the traffic.