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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• Future work
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., PM10/PM2.5, Lidar ext. profiles).

• Allow simultaneous assimilation of aerosol and meteor. observations (e.g., humidity and hydrophilic aerosols).
  – though NOT for the results shown here
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/

One HDF file consists of 5 min data ("Granule")

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Standard AOD product over ocean & land

Assimilate only 0.55 µm band from both Terra and Aqua.

“Deep Blue” AOD product over bright land surface
After DA

Minimization

WRF-Chem under-predict AOD

Before DA

After DA

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Dust storm affected Nanjing on Mar. 21, 2010

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CMA dust model forecast
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:
- MET fields updated from GFS.
- Aerosol fields updated from AOD DA.
L2 MODIS AOD@0.55μm coverage

0000 UTC, 21 March 2010

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

0600 UTC, 21 March 2010

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
Column dust vs. MODIS true color image.
2010032003
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)

(a) 100 µgm$^{-3}$

(b) 200 µgm$^{-3}$
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., PM2.5/PM10, 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)

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RMSE for PM$_{2.5}$ forecasts

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

![Graph showing RMSE over forecast hours]

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Questions?

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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.

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OMB/OMA of MODIS AOD

(a) Bias

(b) RMSE

Valid Time in March 2010 (UTC)

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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.