Air Quality Forecasting and Reanalysis

(optimizing assimilation of column AOT & sfc data)

Pius Lee¹, Youhua Tang¹, Jeff McQueen²,
Shobha Kondragunta³, Li Pan¹, Daniel Tong¹, Hyun Kim¹, Mark Liu³,
Sarah Lu⁴, Jun Wang⁵, Greg Carmichael⁶, Ted Russell⁷,
Dick McNider⁸, Brad Pierce⁹, Edward Hyer¹⁰, Jim Szykman¹¹,
Yang Liu¹², Min Huang¹, Chuanyu Xu⁵, Ho-Chun Huang⁵

¹Air Resources Lab. (ARL), NOAA Center for Weather and Climate Prediction (NCWCP), College Park, MD
²Environmental Modeling Center (EMC), NCEP, NCWCP, College Park, MD
³NOAA/ESDIS/STAR, College Park, MD
⁴State University of New York, Albany, NY
⁵I.M. Systems Group Inc. Rockville, MD
⁶College of Engineering, University of Iowa, Iowa City, IA
⁷School of Civil and Environmental Engr., Georgia Institute of Technology, Atlanta, GA
⁸Department of Atmospheric Science, University Alabama, Huntsville AL
⁹National Environmental Satellite and Information Service (NESDIS), Madison, WI
¹⁰Naval Research Laboratory, Monterey, CA
¹¹U.S. EPA, Hampton, VA
¹²Department of Environmental Health, Emory University, Atlanta, GA
Upcoming AQAST Project: Air Quality Reanalysis
(Translating Research to Services)

- AQ Assessments
- State Implementation Plan Modeling
- Rapid deployment of on-demand rapid-response forecasting; e.g., new fuel type, etc.
- Health Impacts assessments
- Demonstration of the impact of observations on AQ distributions
- Ingestion of new AQAST products into operations

http://acmg.seas.harvard.edu/aqast/projects.html
Public Health Burden of PM$_{2.5}$
(Fann et al., 2011)

Percentage of PM$_{2.5}$ related deaths due to 2005 air quality levels by county

### Summary of National PM$_{2.5}$ impacts due to 2005 air quality

<table>
<thead>
<tr>
<th>Impact</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excess mortalities (adults)$^A$</td>
<td>130 to 320,000</td>
</tr>
<tr>
<td>Percentage of all deaths due to PM$_{2.5}$$^B$</td>
<td>5.4%</td>
</tr>
</tbody>
</table>

### Impacts among Children

<table>
<thead>
<tr>
<th>Condition</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ER visits for asthma (&lt;18 yr)</td>
<td>110,000</td>
</tr>
<tr>
<td>Acute bronchitis (age 8-12)</td>
<td>200,000</td>
</tr>
<tr>
<td>Exacerbation of asthma (age 6-18)</td>
<td>2,500,000</td>
</tr>
</tbody>
</table>

$^A$ Range reflects use of alternate PM mortality estimates

$^B$ Population-weighted value using Krewski et al. (2009) PM mortality estimates
WRF_ARW-MCIP-CMAQ forward model

WRF-ARW (LCC)
(42 $\sigma$-P model Layers)

LBC from GFS

EPA Emissions Inventory + simple obs-based adjustment

Projection of endo-domain intermittent sources: Obs’d wild fire and prescribed burns

CMAQ 4.7.1

VIIRS/MODIS-AOD-based adjusted IC, BC: RAQMS

Column integrated AOD

Hourly 3-D Gridded Chemical Concentration
### WRF_ARW-MCIP-CMAQ model physics and chemistry options

#### WRF-ARW
- Both North America (12 km) & CONUS (4 km)

#### Map projection & grid
- Lambert Conformal & Arakawa C staggering

#### Vert. co-ordinate
- 42 $\sigma$-p unevenly spaced levels

#### Advection
- RK3 (Skamarock and Weisman (2008))

#### SW & LW radiation
- RRTMG (Iacono et al. 2008))

#### PBL Physics
- Mellor-Yamada-Janjic (MYJ) level 2.5 closure

#### Surface layer scheme
- Monin-Obukhov Similarity with viscous sub-layer

#### Land Surface Model
- NCEP/NOAH

#### Cloud Microphysics
- Thompson et al. (2008)

#### Cloud convective mixing
- Betts-Miller-Janjic Mass adjustment

### CMAQ4.7.1
- Both CONUS (12 km) & SENEX (4 km)

#### Map projection & grid
- Lambert Conformal & Arakawa C staggering

#### Vert. co-ordinate
- 42 $\sigma$-p unevenly spaced levels

#### Gas chemistry
- Cb05 with 156 reactions

#### Aerosol chemistry
- Aero5 with updated evaporation enthalpy

#### Anthropogenic emission
- 2008NEI as base year, mobile projected using AQS*, area and off-road used CSPR^, point source uses 2012 CEM data

#### Biogenic emission
- BEIS-3.14

#### Lateral BC
- RAQM (B. Pierce)

#### AQ forecast
- ^12 km nested to 4 km
AIRNOW PM2.5, PM10, Ozone (applied to below PBL)

CMAQ base v5.0.2: cb05_ae5)

- 2008 anthropogenic emission inventory projected to 2011
- NOAA HMS (hazard mapping system) fire emission with Bluesky algorithm
- GOES cloud fraction adjustment provided by U. of Alabama at Huntsville
- RAQMS lateral boundary condition every 6 hours.

Prediction Cycle
00Z 06Z 12Z 14Z 17Z 19Z

VIIRS/MODIS AOD (Terra and Aqua)
Optimal Interpolation (OI)

- OI is a sequential data assimilation method. At each time step, we solve an analysis problem

\[ X^a = X^b + BH^T (HBH^T + O)^{-1} (Y - HX) \]

- We assume observations far away (beyond background error correlation length scale) have no effect in the analysis.
- In the current study, the data injection takes place at 1700Z daily.

Chai et al. *JGR* 2006
Objective (A): Improve PM forecast

Methodology of OI: Take account for background input; Obs; and physical processes from model

Observation Input → OI → Analysis output

MODIS_FINE: 0 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4 0.45 0.5

AOD_OI: 0 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4 0.45 0.5

AOD_Recon: 0 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4 0.45 0.5
Hourly Statistic Results for CONUS 12Z, 07/06/2011-12Z, 07/07/2011

<table>
<thead>
<tr>
<th>Cases</th>
<th>$O_3$ R=0.53 MB=2.54</th>
<th>PM2.5 R=0.23 MB= -7.14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OI1</td>
<td>R=0.56 MB=2.36</td>
<td>R=0.24 MB= -2.63</td>
</tr>
<tr>
<td>OI2</td>
<td>R=0.58 MB=1.06</td>
<td>R=0.39 MB= -1.33</td>
</tr>
<tr>
<td>OI3</td>
<td>R=0.52 MB=2.08</td>
<td>R=0.36 MB= -1.89</td>
</tr>
<tr>
<td>OI4</td>
<td>R=0.56 MB=1.55</td>
<td>R=0.40 MB= -0.11</td>
</tr>
</tbody>
</table>

CMAQ Runs Compared to AirNOW PM2.5 (nsite=740)
<table>
<thead>
<tr>
<th>Feature</th>
<th>Aqua-MODIS</th>
<th>Suomi NPP-VIIRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbit altitude</td>
<td>705 km</td>
<td>824 km</td>
</tr>
<tr>
<td>Equator crossing time</td>
<td>13:30 LT</td>
<td>13:30 LT</td>
</tr>
<tr>
<td>Granule size</td>
<td>5 minutes</td>
<td>86 seconds</td>
</tr>
<tr>
<td>Swath</td>
<td>2330 km</td>
<td>3040 km</td>
</tr>
<tr>
<td>Sensor zenith angle range</td>
<td>±64°</td>
<td>±70°</td>
</tr>
<tr>
<td>Valid solar zenith angle (for high quality)</td>
<td>&lt; 82°</td>
<td>≤ 65°</td>
</tr>
<tr>
<td>Sensor bands used for aerosol retrieval</td>
<td>0.412, 0.466, 0.554, 0.646, 0.856, 1.24, 1.63, 2.11 µm</td>
<td>0.412, 0.445, 0.488, 0.555, 0.672, 0.746, 0.865, 1.24, 1.61, 2.25 µm</td>
</tr>
<tr>
<td>Pixel size, nadir</td>
<td>0.25, 0.5, and 1 km</td>
<td>0.375 and 0.75 km</td>
</tr>
<tr>
<td>Bow-tie effects</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Product resolution, nadir</td>
<td>10 km</td>
<td>6 km (AOT and Angstrom exponent)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.75 km (Suspended matter)</td>
</tr>
<tr>
<td>Product resolution, edge</td>
<td>40 km</td>
<td>10 km (AOT and Angstrom exponent)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.2 km (Suspended matter)</td>
</tr>
<tr>
<td>Products, land (vegetated regions)</td>
<td>AOT (Dark Target Approach)</td>
<td>AOT, Angstrom exponent, Suspended matter</td>
</tr>
<tr>
<td>Product, land (deserts, urban regions)</td>
<td>AOT, Angstrom exponent, Dust single scattering albedo (Deep Blue Approach)</td>
<td>None</td>
</tr>
<tr>
<td>Products, ocean</td>
<td>AOT (7 wavelengths), Size (fine mode fraction)</td>
<td>AOT (11 wavelengths), Angstrom exponent, Suspended matter</td>
</tr>
<tr>
<td>Global gridded product</td>
<td>Level 3 daily, 8-day, monthly mean</td>
<td>None</td>
</tr>
</tbody>
</table>

Courtesy: C. Hsu et al.
Summary

• The optimal interpolation (OI) assimilation combining AirNOW surface measurements and VIIRS/MODIS AOD yielded significantly better results than the base case, especially on reducing mean biases, and the OI technique is sensitive to its uncertainty setting.

• The assimilation relies on the temporally and spatially available measurement data, which is always limited.

• Some of our assumptions, such as the aerosol speciation ratios and vertical distribution, need to be further verified.
EXTRA SLIDES

Contact:
Pius.Lee@noaa.gov
http://www.arl.noaa.gov/
Next data set
To be include
In data assimilation?

MLS & MODIS
AOD from global
Model: e.g., RAQMS

Exo-domain as well
as endo-domain
wild fires &
prescribed burns
Cloud-obs Photolysis rates

GOES-MCIP INTERFACE
Cloud transmissivity (calculated from satellite retrieved cloud albedo), cloud top pressure, and cloud fraction are prepared for input to MCIP

MODIFIED MCIP
GOES retrievals replaces MM5 cloud information being passed to CMAQ. Cloud fraction, transmissivity, cloud base and top heights are passed to CMAQ.

PHOT in CMAQ
In subroutine PHOT, clear sky photolysis rates will be adjusted for cloud cover based on GOES cloud fraction and cloud transmissivity information.

Interpolated in between.
CO (ppb) along the P3 Flight – July 2 2011: AOD_DA case vs. Obs

P3 Three and a half loops:
- Beltville
- Padonia
- Fairhill
- Aldino
- Edgewood
- Essex
- Chesapeake Bay