Experiment to Improve Air-Quality Forecasts with NASA Satellite Observations

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PART I: Assimilation of Satellite Trace gases

(1) Aura/OMI O₃ retrieval & IONS06 Network

Aura/OMI Level 2 O₃ profiles (24 layers; credit: Xiong Liu) are mapped to CMAQ horizontal domain (36km x 36km) using a “drop-in-the-box” method; The daily-mean profiles are then interpolated to CMAQ 39 vertical layers (altitude-based).

Left: OMI O₃ plotted with fixed pixel size (not real size)

Right: OMI O₃ mapped to CMAQ 3-D domain (36kmx36km, 39 layers)

424 ozonesondes were launched from 23 North American sites during August 2006, providing the best set of free tropospheric ozone measurements ever gathered across the continent in a single season.

(http://croc.gsfc.nasa.gov/intexb/ions06.html)
This ozonesonde network was specifically designed to quantify: 1) the background ozone that flows into western and southern North America, 2) the ozone exported from North America in polluted air masses, and 3) the enhanced ozone mixing ratios in the upper tropospheric anticyclone above the southern USA. (Cooper et al., 2007)

(Credit to: ANNE M. THOMPSON; Jacquelyn C. Witte)
PART I:
(2) Other satellite trace gases (NO2/HCHO/CO) (8/21/2006)

OMI Trop. NO2 column

OMI HCHO column

AIRS CO at 700mb

(Credit to: Thomas P. Kurosu,
Kelly Chance,
Wallace McMillian)
PART I
O3 (ppbv) 1900 UTC, 8/21/2006 simulated by 3 CMAQ runs; over plotted with 9 ozonesondes found within 1500~2300 UTC

- cntrl
- raqms_bc
- sat_bc
PART I
Huntsville ozonesondes compared with 3 CMAQ runs
((1) cntrl (2) raqms_bc (3) sat_bc)
PART I
Evaluation OMI O3 and CMAQ results with ozonesondes (Aug. 2006)
(1) Huntsville, AL

Mean and standard deviation of percent differences \(((x-\text{sonde})/\text{sonde})\%)\) are plotted above, where \(x\) represents O3 simulated from 4 CMAQ runs or OMI/O3, respectively.
PART I
Evaluation OMI O3 and CMAQ results with ozonesondes (Aug. 2006)
(2) 17 stations together (total 328 ozonesondes)

Mean and standard deviation of percent differences (x-sonde)/sonde (%) are plotted above, where x represents O3 simulated from 4 CMAQ runs or OMI/O3, respectively.
(Note: large variances at surface are mainly from Narragansett, Beltsville, and Houston.)
USING RAQMS TO PROVIDE LATERAL BC FOR CMAQ IMPROVED SURFACE O3 PREDICTIONS

<table>
<thead>
<tr>
<th>Metric</th>
<th>VISTAS</th>
<th>MWRPO</th>
<th>MANEVU</th>
<th>CENRAP</th>
<th>WRAP</th>
<th>Overall</th>
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<td>15470</td>
<td>1186</td>
<td>10620</td>
<td>7907</td>
<td>15903</td>
<td>51086</td>
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Observed O3>60 ppb

\[
\frac{1}{N} \sum_{i=1}^{N} \left( \frac{C_i^r - C_i^o}{C_i^o} \right) \times 100\%
\]
OZONE DIFFERENCE PLOTS @ 1-km
SATBC – CNTRL
SATBC: Simulation with OMI BC
CNTRL: Simulation With Standard CMAQ BC

ANIMATION FROM July 15 - September 6, 2006
Z (METER) : 1034
TIME : 15–JUL–2006 03:00

Ozone Diff (SATBC–CNTRL) (ppb)
OZONE DIFFERENCE PLOTS
ZONAL CROSS SECTION
21N-57N averaged
SATBC – CNTRL
SATBC: Simulation with OMI BC
CNTRL: Simulation With Standard CMAQ BC

ANIMATION FROM July 15-September 6, 2006
PART II: Assimilation of MODIS & CALIPSO Aerosol Products

- MODIS L2 from Terra(10:30) and Aqua(13:30) are combined and mapped to CMAQ 36-km grid spacing
- Data coverage is increased by replacing missing pixels by the average of surrounding pixels
- MODIS fine fraction is used to partition fine & coarse mode aerosols
- CMAQ AOD is based on IMPROVE equation
- For fine mode, CMAQ aerosol profiles are scaled as
  \[ C(z) = C_{CMAQ}(z) \times \frac{\tau_{MODIS}}{\tau_{CMAQ}} \]

Fig. Along the track mass concentration from MODIS and CMAQ.
INCREASING DATA COVERAGE

Original MODIS AOD Map for August 14, 2007 (AQUA & TERRA)

50% of pixels were removed randomly

MODIS AOD from AQUA & TERRA were combined

➢ 50% of pixels were removed randomly
➢ Data coverage were increased by replacing each missing pixel with the average of surrounding pixels
➢ Final product was well correlated with the original data

\[ R = .97 \]
FINE Mode Assimilation of MODIS Aerosol Products

- Scaled CMAQ fine aerosol profiles
- CMAQ: 36km grid spacing
- MODIS L2 from Terra(10:30) and Aqua(13:30) was used

Elemental carbon mass ((a),(b)) and Anthropogenic organic mass ((c),(d)) (red line: scaled mass, blue line: original mass)
Aerosol prediction
PM2.5 Animations

(BC adjusted for satellite observed AOD)

Animations of PM2.5 difference
(sat_bc – control)
PART III: LIGHTNING INFLUENCE ON TROPOSPHERIC NOx and OZONE

Anthropogenic emissions from lightning are dominant source of mid- and upper-tropospheric NOx and ozone [Hudman et al., 2007; Singh et al., 2007; Cooper et al., 2006; Li et al., 2005, Biazar and McNider, 1995].

OMI NO2 column retrievals, Fig 1a, suggest some correspondence with lightning data (Fig 2).

Lightning NOx calculations, adjusted for IC/CG, molar fractions and altitude, become CMAQ model emission input (Fig 1b).

Using OMI NO2 as CMAQ IC/BC and lightning NOx as anthropogenic emission source should help improve NOx and ozone forecasts (red and white arrows).
LIGHTNING INFLUENCE ON TROPOSPHERIC NOx and OZONE

16 Aug 2006 – OMI Tropospheric NO2

16 Aug 2006 – CMAQ Modeled NOx + LNOx

Fig 1. (a) OMI NO2 columns resampled to CMAQ grids (36km x 36km) and interpolated to minimize no-data (credit: L. Wang). (b) CMAQ modeled NO+NO2 (credit: M. Khan and A. Biazar) with lightning NOx. LNOx scenario variables: IC/CG=1 [Ott, et al., 2007], NOx=500 moles/stroke [Hudman et al., 2007 and references therein], IC altitude=upper troposphere only

- Anthropogenic emissions from lightning are dominant source of mid- and upper-tropospheric NOx and ozone [Hudman et al., 2007; Singh et al., 2007; Cooper et al., 2006; Li et al., 2005, Biazar and McNider, 1995].
- OMI NO2 column retrievals, Fig 1a, suggest some correspondence with lightning data (Fig 2).
- Lightning NOx calculations, Fig 2, adjusted for IC/CG, molar fractions and altitude
- Using OMI NO2 as CMAQ IC/BC and lightning NOx as anthropogenic emission source should help improve NOx and ozone forecasts (red and white arrows).

Fig 2. Lightning NOx calculated from daily total lightning recorded by U.S. National Lightning Detection Network sampled by CMAQ grids.
QUANTIFICATION OF LIGHTNING GENERATED NOX:
SOUTHEASTERN U.S. TROPOSPHERIC NOX AND OZONE ENHANCEMENT DURING IONS06

- Significance of vertical lightning emission profile
- Forward particle trajectories (PT) from lightning [Cooper, 2007], backward PT from ozonesonde measurements, intersection of PT is lightning signature probability distribution.
- Adjust for STE [Cooper, 2006] and trajectory intersection with convective systems
- Compare results with CMAQ chemistry, OMI retrievals, North American Lightning Climatology, and published laboratory experiments for stroke signal strength and LNOx emission

Case Studies:
- Recurring Summertime Stagnant Southeastern Anticyclonic Circulation – pollution aging [Cooper (2006); Owen (2006)], horizontal and downward transport
- North Alabama Lightning Mapper Array – vertical emission profile, CG/IC ratios, compare to current parameterizations
Conclusions

• Satellite O3 boundary conditions (directly or through RAQMS) improve surface and middle to upper tropospheric O3 predictions; Continuity of O3 across the edge of model domain is improved.

• Satellite aerosol boundary condition improves the continuity of aerosol across the edge of model domain.

• Preliminary evidence shows influences of lightning-produced NOx on atmospheric O3/NOx.

• Potential improvement: satellite initial condition assimilation of NO2, HCHO, O3, aerosols to improve PBL calculations.
References:


