Relationships and Trends among Satellite NO₂ Columns, NOₓ Emissions, and Air Quality in North America

Tiger Team Update

David Streets, Greg Carmichael, Dan Cohan, Ben de Foy, Bryan Duncan, Arlene Fiore, and Tracey Holloway

Presented at AQAST 8 Meeting
Georgia Institute of Technology, Atlanta, GA
December 2-4, 2014
Concept

NO₂ columns, measured and modeled

wildfires          cities          soil          power plants          transport

Stratosphere/
background
Complete OMI processing and model runs for the entire U.S. and sort the NO$_2$ columns into source-dominant categories; then begin to compare NO$_2$ column amounts in each category with source-based emission estimates.
Processing Columns: New OMI NO$_2$ retrievals from Lok Lamsal

Filters:
- Summertime (May to August)
- Solar zenith angle < 80 degree
- Cloud radiance fraction < 0.5
- Surface albedo < 0.3
- Cross track positions 6-55
- Anomaly and error pixels

2005 May-Aug

2005 vs. 2011

2011 May-Aug
Processing Columns: Weekdays vs. Weekends

2005

2011

2005 May-Aug weekdays

2011 May-Aug weekdays

10^15 molecules/cm^2
Processing Columns: Effect of wind speed

Urban areas
Slow-WS OMI vs NO\textsubscript{x} emissions

Urban NO\textsubscript{2} signals are enhanced in the slow wind speed OMI map

2005 -2013 all valid data

2005 -2013 wind speed < 3 m/s
Background: Exploring potential for detecting specific source signatures in summertime NO$_2$ columns

Fraction of trop. NO$_2$ column attributed to selected sources: 2004-2012 JJA mean
GEOS-Chem 2x2.5 v. 9.02 MERRA-driven simulations
(NLDN lightning, NEI05, CAC, BRAVO emission inventories scaled to specific years)

**US ANTH.**

**N. AMER. BACKGROUND**

Attributions via sensitivity simulations:
- **N. Amer. Background:** zero N. Amer. anth. emis.
- **SOIL:** Base – zero soil NO$_x$
- **LIGHTNING:** Base – zero N. Amer. lightning NO$_x$

EUS largely reflects anthropogenic source (other seasons mainly anthrop.; not shown);
- Summer SE US ~20-40% lightning
- Summer NW US ~30-40% soil
Background: Variability in summer (JJA) monthly mean tropospheric NO$_2$ columns reflects background sources: lightning NO$_x$ in SE/SW USA

Fraction of variability in total monthly trop. NO$_2$ column from selected sources
GEOS-Chem 2x2.5 v. 9.02 MERRA-driven simulations
(NLDN lightning, NEI05, CAC, BRAVO emission inventories scaled to specific years)

$\sigma$N. Amer. Background / $\sigma$Base

$\sigma$Lightning / $\sigma$Base

< 0.50 0.60 0.70 0.80 0.90 1.00
Ratio of standard deviations in monthly trop. NO$_2$ column to total
(\(\sigma\) source / \(\sigma\) Base)

Source Attributions via sensitivity simulations:
N. Amer. Background = zero N. Amer. anth. emis.
Lightning = Base – zero N. Amer. lightning NO$_x$

Fiore, Murray, Milly, Columbia/LDEO
Cities: Journal article in preparation (Lu et al., 2014)

- Screened the top 60 U.S. urban areas on the basis of population
- Combined adjacent urban areas sharing the same NO$_2$ hotspot
- Excluded a few urban areas, the NO$_2$ signals of which were not isolated
- Ultimately analyzed 40 urban areas, representing ~23% total NO$_x$ emissions and ~53% total urban population
Cities: Good agreement among OMI NO$_2$ burden, NEI NO$_x$ emissions, mean NO$_2$ concentrations, and OMI-derived NO$_x$ emissions (Chicago)
Soils: Soil NO updates (more detail in Cohan DYNAMO presentation)

- Berkeley-Dalhousie Soil NO$_x$ Parameterization (BDSNP) implemented in CMAQ and provided to EPA

- Full year 2005 CMAQ simulation
  - Now being applied in 2011 EPA case during DISCOVER-AQ Maryland period

- CMAQ-BDSNP compared to OMI NO$_2$ in 2005 (next slide)

- Additional improvements underway
Soils: CMAQ_BDSNP overpredicts OMI NO$_2$ columns, but mostly in urban areas

OMI NO$_2$ v. 2.1 columns provided by Lok Lamsal

<table>
<thead>
<tr>
<th>Month</th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite</td>
<td>1.50</td>
<td>1.23</td>
<td>1.22</td>
<td>1.04</td>
<td>1.06</td>
</tr>
<tr>
<td>BDSNP</td>
<td>1.71</td>
<td>1.50</td>
<td>1.42</td>
<td>1.43</td>
<td>1.43</td>
</tr>
</tbody>
</table>

Monthly averages in 2005 (*$10^{15}$ molecules)

August 2005
Exponentially-Modified Gaussian requires long time period for accurate estimates (2005-2011)

Short lifetimes are not reliable indicators of chemistry
Transportation: ES&T paper published (2013) and ES&TL paper in review (2014) identify highway routes for future analysis
Outreach: Provided analysis to Tad Aburn (MDE) upon request
Outreach: Provided analysis to Mark Estes (TCEQ) upon request for Dallas SIP
Outreach: Will deliver similar analyses for 25 major US cities to ARSET website

[Data in Excel spreadsheets & downloadable images; AQ managers can provide feedback.]
Proposed new task for TT4

Very FAQ: “Which OMI NO$_2$ data product should I use?”

• We propose to compare the differences and commonalities of the main retrieval algorithms, evaluate the trends and monthly anomalies calculated from the data products with EPA AQS surface data, better quantify uncertainties, and highlight the implications of our findings for AQ applications.

• We propose to investigate the roles of the differing input parameters and assumptions used to develop the data products, and assess the strengths and weaknesses of those implementations using EPA AQS data.
**“Family Tree” of OMI NO₂ Data Products**

**Main Products**
- SP: Standard Product from NASA Goddard
- DP: DOMINO Product from KNMI (Netherlands)
- SP-HR: NASA’s Standard Product - High Resolution
- BEHR: Berkeley’s Product - High Resolution

**HR Regional Products (North America)**
- NO₂ SCD
- SP NO₂ VCD (NASA)
- DP NO₂ VCD (KNMI)
- SP-HR (NASA)
- BEHR (Berkeley)

**Levels**
- L0/L1 = raw radiance data obtained by OMI
- L2 = original geolocated observations (i.e., not spatially gridded) for each daily satellite overpass
- L3 = data mapped to a regular spatial grid and averaged over time (e.g., month)

**Acronyms**
- SCD: Slant Column Density from DOAS spectral fit
- VCD: Vertical Column Density = SCD/AMF
- AMF: Air Mass Factor from radiative transfer model to convert SCD to VCD

**Various “Levels” of data indicate the degree of processing.**

**The differences between the four products’ retrieval methods are too many to indicate here.**