Constraining NO$_x$ Emissions with Space-Based Data:

*Step 1: Understanding the correspondence of Ozone Monitoring Instrument (OMI) NO$_2$ column observations to U.S. AQS and CEMS data*

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_Greenbelt, MD_
The Aura Mission: **3 Main Science Questions**

- What are the processes that control air quality?
- What are the roles of ozone, aerosols and water vapor in climate change?
- Is the stratospheric ozone layer changing as expected?
Aura Satellite

- Orbit: Polar: 705 km, sun-synchronous, 98° inclination, ascending 1:45 PM equator crossing time.


  OMI measures UV & visible wavelengths of light backscattered from the Earth & atmosphere: NO₂, SO₂, & HCHO.

HIRDLS
High Resolution Dynamics Limb Sounder (defunct)

MLS
Microwave Limb Sounder

OMI
Ozone Monitoring Instrument

TES
Tropospheric Emission Spectromter
Spatial Coverage is the Primary Advantage of Satellite Data

OMI NO$_2$
% Difference in OMI NO$_2$: 2005 - 2014

20-40% decrease over US
Aura Ozone Monitoring Instrument (OMI)

How do OMI NO$_2$ data compare to surface observations?

OMI detects pollution in the free troposphere & boundary layer; footprint = 5-9 square miles.

The AQS surface sites only detect “nose-level” concentrations.
How do trends and variations in AQS NO$_2$ & CEMS NO$_x$ relate to OMI NO$_2$?

**OMI NO$_2$ & AQS data**


**OMI NO$_2$ & CEMS data**


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Part 1: EPA AQS NO$_2$ vs Aura OMI NO$_2$
Spatial Coverage is the Primary Advantage of Satellite Data
Model Simulation: Correspondence of a Tropospheric Column to Surface Data

% Reduction of NO₂ (2005-2010)

Tropospheric NO₂ column, r = 0.83
NO₂ column (0-1 km), r = 0.90

Tropospheric NO₂ [10¹⁵ molec cm⁻²], 2005
Provided analysis to Mark Estes (TCEQ) upon request for Dallas SIP

Dallas-Ft. Worth Metro Area

AQS     OMI

Change from 2005 [%]

2005  2006  2007  2008  2009  2010  2011  2012  2013

OMI [x 10^6 molec/cm^2]
Provided analysis to Mark Estes (TCEQ) upon request for Dallas SIP

Houston Metro Area

AQS     OMI

Change from 2005 [%]

Anomaly

AQS [ppbv]

OMI [x 10^15 mole/cm^2]
Regional, Linear Trends agree pretty well too

<table>
<thead>
<tr>
<th>Region</th>
<th>Domain</th>
<th>Number of sites</th>
<th>NO$_2$ reduction (%) 2005-2013</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mid-Atlantic</td>
<td>41-45 N, 70-75 W</td>
<td>13</td>
<td>38.3</td>
<td>37.9</td>
</tr>
<tr>
<td>New England</td>
<td>36-41 N, 72-81 W</td>
<td>19</td>
<td>41.4</td>
<td>43.1</td>
</tr>
<tr>
<td>S. California</td>
<td>31-36 N, 116-122 W</td>
<td>50</td>
<td>42.8</td>
<td>47.2</td>
</tr>
<tr>
<td>Central Valley</td>
<td>36-41 N, 118-124 W</td>
<td>30</td>
<td>37.2</td>
<td>41.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Land type</th>
<th>Number of sites</th>
<th>NO$_2$ reduction (%) 2005-2013</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>88</td>
<td>37.9</td>
<td>40.3</td>
</tr>
<tr>
<td>Commercial</td>
<td>74</td>
<td>39.5</td>
<td>37.0</td>
</tr>
<tr>
<td>Agriculture</td>
<td>19</td>
<td>35.7</td>
<td>38.7</td>
</tr>
<tr>
<td>Industrial</td>
<td>15</td>
<td>37.2</td>
<td>34.7</td>
</tr>
<tr>
<td>Mobile</td>
<td>6</td>
<td>34.9</td>
<td>43.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Land use</th>
<th>Number of sites</th>
<th>NO$_2$ reduction (%) 2005-1013</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban and center city</td>
<td>88</td>
<td>37.6</td>
<td>37.2</td>
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<tr>
<td>Suburban</td>
<td>89</td>
<td>39.0</td>
<td>40.1</td>
</tr>
<tr>
<td>Rural</td>
<td>30</td>
<td>35.1</td>
<td>35.5</td>
</tr>
</tbody>
</table>
Observed Correspondence of a Tropospheric Column to Surface Data

% Reduction of NO$_2$ (2005-2013)

Individual AQS Sites
Why is the Observed Correspondence Weaker?

**AQS**
1) Molybdenum converter
2) Sparse network/siting

**OMI**
1) Coarse spatial resolution
2) Free tropospheric NO$_2$
3) Retrieval algorithm assumptions

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Yorkville, GA

Measures some fraction of NO$_2$.

AQS % reduction lower.
Part 1: Conclusions

→ The trends & variations in NO₂ agree well for most major US metropolitan area, despite limitations of satellite and AQS data.

→ There are significant and interesting spatial trends within a given metropolitan area that are not captured by the relatively sparse AQS network.

→ The satellite data provide complementary information to the AQS data.
Part 2: CEMS NO$_x$ vs Aura OMI NO$_2$
Regulations of NO\textsubscript{x} Emissions

1) **Power Plants** (~68% decrease since late 1990s)

   → 1998 NO\textsubscript{x} State Implementation Plan (SIP) Call
   22 eastern states during summer
   → 2005 Clean Air Interstate Rule (CAIR)
   27 eastern states
   → 2011 Cross-State Air Pollution Rule (CSAPR)
   28 eastern states
   → Emission controls devices (ECDs) were installed on power plants, reducing emissions (e.g., 90%).

2) **Mobile Source** (~43% decrease since late 1990s)

   → Clean Air Act Amendments (CAAAA) of 1990
   Tier 1 (phased-in between 1994 and 1997) standards
   Tier 2 (phased-in between 2004 and 2009) standards
A Great Test of the Utility of OMI NO$_2$ Data

→ monitor emissions from power plants

*Our Goal:*
Assess the response of the NO$_2$ column to a known change in a power plant’s emissions.

*What is the relationship between $\Delta E$ & $\Delta$NO$_2$?*

*Is this “Response” (i.e., $\Delta$NO$_2$/\Delta E) scalar?*

*Is this “Response” the same for all power plants?*
Correlation ($r^2$) of annual OMI NO$_2$ & E (2005-2011)
Primary Drivers of Variability

→ We identified the primary drivers of variability of $\Delta NO_2/\Delta E$:

  a) magnitude of $\Delta E$
  b) seasonal variation of $NO_x$ lifetime
  c) proximity to urban sources
  d) changes in regional background
  e) statistical significance
  f) meteorology
  g) retrieval issues

Not enough time to discuss them all.
a) Magnitude of $\Delta E$

- Convolved with other factors.
- The range of Responses narrows.
b) Seasonal Variation of NO$_x$ Lifetime

Crystal River, Florida

May 2008

Bowen, Georgia

ECDs used during Ozone Season

Seasonal Variation
c) Proximity to Urban Sources

\[ \Delta E_{\text{OtherSources}} = \text{Big Bend plume convolved with Tampa plume.} \]

<table>
<thead>
<tr>
<th>Location</th>
<th>( \Delta E_{\text{PP}} )</th>
<th>( \Delta \text{NO}_2 / \Delta E )</th>
<th>( r^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Big Bend</td>
<td>4.2</td>
<td>0.53</td>
<td>0.89</td>
</tr>
<tr>
<td>Crystal River</td>
<td>5.4</td>
<td>0.28</td>
<td>0.91</td>
</tr>
</tbody>
</table>
\[ \frac{\Delta \text{NO}_2^{PP}}{\Delta E^{PP}} = \frac{(\Delta \text{NO}_2^{\text{Total}} - \Delta \text{NO}_2^{\text{Regional}})}{\Delta E^{PP}} \]
Part 2: Conclusions

→ Aura OMI NO₂ column data can be used to monitor emissions from power plants, **BUT** careful interpretation of the data is necessary & many facilities have a unique set of factors affecting it.
Will deliver similar analyses for 25 major US cities to a website. Data in Excel spreadsheets & downloadable images. AQ folks can provide feedback.

**Metropolitan Areas**

2005-2013 NO2 reduction [%]

Annual NO2 trend [%]

**Power Plants**

Annual trend in OMI tropospheric NO2:

2005-2008

2010-2013
Two Important & Free NASA Resources

1) Air Quality Applied Sciences Team (AQAST; aqast.org)

**Goal:** to serve the needs of US air quality management through the use of Earth Science satellite data, suborbital data, and models.

2) Applied Remote SEnsing Training (ARSET; arset.gsfc.nasa.gov)

**Goal:** to increase the utility of NASA earth science and model data for policy makers, regulatory agencies, and other applied science professionals in the areas of Health and Air Quality, Water Resources, Eco Forecasting, and Disaster Management.
Two AQAST Review Articles

Satellite Data of Atmospheric Pollution for U.S. Air Quality Applications: Examples of Applications, Summary of Data End-User Resources, Answers to FAQs, and Common Mistakes to Avoid

→ This article is “open access” so it’s free to download!

Emissions Estimation from Satellite Retrievals: A Review of Current Capability