Relationships and Trends among Satellite NO₂ Columns and NOₓ Emissions

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... with the support of NASA AQAST and acknowledgment of the contributions of AQAST colleagues working on emissions:

Greg Carmichael, U Iowa; Dan Cohan, Rice U; Ben de Foy, Saint Louis U; Bryan Duncan, NASA/GSFC; Arlene Fiore, Columbia U; Tracey Holloway, U Wisconsin; Lok Lamsal, NASA/GSFC; Can Li, NASA/GSFC

Daniel Jacob, Harvard University, AQAST team leader
John Haynes, NASA program manager
The AQAST goal is to transfer Earth Science knowledge to serve the needs of U.S. air quality management with focus on the use of NASA satellites, suborbital platforms, and models.

Air Quality Management Needs

- Pollution monitoring
- Exposure assessment
- AQ forecasting
- Source attribution of events
- Quantifying and monitoring emissions
- Assessment of natural and international influences
- Understanding of transport, chemistry, aerosol processes
- Understanding of climate-AQ interactions

(http://aqast.org)
Objective of the emissions component: Assessment of the applicability of current worldwide studies of satellite retrievals and emissions estimation to U.S. air quality management

**Issue:** How can U.S. air quality managers make use of satellite retrievals to improve emission estimates, and what developments are needed to improve the usefulness of those retrievals?

Some potential applications in the U.S. (not exhaustive):

- problematic industrial sources and industrial complexes,
- uncertain area sources (including biogenic),
- oil/gas extraction,
- verification of regional emission reductions and trends,
- quantification of atmospheric lifetimes,
- quantification of uncertain Mexican and Canadian emissions, etc., etc.
The complexity of satellite platforms, instruments, pollutants, sources, and world regions. How to process the information?
Initial studies of high-NO$_x$ source regions in Asia were promising
There is the potential to quantify point sources of NO$_x$, SO$_2$, etc., from OMI, if pollutant transport and chemical conversion cooperate.

Coming in ~2019: TEMPO, in geosynchronous orbit over North America at 2 × 4.5 km, 1-hour resolution!
$\text{NO}_x$ emissions from U.S. power plants [Duncan et al., 2013]

(size of circle represents change in emissions between 2005 and 2011; color of circle represents $r^2$ correlation between annual-average OMI and CEMS data)
Sample measurement data sets for four power plants in FL, GA, NM, and PA over a seven-year period, 2005-2011 [Duncan et al., 2013]

- Monthly OMI NO₂
- Daily CEMS NOₓ
- Annual mean NO₂

Sample size (days per month)

$\text{OMI NO}_2$ vs $\text{CEMS NO}_x$

- $r^2 = 0.91$
- $r^2 = 0.75$
- $r^2 = 0.18$
- $r^2 = 0.94$
Identification of NO$_x$ source regions using seasonality [Lu et al., 2013]

Anthropogenic emissions dominant (Dec/Jan peak)

Biomass burning emissions dominant (Mar/Apr peak)

Soil emissions dominant (Jun peak)

Example: OMI NO$_2$ (2005-2011)
Application of satellite observations for timely updates to NOx emission inventories (Randall Martin group)

Use CTM to calculate local sensitivity of changes in trace-gas column to changes in emissions

\[ \Delta E = \theta \times \Delta \Omega \]

Forecast global inventory for 2009, based on bottom-up inventory for 2006 and monthly OMI NO2 for 2006-2009

Lamsal et al., 2011
General decrease of OMI NO$_2$ over U.S. since 2005

Summertime BEHR OMI NO$_2$ (2005 vs. 2011)

Summertime NASA SP OMI NO$_2$ (2005 vs. 2013)
New examination of urban NO\textsubscript{x} emissions using OMI

Examined the top 80 urban areas on the basis of population

Combined adjacent urban areas that share the same NO\textsubscript{2} hotspot

Excluded some urban areas, the NO\textsubscript{2} signals of which are not isolated

51 urban areas selected for further examination

Represent about 40% of total NO\textsubscript{x} emissions in the U.S.
Example: Chicago

Urban Area

OMI BEHR 2005

2-D Gaussian Fit

% Difference

NO\textsubscript{x} Emissions (EI)

-90 -70 -50 -30 -10 10 30 50 70 90

OMI NO\textsubscript{2} (10\textsuperscript{15} molecules/cm\textsuperscript{2})

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<th>Emissions (kg/h/grid)</th>
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OMI BEHR 2005 - D Gaussian Fit

% Difference

NO\textsubscript{x} emissions (Mg/h)

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OMI NO\textsubscript{2} burden (Mg)

OMI NO\textsubscript{2} burden and 95% CI, 30% decrease

NO\textsubscript{x} emissions (R=0.93), 25% decrease

Annual mean NO\textsubscript{2} (R=0.96), 25% decrease
Example: Houston

- Urban Area
- OMI NASA SP 2005
- 2-D Gaussian Fit
- % Difference
- NOx Emissions (EI)

Graphs and images showing emissions and % difference over time.
**NO\textsubscript{x} emissions vs OMI \textsubscript{NO}_2 burden**

- Good agreement between NO\textsubscript{x} emissions and OMI NO\textsubscript{2} observations
- The 95% CI of the summertime NO\textsubscript{2} dispersion lifetime in U.S. urban areas
  - Berkeley retrievals 2.1~5.6 h
  - NASA retrievals 1.4~4.6 h
- Uncertainties of urban NO\textsubscript{x} emissions estimated from OMI NO\textsubscript{2} observations
  - Berkeley retrievals ±45%
  - NASA retrievals ±57%

*Each point represents a yearly fitted result for an urban area: 9 yr × 51 cities for the NASA SP.*
Trend of the OMI NO\textsubscript{2} burden summed over all selected urban areas

From 2005 to 2011

- Total amount of NO\textsubscript{2} observed by the OMI over selected urban areas: 24% decrease
- Total NO\textsubscript{X} emissions from selected urban areas: 26% decrease
- Averages of annual mean NO\textsubscript{2} concentrations in selected urban areas: 25% decrease

From 2005 to 2013

- Total amount of NO\textsubscript{2} observed by the OMI over selected urban areas: 36% decrease
- Total NO\textsubscript{X} emissions from selected urban areas: 33% decrease
- Averages of annual mean NO\textsubscript{2} concentrations in selected urban areas: 30% decrease
OMI NO$_2$ around Atlanta using oversampling—a transportation signal?

Bryan Duncan, unpublished, 2012
Relationships and trends among satellite NO$_2$ columns, NO$_x$ emissions, and air quality in North America

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

Holloway: mobile sources
Carmichael, Fiore: Modeled NO$_2$ columns
de Foy: oversampling, surface monitoring
Streets: urban areas
Duncan: power plants
Cohan: soil NO$_x$

NEI 1999 NO$_x$ emissions
GOME-2: 2010-2012

Freight Truck Volumes
Average Trucks per Day (2002)


