Relationships and trends among satellite NO$_2$ columns, NO$_x$ emissions, and air quality in North America (continuation of Year 3 project with one new component)

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**Problem to be solved:** To enable U.S. air quality managers to use satellite retrievals to verify, correct, and supplement (spatially, temporally) estimates of current NO$_x$ emissions and recent trends in North American inventories (for the U.S., Canada, and Mexico).

**AQ responsiveness:** We have consistently received enthusiastic support from AQ managers for the application of satellite retrievals to the quantification of “difficult” source types and “background” pollution levels.

**Accomplishments in Year 3:** Two major tasks are underway in this project. The first task is still ongoing and will be completed in Year 4. The second task is proposed to continue in a new, but related direction. The third task was completed and will not be re-proposed.

The aim of the **first task** is to move toward a common platform for quantification of emissions from different source types. The latest OMI NO$_2$ product [Lamsal] at 2 km $\times$ 2 km resolution over the U.S. was processed for 2005–2013 [Streets/Lu] and distributed to the group. The new NO$_2$ retrievals were shown in Year 3 activities to have smaller errors and better data quality over urban areas due to the use of higher-resolution profiles for the air mass factor calculation and more realistic NO$_x$ emissions. During Year 3, the U Iowa team [Carmichael] began performing WRF-Chem simulations to prepare modeled NO$_2$ columns and to calculate column contributions from specific source sectors. While this necessary work on modeled and observed NO$_2$ columns went forward, specific studies on individual NO$_x$ source sectors (cities, highways, power plants, soils, etc.) proceeded in anticipation of the comparison to come in Year 4. For urban areas [Streets/Lu], time trends of OMI NO$_2$ over ~40 U.S. cities during 2005–2013 were developed and their NO$_x$ emissions quantified using the exponentially modified Gaussian fit technique. For highways [Holloway/Bickford], the work on freight activity levels and OMI NO$_2$ was completed, and the final journal article is presently in review. For point sources, work was completed and published on a comparison of different approaches to simulating column densities from a point source [de Foy]. The sensitivity of emission estimates to plume speed and direction, as well as relationships to chemical lifetimes were assessed. In addition, the work on OMI observations of SO$_2$ emissions from power plants in India was published [Streets/Lu], and papers on OMI observations of NO$_x$ emissions from U.S. power plants and a review of the use of satellite data for AQ applications were published [Duncan]. For the soil component [Cohan], implementation of the Berkeley/Dalhousie soil NO emissions scheme in CMAQ was completed as part of DYNAMO, and the code was provided to EPA for inclusion in a future release of CMAQ. Its impact was tested in a 2005 simulation relative to the base Yienger/Levy soil emission model and to the new OMI NO$_2$ data [Lamsal]. Finally, to separate these direct anthropogenic and natural emissions from background contributions, work continued on the contribution of regional emissions to NO$_2$ columns, their long-term trends, and interannual variability [Fiore/Murray/Valin]. It was demonstrated that at some times
of the year more than 50% of the column NO\textsubscript{2} is contributed by background sources. Lightning was shown to dominate the background variability.

The **second task** is intended to develop time trends of OMI NO\textsubscript{2} data (2005–2013) for specific metropolitan regions and to create targeted, user-friendly datasets that will help AQ managers meet their regulatory, monitoring, and permitting requirements [Duncan/Prados/Lamsal/Krotkov]. In Year 3, the time trends were developed and analyzed, and a journal article is anticipated to be submitted by the end of October 2014. The user-friendly datasets of OMI NO\textsubscript{2} trends and monthly anomalies have been generated for 20+ cities. The figures and data will shortly be posted on the ARSET and WHIPS websites. The related webpage is anticipated to be completed by the end of October 2014, and responses will be made to questions from the AQ community concerning the data/plots. In addition, Mark Estes (TCEQ) requested an OMI NO\textsubscript{2} trend analysis of six Texas cities and three play shale areas. Data/plots were provided to him in July 2014, and Mark has indicated that he will use the analysis in their upcoming Dallas SIP. Plots were provided to Tad Aburn (MDE), who requested an OMI NO\textsubscript{2} monthly anomaly analysis for various power plants in PA to confirm that the plants had stopped using their emission control devices.

**Proposed Work in Year 4:** The **first task** will draw together and intercompare the OMI column NO\textsubscript{2} and NO\textsubscript{x} emission data for grid cells dominated by individual source types (cities, highways, power plants, soils, etc.). The analysis will address seasonal, spatial, time-of-day, release height, meteorology, and other constraints. The analysis will be conducted with overarching calculations of NO\textsubscript{2} columns using global and regional models to evaluate methods and estimate uncertainty. New techniques will be developed to gain information about the components of columns above specific grid cells and to diagnose dominant contributors to the total column, including stratospheric NO\textsubscript{2}, transported pollution aloft, ground-level point and area sources, and regional background. Daily and seasonal variability in the roles of these source types will be examined. Once the NO\textsubscript{2} column data are parsed out according to their dominant source contributions, all team members will participate in analysis of the results by source type. Work will also continue on the individual source component tasks that were described in the previous section. For point sources, for example, we will take the CEMS data down to a daily resolution and compare with estimates from the satellite retrievals. In particular, we will try to identify why there is considerable variability in the accuracy of the methods from plant to plant. We will also evaluate the chemical lifetime estimates that are obtained at the same time as the emission estimates. Finally, the methods will be applied to large point sources for which there are no CEMS data, in order to gain insights into unknown sources.

For the **second task,** a new area of work is proposed, building on the favorable results achieved in Year 3. One finding from that work was that many AQ managers requested guidance on the question: “**Which OMI NO\textsubscript{2} Data Product Should I Use?**” The problem is complicated, as there are two operational global OMI NO\textsubscript{2} products, one each from NASA and KNMI. The problem is further exacerbated by the release over time of multiple “improved” research versions of the two operational products, as “value-added” incremental improvements were made. The proposed new task will provide informed advice on which product is recommended for particular applications. For this task we will work closely with the researchers involved in the development of these products: Lamsal, Boersma, and Valin. We will 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 will 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.
Deliverables:

- **Deliverable 1**: Journal article that assembles and intercompares observed satellite NO₂ columns with modeled NO₂ columns for different source types under varying conditions [all team members].
  - **Delivery date**: Aug 31, 2015.
- **Deliverable 2**: Journal article analyzing NO₂ columns and NOₓ emissions for ~40 U.S. urban areas, using new retrievals and column calculations [Streets/Lu].
  - **Delivery date**: Jan 31, 2015.
- **Deliverable 3**: Journal article assessing U.S. NO₂ trends from OMI and AQS intercomparison [Duncan/Lamsal].
  - **Delivery date**: Oct 31, 2014.
- **Deliverable 4**: Journal article comparing the different OMI NO₂ retrieval methods, comparing data trends and monthly anomalies to AQS surface data [Duncan and others].
  - **Delivery date**: Sep 30, 2015.
- **Deliverable 5**: Journal article comparing emission estimates from OMI retrievals using the EMG method and CEMS data, and analyzing chemical lifetime estimates [de Foy].
  - **Delivery date**: Aug 31, 2015.

Publications:


