Evaluating NO_x Emissions Using Satellite Observations

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Abstract

Atmospheric NO_2 columns retrieved from satellites provide a useful top-down constraint on bottom-up NO_x emissions inventories. We present three case studies of an approach to evaluate NO_x emissions at a sector level by comparing satellite retrievals to regional chemical-transport model calculations of NO_2 columns. In the first example, the atmospheric impact of implementing NO_x controls at eastern US power plants is demonstrated [Kim et al., 2006]. In the second study, we use NO_x monitors at western US power plants to calibrate our satellite-model comparisons [Kim et al., 2009]. We then apply our approach to evaluate bottom-up estimates of NO_x emissions from western US cities. In the third example, we validate our satellite-model approach using in-situ aircraft measurements and assess NO_x emissions from power plants, cities, industrial facilities, and ports in eastern Texas [Kim et al., 2011].

Introduction

Ozone, a key ingredient of smog, is formed in the sunlit atmosphere by reactions of nitrogen oxides (NO_x =NO+NO_2) and volatile organic compounds (VOCs). Most NO_x emitted in the United States comes from transportation and electricity generation using fossil fuels. Pollution controls over the past two decades have specifically targeted NO_x emissions from these sources, since their emissions can increase ozone levels in downwind areas, in turn affecting compliance with US ozone standards.

The decreases in NO_x emitted by motor vehicle and power plant sources resulting from pollution controls have been measured directly by a variety of methods, including in-stack continuous emissions monitors (CEMs) at most US power plants and pollution monitors deployed along roads, throughout cities and suburbs, and in more rural areas. However, detecting the atmospheric impacts of power plant NO_x emission controls across large regions and over multi-year periods has been more challenging.

Vertical column retrievals of NO_2 from satellites scanning the entire globe every few days give nearly continuous views of large NO_x sources, including power plants and urban areas, since the mid-1990s (Figure 1). Atmospheric NO_2 levels can be simulated by atmospheric chemical-transport models, which convert emissions into vertical columns that can be directly compared with the satellite observations. The model can also be used to simulate the impact of emission reductions on surface ozone levels.

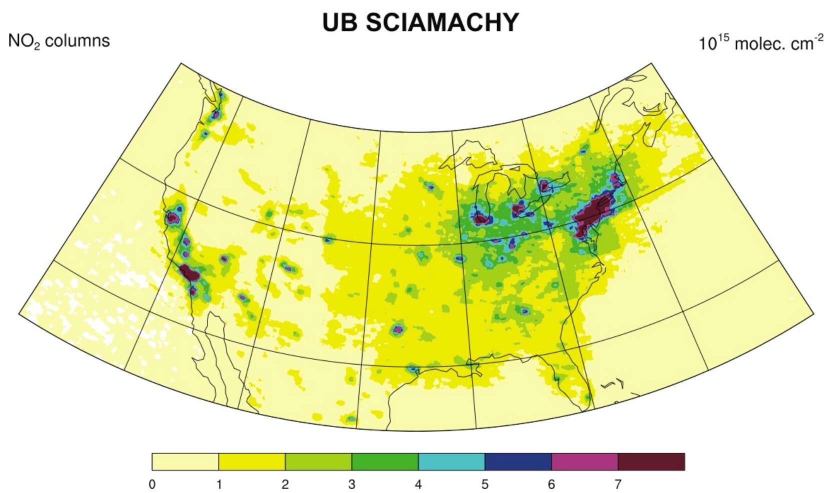

Figure 1. Average NO_2 vertical columns from the SCIAMACHY satellite instrument retrieved by the University of Bremen for the summer of 2004.

Case Study 1 – Eastern US Power Plants

Regulatory actions in the 1990s targeted NO_x emissions from fossil-fueled power plants, which are often located in rural areas with large natural emissions of VOCs and therefore have a high potential for smog ozone production. The nitrogen oxide emissions from these power plants can increase ozone levels in downwind areas and can impact compliance with ozone standards.

EPA-mandated controls on nitrogen oxide emissions from Eastern US power plants, which are primarily fueled by coal, were mostly implemented by 2004. The resulting decreases in NO_x emitted by individual US power plants have been measured and documented using CEMs.

Vertical column measurements of NO_2 from the satellite instruments Global Ozone Monitoring Experiment (GOME) and Scanning Imaging Absorption Spectrometer for Atmospheric Chartography (SCIAMACHY) for the entire world have been retrieved every few days. These retrievals provide continuous views of large NO_x sources, including power plants, since the mid-1990s.

Atmospheric NO_2 levels simulated by the Weather Research and Forecasting-Chemistry (WRF-Chem) regional air quality model, which accounts for emissions before and after implementation of the power plant pollution controls, are compared with the satellite observations [Kim et al., 2006]. The model is also used to investigate the impact of power plant emission reductions on surface ozone levels.

Satellite retrievals during the summer of 2004 are captured well by the model for the Northeast US urban corridor, where NO_x emissions are dominated by mobile sources [Kim et al., 2006]. In the Ohio River Valley region, with its high density of coal-fired power plants, the model reproduces the satellite data only when accounting for the lower power plant emissions resulting from pollution controls.

Satellite NO_2 levels over the Ohio River Valley declined by 40% during the past decade, a trend consistent with reported declines in power plant NO_x emissions (Figure 2). Only small changes in satellite and model NO_2 are seen over the Northeast US, suggesting that mobile source NO_x emissions have not decreased much over the same period. The WRF-Chem model predicts lower summertime ozone across much of Eastern US in response to power plant NO_x emission reductions.

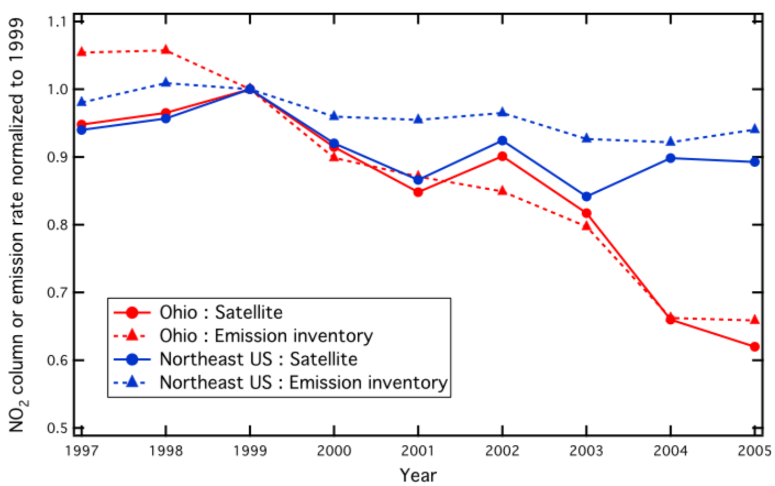

Figure 2. Trends in summertime average NO_2 vertical columns retrieved from the GOME and SCIAMACHY satellite instruments (solid curves) and in the NO_x emissions (dotted curves) from the Ohio River Valley region (red curves) and the northeast US (blue curves). *[Source: Kim et al., 2006]*

This work verifies that pollution controls at US fossil-fueled power plants have resulted in reductions in atmospheric nitrogen oxide levels across a large region, the Ohio River Valley. This was the first report of a space-based instrument detecting a change in atmospheric NO_x in response to pollution regulations placed on power plants. While the model predicted near-surface ozone levels should decrease in response to power plant NO_x controls if other pollution sources and atmospheric conditions remain constant, further direct observations and analysis are needed to confirm that regional ozone levels have indeed declined.

For more information, please see the article by Kim et al. [2006] in *Geophysical Research Letters*.

Case Study 2 – Western US Sources

There are many isolated sources of NO_x emissions across the western United States, including power plants and urban areas. In this study [Kim et al., 2009], two satellite instruments measuring NO_2 vertical columns over these sources and an atmospheric chemical-transport model were used to evaluate bottom-up NO_x emission inventories, model assumptions, and satellite retrieval algorithms.

We carried out simulations with the WRF-Chem model for the western U.S. domain during the summer of 2005 using CEMs-measured power plant NO_x emissions. Model NO_2 vertical columns are compared with a retrieval of the SCIAMACHY satellite instrument data by the University of Bremen and retrievals of the Ozone Monitoring Instrument (OMI) data by the U.S. National Aeronautics and Space Administration (NASA) and a modified version of the NASA OMI retrieval produced by the University of Bremen.

For areas dominated by power plant NO_x emissions, the model NO_2 columns serve as a comparison standard for satellite retrievals because emissions are continuously monitored at all large U.S. power plants. An extensive series of sensitivity tests of the assumptions in both the satellite retrievals and the model are carried out over the Four Corners and San Juan power plants, two adjacent facilities in the northwest corner of New Mexico that together represent the largest NO_x point source in the United States. Overall, the SCIAMACHY and OMI NO_2 columns over western U.S. power plants agree well with model NO_2 columns, with differences between the two being within the variability of the model and satellite (Figure 3).

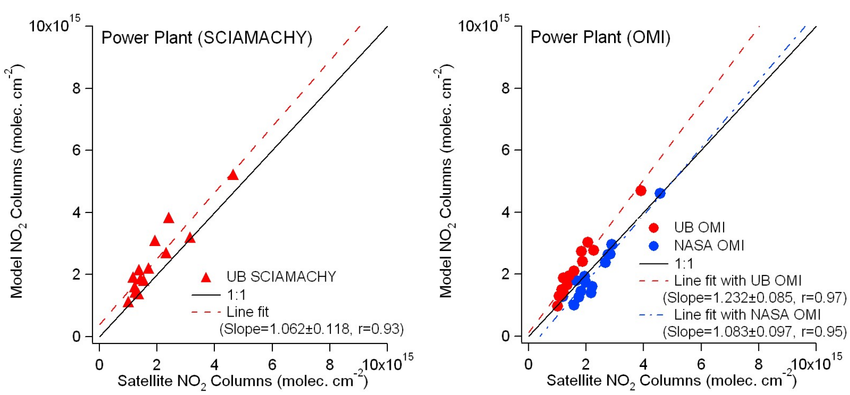

Figure 3. Comparison of average NO_2 vertical columns simulated by the WRF-Chem model to those retrieved from the SCIAMACHY (left) and OMI (right) satellite instruments by the University of Bremen (UB, in red) and NASA (blue) for the summer of 2005 over a variety of western US power plants. *[Source: Kim et al., 2009]*

In contrast to regions dominated by power plant emissions, model NO_2 columns over large urban areas along the U.S. west coast are approximately twice as large as satellite NO_2 columns from SCIAMACHY and OMI retrievals (Figure 4). The discrepancies in urban areas are beyond the sensitivity ranges in the model simulations and satellite observations, implying overestimates of these cities' bottom-up NO_x emissions, which are dominated by motor vehicles. Taking the uncertainties in the satellite retrievals into account, our study demonstrates that the tropospheric columns of NO_2 retrieved from space-based observations of backscattered solar radiation can be used to evaluate and improve bottom-up emission inventories.

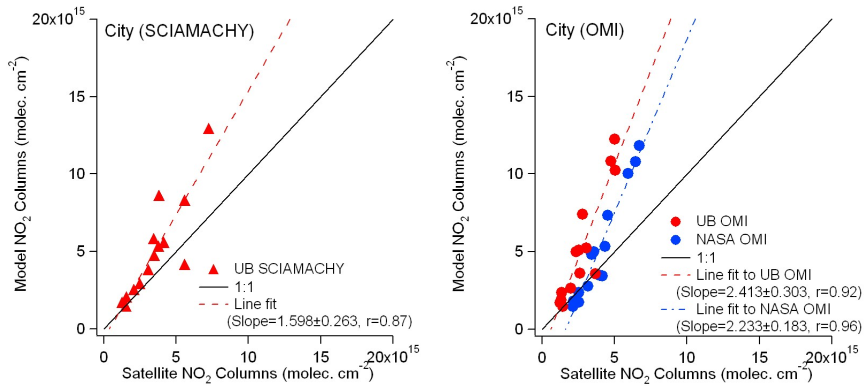

Figure 4. Comparison of average NO_2 vertical columns simulated by the WRF-Chem model to those retrieved from the SCIAMACHY (left) and OMI (right) satellite instruments by the University of Bremen (red) and NASA (blue) for the summer of 2005 over selected western US urban areas. *[Source: Kim et al., 2009]*

For more information, please see the article by Kim et al. [2009] in the *Journal of Geophysical Research*.

Case Study 3 – Texas Sources

Satellite and aircraft observations made during the 2006 Texas Air Quality Study (TexAQS) detected strong urban, industrial and power plant plumes in Texas. We simulated these plumes using the WRF-Chem model with input from the US EPA's 2005 National Emission Inventory (NEI- 2005), in order to evaluate emissions of NO_x and VOCs in the cities of Houston and Dallas-Fort Worth [Kim et al., 2011]. We compared the model results with satellite retrievals of tropospheric nitrogen dioxide (NO_2) columns and airborne in-situ observations of several trace gases including NO_x and a number of VOCs.

The model and satellite NO_2 columns agree well for regions with large power plants and for urban areas that are dominated by mobile sources, such as Dallas (Figure 5). However, in Houston, where significant mobile, industrial, and in-port marine vessel sources contribute to NO_x emissions, the model NO_2 columns are approximately 50%–70% higher than the satellite columns.

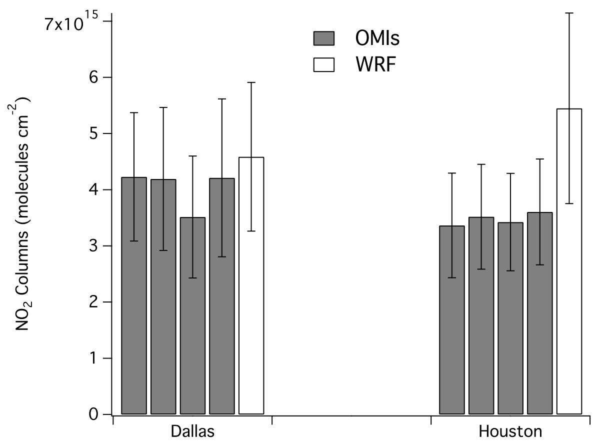

Figure 5. Comparison of average NO_2 vertical columns simulated by the WRF-Chem model (open bars) to those retrieved from the OMI satellite instrument (solid bars) by a variety of institutions for the summer of 2006 over Dallas-Ft Worth (left) and Houston (right). *[Source: Kim et al., 2011]*

Similar conclusions are drawn from comparisons of the model results with the TexAQS 2006 observations by the NOAA WP-3D aircraft in Dallas and Houston (Figure 6). For Dallas plumes, the model-simulated NO_2 showed good agreement with the aircraft observations. In contrast, the model-simulated NO_2 is ~60% higher than the aircraft observations in the Houston plumes. Further analysis indicates that the NEI-2005 NO_x emissions over the Houston Ship Channel area are overestimated while the urban Houston NO_x emissions are reasonably represented.

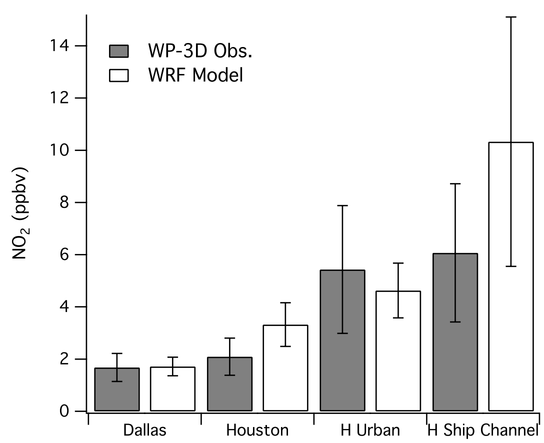

Figure 6. Comparison of average boundary layer NO_2 concentrations simulated by the WRF-Chem model (open bars) to those measured onboard the NOAA WP-3D aircraft (solid bars) during TexAQS2006 over Dallas-Ft Worth, the greater Houston area, the urban core of Houston, and the Houston Ship Channel industrial and port facility. *[Source: Kim et al., 2011]*

The comparisons of model and aircraft observations confirm that highly reactive VOC emissions originating from industrial sources in Houston are underestimated in NEI-2005. The update of VOC emissions based on Solar Occultation Flux measurements during the field campaign leads to improved model simulations of ethylene, propylene, and formaldehyde.

Reducing NO_x emissions in the Houston Ship Channel and increasing highly reactive VOC emissions from the point sources in Houston improve the model's capability of simulating O_3 plumes observed by the aircraft, although the deficiencies in the model O_3 simulations indicate that many challenges remain for a full understanding of the O_3 formation mechanisms in Houston.

For more information, please see the article by Kim et al. [2011] in the journal *Atmospheric Chemistry and Physics*.

References

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