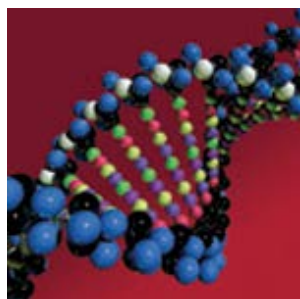


Evaluating NO_x Emission Inventories for Air Quality Modeling Using Satellite, Model and SEARCH NO₂ Data



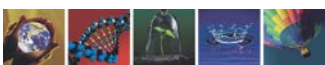
Greg Yarwood, Sue Kemball-Cook, Jeremiah Johnson and Gary Wilson

ENVIRON

Bright Dornblaser and Mark Estes

Texas Commission on Environmental Quality

11th Annual CMAS Conference, Chapel Hill, NC, October 16, 2012

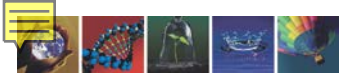


Acknowledgment

Sponsored by the Texas Commission on Environmental Quality

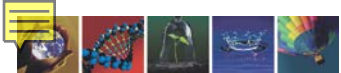
Overview

- Can OMI satellite data for column NO₂ be used to evaluate and/or improve regional NO_x emission inventories in the TCEQ's SIP Modeling?
 - CAMx 36/12/4 km model for June 2006
- Appropriate comparison methodology
- Model improvements needed for the comparison
- CAMx NO₂ agreement with satellite data, ground stations, INTEx aircraft data
- Can the OMI satellite distinguish a 30% change in CAMx ground-based NO_x emissions?

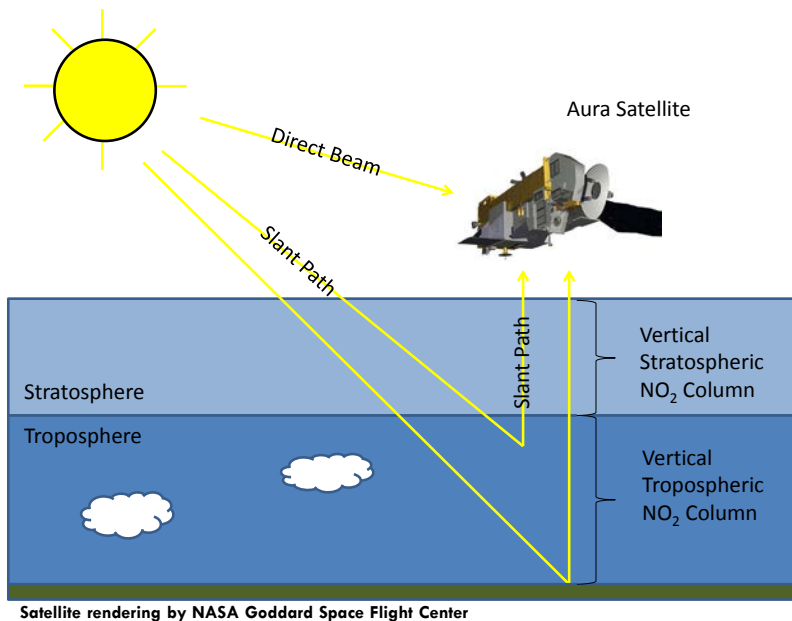


Method for Evaluating NO_x Emissions

- Comparison of satellite-retrieved and CAMx modeled NO₂ columns (e.g. Lamsal et al. 2008, 2010)
 - NO₂ columns from Ozone Monitoring Instrument
 - Weight CAMx vertical columns in the same way as each satellite retrieval (OMI averaging kernel)
- Research-grade SEARCH network NO₂ data for model evaluation at ground level

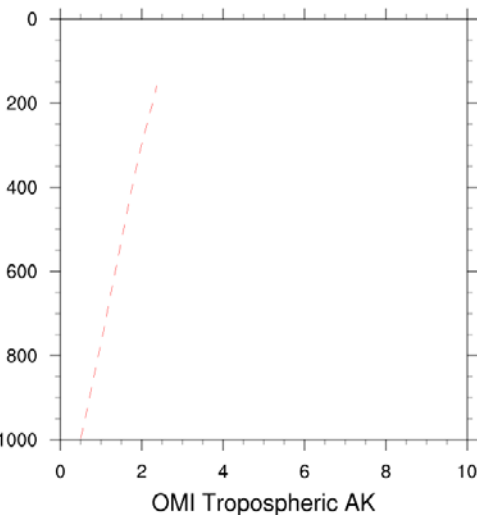


KNMI DOMINO v2.0 NO₂ Column Retrieval

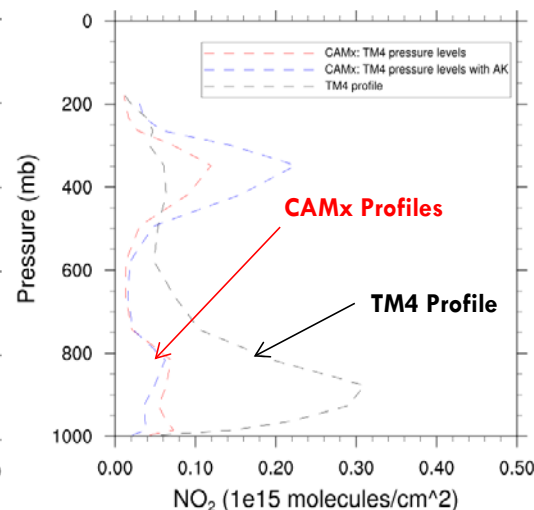


- v2.0 retrieval released in 2011
 - Previous version, v1.02, known to have a high bias due to errors in air mass factors
 - KNMI finds high bias is reduced in v2.0 relative to v1.02
- Peer-reviewed evaluations of the v2.0 retrieval not yet available when this study was performed

Averaging Kernel profile at 31.7612N 83.769°

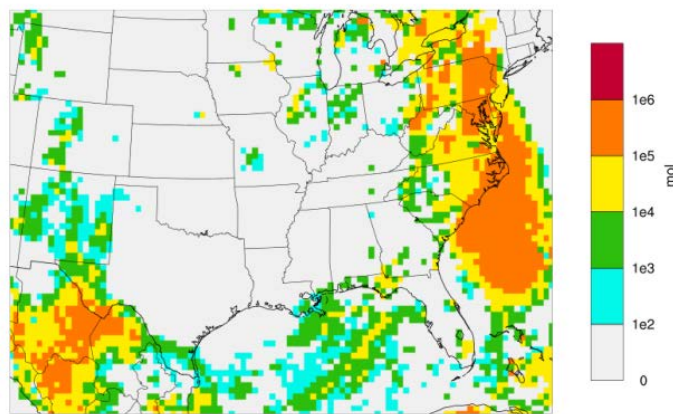


NO₂ profile at 31.7612 N 83.7691 W



Lightning and Aircraft NO_x Emissions

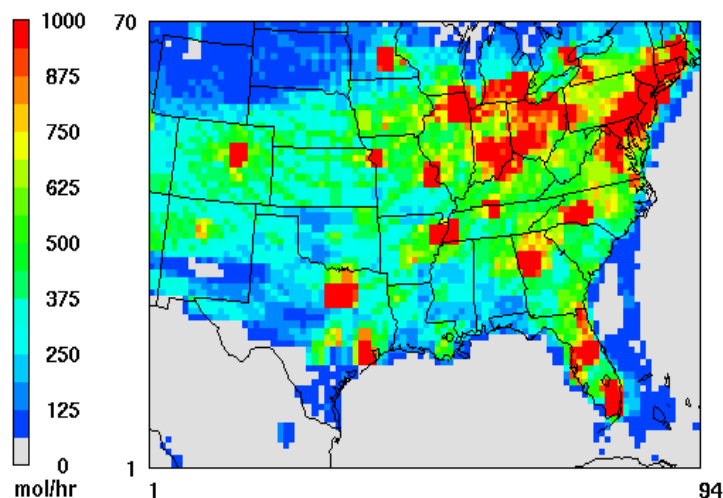
Lightning NO emissions
base



June 27, 2006

Min(1,1) = 0.00, Max(80,59) = 852532.62

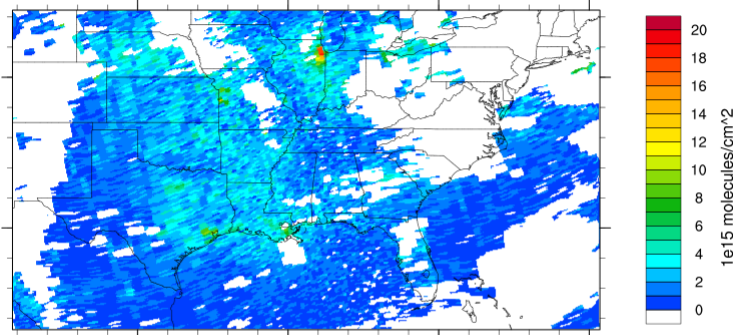
EDGAR Aircraft NO_x Emissions



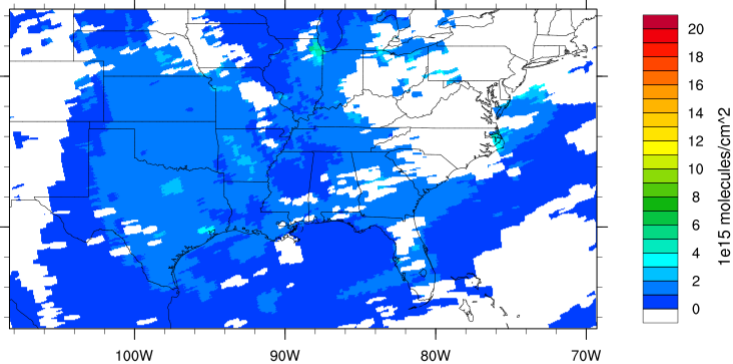
- Lightning and aircraft NO_x emissions added to the TCEQ SIP modeling emission inventory
- LNO_x parameterization of Koo et al. (2010)
 - LNO_x emissions distributed in the vertical according to Ott et al. (2010)
- EDGAR aircraft emissions from 2005
 - Emissions inserted in model at ~7-9 km altitude
- Re-evaluated model performance
 - Little change at surface

Comparison of CAMx and OMI NO₂ Columns

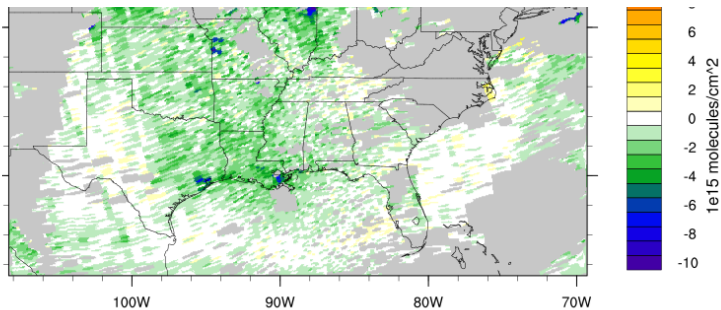
OMI NO₂ Tropospheric VCD



CAMx NO₂ Tropospheric VCD with AK



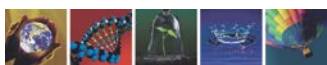
June 8, 2006 11 CST - June 8, 2006 14 CST



June 8, 2006 11 CST - June 8, 2006 14 CST

Min = -16.26, Max = 3.15

- Compare columns where OMI data report cloud fraction < 0.3
- Applied OMI averaging kernel to CAMx NO₂ columns
- CAMx has a consistent low bias relative to OMI
 - CAMx columns generally lower than OMI over land in both urban areas as well as in rural areas
 - In some offshore areas in Atlantic and Gulf, CAMx columns are larger than OMI
 - Results consistent across the June episode

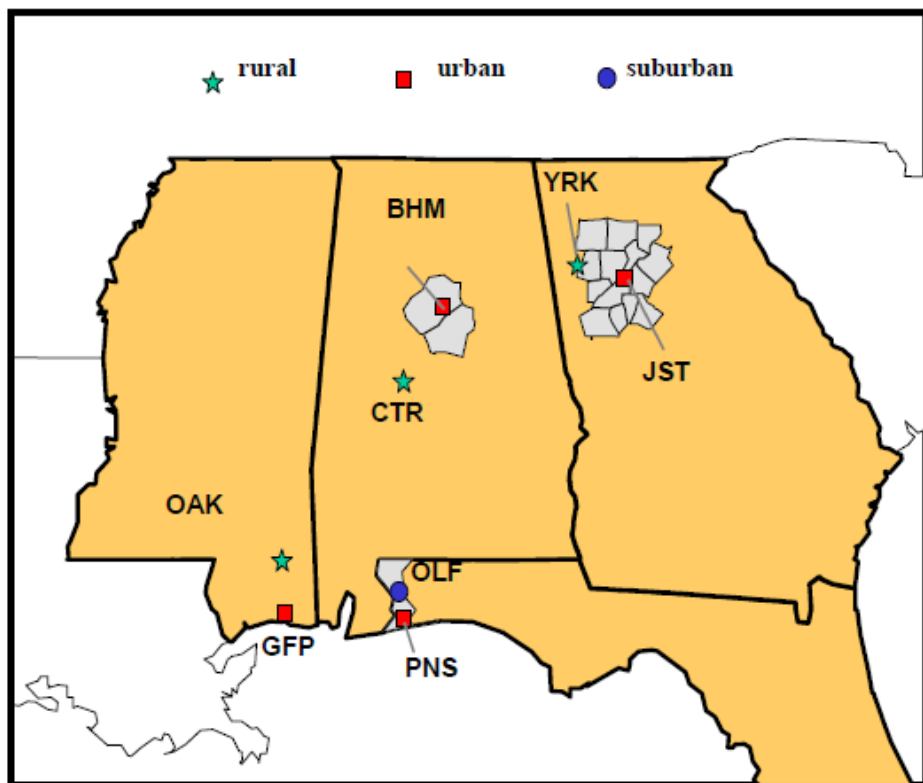


Possible Causes of Differences in CAMx and OMI Tropospheric NO₂ VCD

- DOMINO v2.0 retrieval has a high bias
 - Evaluation of this possibility requires comparison of OMI column data with other measurements (e.g. aircraft flight data)
 - Beyond the scope of this study
- CAMx has a low bias for NO₂
 - Near surface NO₂ is too low and/or
 - Aloft NO₂ is too low

Evaluate CAMx Near-Surface NO₂

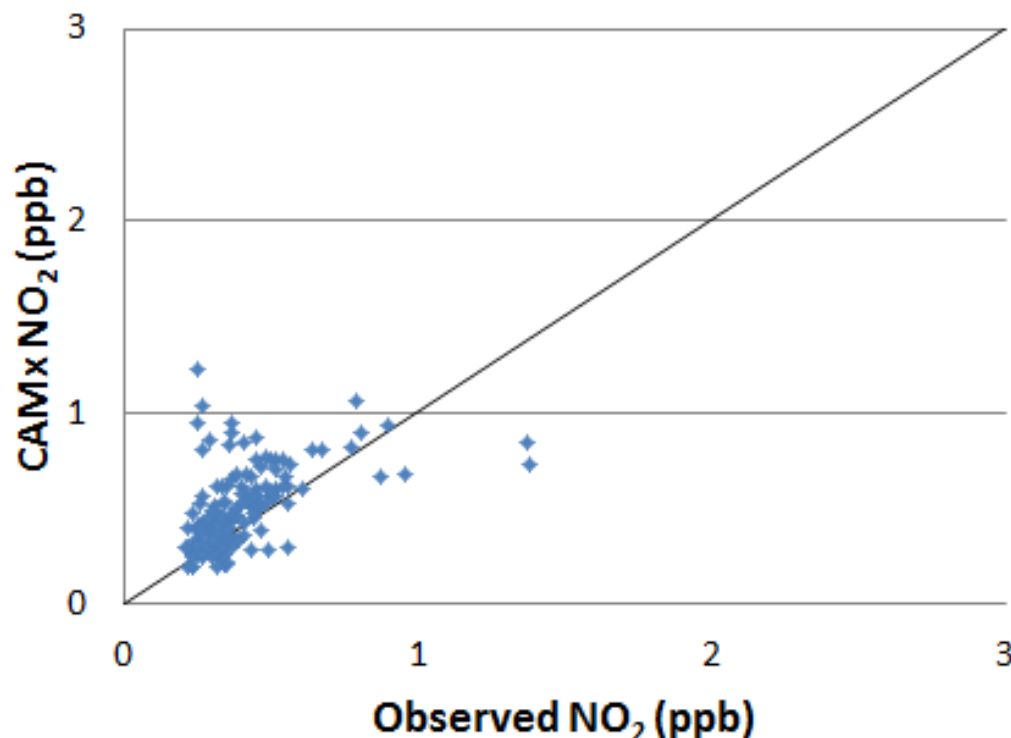
SEARCH Network Sites



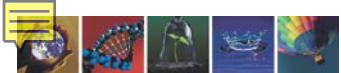
- Can CAMx low bias with respect to OMI columns be attributed to near-surface performance?
- Evaluate CAMx surface layer NO₂ at rural SEARCH sites
 - Research-grade photolytic NO₂ measurements
- Compare CAMx and SEARCH NO₂ during OMI overpass hours
 - SEARCH obs representative of the mixed layer during these midday hours

CAMx NO₂ at Rural SEARCH Sites during OMI Overpasses: Centreville, AL (CTR)

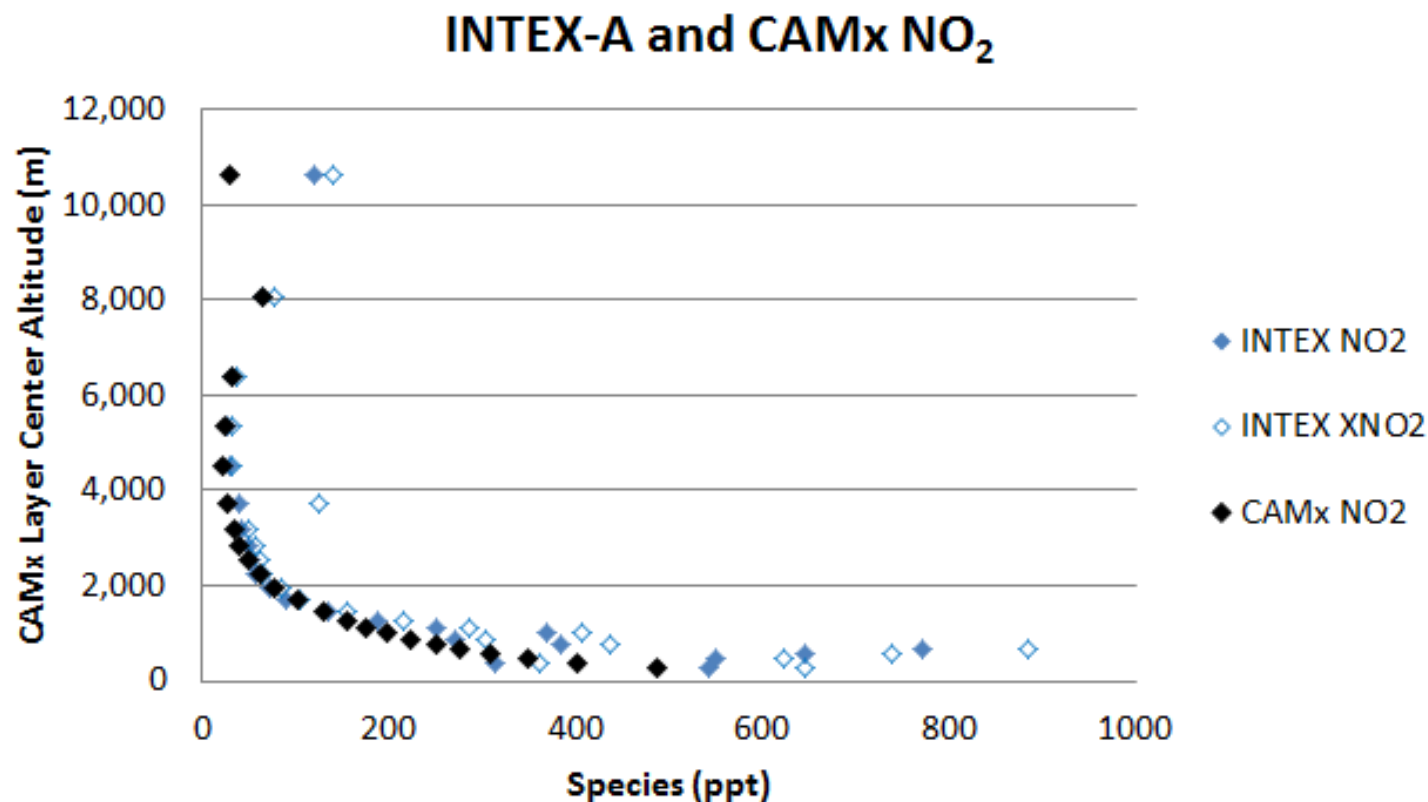
Observed vs. Modeled 1-Hour NO₂
CTR: OMI Overpass Hours



- Reasonably good agreement between CAMx surface layer NO₂ predictions and SEARCH measurements
 - CAMx tends to overestimate the background values < 1 ppb
- Similar results for other SEARCH sites
- No evidence of systematic CAMx low bias



Comparison of Domain-Wide NO₂ Profiles



- INTEX-A NASA DC-8 flight dataset provided by Barron Henderson
- Original INTEX-measured NO₂, denoted XNO₂, is biased high due to interference from methyl peroxy nitrate and HO₂NO₂. NO₂ has estimated interference removed (Browne et al. 2011)
- Reasonable agreement between CAMx and INTEX-A below 8,000 m
- CAMx has a low bias above 8,000 m compared to NO₂ and XNO₂-similar bias noted for other models (e.g. CMAQ; see Allen et al. 2012)

Can Satellite NO₂ Data be used to Evaluate Surface NO_x Emission Inventories?

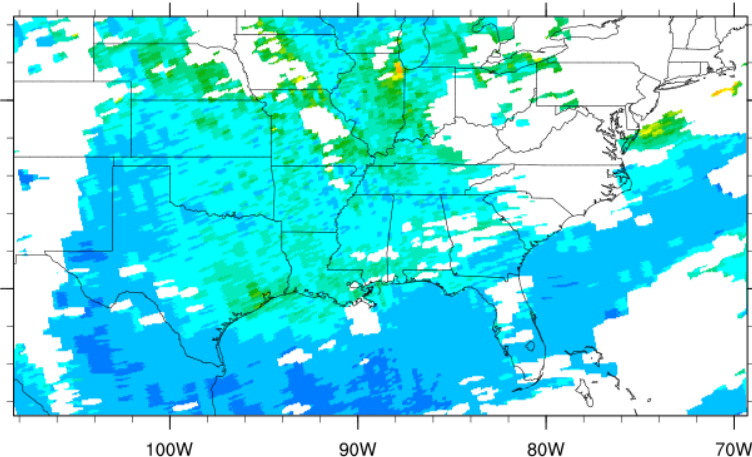
- Test effect of change in anthropogenic near-surface NO_x emissions on modeled NO₂ columns
 - OMI is more sensitive to NO₂ in upper troposphere (UT) than surface NO₂
 - OMI averaging kernel has been applied to the CAMx NO₂ columns so that they share this sensitivity to UT NO₂
- How sensitive are CAMx NO₂ columns to changes in near-surface NO_x emissions?
 - Compare resulting changes in modeled NO₂ columns with error in the OMI NO₂ columns
 - DOMINO product provides tropospheric VCD error estimate for each OMI pixel
 - Evaluate whether current retrievals can provide useful information for inventory evaluation

Two 30% Emissions Reductions Tests

- 30% reduction in surface anthropogenic NOx emissions
- 30% reduction in the entire anthropogenic NOx emission inventory
 - Includes elevated points
- No change was made to aircraft cruise NOx emissions or to the lightning NOx emission inventory

Evaluate Feasibility of Method for Diagnosing Bias in NO_x Emission Inventory

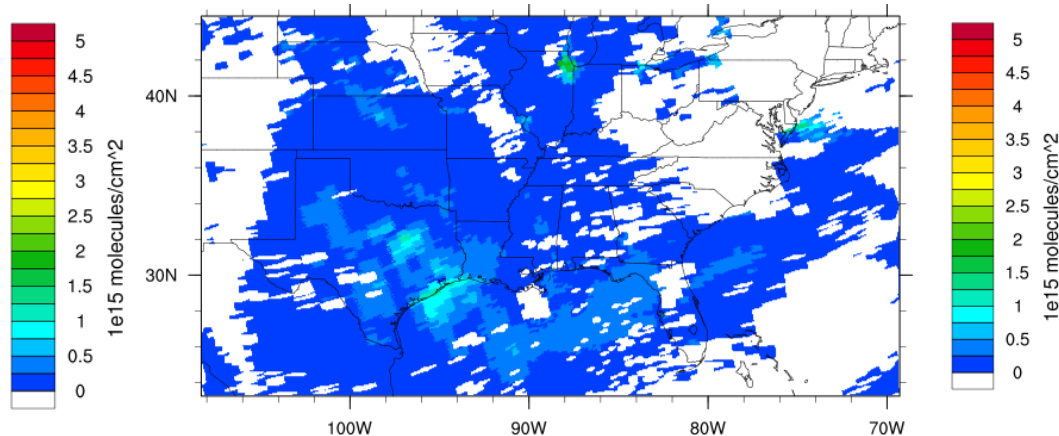
OMI NO₂ Tropospheric VCD Error with AK



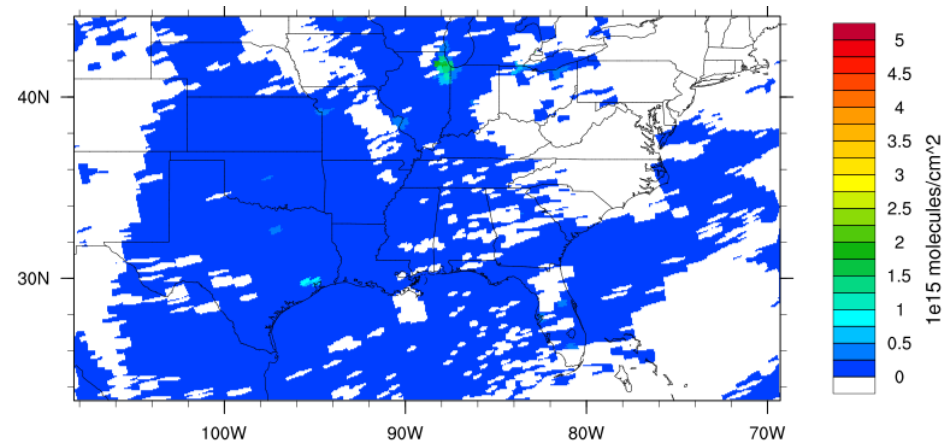
June 8, 2006 11 CST - June 8, 2006 14 CST

- Change in CAMx VCD due to 30% emissions reduction generally less than error in OMI VCD
- Similar results on all other episode days

30% Reduction in All NO_x emissions: | Change in VCD |

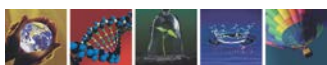


30% Reduction in SFC NO_x emissions: | Change in VCD |



June 8, 2006 11 CST - June 8, 2006 14 CST

Min = 0.00, Max = 1.89



Error in Tropospheric NO₂ VCD

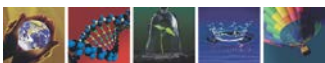
- Error in OMI NO₂ column retrieval dominated by atmospheric mass factor, AMF
 - Largest uncertainties in AMF due to errors in specification of clouds, surface albedo, a priori NO₂ profile shape and aerosols
- These errors have a significant systematic component with characteristic spatial and temporal scale-may not average out over time
 - We present the OMI error comparison day by day without averaging in time
 - Tropospheric VCD error reflects the application of the averaging kernel (used DOMINO variable VCDTropErrorUsingAvKernel)

Results of Comparison

- Changes in modeled NO₂ columns due to NO_x emissions perturbation are smaller than reported errors in OMI NO₂ columns
 - Modeled columns show far greater sensitivity to NO_x emissions sources in the upper troposphere than near-surface sources
- Retrieved OMI and modeled NO₂ columns are not sensitive enough to changes in near-surface NO_x emissions to be used for evaluation of the TCEQ's SIP modeling NO_x emission inventory

Summary

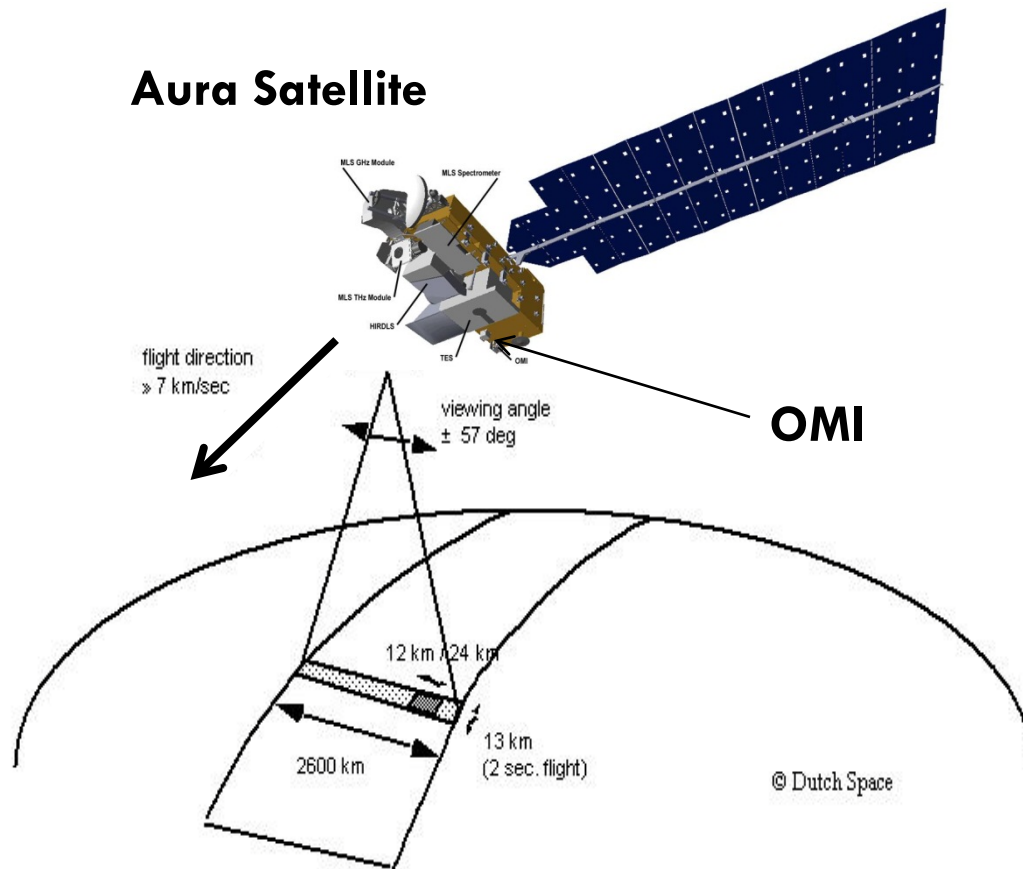
- Current DOMINO OMI product cannot be used to evaluate the TCEQ's SIP modeling NO_x inventory using the column comparison method
 - However, satellite data were instrumental in diagnosis of bias in CAMx upper tropospheric NO_x
- Method may be viable in the future if:
 - Future OMI products have smaller error AND
 - Causes of CAMx low bias in the upper troposphere and possibly the lower stratosphere are identified and remedied



End

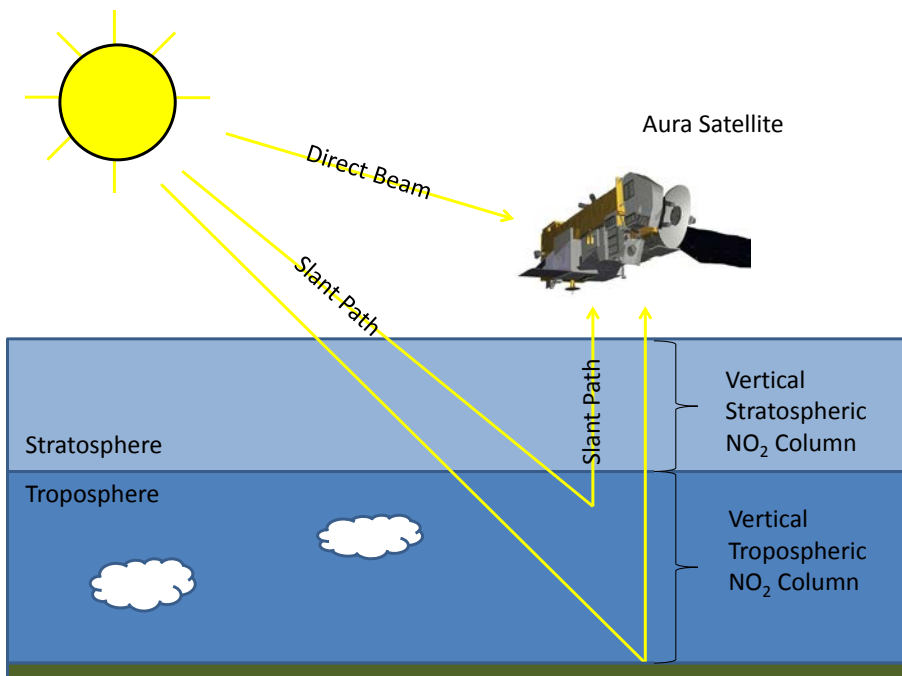
Ozone Monitoring Instrument (OMI)

Aura Satellite



- OMI flies aboard the Aura satellite
 - Polar orbiter
 - Global coverage each day
 - Sun-synchronous orbit with early afternoon overpass
 - 13 km x 24 km footprint at nadir
 - Data swaths 2600 km across
- OMI measures backscattered solar radiation in UV and visible
 - Does not directly measure NO_2
 - Conversion of measured radiation from OMI to tropospheric NO_2 columns is a multi-step process called a retrieval

OMI Tropospheric NO₂ Column Retrieval

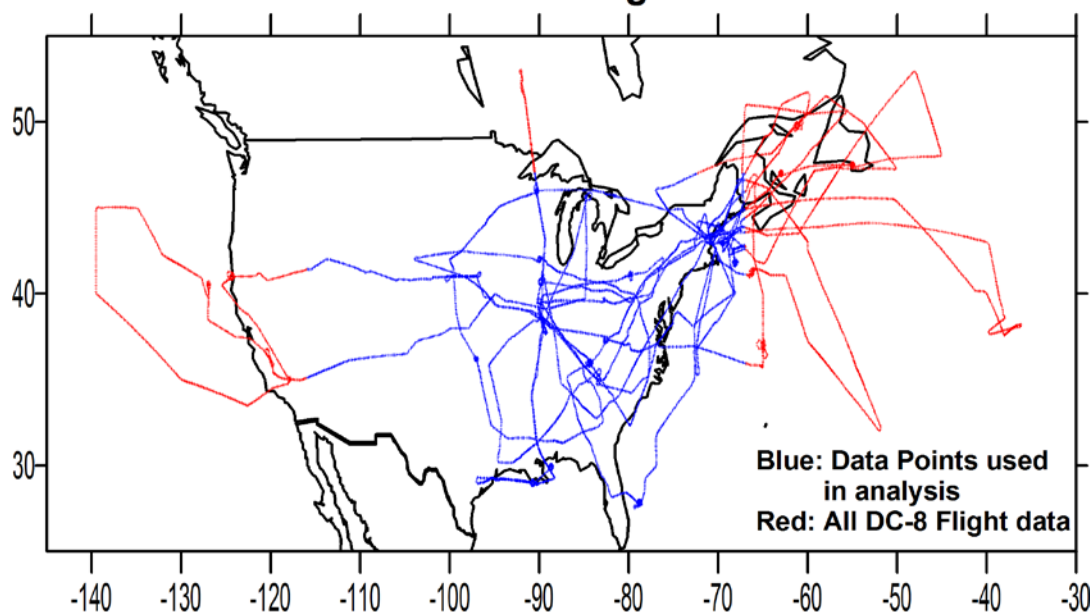


- Obtain slant column NO₂ amounts Ω_s (along average photon path from sun to OMI) via DOAS
 - Spectral fit of OMI-measured attenuation spectra in 405–465 nm window to reference
- Go from slant to vertical column via application of air mass factor:

$$AMF = \Omega_s / \Omega_v$$
- Remove stratospheric contribution to obtain tropospheric vertical NO₂ column $\Omega_{v(trop)}$

Comparison of CAMx Modeled Reactive Nitrogen Species with INTEX-A Aircraft Measurements

INTEX-A DC-8 Flight Tracks



- INTEX-A field experiment held July 1-August 15, 2004
 - Does not overlap June 2006 episode
- Compare mean NO_y species profiles from INTEX-A flights with episode average CAMx NO_y profiles over similar geographic regions
- NASA DC-8 flight dataset provided by Barron Henderson