Application of satellite observations to ozone attainment planning in Texas: Update on NASA project

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Project Team

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Ozone Photochemical Modeling

Ozone and its sensitivity to ΔEmissions

Could satellite-based NO$_x$ and photolysis inputs improve ozone modeling??
Project Objectives

- GOES cloud data to improve photolysis rates
- OMI NO$_2$ columns and other data to create top-down NO$_x$ inventory via inverse modeling
- CAMx-HDDM to assess how satellite-derived inputs influence ozone-precursor response in Texas SIP modeling episodes
  - Seek stakeholder input on how to target these analyses to inform decision-making
Approach

1. Photolysis Rates assimilated using GOES data
2. NOx Emissions inverted from OMI and TexAQS-II data
3. Model how revised inputs affect ozone responsiveness metrics
4. Provide results to TCEQ and stakeholders for upcoming attainment planning
Motivation: Misplacement of clouds by meteorology models

Figure 1. MM5 predicted and satellite observed cloud fields for (a) 24 August 2000, 2100 UT, and (b) 28 August, 1900 UT.

Pour-Biazar et al., JGR, 2007
Motivation: Impact of satellite-based clouds on NOx & O3 concentrations

Figure 7. Largest differences in (a) NOx and (b) O3 between assimilation and control simulations (assim-control) for the entire period of study covering from 0000 UT, 24 August 2000, to 0000 UT, 1 September 2000.
Motivation: Influence of Photolysis Rates on Ozone-NOx Sensitivity

Fig. 5. Sensitivity of ozone to Houston anthropogenic NOx emissions, if the rate of all photolysis reactions is 30% smaller (L) or larger (R) than in base case, for June 21 (top) and June 23 (bottom). Contours show O₃ > 85 ppb in each case.
Motivation: Influence of NO\textsubscript{x} inventory on O3 sensitivity to NOx

- O3 sens to NOx under a 50% smaller NOx inventory
- O3 sens to NOx under a 50% larger NOx inventory

Xiao et al., JGR 2010
Motivation: Influence of NO$_x$ inventory on O$_3$-precursor response

O$_3$ Sens to NOx as Function of Baseline ENOx
(Harris County average, 9/1/2006, 3pm)

Xiao et al., JGR 2010
Approach: GOES-based photolysis rates

- Derive transmissivity fields based on GOES data (cloud albedo & cloud top pressure)
- Use original MM5-CAMx photolysis rates when satellite data unavailable
- Compute adjusted photolysis rates in CAMx-TUVRM
GOES-based photolysis rates in CAMx

**GOES-CAMx INTERFACE**

Cloud transmissivity (calculated from satellite retrieved cloud albedo), cloud top pressure, and cloud fraction are prepared for input to MM5CAMx

\[ tr_{cld} = 1 - (alb_{cld} + abs_{cld}) \]

**MODIFIED MM5CAMx**

GOES retrievals replaces MM5 cloud information being passed to CAMx. Cloud fraction, transmissivity, cloud base and top heights are used to calculate cloud transmissivity to be passed to CAMx.

**READINP in CAMx**

In subroutine READINP, clear sky photolysis rates will be adjusted for cloud cover based on GOES cloud fraction and cloud transmissivity information.

\[
J_{below} = J_{clear}[1 + cfrac(1.6tr \cos(\theta) - 1)] \\
J_{above} = J_{clear}[1 + cfrac((1-tr) \cos(\theta))] 
\]

Interpolated in between.

Cloud Base According to Lifting Condensation Level

\[
T_c = B \ln \left[ \frac{A \varepsilon}{wp_0 \left( \frac{T_o}{T_c} \right)^{1/k}} \right] 
\]
Limitations of satellite-based photolysis rates

• Missing data at some times/locations
• Inconsistency between photolysis rates and other cloud properties (wet deposition, cloud processing)
Approach: NOx inverse modeling

1. Baseline SIP modeling inputs from TCEQ
2. Photolysis rates assimilated using GOES data
3. NO₂ column densities (OMI satellite retrievals)
4. NO₂ observations (aircraft & surface monitors)
5. Simulated NO & NO₂ concentrations and their sensitivities to emissions
6. Convert NO₂ column densities
7. Kalman Filter Optimal Estimator
8. Updated Emission Inventory \( E_{n+1} \)
9. \( |E_{n+1} - E_n| < \delta \) ?
10. Final Emission Inventory
Approach: NOx Inverse Modeling

• Similar to Napelenok et al (ACP, 2008) Kalman filter inversion, except:
  – Use data from newer, higher-resolution OMI instead of SCIAMACHY
  – Incorporate other observations (including TexAQS2 field campaign) into inversions
3-D measurements of air pollutants

OMI satellite

NOAA R/V vessel

NOAA P-3 aircraft

NO2 monitors
Ozone Monitoring Instrument (OMI)

- NO₂ spectral range (405-465 nm)
- Over-pass time: 13:45 local time (North America)
- Daily global coverage
- Spatial resolution: 13km × 24km (nadir-view point)
- Products: OMI_DP, OMI_ST, OMI_DP_GC (Lamsal et al., 2010, JGR)

Source: OMI Guide 2009
Challenges in NOx Inversions

• How to “weight” different data sources
• How to define source regions and categories
  – Invert emissions in every cell?
  – Retain spatial patterns of bottom-up inventory?
• Comparing 3D gridded model results with satellite column pixels
• Poor model performance in upper troposphere
  – See next slide
Challenge: Upper Tropospheric NO\textsubscript{x} \n
- Poor model performance for upper tropospheric NO\textsubscript{2} 
  - Important in rural areas
- Will use Lightning Detection Network data with Kaynak et al. scheme for lightning NO 
  - Places NO where cloud-to-ground flashes observed
  - Scales to include cloud-to-cloud
  - Vertical profile from Pickering
- CB-6 may address CB05 NO\textsubscript{x} chemistry problems noted by Henderson et al (2010)

Fig. 7. Vertical distribution of NO\textsubscript{2} concentrations observed by NASA INTEX DC-8 flights over the eastern United States compared to model predictions matched in space and time. Error bars

Napelenok et al, 2008
Assessing the impact of satellite-based inputs

- Run CAMx-HDDM with original and satellite-based inputs to compare O$_3$ concentrations & sensitivities to emissions in TCEQ episodes
  - August-September 2006 for HGB/TexAQS2
  - June 2006 for DFW

- Model future year (2018) to explore impacts on relative reduction factors
Progress to Date

• Obtained both episodes from TCEQ
• Validated CAMx results on Rice system
  – Updated to CAMx v. 5.20; awaiting v. 5.30
  – Working on 3-D CAMx-HDDM outputs
• Obtained DOMINO-GC OMI NO₂ data from Dalhousie U. (L. Lamsal & R. Martin)
  – Mapped onto CAMx domain
  – Scattering weights to compare CAMx vs. OMI
• Obtained Lightning Detection Network data
DOMINO-GC data mapped onto TCEQ 12-km domain

September 2006 average
Units: $10^{15}$ molecules/cm$^2$
Linkage to Texas AQRP Grant

• “Factors influencing ozone-precursor response in Texas attainment modeling”
  – Grant to Rice U. (PI D. Cohan) and ENVIRON (B. Koo and G. Yarwood), 10/2010 – 8/2011
  – Will consider various structural and parametric uncertainties in same CAMx SIP episodes
    • Alternate inputs: Satellite-based photolysis rates and inverse NO$_x$, along with alternate boundary conditions, biogenic VOC, and % changes in parameters
    • Bayesian approaches will use observations to assess the relative likelihood of each case
    • Probability distribution of O3-emissions sensitivities
Comments and Feedback

- How to define NO$_x$ source regions and categories?
- Control scenarios for sensitivity modeling?
- Suggested modifications or extensions?
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