NOx/NO2 measurements – connecting to inventories, spatial/temporal (Lessons 2017 Lake Michigan Ozone Study)

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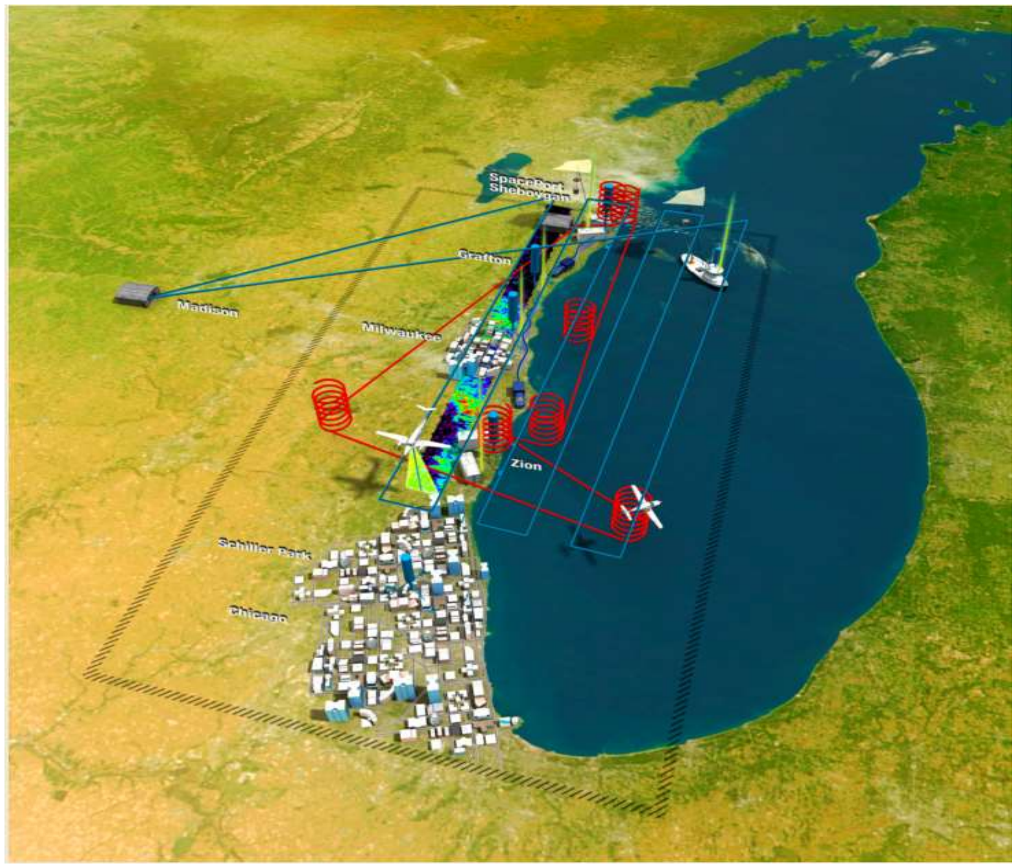
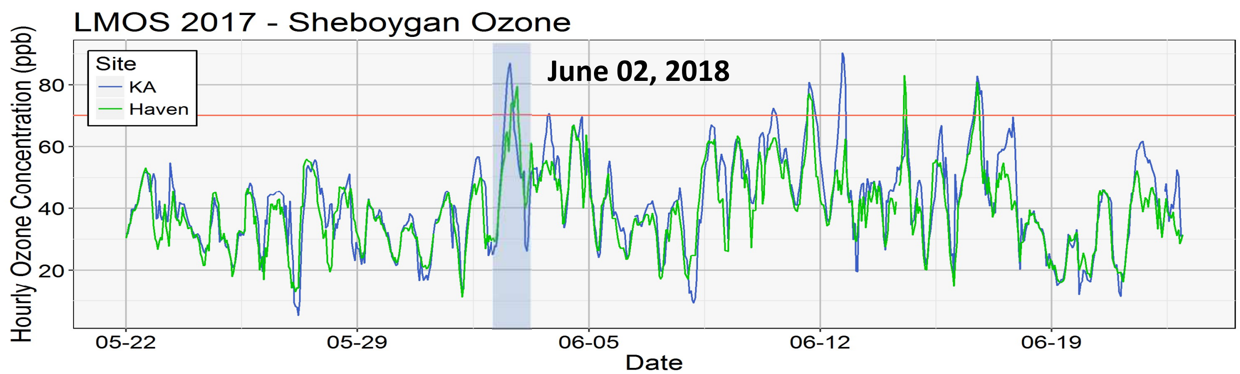
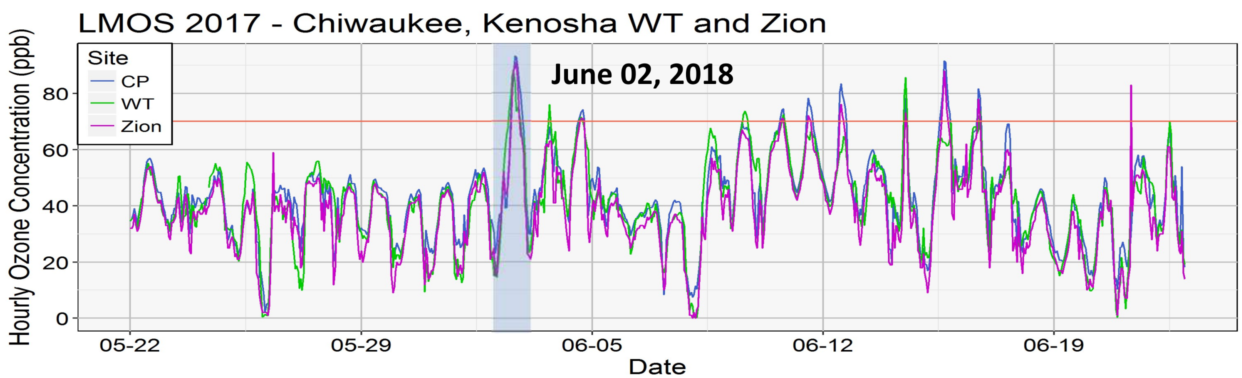
Jassim A Al-Saadi
Hariprasad Dilip Alwe
Timothy Bertram
Megan Christiansen
Patricia A Cleary
Alan Czarnetzki
Angela F Dickens
Marta Fuoco
Carmichael Gregory
Monica Harkey
Laura Margaret Judd
Donna M Kenski
Allen Lenzen
Dylan B Millet
Charles O Stanier
Elizabeth A. Stone
James Szykman
Luke Valin
Timothy J. Wagner



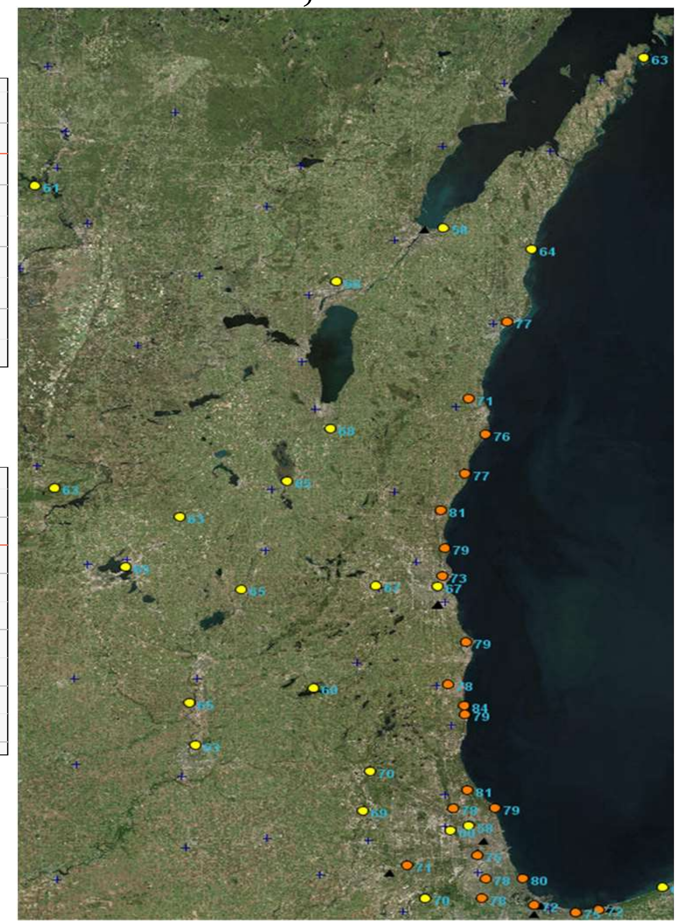
Long Island Sound Tropospheric Ozone Study (LISTOS) Meeting, Albany, NY, April 11, 2019

Lakeshore ozone during LMOS 2017





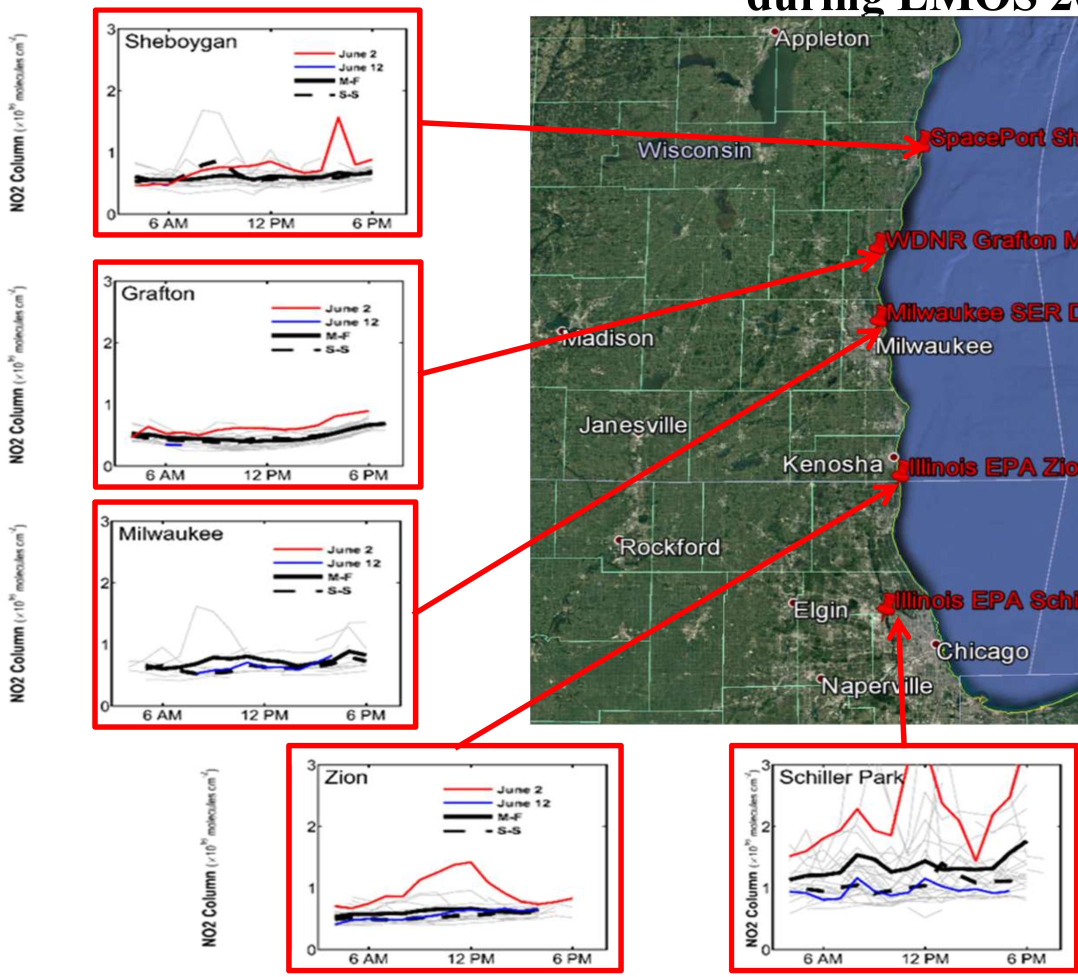
June 02, 2017 MDA8



Provided by Angie Dickens (WDNR)

MDA8=Maximum Daily 8 hour Average

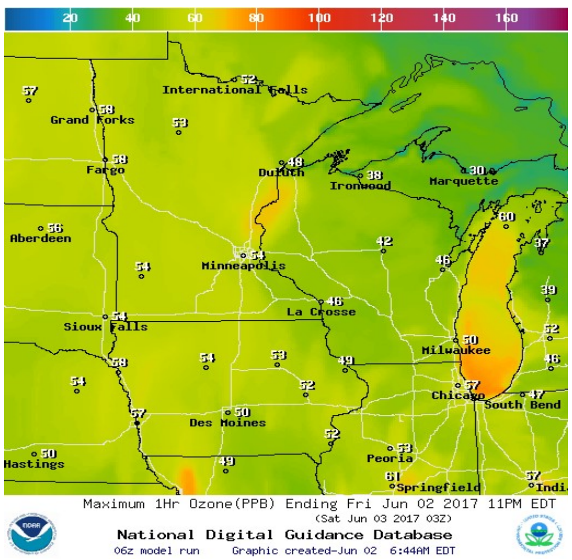
Ground based UV/visible grating spectrometers (Pandoras) column NO2 measurements during LMOS 2017



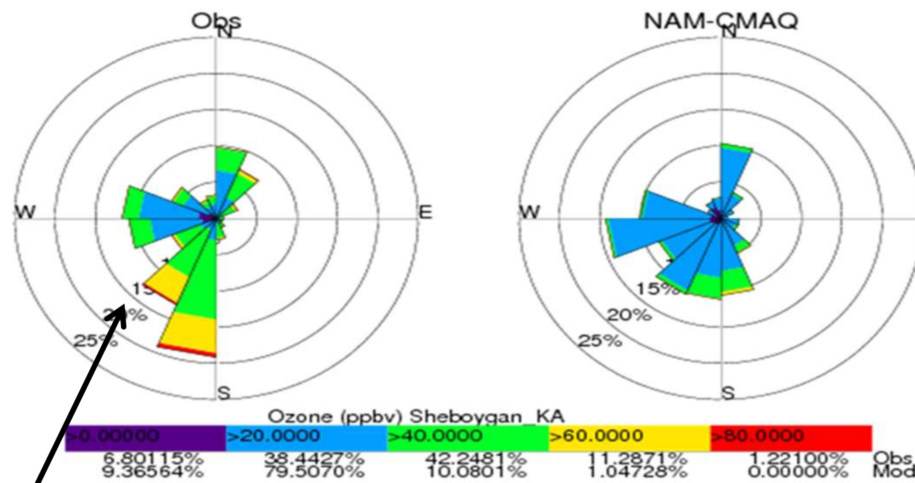
Pandora NO2 column measurements show high values at Zion, Grafton, and Sheboygan on June 2, 2017

(US EPA ORD, Luke Valin)

National Weather Service NAM-CMAQ ozone forecasts during LMOS 2017
(http://airquality.weather.gov/)



May 22 through June 22, 2017

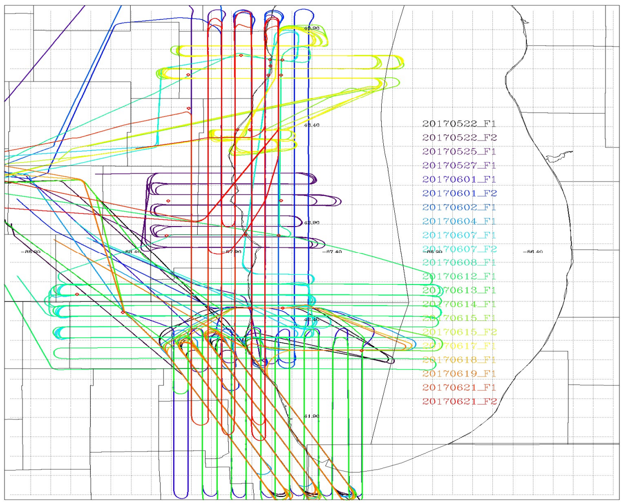


During LMOS 2017 NAM-CMAQ underestimates the occurrence of high ozone (>60ppbv) during Southerly and Southwesterly flow at Sheboygan, KA.

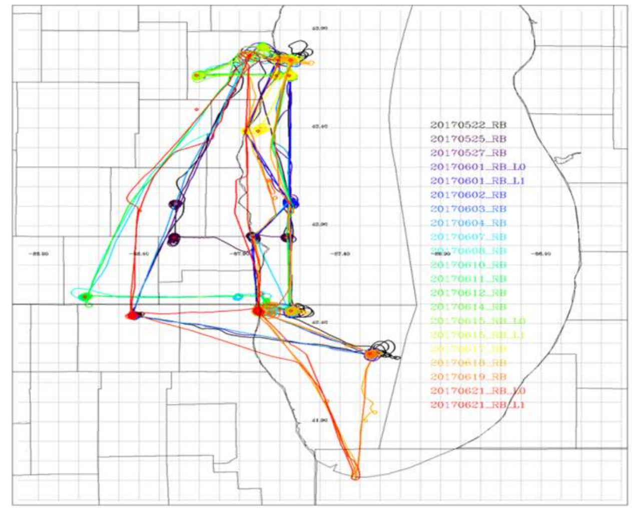
The North American Model (NAM) meteorology drives the Environmental Protection Agency's (EPA) Community Multiscale Air Quality Model (CMAQ)

LMOS 2017 Aircraft Measurements

NASA GeoTASO remote sensing Flights



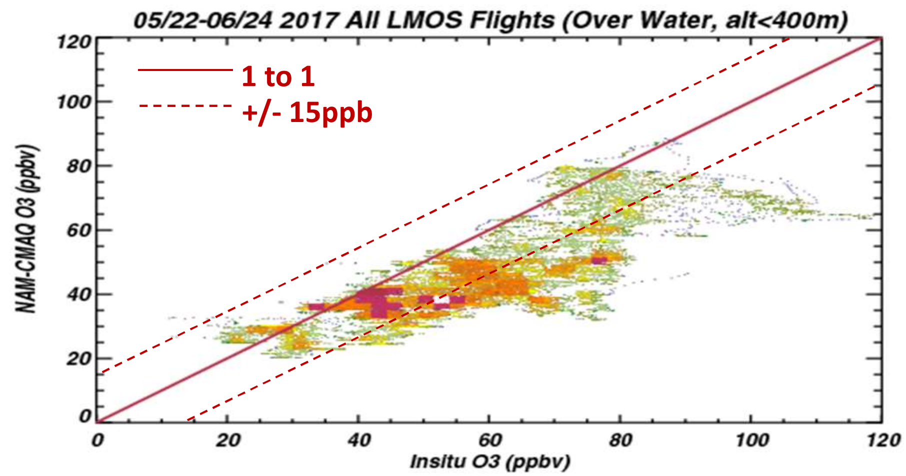
Scientific Aviation insitu sampling Flights

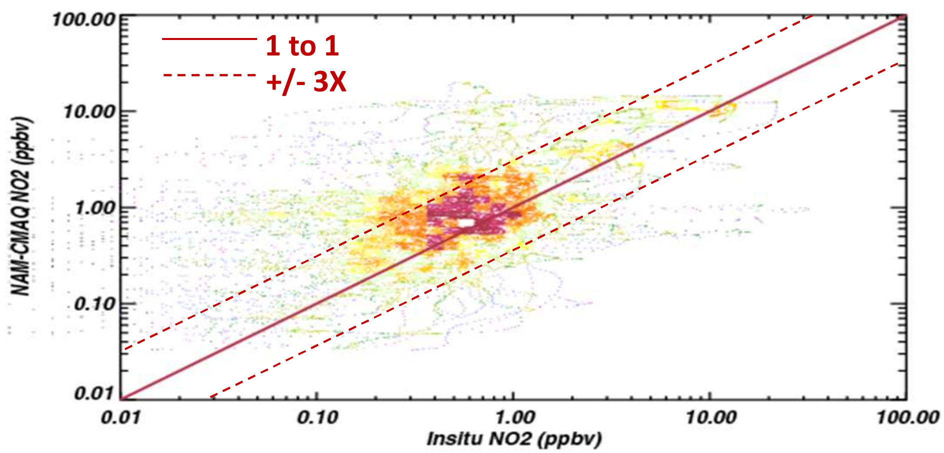


GeoTASO (Geostationary Trace gas and Aerosol Sensor Optimization) is an airborne hyperspectral mapping instrument that is being used as an airborne testbed for future high-resolution trace-gas observations from geostationary sensors such as TEMPO

The Electric Power Research Institute (EPRI) provided funding for Scientific Aviation Flights during LMOS

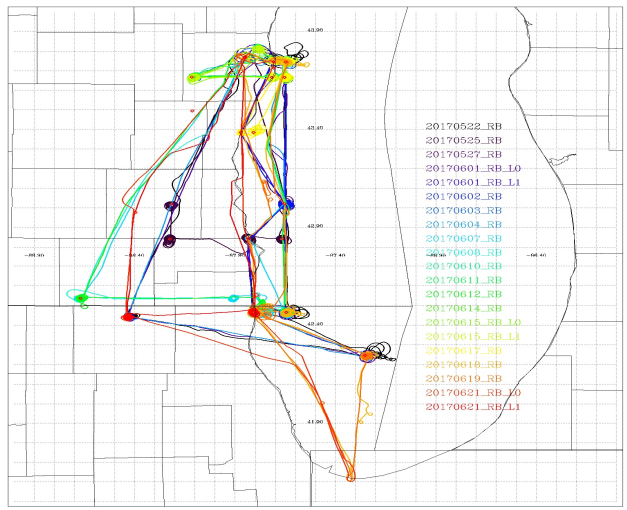
NAM-CMAQ vs Scientific Aviation (Over Water, Altitude <400m)





Steve Conley (Scientific Aviation PI)

All Scientific Aviation Flights

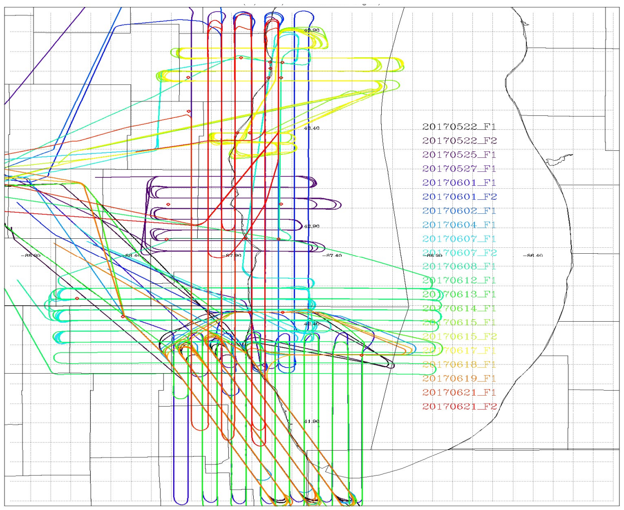


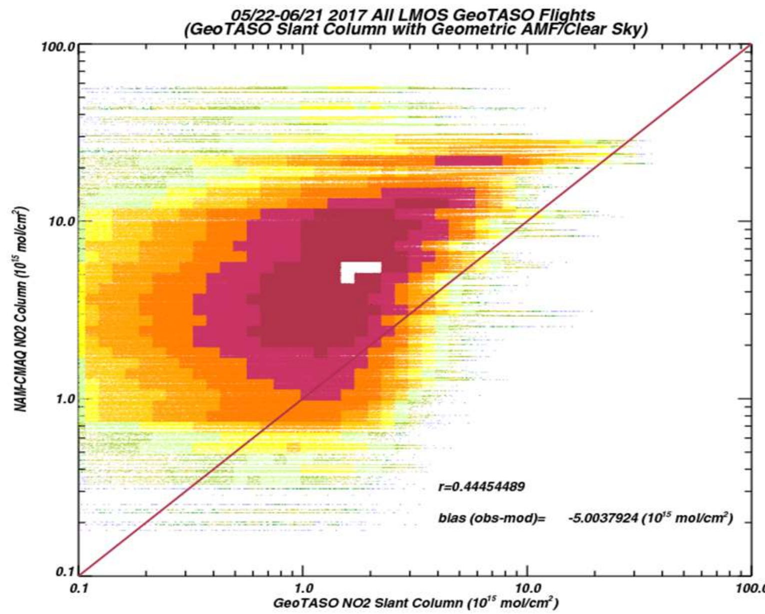
NAM-CMAQ underestimates O3 and overestimates NO2 over Lake Michigan

LMOS May 22 through June 21, 2017

NAM-CMAQ vs GeoTASO Differential Slant Column

All GeoTASO Flights

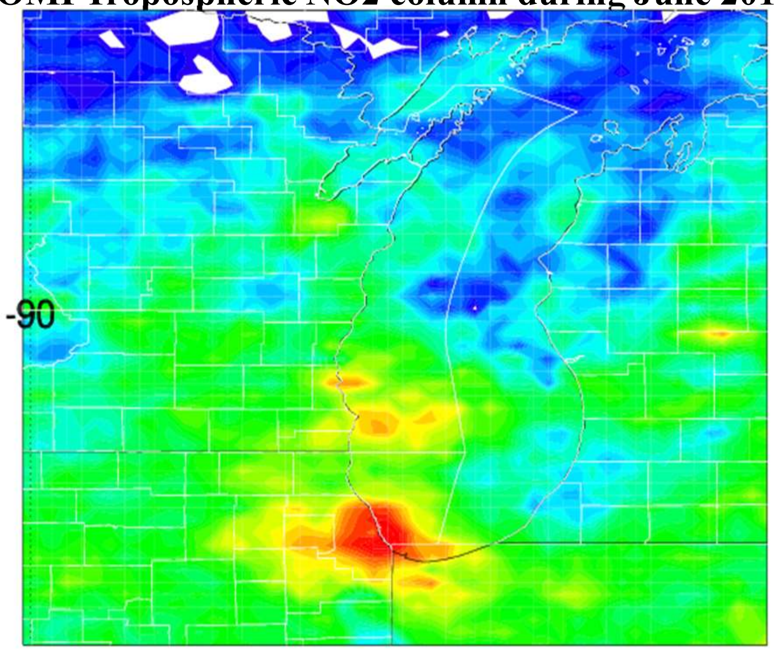




NAM-CMAQ overestimates NO2 columns compared to GeoTASO differential slant columns (currently not accounting for instrument sensitivity to NO2 profile)

Aura Ozone Monitoring Instrument (OMI) Tropospheric NO2 column Data Assimilation

OMI Tropospheric NO2 column during June 2017



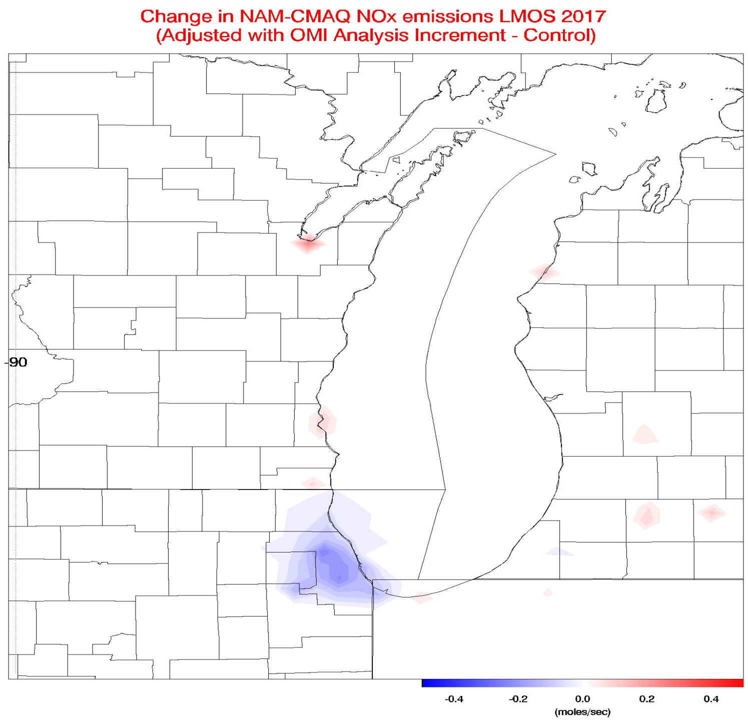
$$\frac{\Delta E}{E} = \beta \times \frac{\Delta\Omega}{\Omega}.$$

NOx emissions adjustments (ΔE) are constrained using OMI tropospheric NO2 column analysis increments (ΔΩ)

β accounts for the sensitivity of the NO2 column to changes in NOx emissions following Lamsal et al 2011.

Lamsal, L. N., et al. (2011), Application of satellite observations for timely updates to global anthropogenic NOx emission inventories, Geophys. Res. Lett., 38, L05810, doi:10.1029/2010GL046476.

Aura Ozone Monitoring Instrument (OMI) Tropospheric NO2 column Data Assimilation

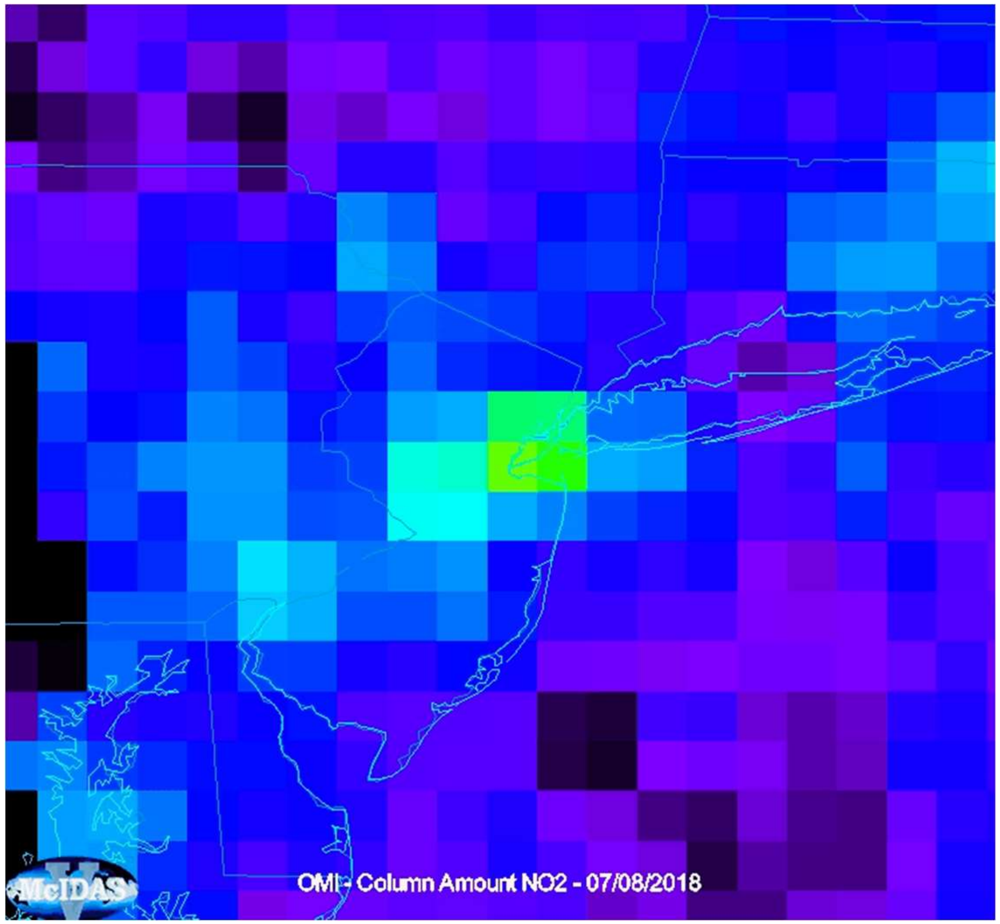


$$\frac{\Delta E}{E} = \beta \times \frac{\Delta \Omega}{\Omega}.$$

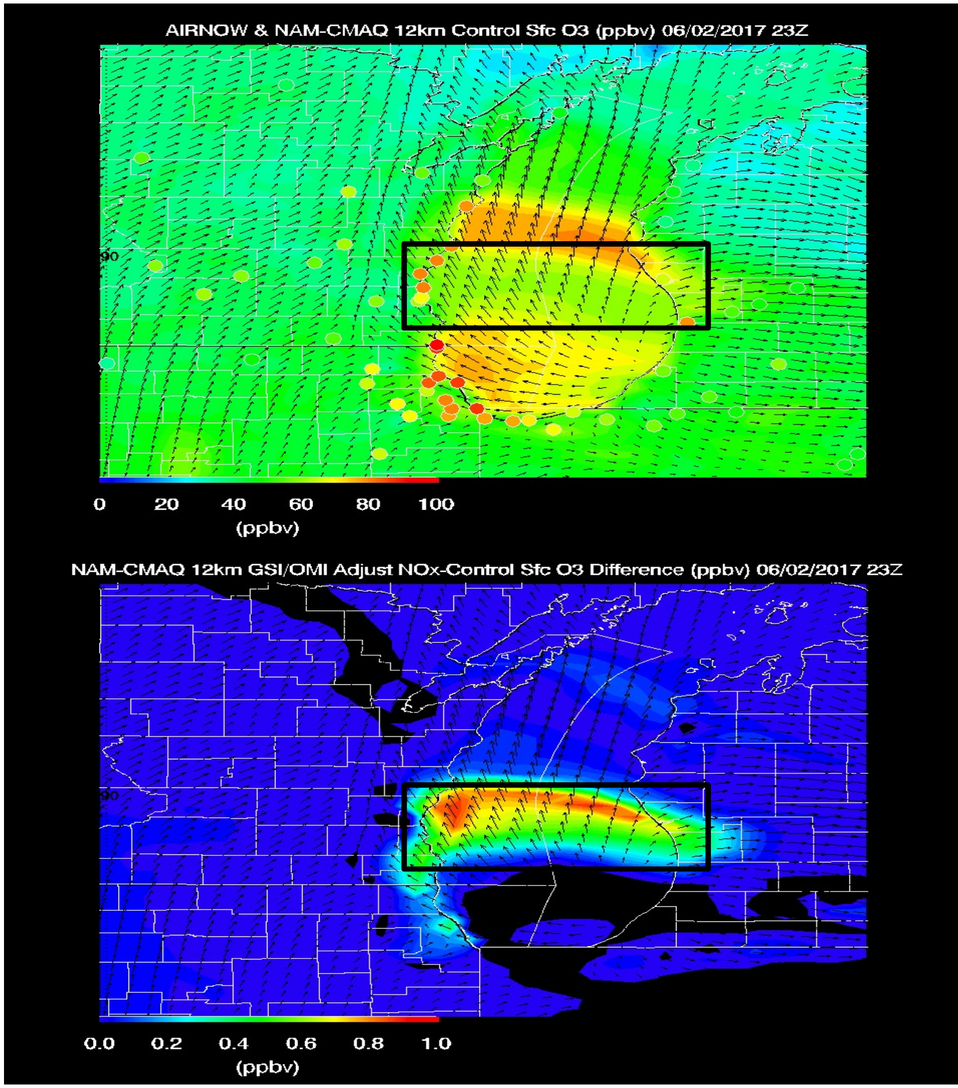
Assimilation of OMI NO2 results in small (~4%) reductions in NOx emissions over Chicago during June 2018

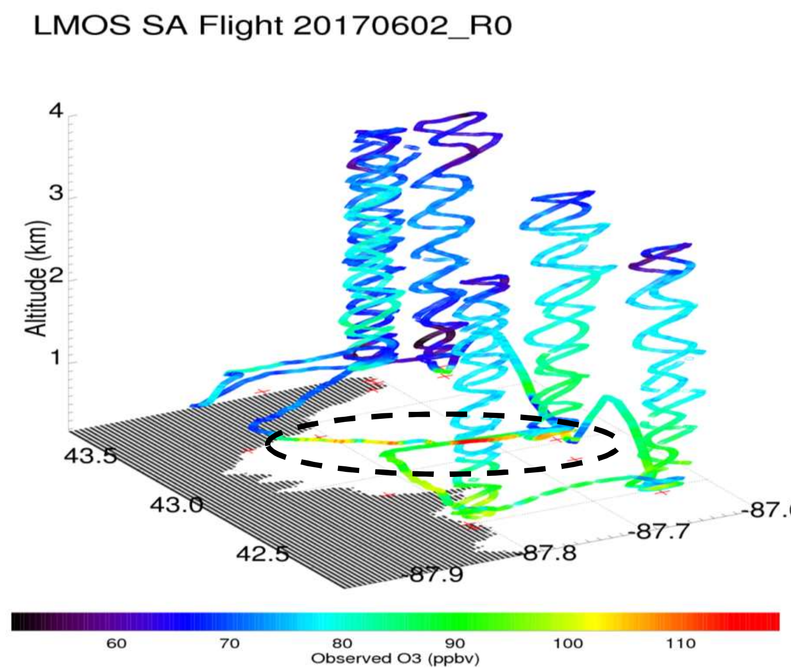
Lamsal, L. N., et al. (2011), Application of satellite observations for timely updates to global anthropogenic NOx emission inventories, Geophys. Res. Lett., 38, L05810, doi:10.1029/2010GL046476.

OMI vs TropOMI tropospheric NO2 columns 07/08/2018



VIIRS Day Night Band (DNB) shows urban lights on 07/08/2018

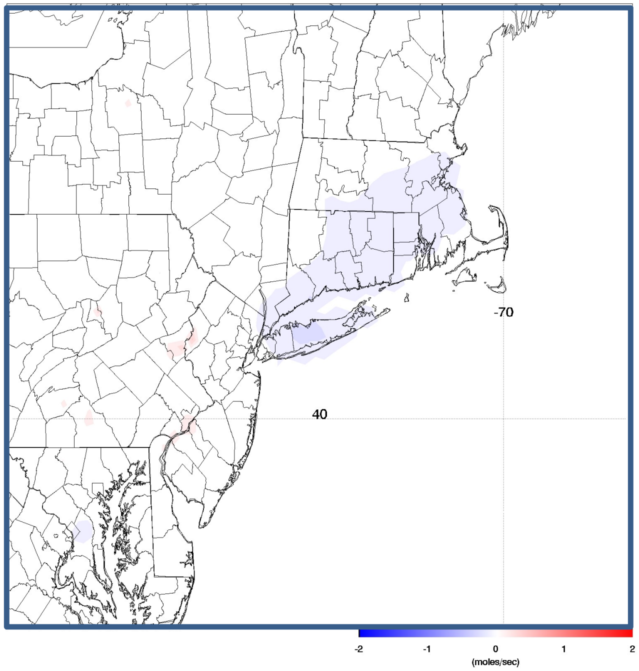




Max Observed O3 > 110ppbv

Reductions in NOx emissions on high ozone day leads to slight (~1ppbv) increases in surface ozone

Aura Ozone Monitoring Instrument (OMI) Tropospheric NO2 column Data Assimilation

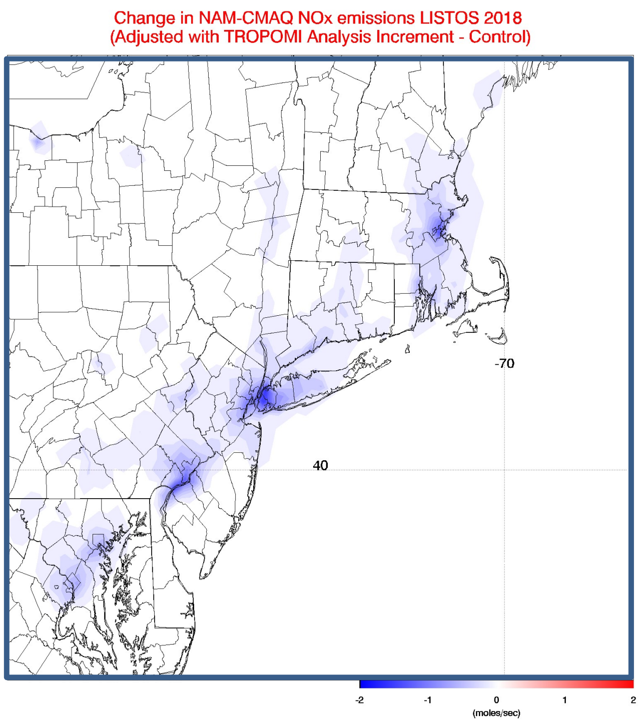


$$\frac{\Delta E}{E} = \beta \times \frac{\Delta \Omega}{\Omega}.$$

Assimilation of OMI NO2 results in small reductions in NOx emissions over NYC in June 2017

Lamsal, L. N., et al. (2011), Application of satellite observations for timely updates to global anthropogenic NOx emission inventories, Geophys. Res. Lett., 38, L05810, doi:10.1029/2010GL046476.

S5-P Tropospheric Ozone Monitoring Instrument (TropOMI) Tropospheric NO2 column Data Assimilation



$$\frac{\Delta E}{E} = \beta \times \frac{\Delta \Omega}{\Omega}.$$

Assimilation of TropOMI NO2 results in significant (~14%) reductions in NOx emissions over NYC in July-August 2018

Lamsal, L. N., et al. (2011), Application of satellite observations for timely updates to global anthropogenic NOx emission inventories, Geophys. Res. Lett., 38, L05810, doi:10.1029/2010GL046476.

Summary and Conclusions

- **The LMOS 2017 aircraft observed polluted layers with rapid ozone formation occurring in a shallow layer near the Lake Michigan surface.**

  ✓ **Comparisons between NAM-CMAQ forecasts, ground based monitors, in situ, and remote airborne measurements showed that NAM-CMAQ underestimated peak ozone concentrations and overestimated NO2 concentrations during ozone exceedance events during LMOS 2017.**

- **Assimilation of relatively coarse OMI NO2 retrievals has small impacts on NAM-CMAQ NOx emissions during June 2017 over Chicago and NYC**

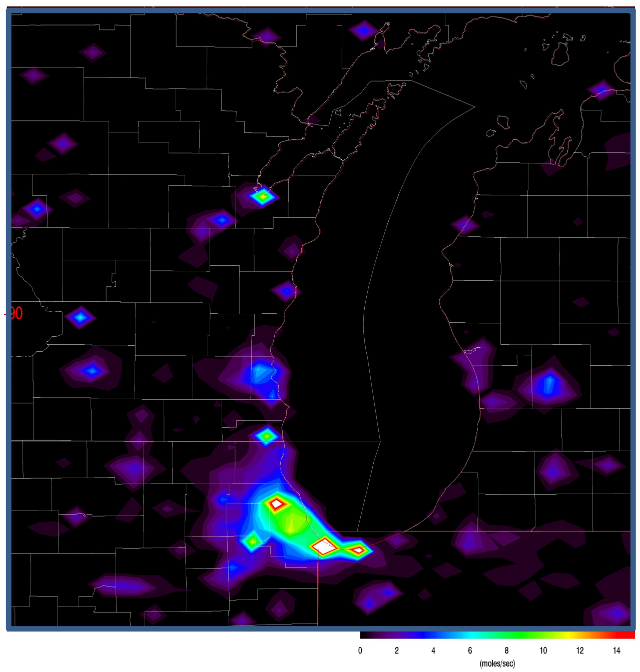
- **Assimilation of higher resolution TropOMI NO2 retrievals has significant impacts on NAM-CMAQ NOx emissions during July-August 2018 over Chicago and NYC**

- **Recommend generation of gridded sectorized emission estimates so that high resolution GeoTASO NO2 retrievals can be used to further constrain urban NOx emissions**

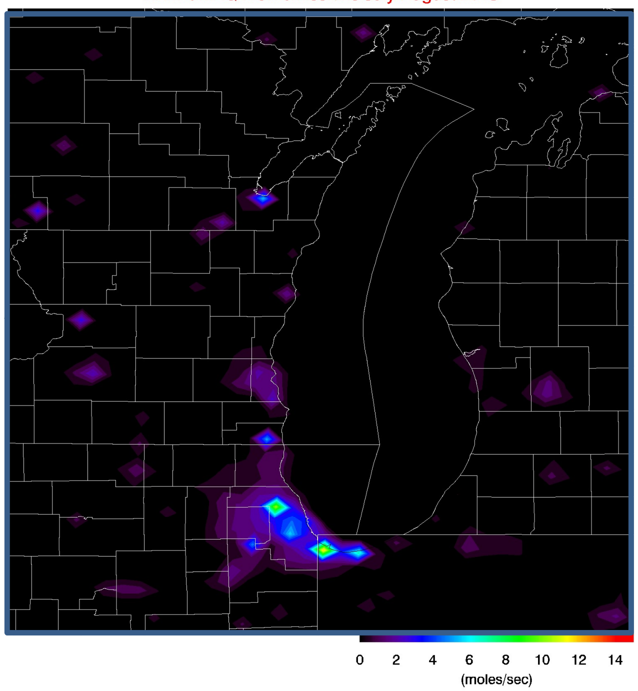
2017 Lake Michigan Ozone Study Synthesis Report
https://www.ladco.org/wp-content/uploads/Documents/LMOS_LADCO_report_final_draft_20180719.pdf

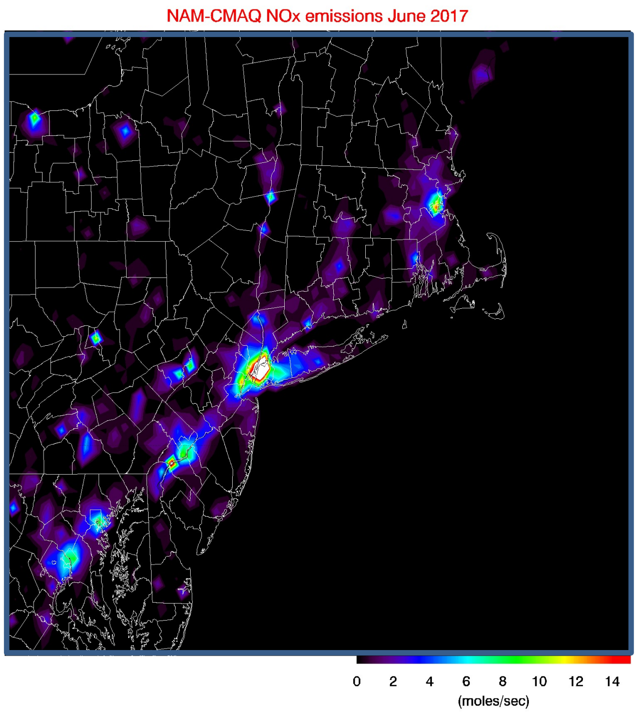
Extra Slides

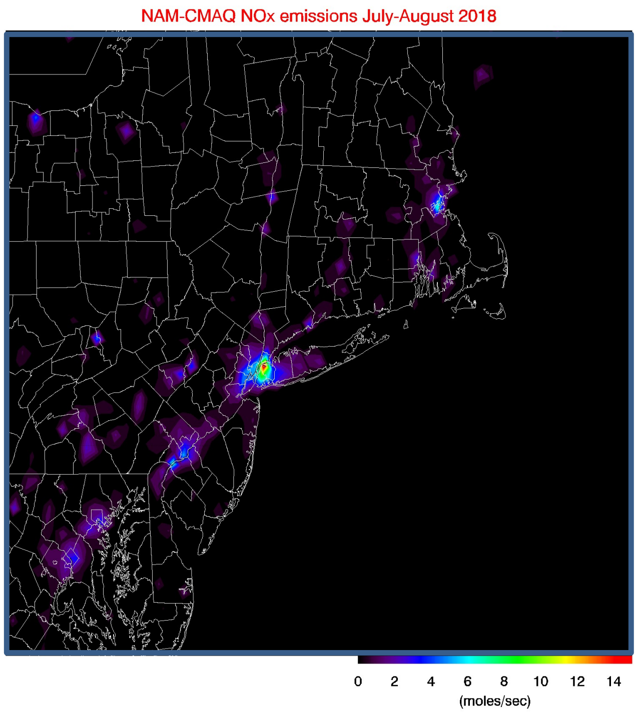
NAM-CMAQ NOx emissions June 2017



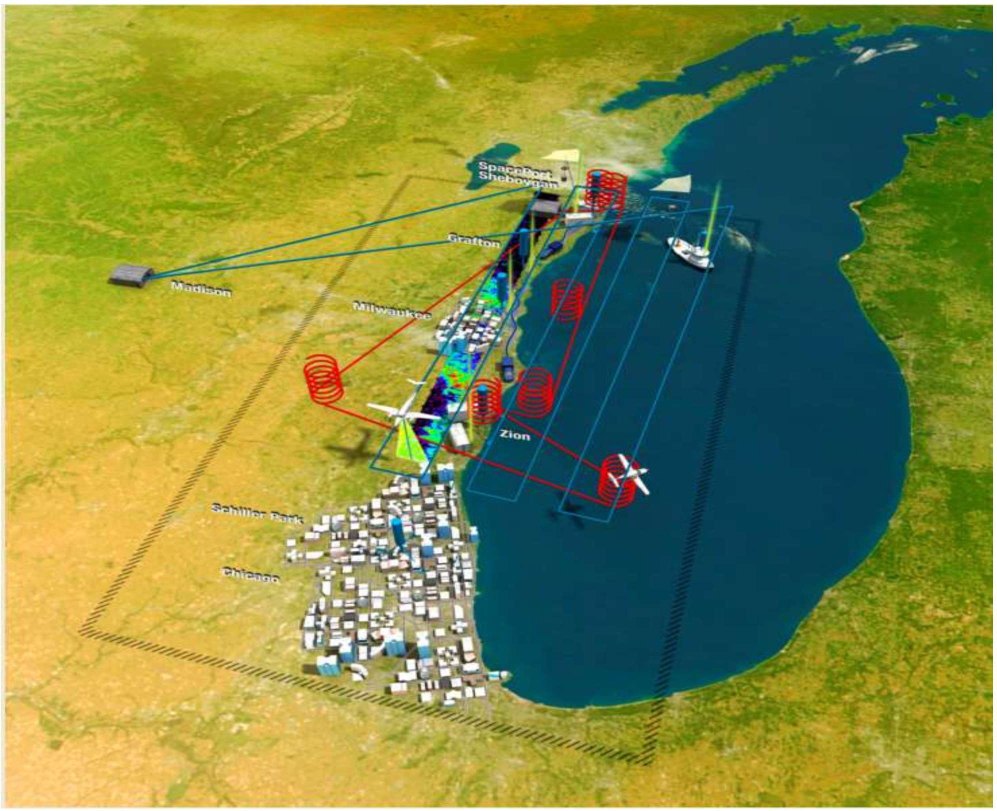
NAM-CMAQ NOx emissions July-August 2018

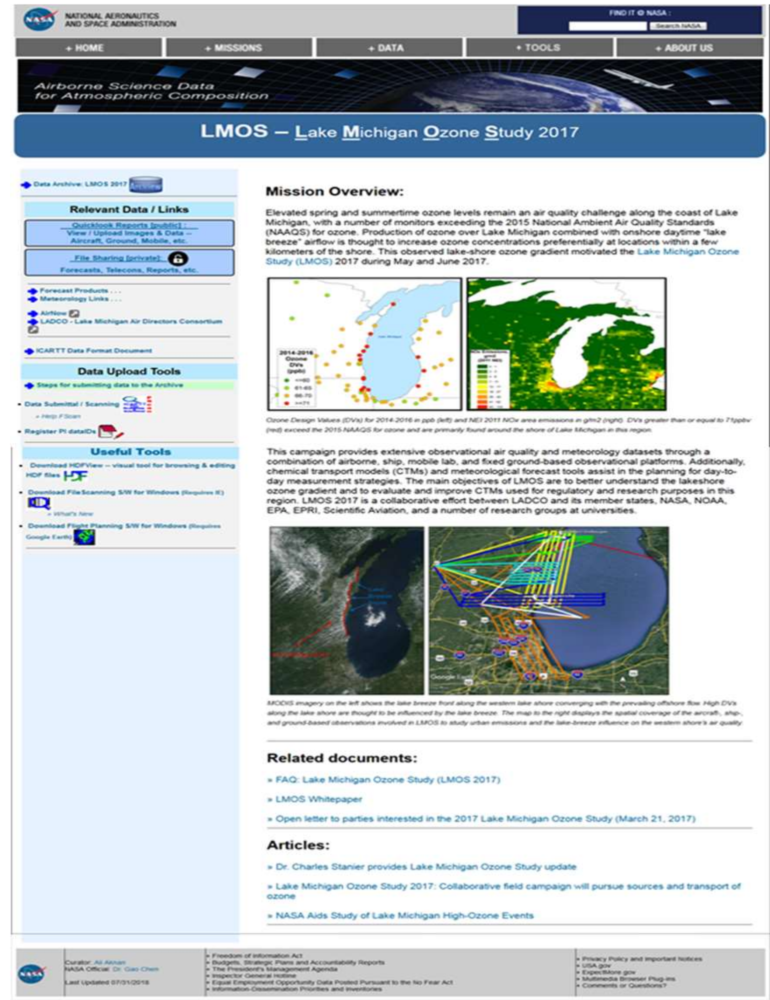



NAM-CMAQ NOx emissions June 2017
0
2
4
6
8
10
12
14
(moles/sec)


NAM-CMAQ NOx emissions July-August 2018
0
2
4
6
8
10
12
14
(moles/sec)

LMOS 2017 Data Archive





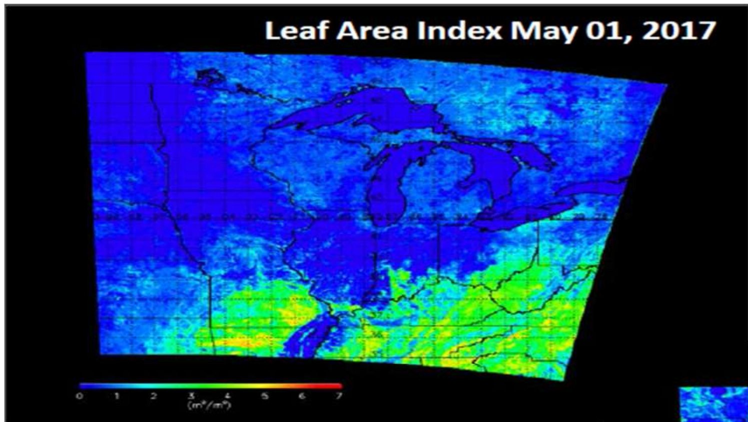
https://www-air.larc.nasa.gov/missions/lmos/index.html

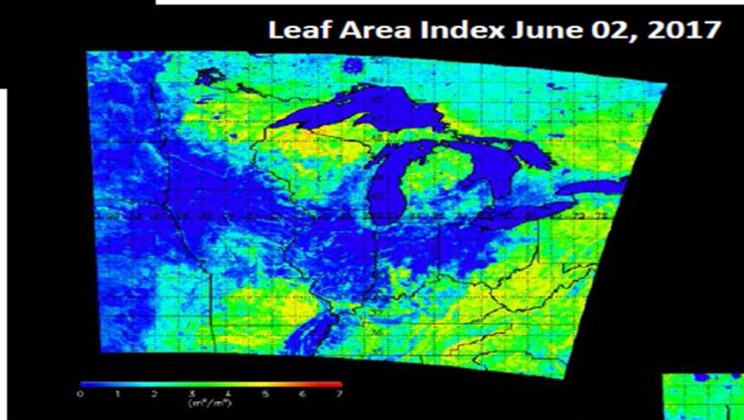
Summary of LMOS 2017 measurements

Location	Measurement*	Research Institution*
Ground Sites		
Spaceport Sheboygan	Remote sensing of meteorology (SPARC Trailer)	UW-Madison -SSEC
	In situ measurements of pollutants	U.S. EPA ORD
Zion, IL	Remote sensing of meteorology (Sodar/MW Radiometer)	Univ. Northern Iowa
	Detailed in situ chemical and aerosol measurements	Univ. Iowa, UW-Madison, Univ. Minnesota
	Routine measurements of ozone	Illinois EPA
Various†	Remote sensing of pollutants and boundary layer height (Pandora and Ceilometer)	U.S. EPA ORD
Sheboygan transect	In situ measurements of ozone at four locations	U.S. EPA ORD
Airborne Platforms		
Lakeshore region	Airborne remote sensing of NO_2 (GeoTASO)	NASA
	Airborne remote sensing of clouds (AirHARP)	Univ. Maryland, Baltimore County
	Airborne in situ profiling of pollutants and meteorology	Scientific Aviation
Shipboard Platform		
Lake Michigan	In situ measurements of pollutants	U.S. EPA ORD
	Remote sensing of pollutants and boundary layer height (Pandora and Ceilometer)	U.S. EPA ORD
Mobile Platforms		
Northeast IL and Southeast WI	In situ measurements of pollutants (GMAP)	U.S. EPA Region 5
Grafton to Sheboygan	In situ measurements of ozone and meteorology	UW-Eau Claire

Biogenic VOC Sensitivity Studies

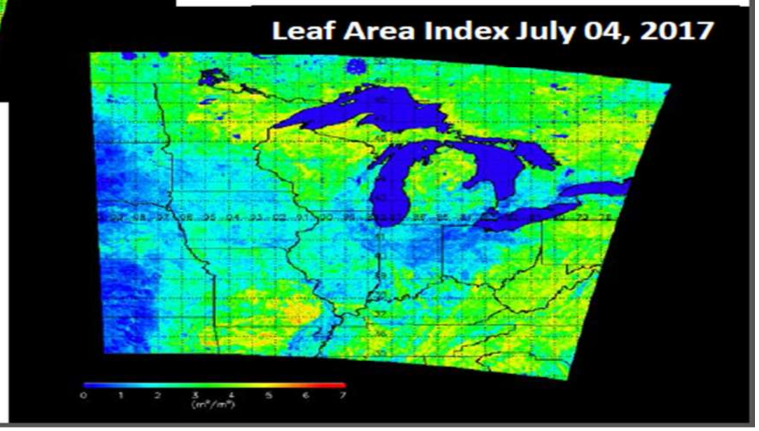
NAM-CMAQ 2x Biogenic emission Experiment
May 22 – June 13, 2018

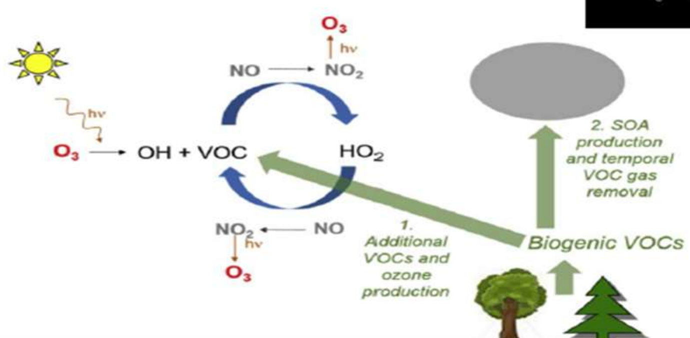


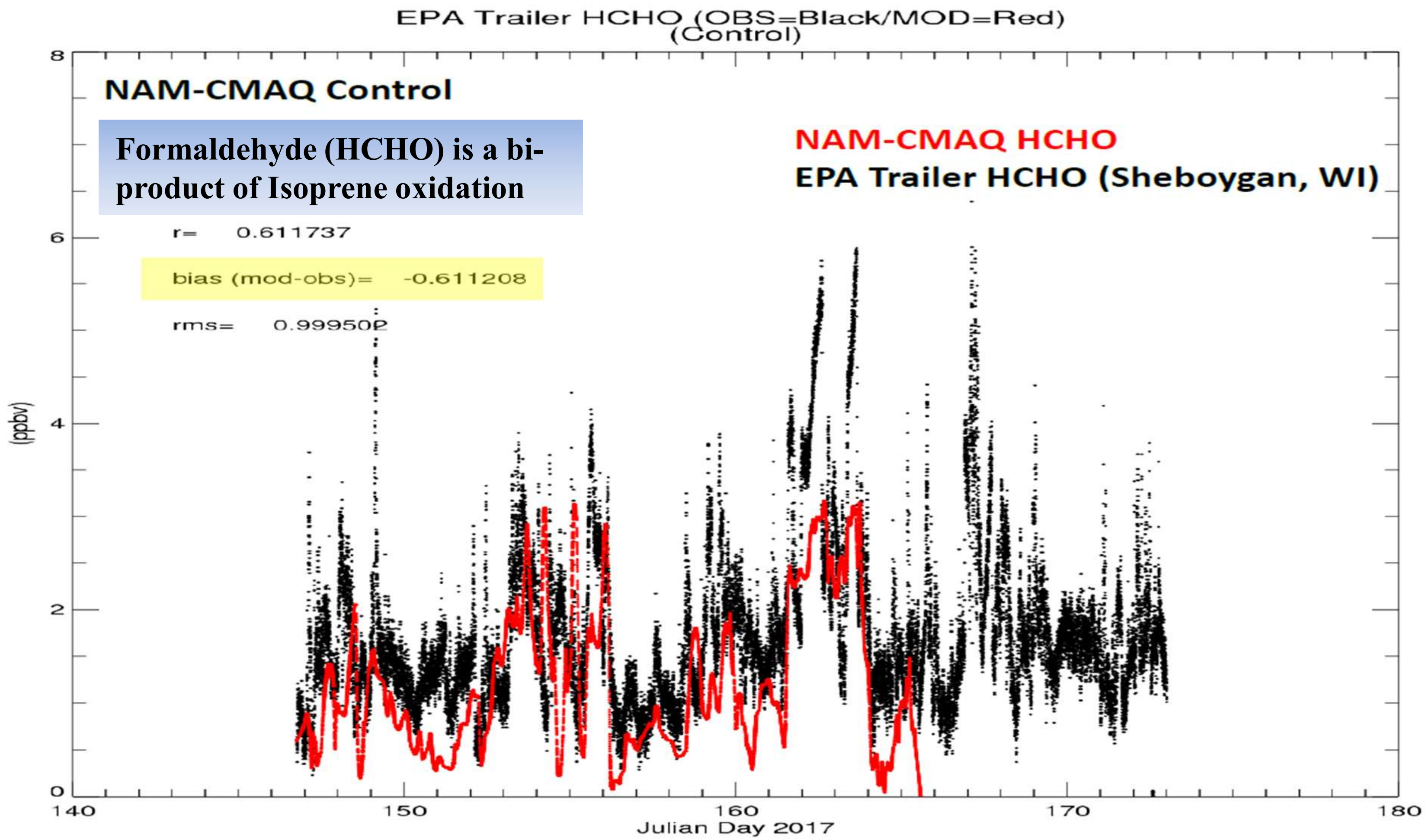


Increased biogenic VOCs can enhance ozone production in urban plumes

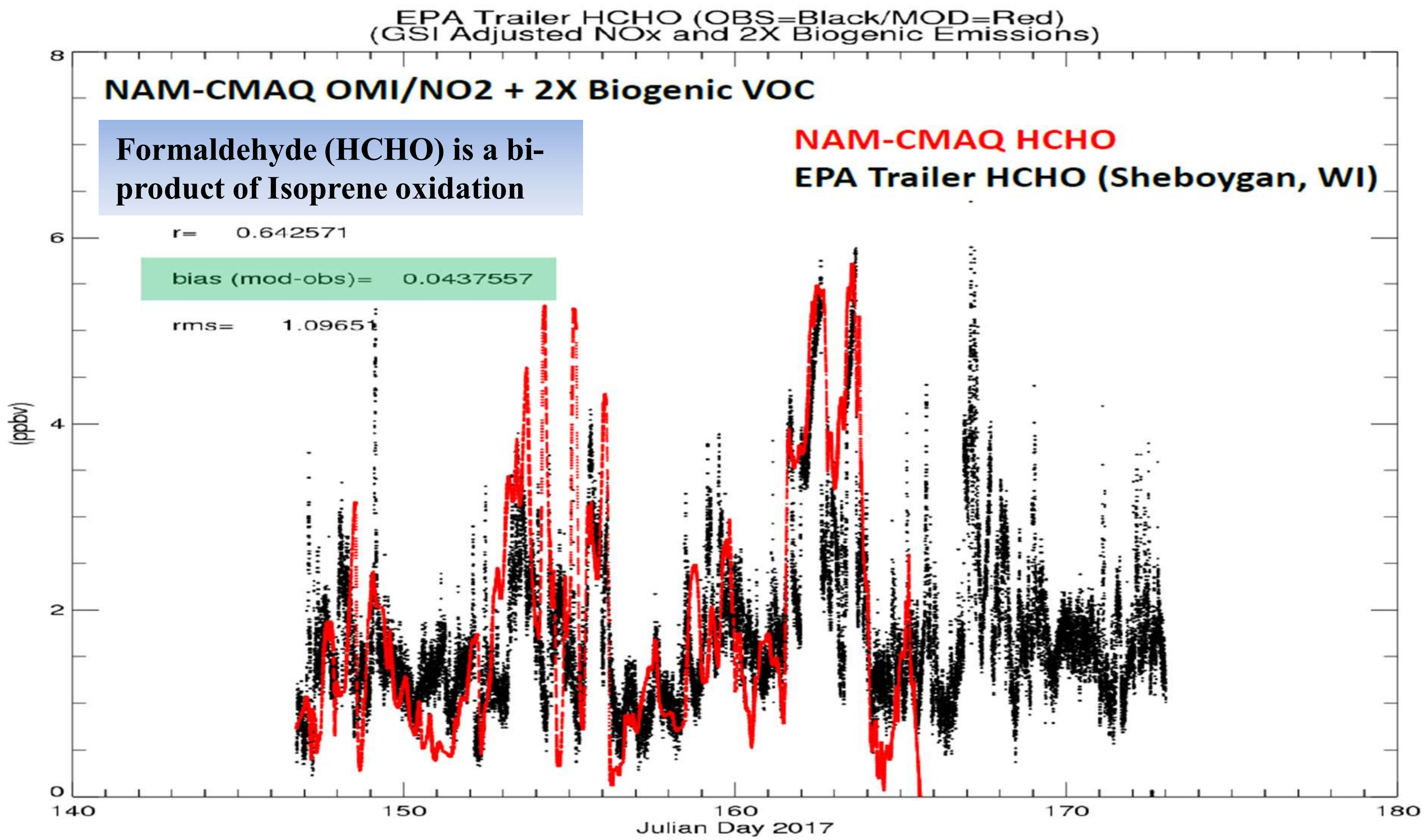
Isoprene (biogenic VOC) emissions increase with leaf area (leaf out)







Insitu HCHO provided by (US EPA, ORD Andrew Whitehill)



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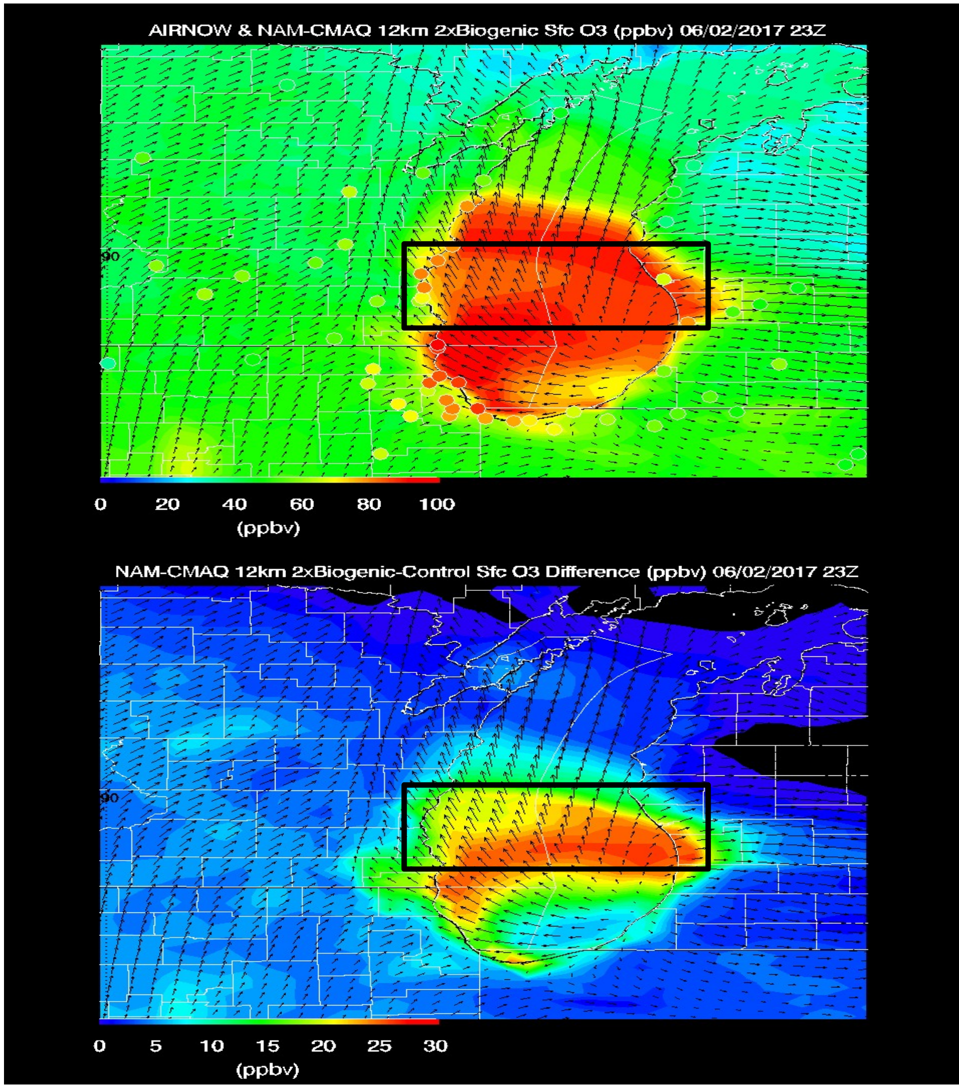

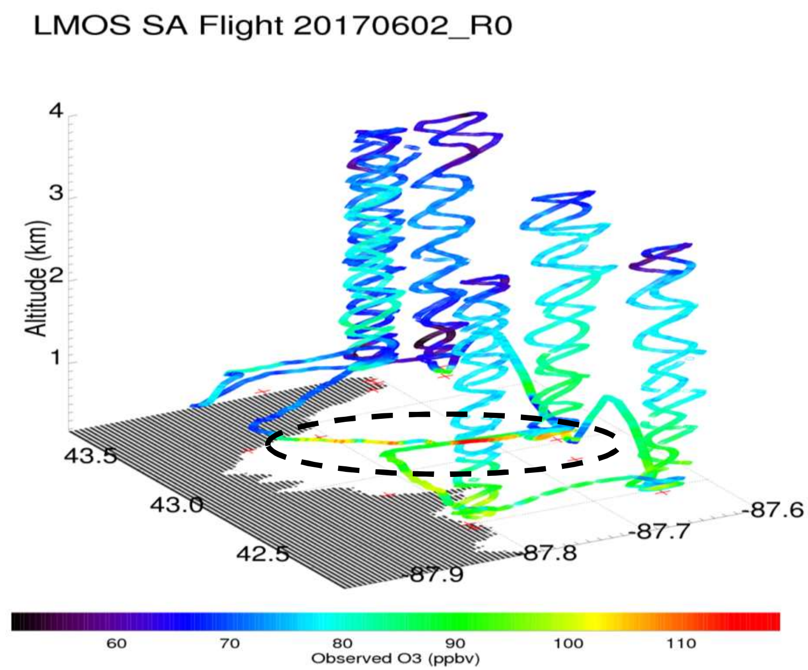

Max Observed O3 > 110ppbv

Doubling Biogenic VOC emissions within NAM-CMAQ leads to large (25-30 ppbv) increases in surface ozone on the June 2nd ozone exceedance day