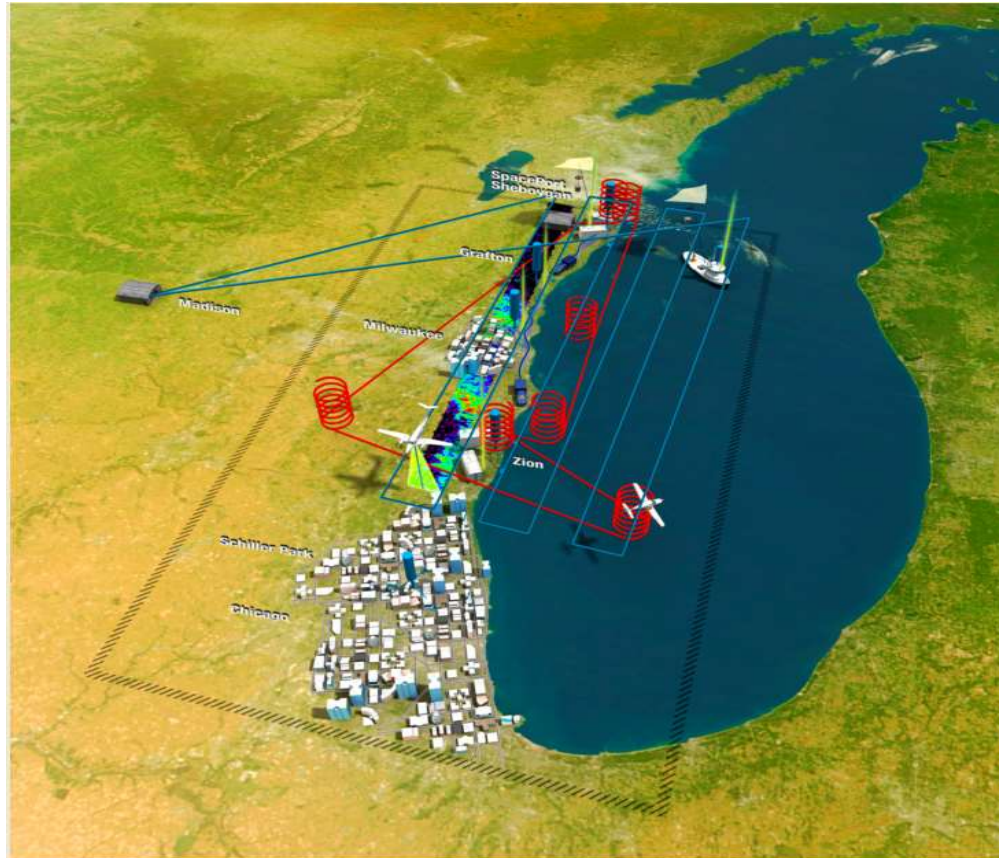


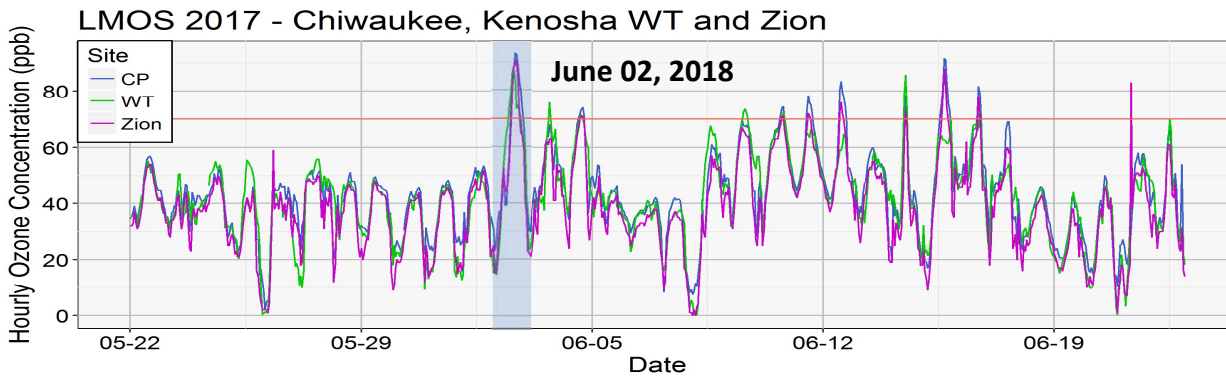
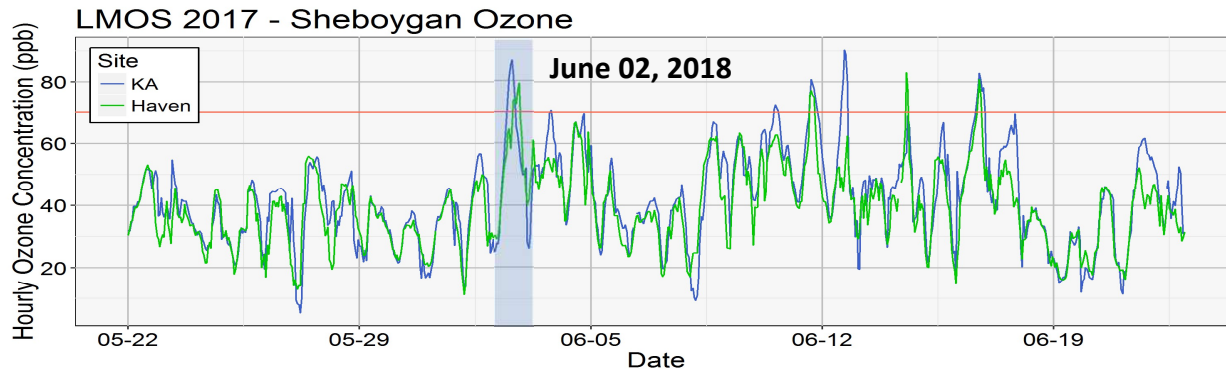
NO_x/NO₂ measurements – connecting to inventories, spatial/temporal (Lessons 2017 Lake Michigan Ozone Study)

R. Bradley Pierce
Maryam Abdioskouei
Zac Adelman
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

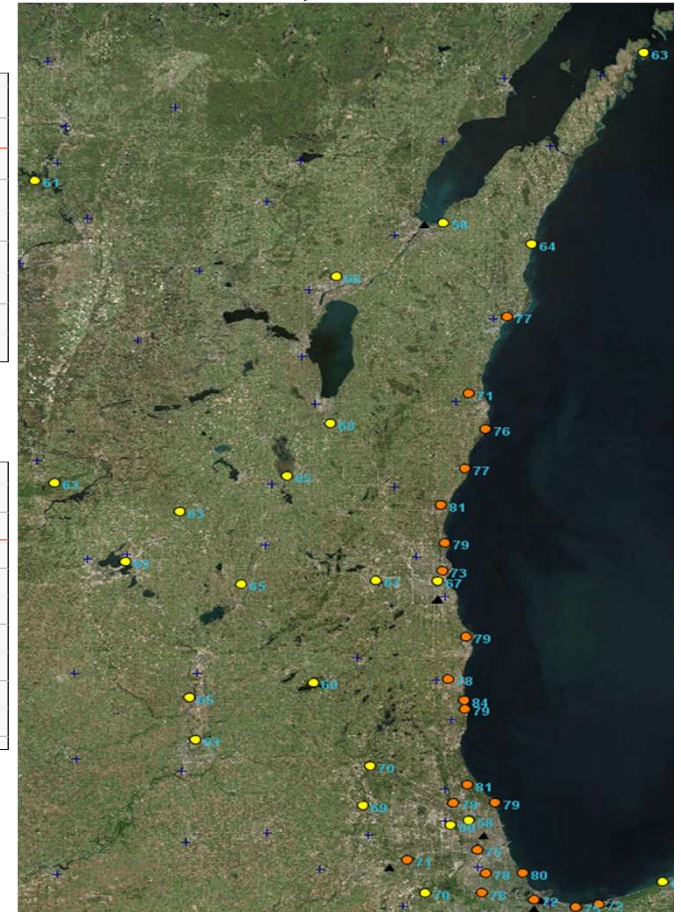


Long Island Sound Tropospheric Ozone Study (LISTOS) Meeting, Albany, NY, April 11, 2019

Lakeshore ozone during LMOS 2017



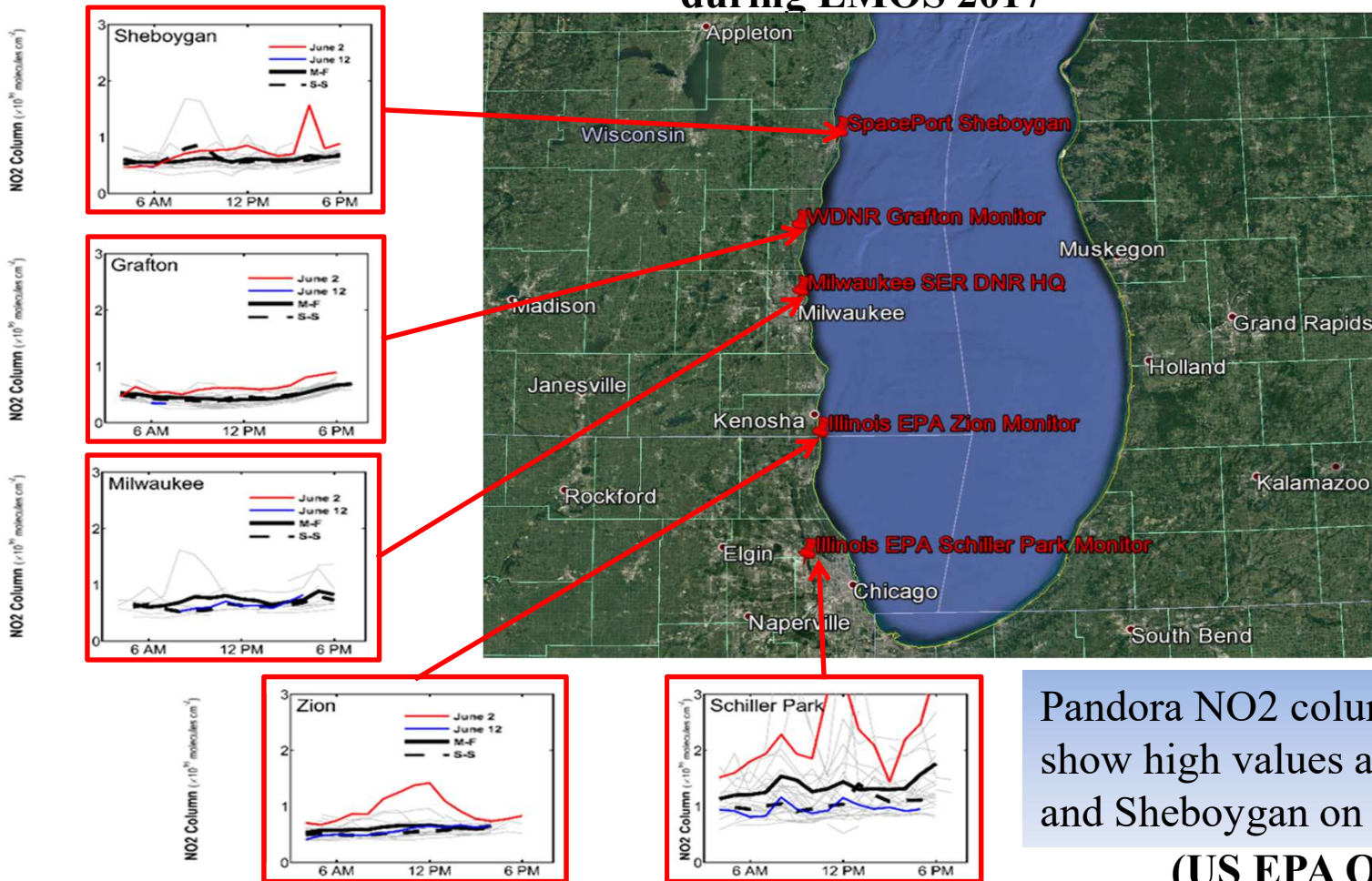
June 02, 2017 MDA8



Provided by Angie Dickens (WDNR)

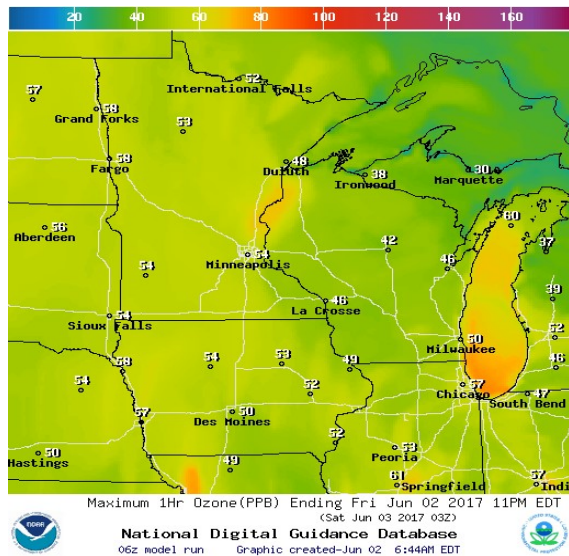
MDA8=Maximum Daily 8 hour Average

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

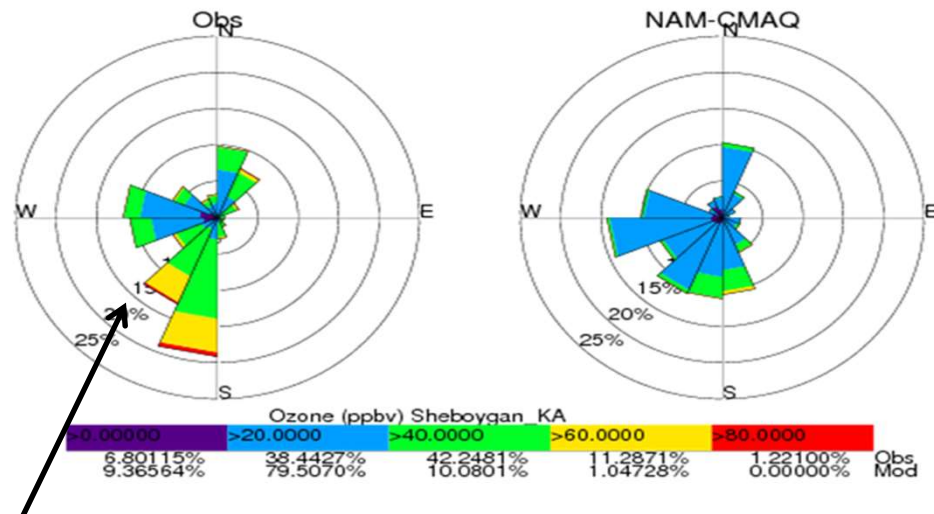


Pandora NO₂ column measurements show high values at Zion, Grafton, and Sheboygan on June 2, 2017
(US EPA ORD, Luke Valin)

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



May 22 through June 22, 2017

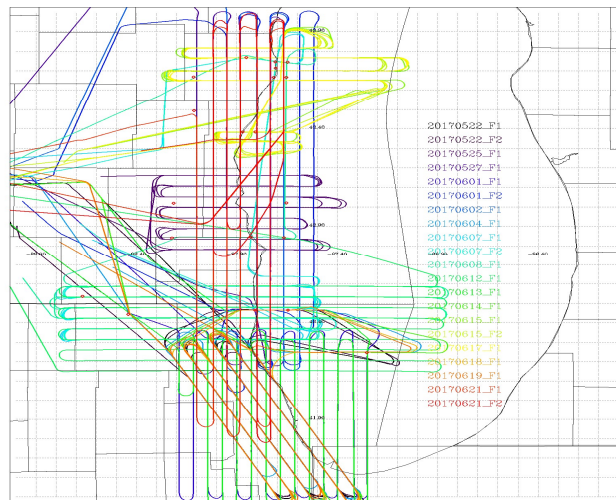


During LMOS 2017 NAM-CMAQ underestimates the occurrence of high ozone (>60ppbv) during Southerly and Southwesterly flow at Sheboygan, KA.

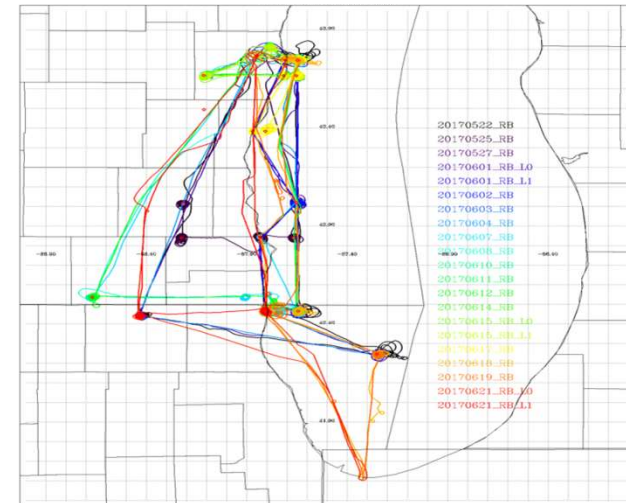
The North American Model (NAM) meteorology drives the Environmental Protection Agency's (EPA) Community Multiscale Air Quality Model (CMAQ)

LMOS 2017 Aircraft Measurements

NASA GeoTASO remote sensing Flights



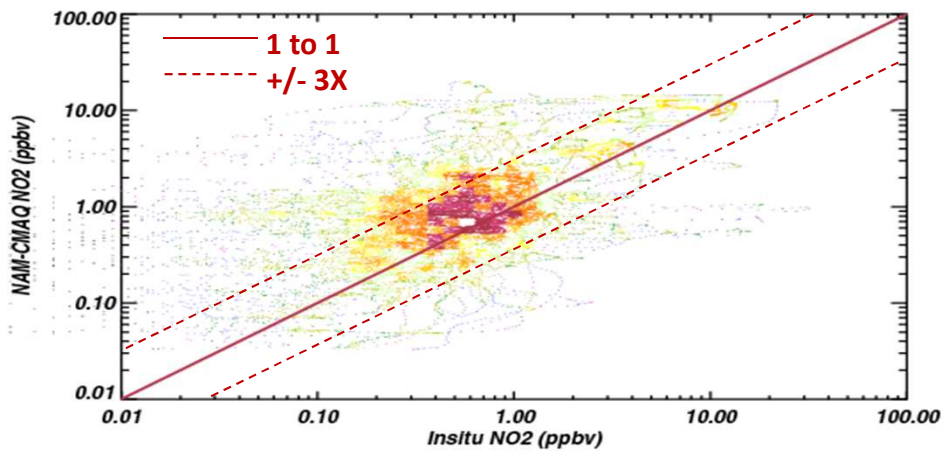
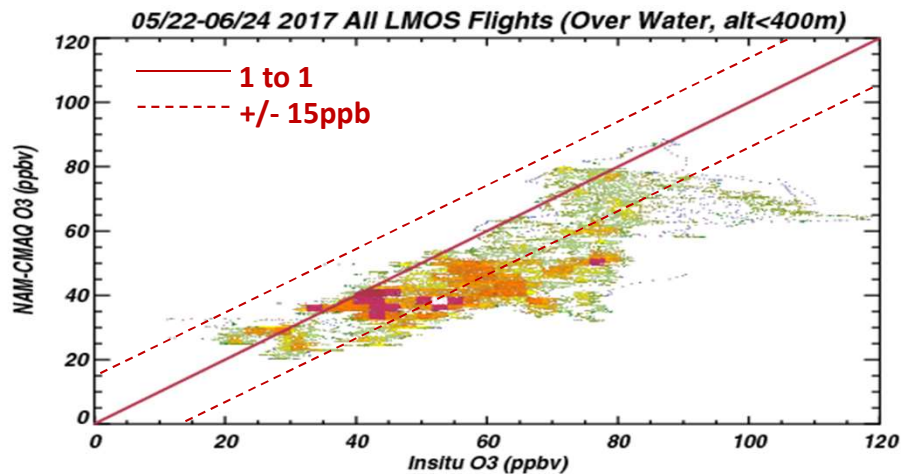
Scientific Aviation insitu sampling Flights



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

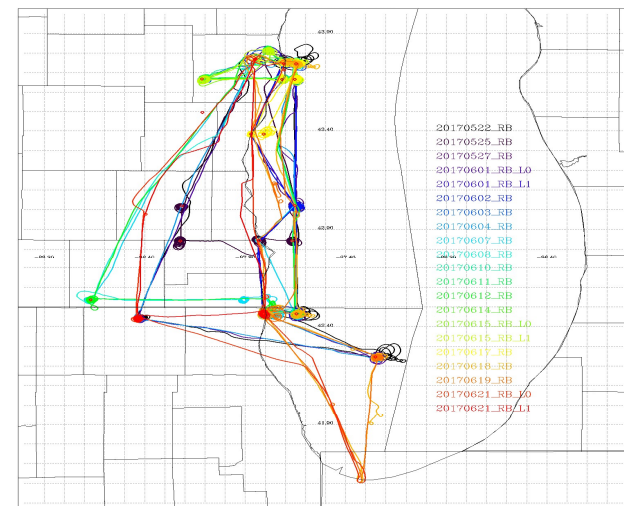
The Electric Power Research Institute (EPRI) provided funding for Scientific Aviation Flights during LMOS

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



Steve Conley (Scientific Aviation PI)

All Scientific Aviation Flights

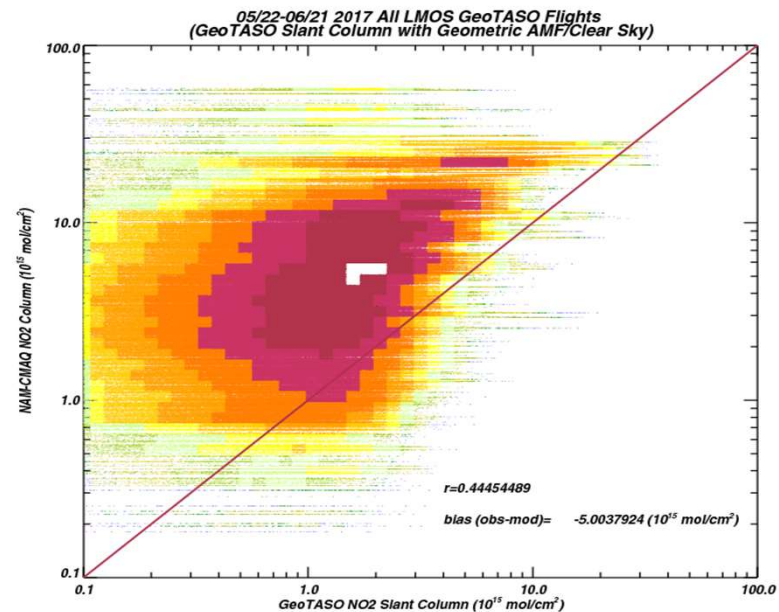
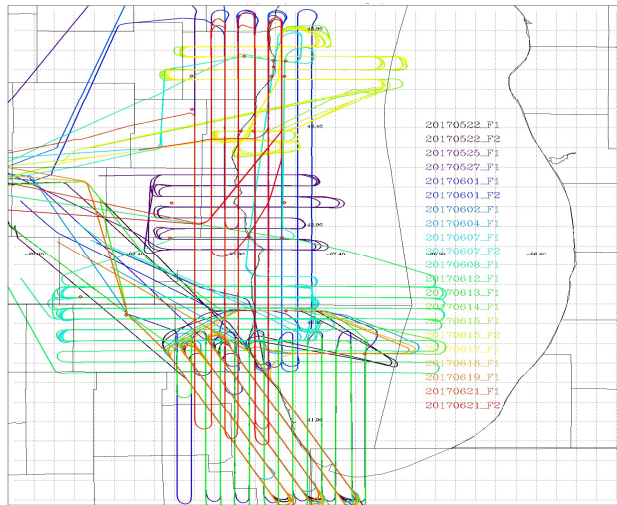


NAM-CMAQ underestimates O3 and
overestimates NO2 over Lake Michigan

LMOS May 22 through June 21, 2017

NAM-CMAQ vs GeoTASO Differential Slant Column

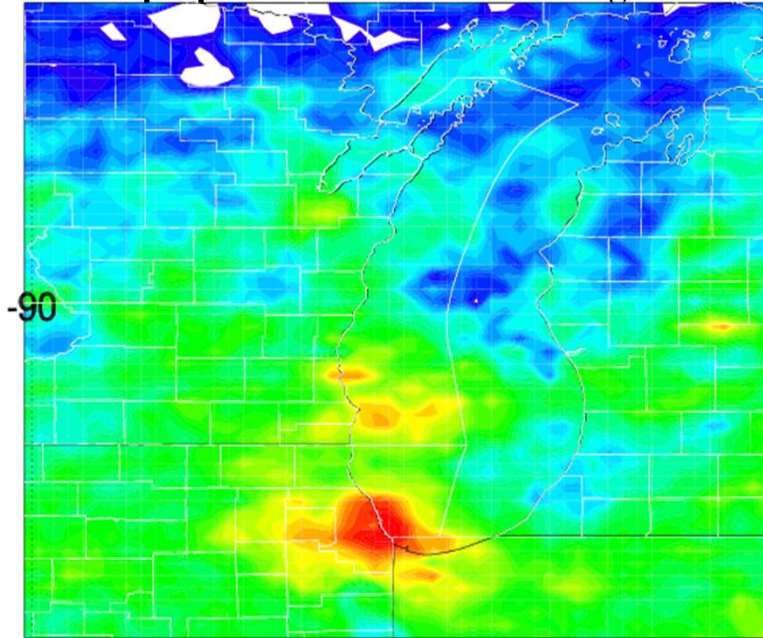
All GeoTASO Flights



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



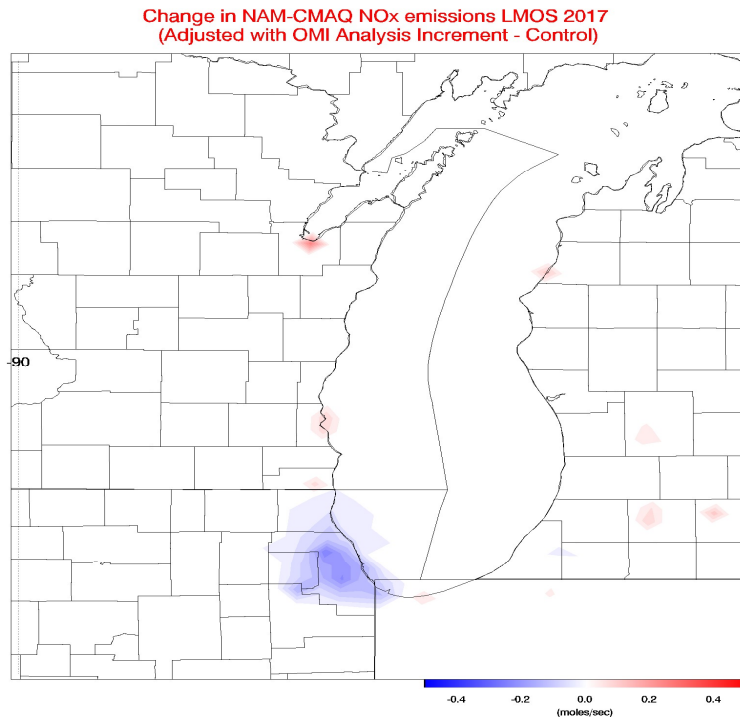
$$\frac{\Delta E}{E} = \beta \times \frac{\Delta \Omega}{\Omega}.$$

NO_x emissions adjustments (ΔE) are constrained using OMI tropospheric NO₂ column analysis increments ($\Delta \Omega$)

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

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

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

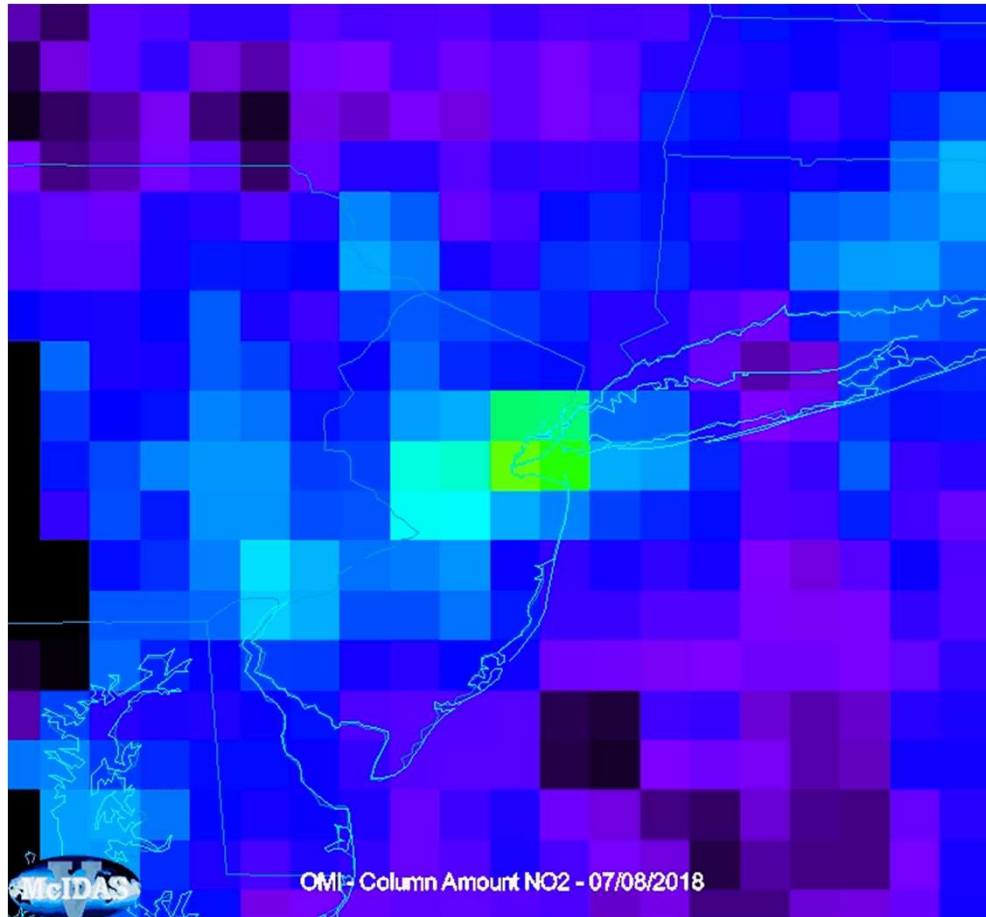


$$\frac{\Delta E}{E} = \beta \times \frac{\Delta \Omega}{\Omega}.$$

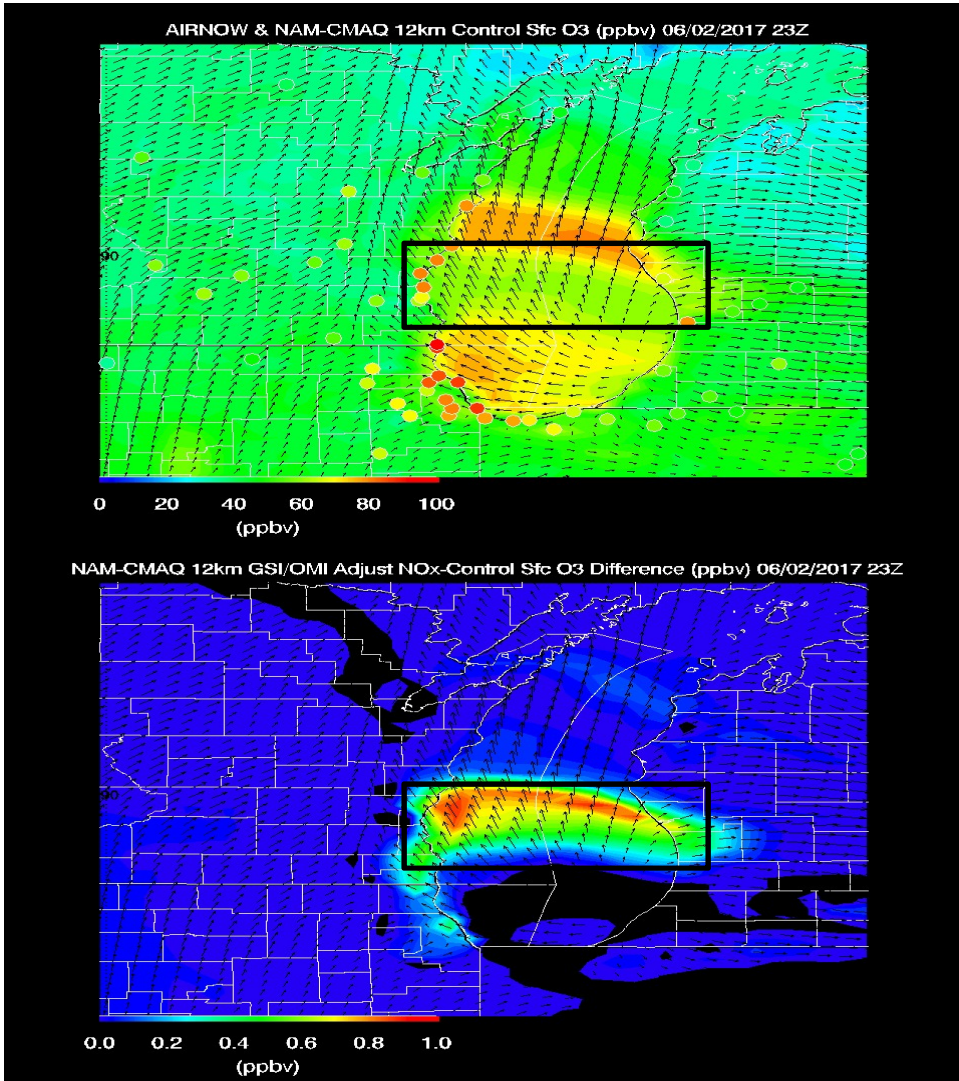
Assimilation of OMI NO₂ results in small (~4%) reductions in NO_x emissions over Chicago during June 2018

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

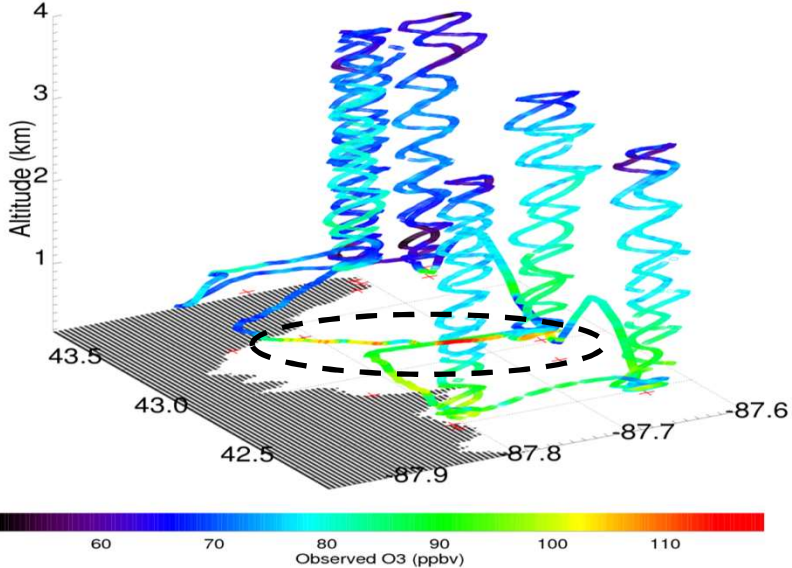
OMI vs TropOMI tropospheric NO2 columns 07/08/2018



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



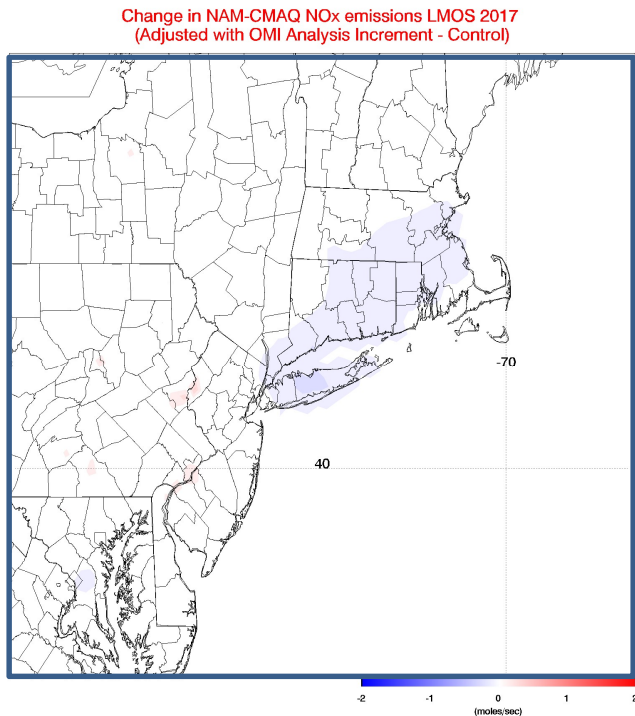
LMOS SA Flight 20170602_R0



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



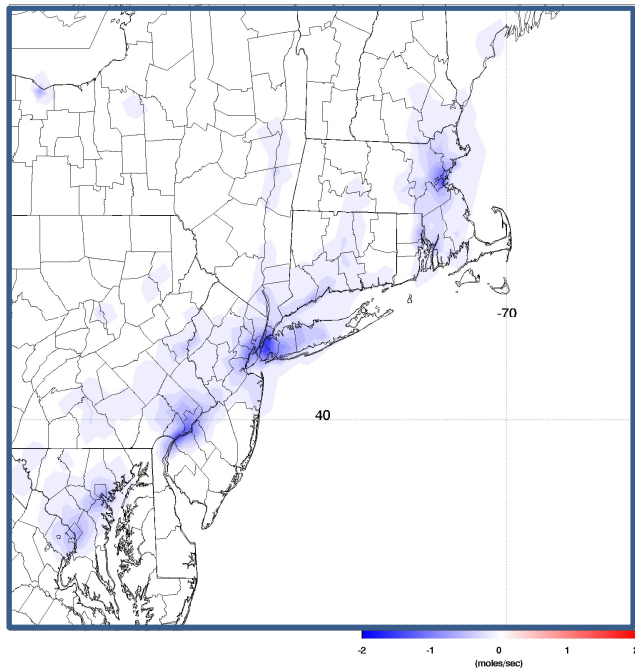
$$\frac{\Delta E}{E} = \beta \times \frac{\Delta \Omega}{\Omega}.$$

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

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

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

Change in NAM-CMAQ NO_x emissions LISTOS 2018
(Adjusted with TROPOMI Analysis Increment - Control)



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

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

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

Summary and Conclusions

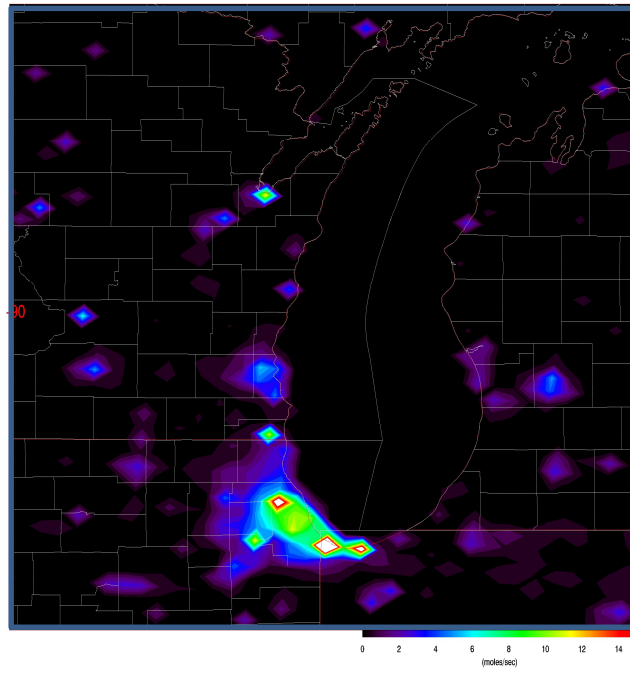
- **The LMOS 2017 aircraft observed polluted layers with rapid ozone formation occurring in a shallow layer near the Lake Michigan surface.**
 - ✓ **Comparisons between NAM-CMAQ forecasts, ground based monitors, in situ, and remote airborne measurements showed that NAM-CMAQ underestimated peak ozone 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 NO_x emissions during June 2017 over Chicago and NYC**
- **Assimilation of higher resolution TropOMI NO₂ retrievals has significant impacts on NAM-CMAQ NO_x 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 NO_x emissions**

2017 Lake Michigan Ozone Study Synthesis Report

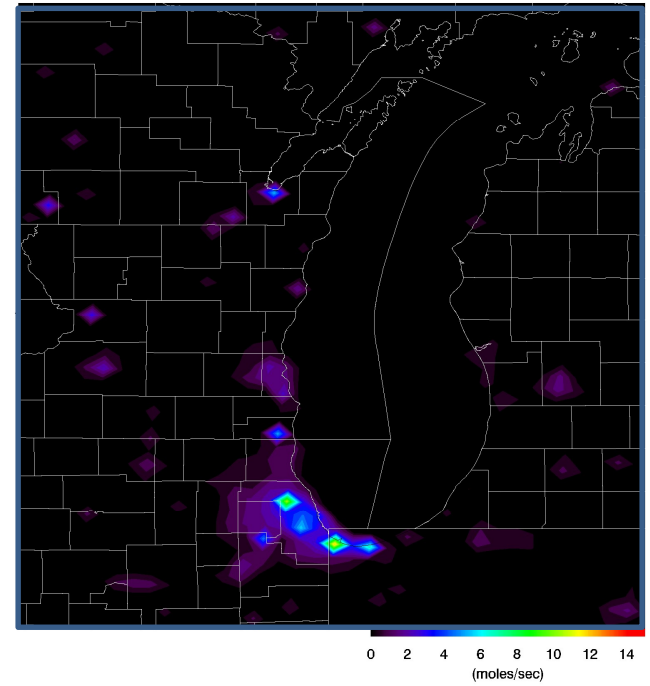
https://www.ladco.org/wp-content/uploads/Documents/LMOS_LADCO_report_final_draft_20180719.pdf

Extra Slides

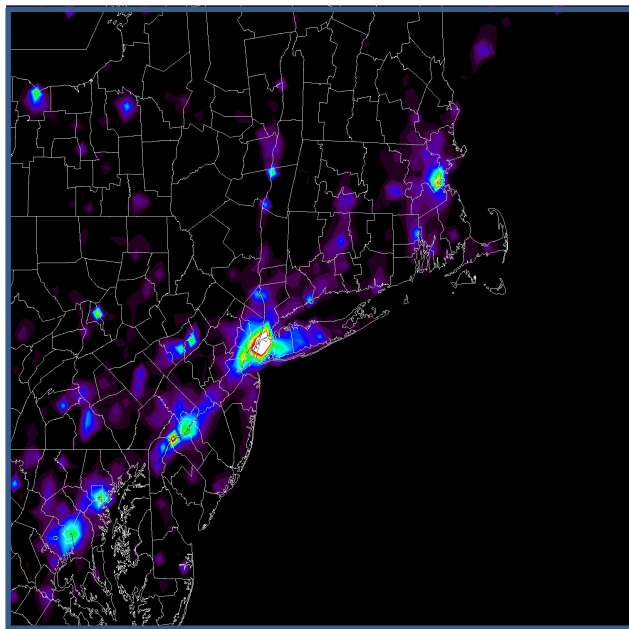
NAM-CMAQ NOx emissions June 2017



NAM-CMAQ NOx emissions July-August 2018

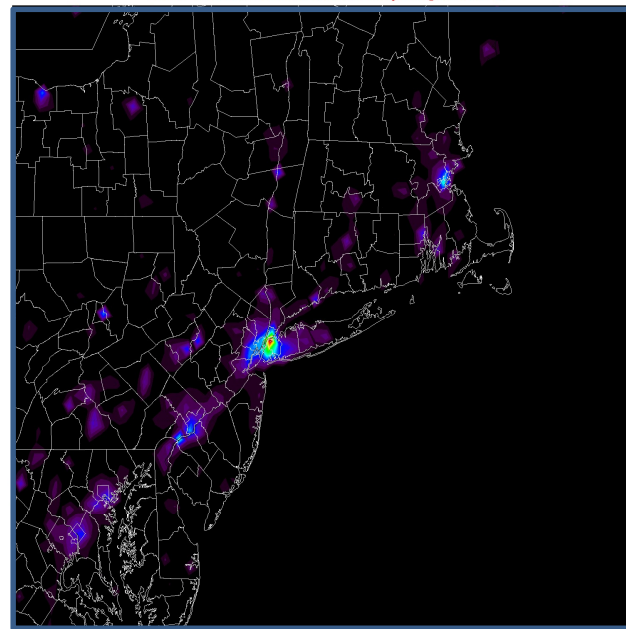


NAM-CMAQ NOx emissions June 2017



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



NASA NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

HOME | MISSIONS | DATA | TOOLS | ABOUT US

Airborne Science Data for Atmospheric Composition

LMOS – Lake Michigan Ozone Study 2017

Relevant Data / Links

- View / Upload Images & Data
- Aircraft Ground Metadata
- File Upload Services
- Forecast Problems
- Meteorology Links
- Airflow
- LADCO - Lake Michigan Air Directors Consortium
- ICARTT Data Format Document

Data Upload Tools

- Stage for submitting data to the Archive
- Data Submitter / Scanner
- Host Files
- Register PI datasets

Useful Tools

- Download HCF files - visual tool for browsing & editing HDF files
- Download File Scanning SW for Windows (requires .NET)
- Download Flight Planning SW for Windows (requires .NET)
- Google Earth

Mission Overview:

Elevated spring and summertime ozone levels remain an air quality challenge along the coast of Lake Michigan, with a number of monitors exceeding the 2015 National Ambient Air Quality Standards (NAAQS) for ozone. Production of ozone over Lake Michigan combined with onshore daytime "lake breeze" airflow is thought to increase ozone concentrations preferentially at locations within a few kilometers of the shore. This observed lake-shore ozone gradient motivated the Lake Michigan Ozone Study (LMOS) 2017 during May and June 2017.

Ozone Design Values (DV) for 2014-2016 in g/m² (left) and NEI 2011 NO_x area emissions in g/m² (right). DVs greater than or equal to 7 g/m² will exceed the 2015 NAAQS for ozone and are generally found around the shore of Lake Michigan in this region.

This campaign provides extensive observational air quality and meteorology datasets through a combination of airborne, ship, mobile lab, and fixed ground-based observational platforms. Additionally, chemical transport models (CTMs) and meteorological forecast tools assist in the planning for day-to-day measurement strategies. The main objectives of LMOS are to better understand the lakeshore ozone gradient and to evaluate and improve CTMs used for regulatory and research purposes in this region. LMOS 2017 is a collaborative effort between LADCO and its member states, NASA, NOAA, EPA, EPRI, Scientific Aviation, and a number of research groups at universities.

LMOS imagery on the left shows the lake breeze front along the western lake shore converging with the prevailing offshore flow. High DVs along the lake shore are thought to be influenced by the lake breeze. The map on the right displays the spatial coverage of the aircraft, ship, and ground-based observations involved in LMOS to study urban emissions and the lake-breeze influence on the western shore's air quality.

Related documents:

- FAQ: Lake Michigan Ozone Study (LMOS 2017)
- LMOS Whitepaper
- Open letter to parties interested in the 2017 Lake Michigan Ozone Study (March 21, 2017)

Articles:

- Dr. Charles Stanier provides Lake Michigan Ozone Study update
- Lake Michigan Ozone Study 2017: Collaborative field campaign will pursue sources and transport of ozone
- NASA Aids Study of Lake Michigan High-Ozone Events

Created: 05/03/2018
NASA Official: Dr. Cui Chen
Last Updated: 07/03/2018

Freedom of Information Act
Budget, Strategic Plans and Accountability Reports
The Privacy Management Agency
Equal Employment Opportunity Data Posted Pursuant to the No Fear Act
Information Collection Burden and Inventions

Privacy Policy and Important Notices
USA.gov
Experience.gov
Multimedia Browser Plugins
Comments or Questions

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

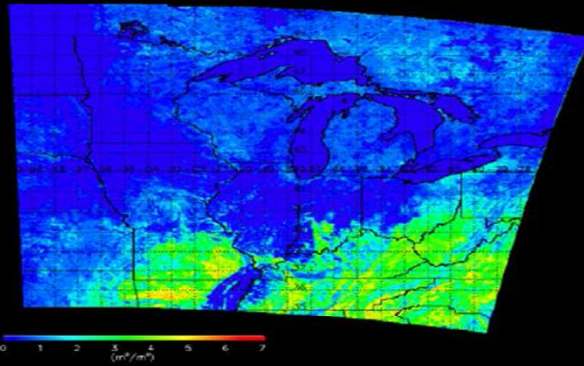
Summary of LMOS 2017 measurements

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

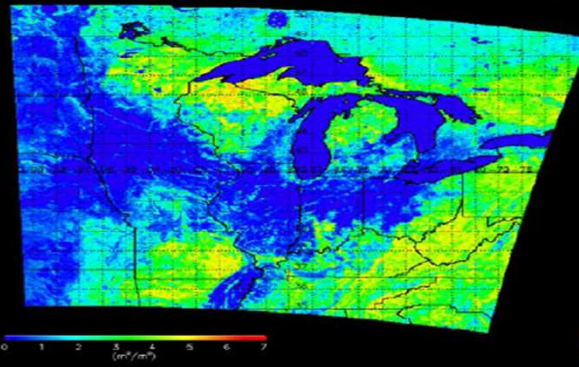
Biogenic VOC Sensitivity Studies

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

Leaf Area Index May 01, 2017

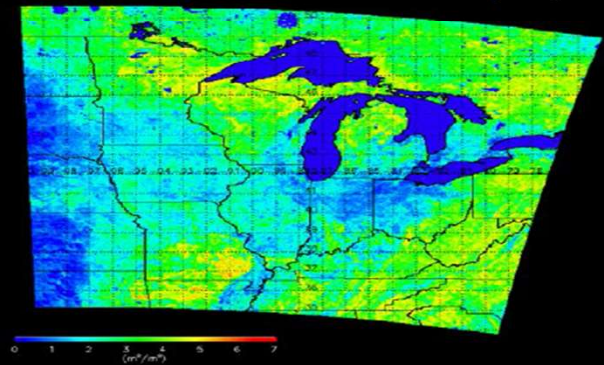


Leaf Area Index June 02, 2017

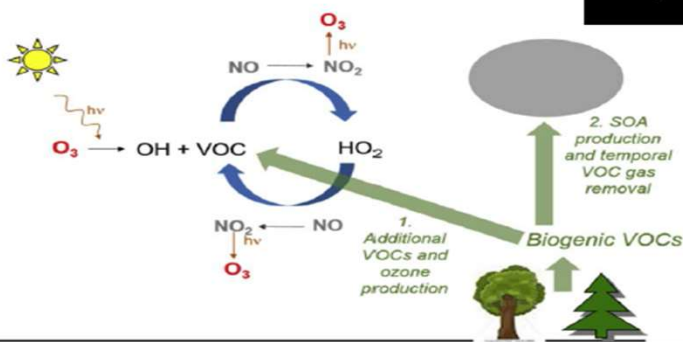


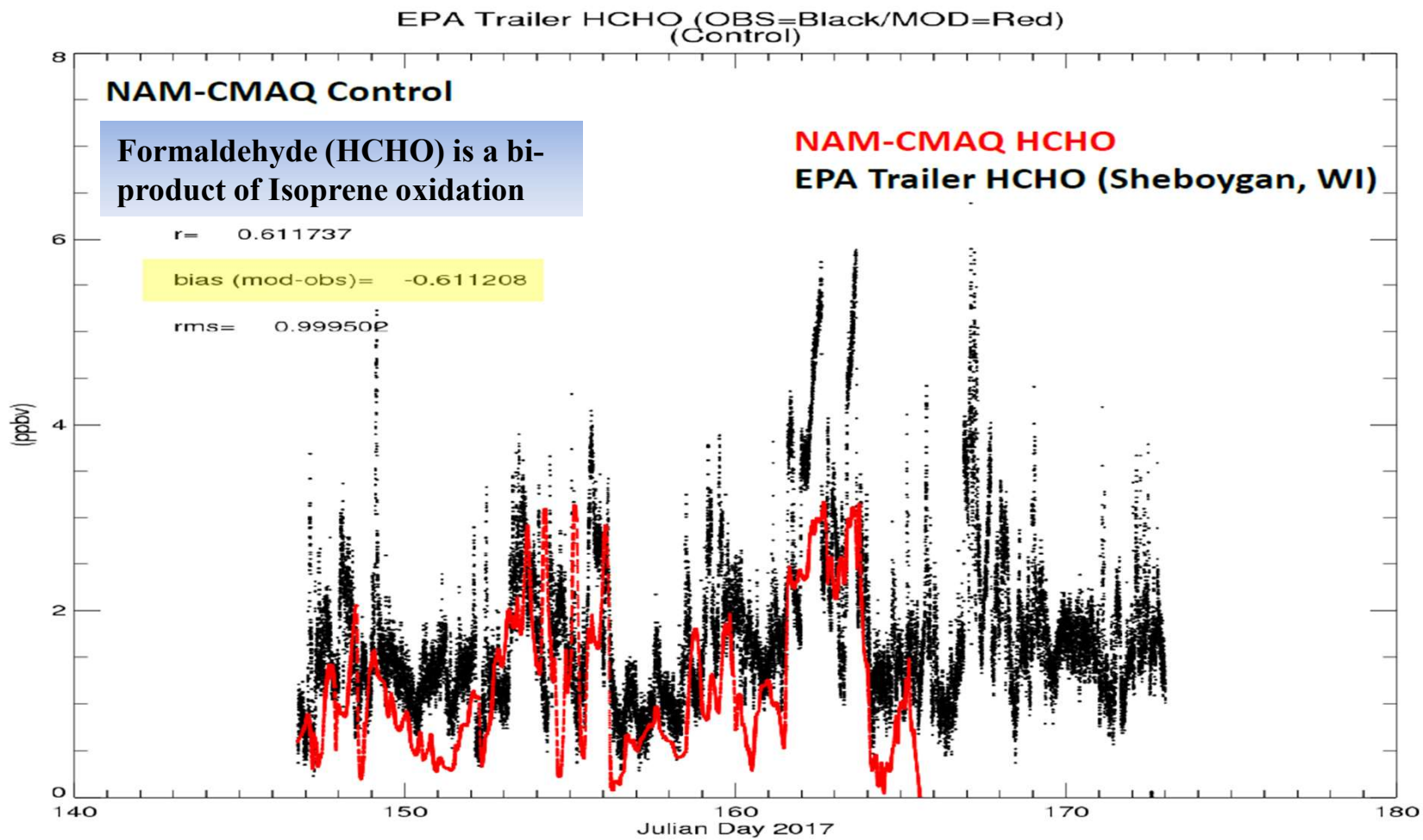
Isoprene (biogenic
VOC) emissions
increase with leaf
area (leaf out)

Leaf Area Index July 04, 2017

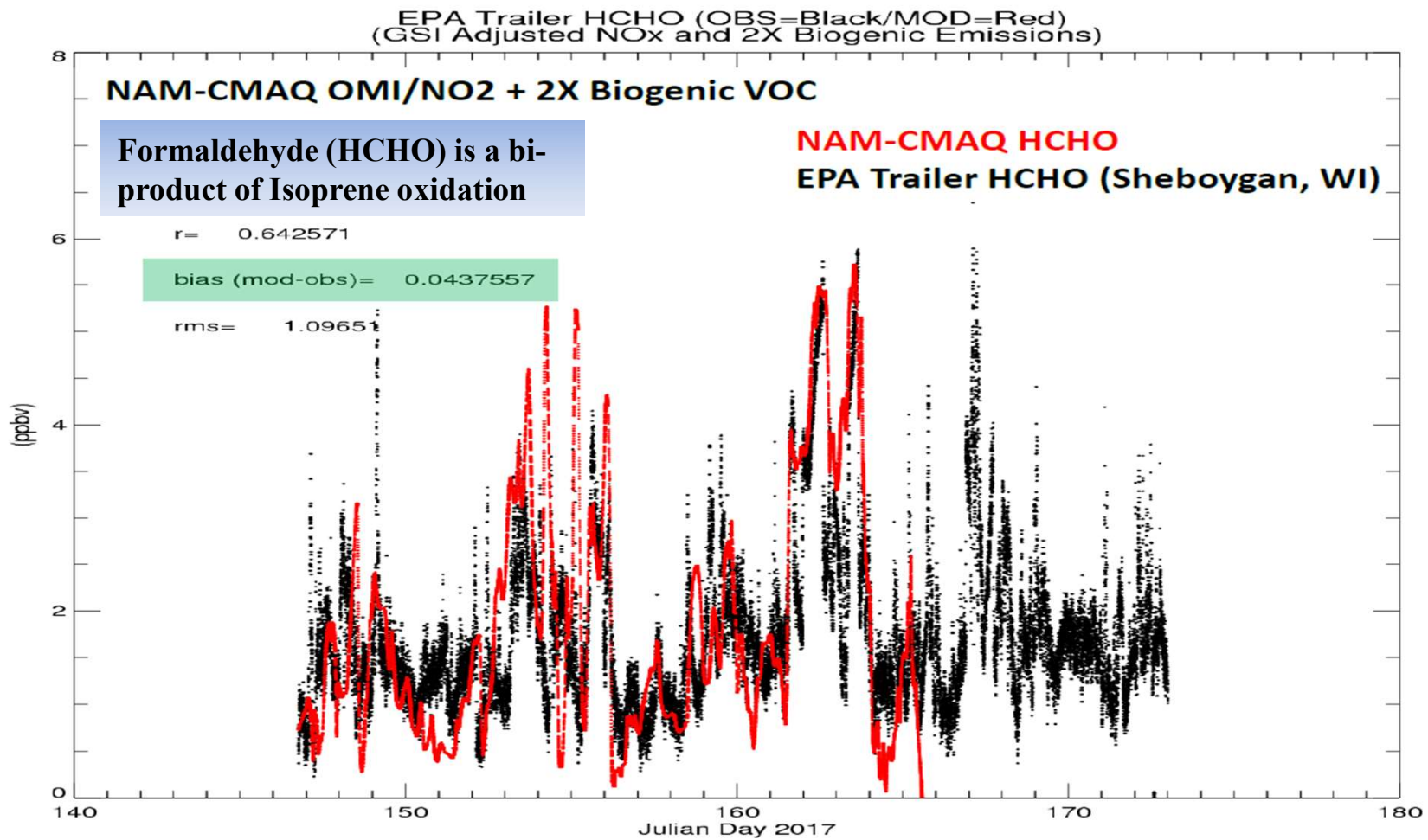


Increased biogenic
VOCs can enhance
ozone production in
urban plumes

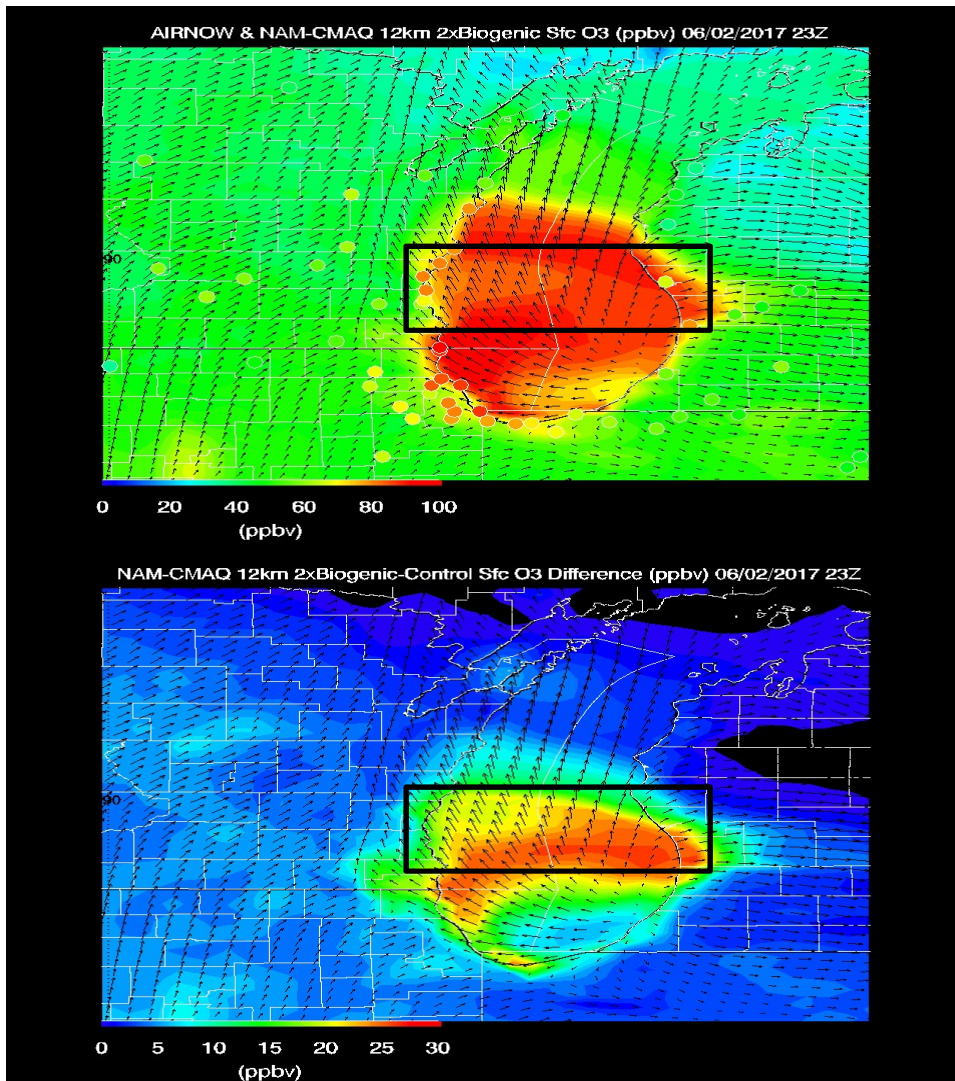




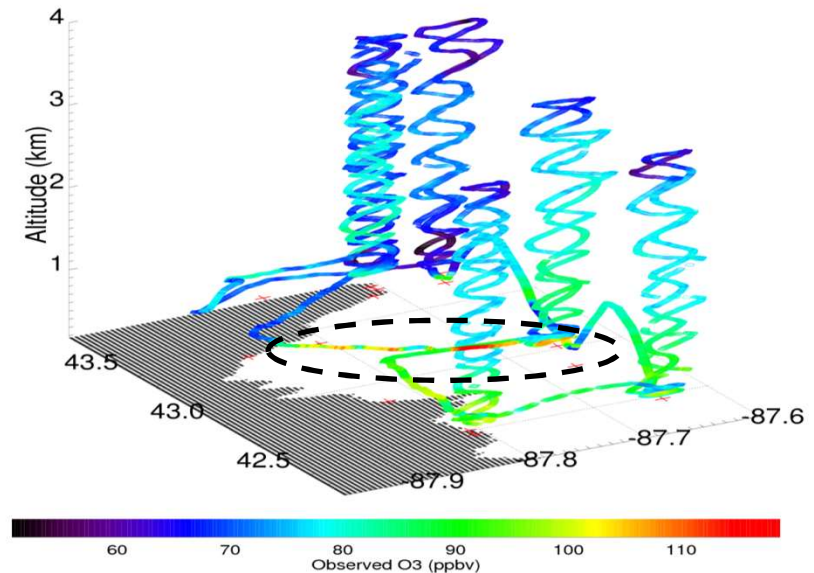
In situ HCHO provided by (US EPA, ORD Andrew Whitehill)



In situ HCHO provided by (US EPA, ORD Andrew Whitehill)



LMOS SA Flight 20170602_R0



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