Using Tropospheric NO2 Column Data Assimilation to Constrain NWS Air Quality Forecasts

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HAQAST4, July 16-17, 2018, Madison WI

HAQAST Tiger Team:

Improved NEI NOx emissions using OMI Tropospheric NO2 retrievals and Potential Impacts on Air Quality Strategy Development

The goal of this HAQAST Tiger Team effort is to support the NWS, EPA/CDC, and the Lake Michigan Air Directors Consortium (LADCO) air quality modeling with improved estimates of NOx emissions using NO2 retrievals from the NASA Ozone Monitoring Instrument (OMI) and the NASA Geostationary Trace gas and Aerosol Sensor Optimization (GeoTASO)

Focus:

- **Collaboration with NWS, EPA, and USDA Forest Service in testing, implementation, and assessment of off-line adjustment of CMAQ area source and wildfire emissions emissions using NOAA Grid-point Statistical Interpolation (GSI) data assimilation of OMI tropospheric NO2 retrievals**

- **Collaboration with LADCO on assessment of using high resolution GeoTASO tropospheric NO2 retrievals obtained during the 2017 Lake Michigan Ozone Study to support LADCO States SIP modeling**

- **Explore the impacts of model, data assimilation method, and OMI NO2 retrieval product through comparison of NOx emissions constraints derived using off-line GSI with CMAQ and in-line 4D-Var with GEOS-Chem**

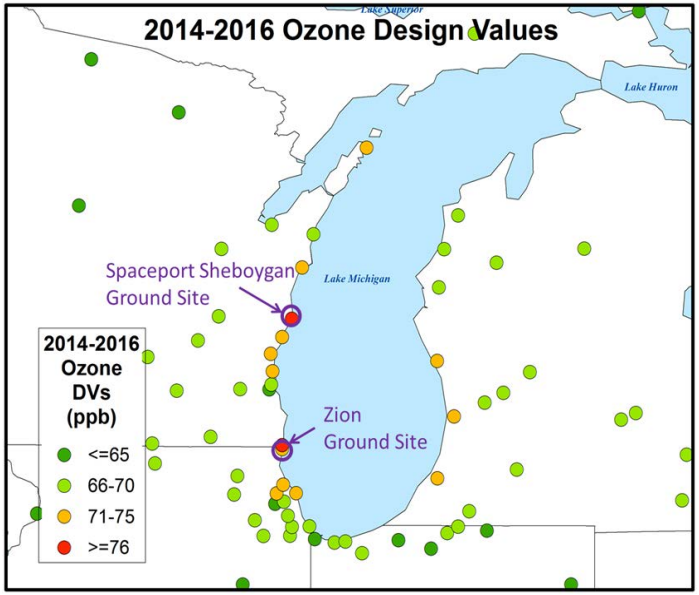
NWS Demonstration

- **OMI NO2 data assimilation based emission constraint studies were conducted during the 2017 Lake Michigan Ozone Study (May 22- June 22, 2017) using the NWS Operational Air Quality forecast system**

- **NWS operational air quality forecasts use the North American Model (NAM) meteorology to drive the EPA Community Multiscale Air Quality Model (CMAQ) to perform twice daily forecasts of air quality over the continental US (http://airquality.weather.gov/)**

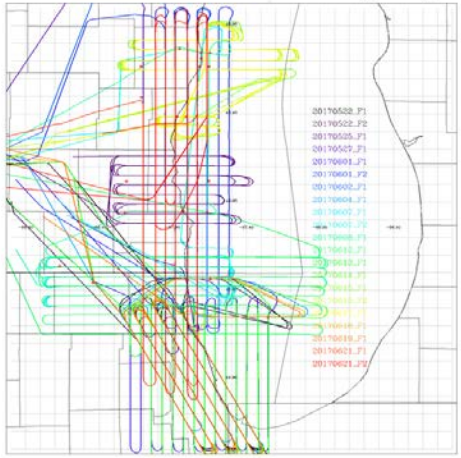
2017 Lake Michigan Ozone Study (LMOS 2017)

LMOS 2017 was designed to collect onshore and offshore measurements during lake-breeze-driven ozone exceedance events. The LMOS 2017 measurements are being used to evaluate chemical transport model skill in predicting ozone along the shore of Lake Michigan.

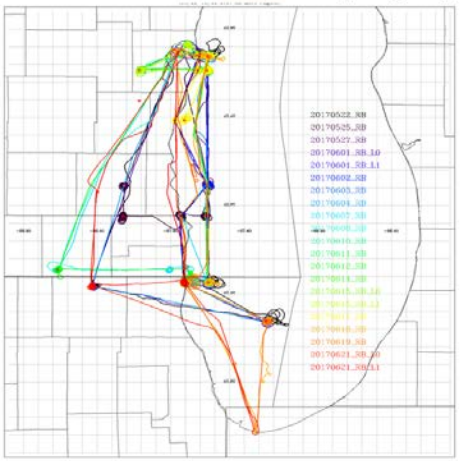


LMOS 2017 Aircraft Measurements

NASA GeoTASO remote sensing Flights



Scientific Aviation insitu sampling Flights

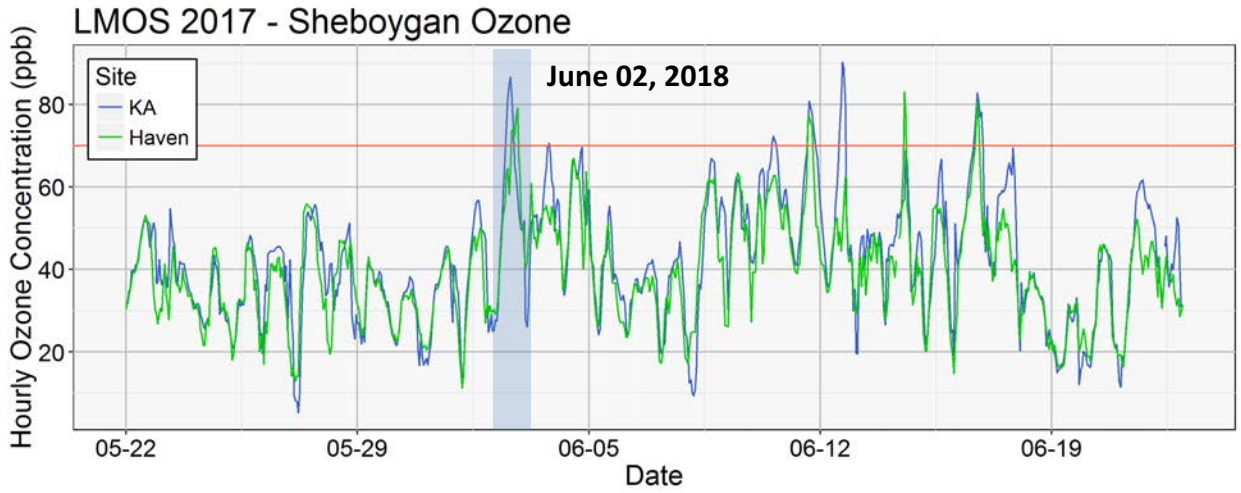


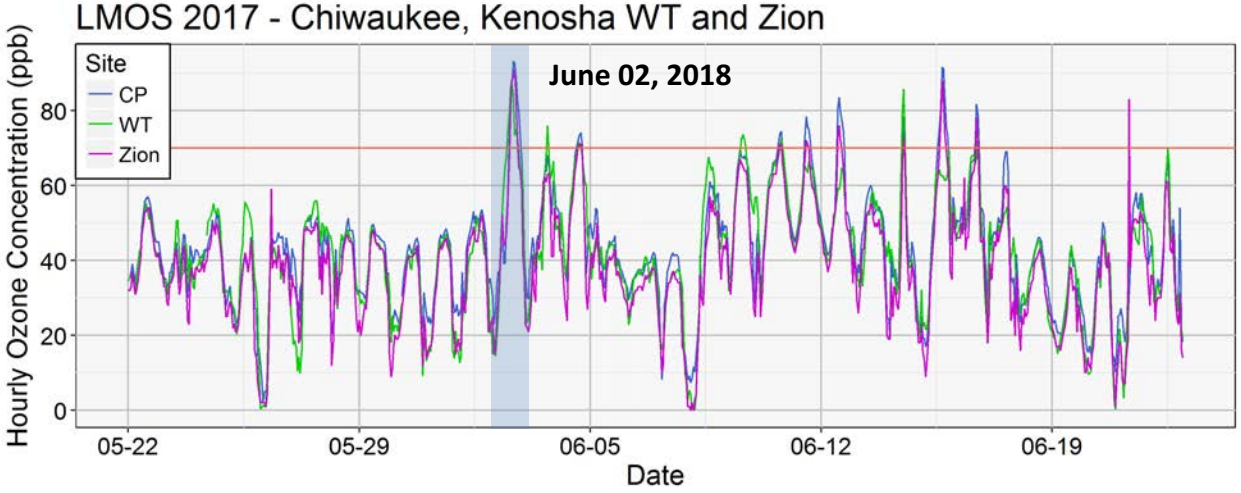
GeoTASO (Geostationary Trace gas and Aerosol Sensor Optimization) is an airborne hyperspectral mapping instrument that is being used as an airborne testbed for future high-resolution trace-gas observations from geostationary sensors such as TEMPO

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

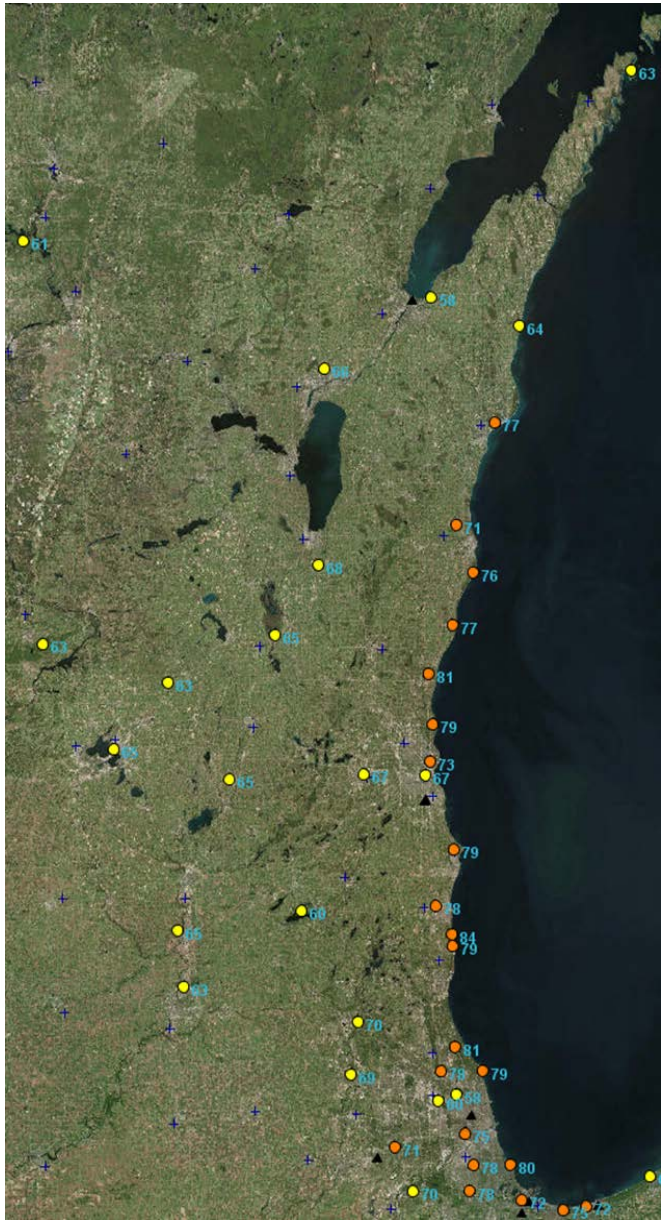
https://www-air.larc.nasa.gov/missions/lmos/

Lakeshore ozone during LMOS 2017





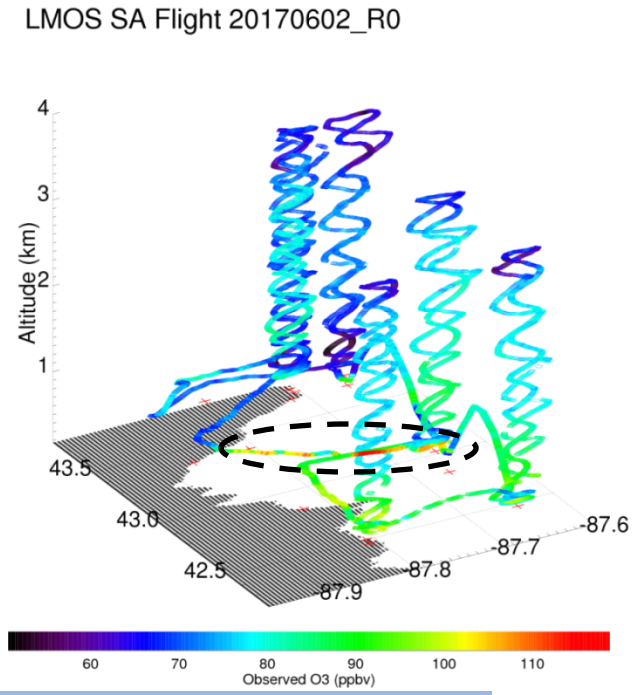
June 02, 2017 MDA8



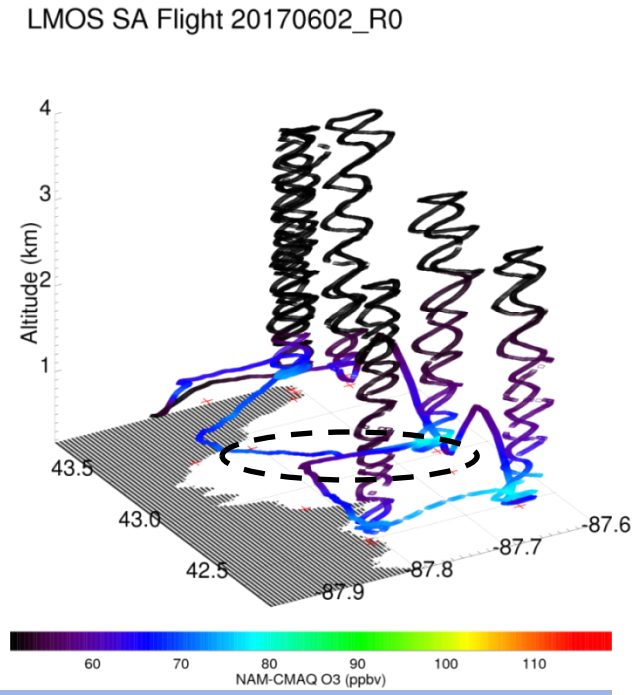
MDA8=Maximum Daily 8 hour Average

Provided by Angie Dickens (WDNR)

Coastal Ozone Exceedance Day

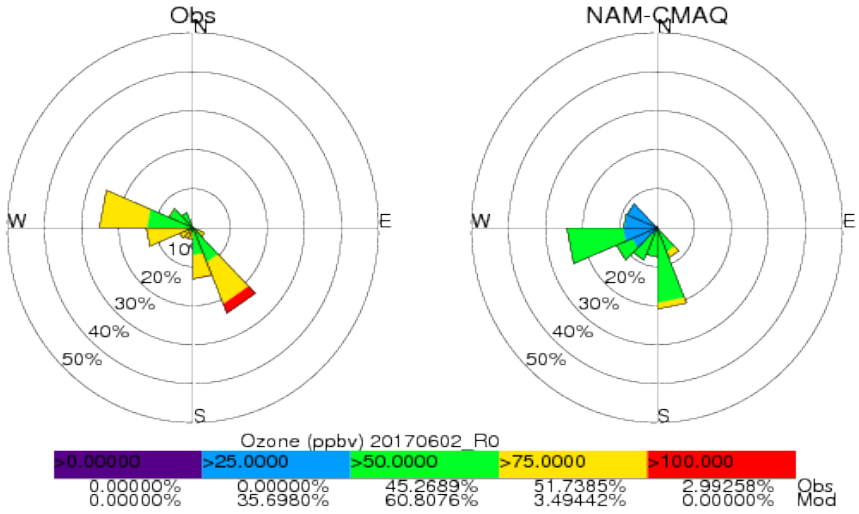


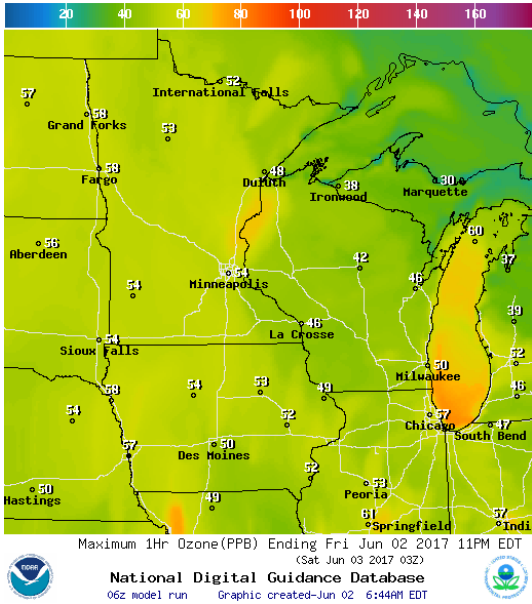
Max Observed O3 > 110ppbv



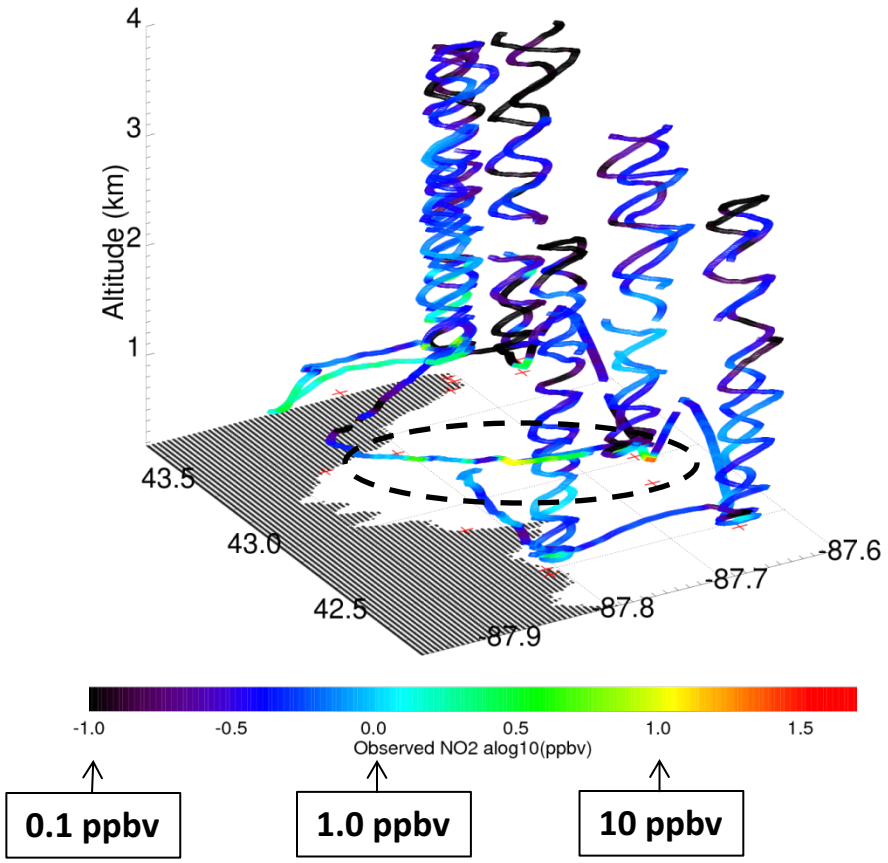
Max NAM-CMAQ O3 < 80ppbv

NWS NAM-CMAQ significantly <u>underestimates</u> ozone concentrations within the marine boundary layer



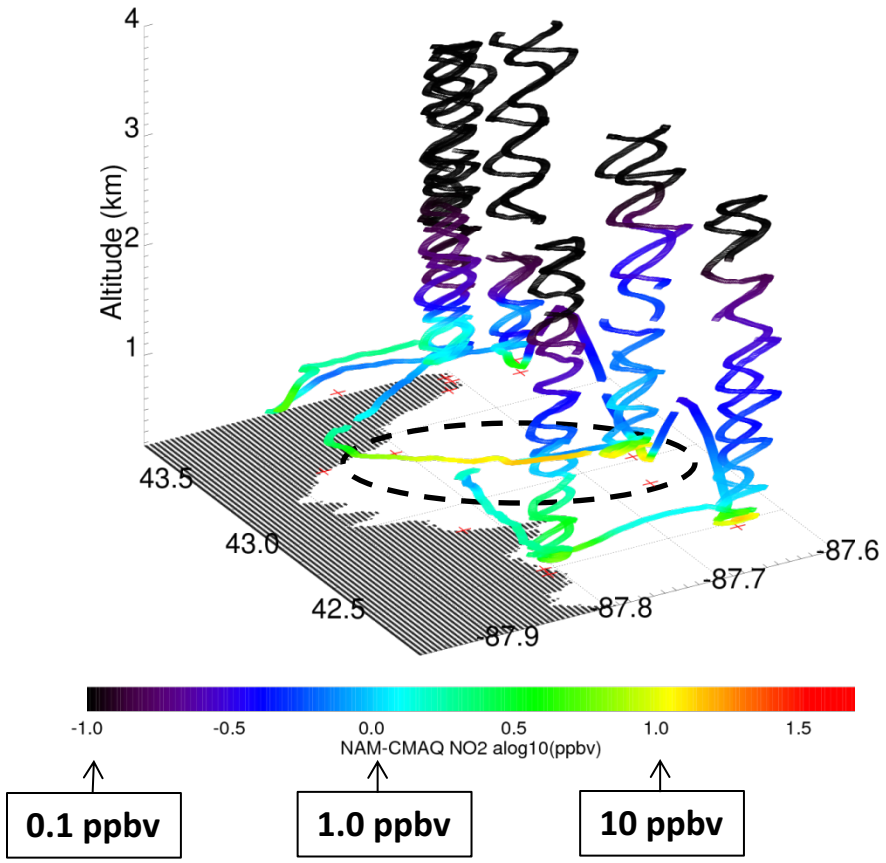


LMOS SA Flight 20170602_R0



Observed NO2 < 10ppbv
Offshore of Milwaukee

LMOS SA Flight 20170602_R0

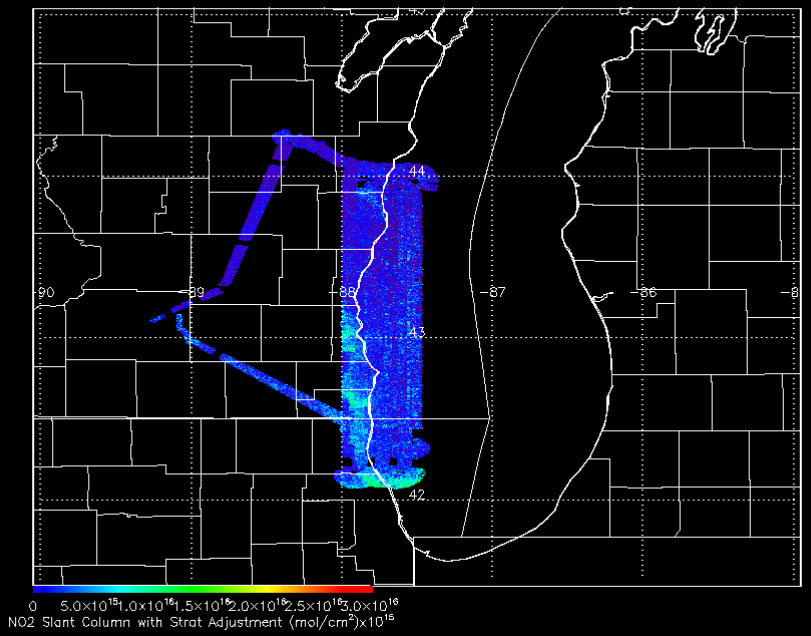


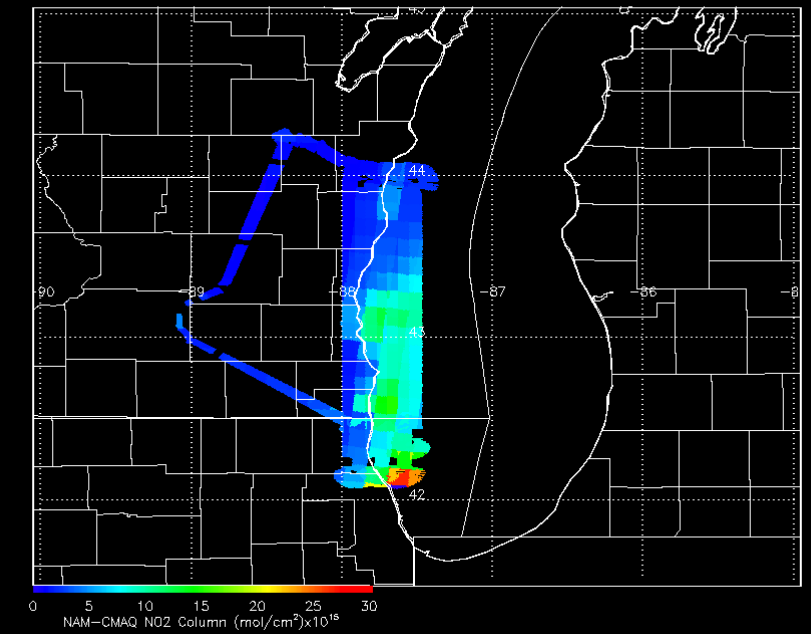
NAM-CMAQ NO2 > 10ppbv
Offshore of Milwaukee

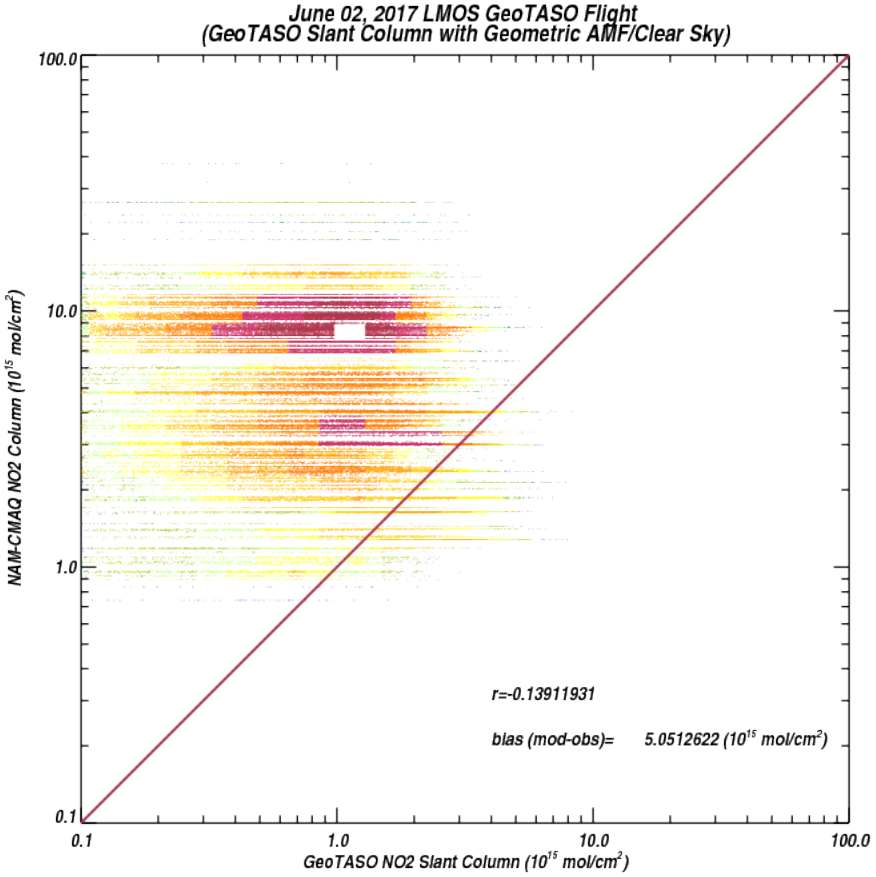
NWS NAM-CMAQ significantly <u>overestimates</u> NO2 concentrations within the marine boundary layer

GeoTASO Coastal Survey Flight June 02, 2017

NWS NAM-CMAQ significantly overestimates observed NO2 column



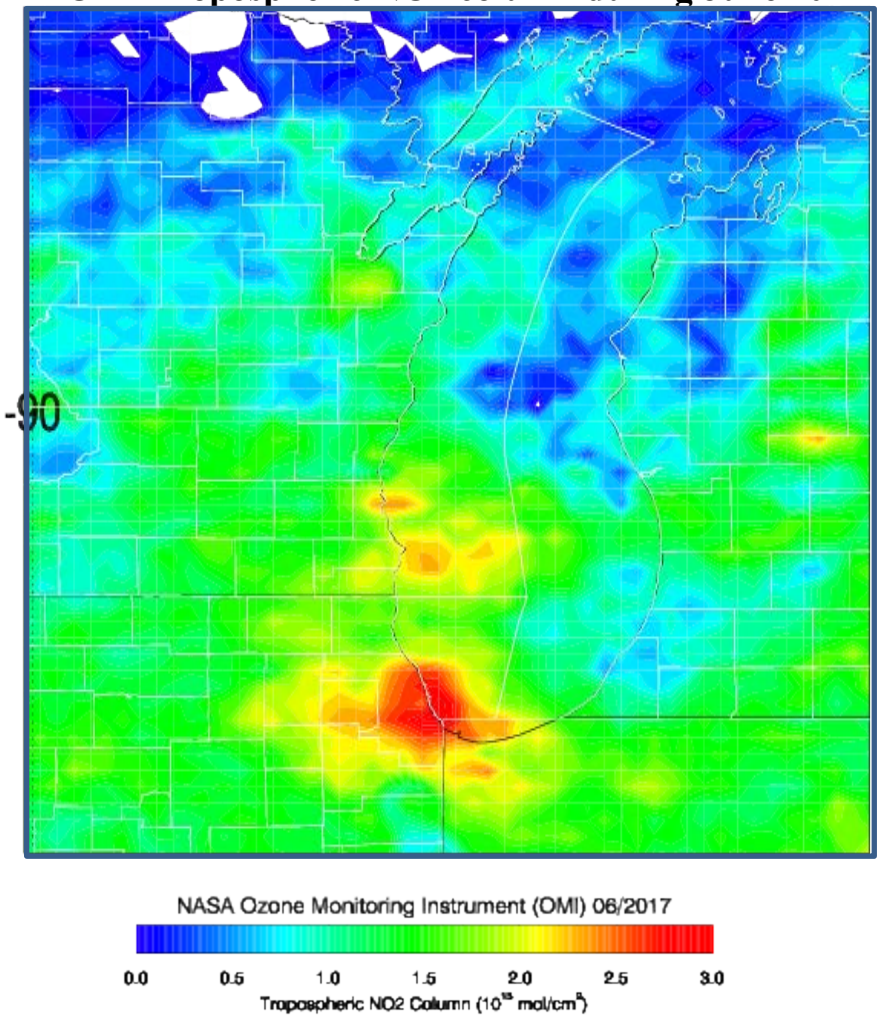




Preliminary GeoTASO retrievals provided by Laura Judd (NASA/LaRC)

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

OMI Tropospheric NO2 column during June 2017



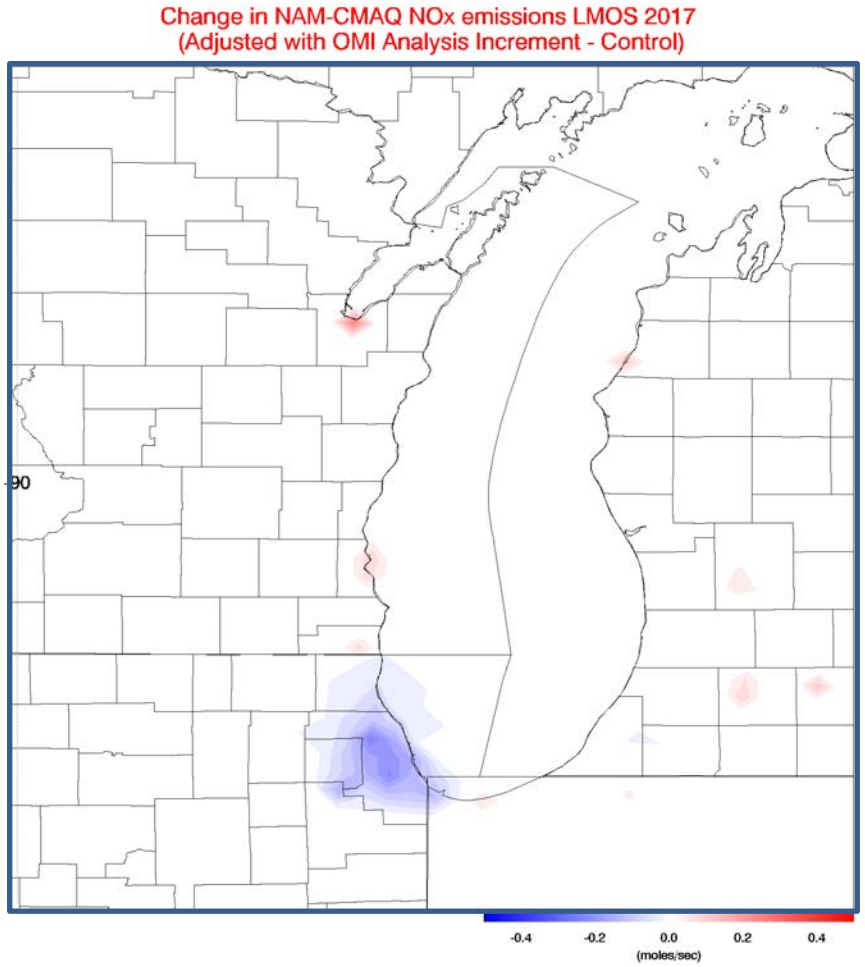
$$\frac{\Delta E}{E} = \beta \times \frac{\Delta \Omega}{\Omega}.$$

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.

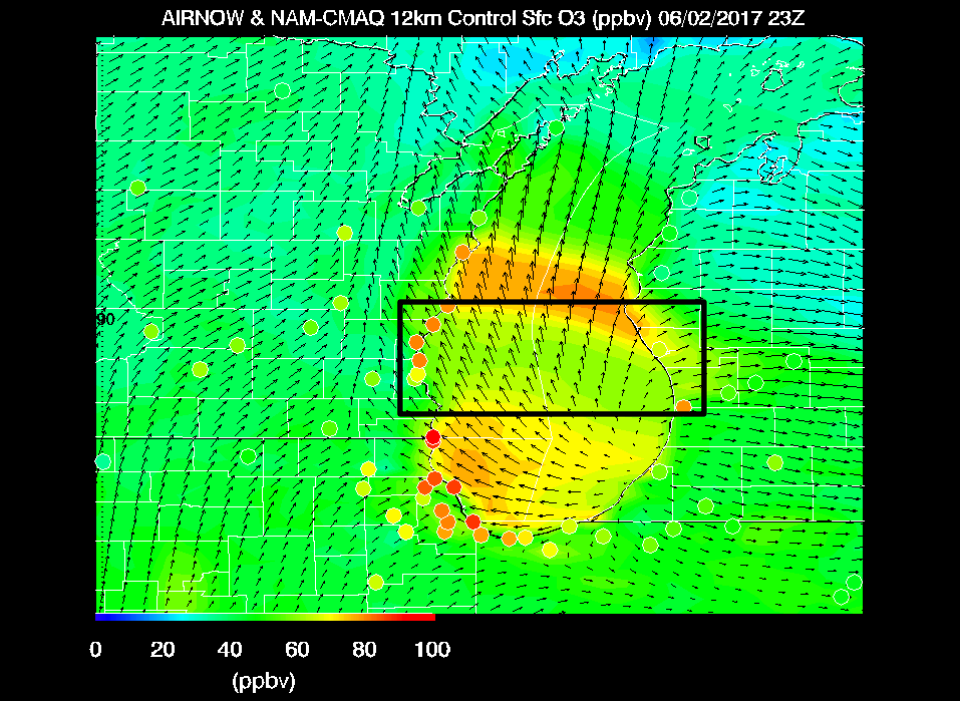
Aura Ozone Monitoring Instrument (OMI) Tropospheric NO2 column Data Assimilation

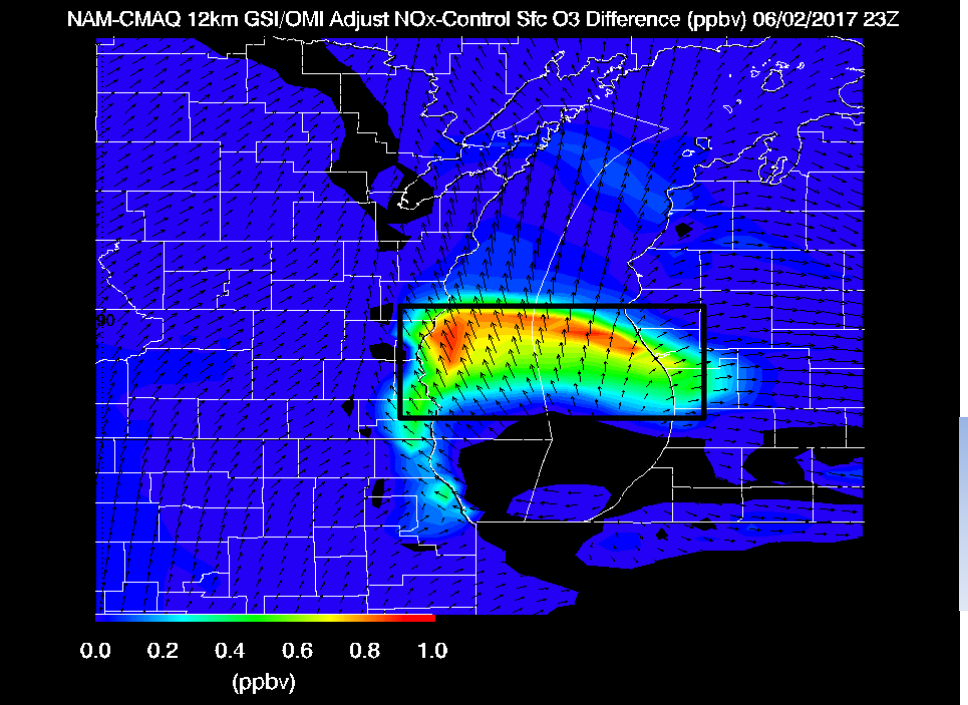


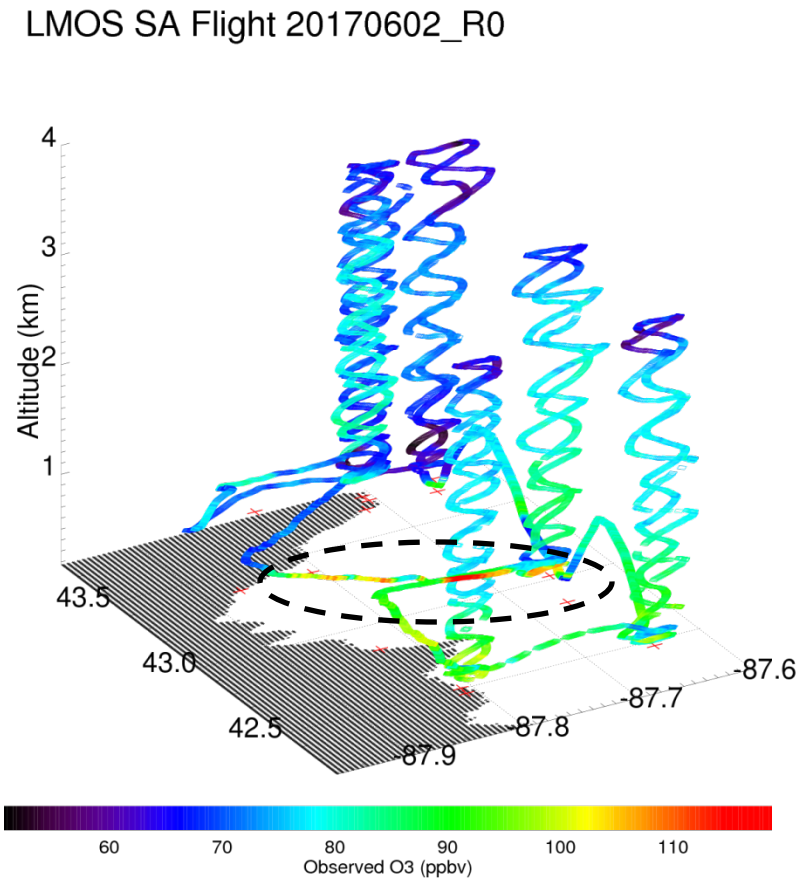
$$\frac{\Delta E}{E} = \beta \times \frac{\Delta \Omega}{\Omega}.$$

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

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.





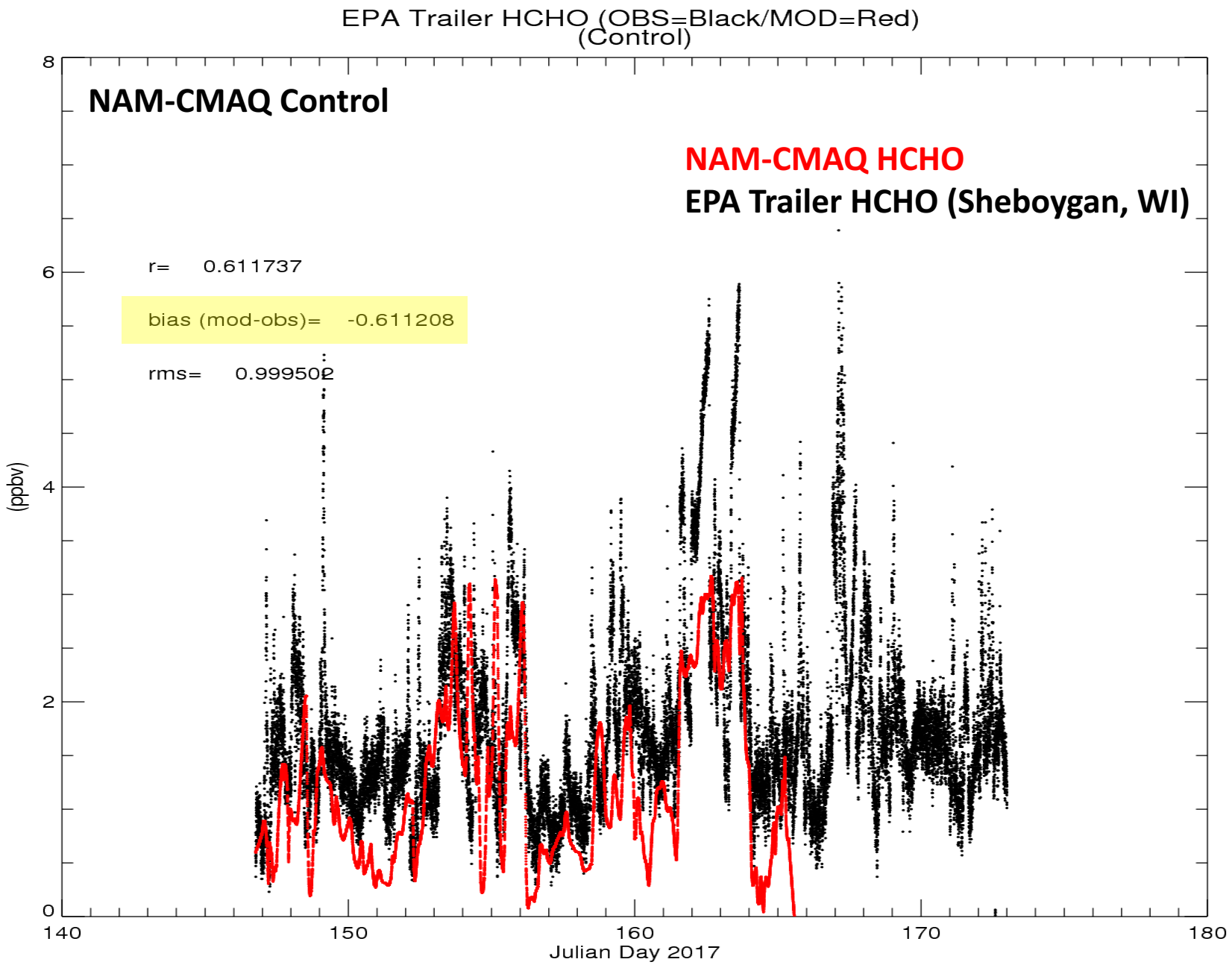


Max Observed O3 > 110ppbv

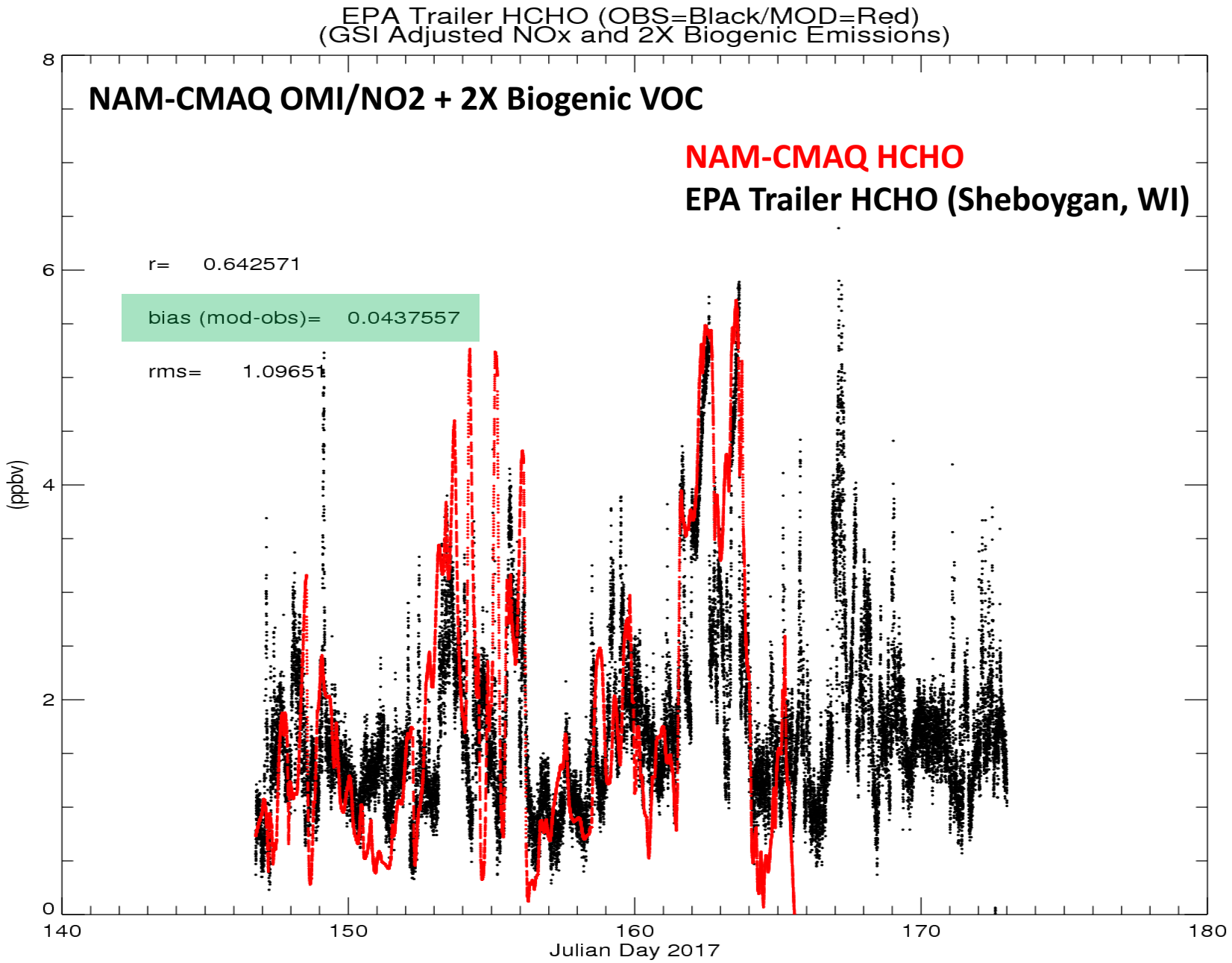
Reductions in NOx emissions on high ozone day leads to slight (~1ppbv) increases in surface ozone

Biogenic VOC Sensitivity Studies

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



Insitu HCHO provided by Jim Szykman (EPA)



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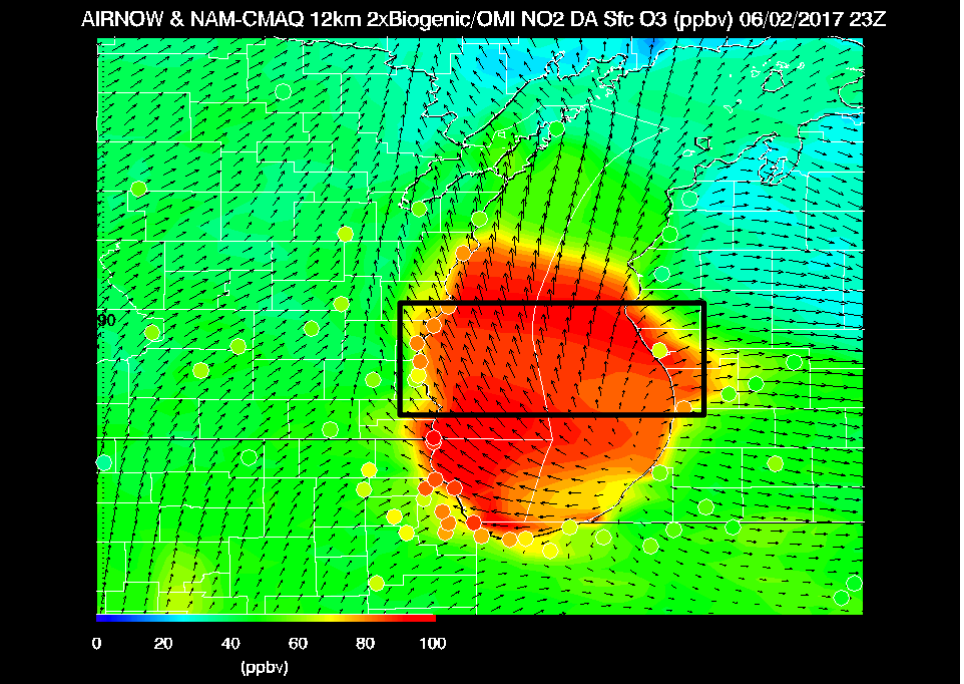
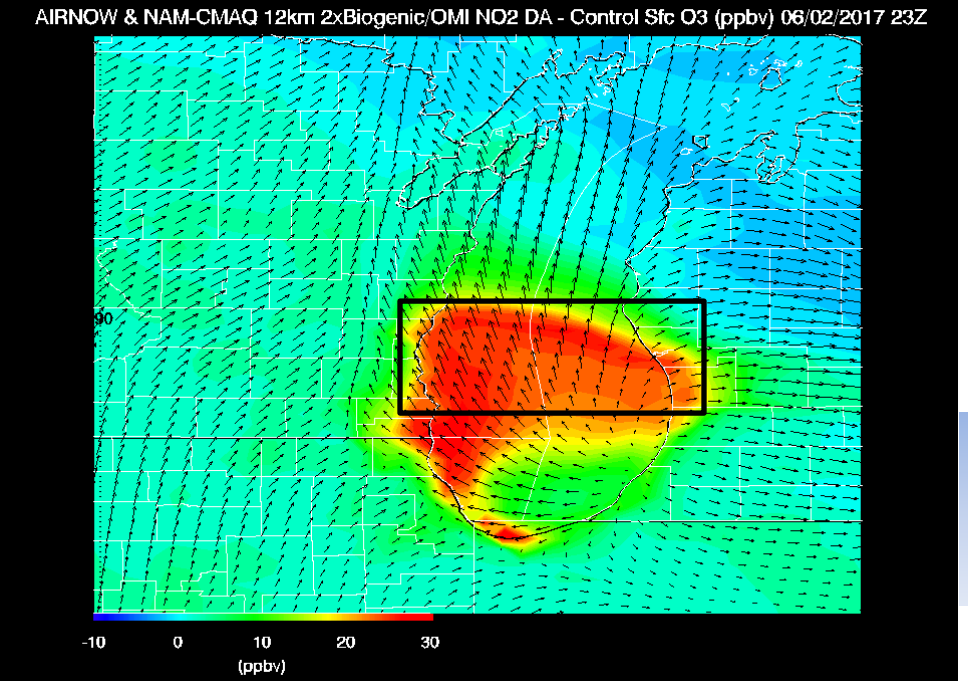
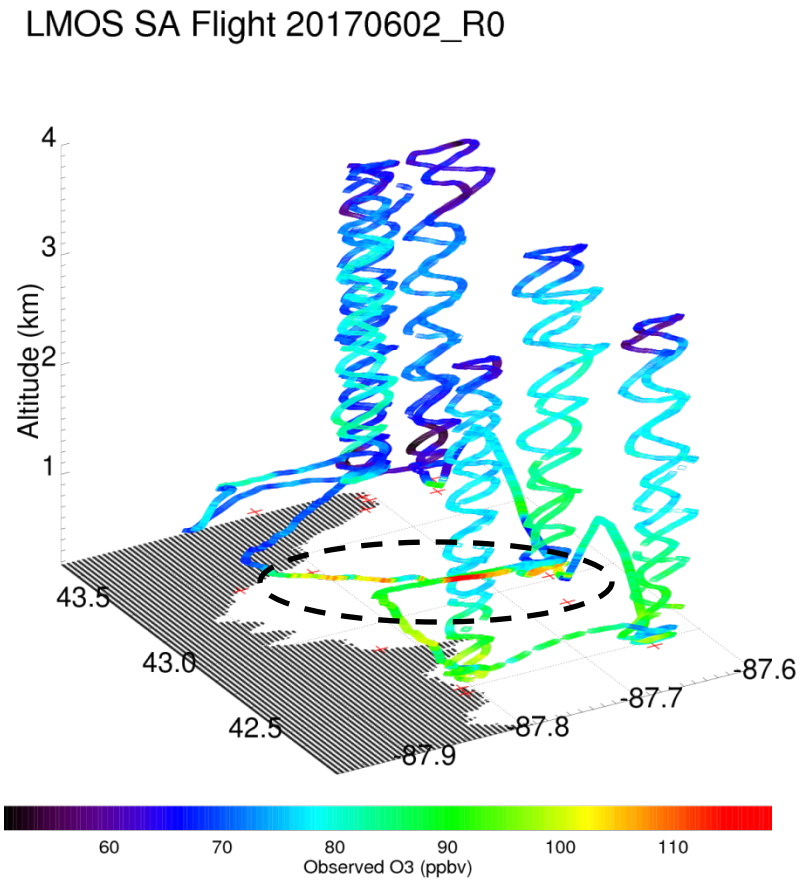


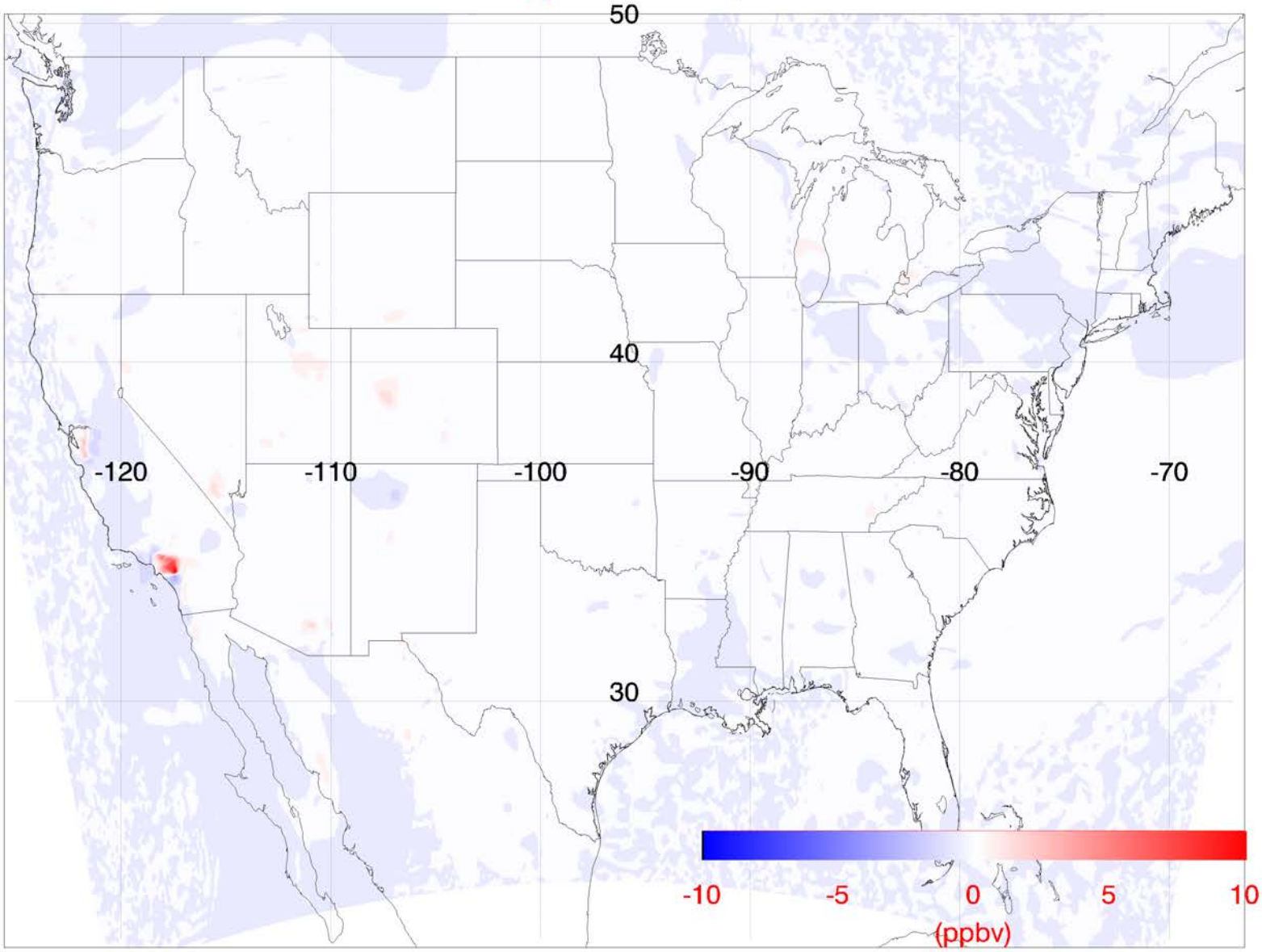




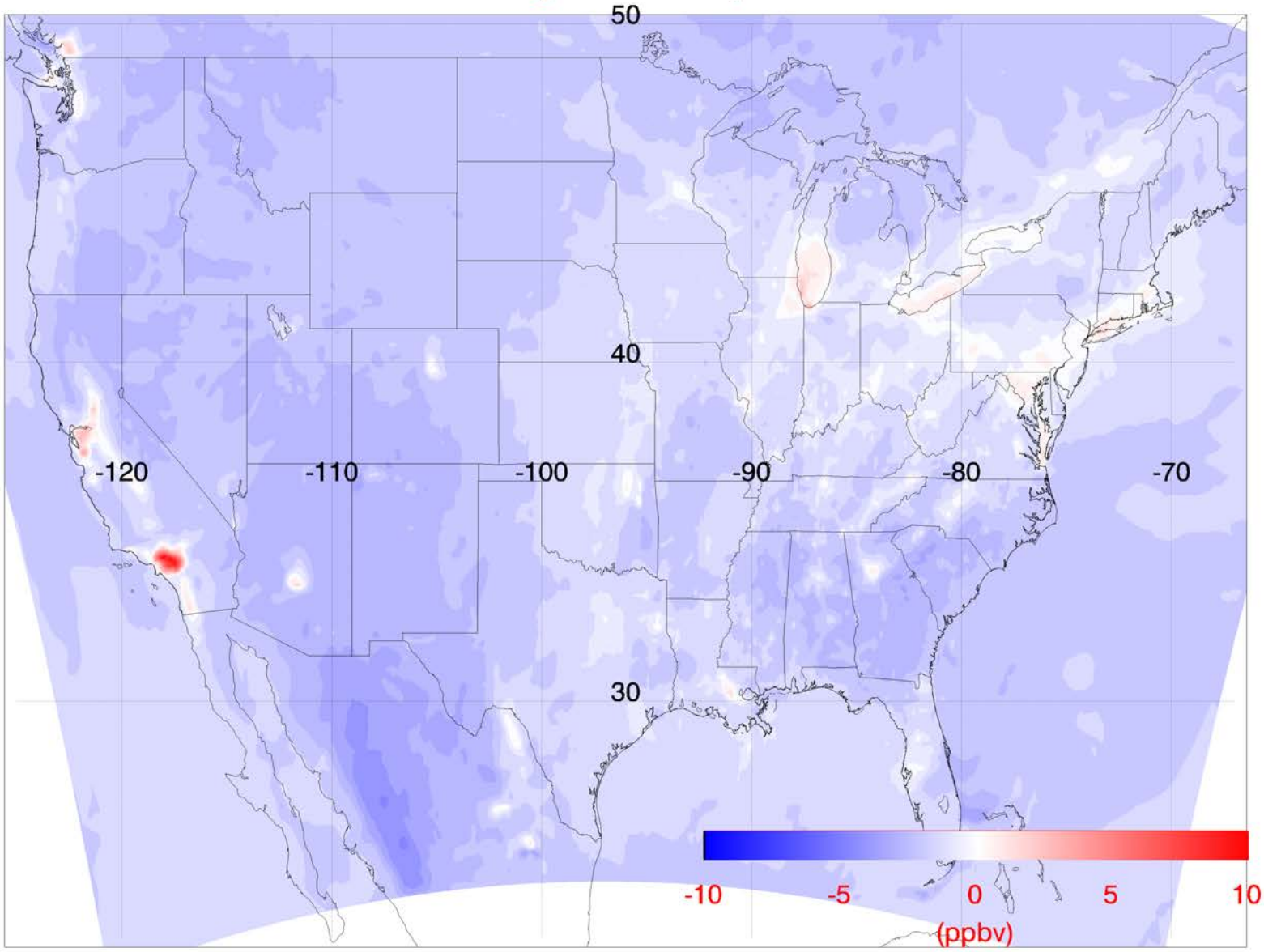
Max Observed O3 > 110ppbv

2X Biogenic emissions on high ozone day leads to large (~30ppbv) increases in surface ozone

NAM-CMAQ 12km OMI NO2 DA - Control Sfc O3 (ppbv)
23Z May 18-June 13, 2017



NAM-CMAQ 12km 2xBiogenic VOC/OMI Adjust NOx - Control Sfc O3 (ppbv)
23Z May 18-June 13, 2017



Summary and Conclusions

- **Comparisons between National Weather Service (NWS) Community Multi-scale Air Quality (CMAQ) forecasts and 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.**

- **Using OMI tropospheric NO2 column retrievals to constrain CMAQ NOx emissions results in significant reductions in surface ozone biases in some regions (LA Basin), but had only small impacts over Lake Michigan**

    - **Convergence of NOx emissions magnitudes after assimilation using two different models and assimilation methods for July 2011 case-study (not shown) provides evidence of the robustness of assimilation results.**

- **2X Biogenic emissions sensitivity studies show that reductions in anthropogenic NOx emissions and increases in biogenic volatile organic compounds (VOCs) emissions are necessary to increase the predicted surface ozone during high ozone events during LMOS 2017.**

Current Status of Tiger Team activities:

- **EPA/CDC CMAQ/GSI OMI NO2 emission constraint development is complete and code has been delivered to EPA. Data assimilation experiments and ozone impact assessment during DISCOVER-AQ need to be conducted**

- **LADCO LMOS 2017 12km CMAQ simulation is underway. Follows LADCO SIP modeling framework and uses EPA NEI 2014 emissions, USDA Forest Service Bluesky fire emissions, 2017 MODIS Leaf Area Index (LAI) and GLERL Great Lakes SSTs**

Future Directions

- **NOAA NESDIS Office of Projects, Planning and Analysis (OPPA) will be supporting development of capabilities to assimilate TROPOMI trace gas retrievals within NAM-CMAQ – builds on NASA funded NAM-CMAQ/OMI Data Assimilation development**

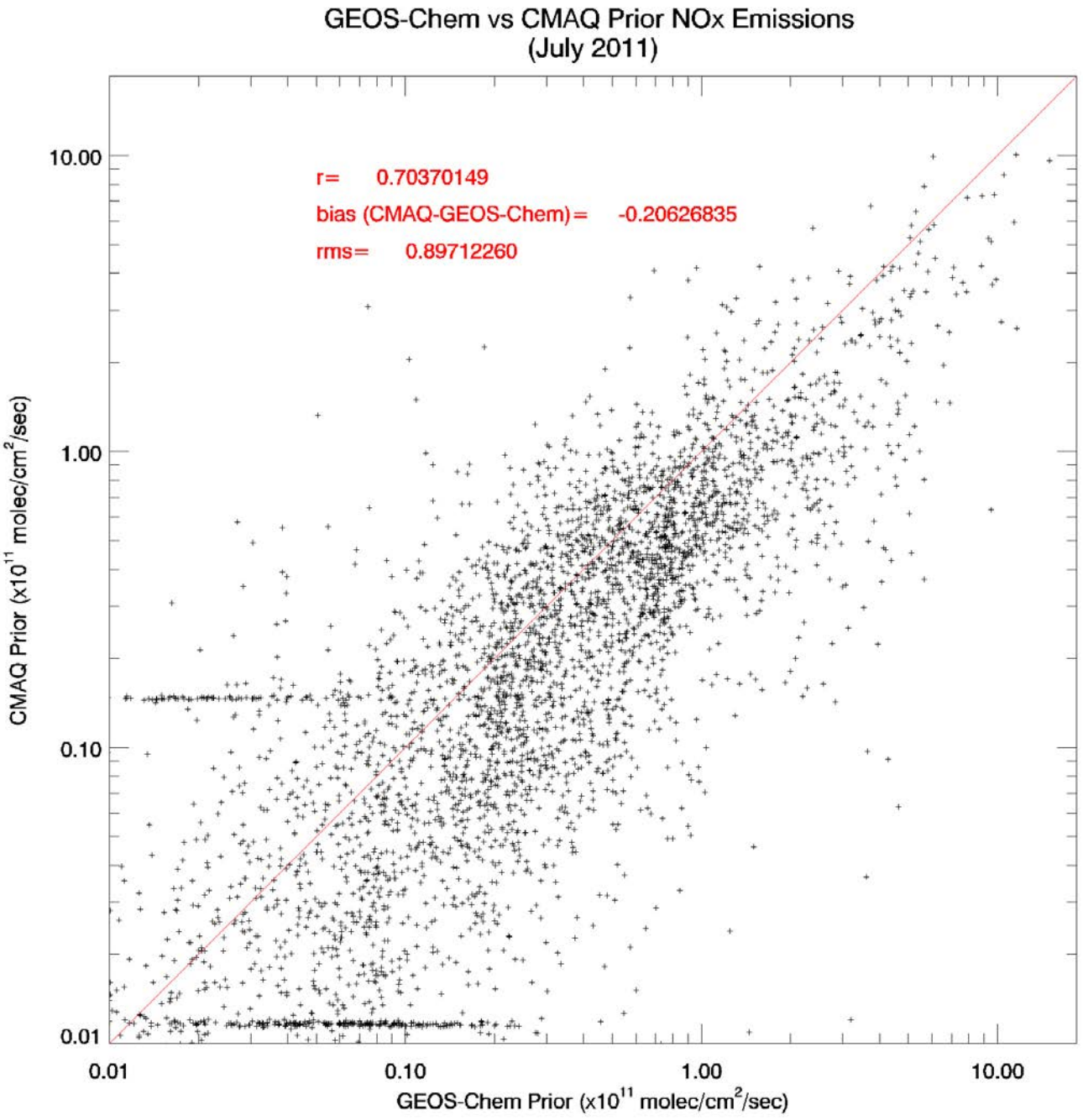
- **CIMSS/LADCO/WDNR/SPORT proposal for satellite constrained meteorological modelling platform for LADCO states SIP development submitted to NASA ROSES (Jason Otkin, CIMSS, PI)**

Additional Outreach:

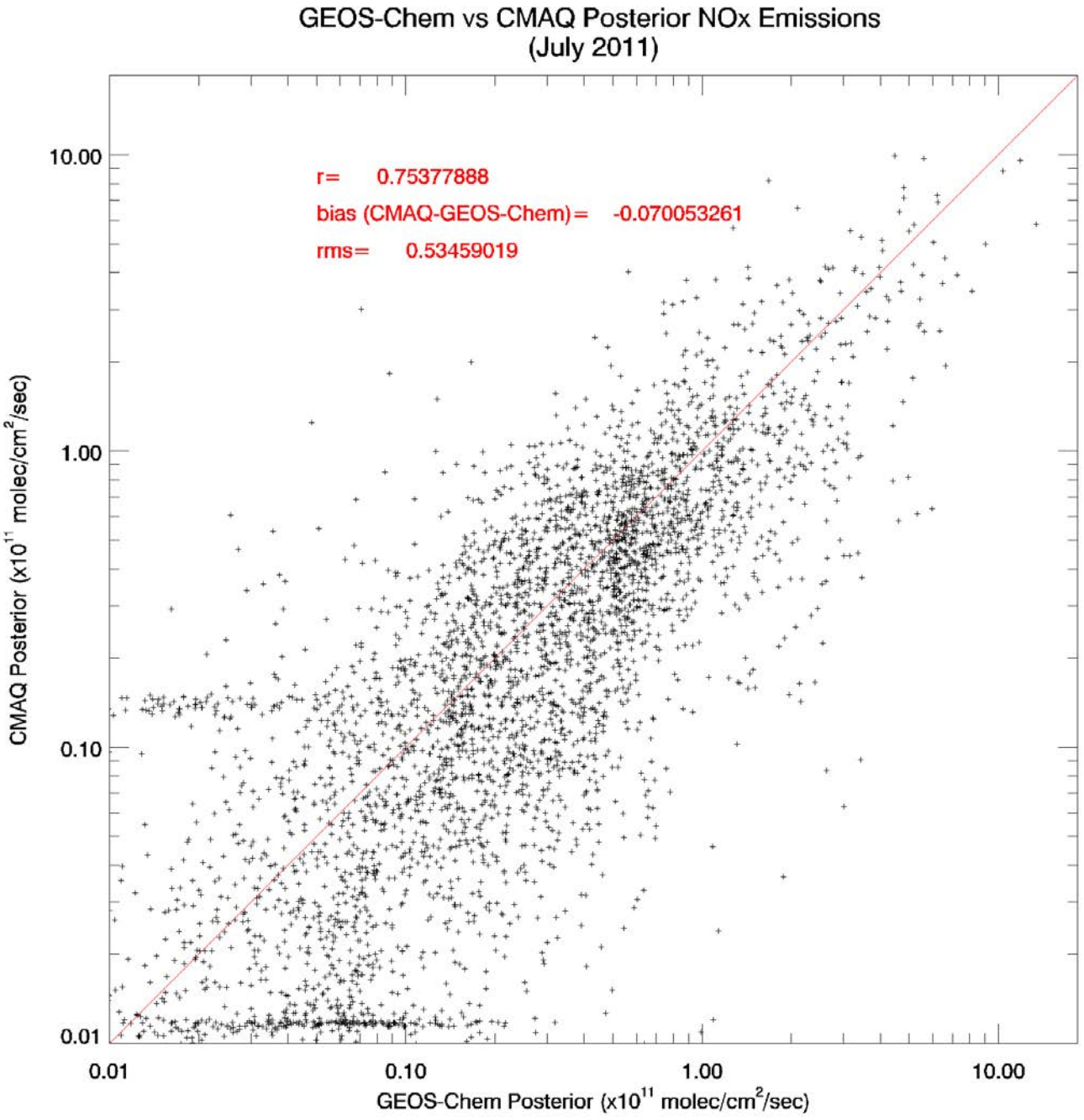
- **Plan to present OMI NO2 based emission constraint approaches (in-line 4D-Var and off-line GSI) to NASA/NOAA/EPA Technical discussions on Emissions and Atmospheric Modeling (TEAM)**

- **Establish link with National Inventory Collaborative (partnership between state emissions inventory staff, MJOs, FLMs, EPA, http://views.cira.colostate.edu/wiki/wiki/9169) to refine biogenic sensitivity experiments**

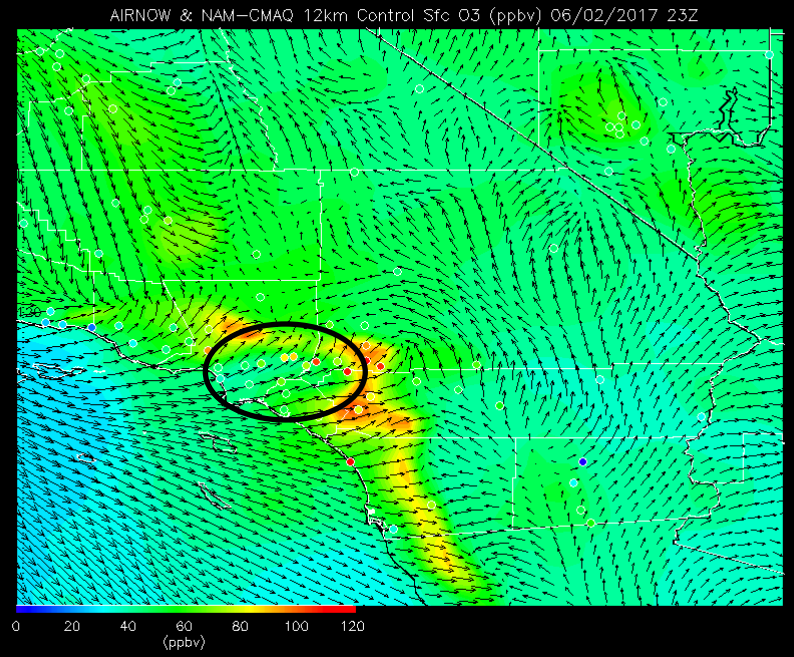
Extra Slides

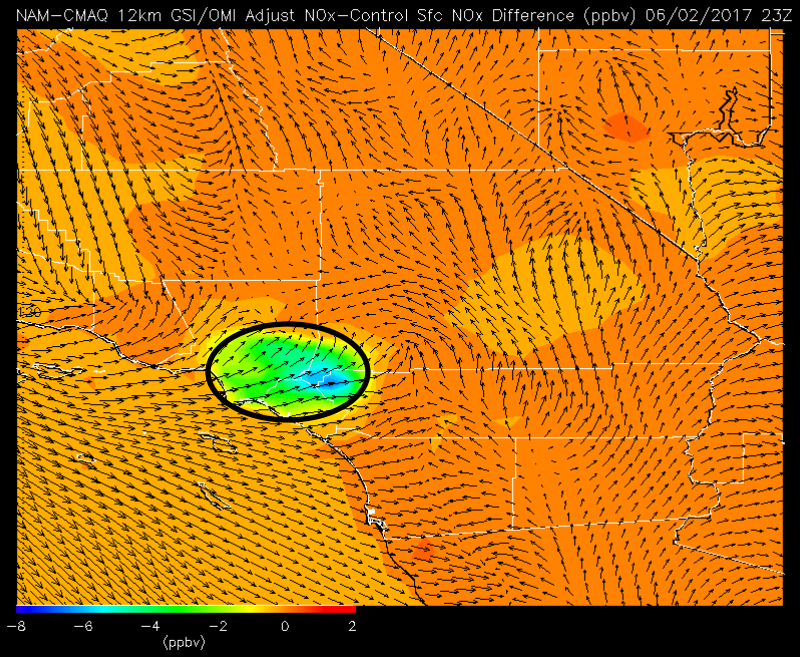


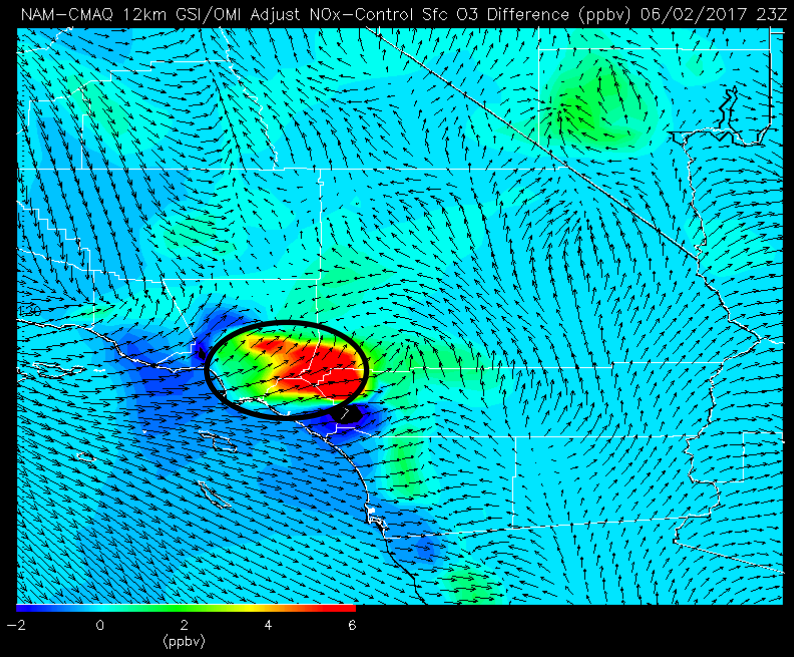
Remapped CMAQ and GEOS-Chem Prior Emissions



Improved agreement between remapped CMAQ and GEOS-Chem Posterior Emissions







NAM-CMAQ LA Ozone Sensitivities to updated NOx emissions:

- **Up to 8 ppbv reductions in NOx on high ozone day leads to 6 ppbv increases in surface ozone**
- **Improvement in prediction relative to AIRNow**

NWS Air Quality Forecasts (https://airquality.weather.gov/)

- CMAQ 5.0.2 with CB05 gas phase and AERO6 aerosol chemistry
- Point source emissions are based on 2015 Continuous Emissions Monitoring System (CEM) and 2017 DoE Energy Outlook
- Area source emissions use NEI2011 (US)
- Mobile source emissions are based on Cross State Air Pollution Rule (CSAPR) 2011 Emission Data.
- Wildfire aerosol emissions use NESDIS Hazard Mapping System (HMS) fire detection and emissions from the US Forest Service (USFS) BlueSky v3.5.1 framework
- Biogenic emissions are estimated inline in CMAQ with the Biogenic Emissions Inventory System (BEIS3) v3.14

Summary of measurements made during the LMOS 2017 field campaign

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 measurements	Univ. Iowa, UW-Madison, Univ. Minnesota
	Routine measurements of ozone	Illinois EPA
Various†	Remote sensing of pollutants and boundary layer height	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 (and NOAA?)
Shipboard Platform		
Lake Michigan	In situ measurements of pollutants	U.S. EPA ORD
	Remote sensing of pollutants and boundary later height	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

GeoTASO = Geostationary Trace gas and Aerosol Sensor Optimization instrument
AirHARP = Airborne Hyper Angular Rainbow Polarimeter
GMAP = Geospatial Mapping of Pollutants
† These measurements were made at Spaceport Sheboygan, Zion, two Wisconsin DNR monitoring locations (Grafton and Milwaukee SER) and one Illinois EPA monitoring location (Schiller Park).