HAQAST Tiger Team Report

Improved National Emissions Inventory NOx emissions using OMI tropospheric NO2 retrievals and potential impacts on air quality strategy development

Co-PIs:
Brad Pierce (NOAA/NESDIS) and Daniel Tong (George Mason University/ARL)

HAQAST Participants:
Ted Russell (Georgia Tech), Tracey Holloway (UW-Madison), Susan O'Neill (USDA Forest Service), Daven Henze (University of Colorado)
Communication and Outreach Participants:
Margaret Mooney (CIMSS), Jean Phillips (SSEC)
Senior Research Staff:
Monica Harkey (UW-Madison)

HAQAST3, Columbia University, Palisades, NY November 28-29, 2017

Stakeholder Partners

National Weather Service (NWS)

- National Air Quality Forecasting Capability (NAQFC)
  - ***Ivanka Stajner***
  - ***Pius Lee***

Environmental Protection Agency (EPA)

- Office of Air Quality Planning and Standards (OAQPS)
  - ***Kirk Baker***
  - ***Barron Henderson***

Center for Disease Control and Prevention (CDC)

- National Environmental Public Health Tracking
  - ***Ambarish Vaidyanathan***

Lake Michigan Air Directors Consortium (LADCO)

- State Implementation Plan (SIP) Modeling
  - ***Zac Adelman***
  - ***Donna Kenski***

NASA/NOAA/EPA Outreach

- Technical discussions on Emissions and Atmospheric Modeling (TEAM)
  - ***Greg Frost***

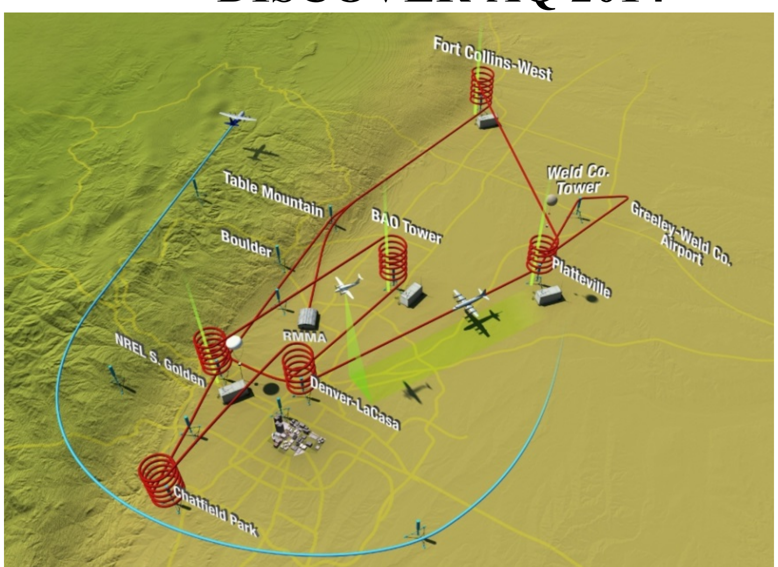
Objective: Support the NWS/EPA/CDC and the Lake Michigan Air Directors Consortium (LADCO) with improved estimates of NEI anthropogenic area and non-EGU point source NOx emissions using NO_2 retrievals from the NASA Ozone Monitoring Instrument (OMI) and the NASA Geostationary Trace gas and Aerosol Sensor Optimization (GeoTASO)

Demonstration Periods:

July-August 2014 DISCOVER-AQ field campaign (Denver, CO) https://www-air.larc.nasa.gov/missions/discover-aq/discover-aq.html)

May-June 2017 Lake Michigan Ozone Study (LMOS 2017) https://www-air.larc.nasa.gov/missions/lmos/

DISCOVER-AQ 2014



LMOS 2017

Approach:

- Assimilate OMI/GeoTASO tropospheric NO2 columns using 3D-variational (GSI) analysis within the Community Multi-scale Air Quality (CMAQ) modeling system
- Use resulting analysis increments and NO2 column/NOx emissions sensitivities to perform offline adjustments to NOx emissions
- Compare CMAQ/GSI based OMI NO2 emission constraints to hybrid mass-balance / 4-Dimensional Variational approaches using GEOS-Chem

Schedule:

First 6 months: Demonstrate the impact of the satellite based emission constraints on the NWS NAM-CMAQ during the 2017 Lake Michigan Ozone Study

Second 6 months: Demonstrate the impact of satellite and aircraft based emission constraints on the NEI 2014 NOx emissions for EPA Bayesian (DISCOVER-AQ) and LADCO State Implementation Plan (SIP) modeling efforts (LMOS 2017)

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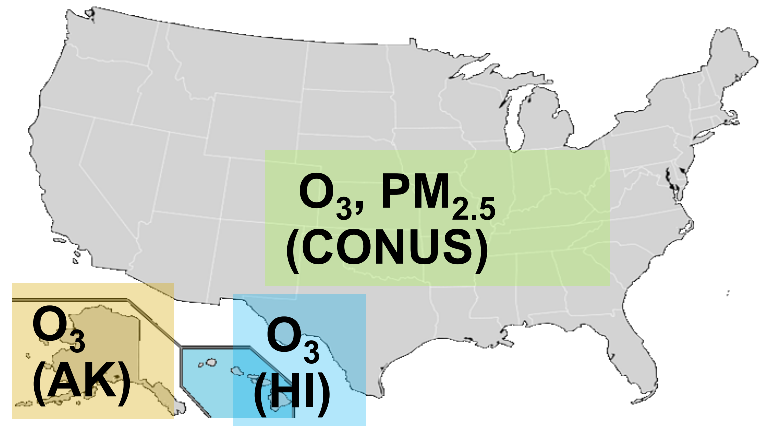
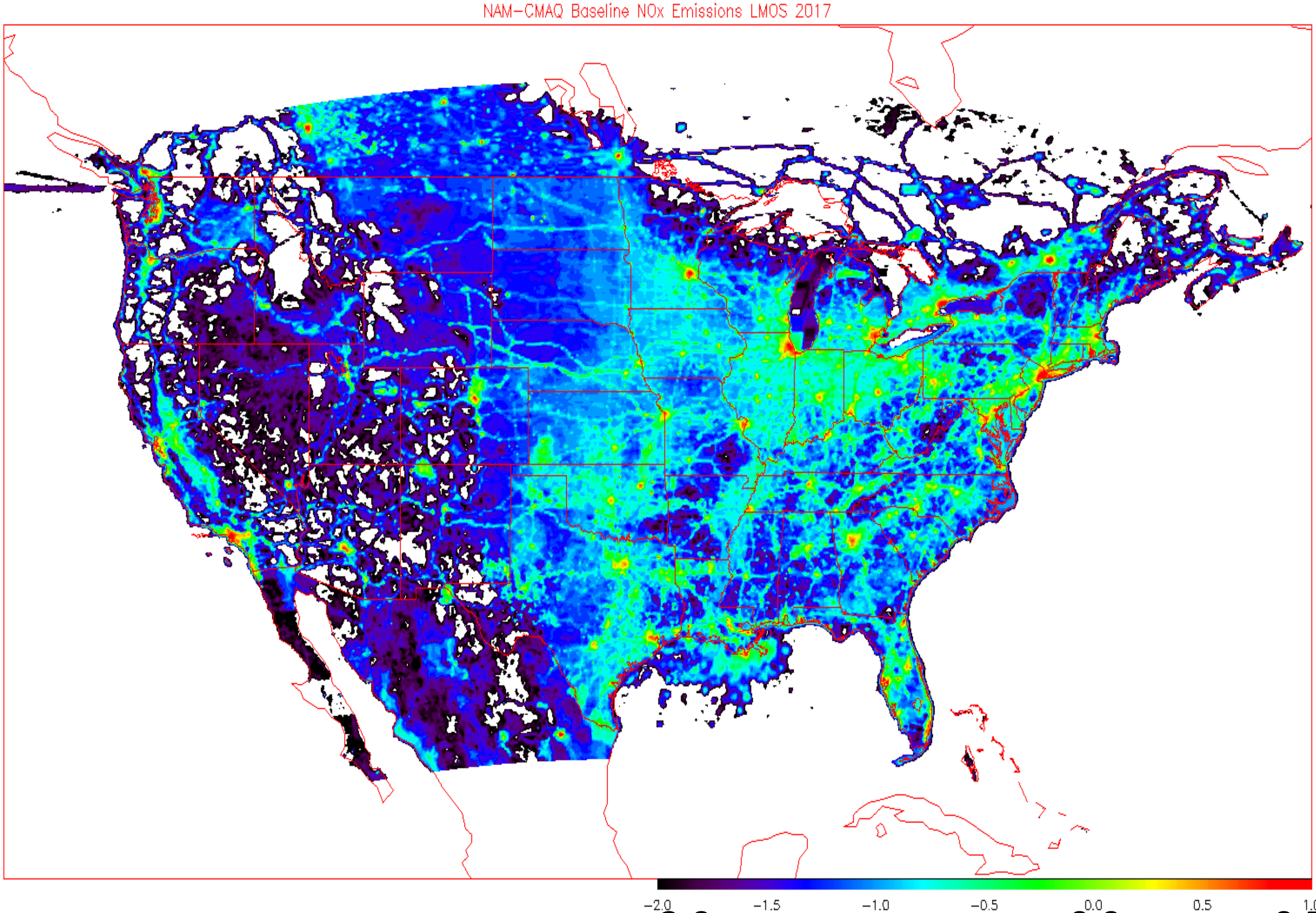
2017 NAM-CMAQ Configuration

2017



- **Meteorology**
  - NWS North American Model (NAM)
- **CMAQ5.0.2**
  - CB05 gas chemistry 157 species
  - Aero6 aerosol chemistry
- **Emissions**
  - **Point source:** 2015 Continuous Emissions Monitoring System (CEM) and 2017 DoE Energy Outlook, Canada 2011 Environment Canada Emission Inventory (ECEI), Mexico inventory (MI) 2012 version2.2
  - **Area source:** NEI2011, ECEI 2006 for Canada; MI 2012 for Mexico
  - **Mobile source:** Cross State Air Pollution Rule (CSAPR) 2011 Emission Data
  - **Wild fires:** NESDIS Hazard Mapping System (HMS) & fuel from New USFS BlueSky v3.5.1
  - **Natural source:** Biogenic with BEIS3 Version 3.14; Sea-salt based on 10m wind

NAM-CMAQ Mean NOx Emissions
LMOS 2017



-2.0 **0.0** **0.5**

log10 (moles/sec)

NAM-CMAQ/GSI NOx emission adjustment experiments

1) Calculate monthly mean NO_2 Jacobian (β) from a 15% NO_X emission reduction perturbation experiment following *Lamsal et al.* 2011

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

2) Calculate monthly mean NO_2 analysis increment using NAM-CMAQ/GSI OMI NO_2 assimilation
   a. Lightning NOx sensitive background errors (to correct LNOx bias)
   b. NEI 2011 NOx sensitive background errors (to correct NEI emissions)

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

3) Adjust 2011 NEI NO_x emissions using Jacobian and analysis increment

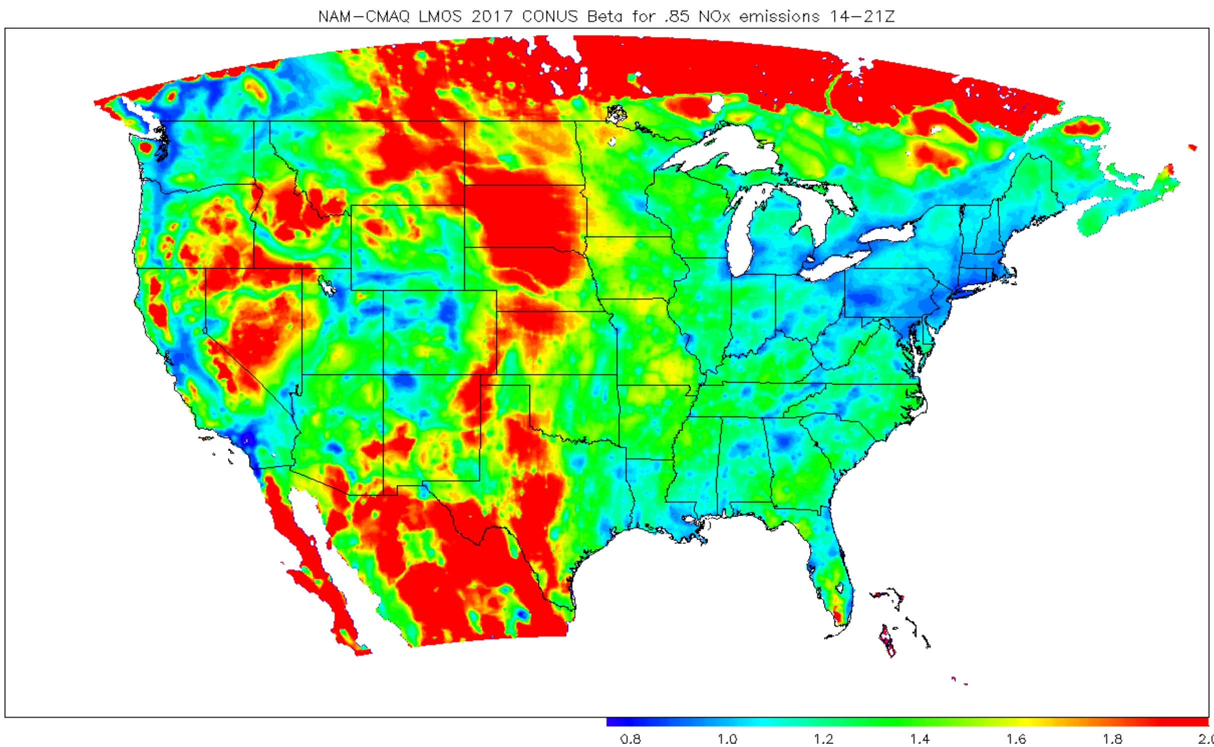
$$\boxed{\frac{\Delta E}{E}} = \beta \times \frac{\Delta \Omega}{\Omega}.$$

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.

NAM-CMAQ Beta Calculations for LMOS 2017

Calculate monthly mean NO_2 Jacobian (β) from a 15% NO_X emission reduction perturbation experiment (conducted by Pius Lee, NOAA/ARL)

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



Urban areas and transport corridors (β<1), rural areas (β>1)

Testing feasibility of off-line (single cycle) GSI NO2 analysis increments for emission adjustment

Motivation:

- Since NO2 lifetime is short the "memory" of the GSI analysis increment is lost, we may be able to obtain similar monthly mean analysis increments through offline (single-cycle) GSI NO2 DA.

- This would remove the issue with online DA associated with large restart files and also reduce the number of times CMAQ needs to be run to compute the offline emission adjustments

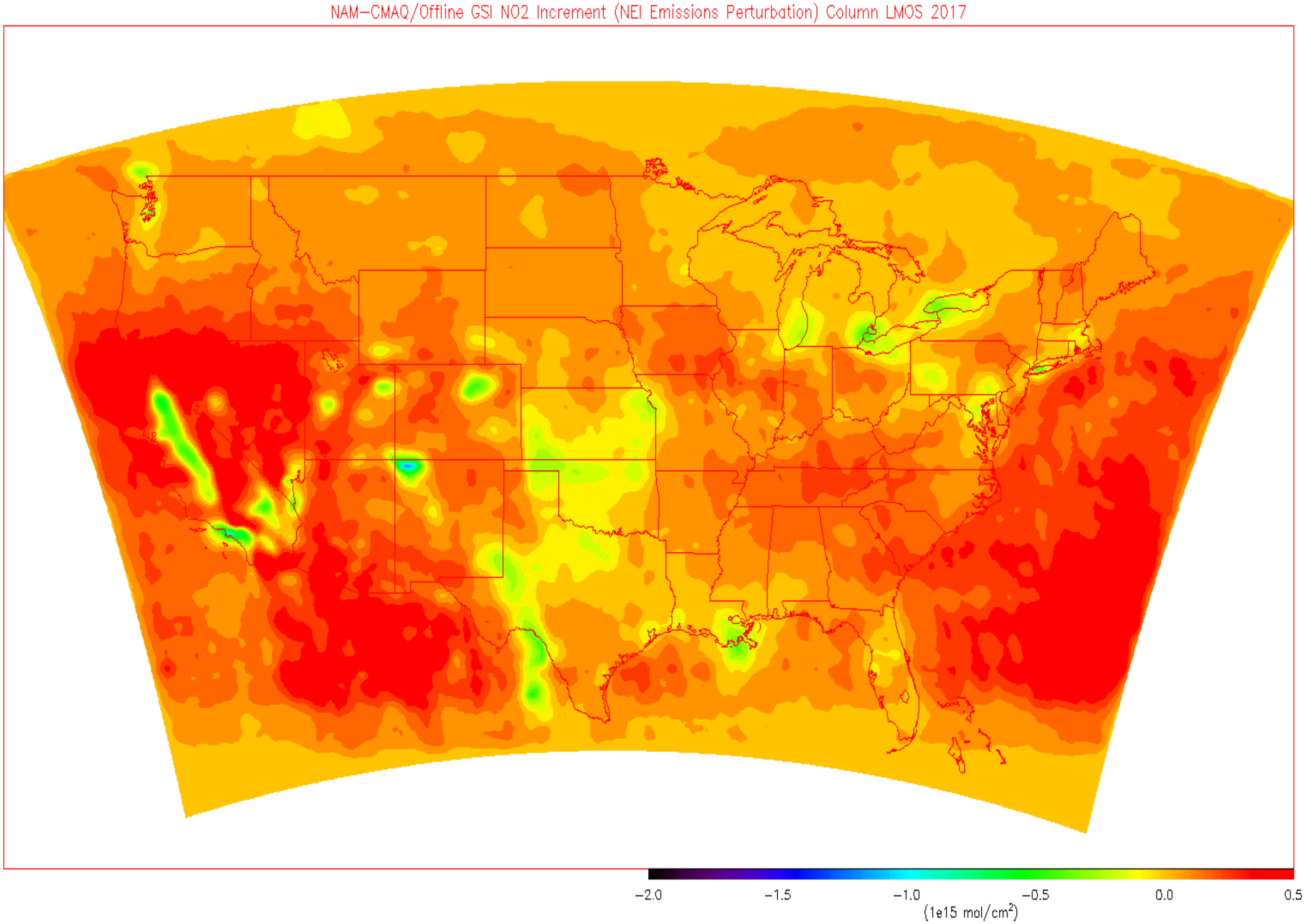
Results (based on CMAQ 2011 testing, see extra slides):

- Online/Offline differences are <5% for most urban and transport routes but reach 10% just outside of the major urban areas.

Conclusion:

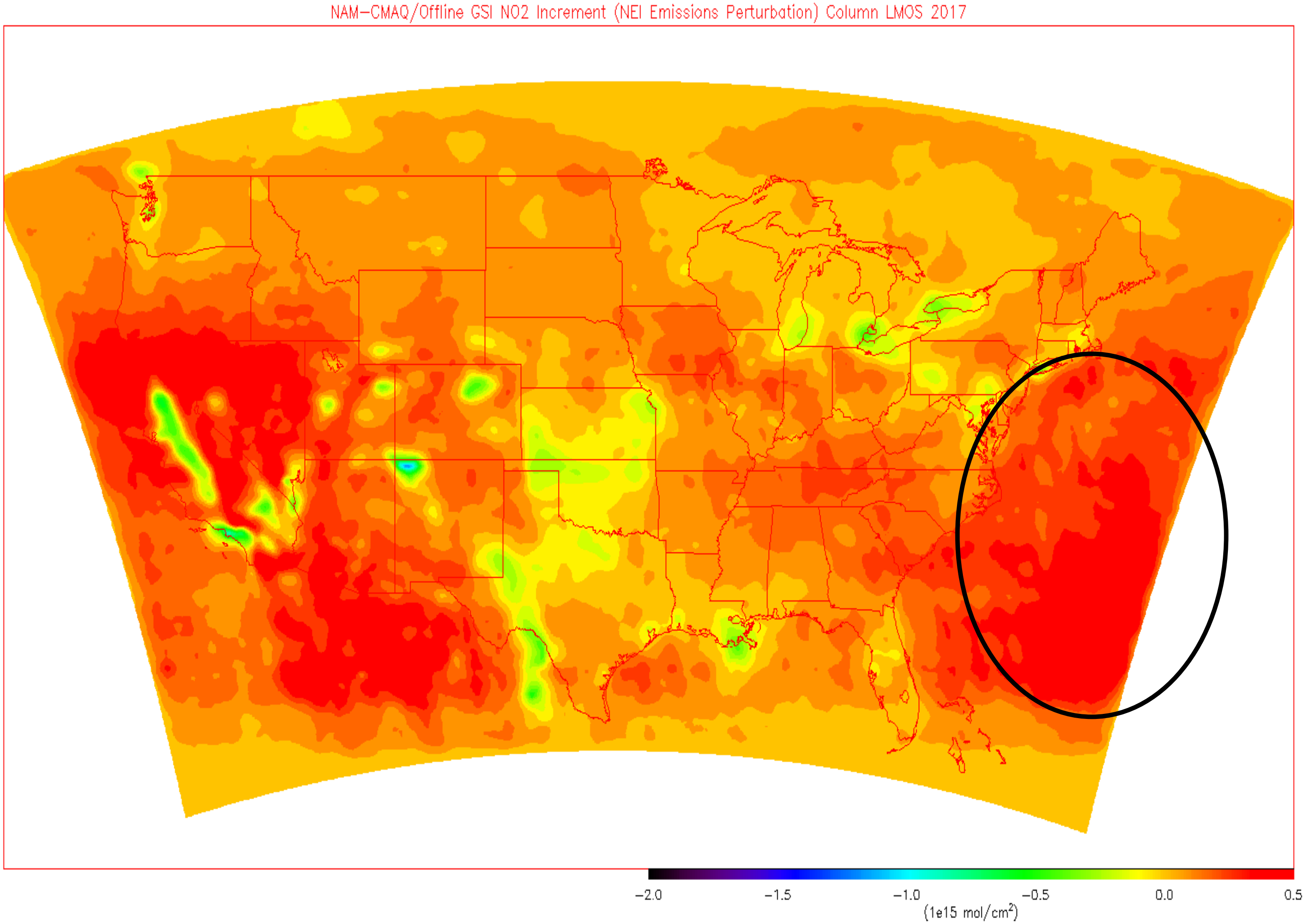
- Can use the Offline OMI/GSI for guidance (for example to see that we need to adjust the LNOX emissions) but shouldn't use the Offline OMI/GSI DA for actual emissions adjustments.

NAM-CMAQ Offline (single-cycle) GSI NO2 DA
LMOS 2017 Mean Analysis Increment



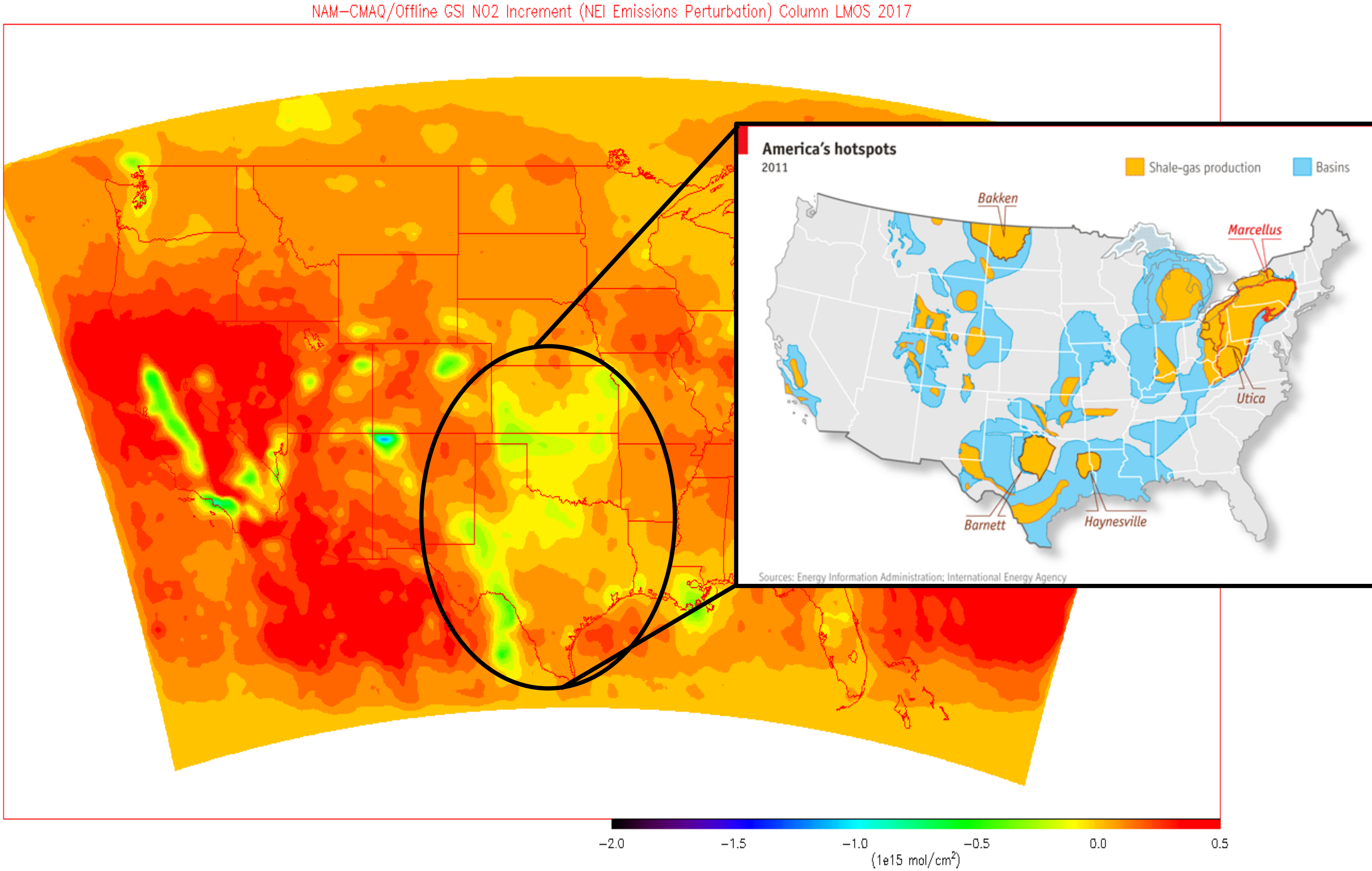
Negative adjustments in urban NO2 columns point to the need for reducing NOx emissions used in NAM-CMAQ

NAM-CMAQ Offline (single-cycle) GSI NO2 DA
LMOS 2017 Mean Analysis Increment



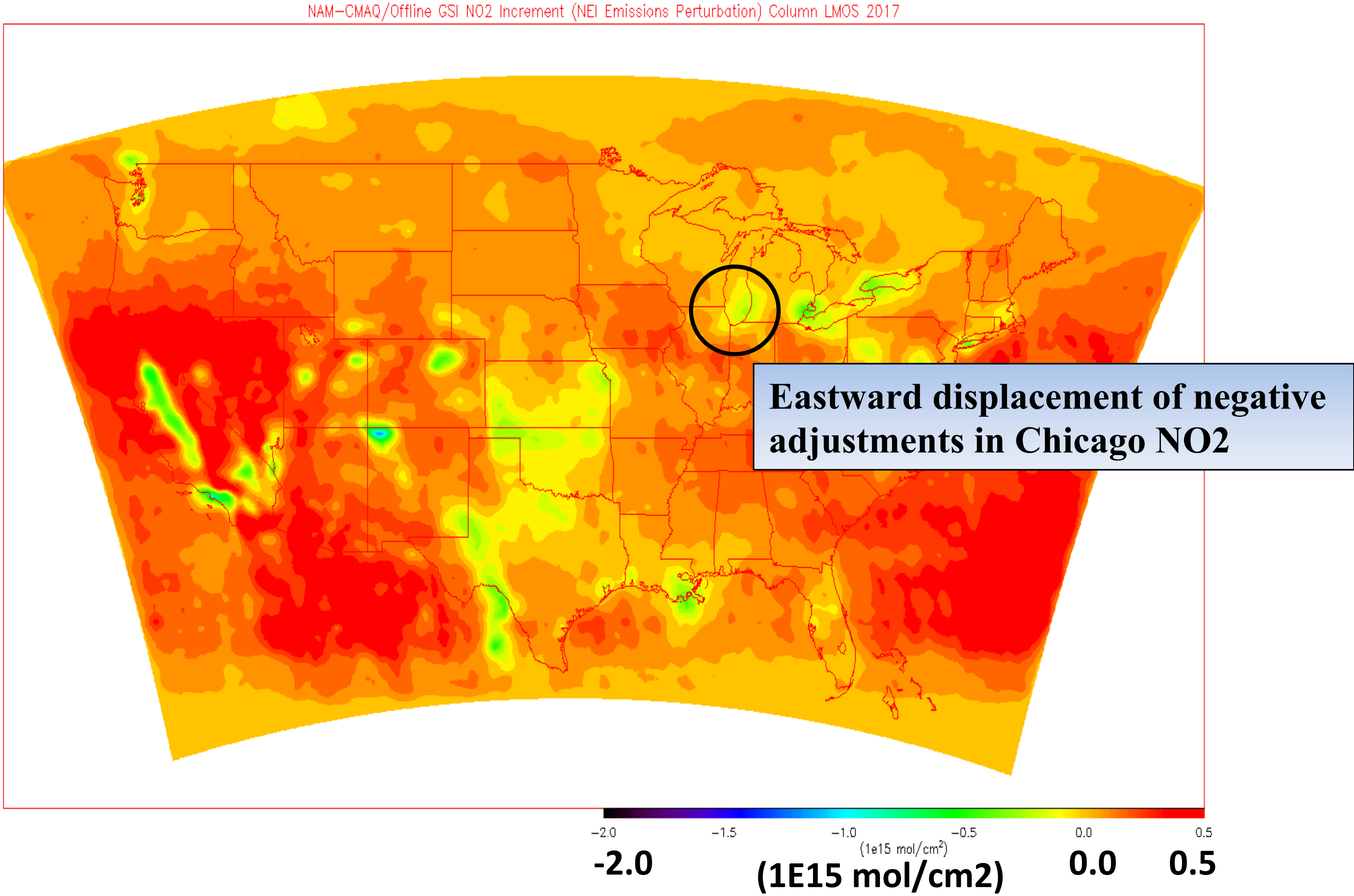
Large positive adjustments in background NO2 point to the need for adding (and adjusting) lighting NOx emissions prior to NEI adjustment

NAM-CMAQ Offline (single-cycle) GSI NO2 DA LMOS 2017 Mean Analysis Increment

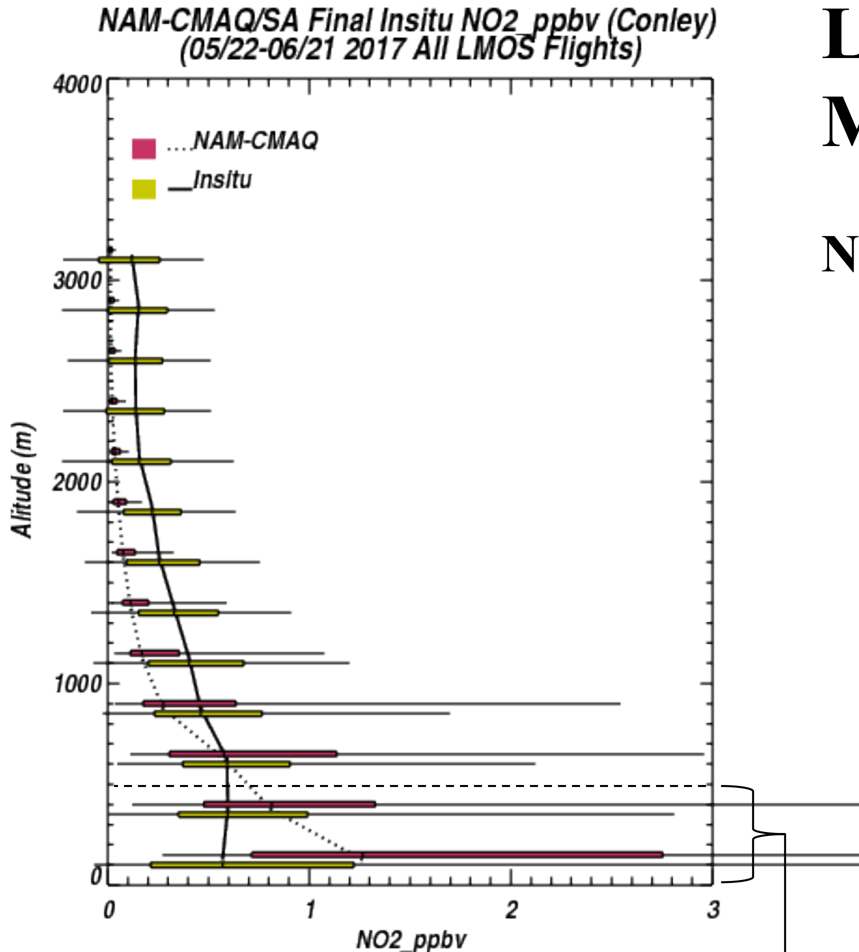


Large negative adjustments in NO2 in Barnett shale-gas production

NAM-CMAQ Offline (single-cycle) GSI NO2 DA LMOS 2017 Mean Analysis Increment

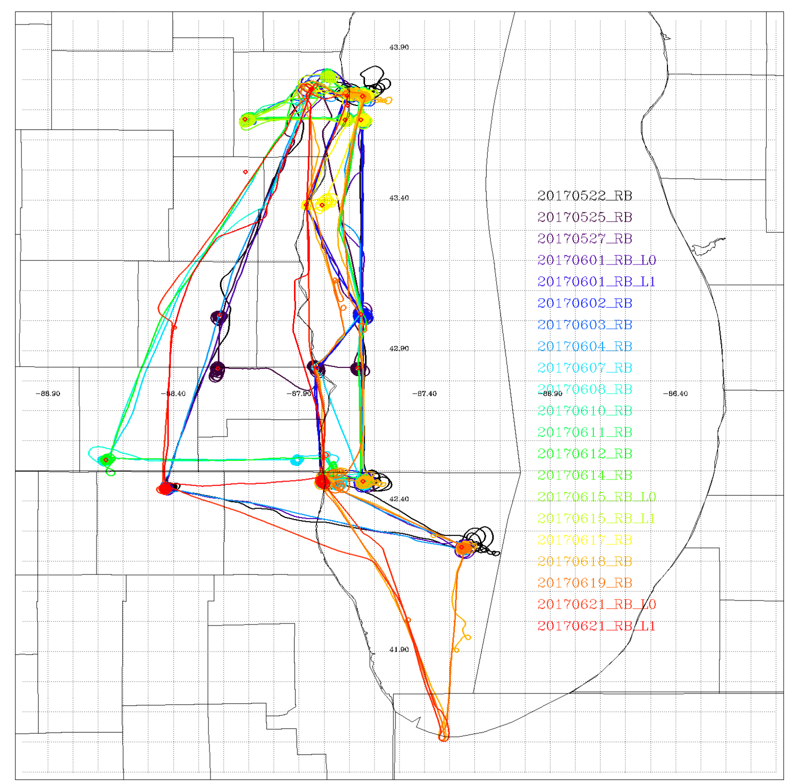


Lake Michigan Ozone Study
May 22 through June 22, 2017



NAM-CMAQ NO2 vs Airborne In-situ

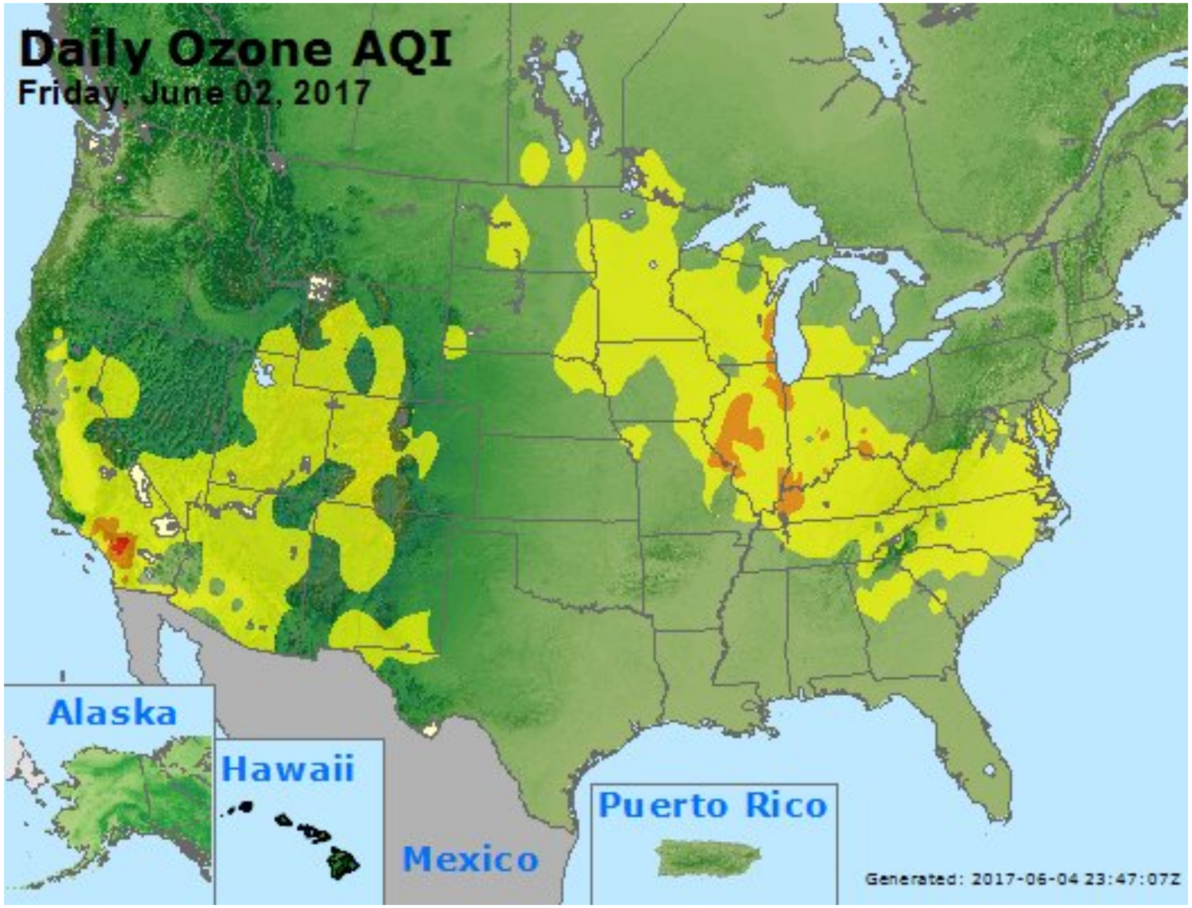
All Scientific Aviation Flights



2x median high bias in lowest 500m

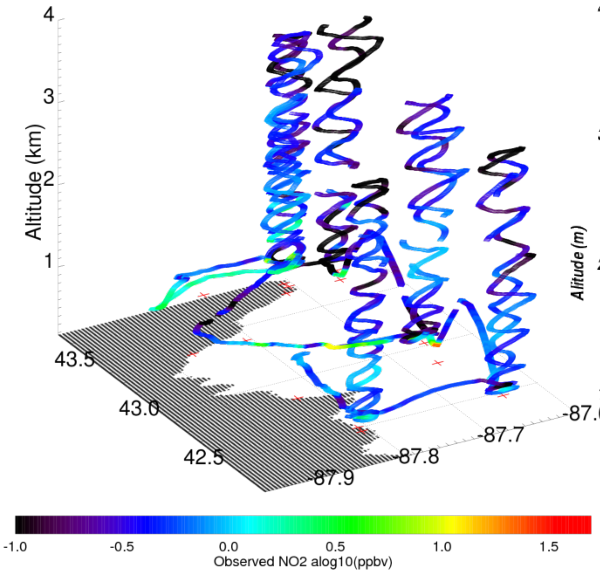
Steve Conley, Scientific Aviation PI, EPRI funding for LMOS deployment

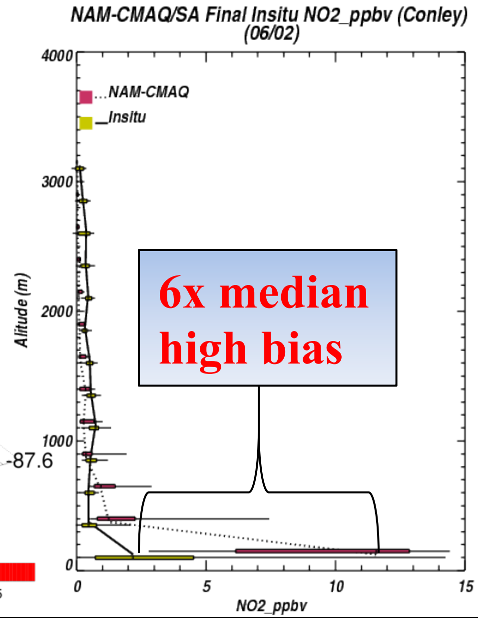
Coastal Ozone Exceedance: June 02, 2017



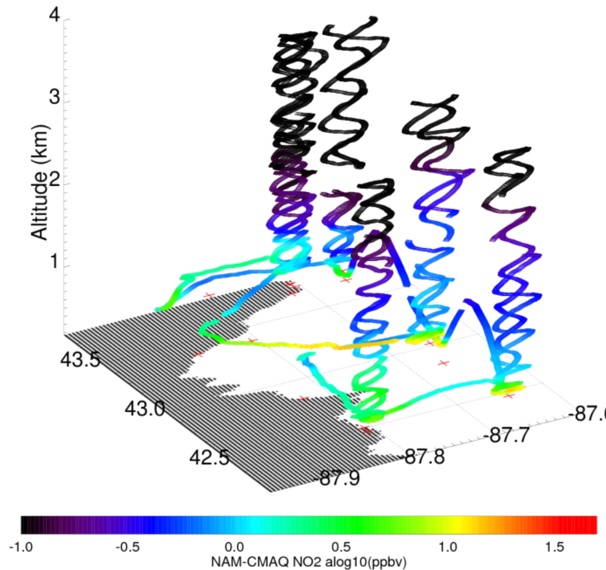
LMOS June 02, 2017

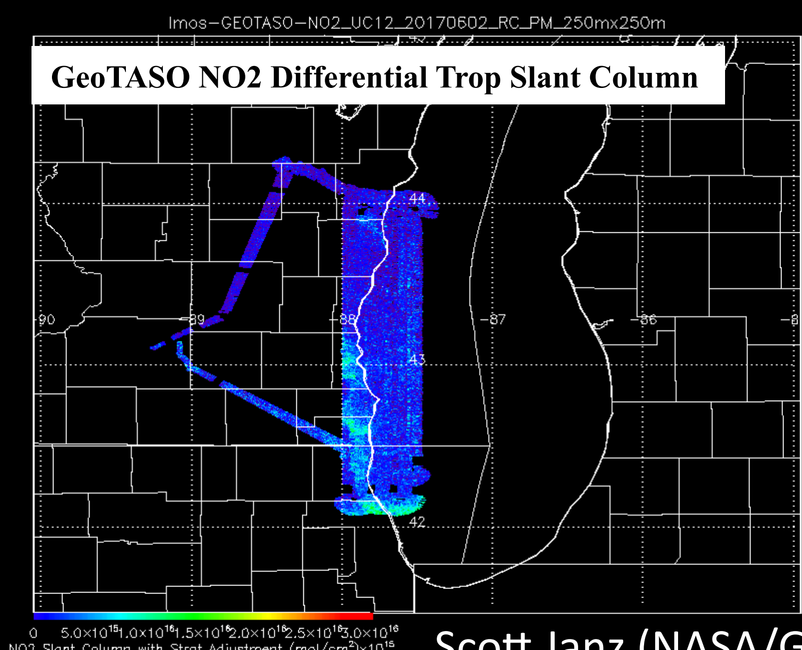
SA NO2

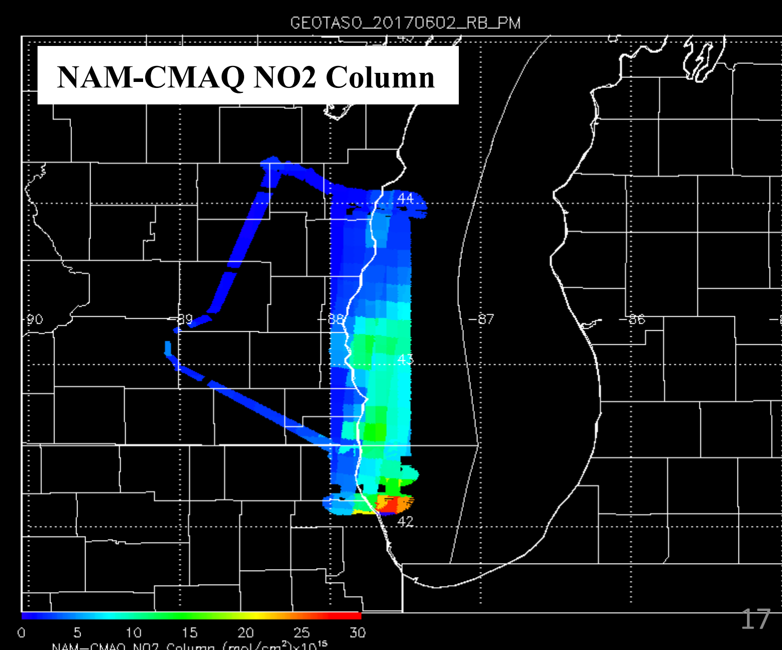




NAM-CMAQ NO2







Scott Janz (NASA/GSFC, PI)

Summary:

- Approach for NWS NAM-CMAQ/GSI OMI data assimilation (DA) demonstration during the 2017 Lake Michigan Ozone Study has been established
    - 15% emission reduction experiment completed and used to compute β and GSI background error covariances for NEI emissions adjustment
- Offline (single-cycle) experiments have been conducted to provide guidance on how to proceed with full online NAM-CMAQ GSI/OMI DA experiments
    - Need to add (and adjust) NAM-CMAQ lightning NOx (LNOx) emissions
    - LNOx experiments to generate background error covariances for LNOx adjustment are underway

Conclusion: Offline NAM-CMAQ GSI/OMI DA leads to reduction in NO2 column over Lake Michigan which is consistent with NAM-CMAQ high biases vs insitu profiles (Scientific Aviation) and tropospheric slant columns (GeoTASO) during LMOS 2017

Next Steps:

- Complete NAM-CMAQ LNOx adjustment experiments
- Conduct Online (full cycling) NAM-CMAQ GSI/OMI DA emission adjustment experiments
- Compare NAM-CMAQ 3D-Var emission adjustments with hybrid mass-balance / 4-Dimensional Variational approaches using GEOS-Chem
- Begin EPA/CDC CMAQ/GSI OMI DA experiments during 2014 DISCOVER-AQ

Extra Slides

Testing feasibility of off-line (single cycle) GSI NO2 analysis increments for emission adjustment

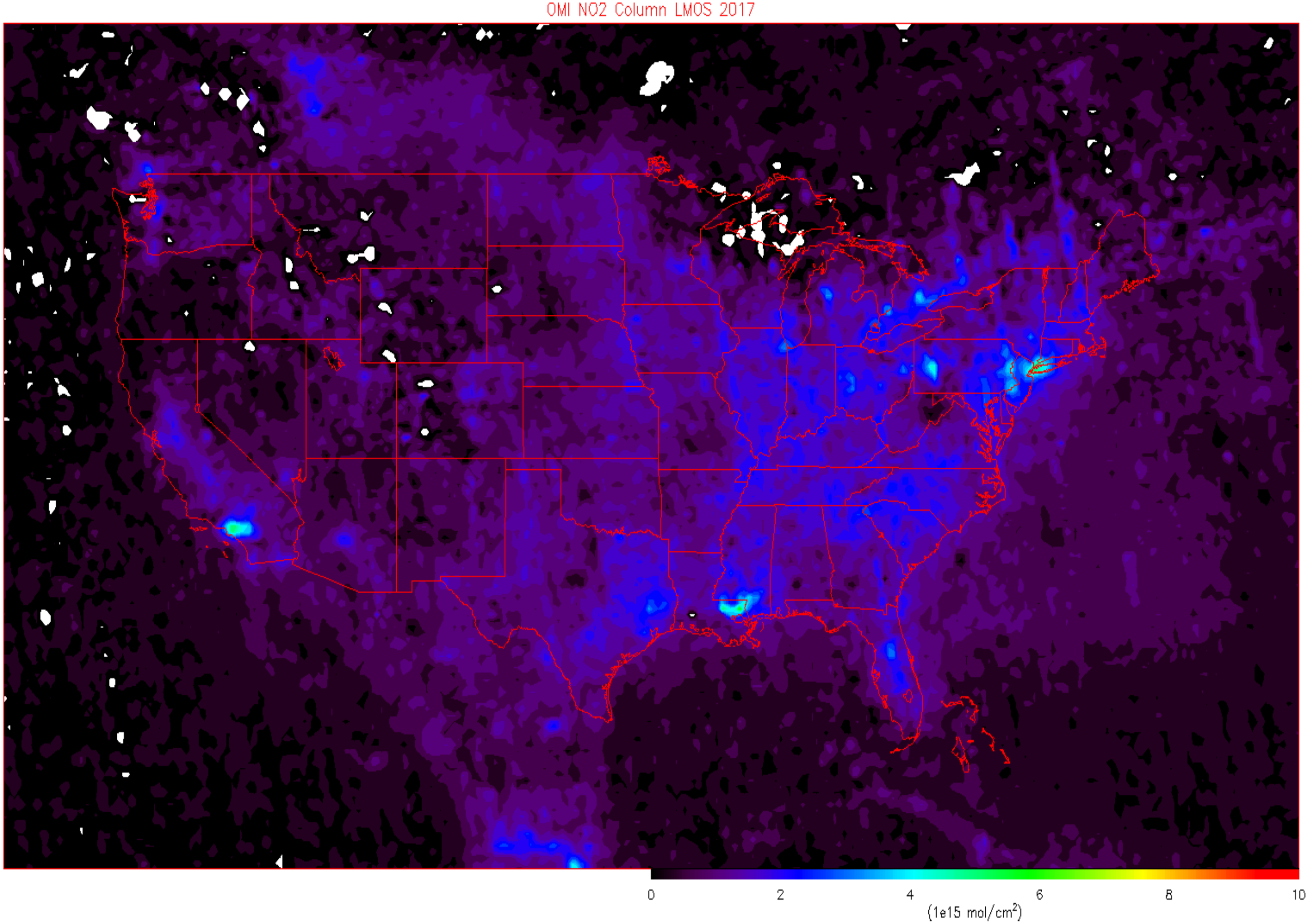
Motivation:

- Since NO2 lifetime is short the "memory" of the GSI analysis increment is lost, we may be able to obtain similar monthly mean analysis increments through offline (single-cycle) GSI NO2 DA.
- This would remove the issue with online DA associated with large restart files and also reduce the number of times CMAQ needs to be run to compute the offline emission adjustments

Feasibility testing:

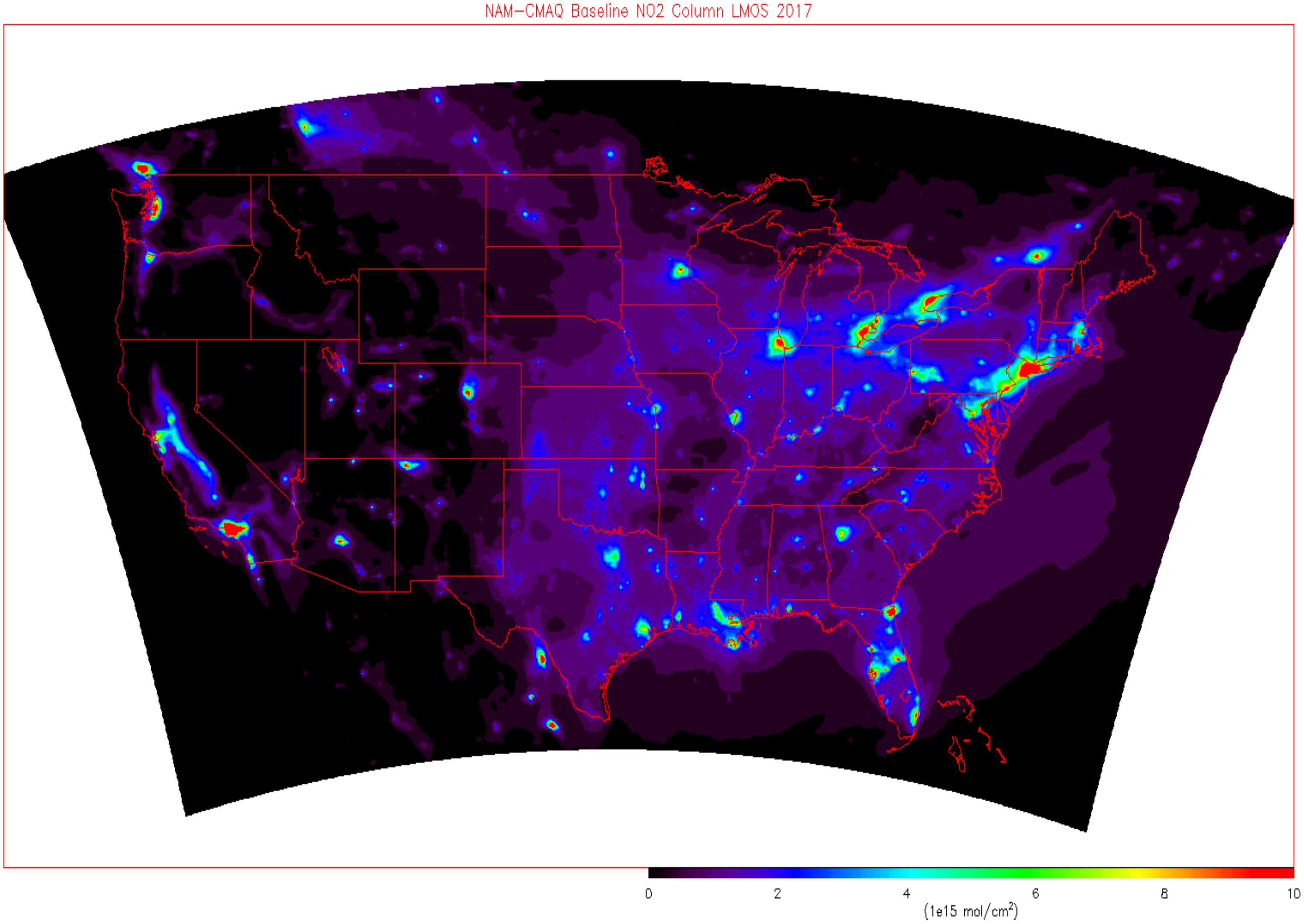
- Compare the monthly mean analysis increments obtained with offline (single-cycle) and online (full cycling) using the July 2011 CMAQ/GSI NO2 DA experiment

OMI Tropospheric NO2 Column
LMOS 2017 Mean



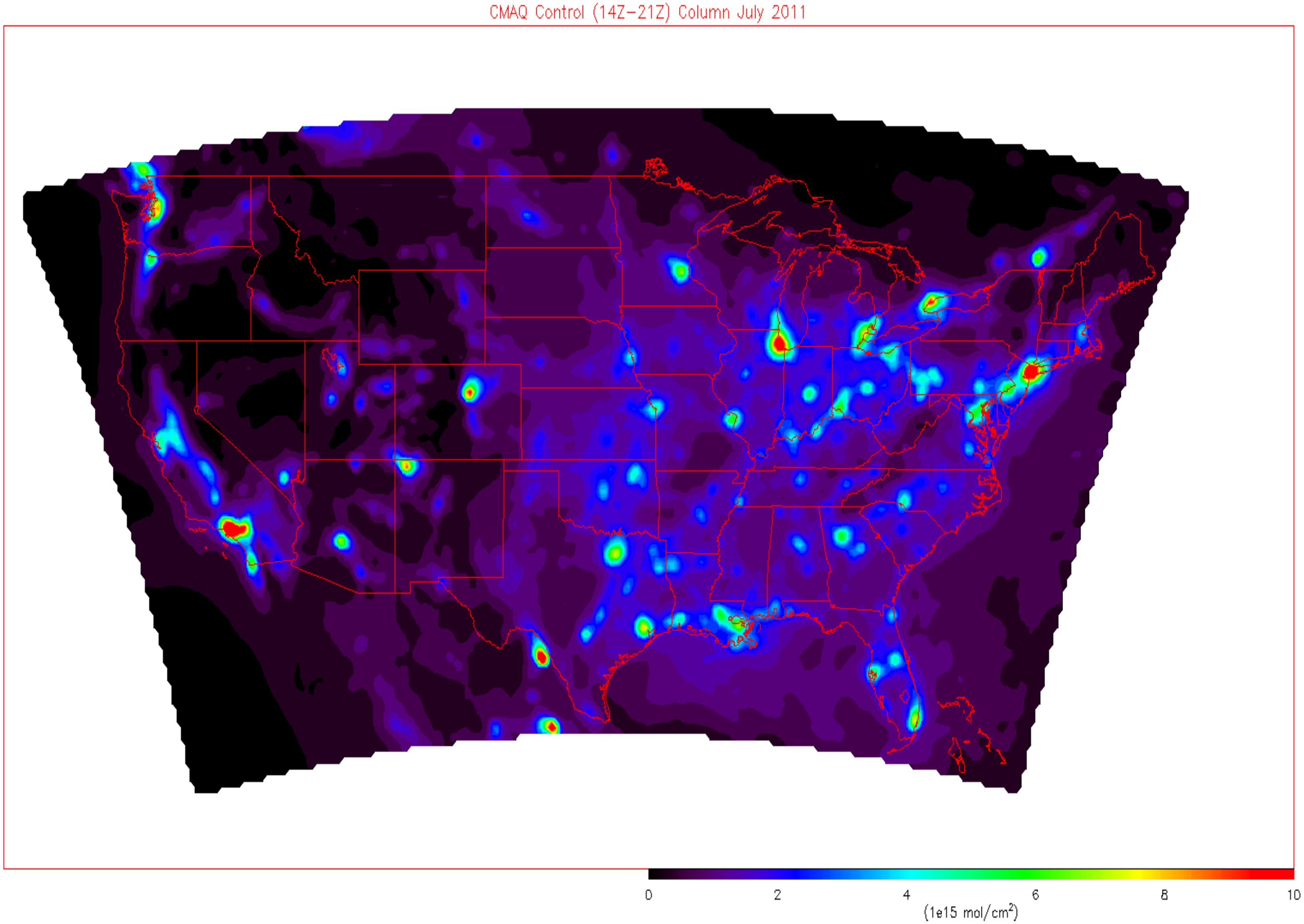
LMOS 2017 OMI NO2 Column was produced with the Giovanni online data system, developed and maintained by the NASA GES DISC

NAM-CMAQ Control Tropospheric NO2 Column
LMOS 2017 Mean

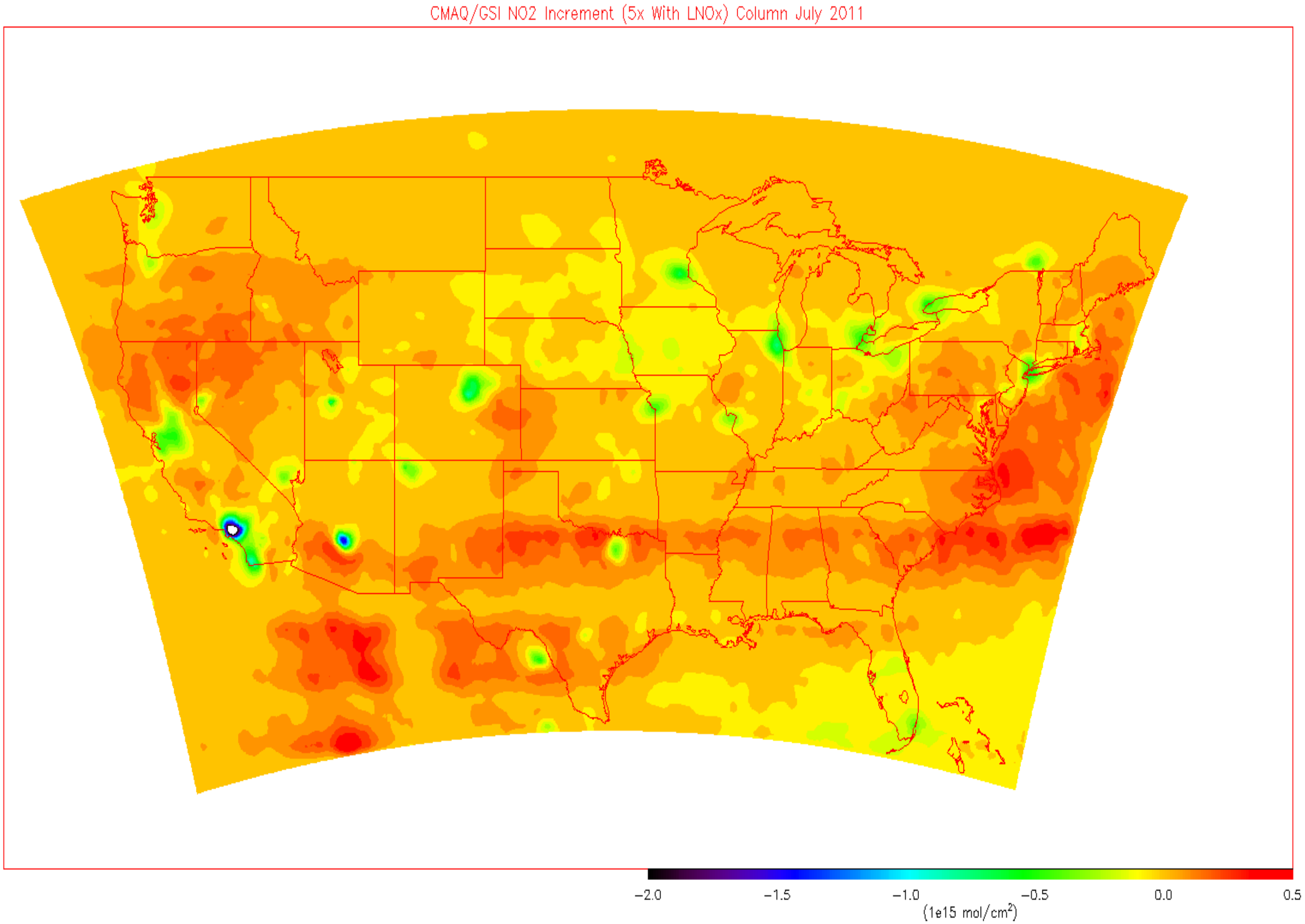


NAM-CMAQ is significantly higher than OMI in urban areas and point sources and lower than OMI in rural areas

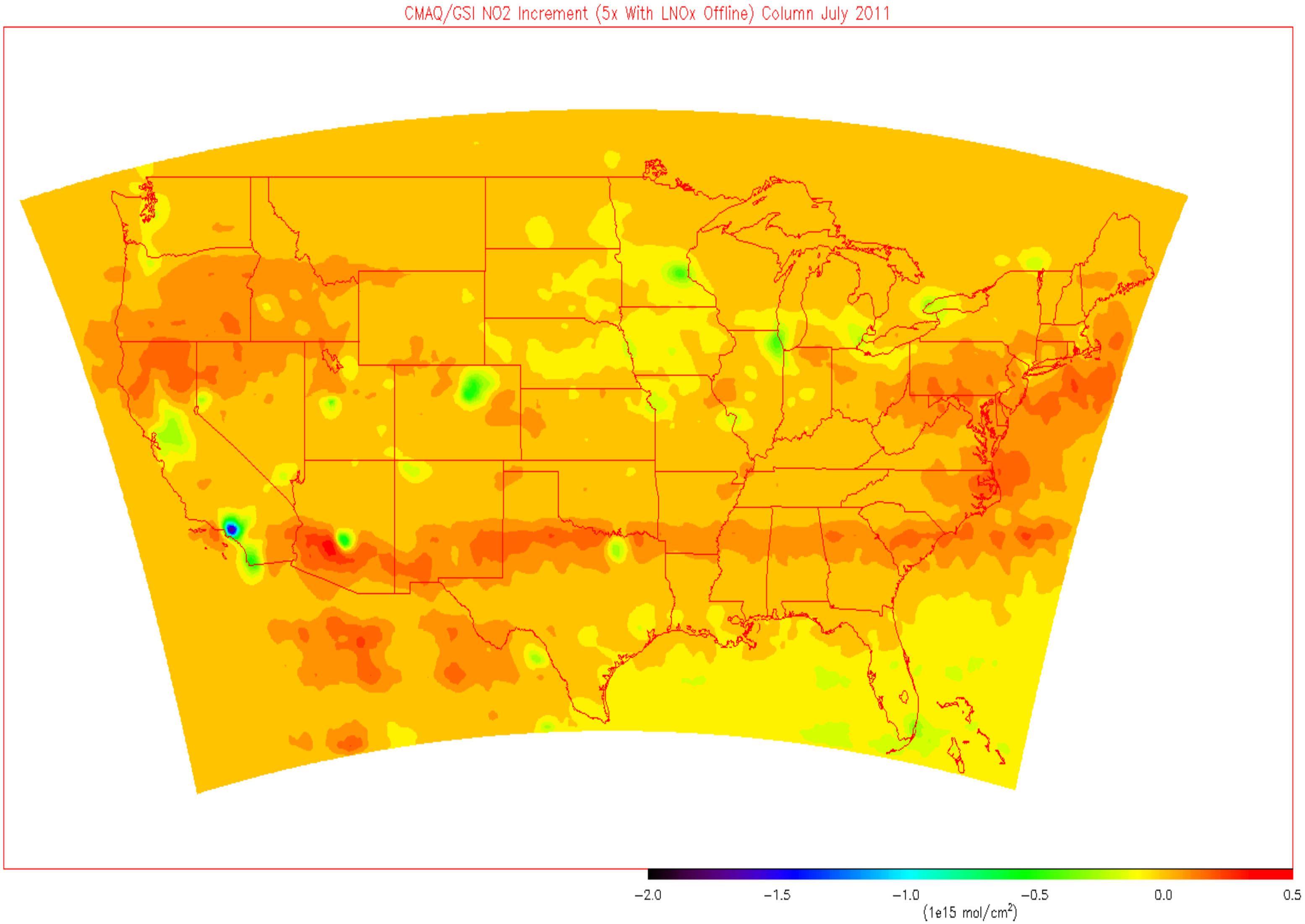
CMAQ Control Tropospheric NO2 Column
July 2011 Monthly Mean



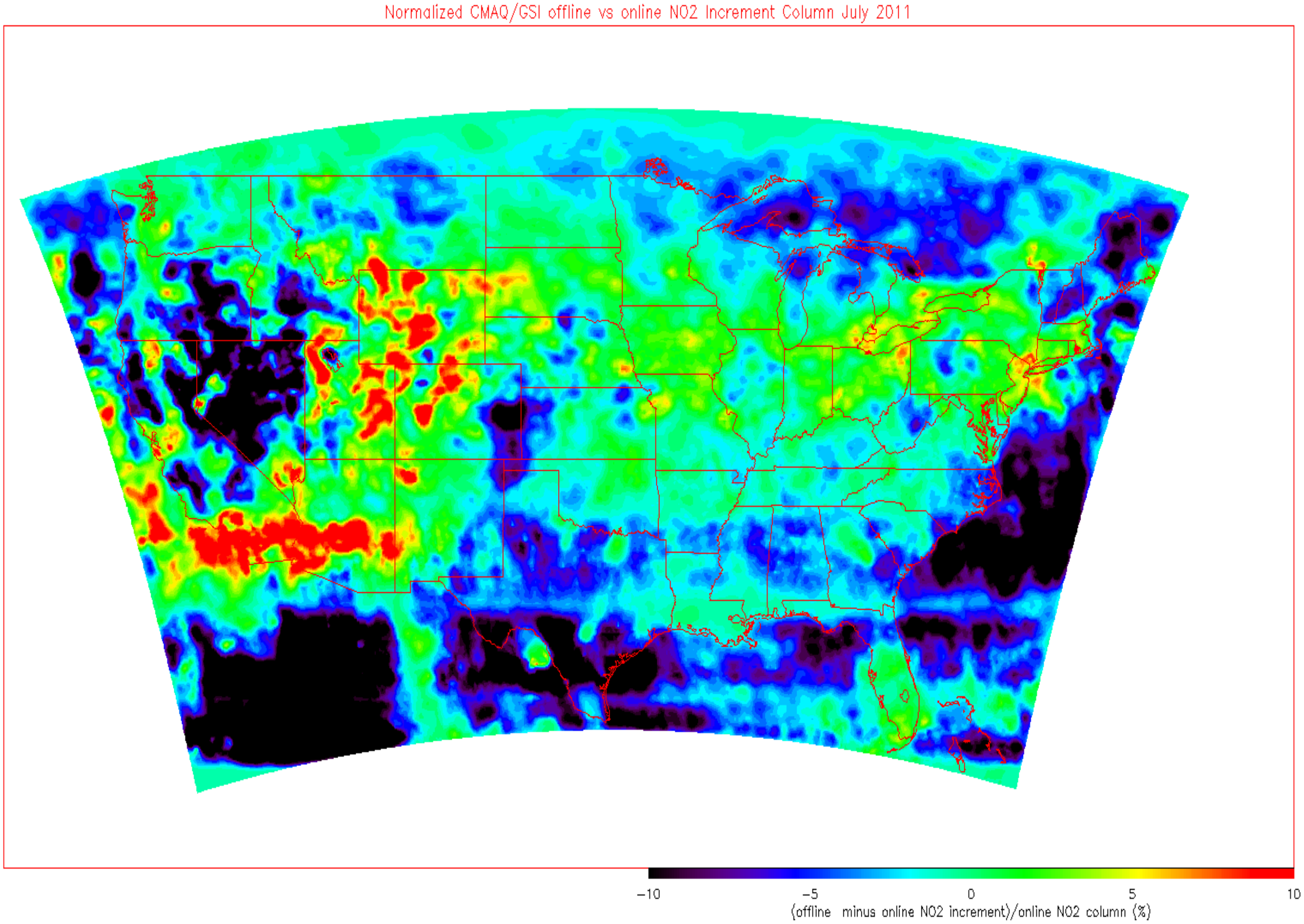
CMAQ Inline (full cycling) GSI NO2 DA
July 2011 Monthly Mean Analysis Increment



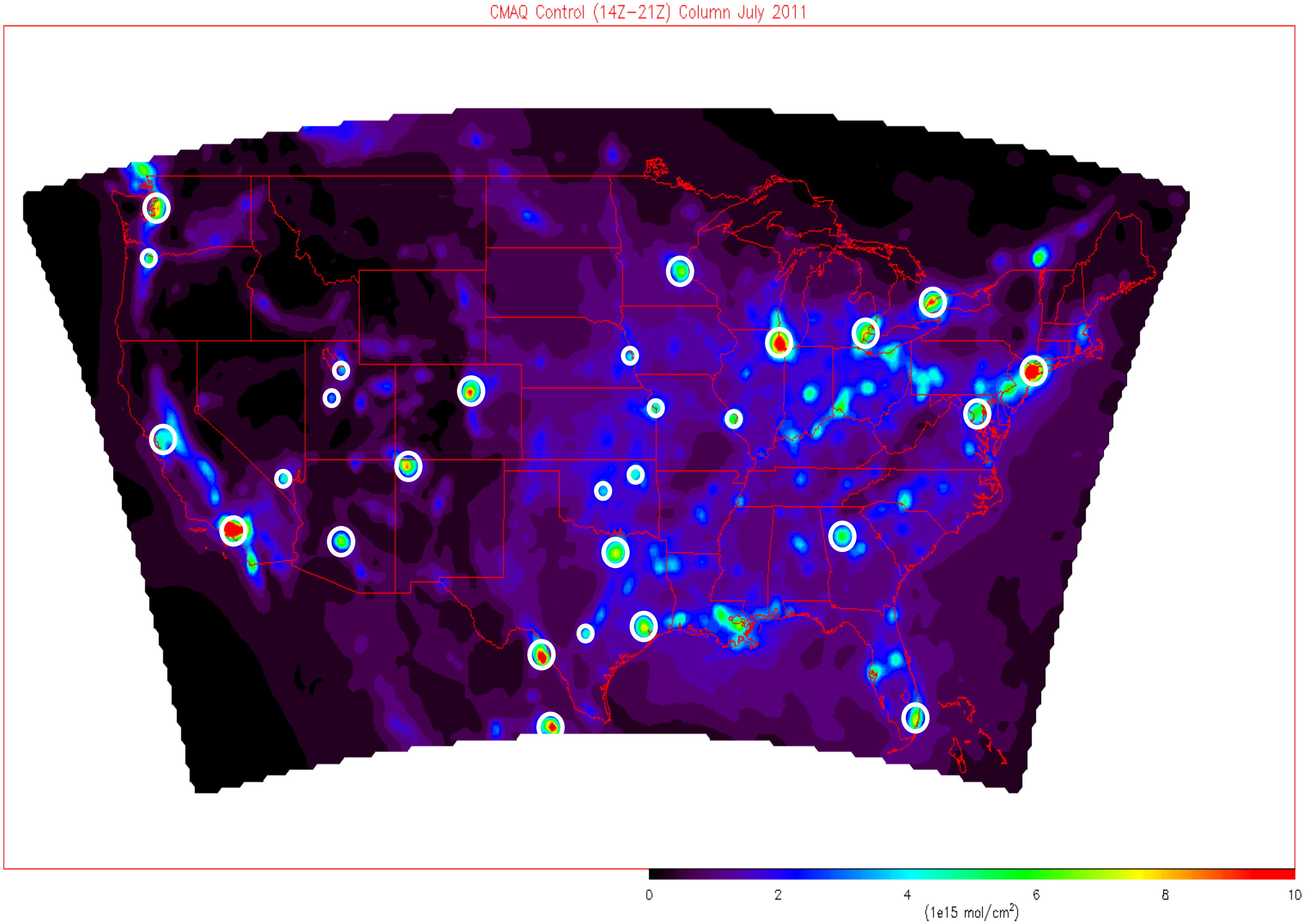
CMAQ Offline (single-cycle) GSI NO2 DA
July 2011 Monthly Mean Analysis Increment



CMAQ Offline minus Online GSI NO2 DA
July 2011 Normalized Monthly Mean Analysis Increment Difference



CMAQ Control Tropospheric NO2 Column
July 2011 Monthly Mean



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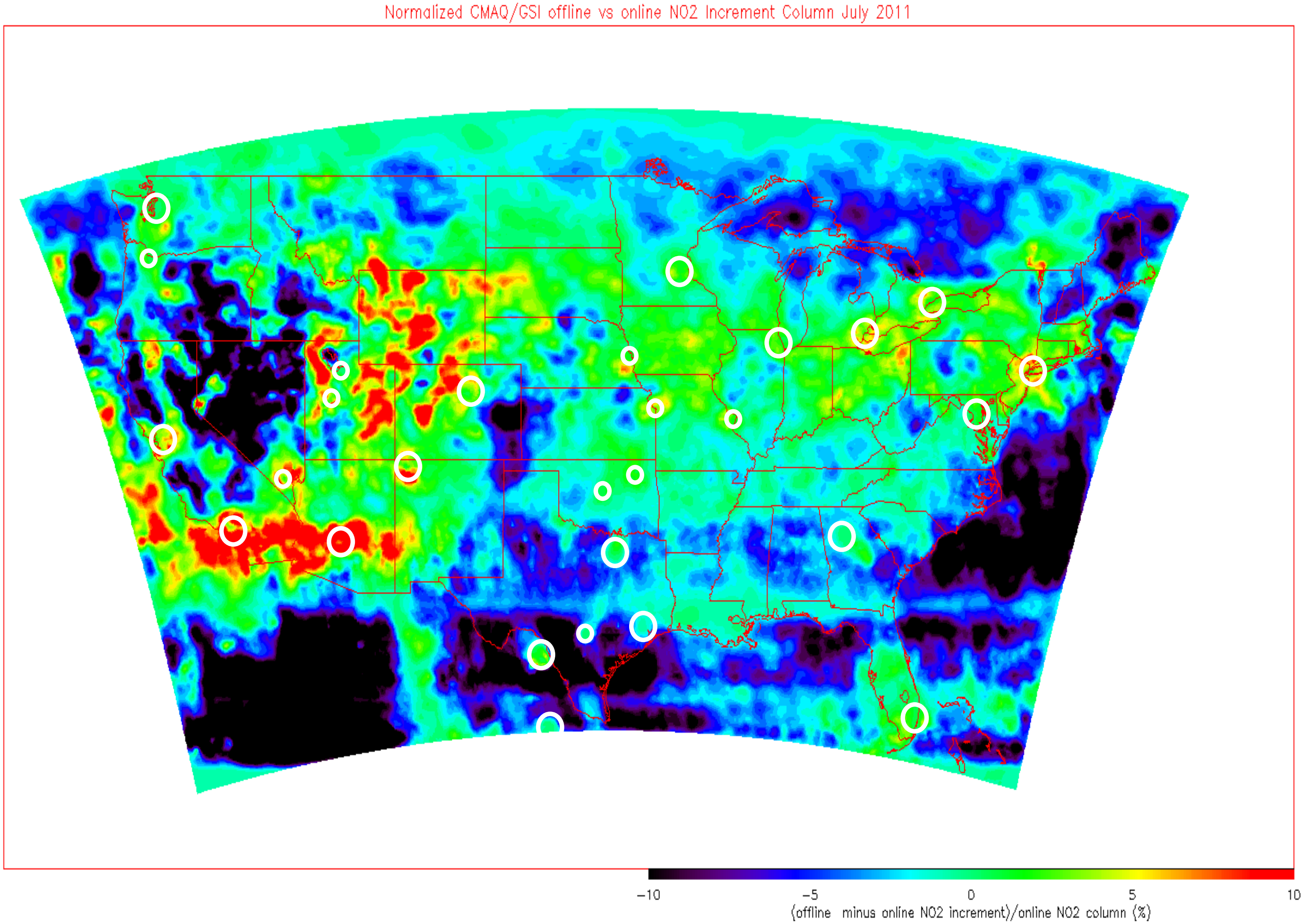

Normalized differences are less than 5% in most urban areas but can reach up to 10% just outside the urban core

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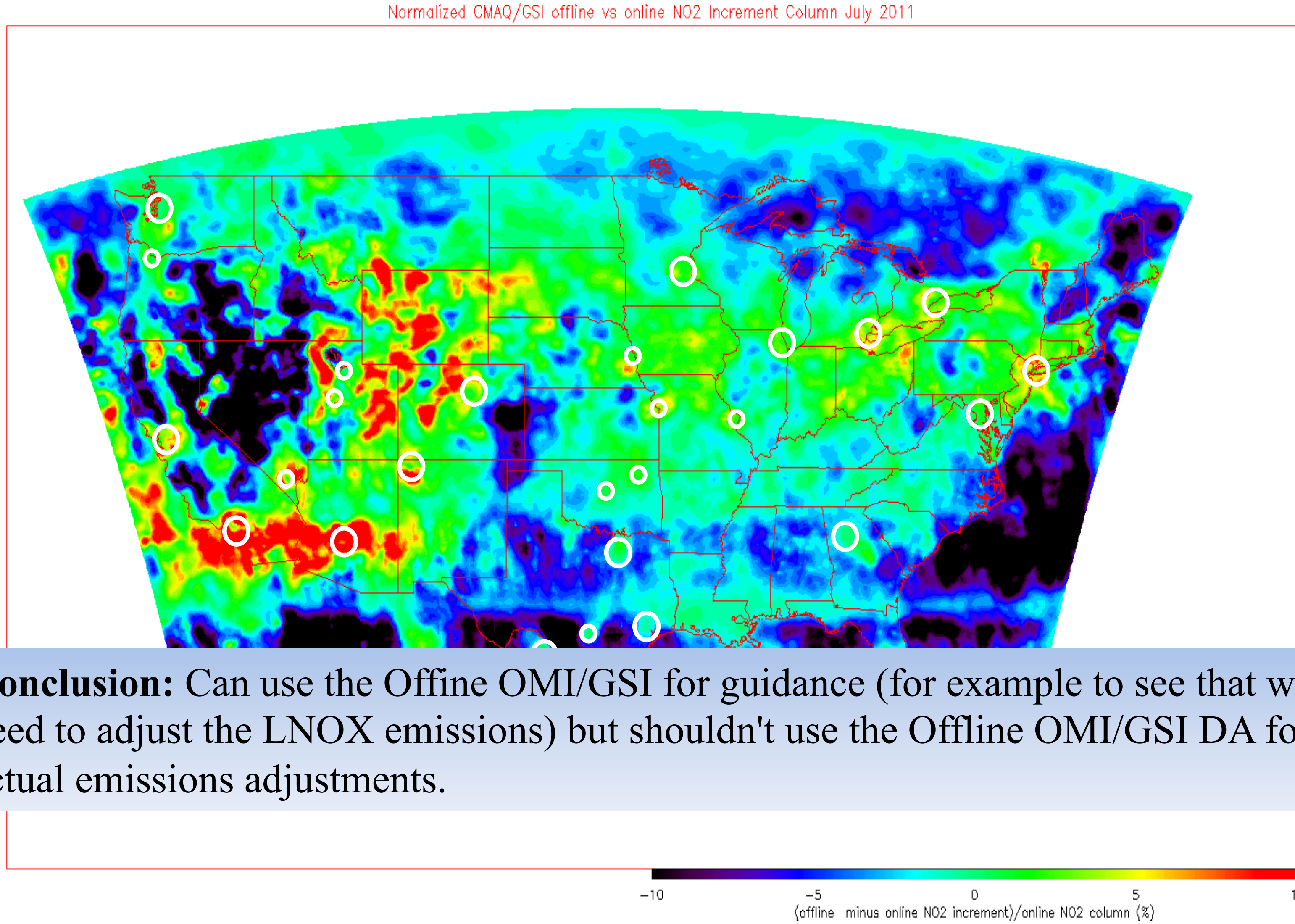

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