Use of OMI Data in Monitoring Air Quality Changes Resulting from NO_x Emission Regulations over the United States

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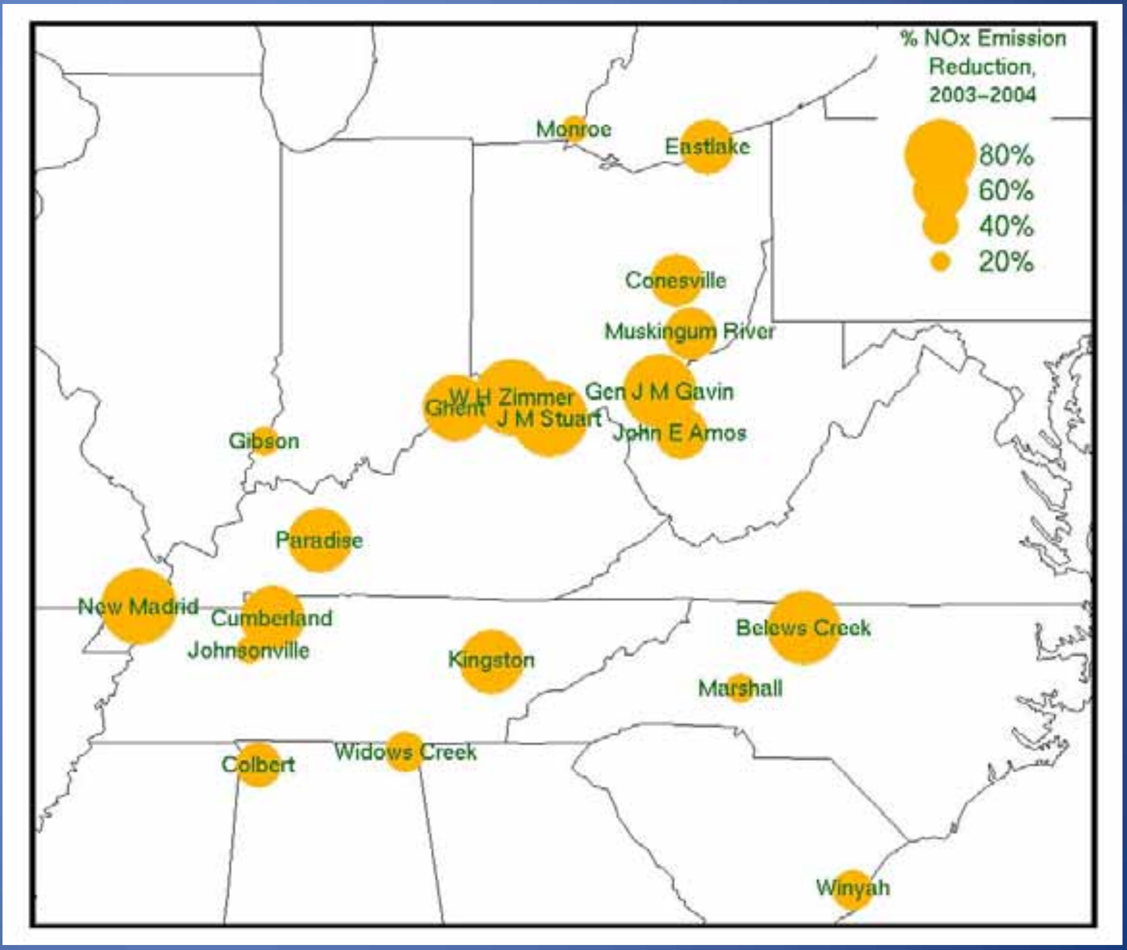
Outline

- US EPA emission regulatory programs for NO_x
- Air quality improvements through 2005
- Use of OMI tropospheric NO2 to examine air quality changes 2005 to 2008
- Implications for ozone production
- Attributing satellite-derived NO2 changes to clusters of power plants using US EPA Community Multiscale Air Quality (CMAQ) model
- Need for addition of lightning and aircraft NO emissions and improvement of soil NO emissions for CMAQ prior to any attribution or inverse modeling studies

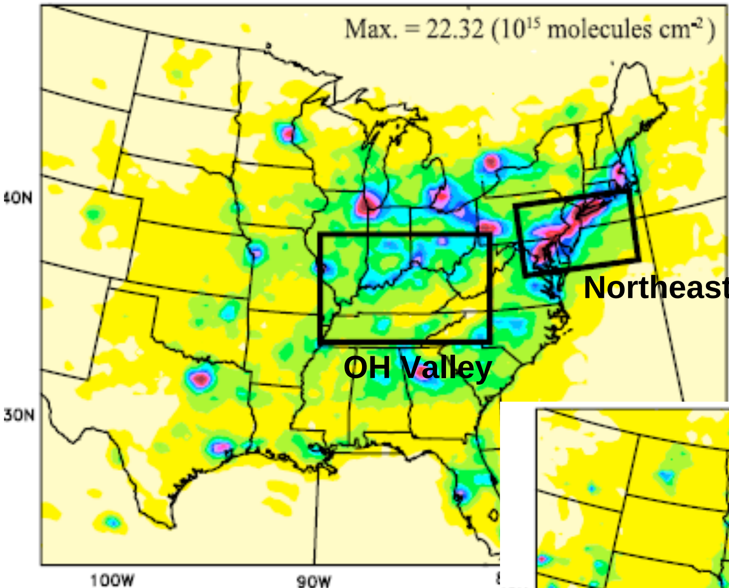
NO_x State Implementation Plan Call

- From 2002 – 2005, NO_x emission reductions from power plants in Midwestern United States (22% ↓)??
- Simultaneous gradual reduction in vehicle NO_x emissions (18% ↓)??
- **Goal:** Use satellite data to infer emission changes

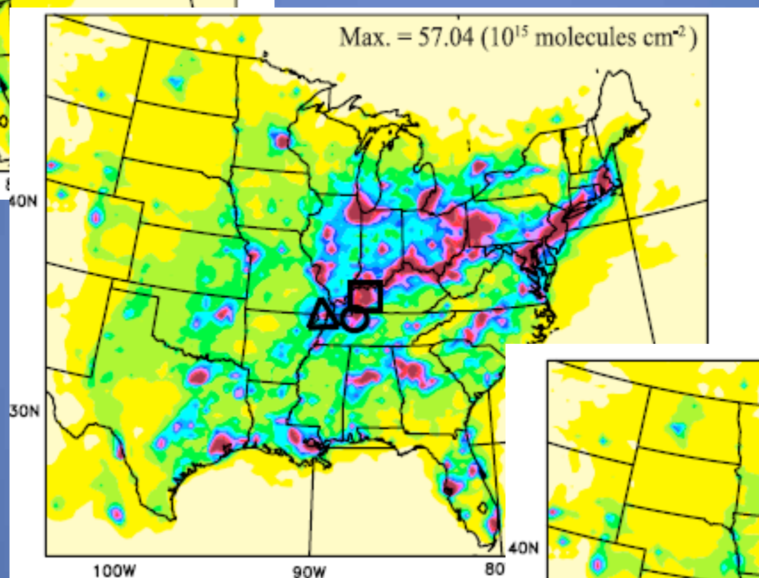


S.-W. Kim et al. (2006)

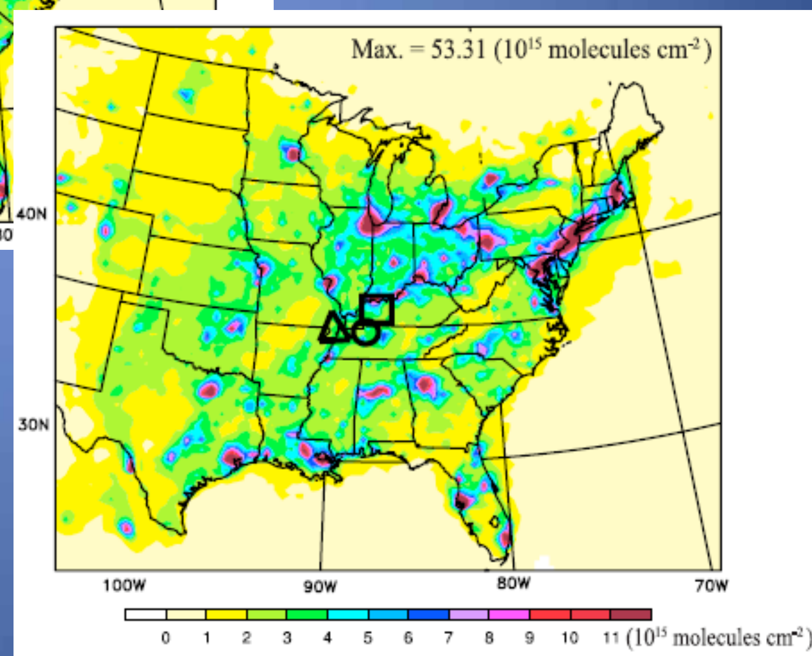
Summer 2004 model analysis



SCIAMACHY
Trop. NO2
Column



WRF-Chem with
NEI-99 emissions



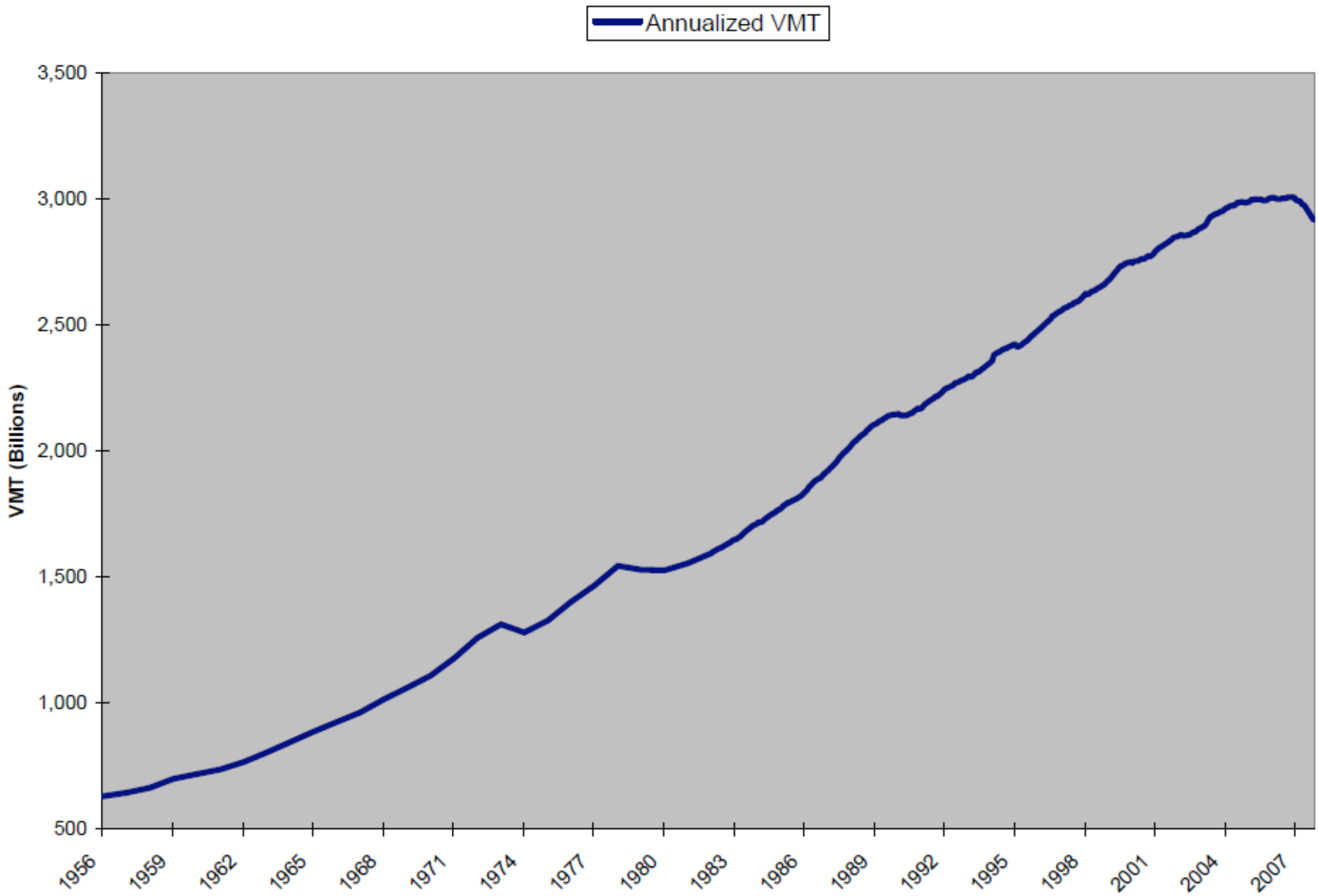
WRF-Chem with
CEMS adjusted
emissions

Region	% Change 1999-2005
OH Valley – Emiss.	-34%
Satellite	-38%
Northeast – Emiss.	-5%
Satellite	-11%

What has happened since 2005?

- OMI tropospheric NO2 data began in late 2004 – higher spatial resolution, complete global coverage.
- US EPA mandated power plant NO_x emission reductions under the 1998 NO_x State Implementation Plan Call have evolved into what is now called the "NO_x Budget Trading Program". Results in further summertime power plant emission reductions over the regulated region (19 eastern states) as a whole, but trading program allow flexibility concerning the magnitude of reduction at specific facilities. Over 2500 large combustion units affected.
- Clean Air Interstate Rule (CAIR) – would have resulted in further reductions (28 states), but rule thrown out by courts; recently reinstated. Some electric utilities reduced emissions regardless.
- Tier II Tailpipe NO_x Emission Standards – 5% reduction in emissions per year for new vehicles over 2002 to 2010. Increasing Vehicle Miles Traveled largely negated the reductions until 2008.

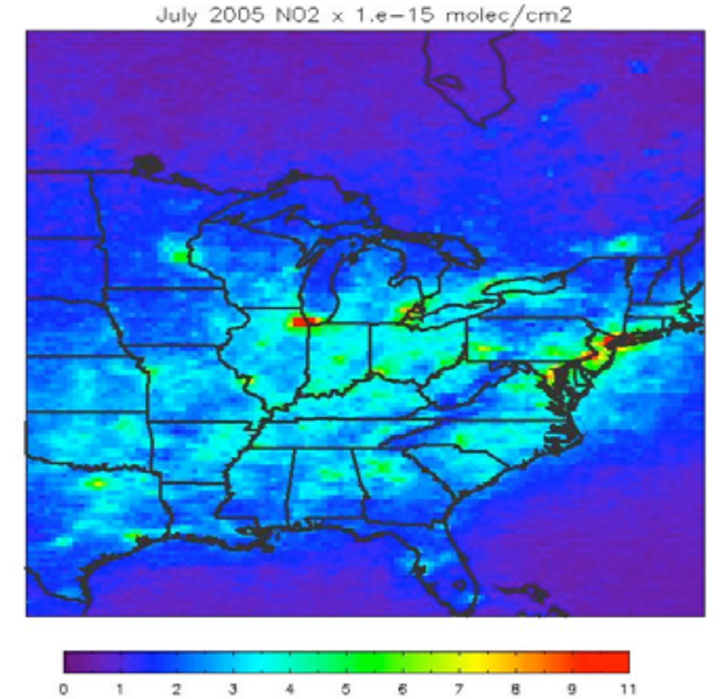
Figure 1a. U.S. Vehicle Miles Traveled, Annualized, December 1956-September 2008

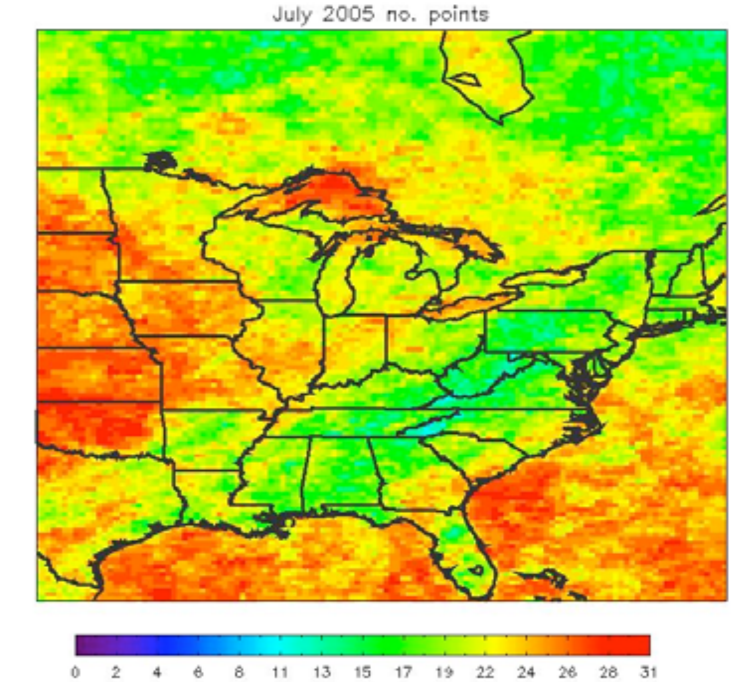


Source: 1956–1982: Highway Statistics, Table VM-201; 1983–September, 2008: Traffic Volume Trends

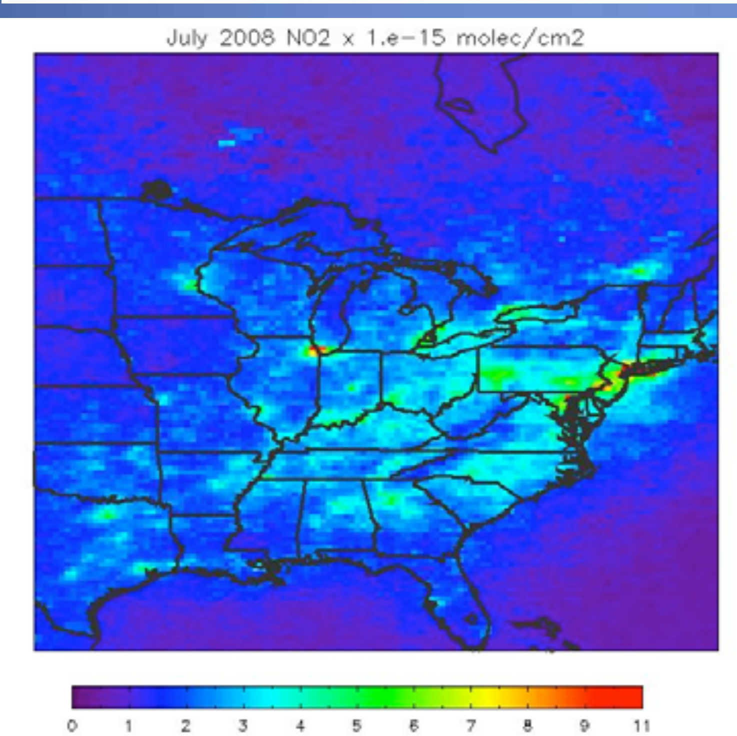
OMI NO2

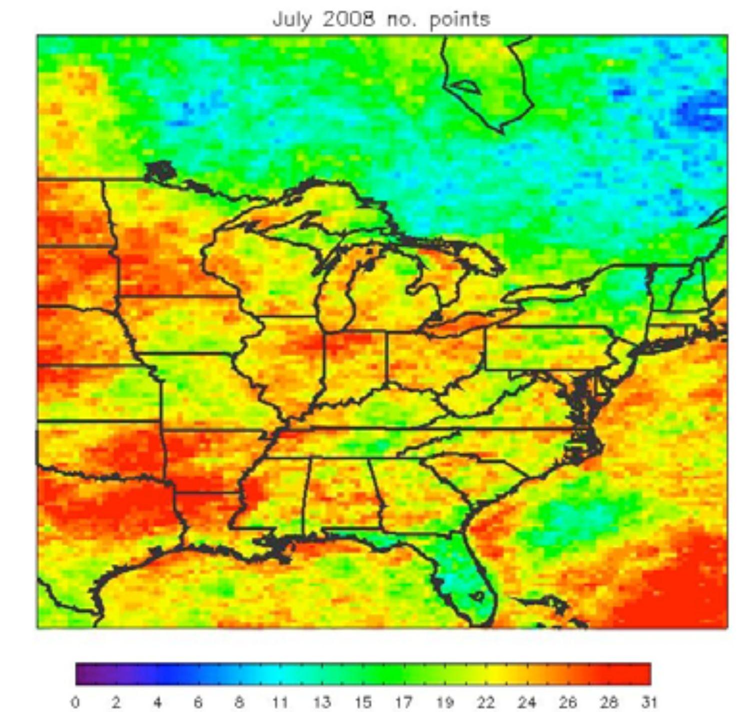
July 2005



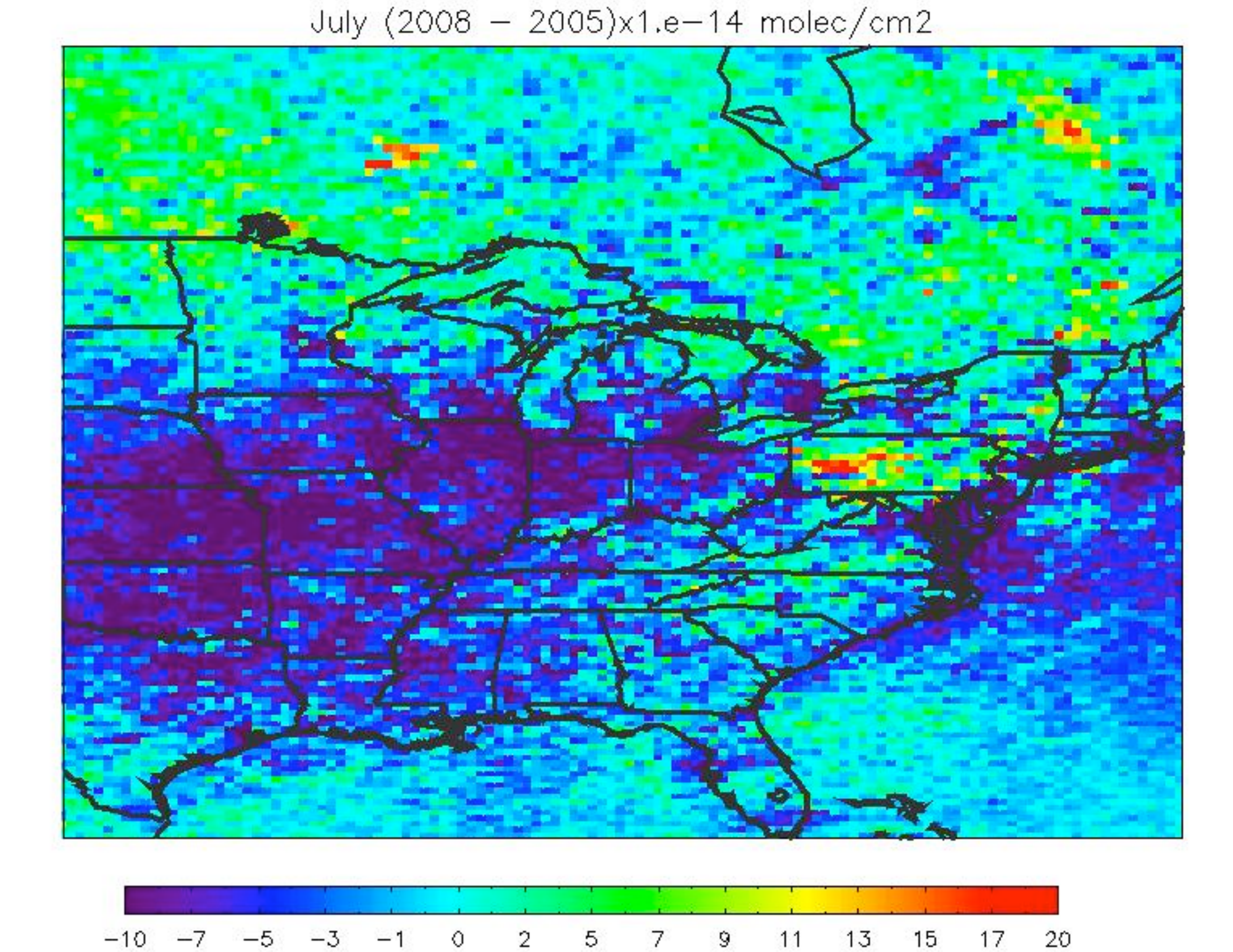


July 2008

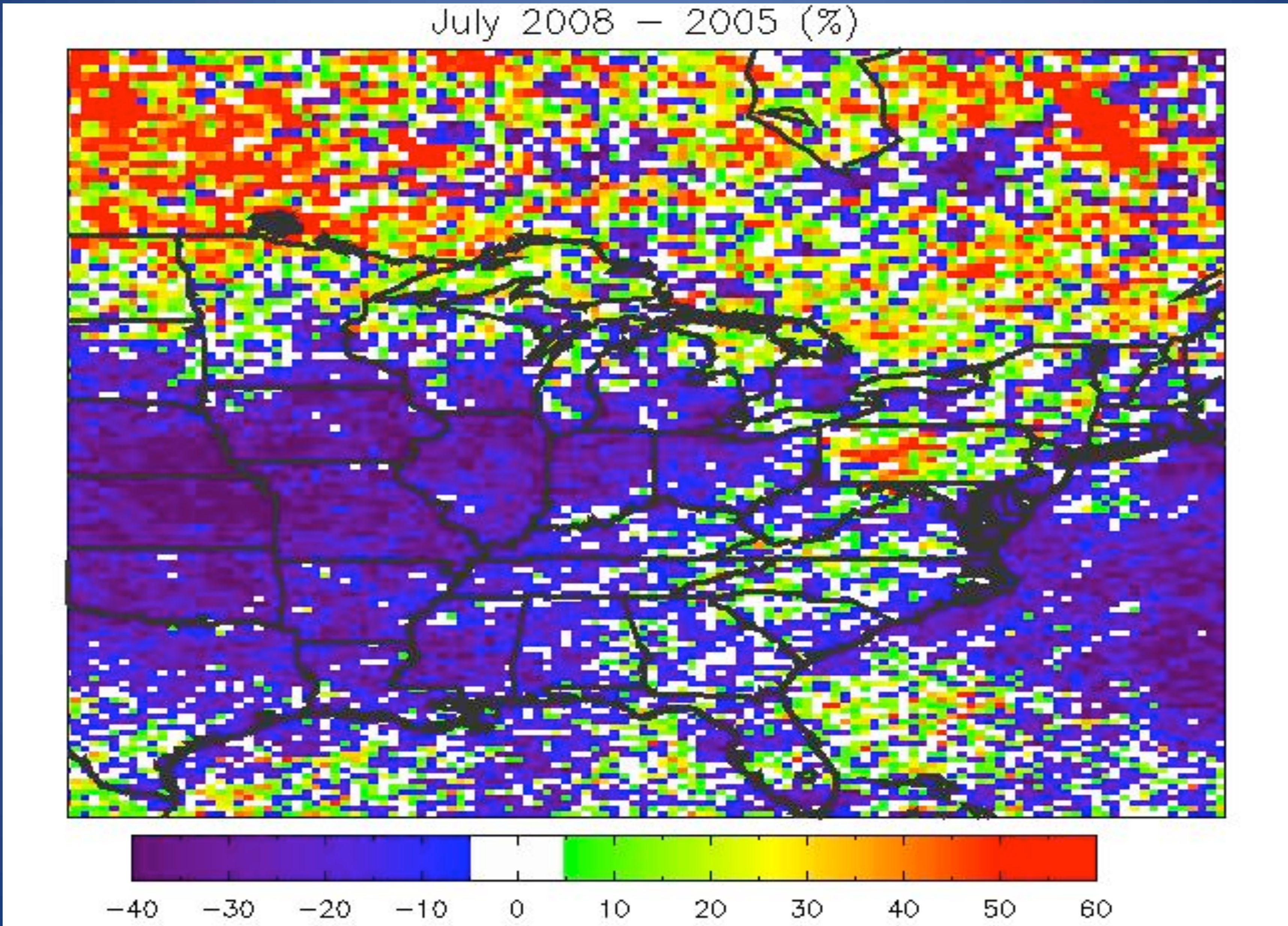




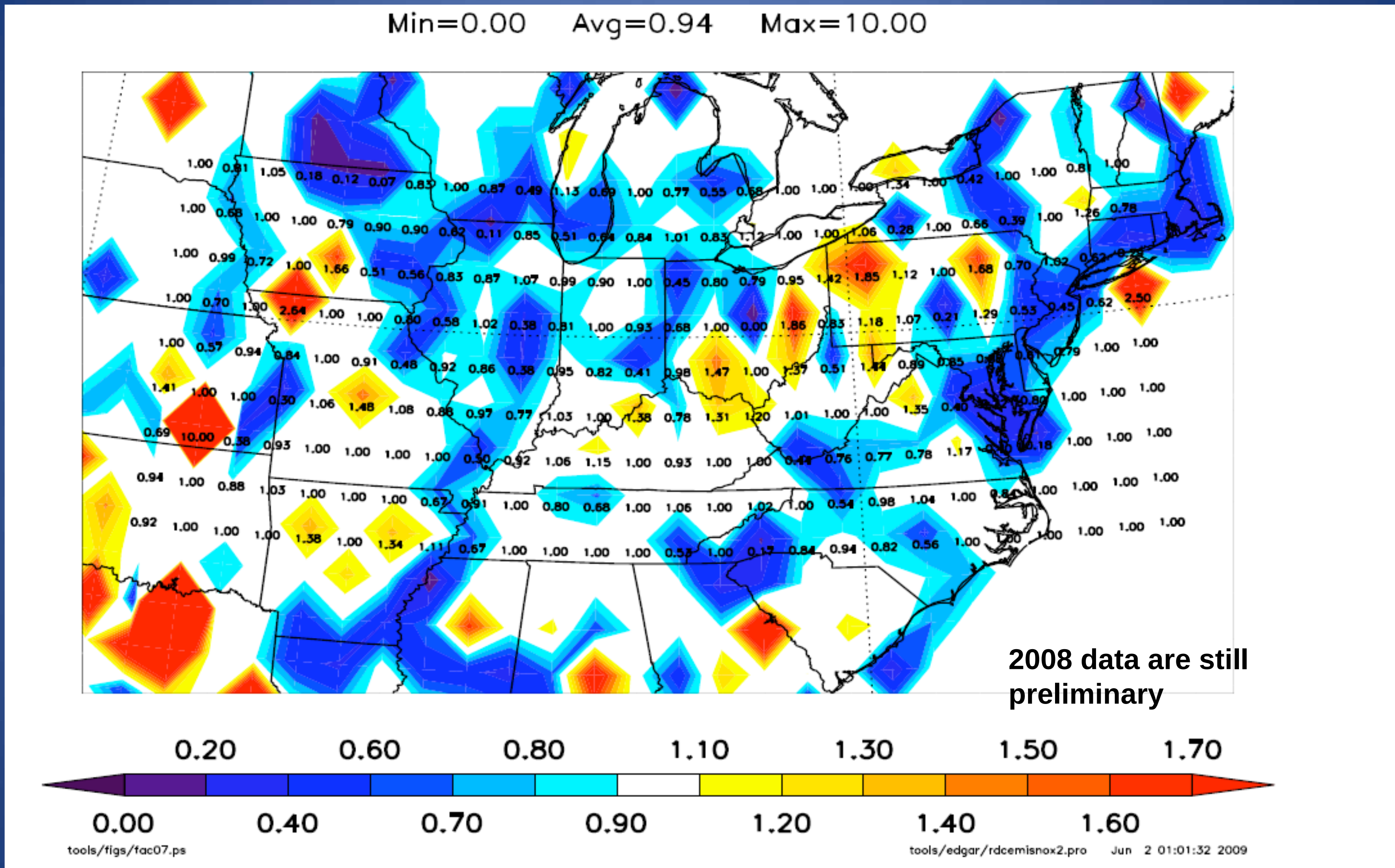
July – OMI NO2 Absolute Difference



July Trend

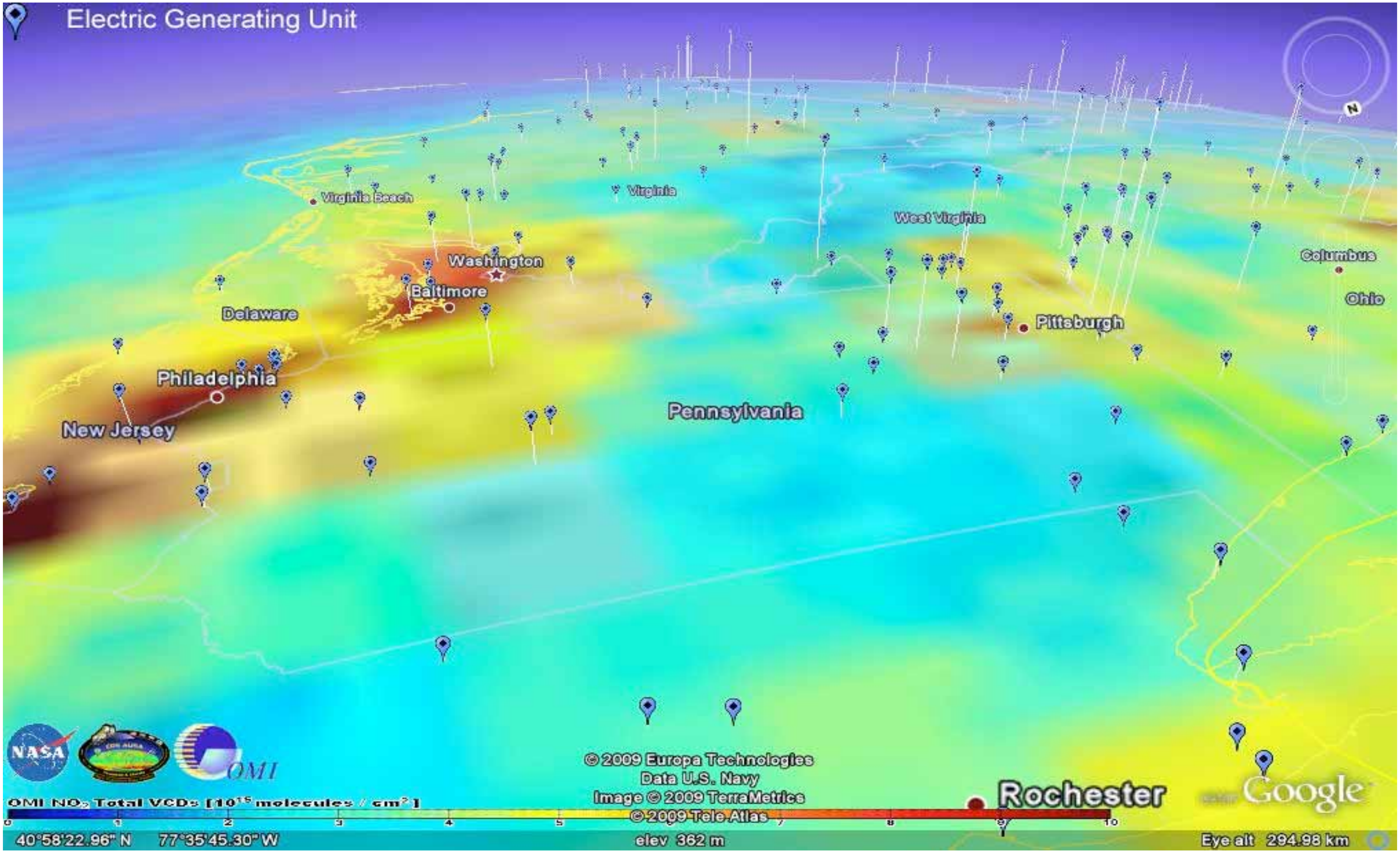


Continuous Emission Monitoring System – Power Plants

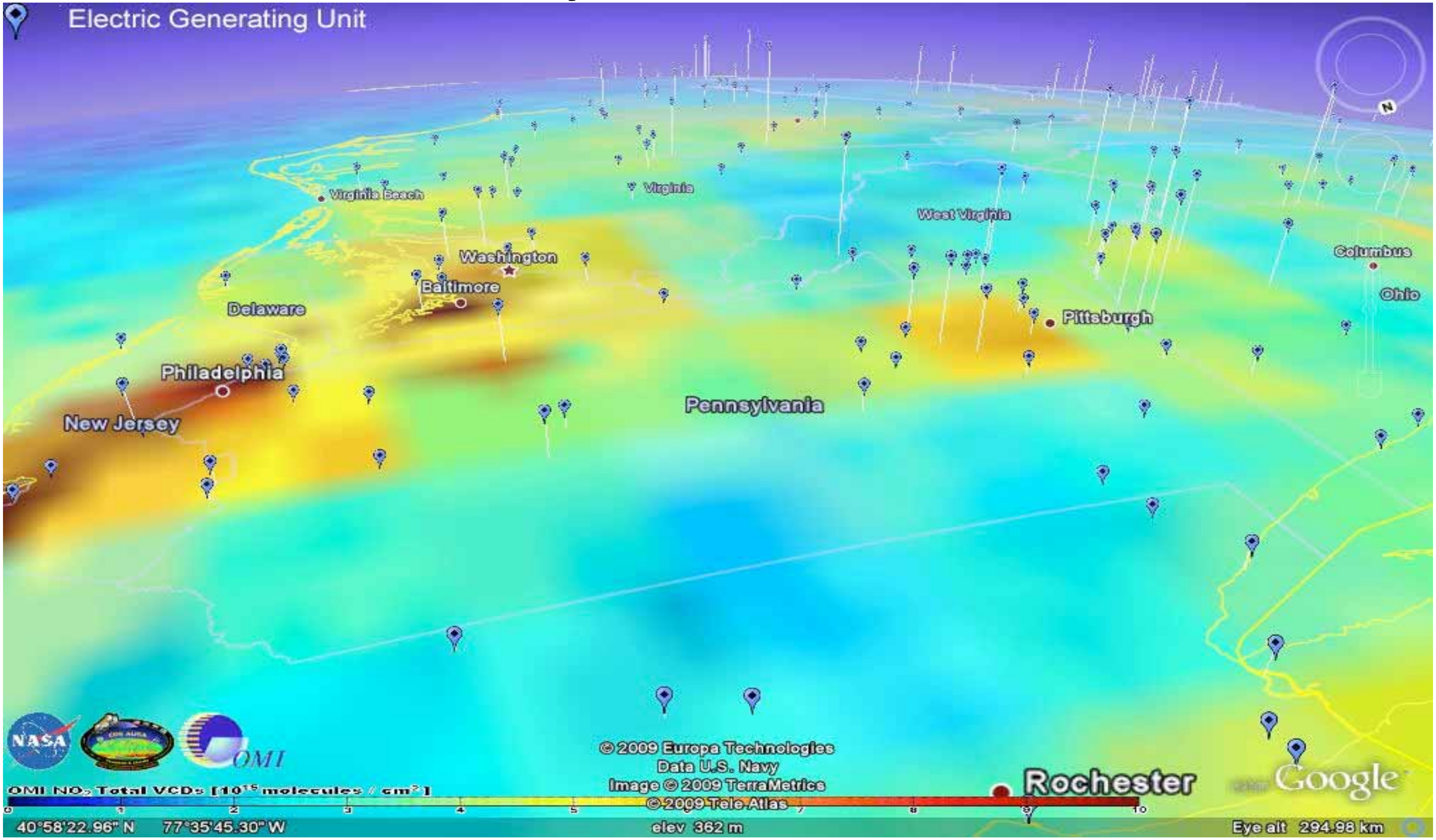


July 2008/July 2005

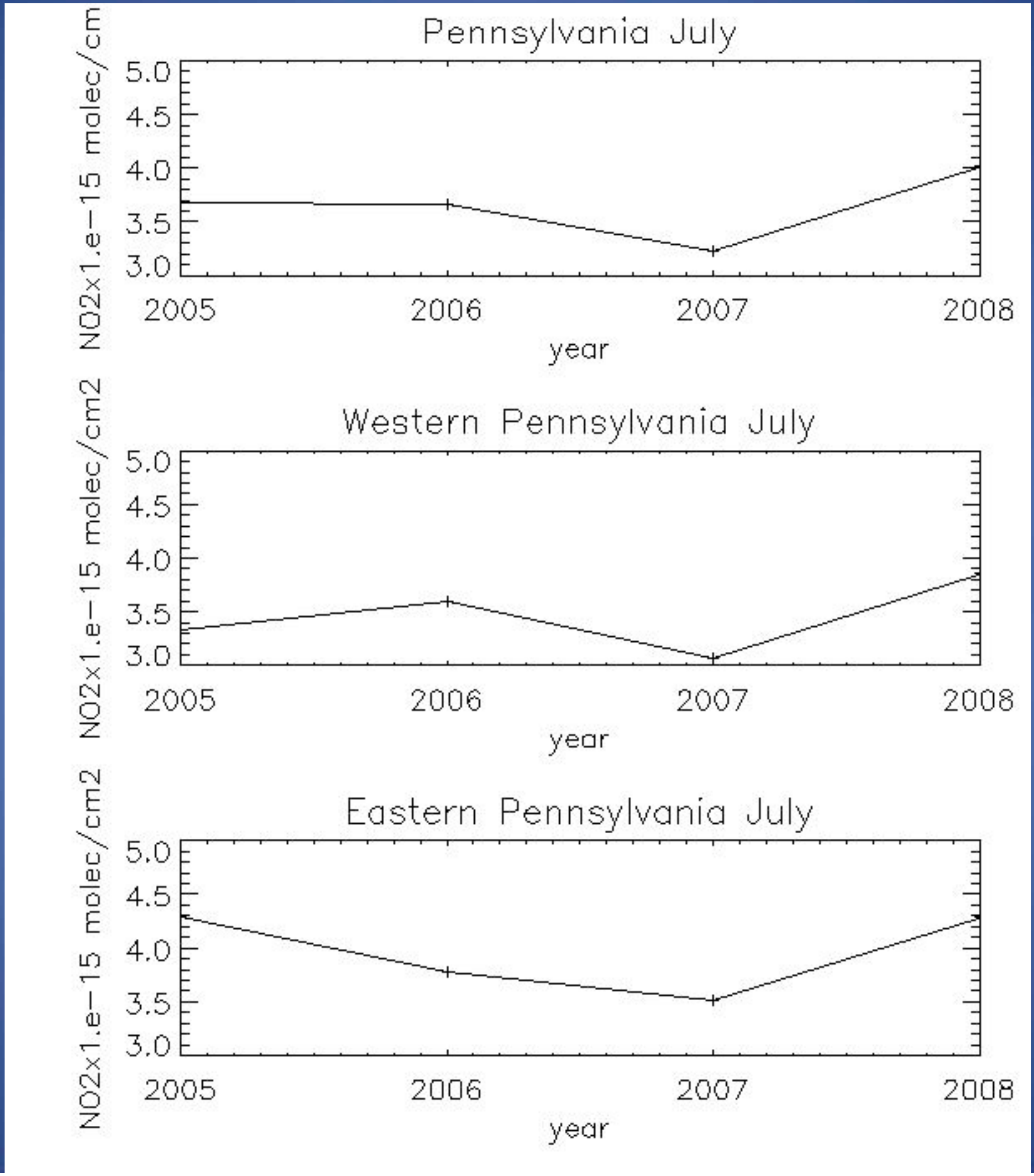
July 2005 NO2



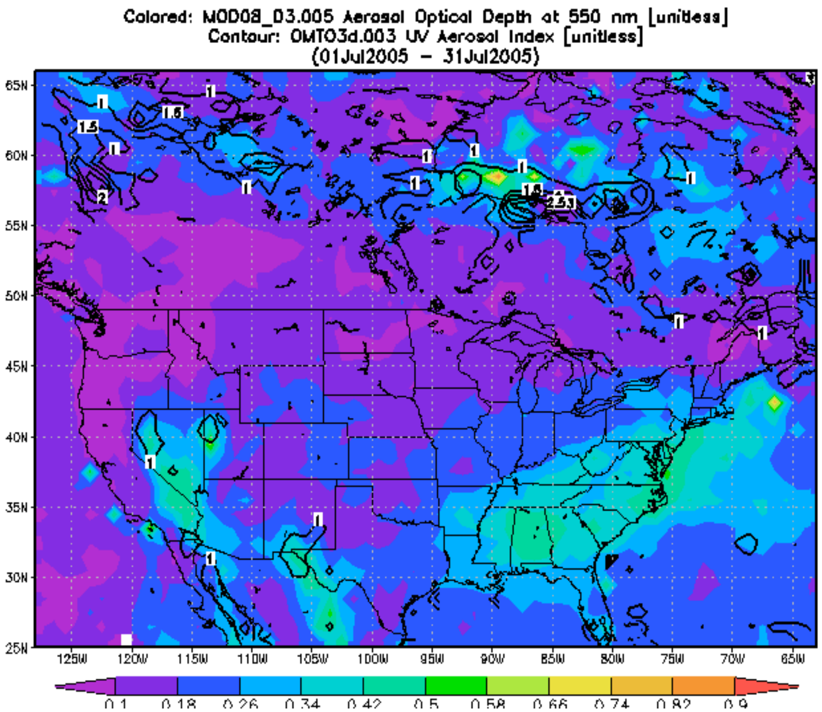
July 2008 NO2



OMI NO2 Regional Trends

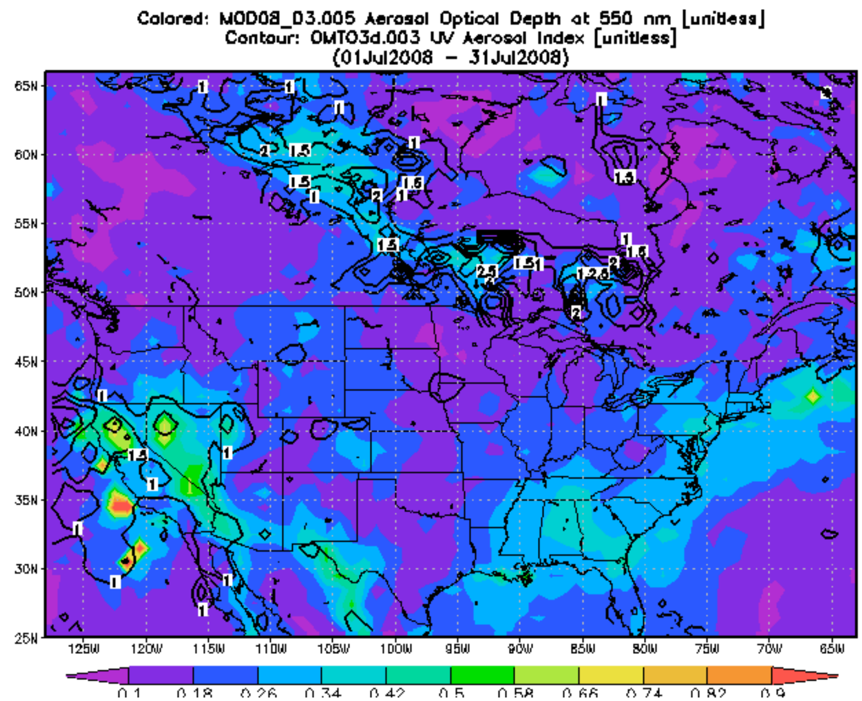


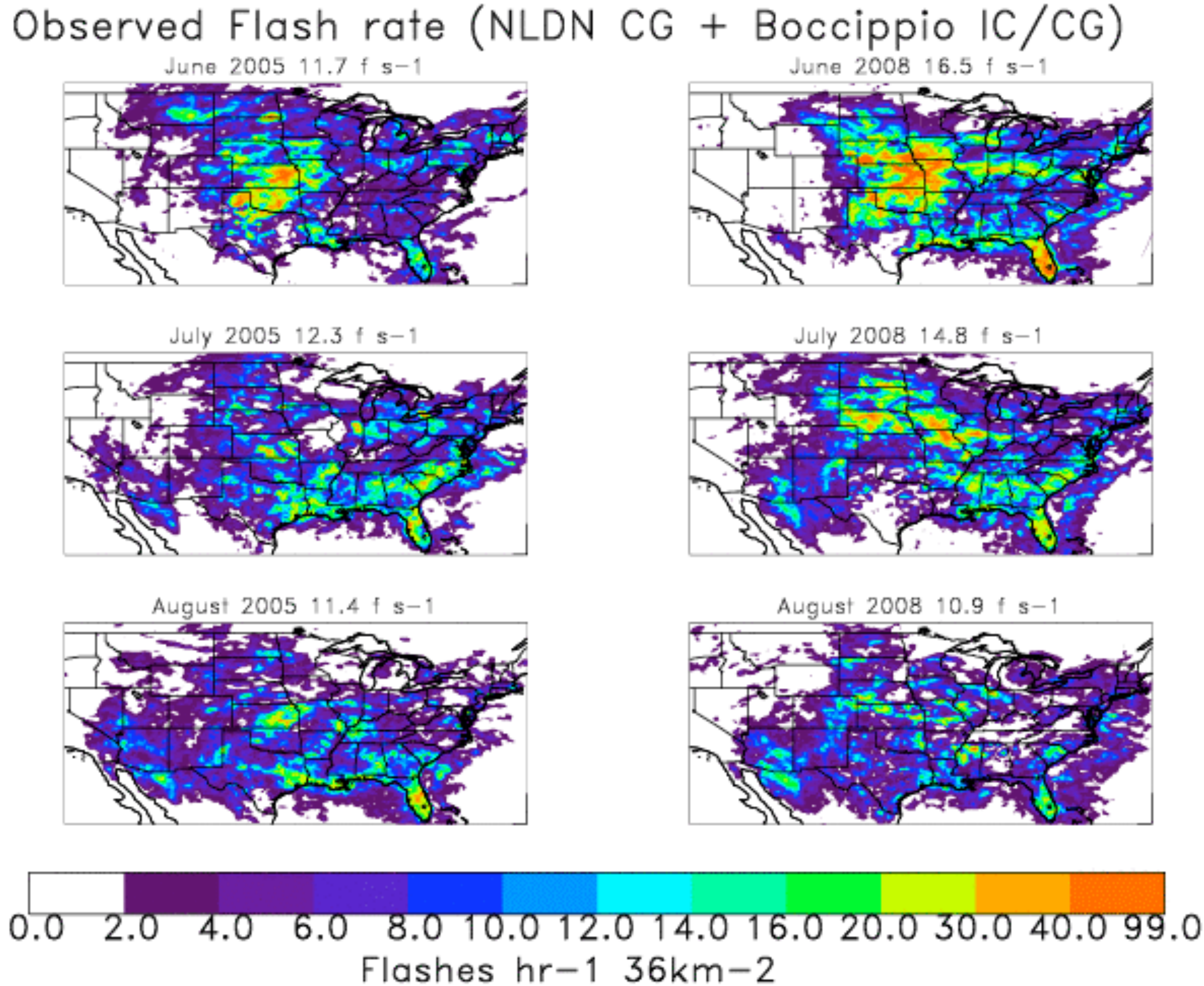
MODIS AOD (color scale) and OMI AI (black contour lines



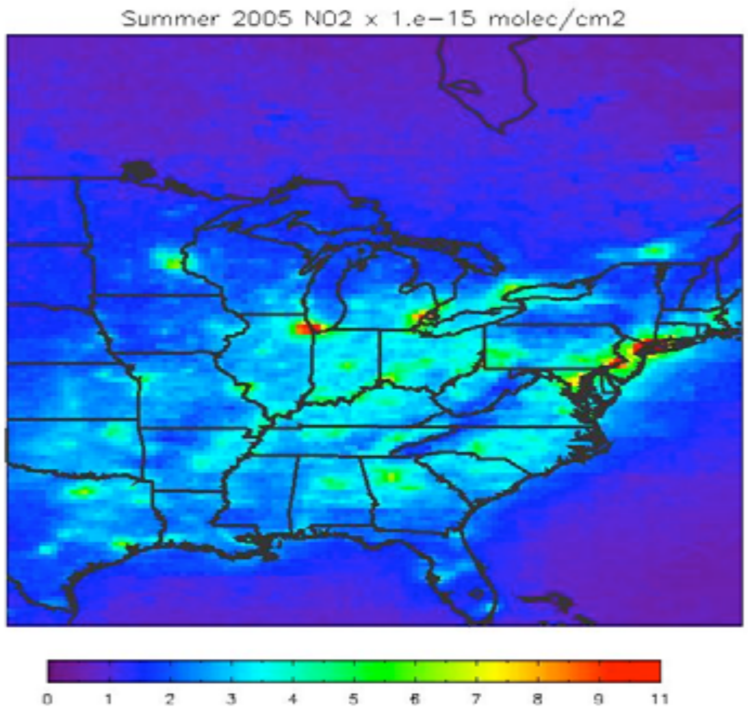
July 2005

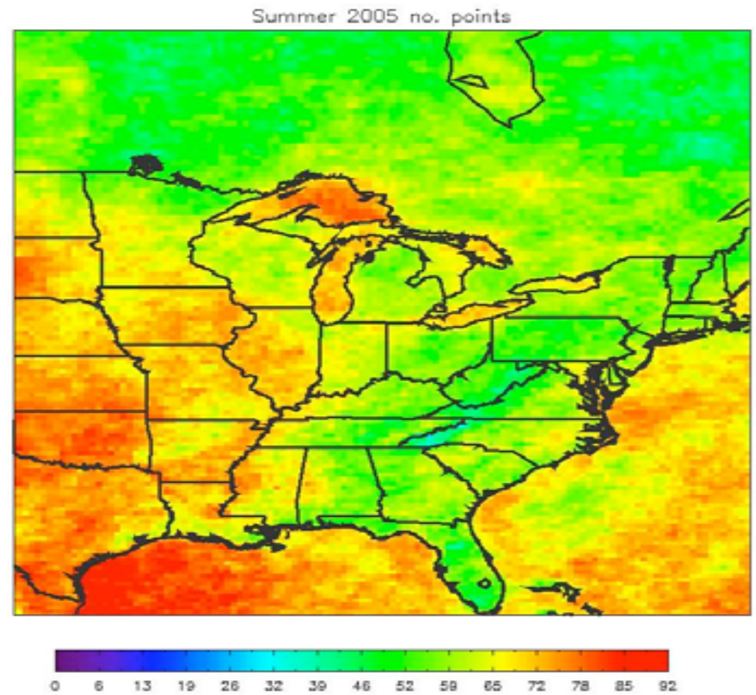
July 2008



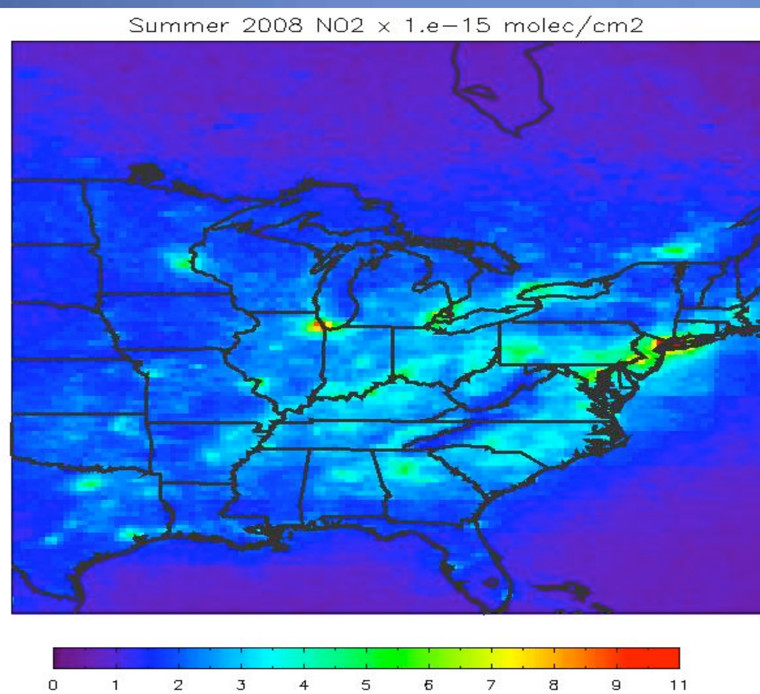

Observed Flash rate (NLDN CG + Boccippio IC/CG)
June 2005 11.7 f s−1
June 2008 16.5 f s−1
July 2005 12.3 f s−1
July 2008 14.8 f s−1
August 2005 11.4 f s−1
August 2008 10.9 f s−1
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0 16.0 20.0 30.0 40.0 99.0
Flashes hr−1 36km−2

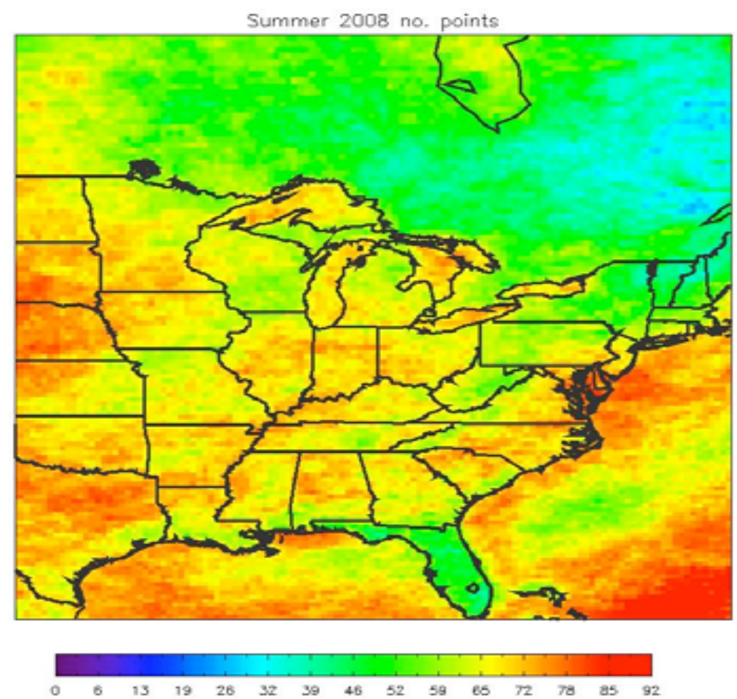
Summer 2005



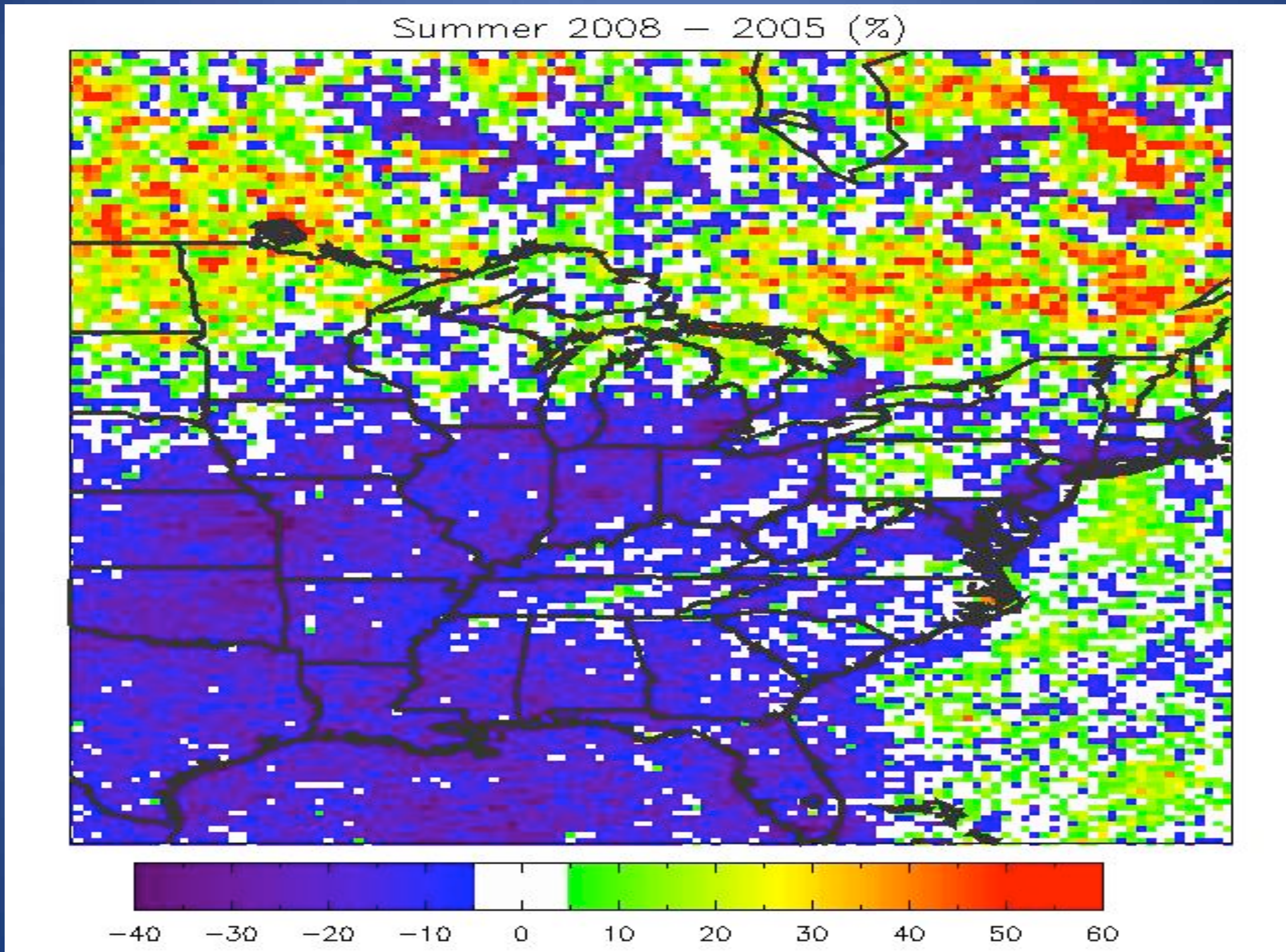


Summer 2008

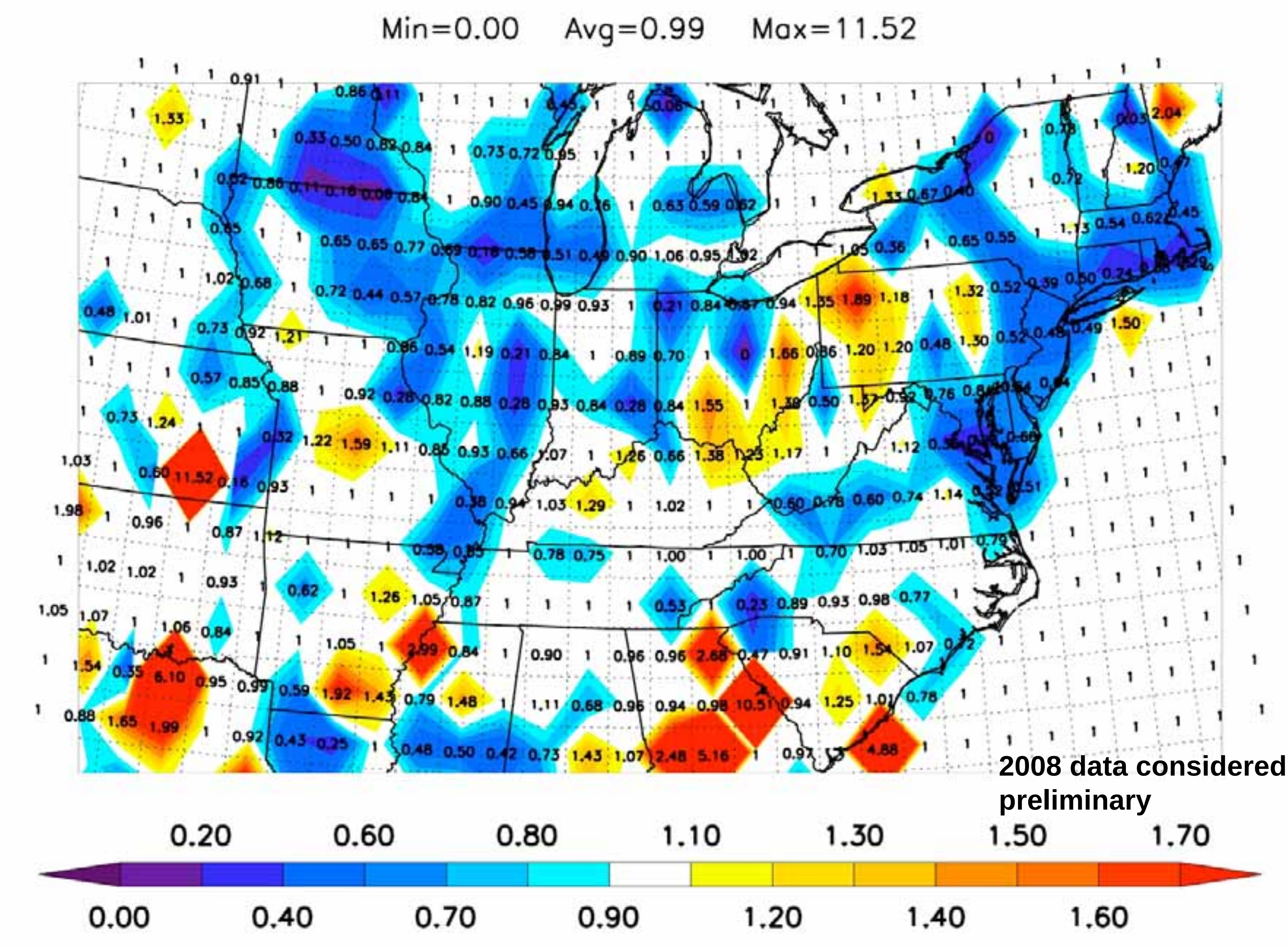




Summer Trends - US

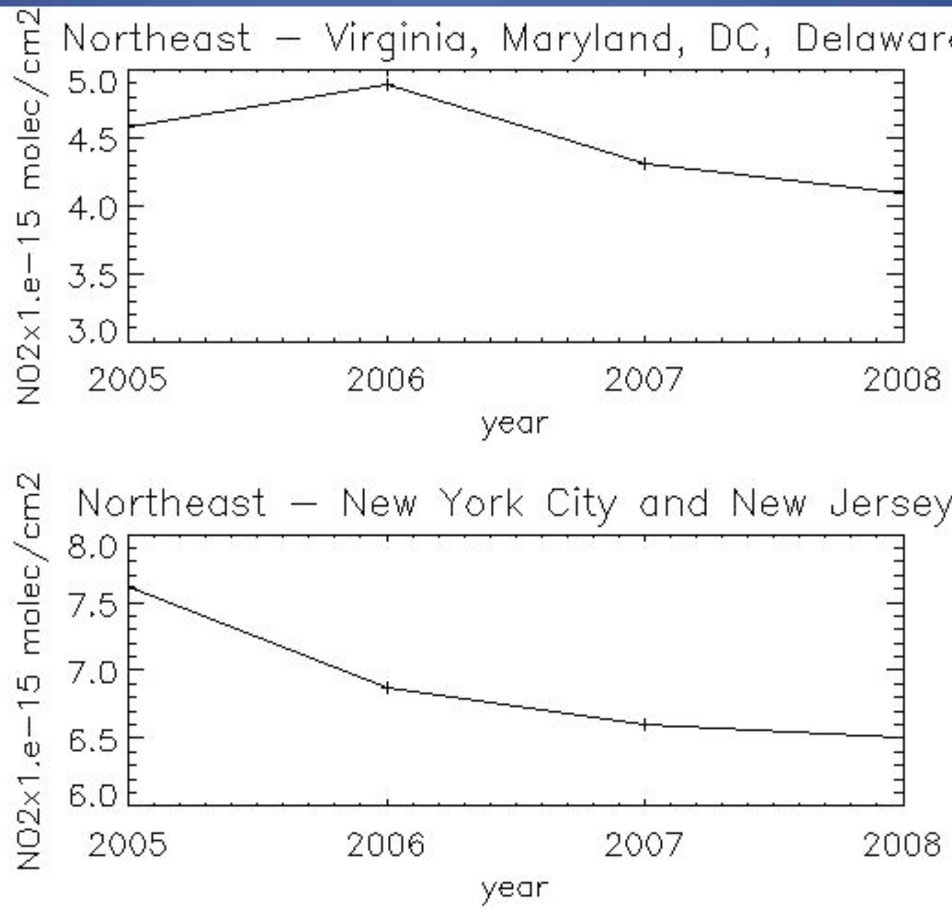


Continuous Emission Monitoring System Data

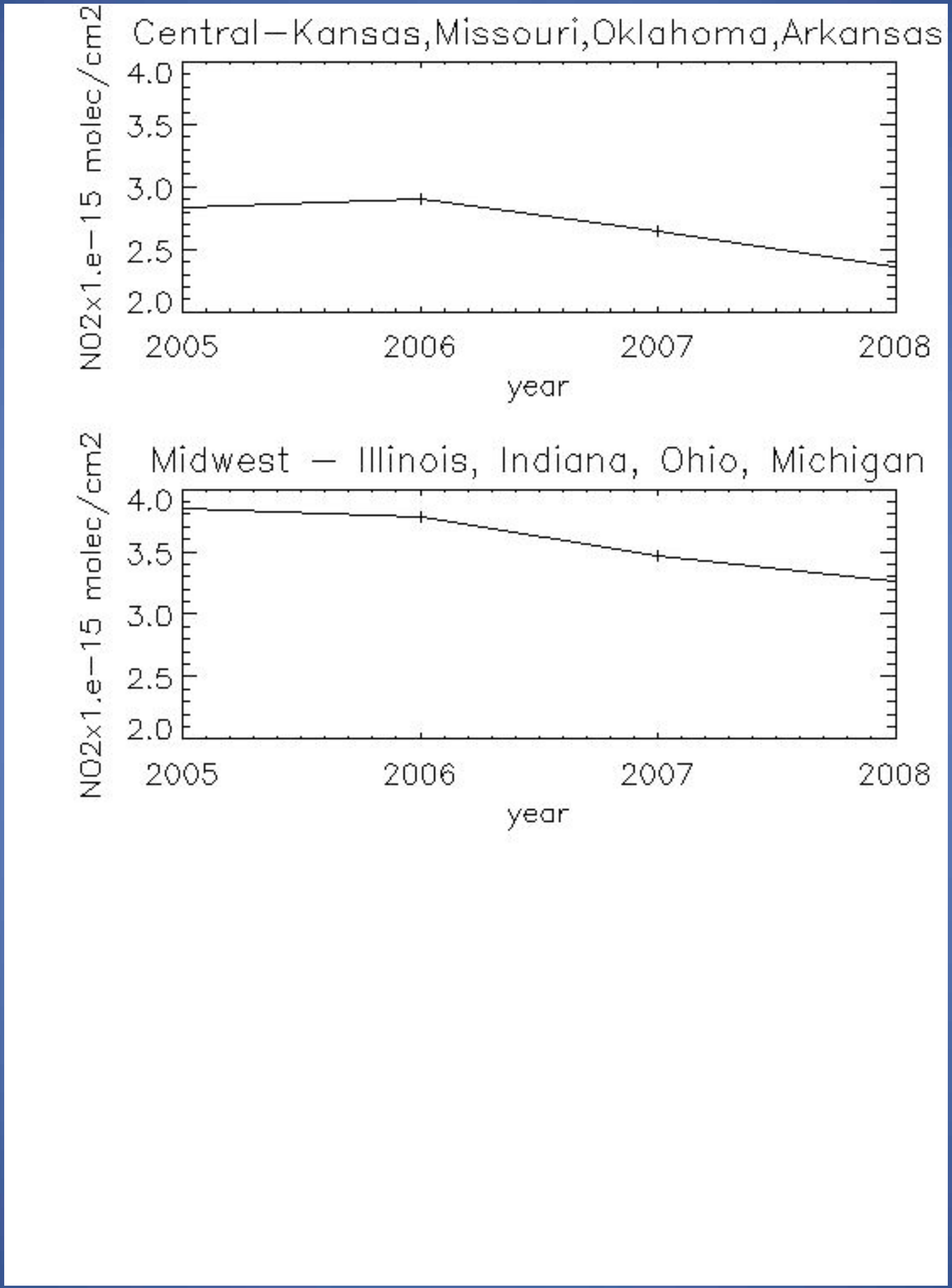


Summer 2008/Summer 2005

OMI NO2 Trend



OMI NO2 Trend



$HCHO/NO_2$: *Air Quality Indicator*

$NO_x + VOCs \longrightarrow Ozone$

Which reactant is the limiting reagent that controls ozone production?

Martin et al. (2004)

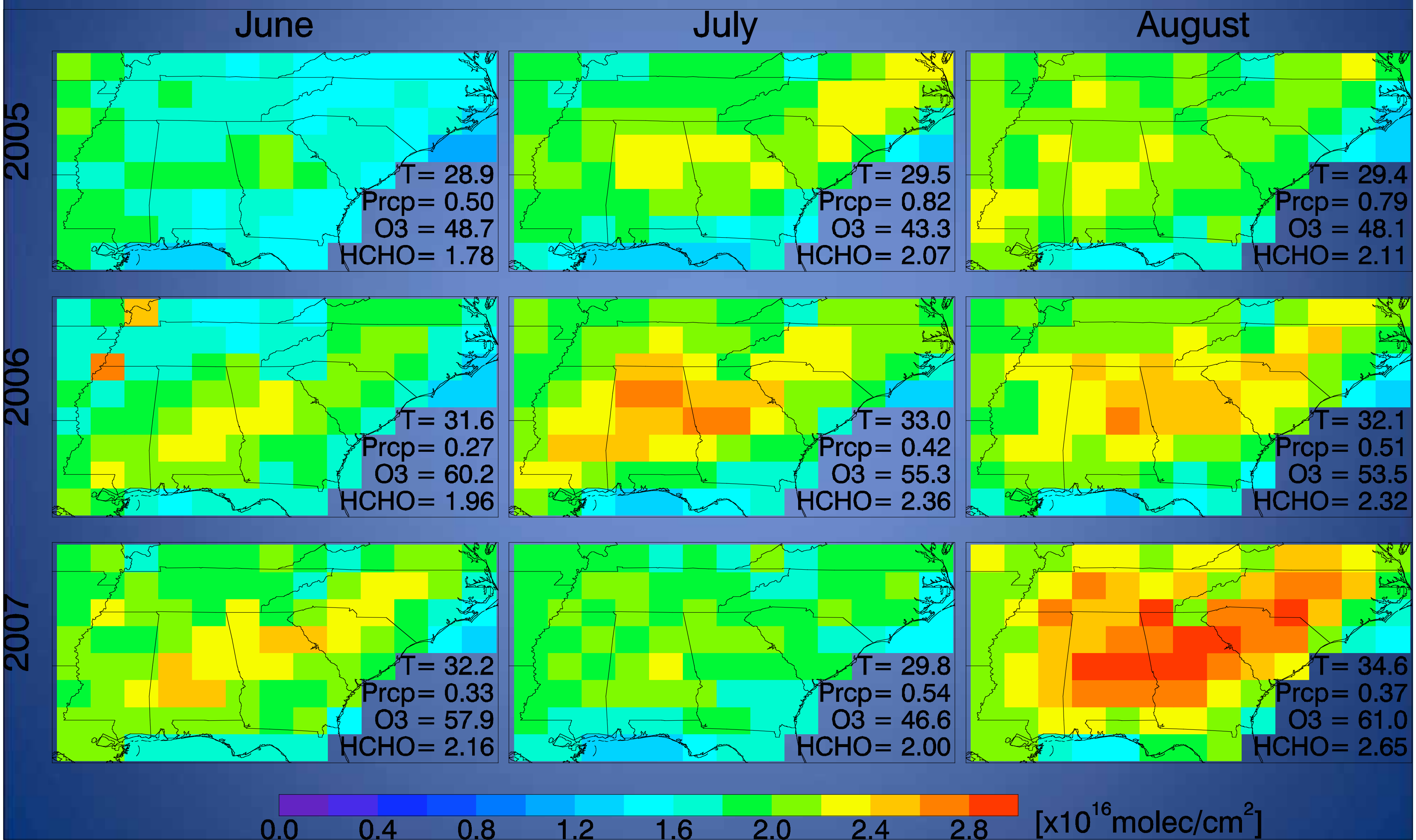
- **If $HCHO/NO_2$ low then VOCs control production**
- **If $HCHO/NO_2$ high then NO_x controls production**

Examine this ratio in relation to NOx reductions

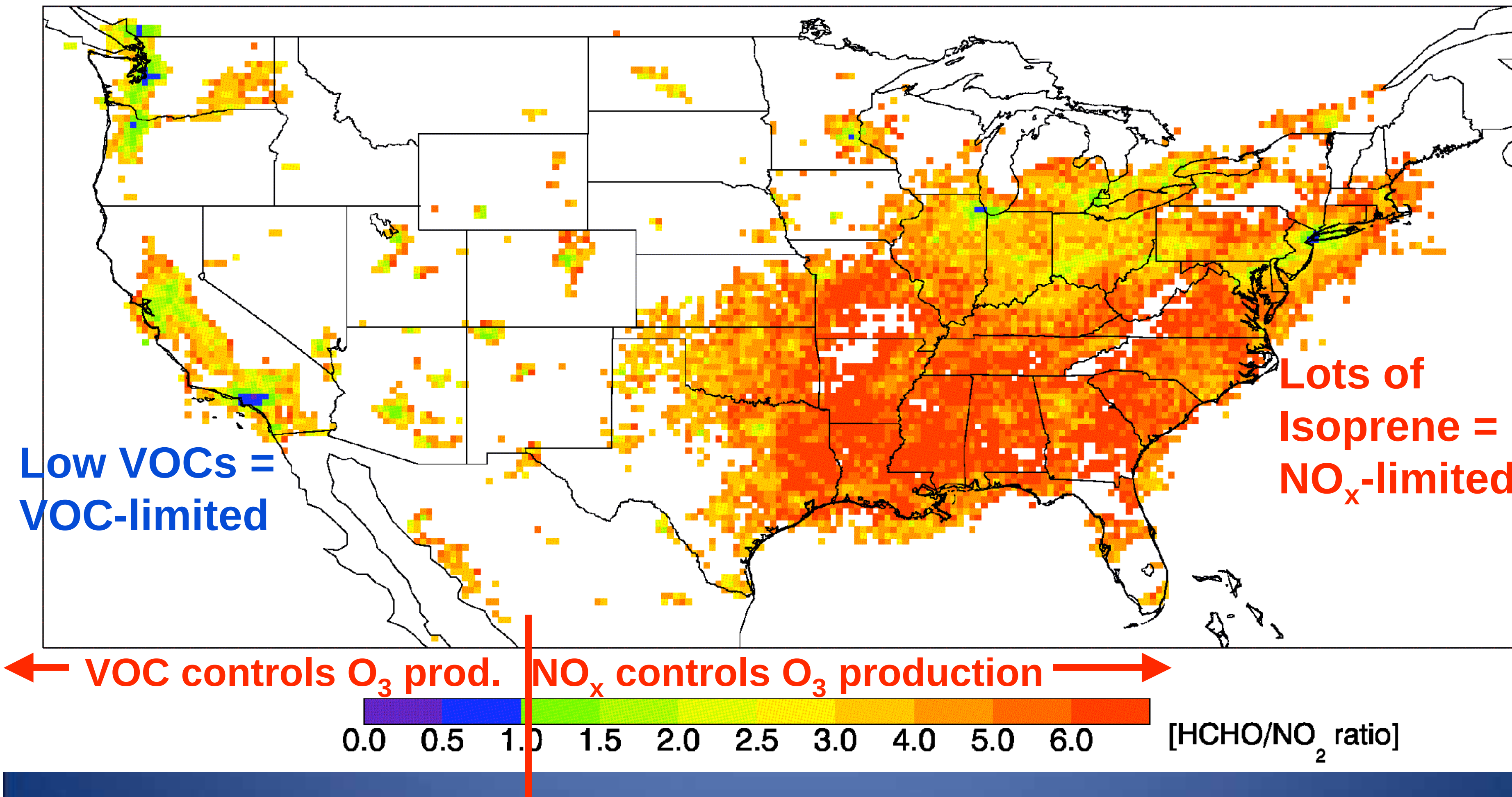
OMI HCHO as Proxy for Variability of Isoprene Emissions

Major player in AQ!

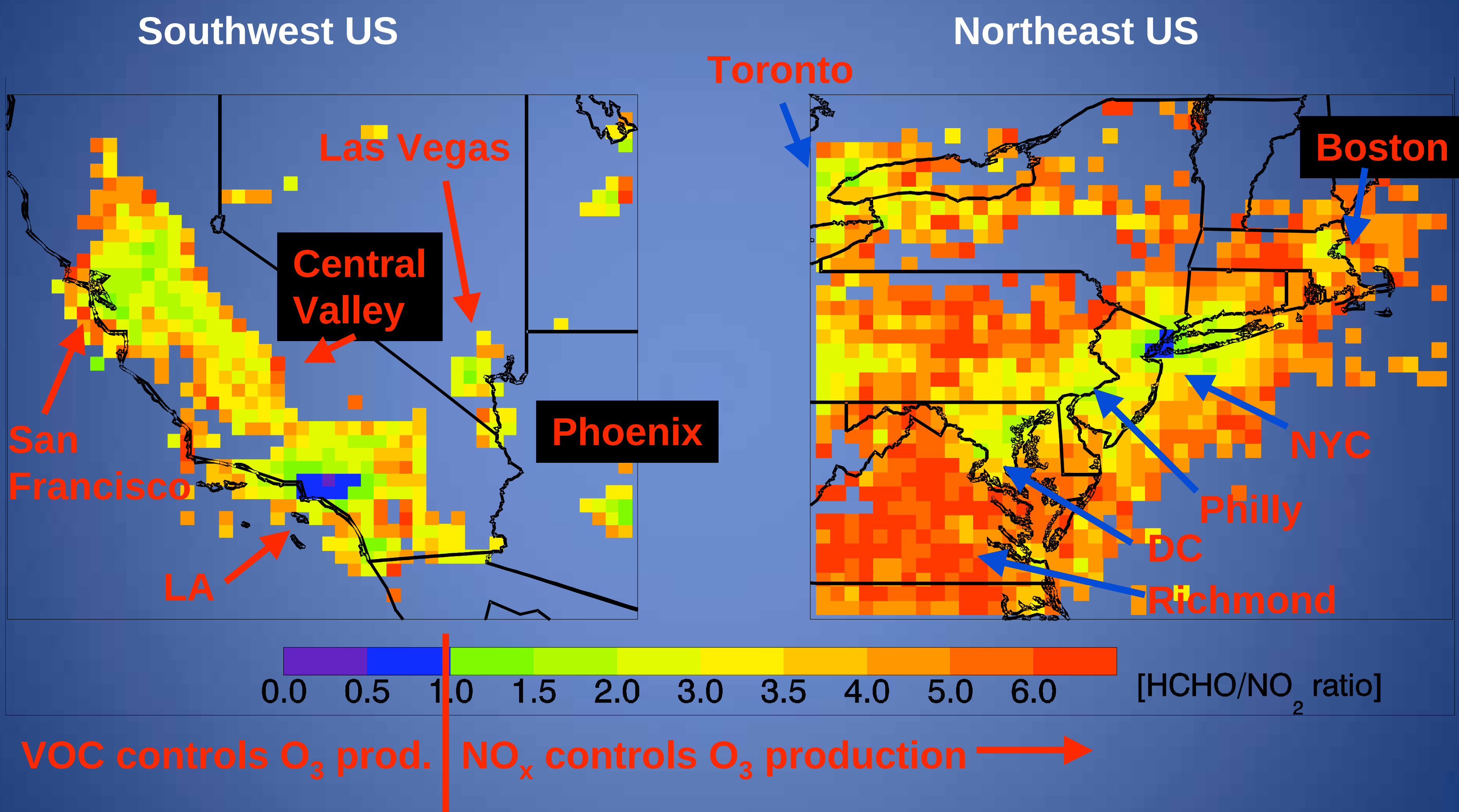
~22% Variation



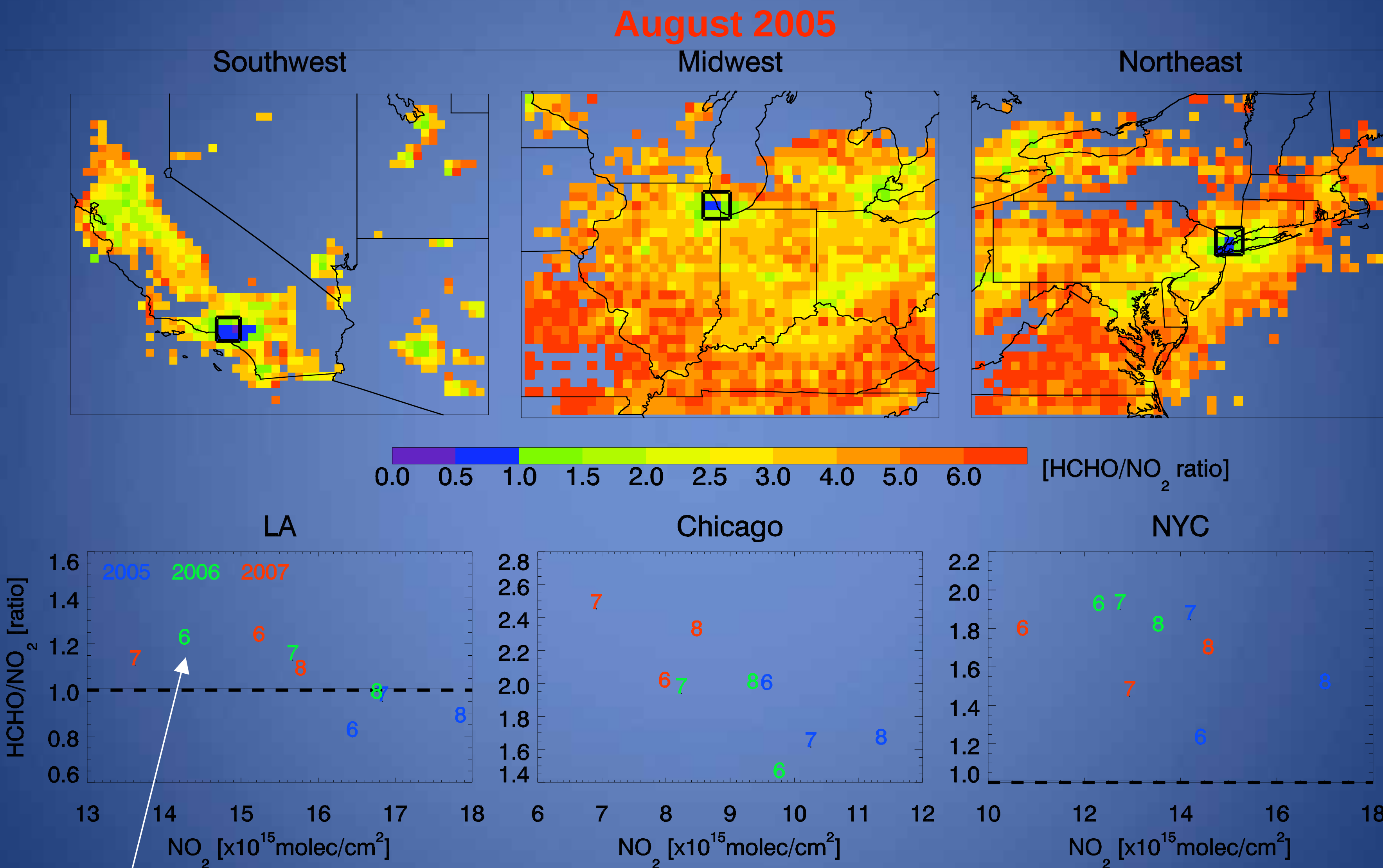
OMI $HCHO/NO_2$: August 2005



OMI HCHO/NO_2 : August 2005



OMI $HCHO/NO_2$



6 = June ; 7 = July ; 8 = August

US O_3 production becoming more NOx-limited

How does the change in the satellite observations correspond to changes in emissions?

Can the local trends seen in the satellite observations be attributed to specific clusters of sources?

(1) Develop method using CMAQ air quality model to relate emissions to column density

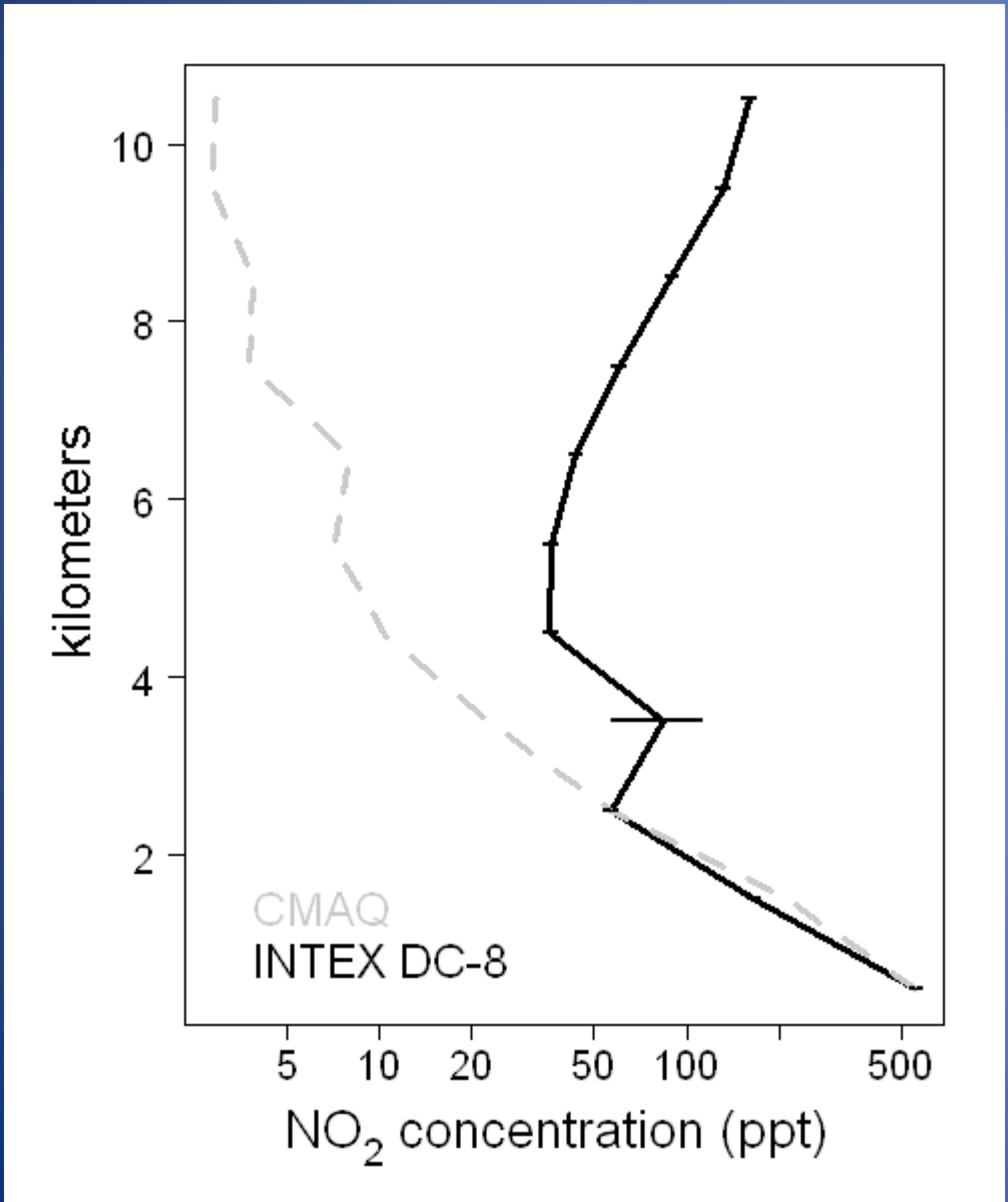
(2) Apply method to relate trend in satellite data to trend in emissions

(3) Use CMAQ to define regions of influence near clusters of sources for satellite trend analysis

Use Air Quality Model and Satellite Data to Infer Emission Change

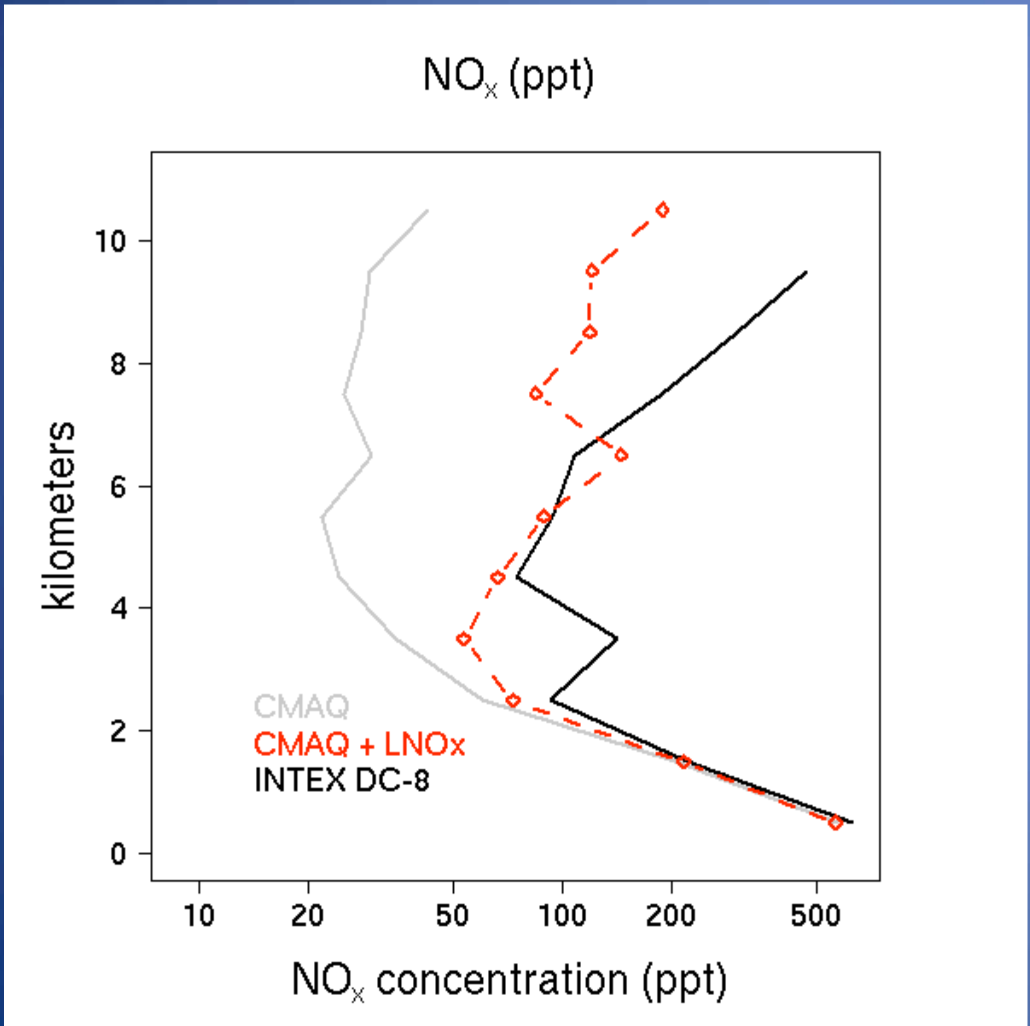
- Begin with *a priori* emission estimate
- Use emissions as input to CMAQ to estimate NO_2 column density
- Based on difference between CMAQ estimate and observed value, use an inverse technique to derive a new emission estimate
- Repeat until emission estimate converges (*a posteriori*)

Missing NO_2 Aloft



- When paired with aloft measurements from NASA INTEX, CMAQ underpredicts NO_2 above the mixed layer
- Consistent on all flights during the summer of 2004
- On average 1.07 (10^{15} molecules cm^{-2})

Lightning NO_x Source Being Added to CMAQ



Lightning flash rates predicted for times and locations of convective precipitation in meteorological model.

Flash rates scaled on a monthly basis to the NLDN + IC estimate from Boccippio IC/CG climatology

Vertical distribution of LNOx production based on observed climatology and direct function of pressure. Production/flash = 500 moles NO

Comparison of CMAQ with INTEX-A aircraft data is good up to ~7 km. Aircraft emissions still needed in CMAQ.

Summary

- OMI tropospheric NO2 observations show large decreases (as much as 40%) over the Central US between the Summers of 2005 and 2008.
- Decreases of 10 – 20% found in Northeast Corridor (Boston to Virginia) over same time period.
- Summer increases of 10-20% noted over state of Pennsylvania (as much as 60% increase in July 2008 compared with July 2005).
- Changes noted in OMI NO2 are generally consistent with Continuous Emissions Monitoring System data.
- Reduction in vehicle emissions may have contributed to reductions particularly in Northeast Corridor.
- Boreal fire emission variability contributes to large percentage changes in OMI NO2 over the northern US and Canada.
- Lightning interannual variability may contribute to changes in NO2 over the Southeastern states and the Western Atlantic.
- Next steps: Use CMAQ model in source attribution and inverse modeling studies – specifically determine if CEMS emission reductions agree with satellite observations and determine air quality improvements associated with specific clusters of sources. Lightning and aircraft NO emissions being added to CMAQ.

Acknowledgements

- Support from NASA's Applied Sciences Air Quality Program