Constraining NO_x Emissions with Space-Based Data:

Step 1: Understanding the correspondence of Ozone Monitoring Instrument (OMI) NO_2 column observations to U.S. AQS and CEMS data

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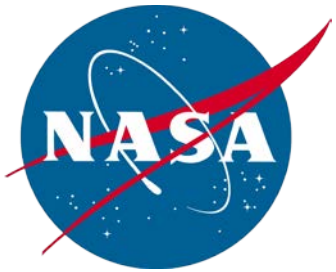


EPA-EIC, April 16, 2015; San Diego

The Aura Mission : *3 Main Science Questions*

- What are the processes that control air quality?
- What are the roles of ozone, aerosols and water vapor in climate change?
- Is the stratospheric ozone layer changing as expected?

Aura Satellite

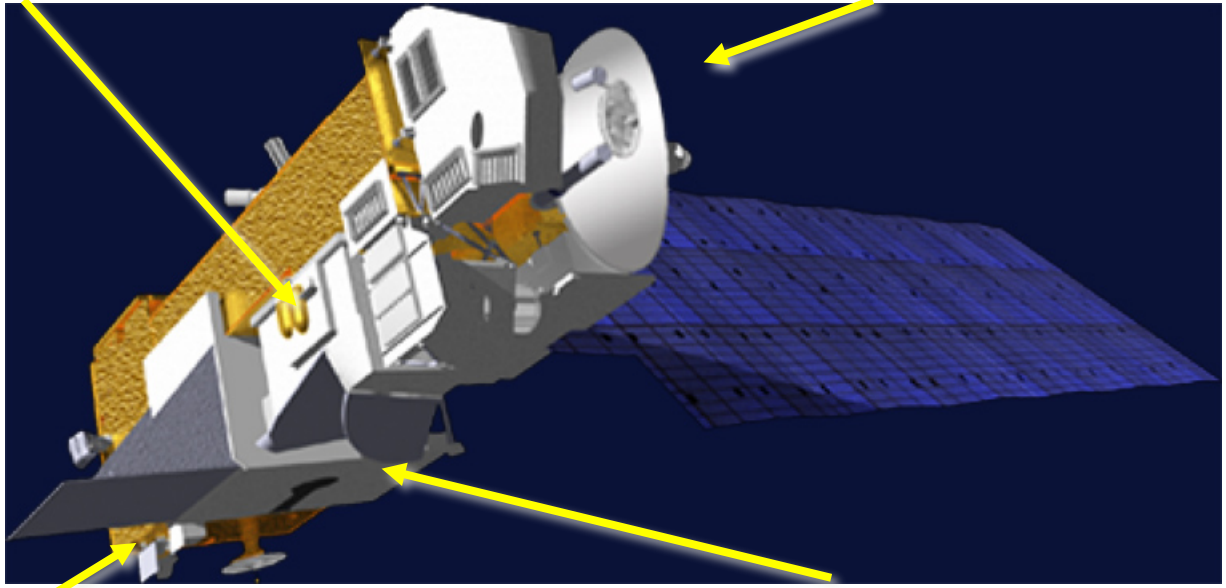
- **Orbit: Polar: 705 km, sun-synchronous, 98° inclination, ascending 1:45 PM equator crossing time.**

- **Launched July 15, 2004.**

OMI measures UV & visible wavelengths of light backscattered from the Earth & atmosphere: NO_2, SO_2, & HCHO.

HIRDLS
High Resolution Dynamics Limb Sounder (defunct)

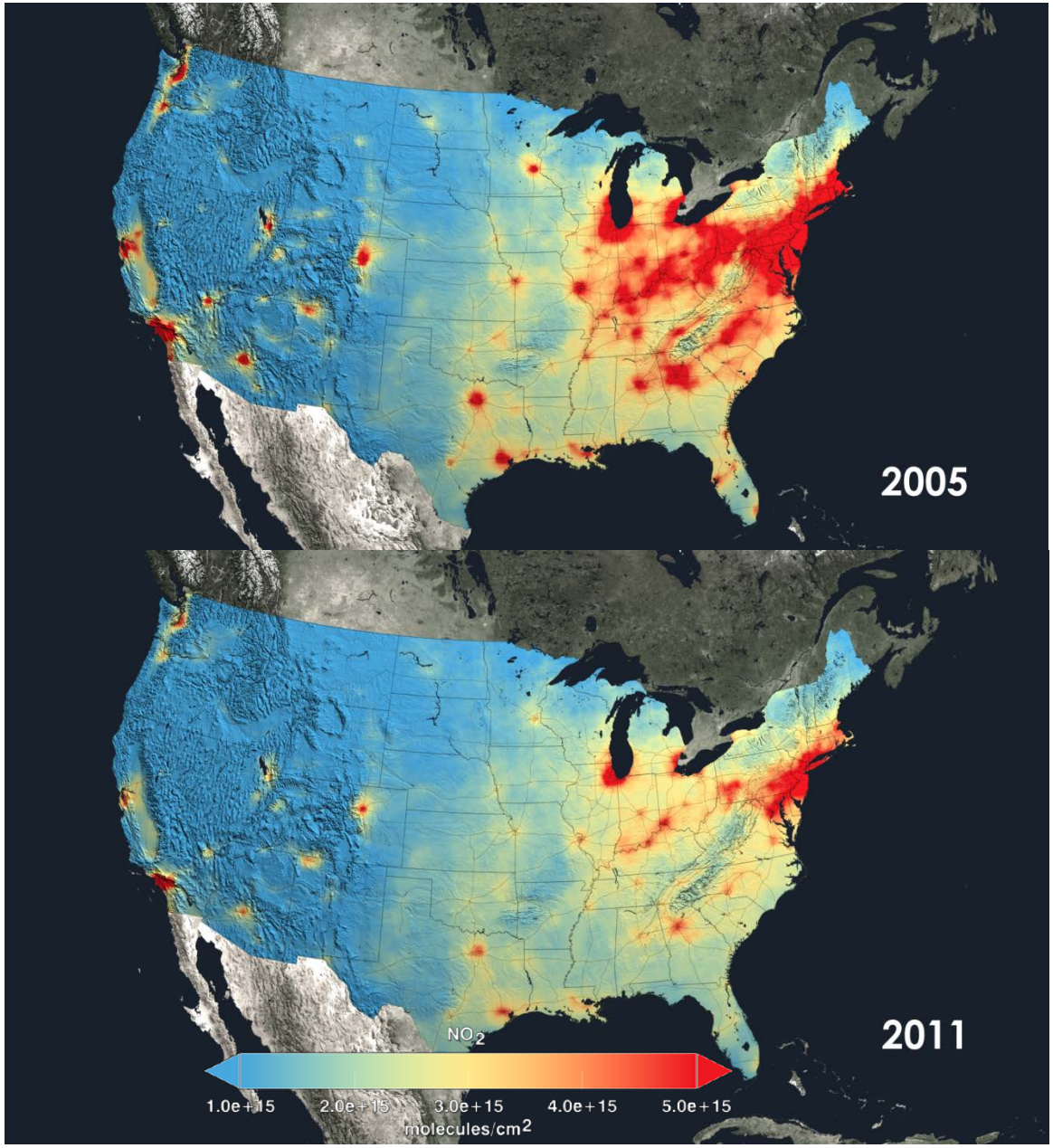
MLS
Microwave Limb Sounder



OMI
Ozone Monitoring Instrument

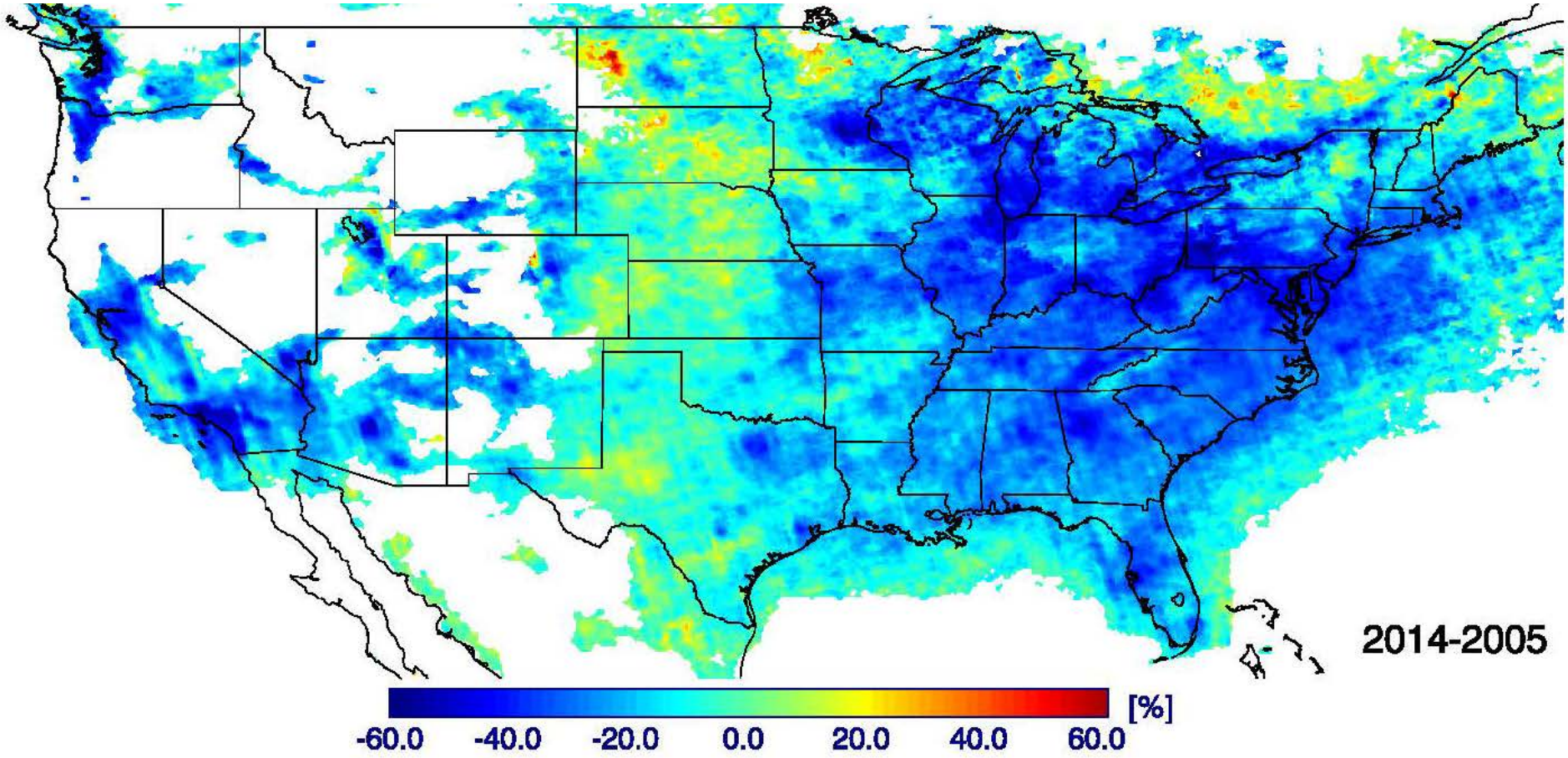
TES
Tropospheric Emission Spectrometer

Spatial Coverage is the Primary Advantage of Satellite Data



OMI NO_2

% Difference in OMI NO_2: 2005 - 2014



20-40% decrease over US

Aura Ozone Monitoring Instrument (OMI)

How do OMI NO_2 data compare to surface observations?

OMI detects pollution in the free troposphere & boundary layer;

footprint = 5-9 square miles.

The AQS surface sites only detect "nose-level" concentrations.

How do trends and variations in AQS NO_2 & CEMS NO_x relate to OMI NO_2?

OMI NO_2 & AQS data

Lamsal, L., B. Duncan, Y. Yoshida et al., *U.S. NO_2 variations and trends (2005-2013) estimated from an improved Ozone Monitoring Instrument (OMI) tropospheric column data product mirror those estimated from AQS surface observations*, doi: 10.1016/ j.atmosenv.2015.03.055, Atmos. Environ., 2015.

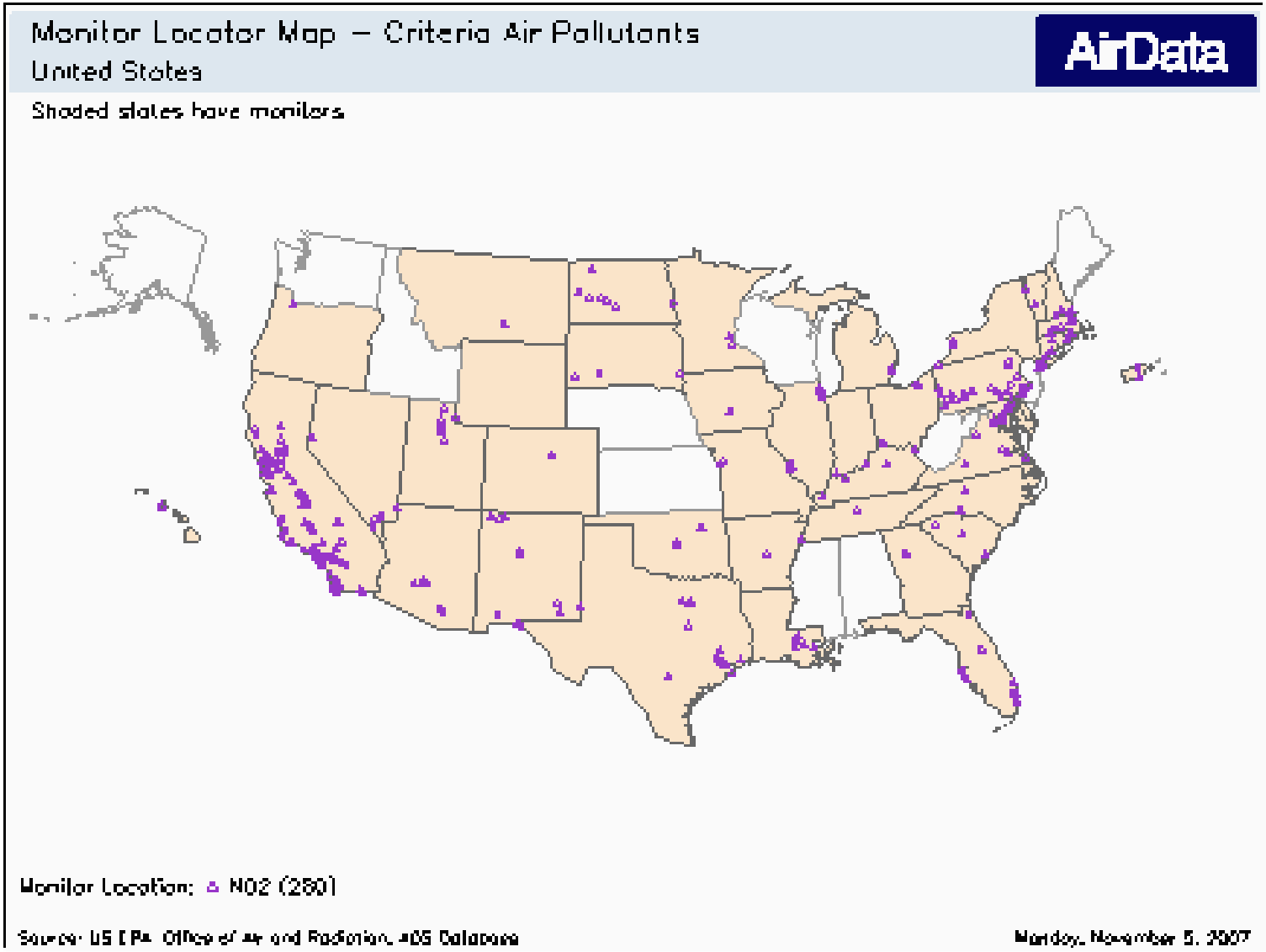
OMI NO_2 & CEMS data

Duncan, B., Y. Yoshida, B. de Foy, L. Lamsal, D. Streets, Z. Lu, K. Pickering, and N. Krotkov, *The observed response of Ozone Monitoring Instrument (OMI) NO_2 columns to NO_x emission controls on power plants in the United States: 2005-2011*, Atmos. Environ., 81, p. 102-111, doi:10.1016/jatmosenv.2013.08.068, 2013.

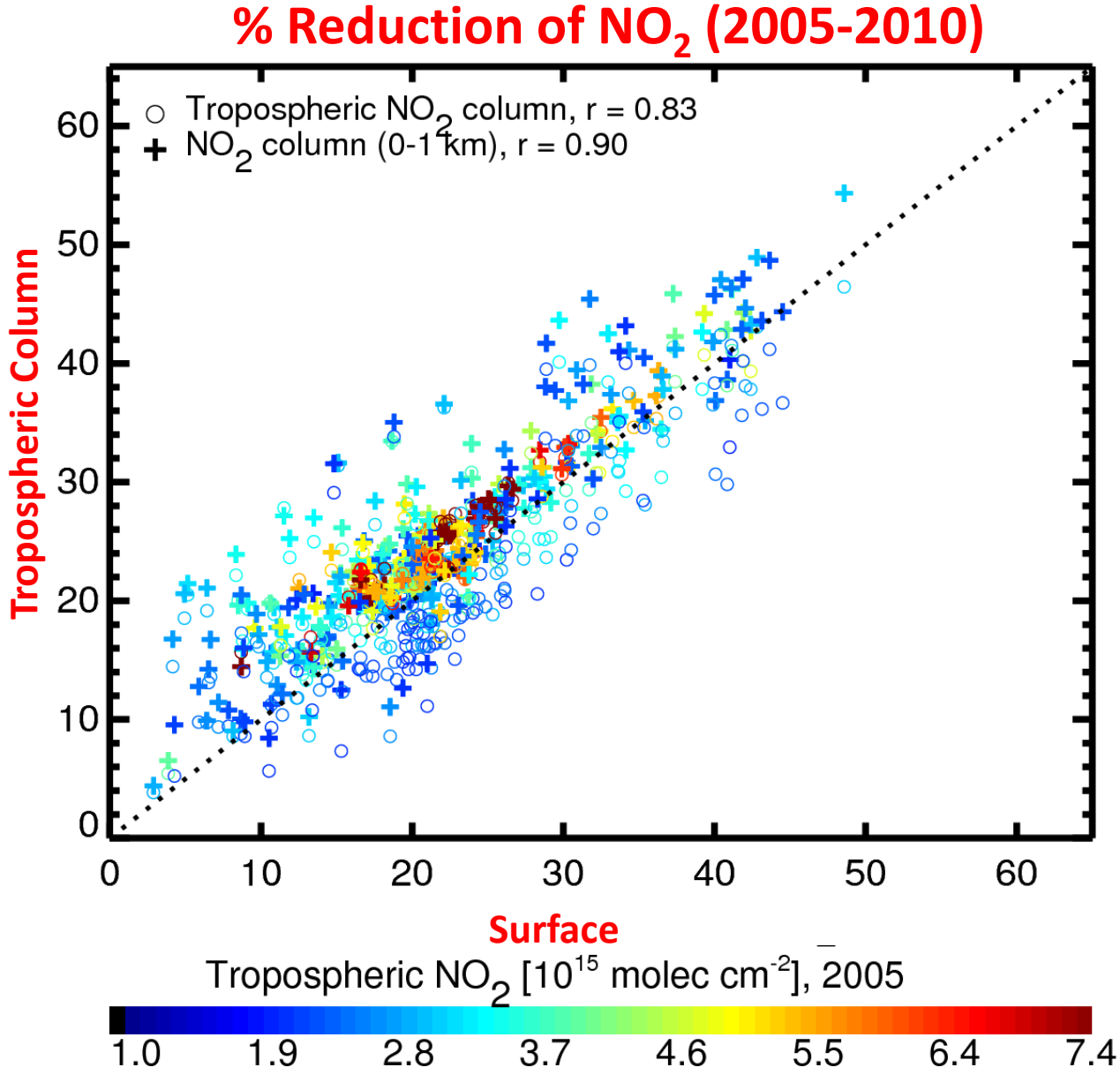
→ These articles are "open access" so they are free to download!

Part 1: EPA AQS NO_2 vs Aura OMI NO_2

Spatial Coverage is the Primary Advantage of Satellite Data

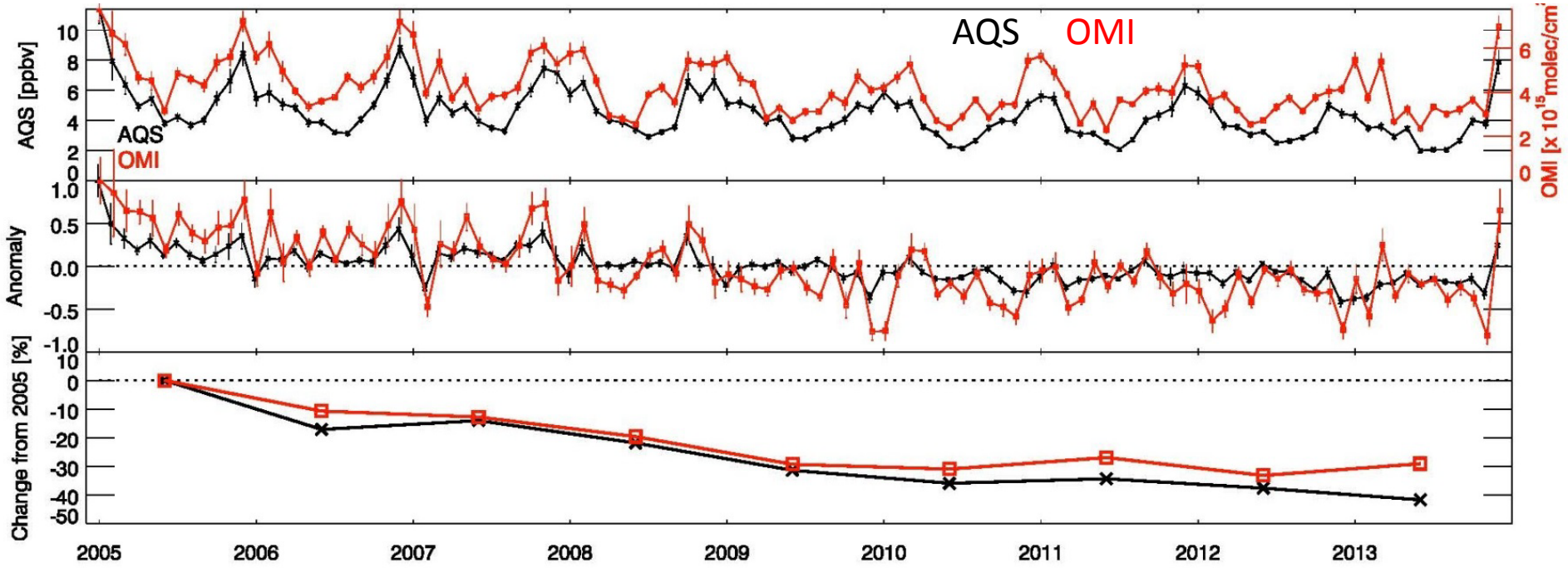


Model Simulation: *Correspondence of a Tropospheric Column to Surface Data*



Provided analysis to Mark Estes (TCEQ) upon request for Dallas SIP

Dallas-Ft. Worth Metro Area



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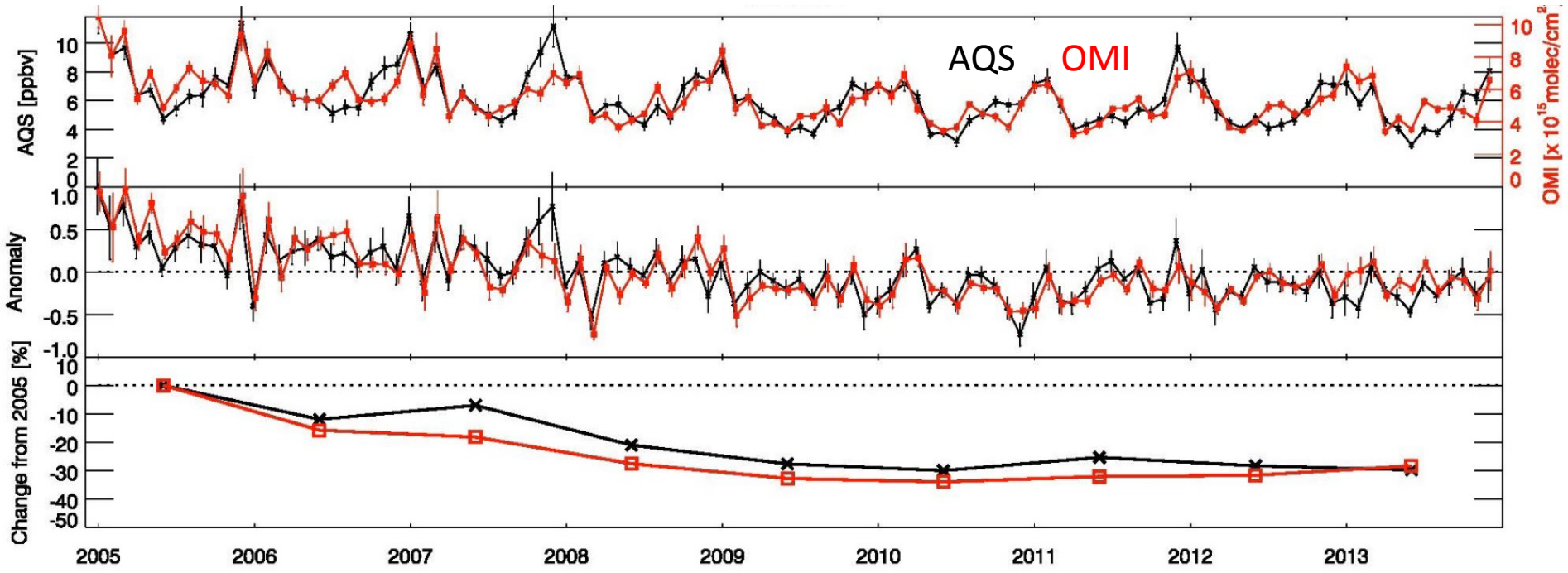
Houston Metro Area



Regional, Linear Trends agree pretty well too

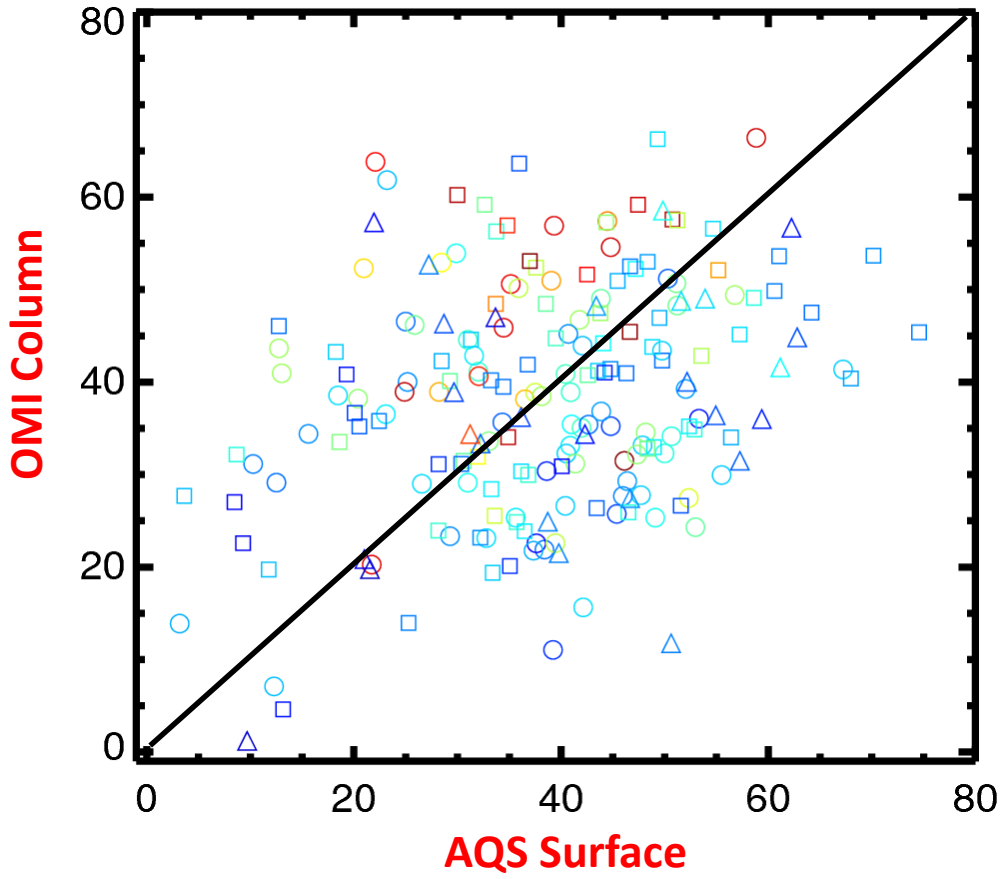
Region	Domain	Number of sites	NO_2 reduction (%) 2005-2013	
			AQS	OMI
Mid-Atlantic	41-45 N, 70-75 W	13	38.3	37.9
New England	36-41 N, 72-81 W	19	41.4	43.1
S. California	31-36 N, 116-122 W	50	42.8	47.2
Central Valley	36-41 N, 118-124 W	30	37.2	41.2

Land type	Number of sites	NO_2 reduction (%) 2005-2013	
		AQS	OMI
Residential	88	37.9	40.3
Commercial	74	39.5	37.0
Agriculture	19	35.7	38.7
Industrial	15	37.2	34.7
Mobile	6	34.9	43.1

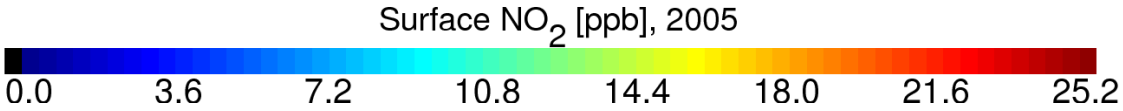
Land use	Number of sites	NO_2 reduction (%) 2005-1013	
		AQS	OMI
Urban and center city	88	37.6	37.2
Suburban	89	39.0	40.1
Rural	30	35.1	35.5

Observed Correspondence of a Tropospheric Column to Surface Data

% Reduction of NO_2 (2005-2013)



Individual AQS Sites



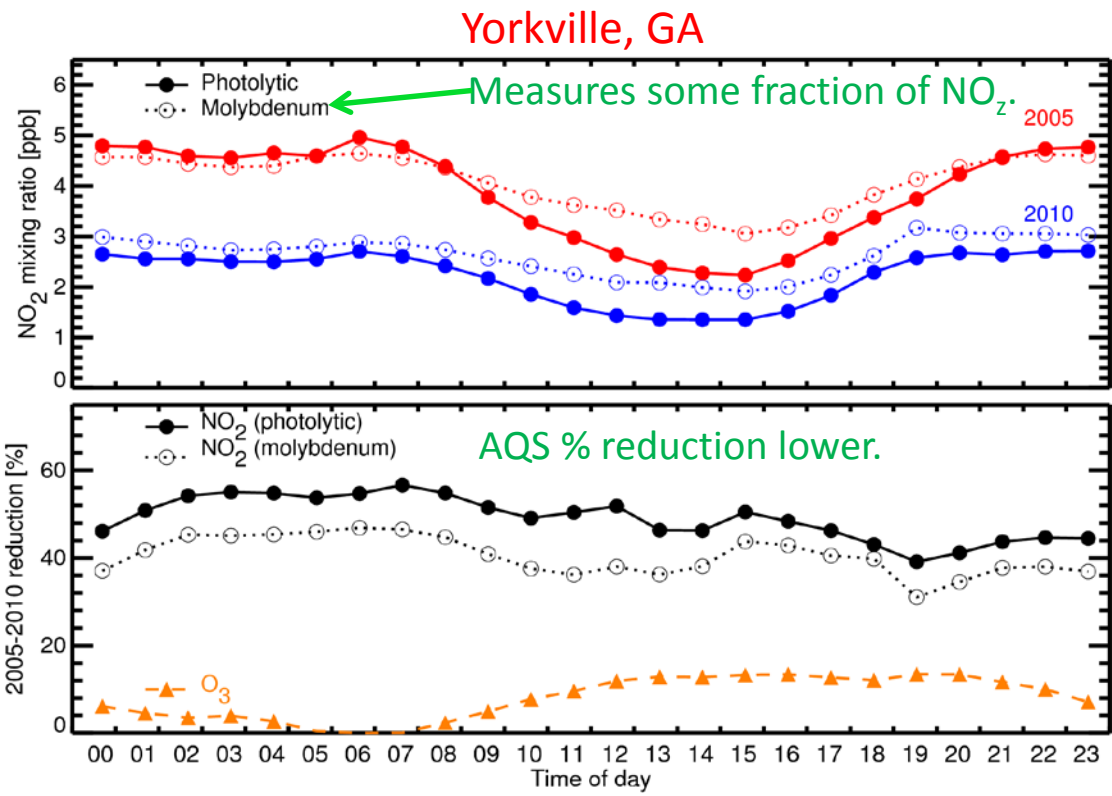
Why is the Observed Correspondence Weaker?

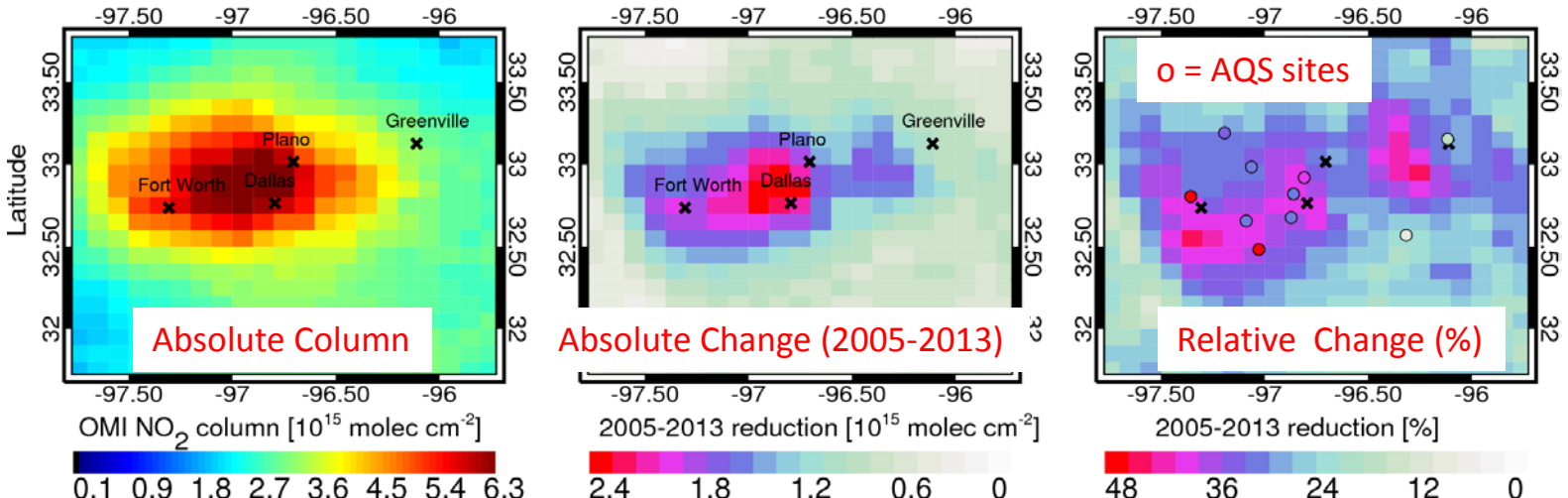
AQS

1) Molybdenum converter
2) Sparse network/siting

OMI

1) Coarse spatial resolution
2) Free tropospheric NO_2
3) Retrieval algorithm assumptions





Part 1: Conclusions

→ The trends & variations in NO_2 agree well for most major US metropolitan area, despite limitations of satellite and AQS data.

→ There are significant and interesting spatial trends within a given metropolitan area that are not captured by the relatively sparse AQS network.

→ The satellite data provide complementary information to the AQS data.

Part 2: CEMS NO_x vs Aura OMI NO_2

Regulations of NO_x Emissions

1) Power Plants *(~68% decrease since late 1990s)*

→ **1998 NO_x State Implementation Plan (SIP) Call**

22 eastern states during summer

→ **2005 Clean Air Interstate Rule (CAIR)**

27 eastern states

→ **2011 Cross-State Air Pollution Rule (CSAPR)**

28 eastern states

→ **Emission controls devices (ECDs) were installed on power plants, reducing emissions (e.g., 90%).**

2) Mobile Source *(~43% decrease since late 1990s)*

→ **Clean Air Act Amendments (CAAA) of 1990**

Tier 1 (phased-in between 1994 and 1997) standards
Tier 2 (phased-in between 2004 and 2009) standards

A Great Test of the Utility of OMI NO_2 Data

→ monitor emissions from power plants

Our Goal:

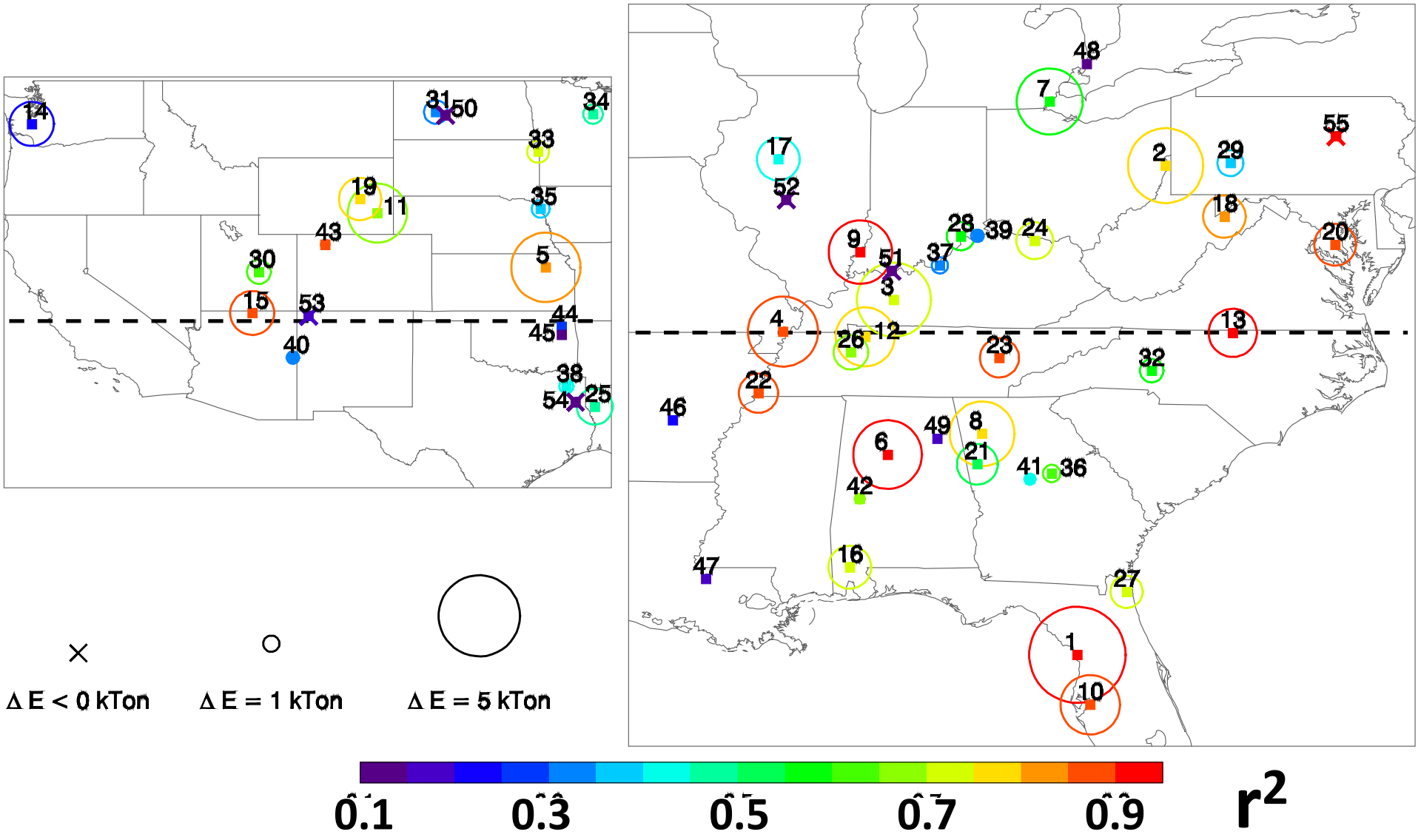
Assess the response of the NO_2 column to a known change in a power plant's emissions.

What is the relationship between ΔE & ΔNO_2?

Is this "Response" (i.e., $\Delta NO_2/\Delta E$) scalar?

Is this "Response" the same for all power plants?

Correlation (r^2) of annual OMI NO_2 & E (2005-2011)



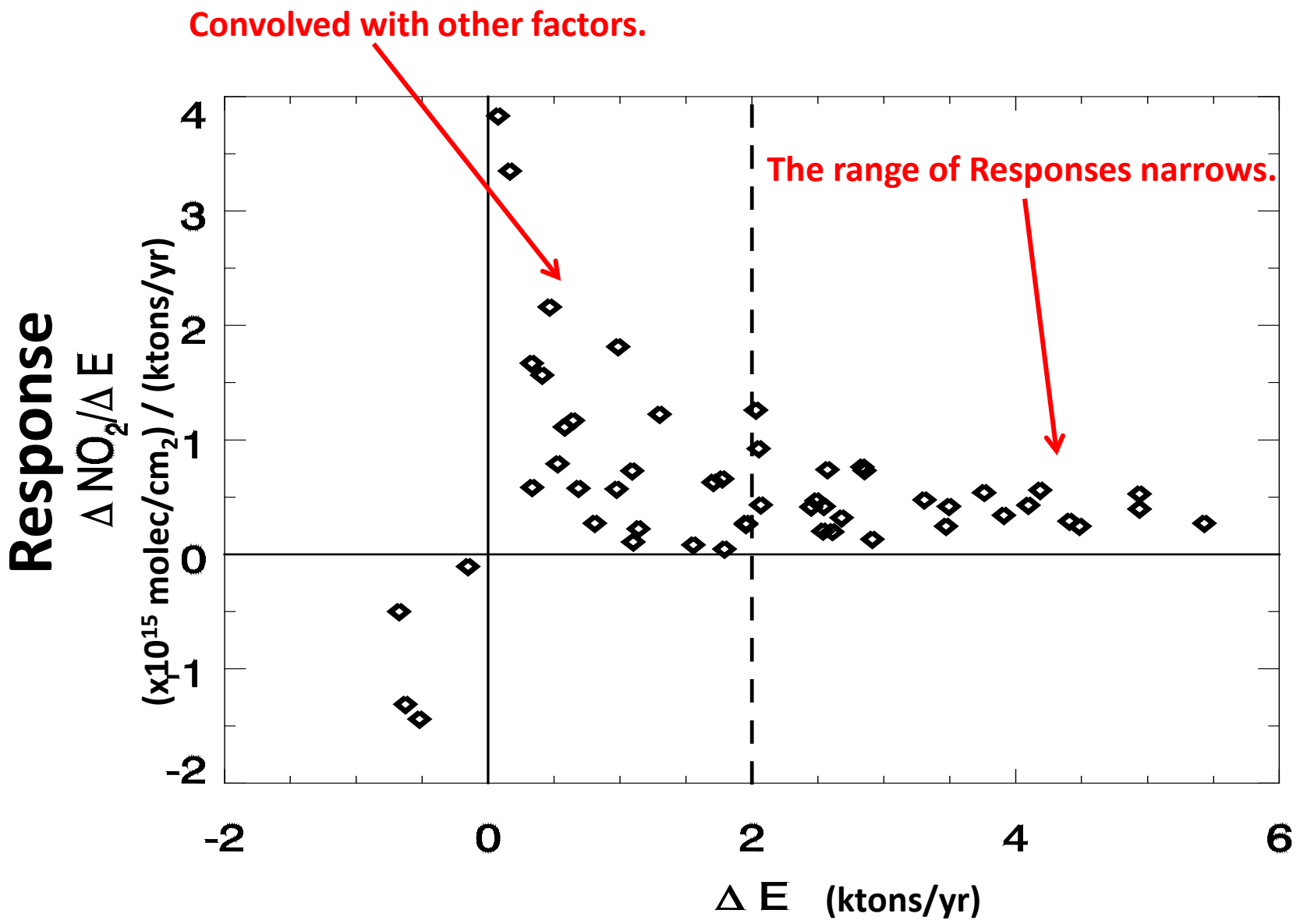
Primary Drivers of Variability

→ **We identified the primary drivers of variability of $\Delta NO_2/\Delta E$:**

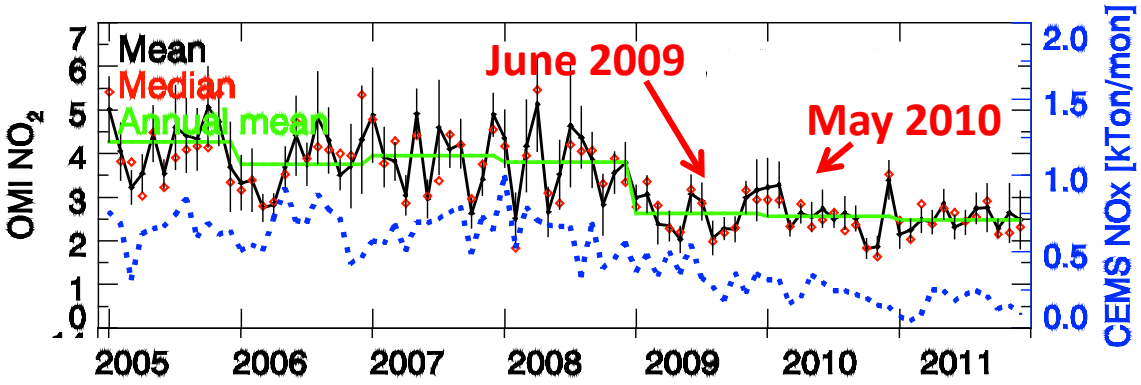
a) magnitude of ΔE
b) seasonal variation of NO_x lifetime
c) proximity to urban sources
d) changes in regional background
e) statistical significance
f) meteorology
g) retrieval issues

Not enough time to discuss them all.

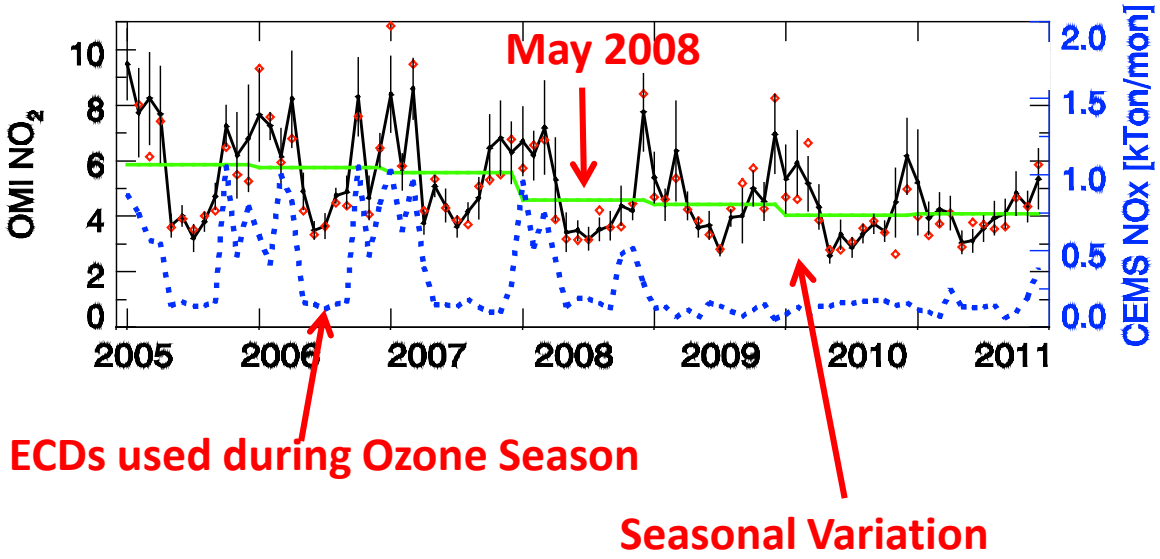
a) Magnitude of ΔE



b) Seasonal Variation of NO_x Lifetime

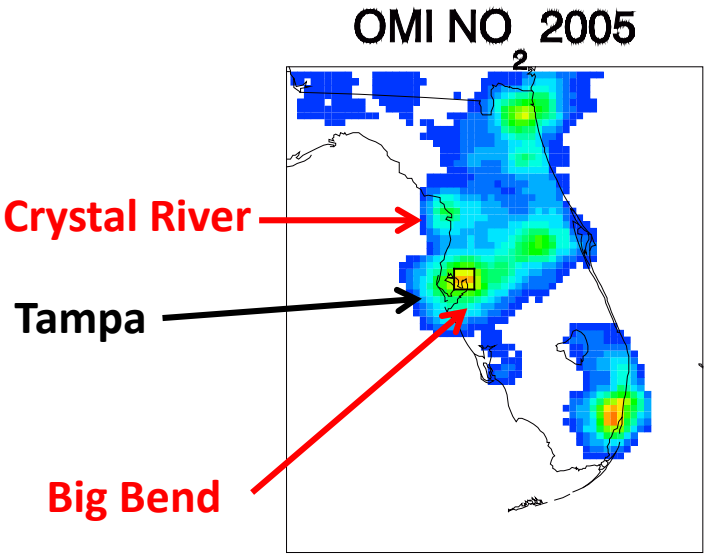


Crystal River, Florida



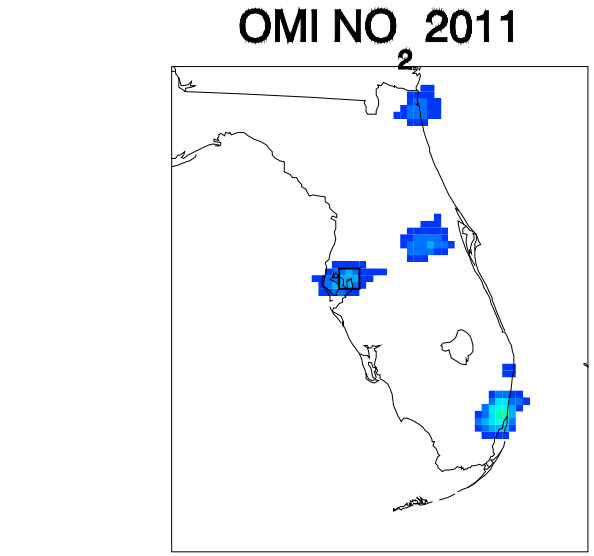
Bowen, Georgia

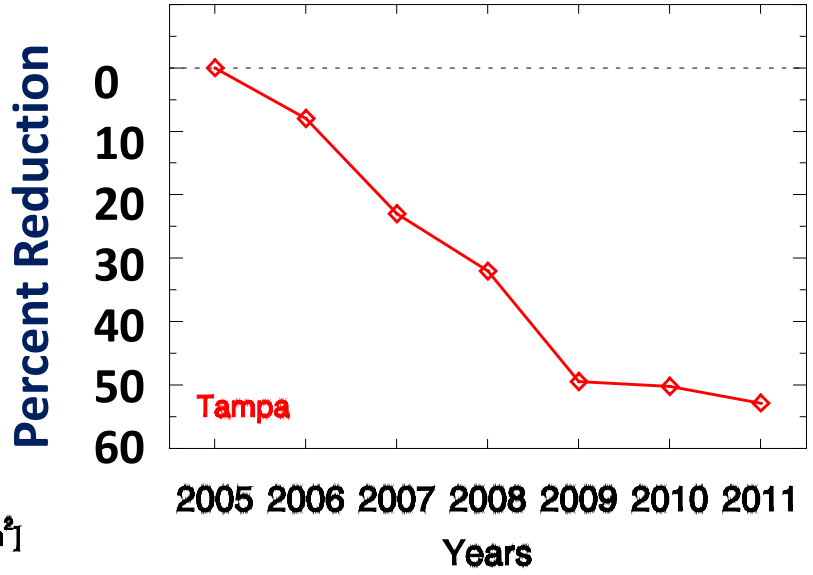
c) Proximity to Urban Sources



	ΔE^{PP}	$\Delta NO_2/\Delta E$	r^2
Big Bend	4.2	0.53	0.89
Crystal River	5.4	0.28	0.91

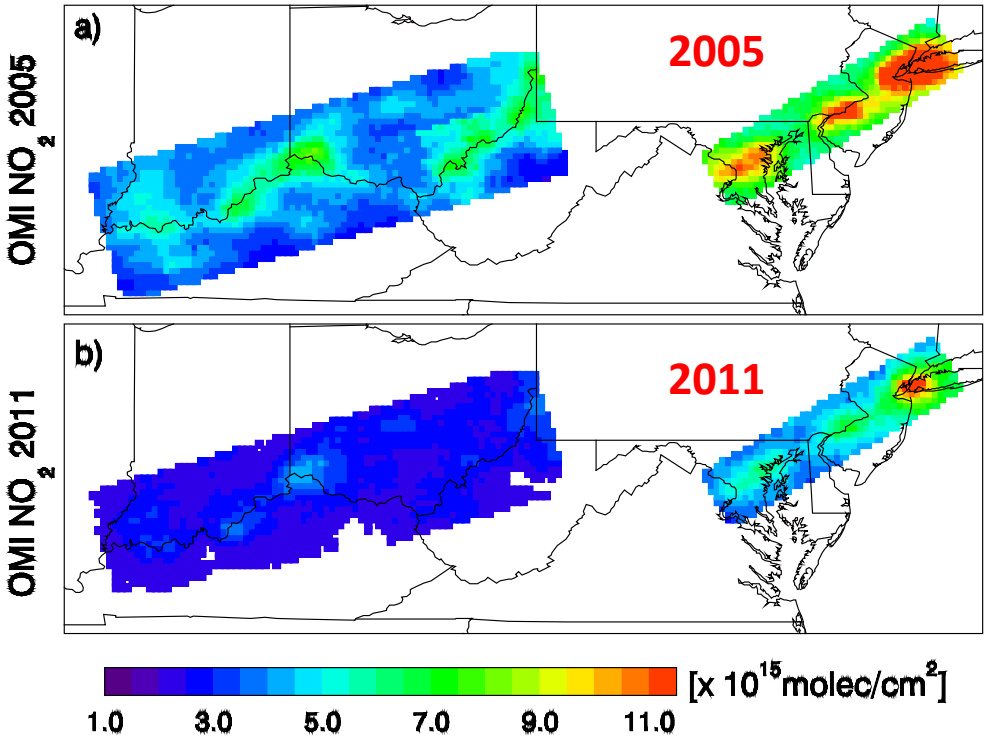
$\Delta E^{OtherSources}$ = Big Bend plume convolved with Tampa plume.

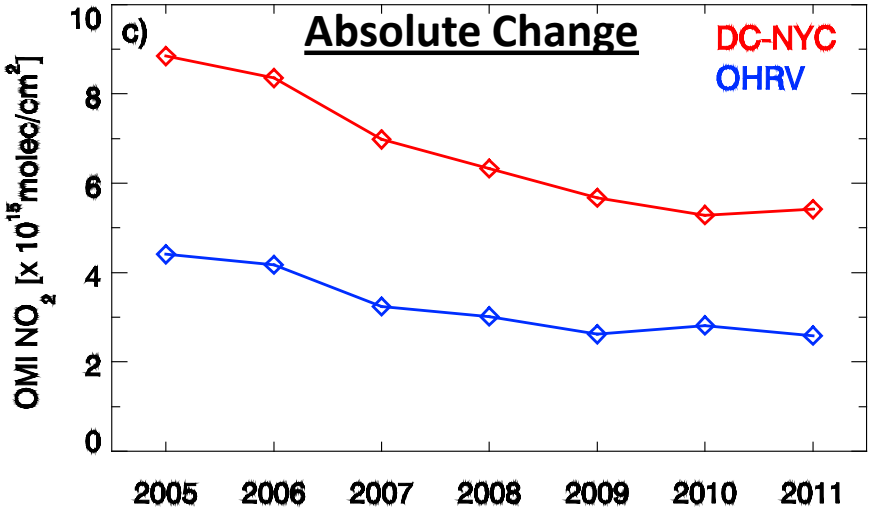


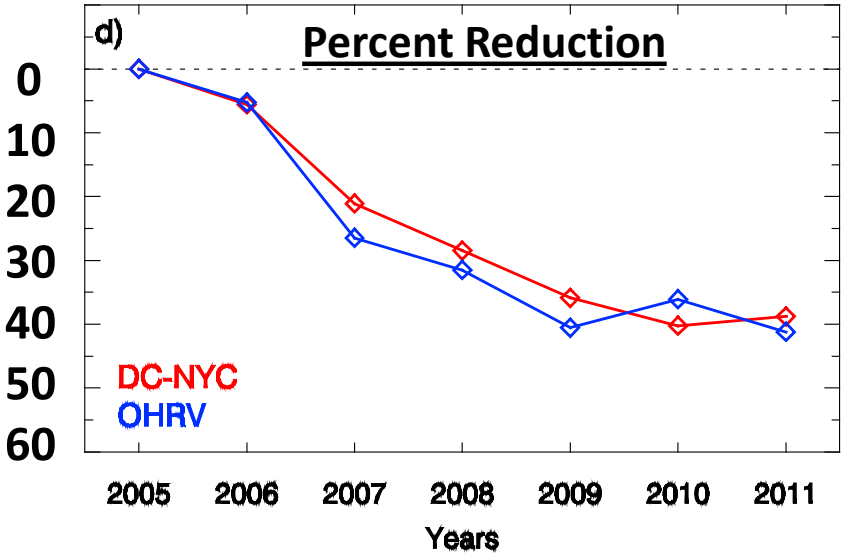


d) Regional Background - OMI

$$\frac{\Delta NO_2^{PP}}{\Delta E^{PP}} = \frac{(\Delta NO_2^{Total} - \Delta NO_2^{Regional})}{\Delta E^{PP}}$$







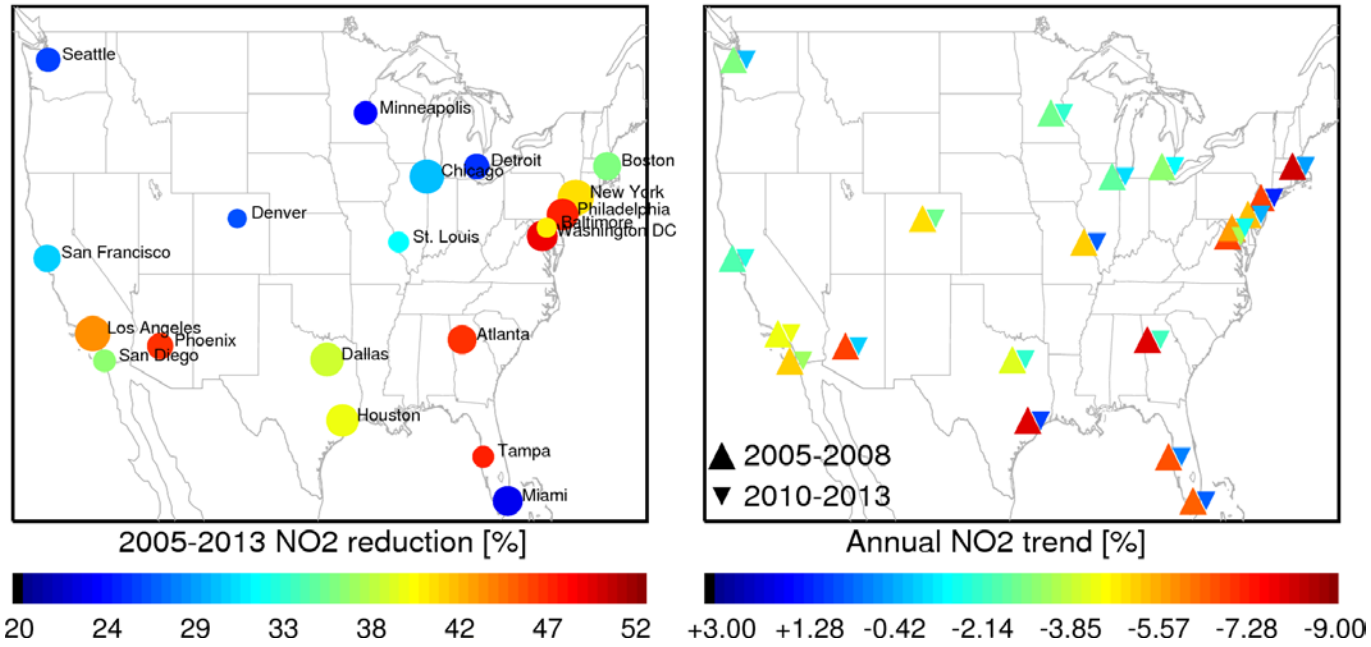
Part 2: Conclusions

→ Aura OMI NO_2 column data can be used to monitor emissions from power plants, **BUT** careful interpretation of the data is necessary & many facilities have a unique set of factors affecting it.

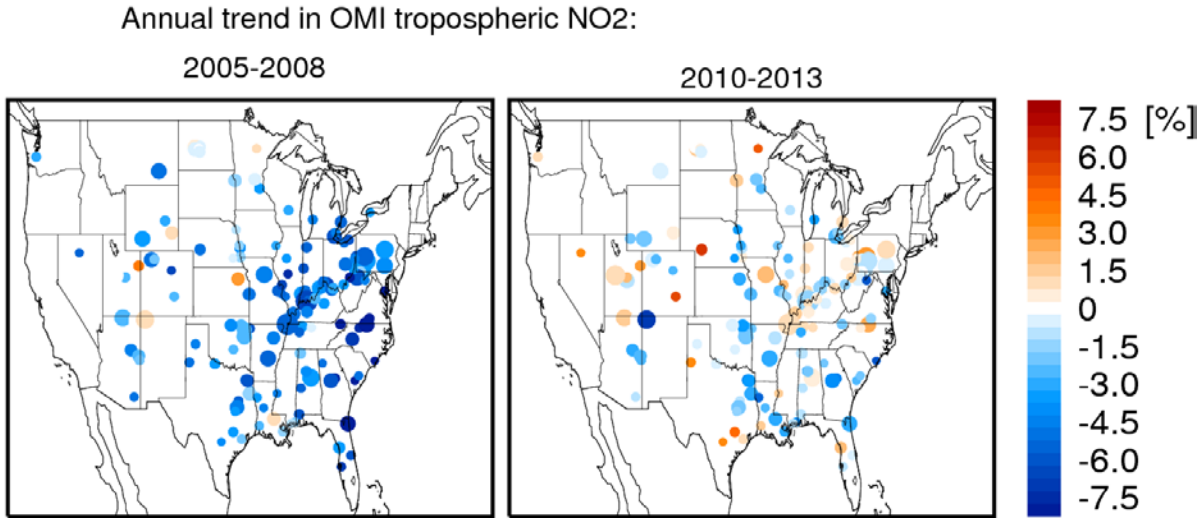
Will deliver similar analyses for 25 major US cities to a website

Data in Excel spreadsheets & downloadable images. AQ folks can provide feedback.

Metropolitan Areas



Power Plants



Two Important & Free NASA Resources

1) Air Quality Applied Sciences Team (AQAST; aqast.org)

Goal: to serve the needs of US air quality management through the use of Earth Science satellite data, suborbital data, and models.

2) Applied Remote SEnsing Training (ARSET; arset.gsfc.nasa.gov)

Goal: to increase the utility of NASA earth science and model data for policy makers, regulatory agencies, and other applied science professionals in the areas of Health and Air Quality, Water Resources, Eco Forecasting, and Disaster Management.

Two AQAST Review Articles

AQAST
NASA Air Quality Applied Sciences Team

Satellite Data of Atmospheric Pollution for U.S. Air Quality Applications: Examples of Applications, Summary of Data End-User Resources, Answers to FAQs, and Common Mistakes to Avoid

Duncan et al., Atmospheric Environment, doi:10.1016/j.atmosenv.2014.05.061, 2014.

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Emissions Estimation from Satellite Retrievals: A Review of Current Capability

Streets et al., Atmos. Environ., doi: 10.1016/j.atmosenv.2013.05.051, 2013.