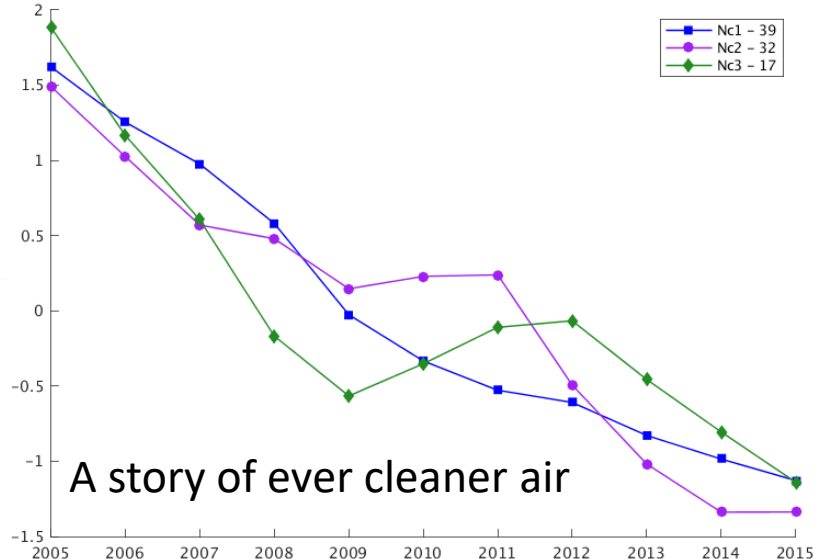
US-EPA 2017 International Emission Inventory Conference
"Applying Science and Streamlining Processes to Improve Inventories"
Session 11: Reconciling NOx Emissions with Ambient Observations

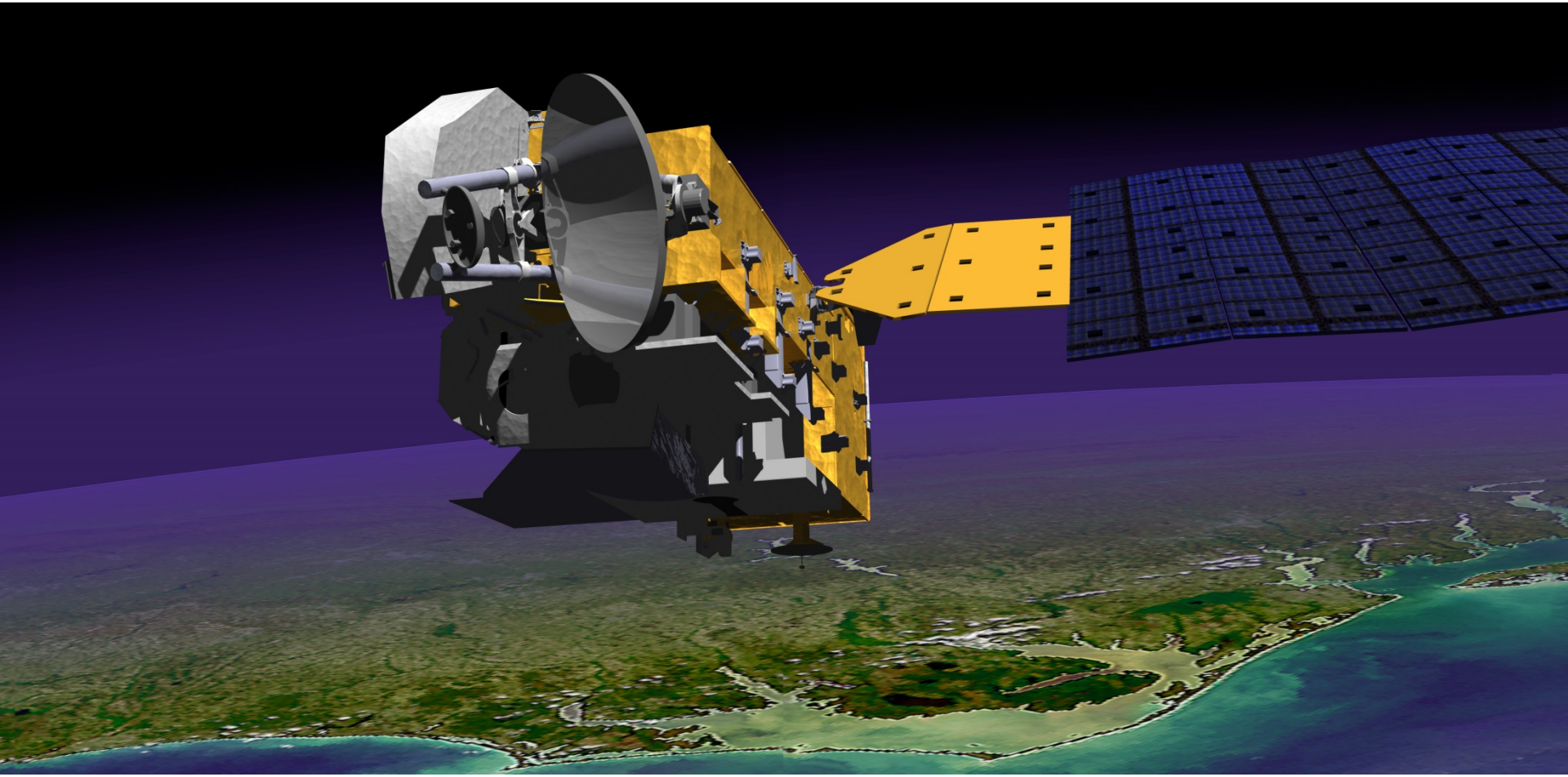
Diurnal, weekday and long-term patterns in NOx emissions based on decade-long time series of hourly AQS data

Benjamin de Foy, Saint Louis University
18 Aug 2017



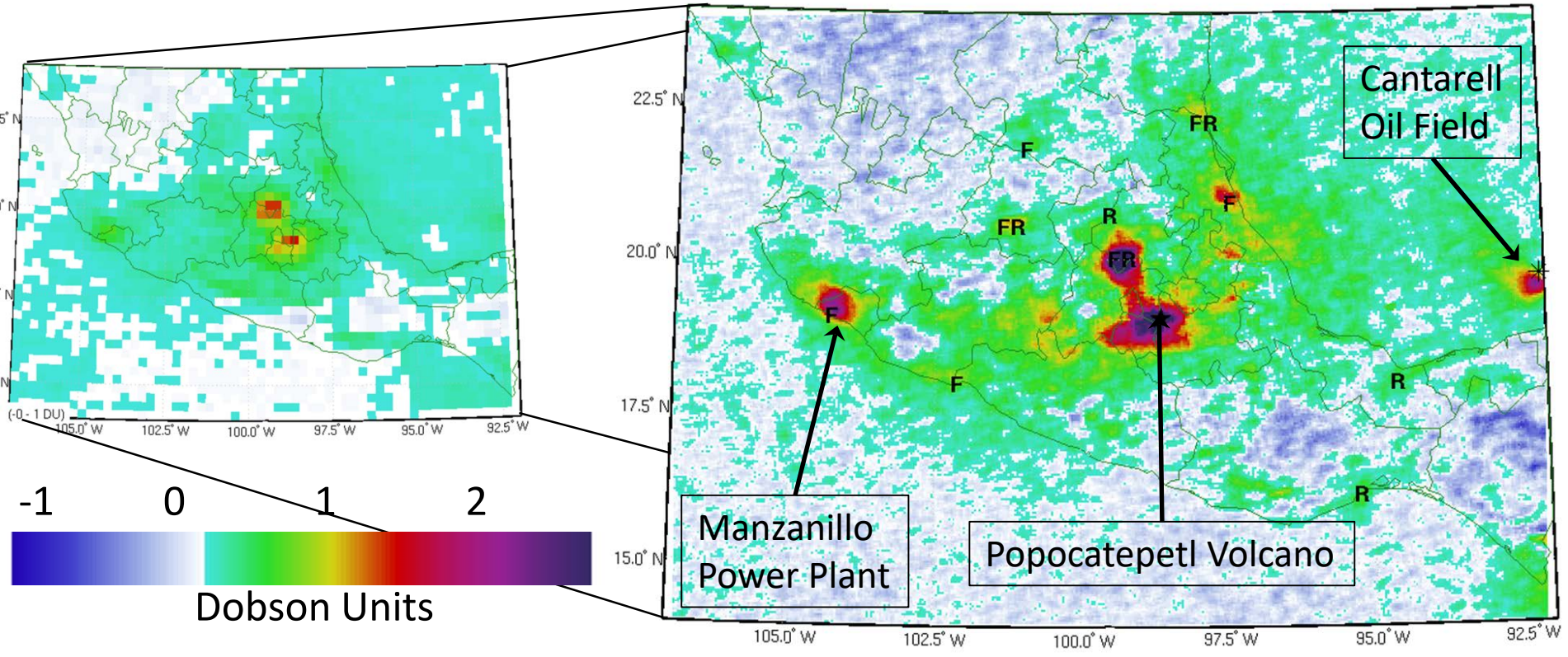
This research is funded by
U.S. EPA - Science To Achieve Results (STAR) Program
Grant # RD 83455701

OMI NO_2 Columns for Emission Inventory Development



de Foy, B., Lu, Z. and Streets, D.G., 2016. Impacts of control strategies, the Great Recession and weekday variations on NO_2 columns above North American cities. *Atmospheric Environment*.

OMI SO_2 Oversampling



Averaging to 0.125° shows the main plumes but smooths out details (OMI SO_2 PBL column over Mexico, 2004-2007 average)

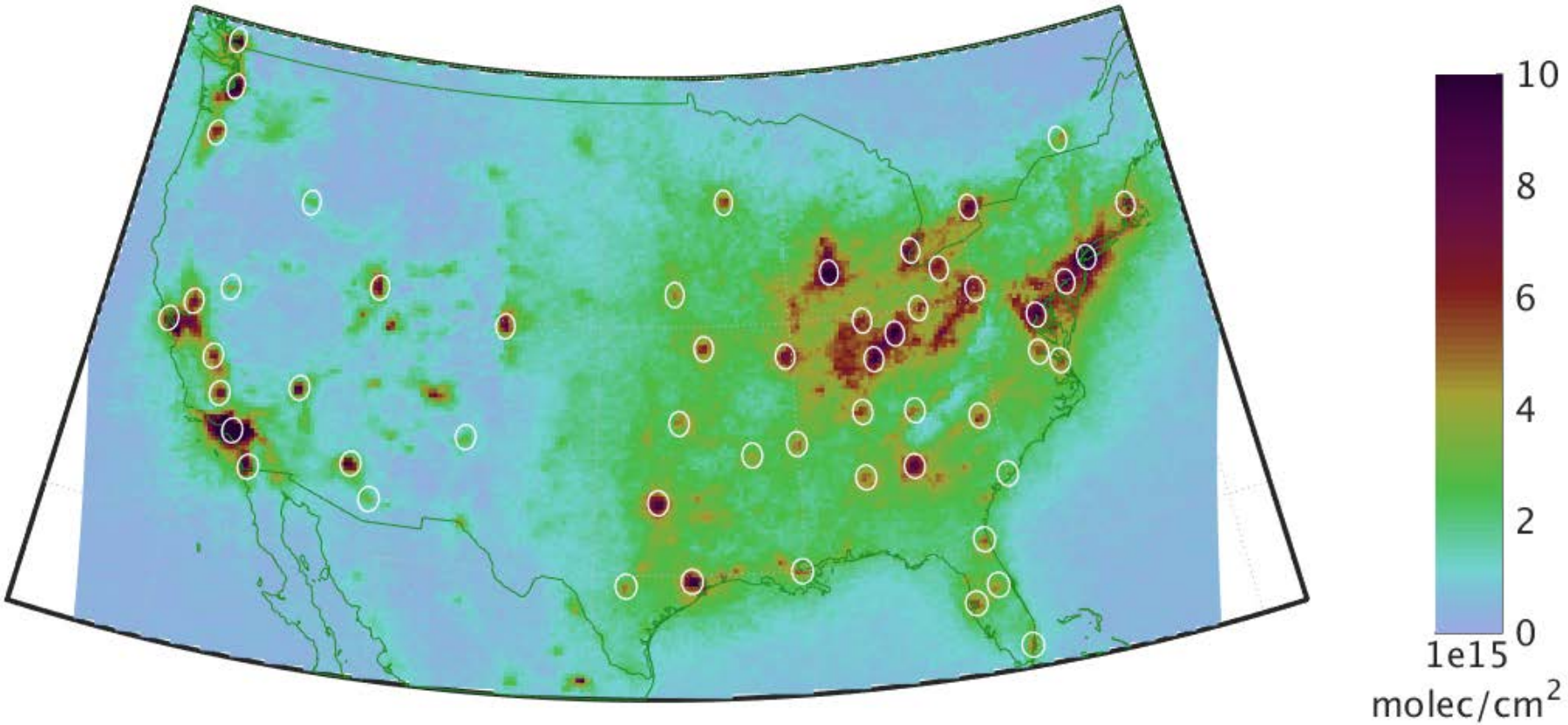
Oversampling to 3km grid reveals sources and plume transport:

F: Fuel Oil Power Plant

R: Refinery

de Foy et al., 2009, Atmospheric Chemistry & Physics

OMI NO_2 over the USA - 2005



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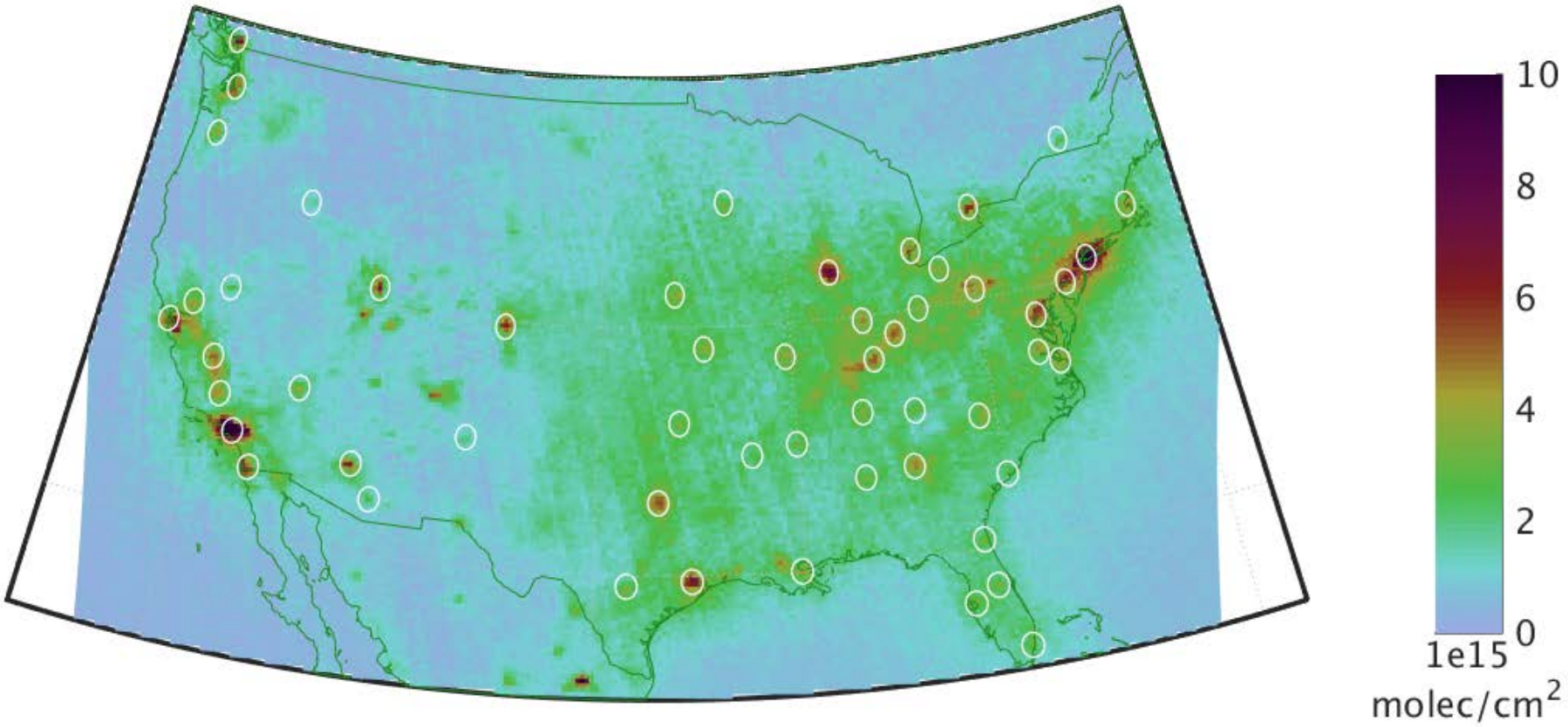
Impacts of control strategies, the Great Recession and weekday variations on NO2 columns above North American cities, Atmospheric Environment, 2016

OMI NO_2 over the USA - 2014



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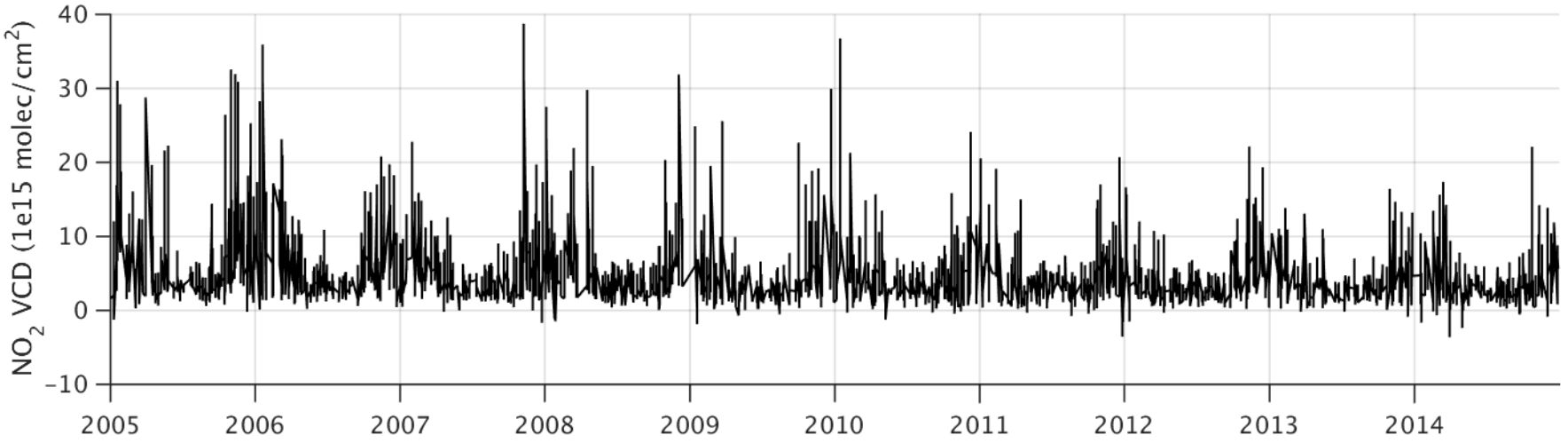
Atlanta: 8,500 OMI Pixels over 10 years
Clear trend, but lots of variability



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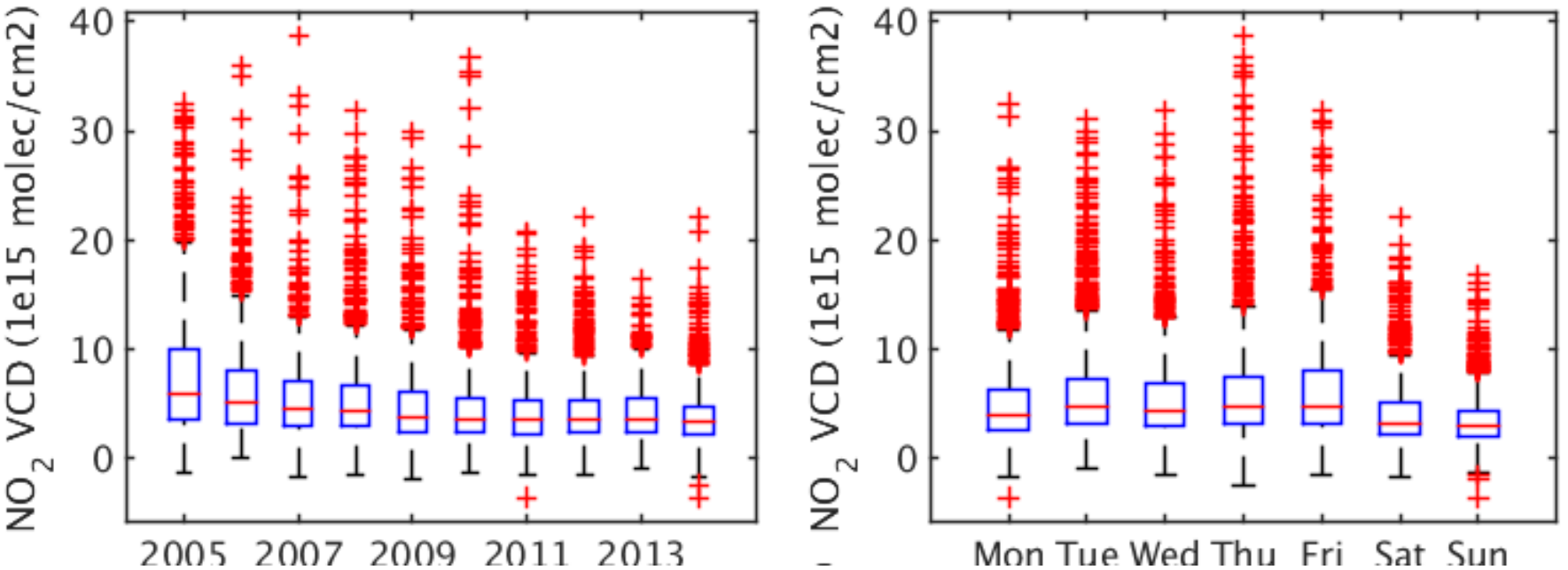
Impacts of control strategies, the Great Recession and weekday variations on NO2 columns above North American cities, Atmospheric Environment, 2016

Boxplots by Different Time Windows over Atlanta:

Clear long term trend and weekend effect, but considerable data variability masks detailed changes



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Factors Contributing to Variation in OMI NO_2 Columns

Annual	Seasonal	Weekday	Meteorology	Pixel Resolution
Linear Trend	Sin 1 year	Monday	Wind Speed	Pixel Size
and/or	Cos 1 year	Tuesday	Wind Direction	Pixel Distance from Urban Center
Annual Factors	Sin 6 months	Wednesday	Temperature	
	Cos 6 months	Thursday		
		Friday		
		Saturday		
		Sunday & Holidays		

Multiple Linear Regression to Estimate Combined Contribution from Different Factors

$$\log(C) = c_{lin}t_{lin} + \sum_{yr=2008}^{2011} c_{yr}t_{yr} + \sum_{wd=Mon}^{Sun} c_{wd}t_{wd} + f(\text{other}) + \epsilon$$

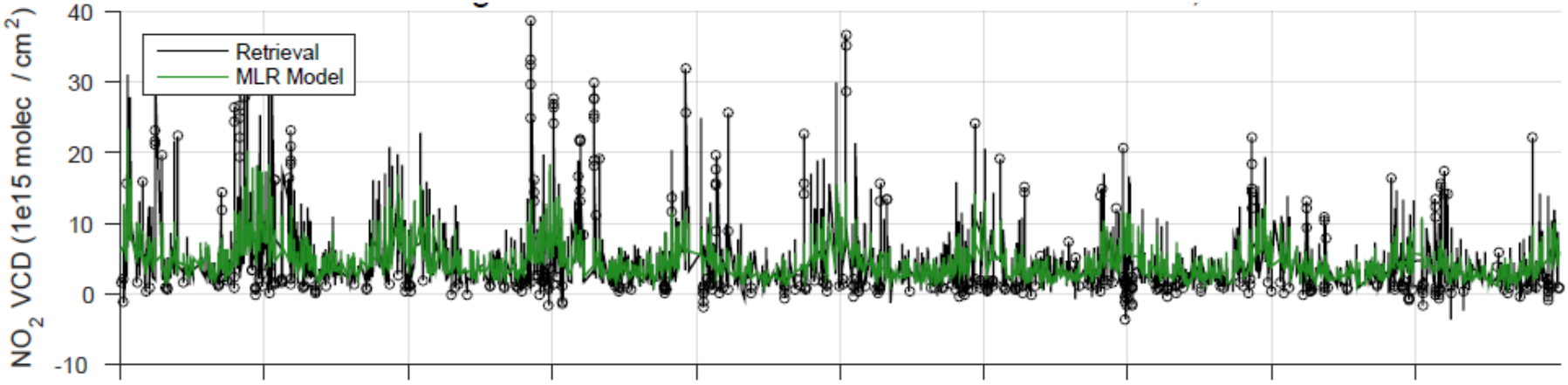
$$f(\text{other})$$

$$f(\text{seasons}) = \sum_{j=1}^{2} c_{sj} \sin\left(\frac{2\pi jt}{365.25}\right) + c_{cj} \cos\left(\frac{2\pi jt}{365.25}\right)$$

$$f(\text{meteorology}) = c_{ws} \left(\log(WS + 3)\right)' + c_{t2}T_2' + c_{u10}U_{10}' + c_{v10}V_{10}'$$

$$f(\text{resolution}) = c_{dmin}D_{min}' + c_{dmax}D_{max}'$$

Multi-Linear Regression Model
OMI NO_2 Columns over Atlanta, GA



Stats		Annual	%	Weekday	%	Met/Pixel	
Nobs	8525	Trend	-5.5	Mon	-9.0	WS10	-0.18
Noutliers	462	2008	-3.6	Tue	2.6	T2	-0.07
r	0.74	2009	-16.4	Wed	-5.1	U10	-0.00
Mean VCD	5.3	2010	-10.8	Thu	-0.5	V10	-0.02
		2011	-2.6	Fri	3.2	Dmin	-0.10
				Sat	-28.7	Dmax	-0.07
				Sun	-37.7		

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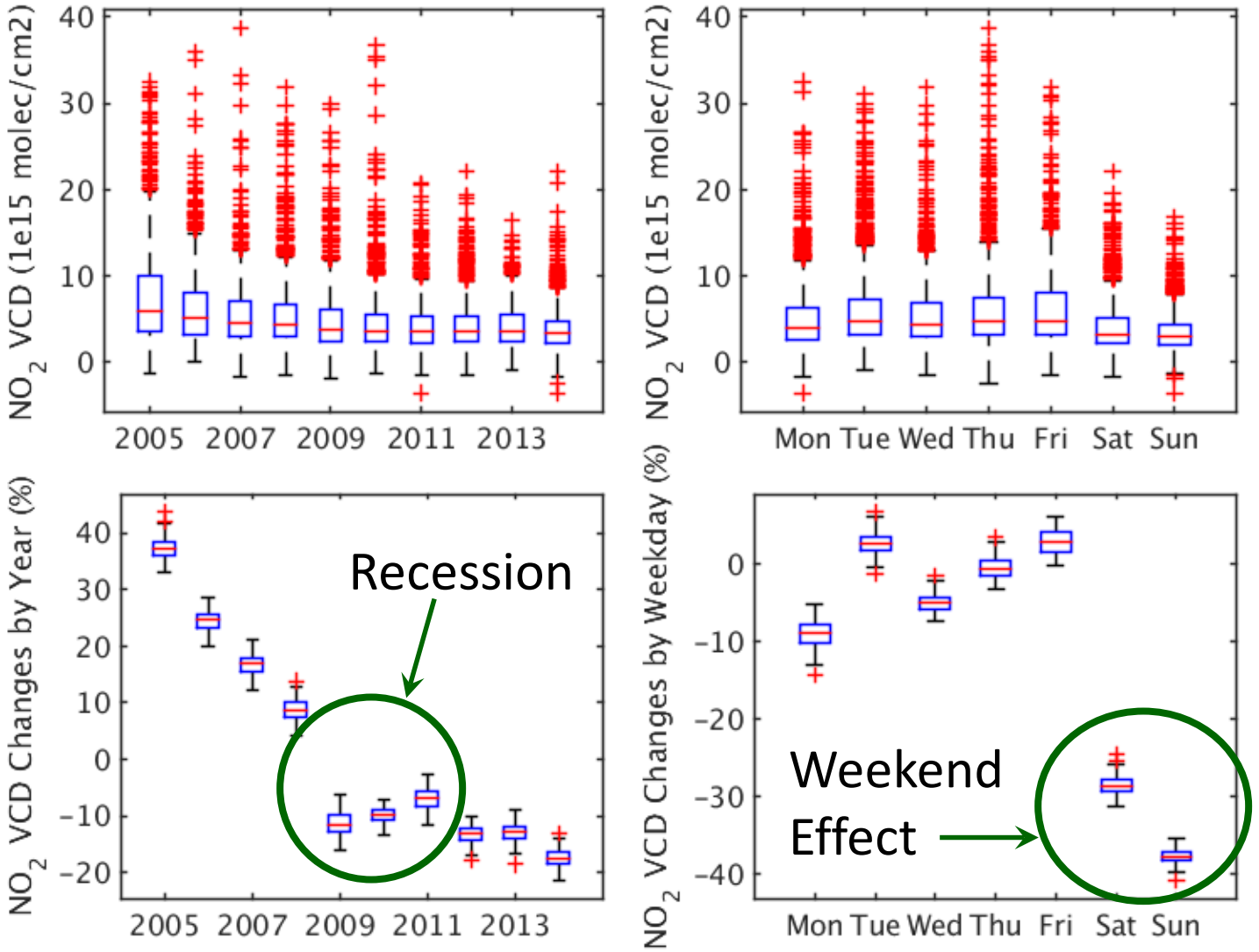
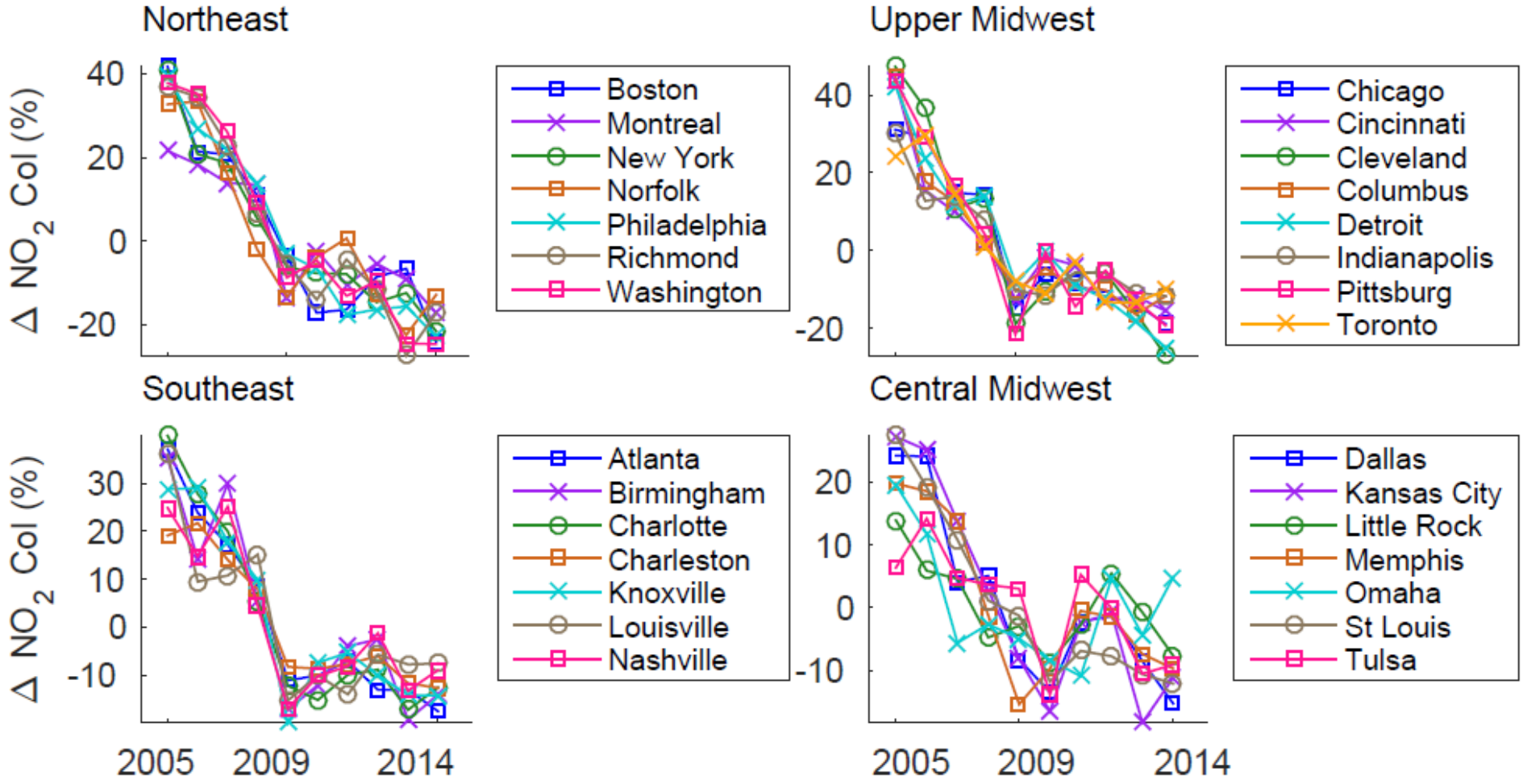
Multiple Linear Regression yields cleaner annual and weekly signals than simple averaging

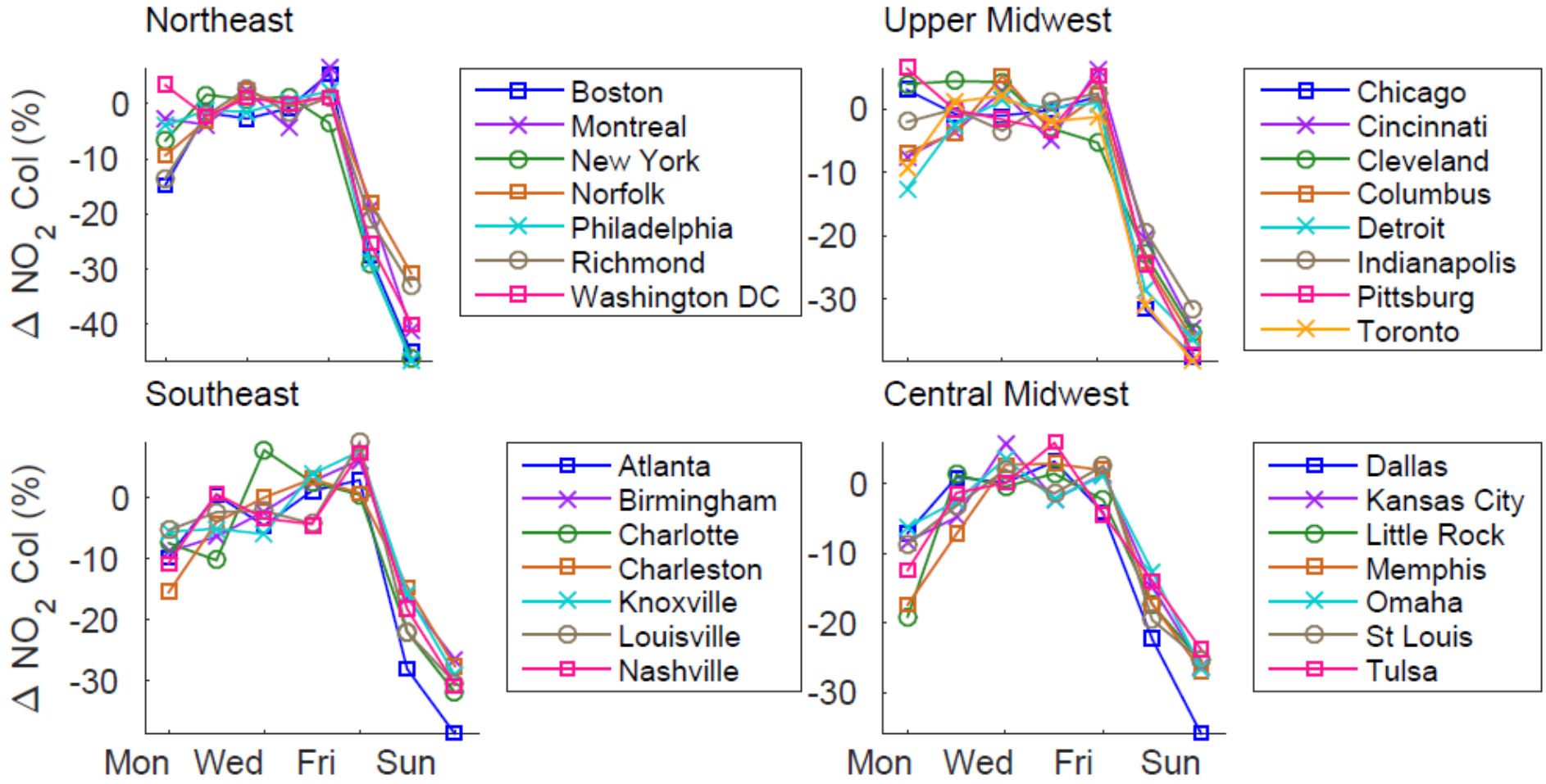


Uncertainty Analysis of Regression Model using Bootstrapping Algorithm

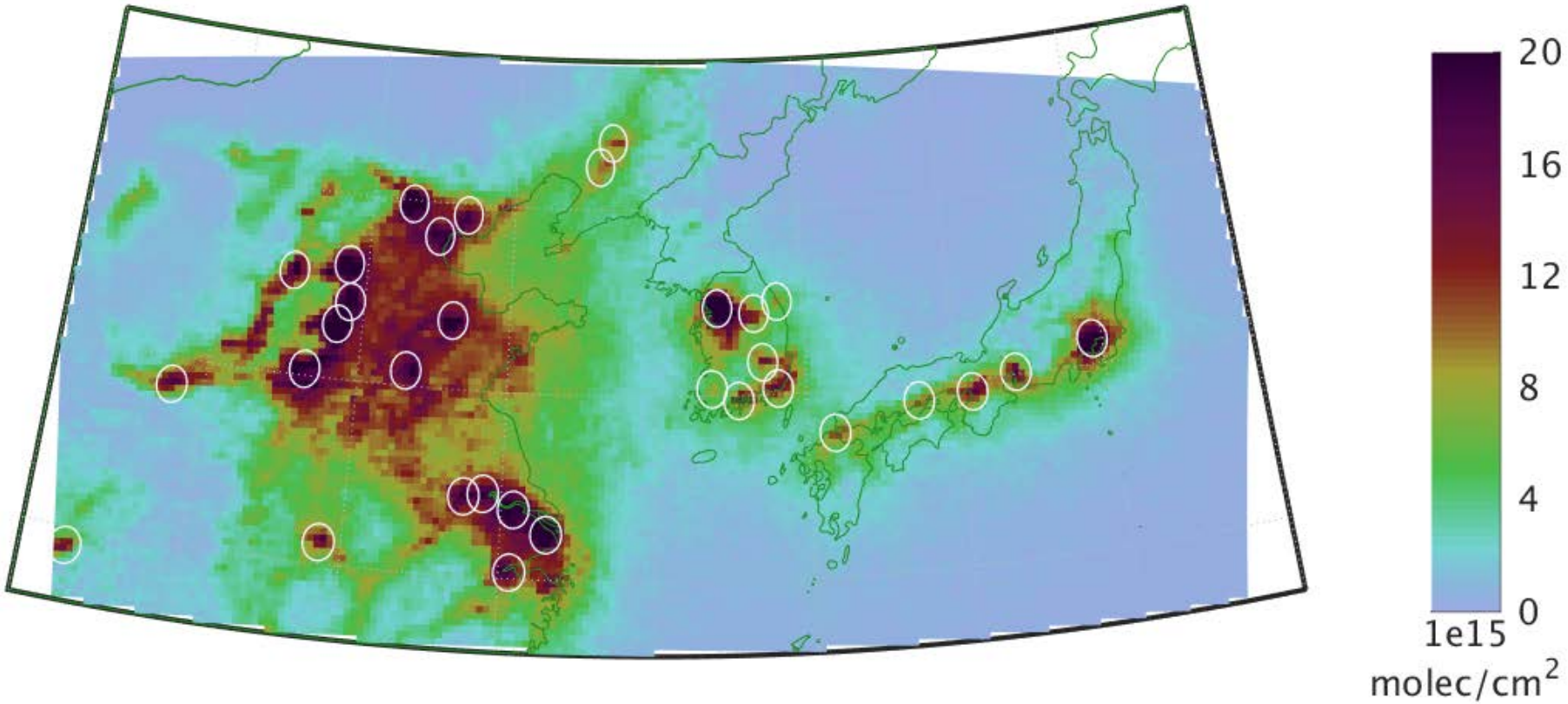
North American Metropolitan Areas: Strong long-term reductions, temporary recession impacts



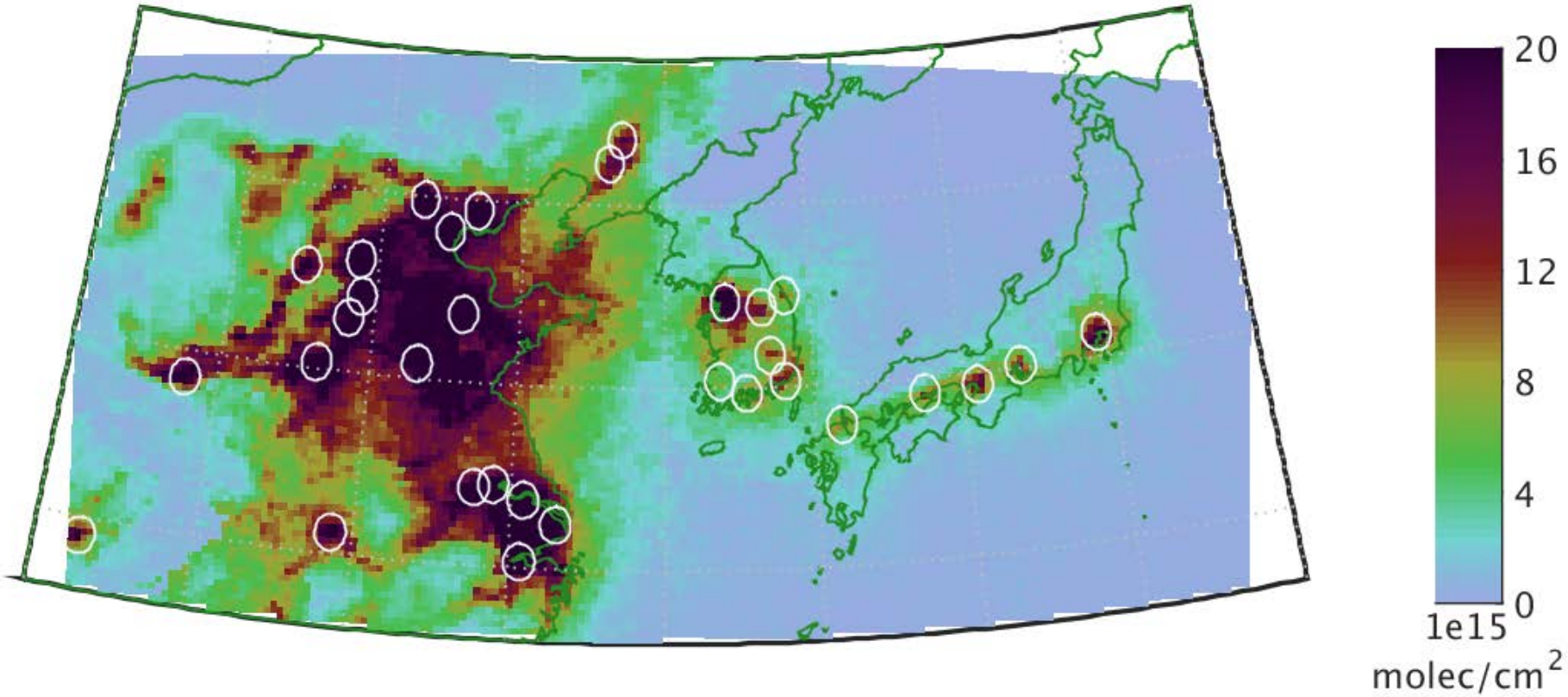
North American Metropolitan Areas: Weekend Effects: Strong, but Variable



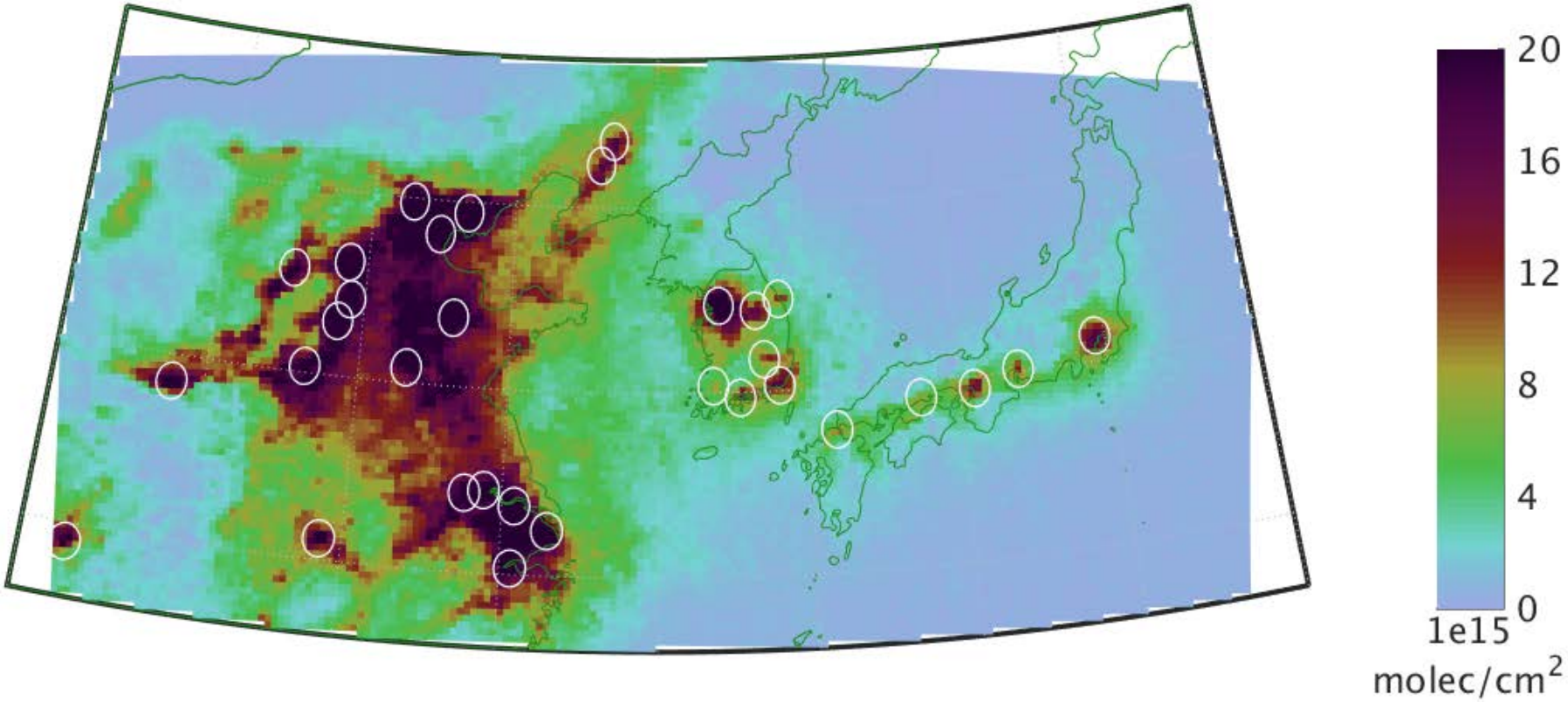
OMI NO_2 over NE Asia - 2005



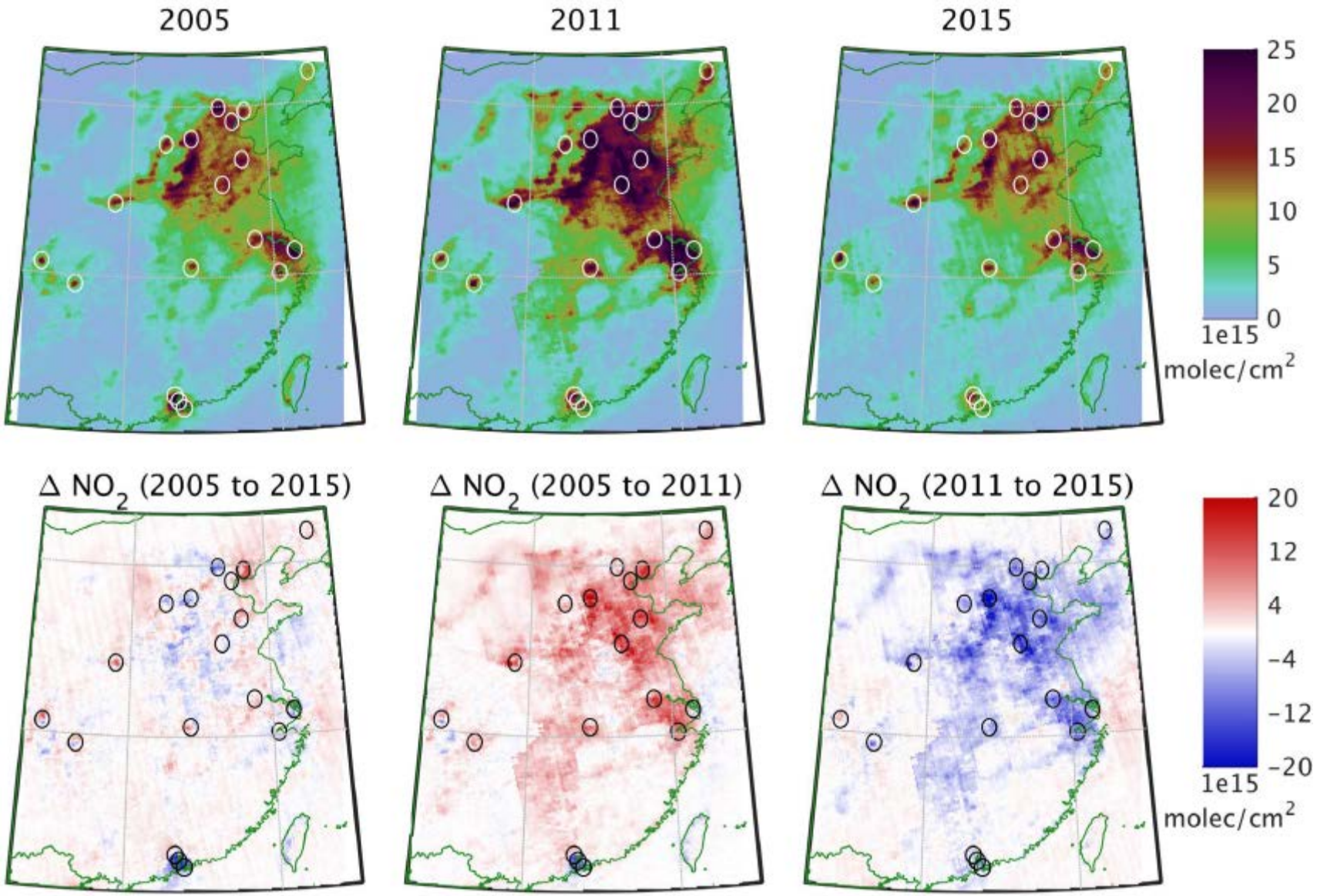
OMI NO_2 over NE Asia - 2011



OMI NO_2 over NE Asia - 2014

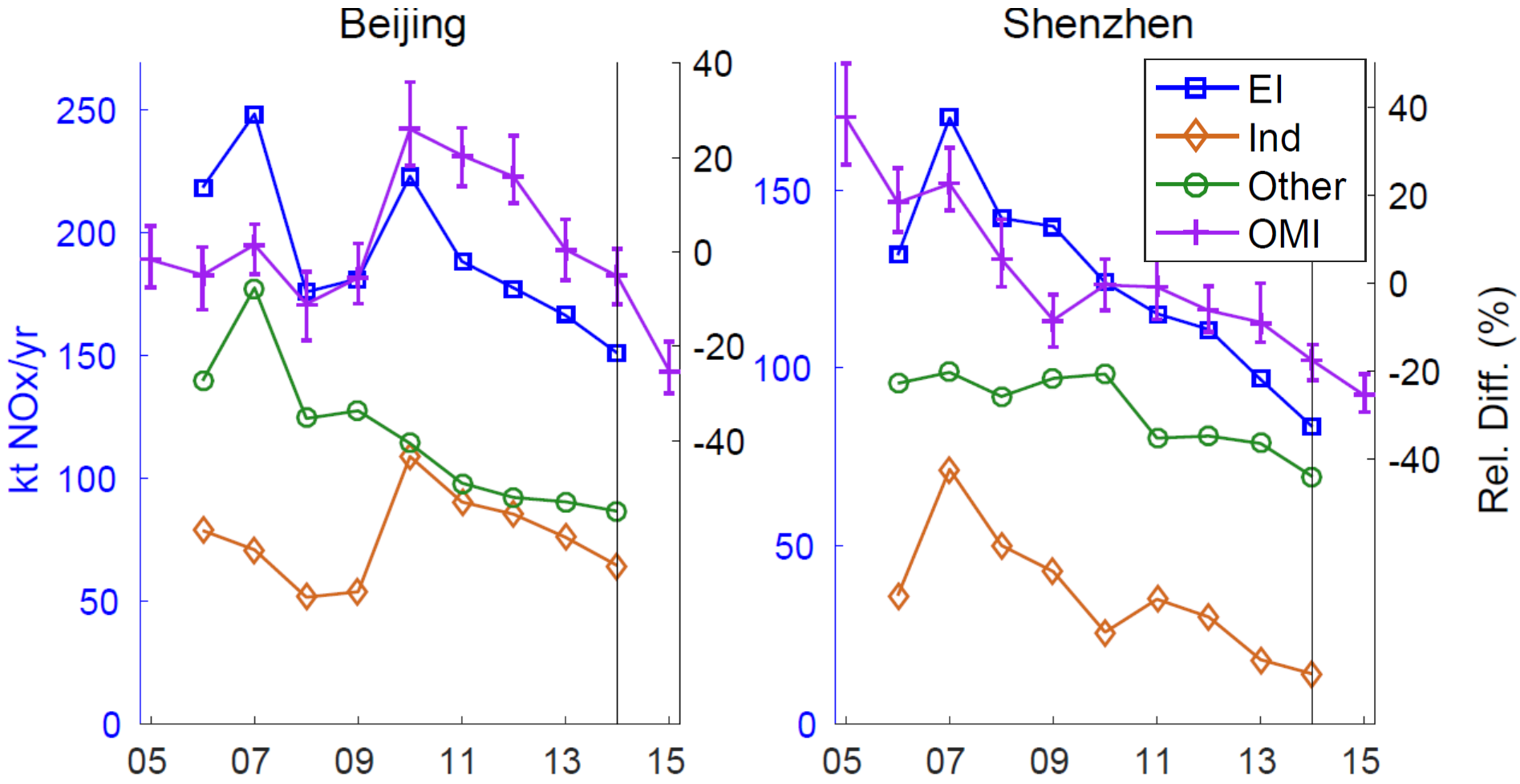


OMI NO_2 over China



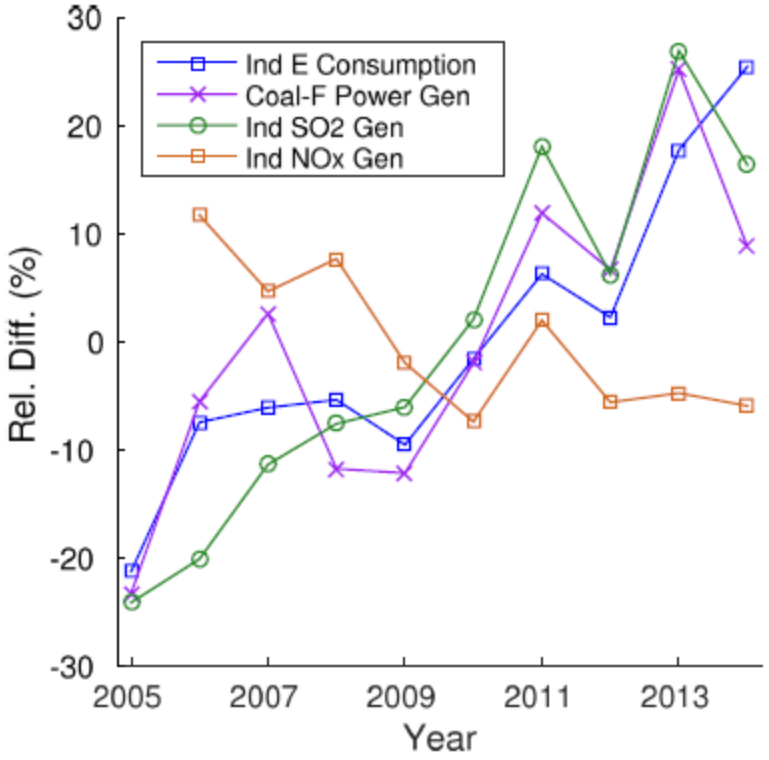
de Foy, Lu, Streets: Satellite NO2 retrievals suggest China has exceeded its NOx reduction goals from the twelfth Five-Year Plan, Scientific Reports, 2016.

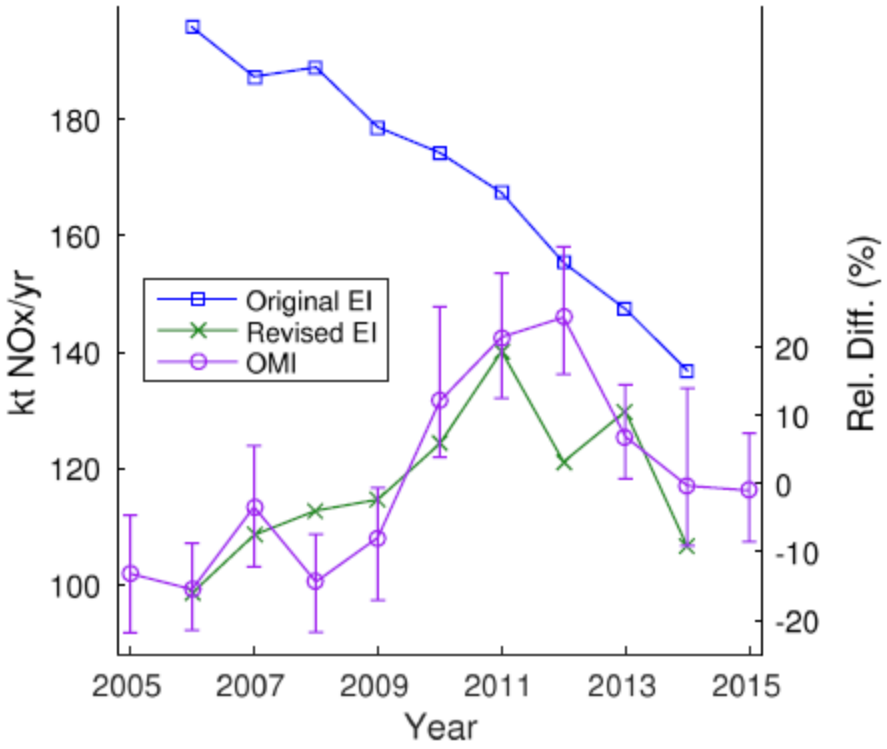
OMI NO_2 over China



de Foy, Lu, Streets: Satellite NO2 retrievals suggest China has exceeded its NOx reduction goals from the twelfth Five-Year Plan, Scientific Reports, 2016.

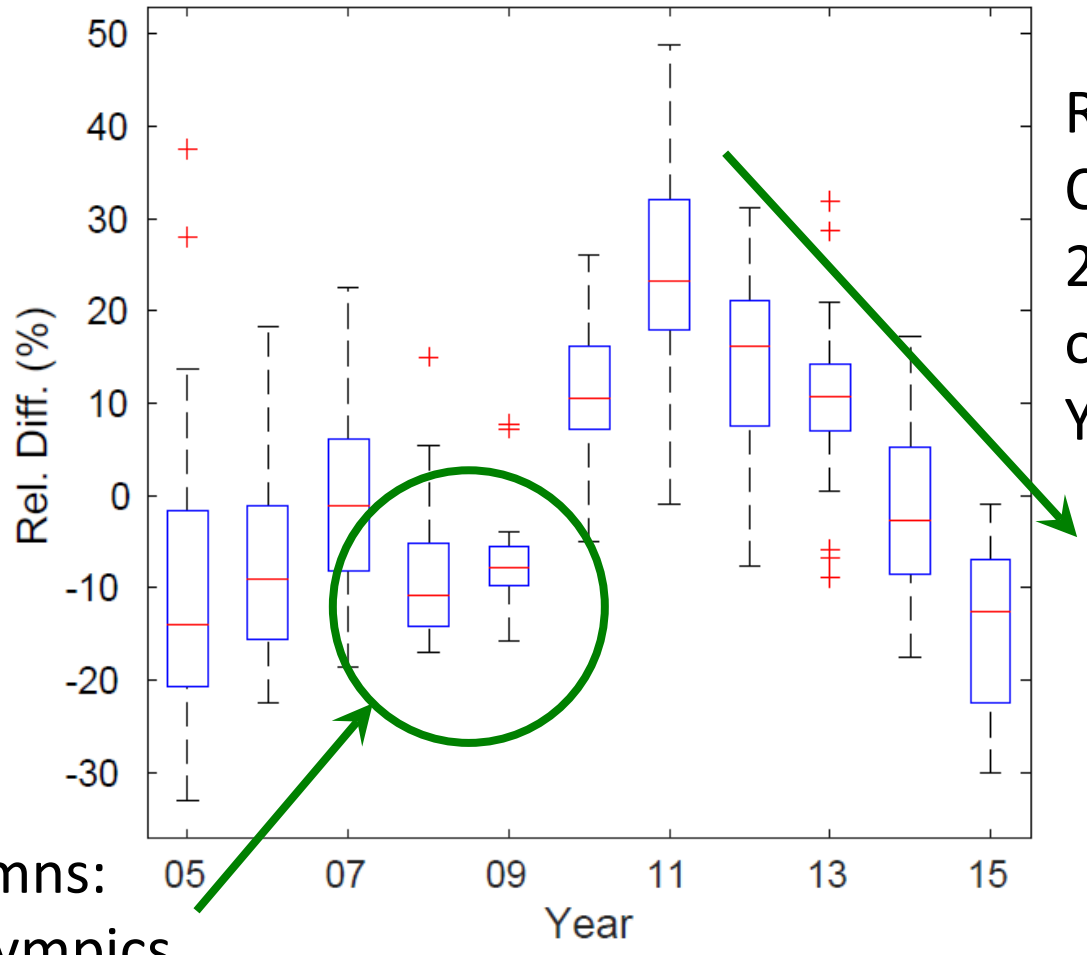
Emissions Inventory Evaluation: Satellite Data Suggest Wuhan Inventory Needs Revisions





de Foy, Lu, Streets: Satellite NO2 retrievals suggest China has exceeded its NOx reduction goals from the twelfth Five-Year Plan, Scientific Reports, 2016.

OMI NO_2 over Multiple Sites in China

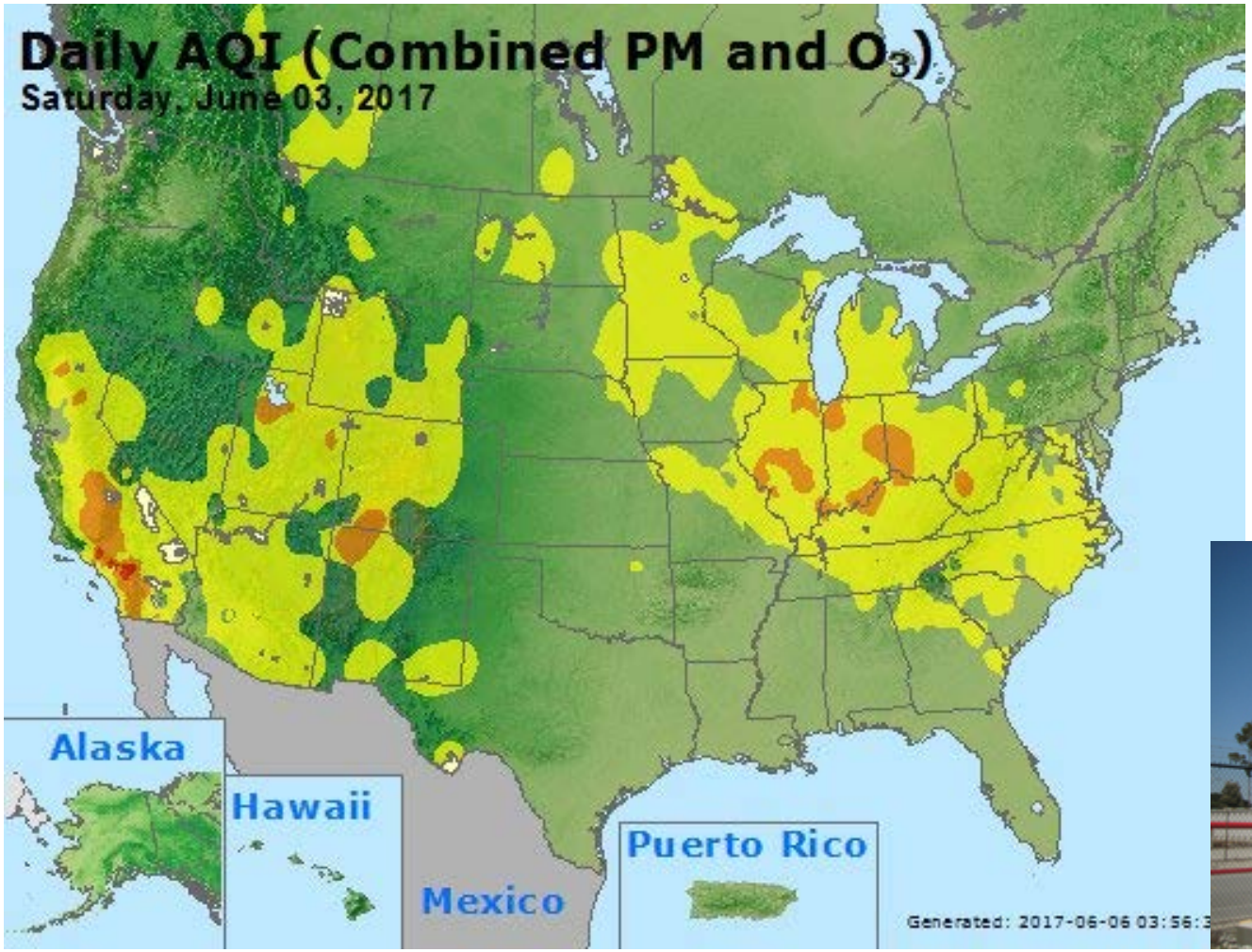


Reduced Columns since 2011 as a result of the 12th Five Year Plan

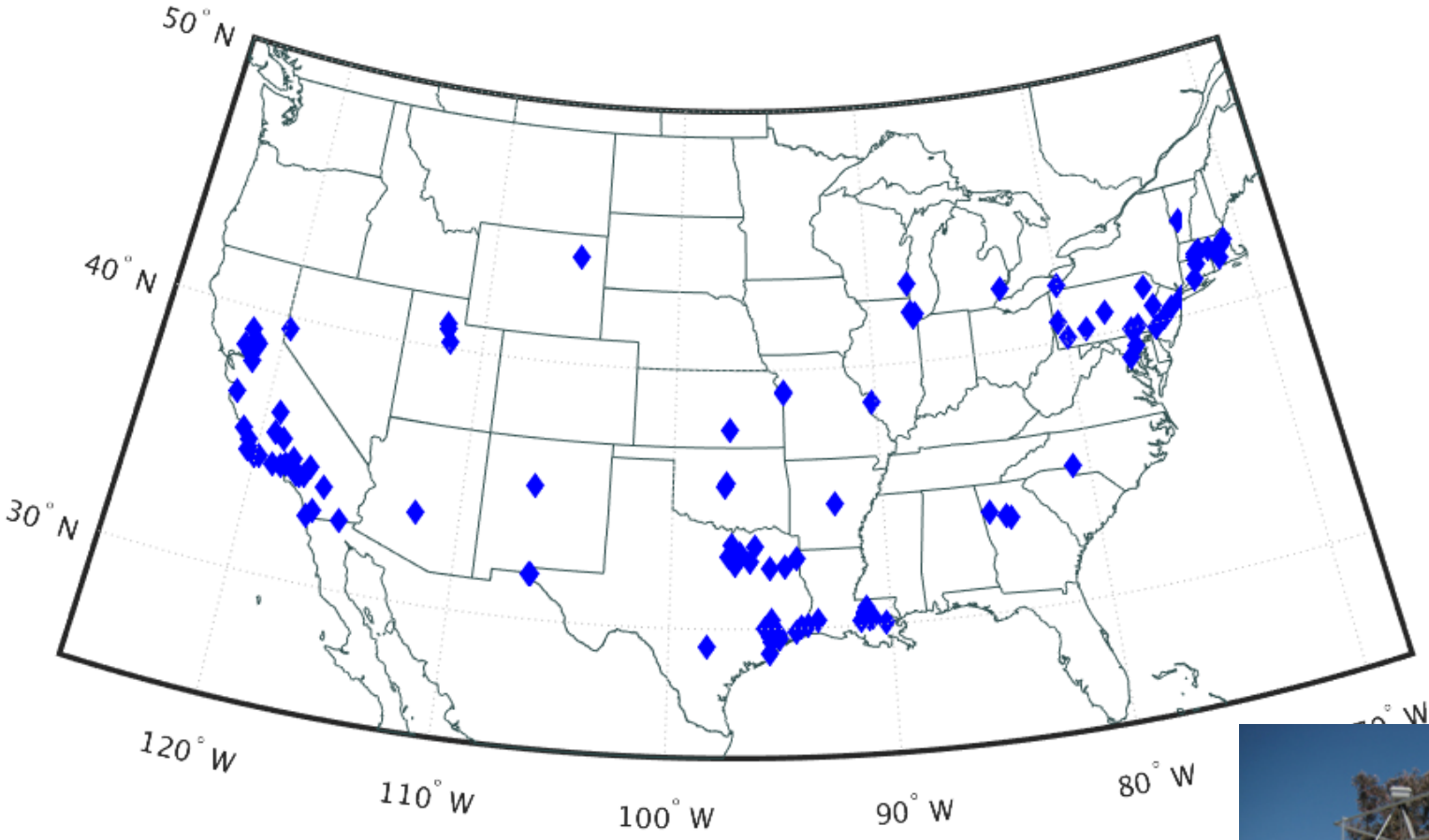
Reduced Columns: Recession / Olympics

de Foy, Lu, Streets: Satellite NO_2 retrievals suggest China has exceeded its NO_x reduction goals from the twelfth Five-Year Plan, Scientific Reports, 2016.

Hourly Air Quality Monitoring at Hundreds of Stations

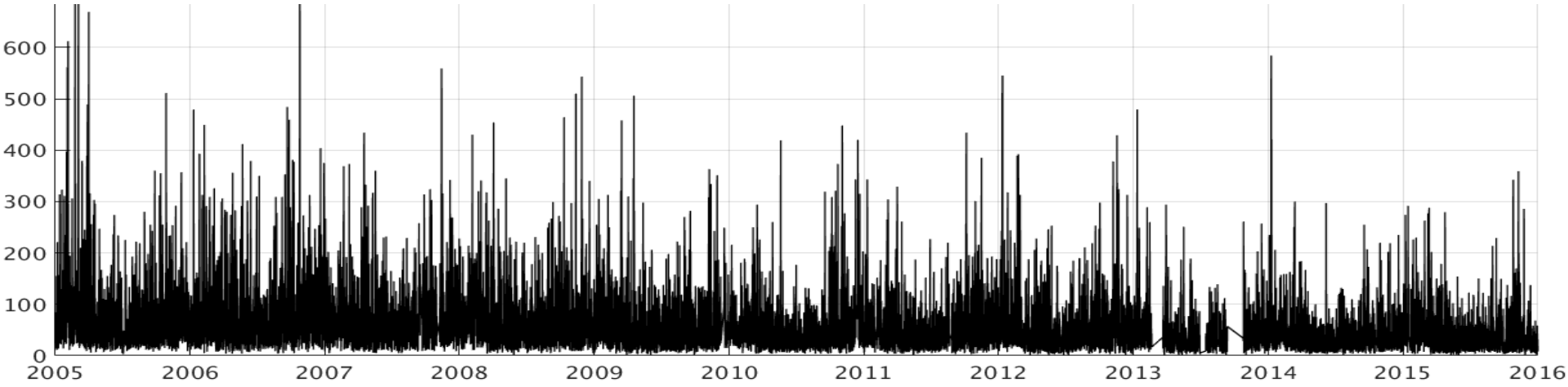


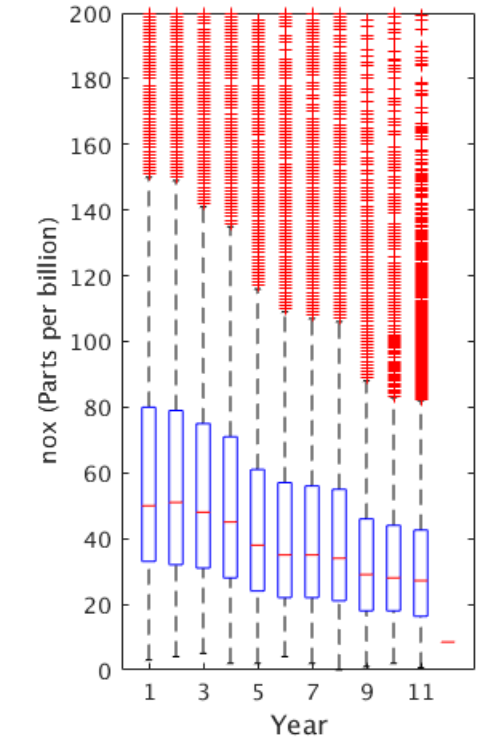
US-EPA AQS Data Analysis of Hourly NO_x Concentrations

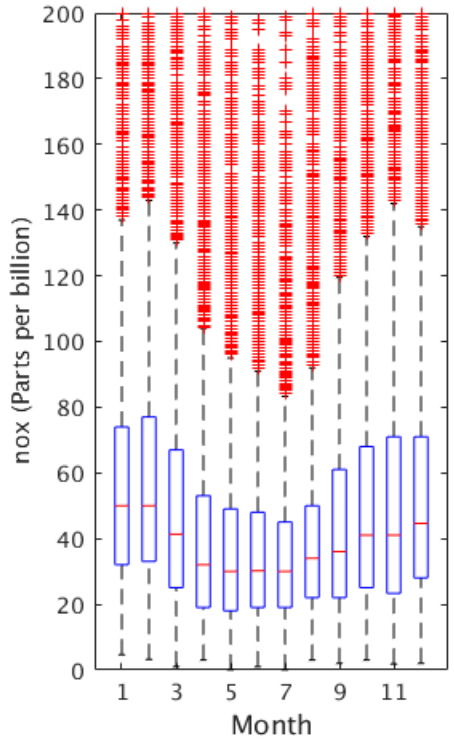


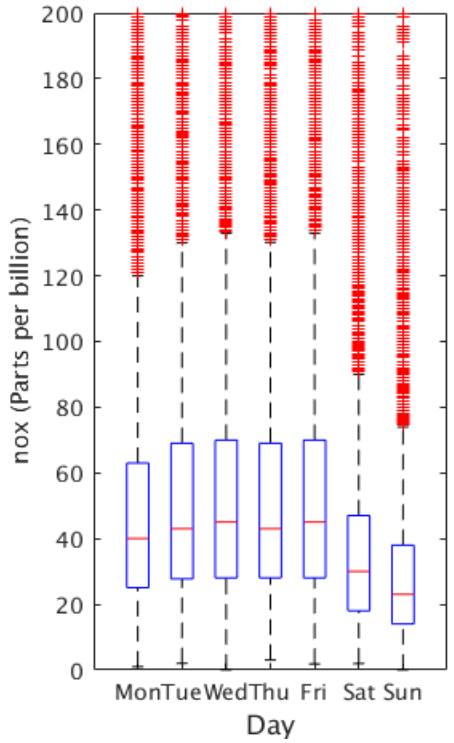
Sites with 90% data for 2005-2015

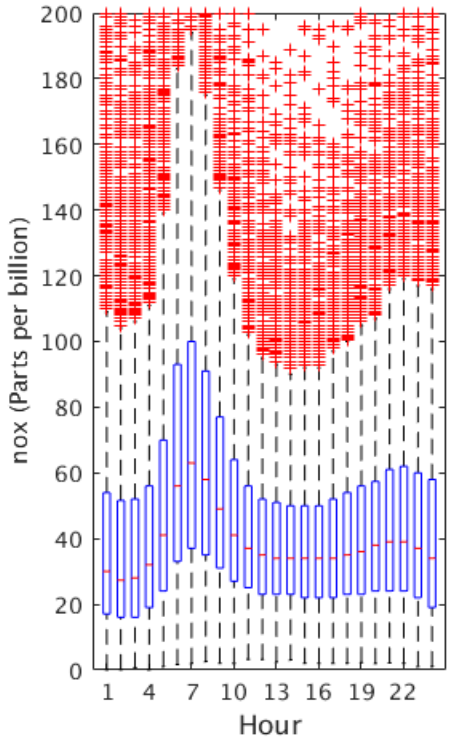
US-EPA AQS Data Analysis: NO_x Concentration in Suburban Chicago









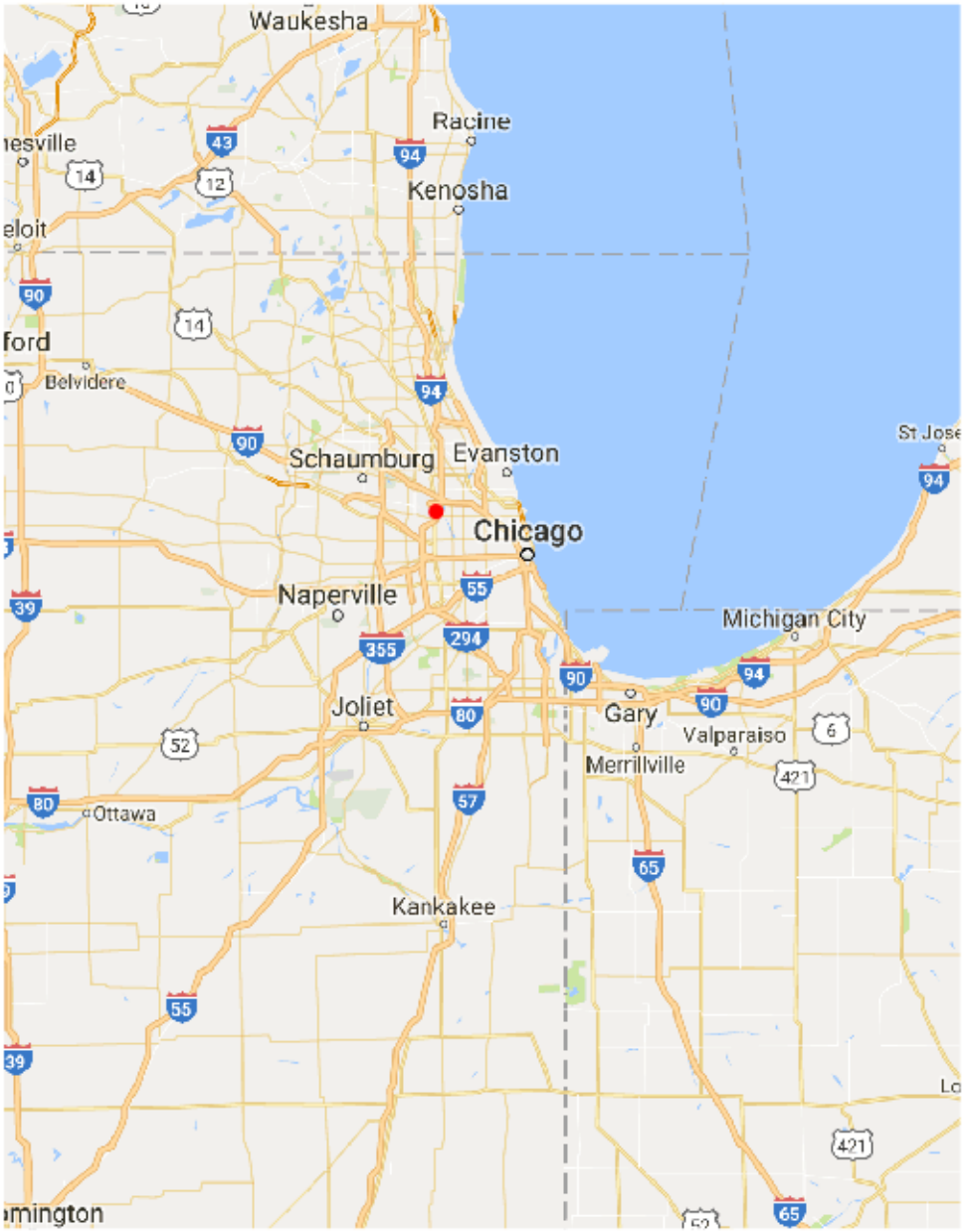


US-EPA AQS Data Analysis: Hourly NO_x Concentrations 2005-2015, 90% data completeness

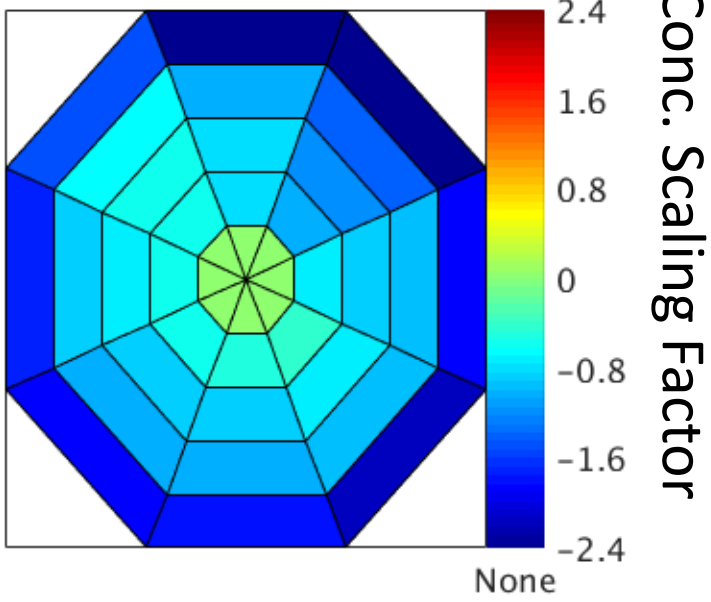
Factors Contributing to NO_x Surface Concentrations:

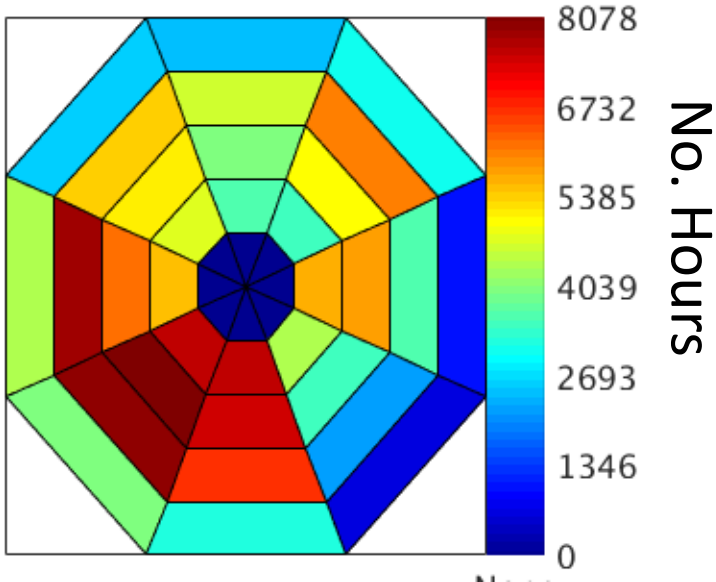
- **Emissions:** diurnal, weekly, seasonal, long-term signals
- **Transport:** wind speed and direction, boundary layer height
- **Chemistry:** NO_x lifetime: rough proxies: ozone, ultraviolet radiation, temperature, humidity

AQS Multi-Linear Regression for Suburban Chicago

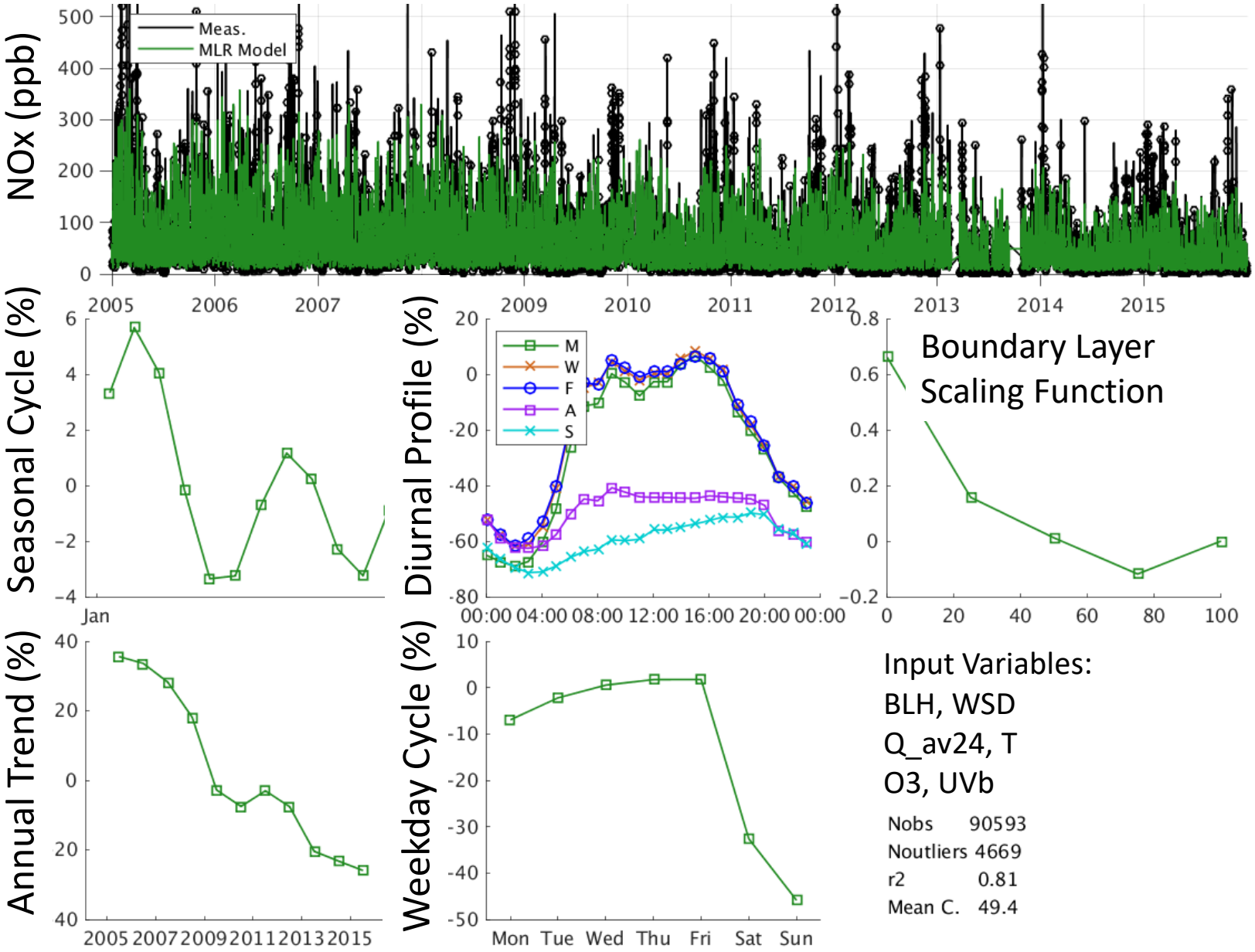


Wind Impacts at the Site



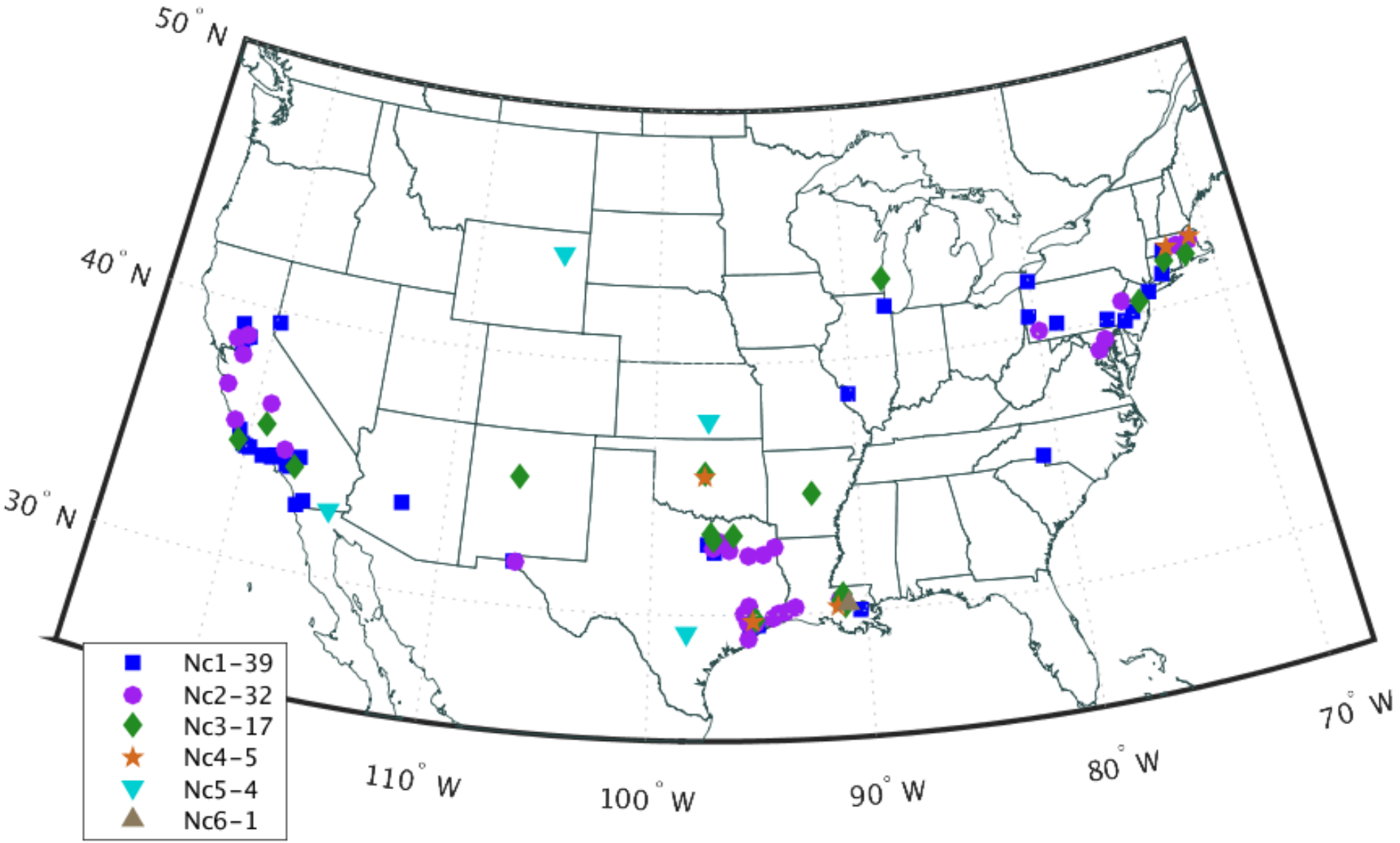


AQS Multi-Linear Regression for Suburban Chicago

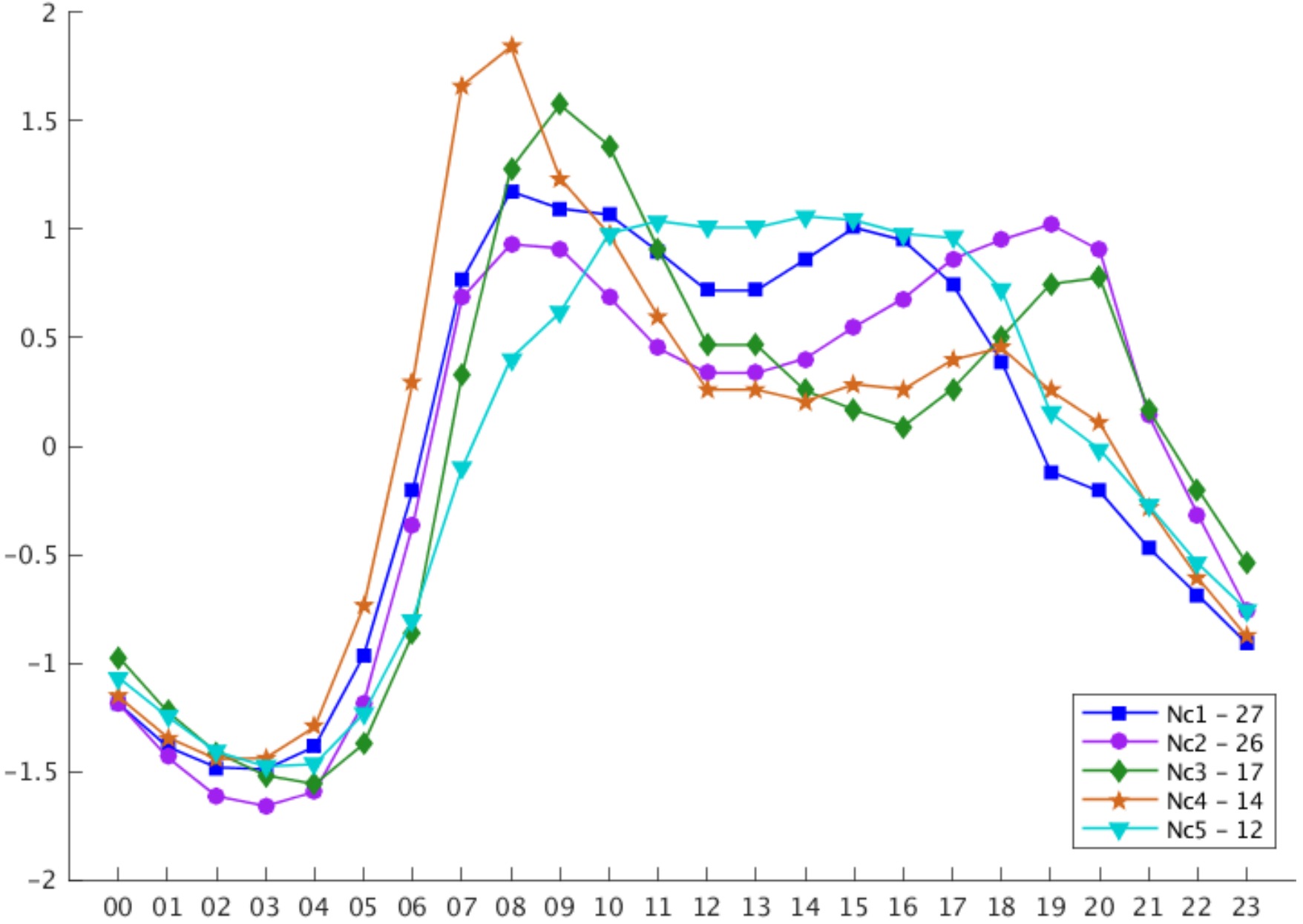


Top 3 Clusters of Annual Patterns for 110 US sites

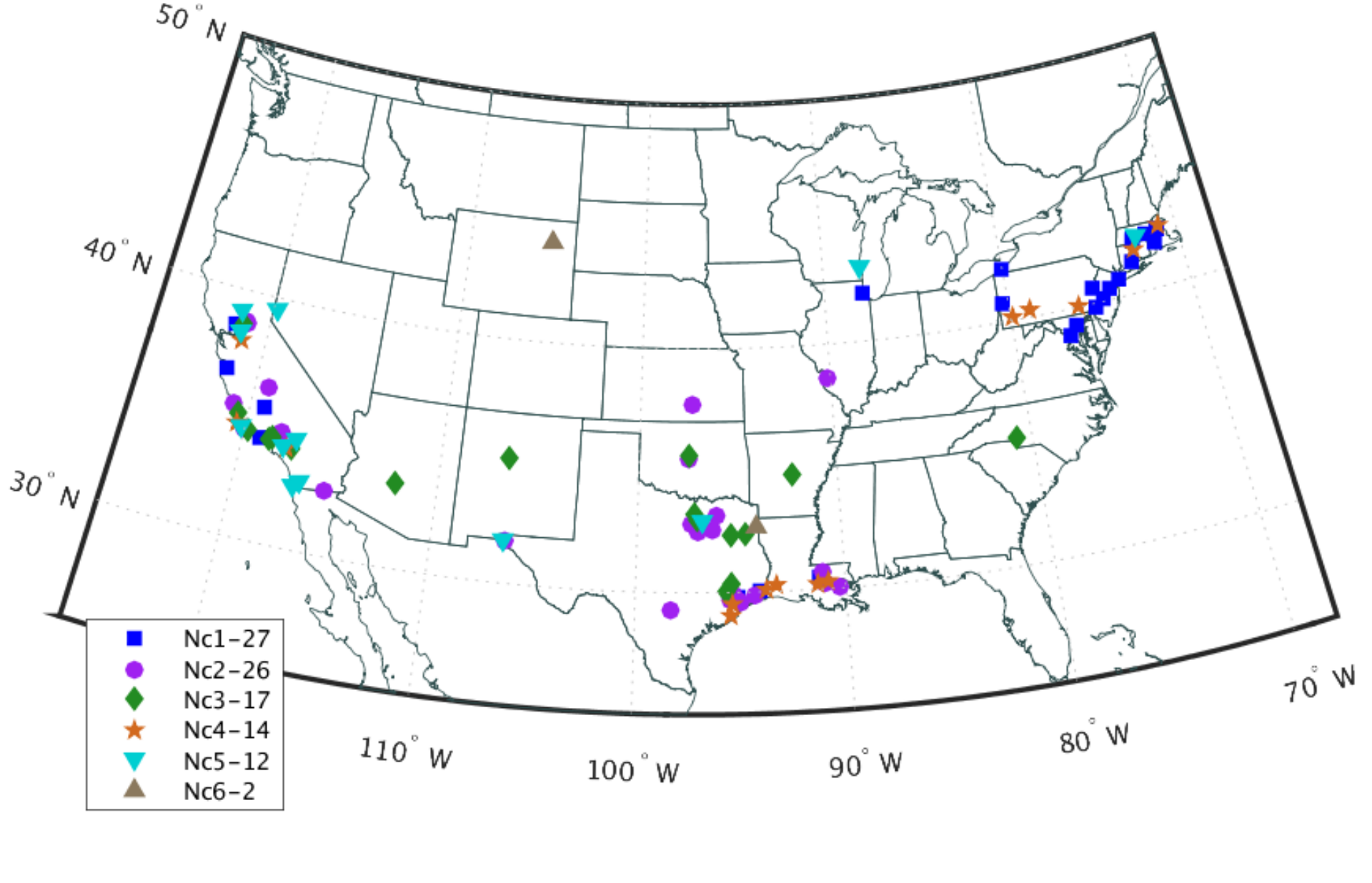
Clusters of Annual Patterns



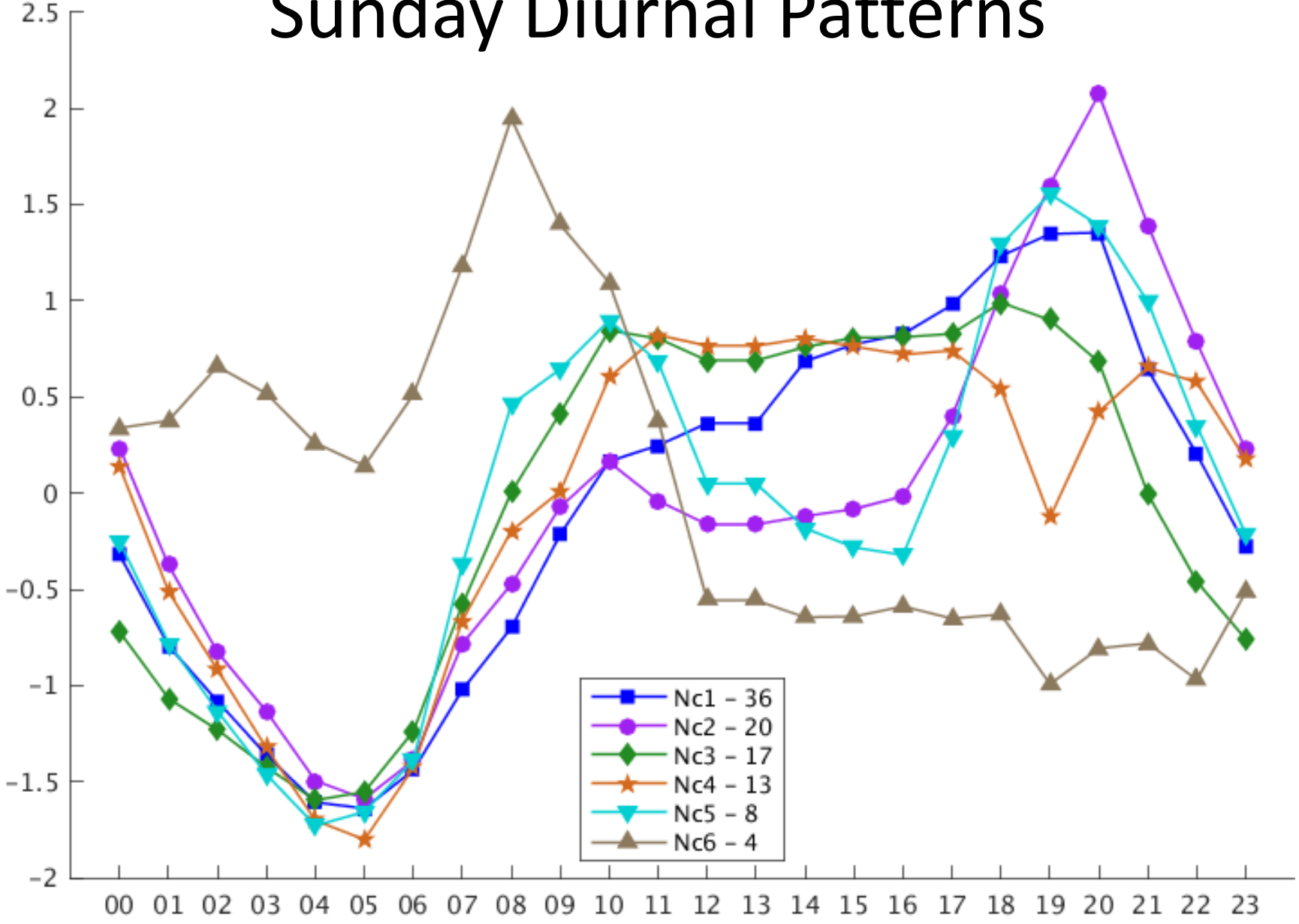
Mid-Week Diurnal Patterns



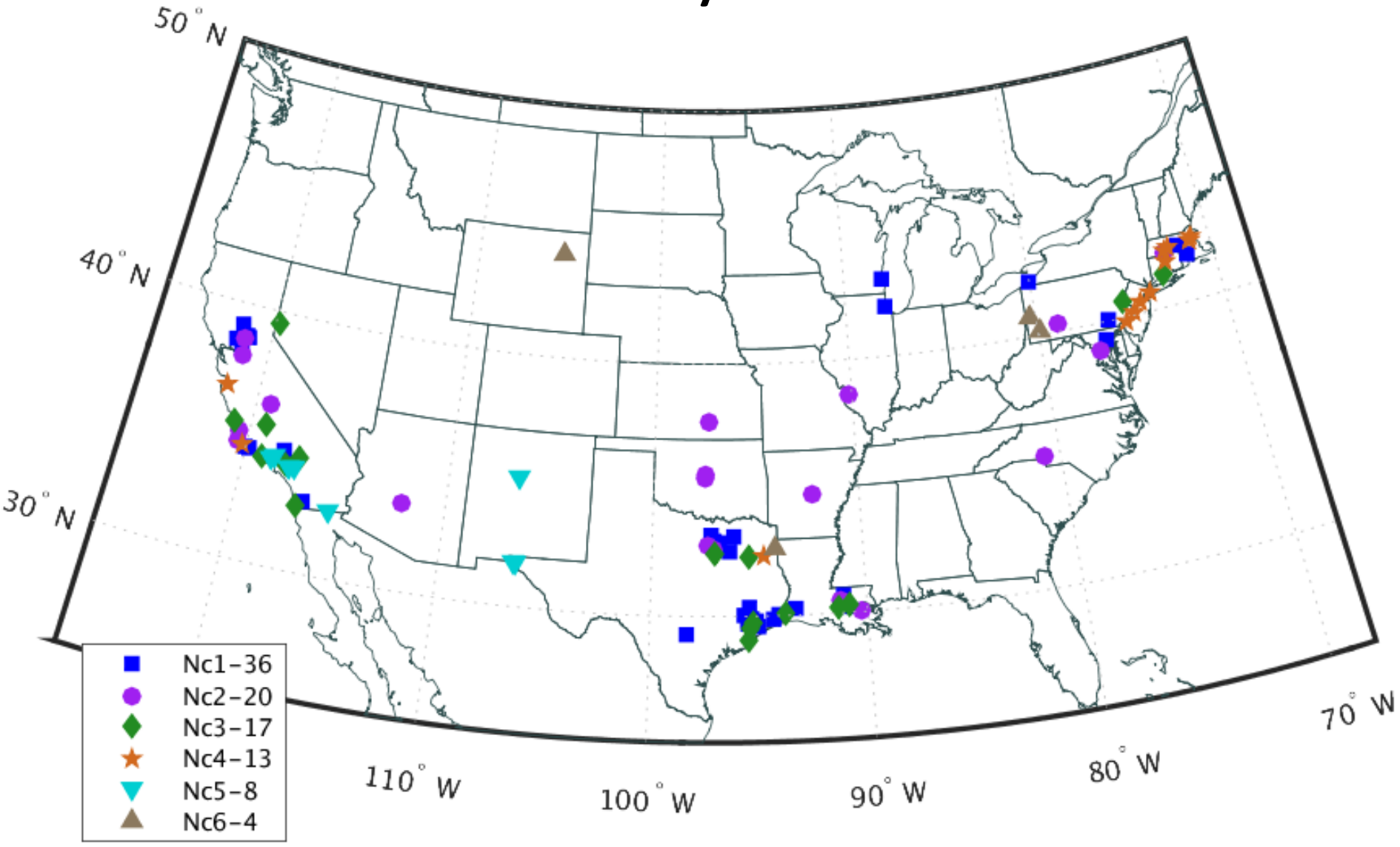
Clusters of Mid-Week Diurnal Patterns



Sunday Diurnal Patterns



Clusters of Sunday Diurnal Patterns



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Diurnal, weekday and long-term patterns in NOx emissions based on decade-long time series of hourly AQS data

Benjamin de Foy

- There have been strong reductions in NOx emissions in the last 10 years
- The recession had a significant temporary impact on emissions
- The week-end effect is stronger in larger cities
- Diurnal emission profiles vary by region in the US

- Multiple Linear Regression Analysis accounts for variations from multiple factors and hence gives clearer estimates of temporal signals in the data

This research is funded by
U.S. EPA - Science To Achieve Results (STAR) Program
Grant # RD 83455701

AQAST
NASA Air Quality Applied Sciences Team