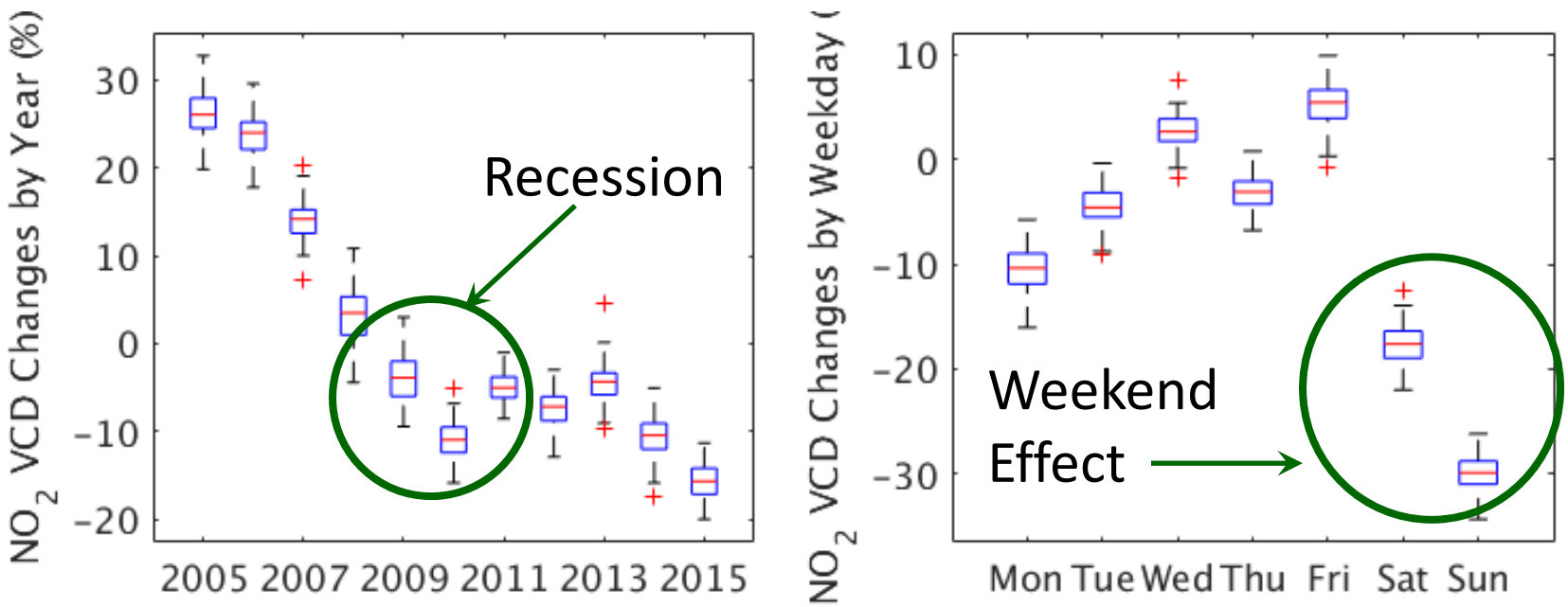
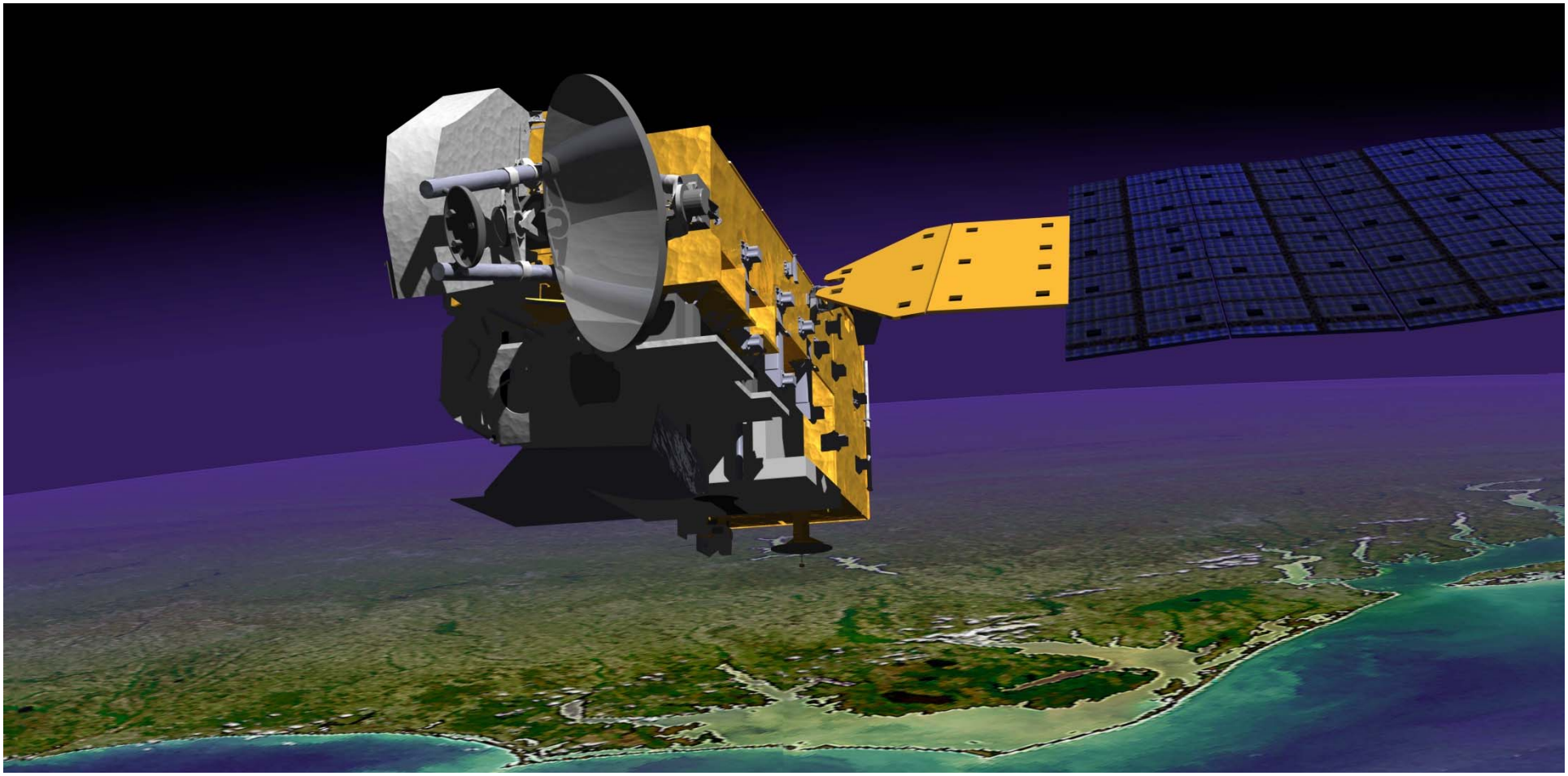
Satellite and Monitoring Data to Estimate NO_x Trends in St. Louis

Benjamin de Foy, Saint Louis University
Air Quality Advisory Committee
East-West Gateway, 25 October 2016



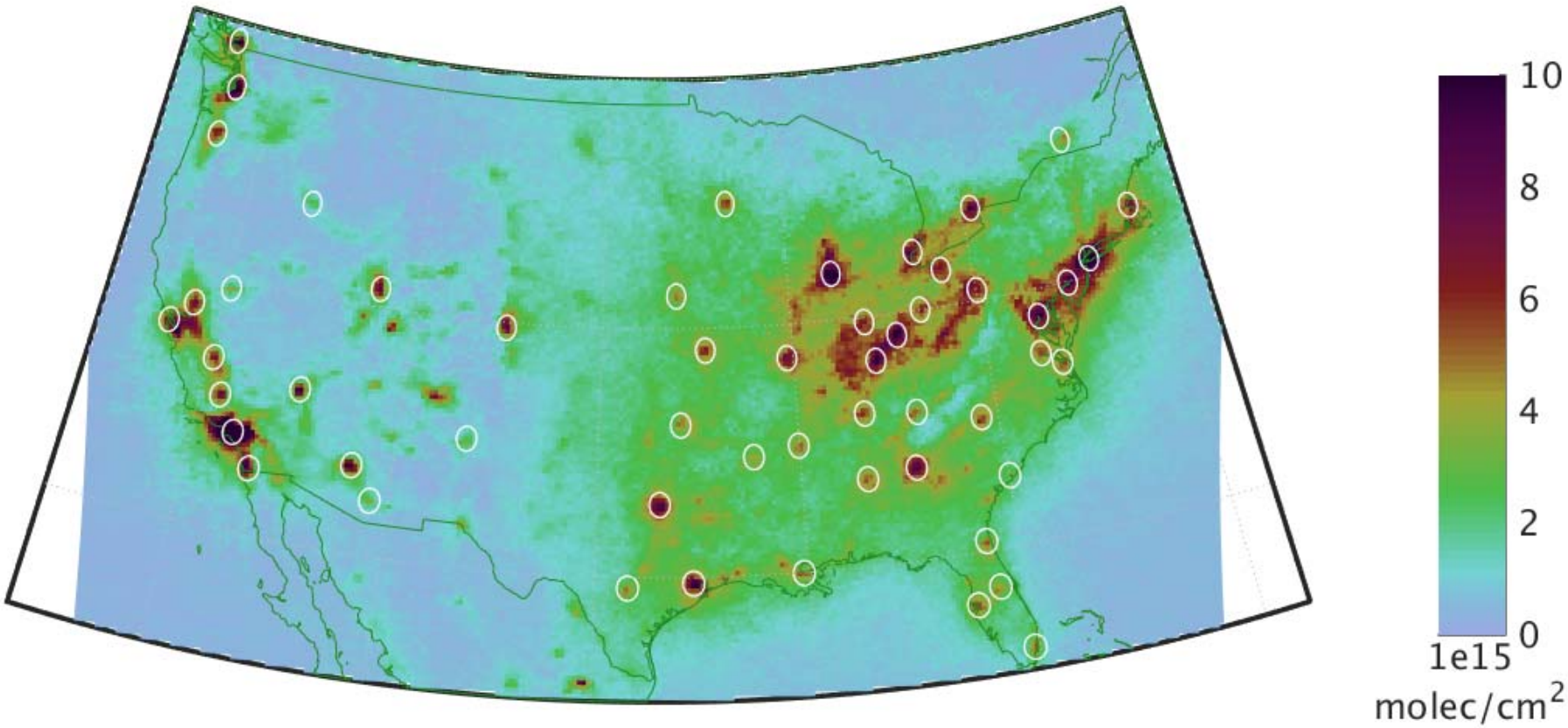
Long-term trends, reductions at the time of the recession and weekend effects over St. Louis

Ozone Monitoring Instrument (OMI) onboard Aura Satellite



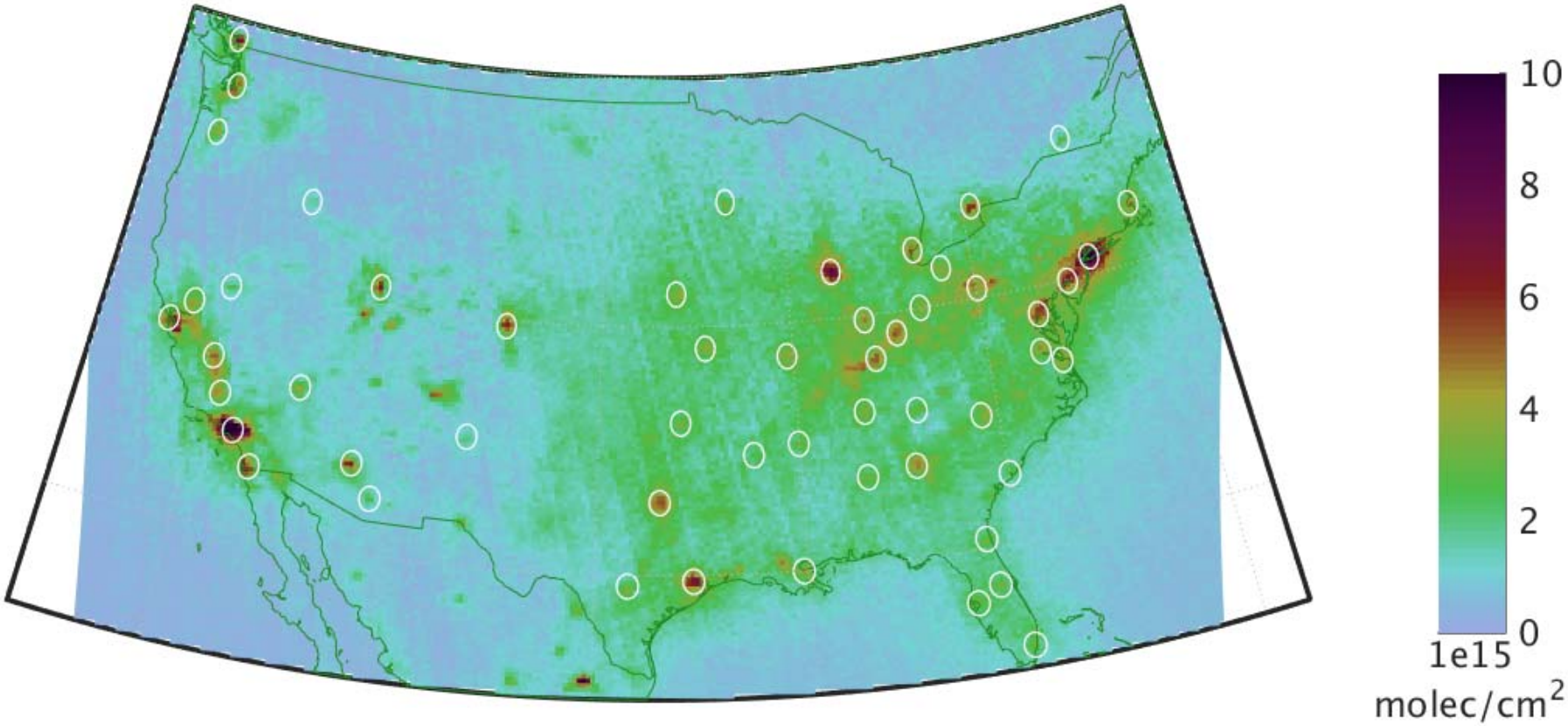
de Foy, B., Lu, Z. and Streets, D.G., 2016. Impacts of control strategies, the Great Recession and weekday variations on NO_2 columns above North American cities. *Atmospheric Environment*.

OMI NO_2 over the USA - 2005



Benjamin de Foy, Zifeng Lu, David G. Streets:
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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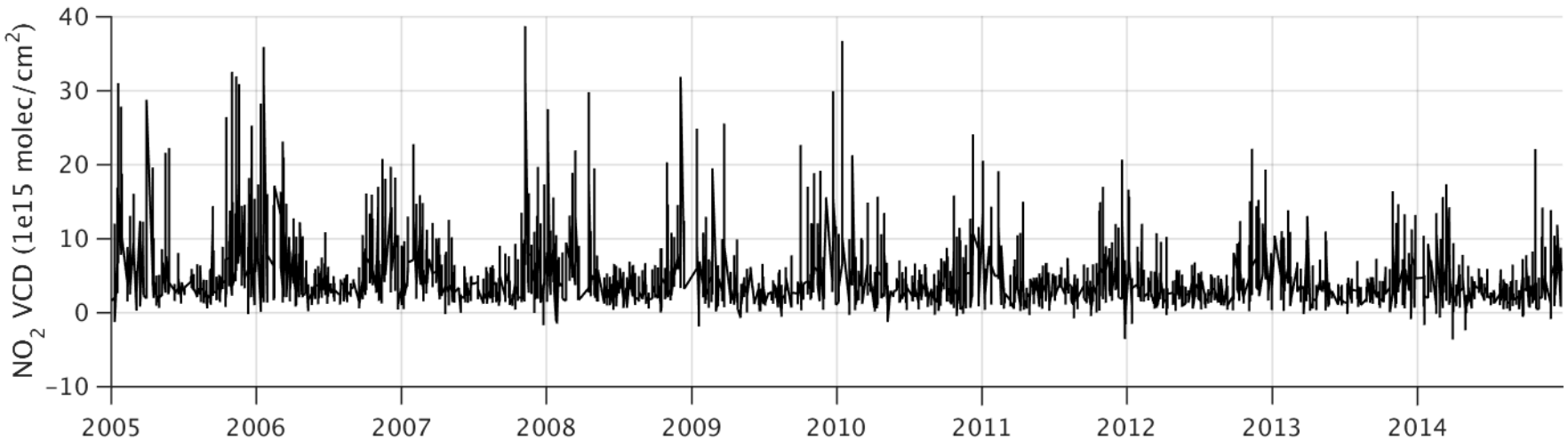
Impacts of control strategies, the Great Recession and weekday variations on NO2 columns above North American cities, Atmospheric Environment, 2016

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



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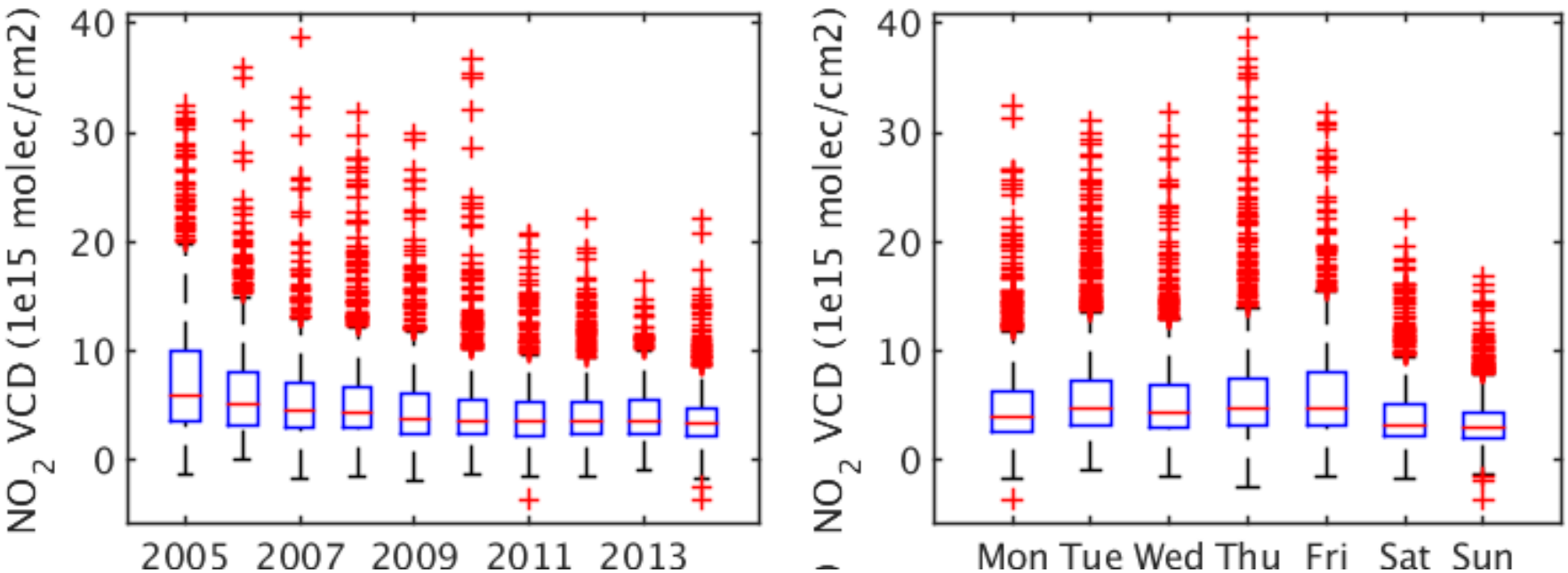
Boxplots by Different Time Windows over Atlanta:

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



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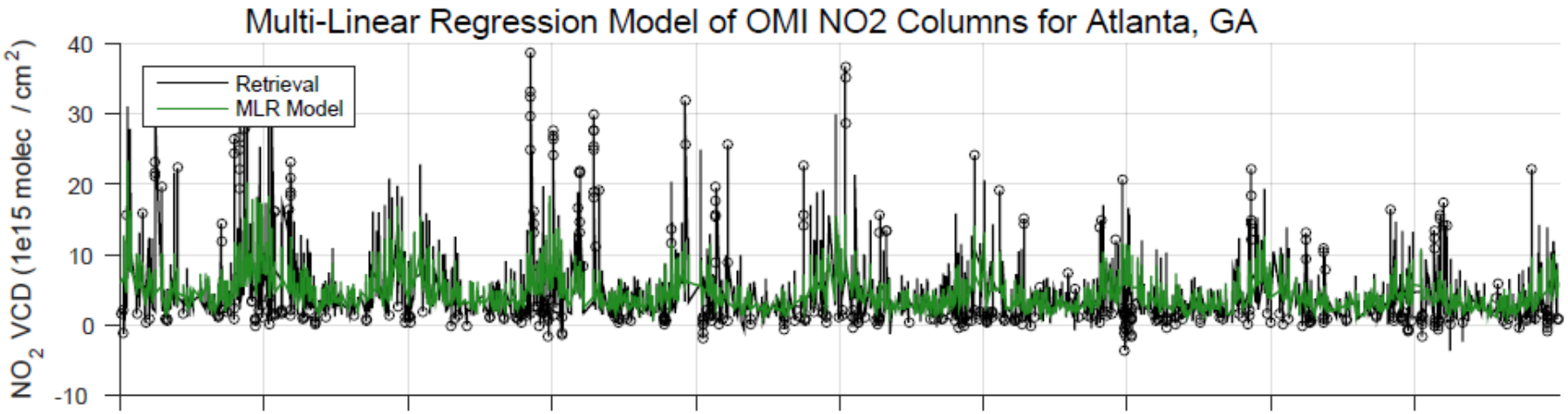
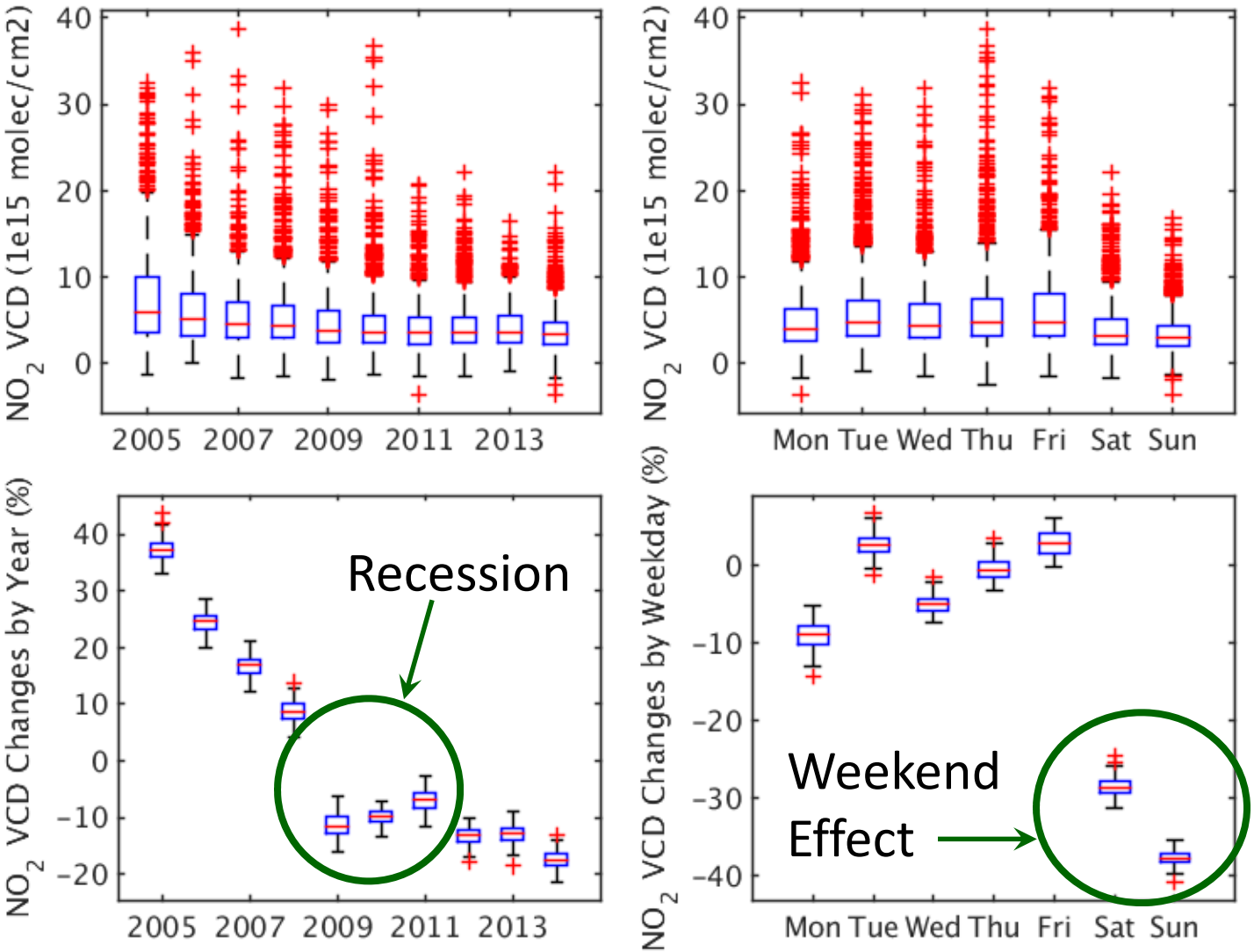
Factors Contributing to Variation in OMI NO_2 Columns

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		



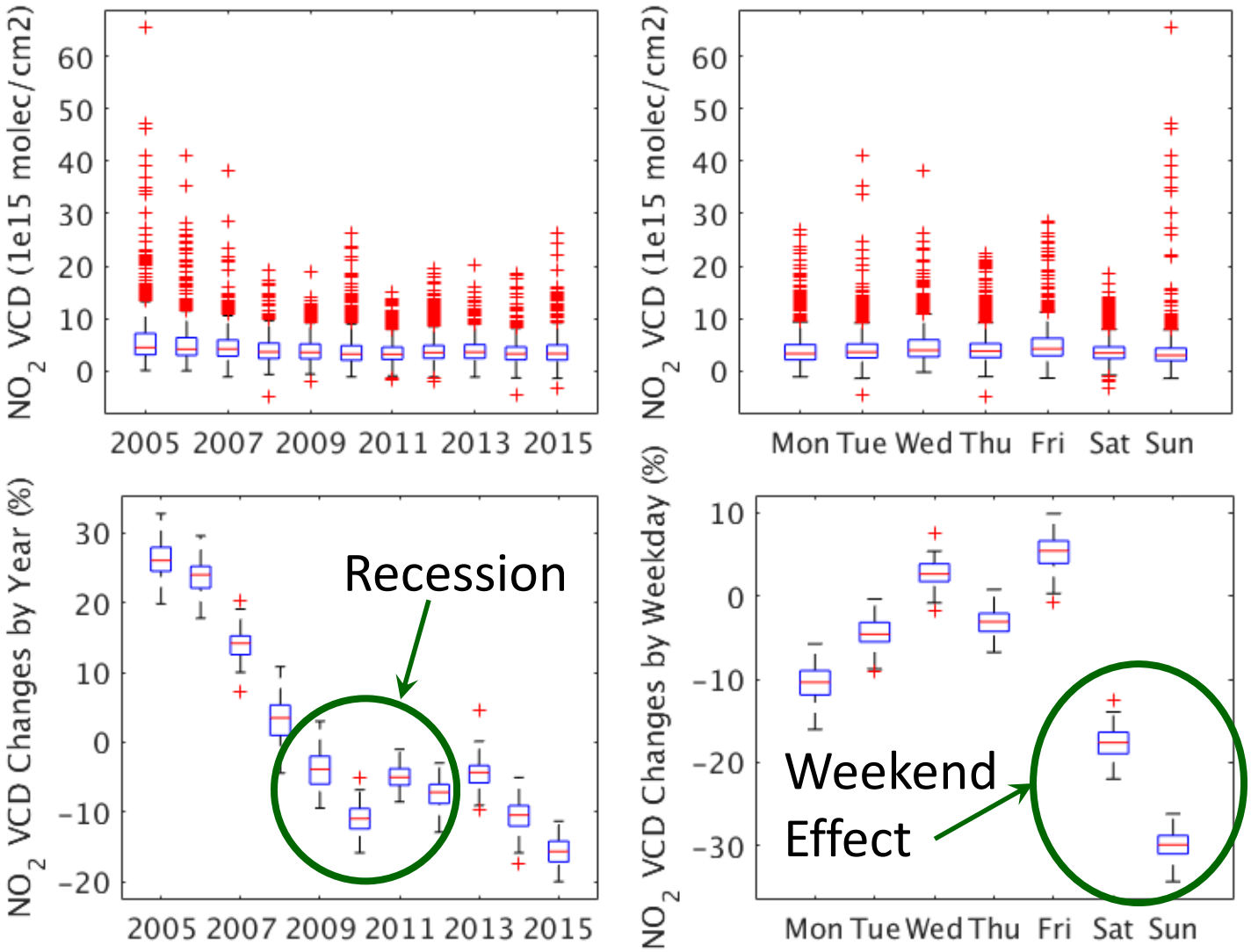
Stats		Annual	%	Weekday	%	Met/Pixel	
Nobs	8525	Trend	-5.5	Mon	-9.0	WS10	-0.18
Noutliers	462	2008	-3.6	Tue	2.6	T2	-0.07
r	0.74	2009	-16.4	Wed	-5.1	U10	-0.00
Mean VCD	5.3	2010	-10.8	Thu	-0.5	V10	-0.02
		2011	-2.6	Fri	3.2	Dmin	-0.10
				Sat	-28.7	Dmax	-0.07
				Sun	-37.7		

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



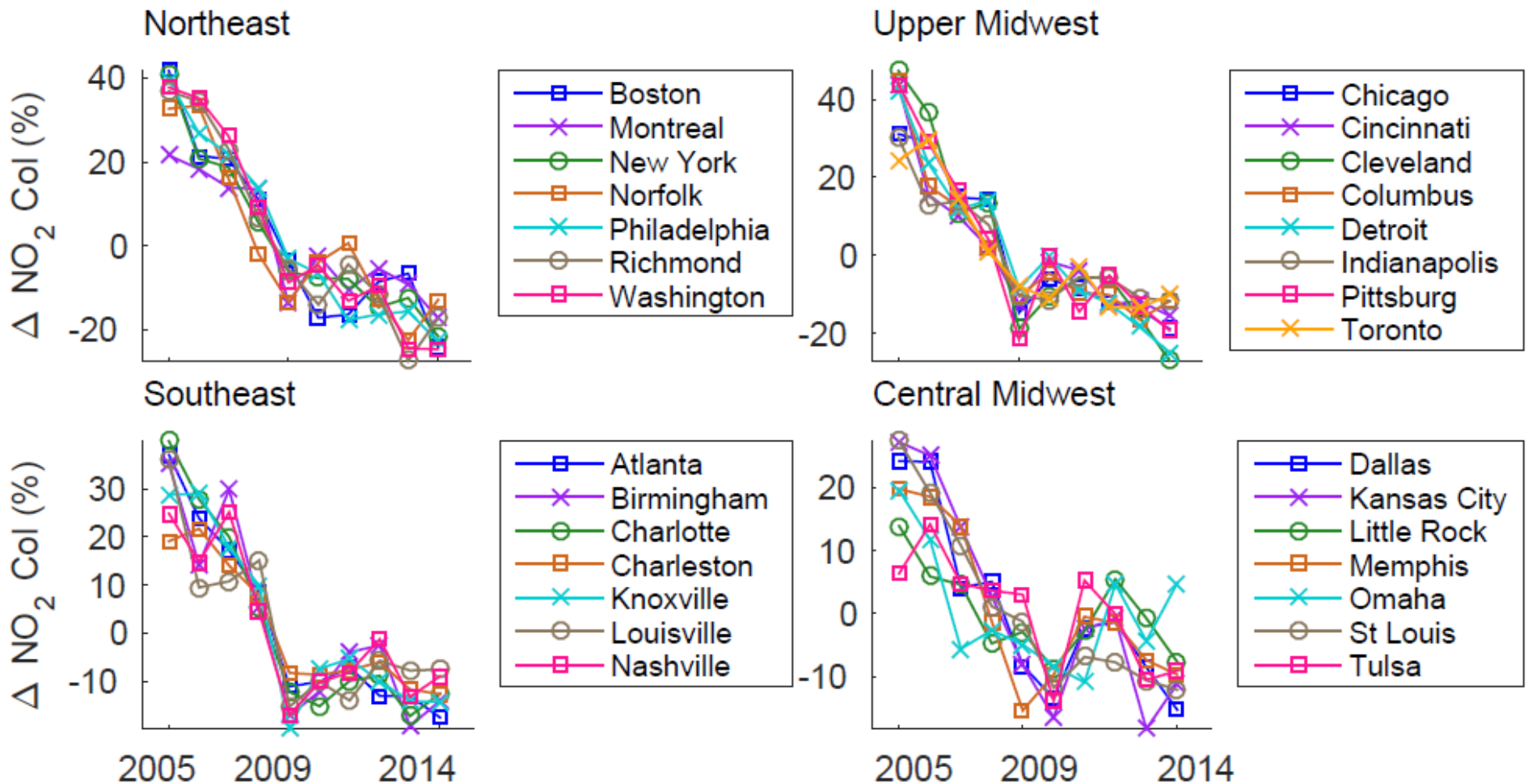
Uncertainty Analysis of Regression Model using Bootstrapping Algorithm

Multiple Linear Regression yields cleaner annual and weekly signals than simple averaging – St. Louis

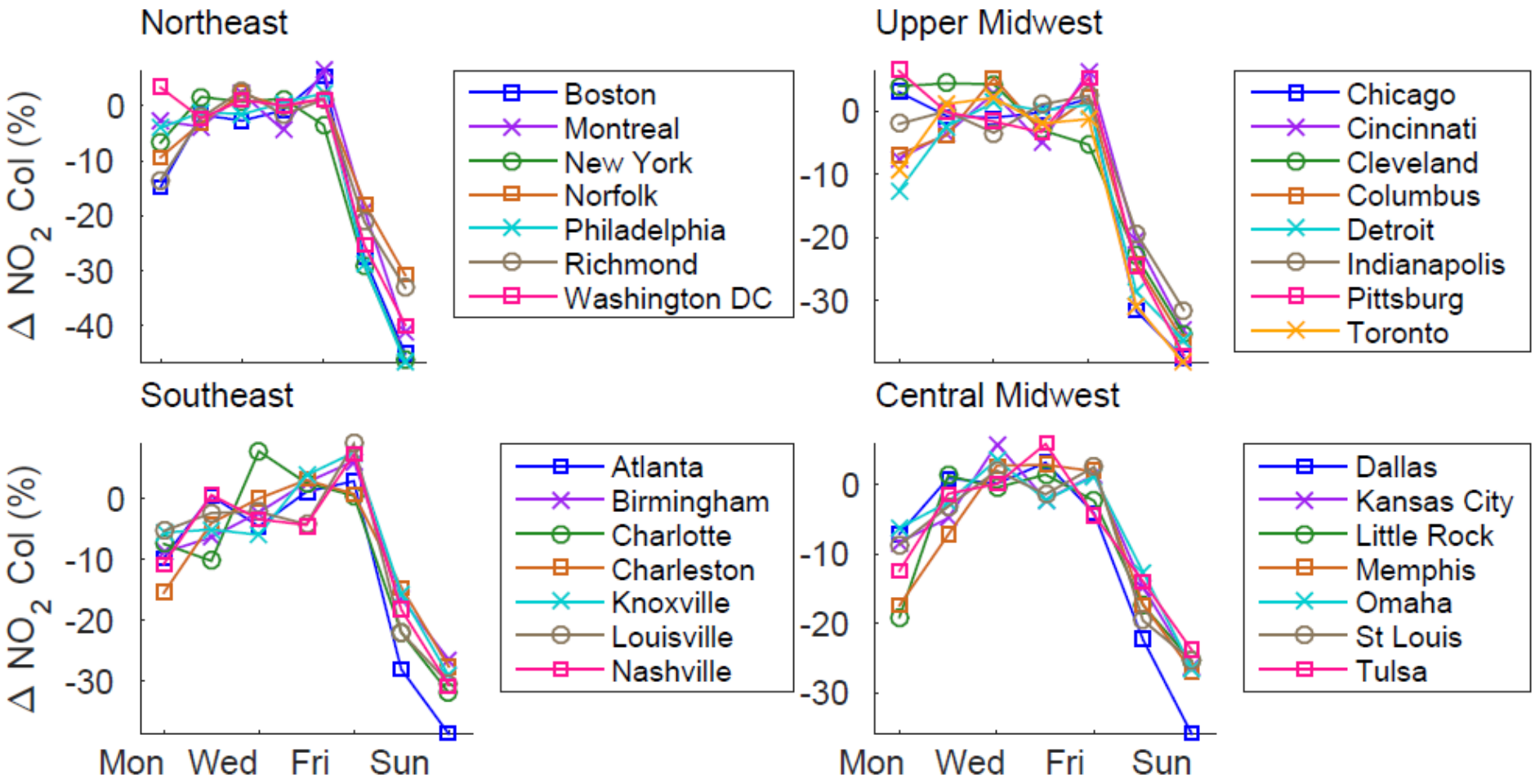


Uncertainty Analysis of Regression Model using Bootstrapping Algorithm

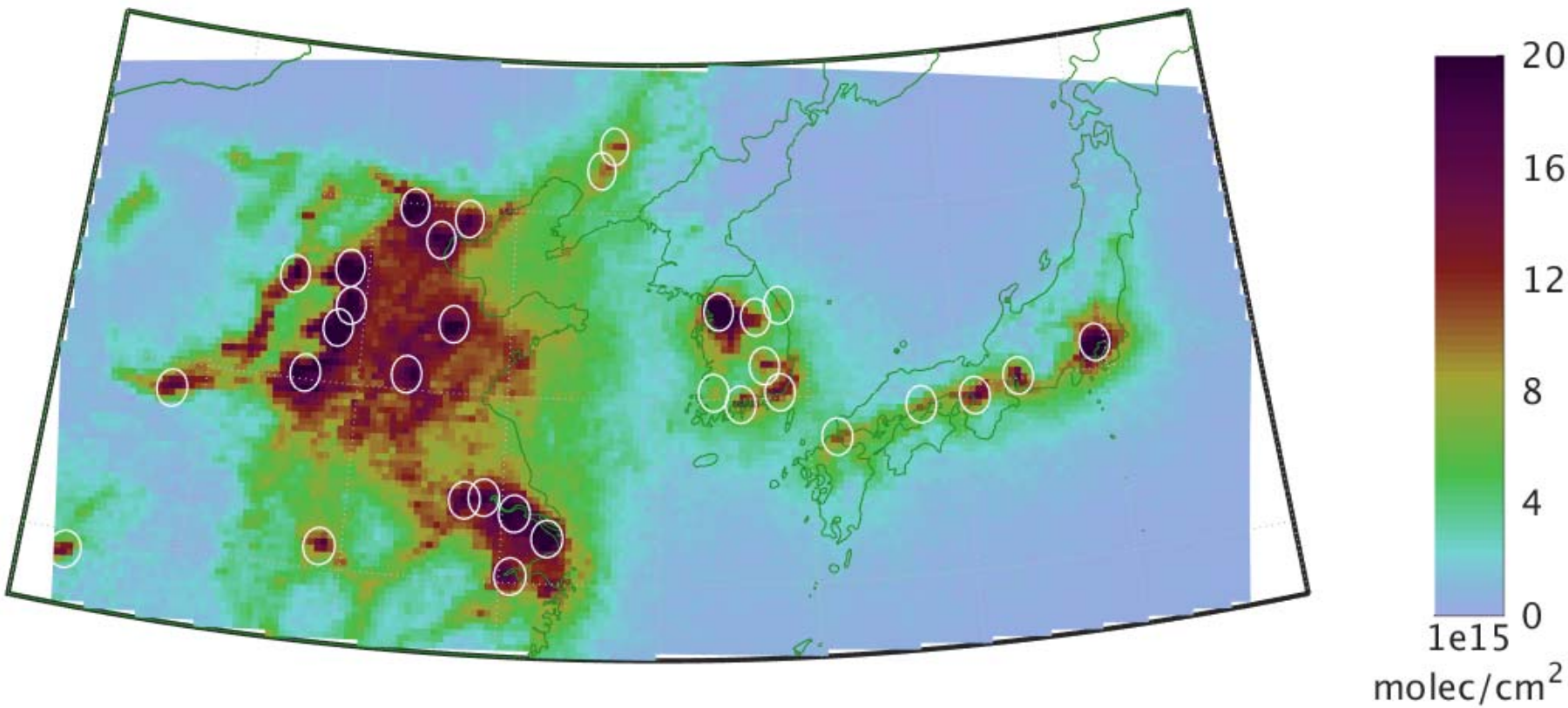
North American Metropolitan Areas: Strong long-term reductions, temporary recession impacts



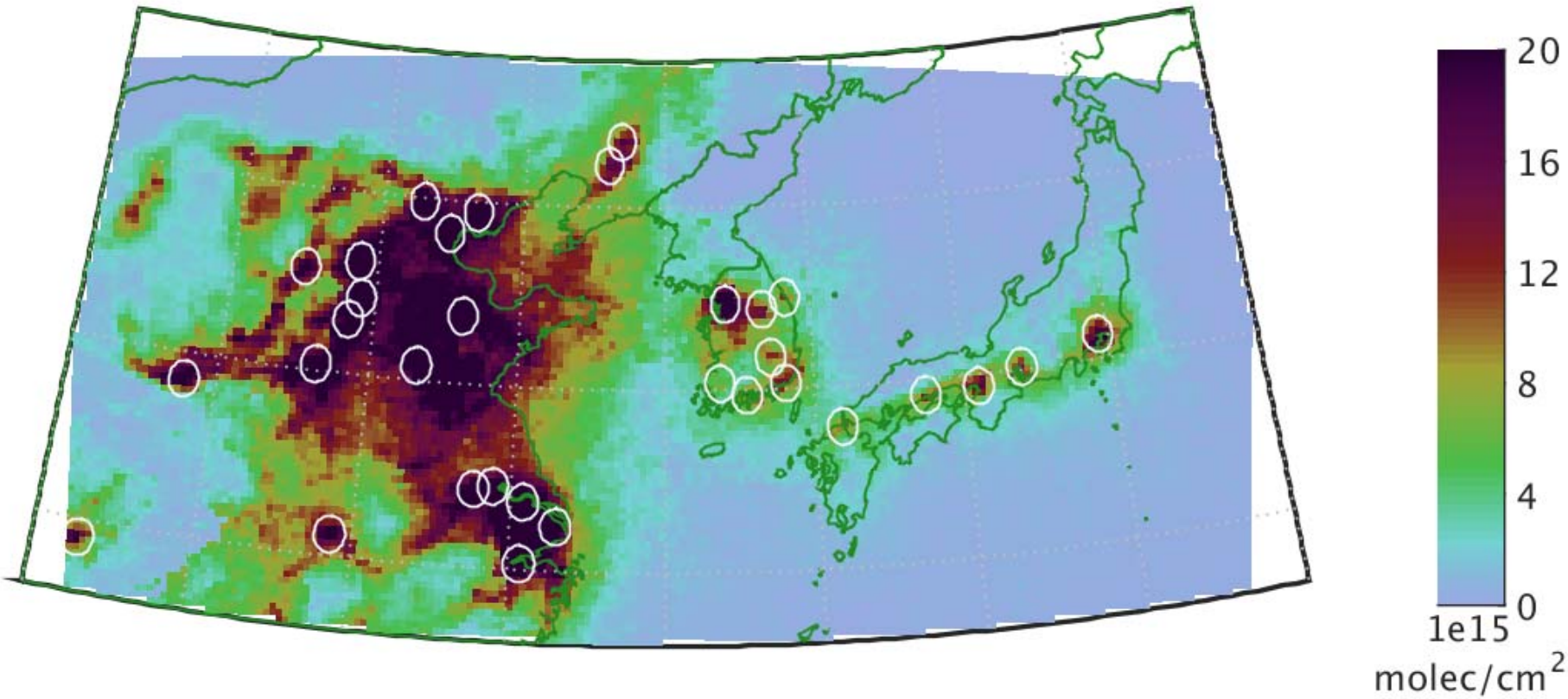
North American Metropolitan Areas: Weekend Effects: Strong, but Variable



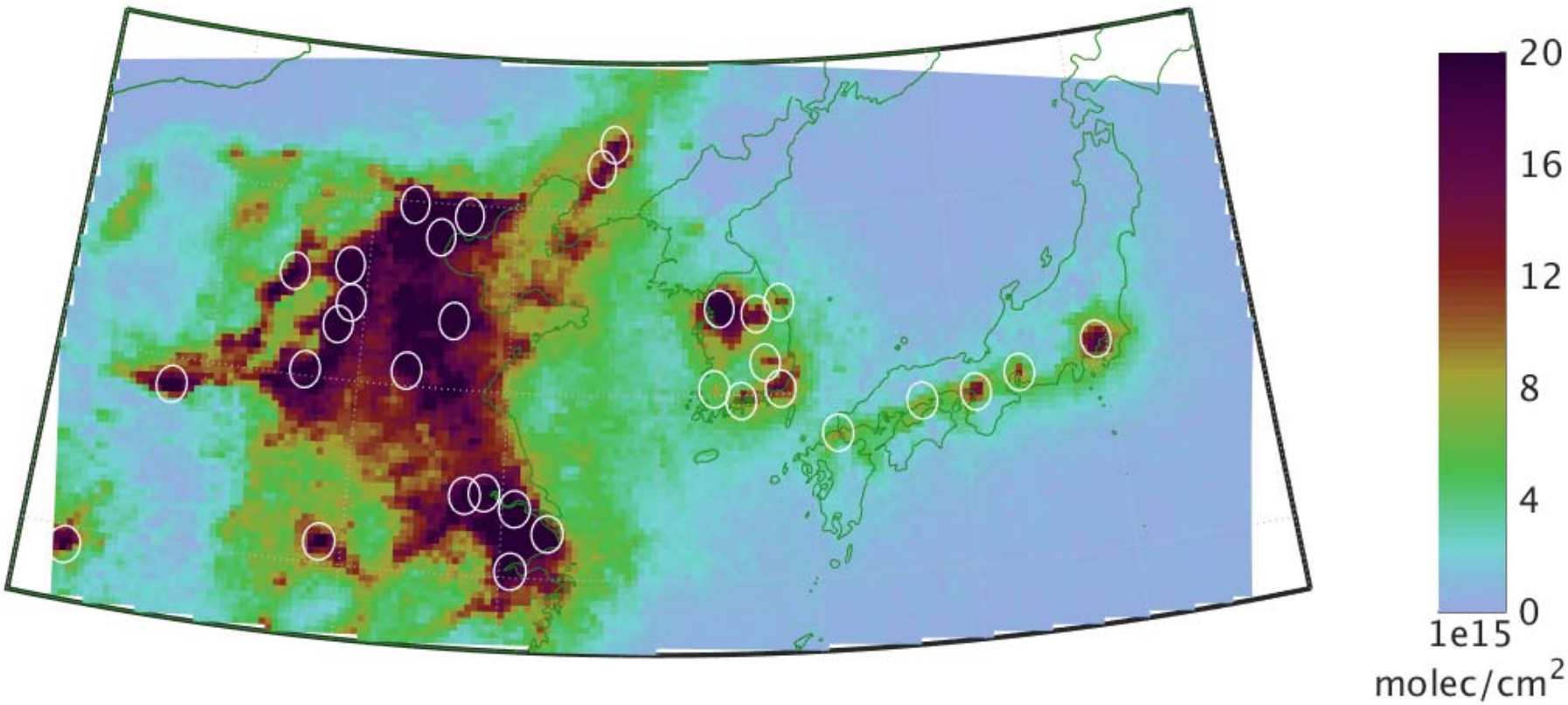
OMI NO_2 over NE Asia - 2005



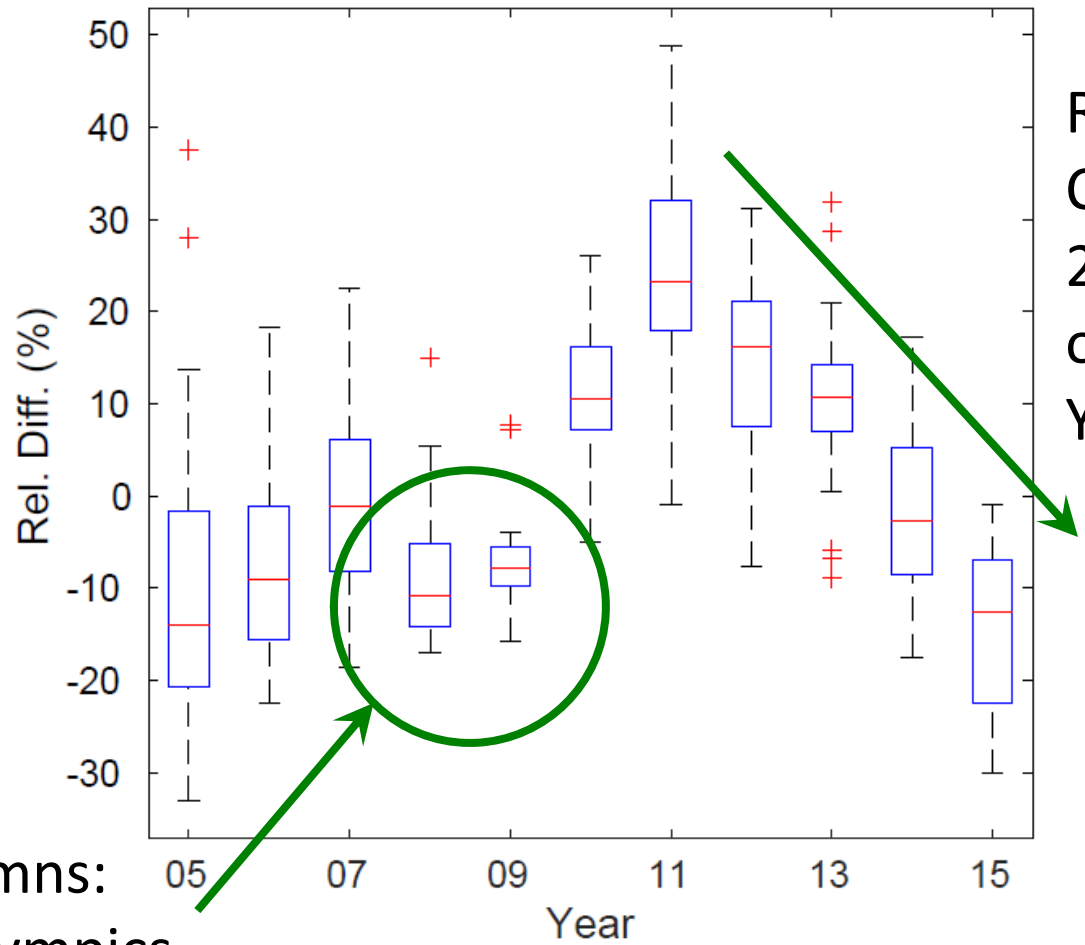
OMI NO_2 over NE Asia - 2011



OMI NO_2 over NE Asia - 2014



OMI NO_2 over Multiple Sites in China

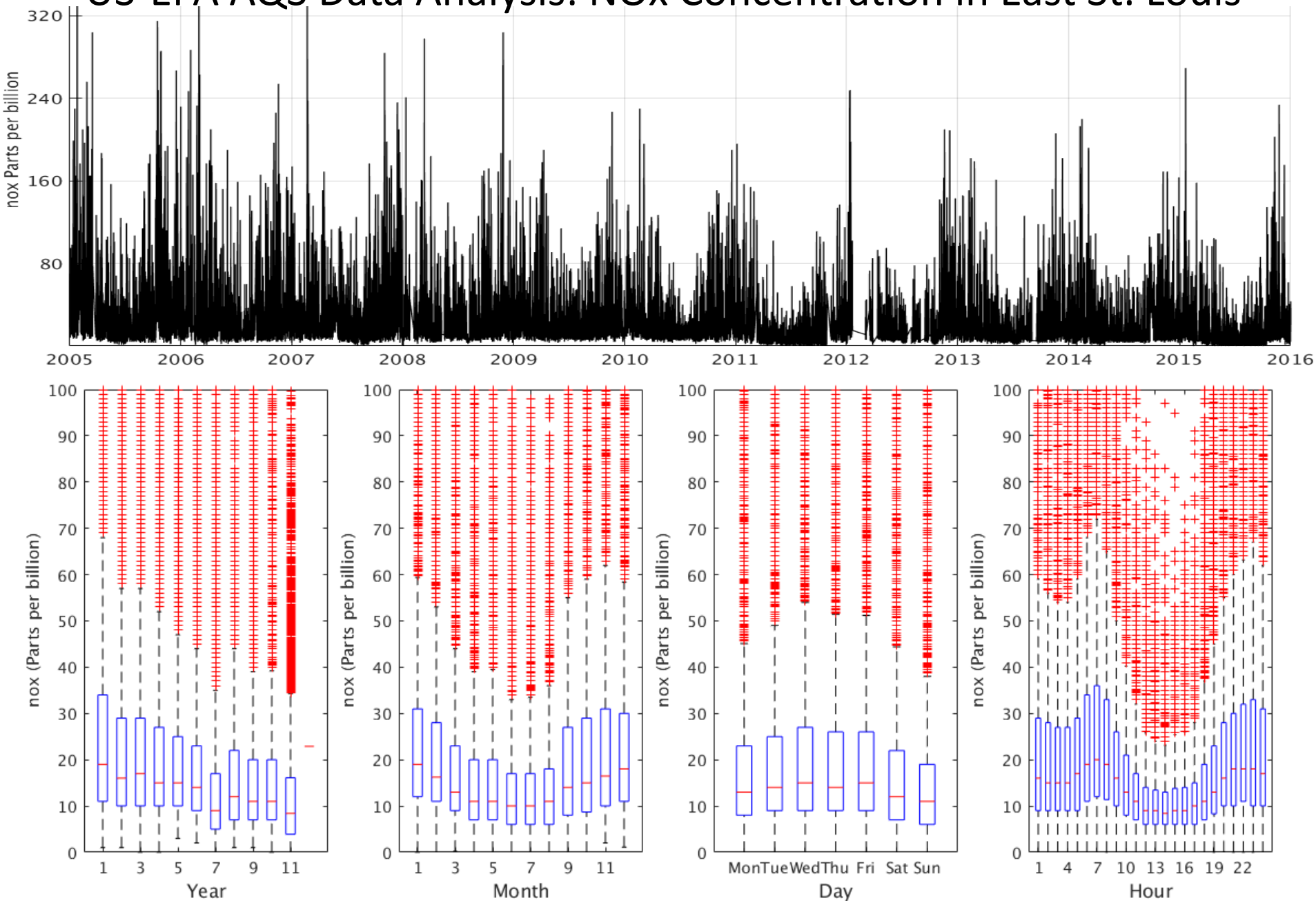


Reduced Columns since 2011 as a result of the 12th Five Year Plan

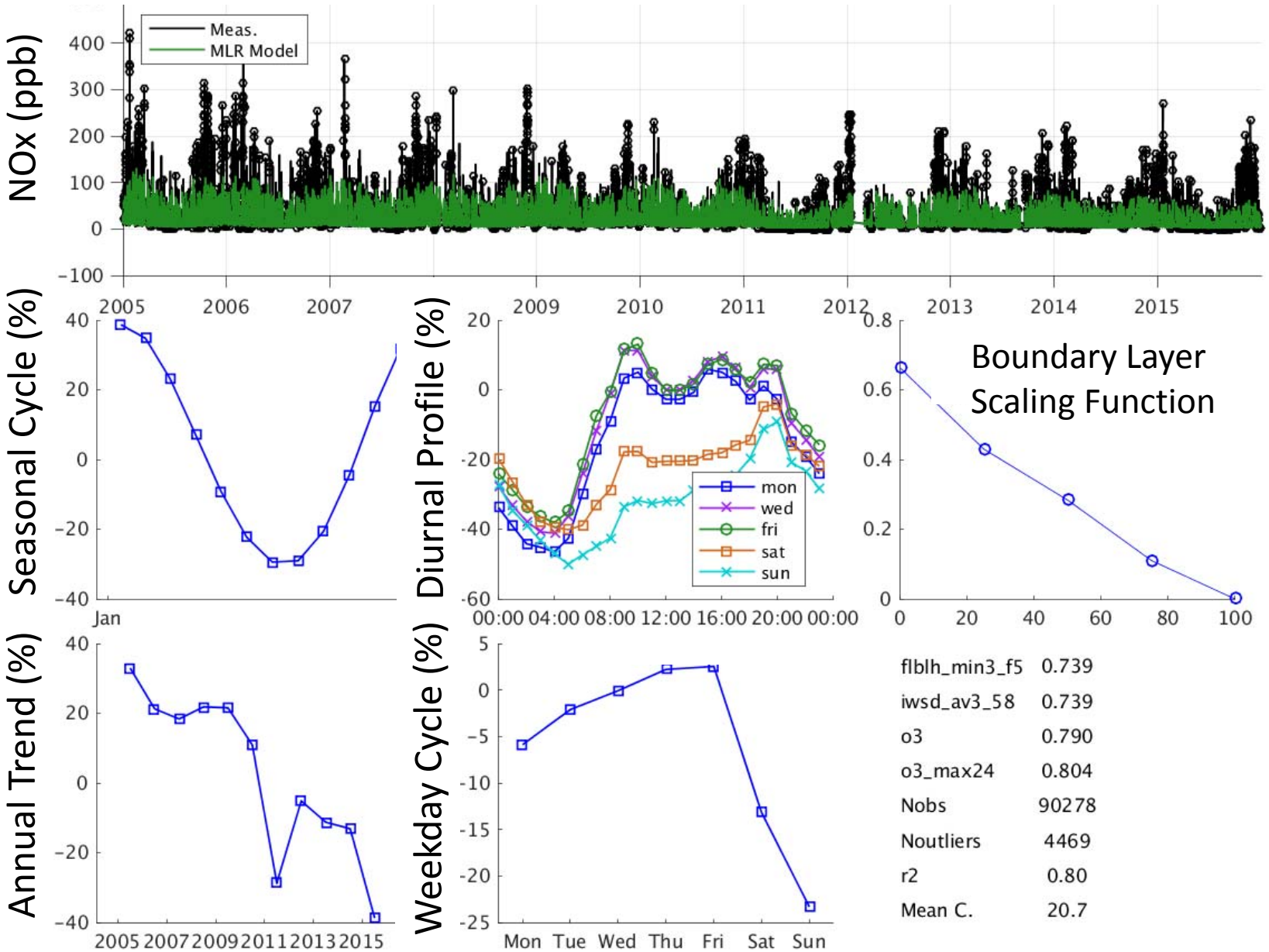
Reduced Columns: Recession / Olympics

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.

US-EPA AQS Data Analysis: NOx Concentration in East St. Louis



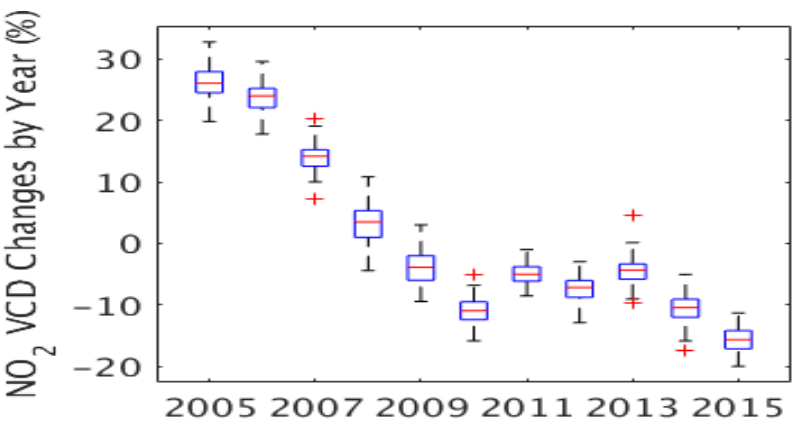
AQS Multi-Linear Regression for East St. Louis

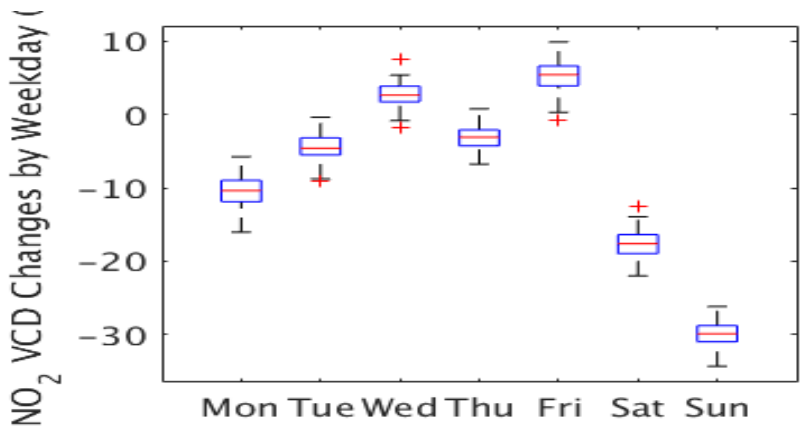


OMI NO_2 Columns for Emission Inventories Development

Benjamin de Foy, Saint Louis University

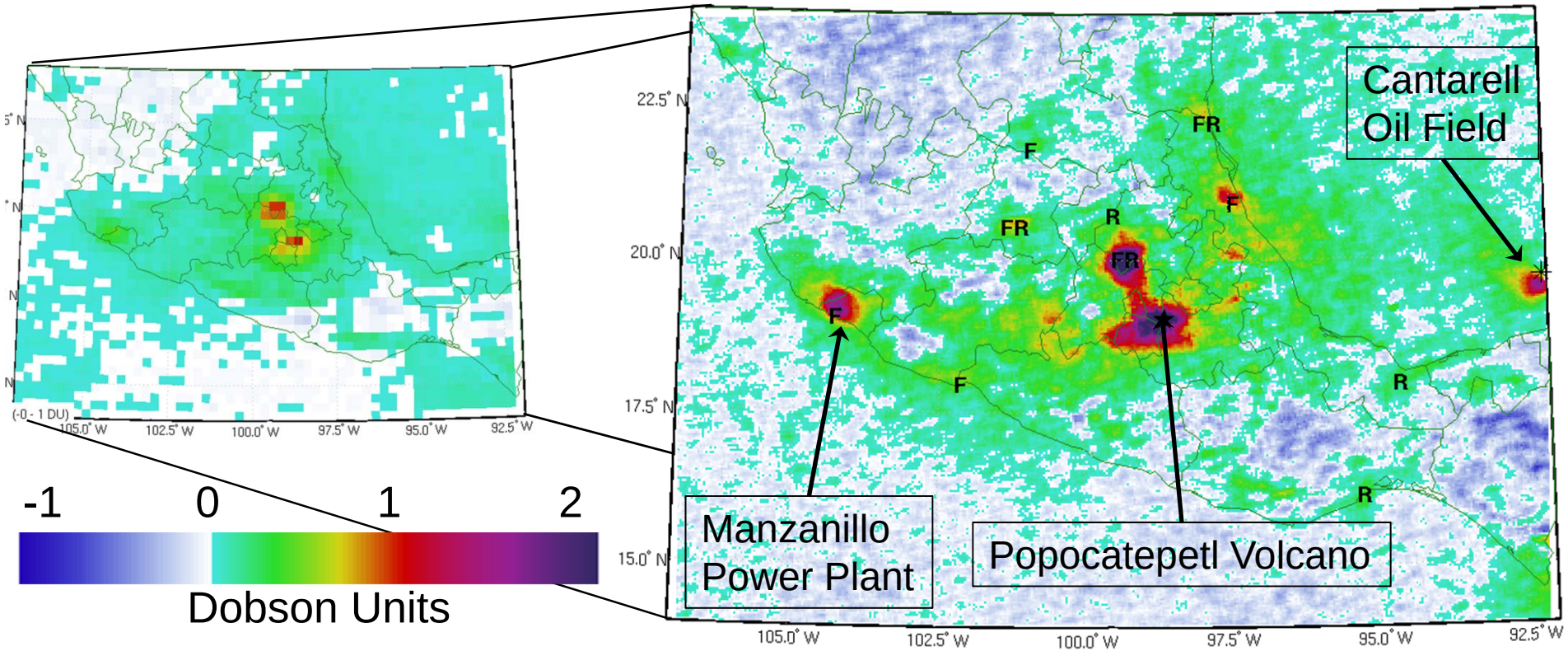
- Policies for reducing NO_2 have had large impacts in both North America and Northeast Asia
- Reductions at the time of the Recession vary in intensity
- Weekend effect differs from city to city
- Multiple Linear Regression Analysis accounts for variations from multiple factors and hence gives clearer estimates of temporal signals in the data





Extras

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., "Hit From Both Sides," Atmospheric Chemistry and Physics, 2009

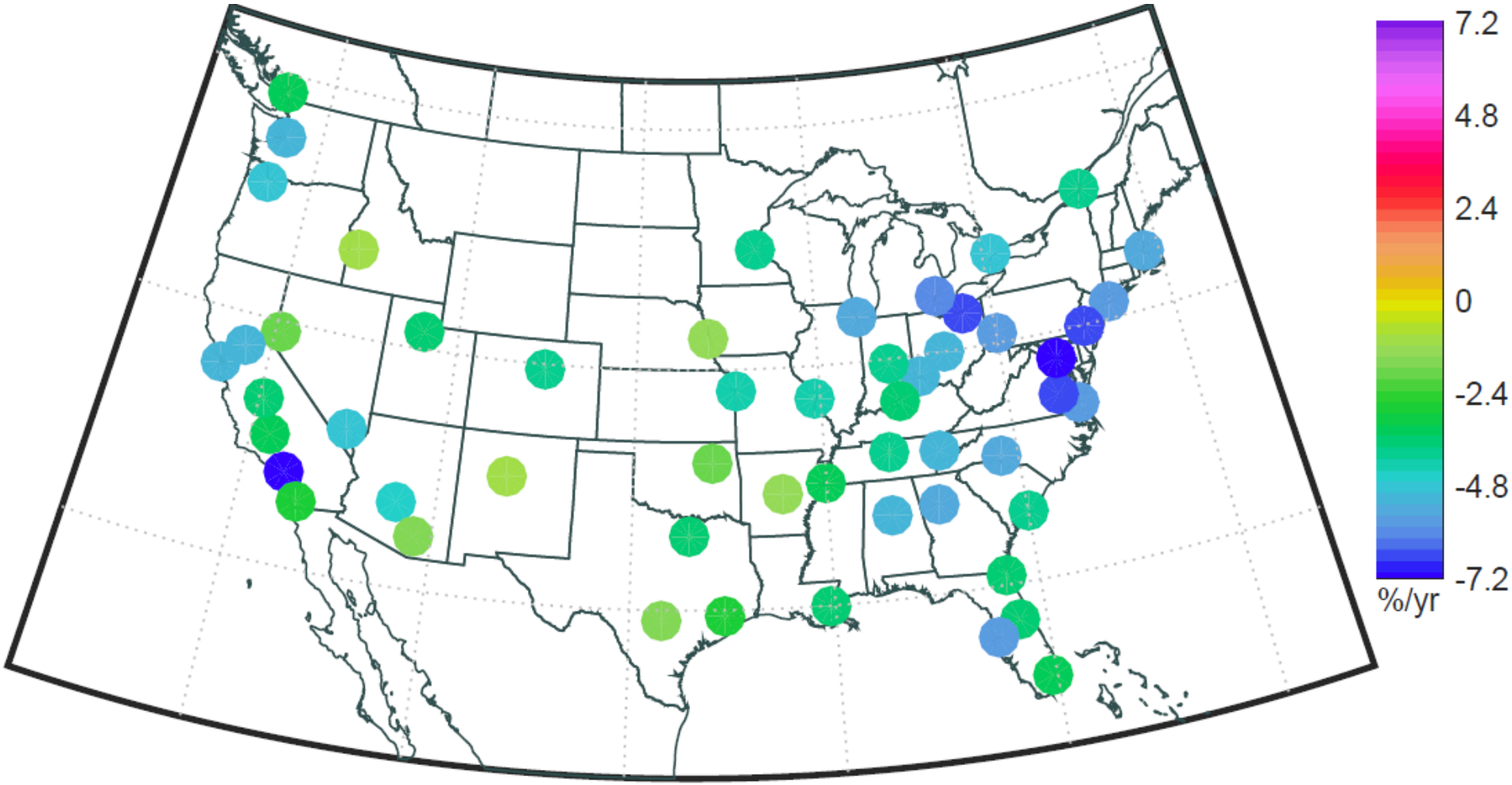
Multiple Linear Regression to Estimate Combined Contribution from Different Factors

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

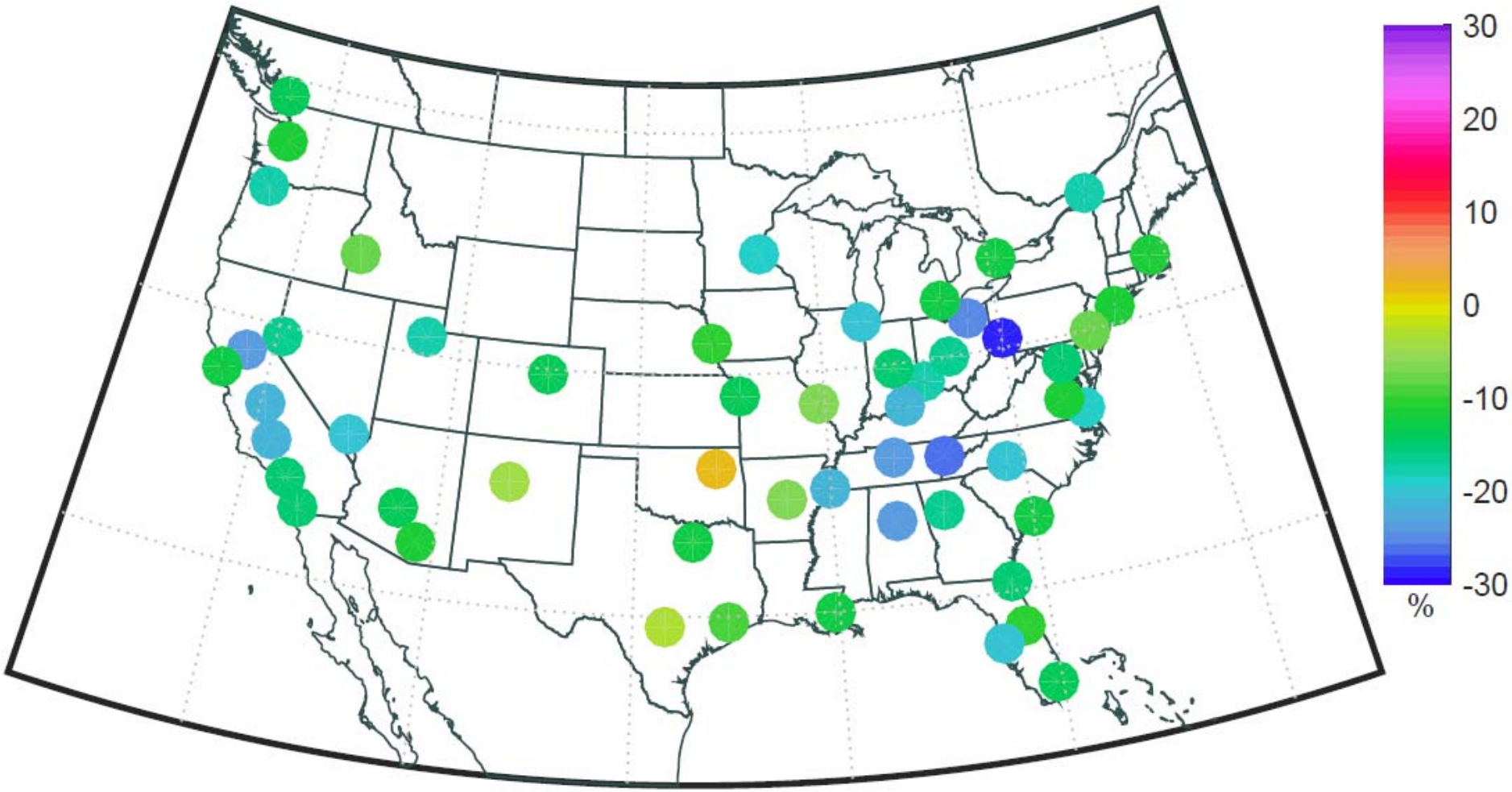
$$f(\text{other})$$

$$\begin{aligned}
f(\text{seasons}) &= \sum_{j=1}^{2} c_{sj} \sin\left(\frac{2\pi jt}{365.25}\right) + c_{cj} \cos\left(\frac{2\pi jt}{365.25}\right) \\
f(\text{meteorology}) &= c_{ws}\left(\log(WS+3)\right)' + c_{t2}T_2' + c_{u10}U_{10}' + c_{v10}V_{10}' \\
f(\text{resolution}) &= c_{dmin}D_{min}' + c_{dmax}D_{max}'
\end{aligned}$$

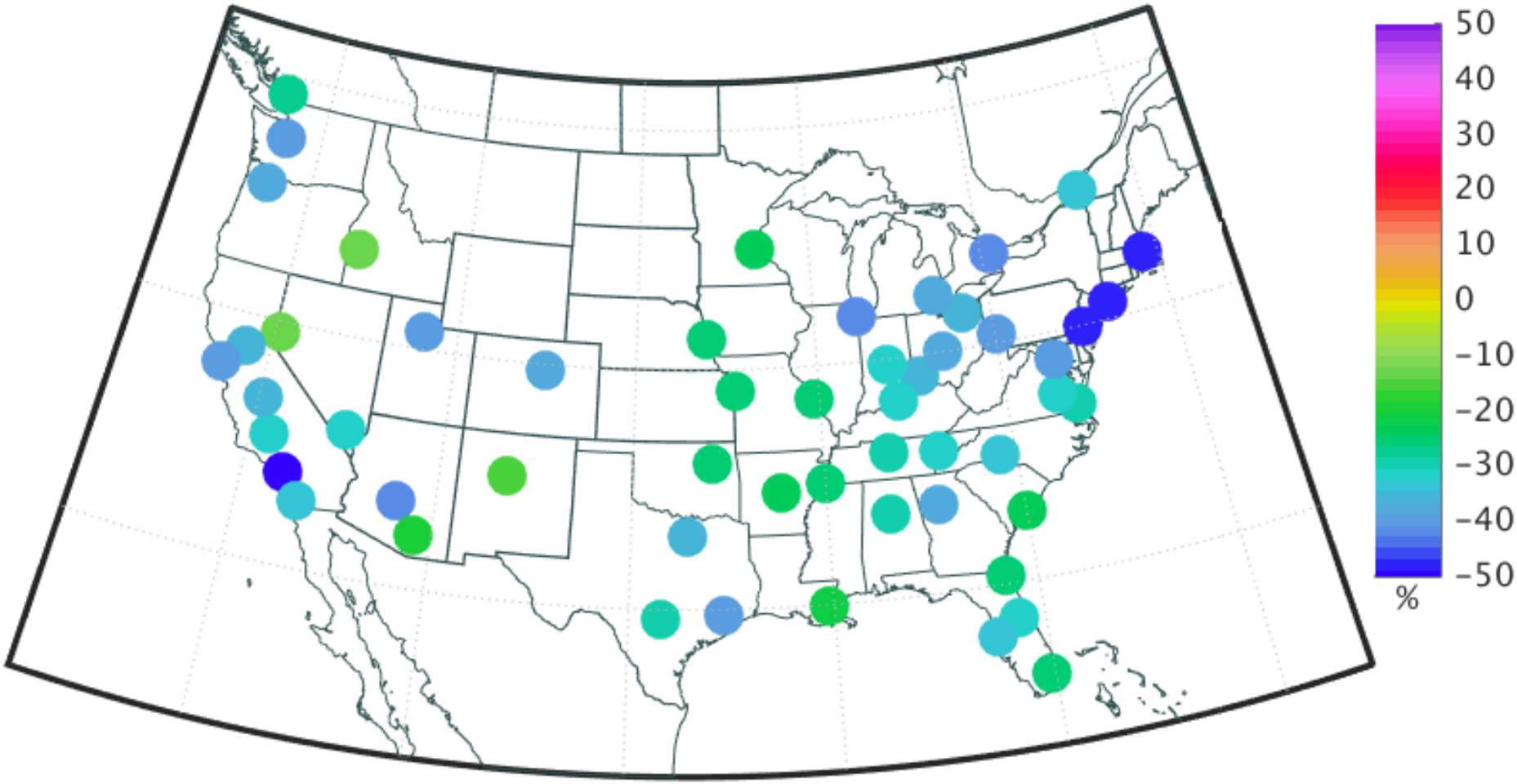
Map of 10-year Trends: Reductions of up to 7% per year



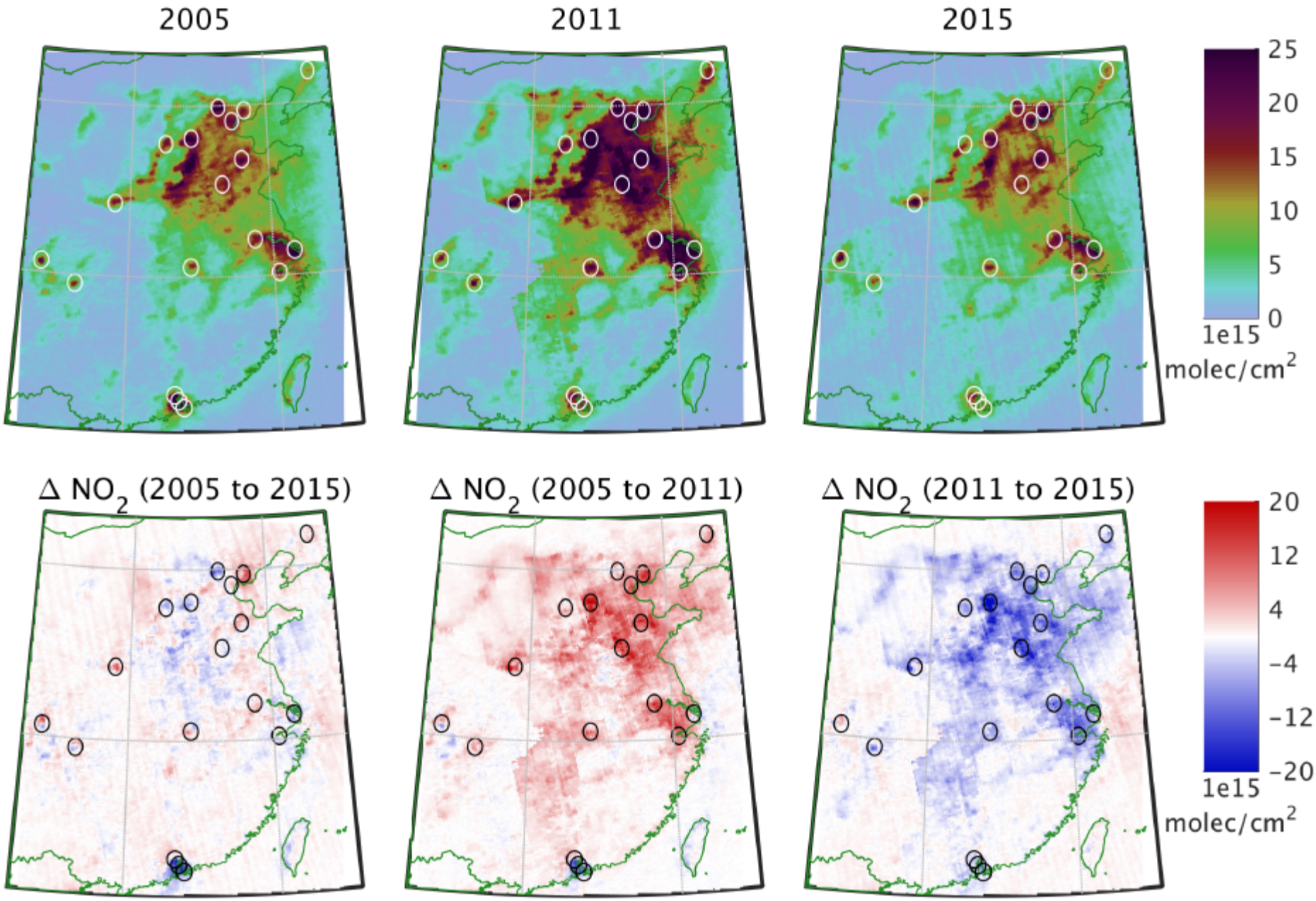
Reductions in 2009: Some urban areas had NO_2 columns 30% lower than the linear trend would have predicted



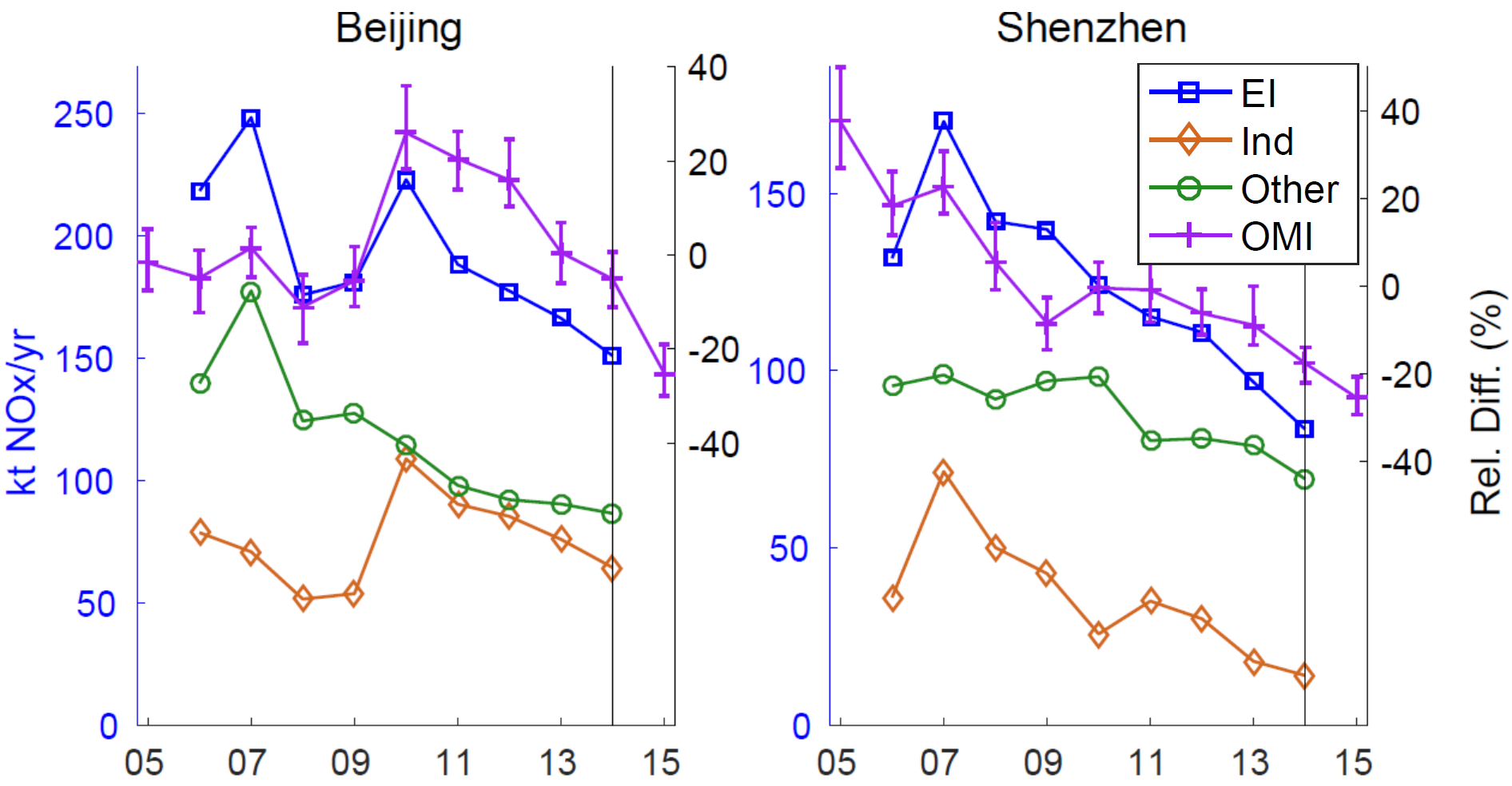
Sunday reductions in OMI NO_2 columns by urban region (%)



OMI NO_2 over Eastern China



OMI NO_2 over China



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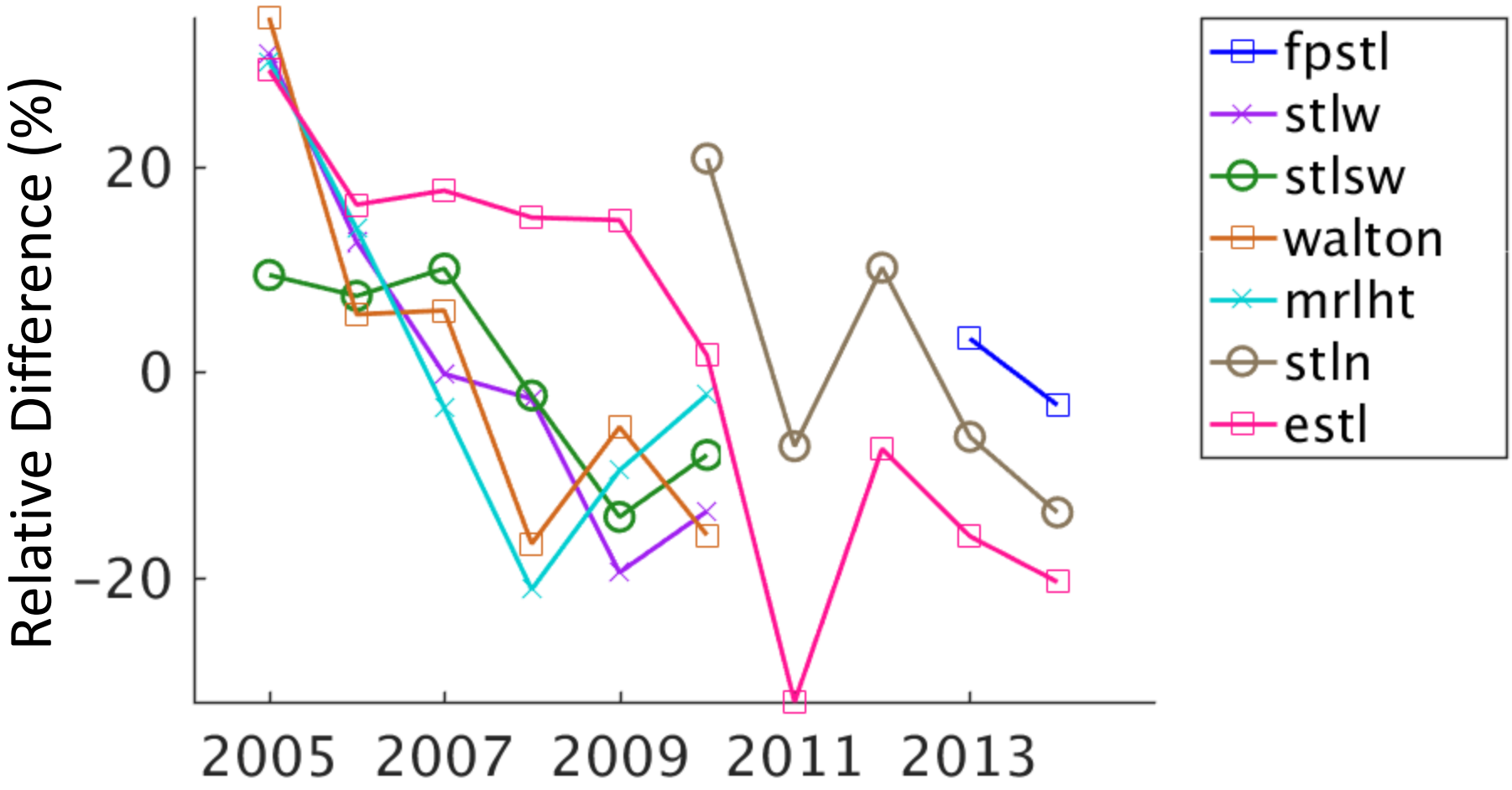
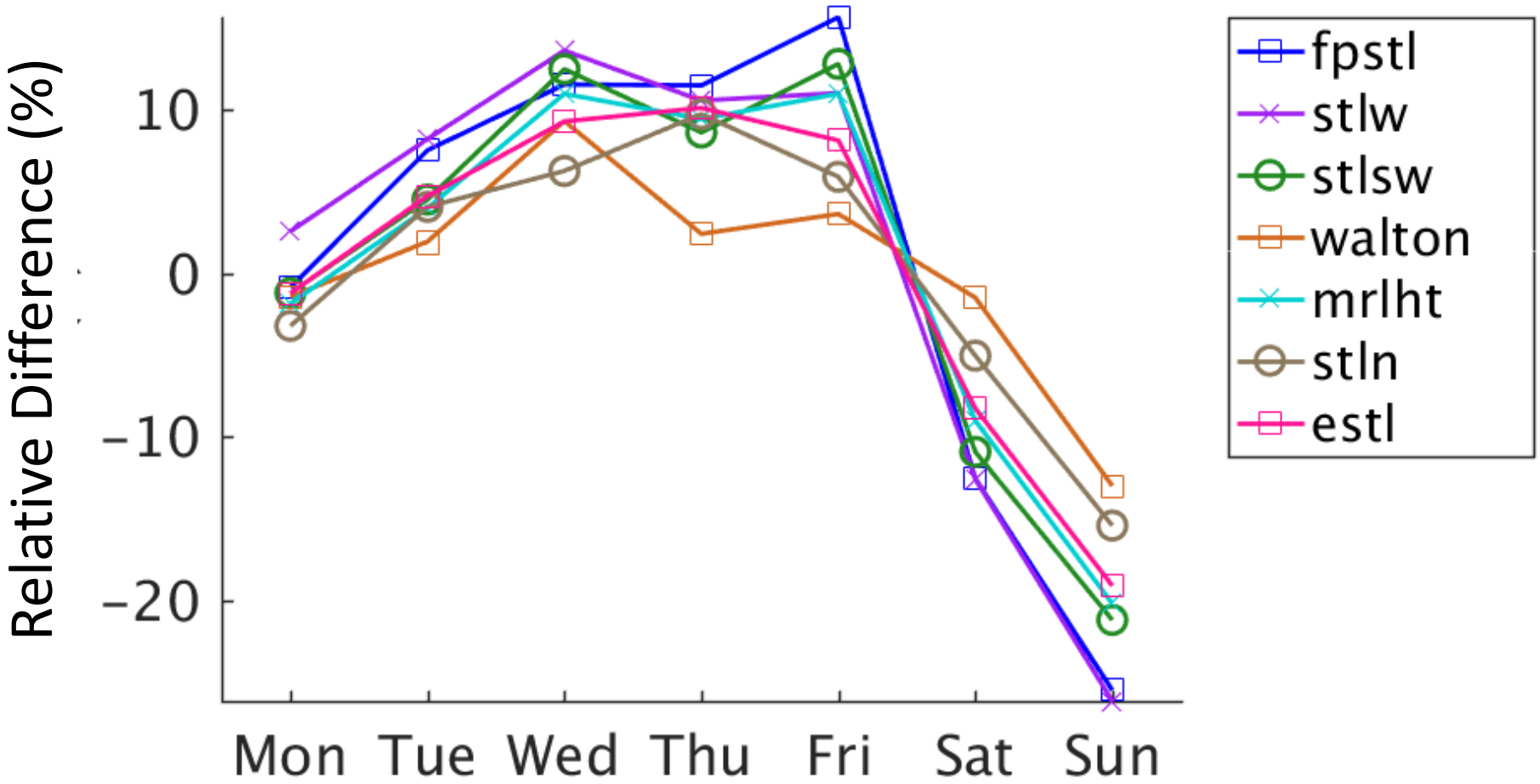
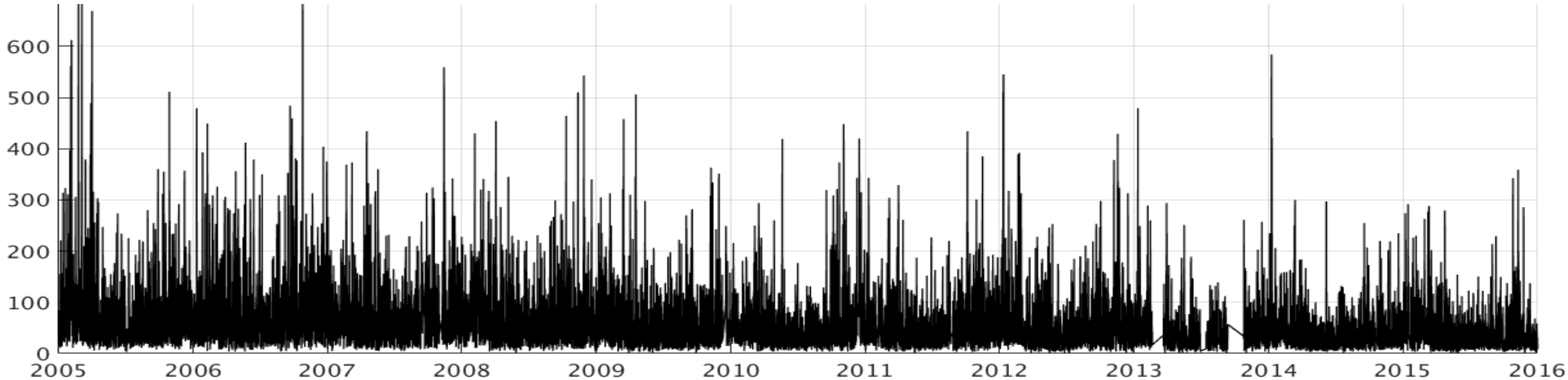
Analysis of St. Louis Monitoring Data
Annual Trends for NOx Concentrations

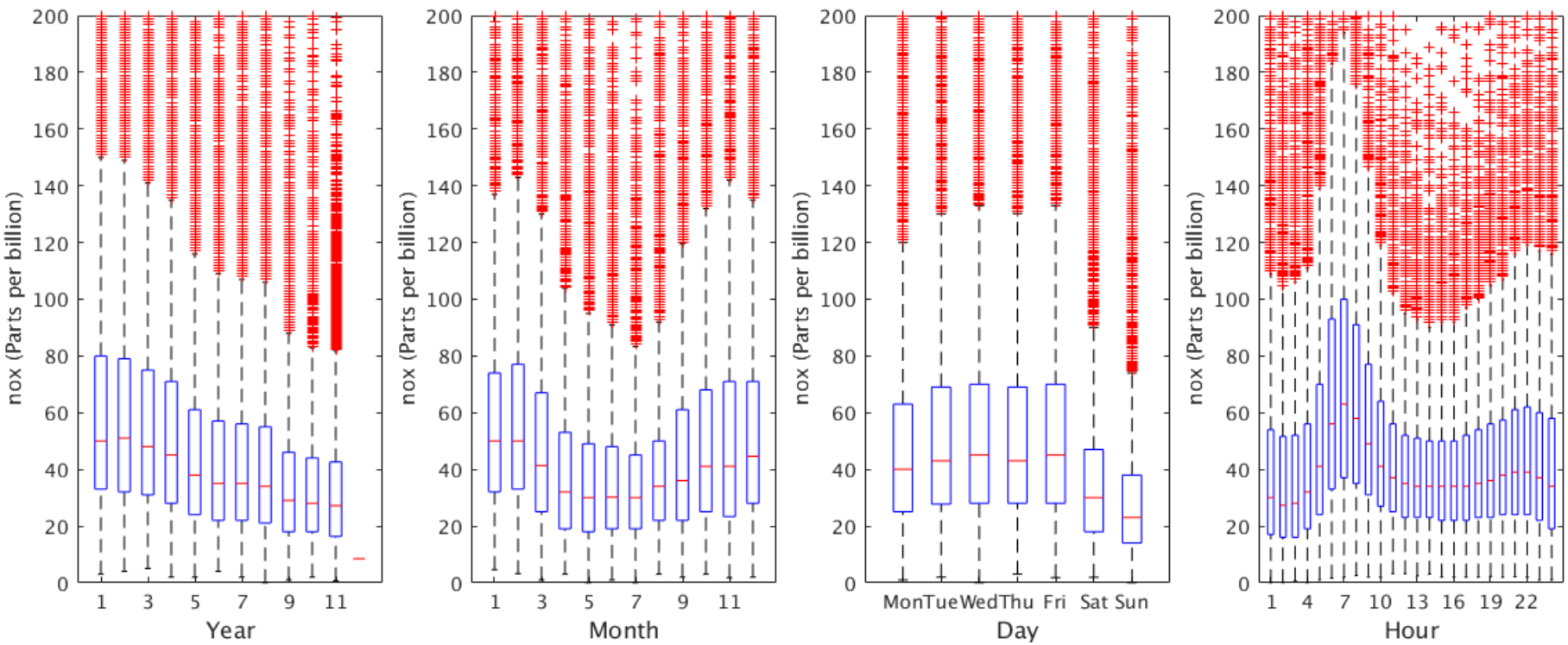
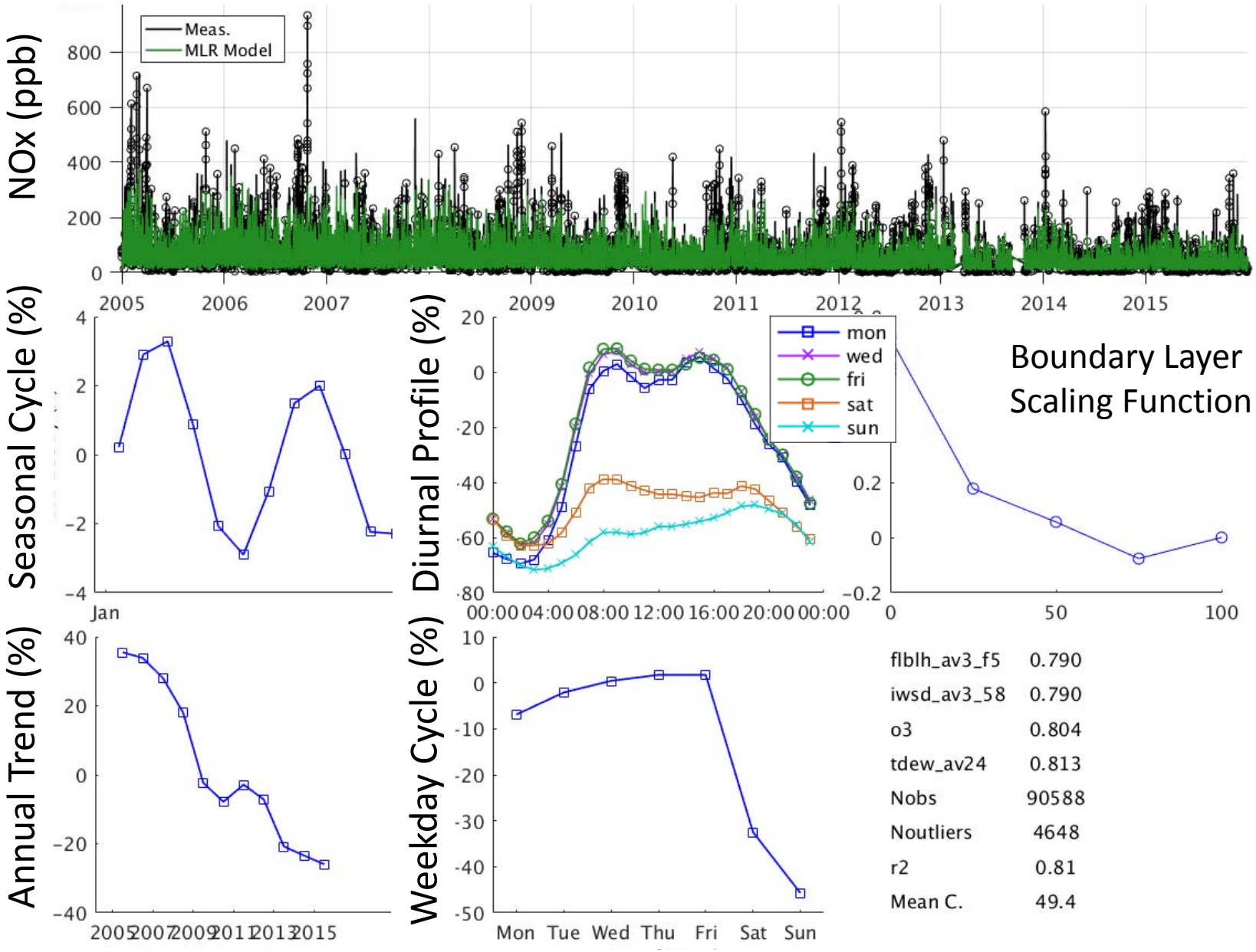


Analysis of St. Louis Monitoring Data: Weekday Patterns of NOx Concentrations



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





AQS Multi-Linear Regression for Suburban Chicago