Applications of satellite NO2 observations in US National Air Quality Forecasting Capability

Pius Lee[1], Daniel Tong[1,2,3*], Lok Lamsal[4,5], Li Pan[1,2], Charles Ding[1,6], Hyuncheol Kim[1,2], Tianfeng Chai[1,2], Kenneth E. Pickering[5], Shobha Kondragunta[7], and Ivanka Stajner[7], Barry Baker[1,9]

1) NOAA ARL; 2) UMD CICS; 3) GMU CSISS; 4) USRA;
5) NASA GSFC; 6) UC-Berkeley; 7) NOAA/NESDIS/STAR; 8) NOAA NWS
9) NRC

The Great Recession

- **Starting – Ending time: December 2007 – October 2009;**

- **Cause: Bursting of the housing bubble in 2007, followed by a subprime mortgage crisis in 2008;**

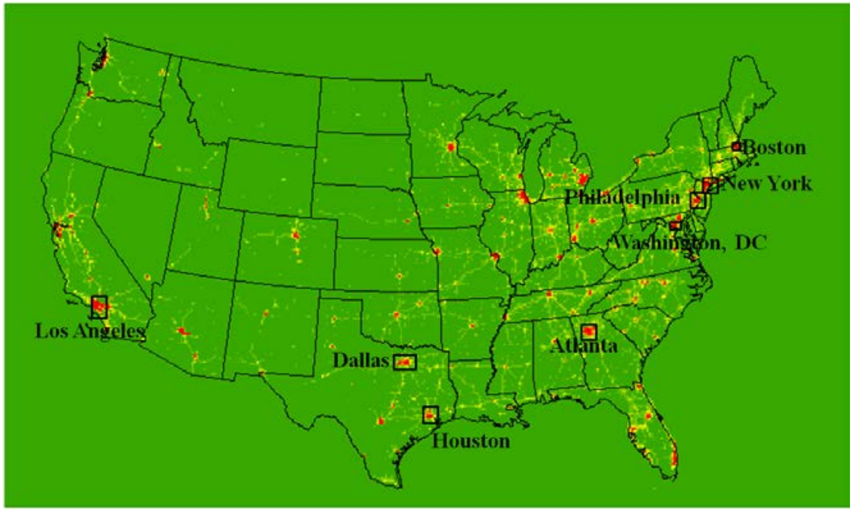
- **Impacts:**
  - **Unemployment rate: 4.7% in Nov 2007 → 10.1% in Oct 2009.**
  - **Income level: dropped to 1996 level after inflation adjustment;**
  - **Poverty rate: 12% → 16% (50 millions);**
  - **GDP: contract by 5.1%;**

- **Worst economic recession since the Great Depression**

Question: What does it mean to Air Quality (and Emissions)?

Methodology

- **Emission Indicator – Urban NOx in Summer**
  - **Short lifetime → proximity to emission sources**
  - **Urban NO2 dominated by local sources;**
  - **High emission density → low noise/signal ratio;**
- **NOx Data sources**
  - **Satellite remote sensing (OMI-Aura NO2).**
  - **Ground monitoring (EPA AQS NOx);**
  - **Emission data (NOAA National Air Quality Forecast Capability operational emissions);**
- **Deriving the trend:** (Y2–Y1)/Y1 × 100%
- **Selection of urban areas**



NO_x Regulatory Actions Since 2005

- **2003 – 2008: NO_x Budget Trading Program (SIP Call)**
  - Summer time power plant emission reductions in 20 states
  - Point sources can pay for reductions at other facilities (trading)
  - 2500 large combustion units affected.

- **2005: Clean Air Interstate Rule (CAIR)**
  - NO_x reductions of 53% by 2009 (2003 baseline). Affects 28 states
  - Thrown out by courts in 2008.

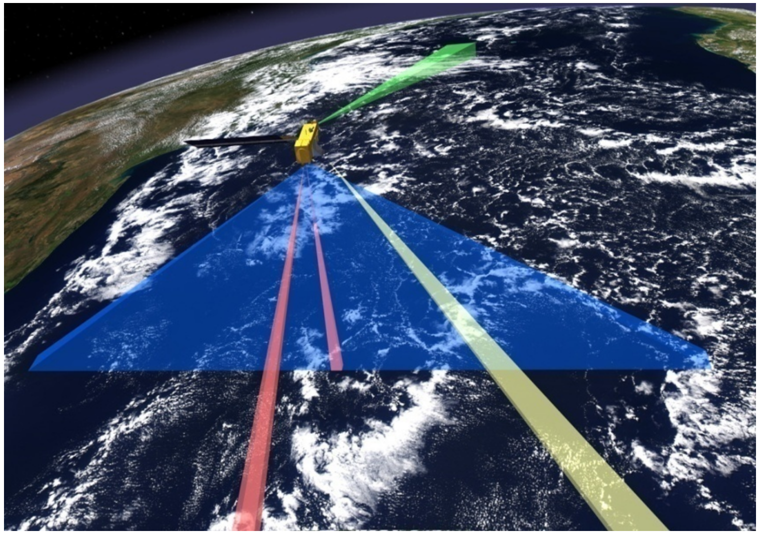
- **State-specific rules beyond Federal CAIR have led to further NO_x reductions in some states.**

- **2011: Cross-State Air Pollution Rule (CSAPR)**
  - Replacement of CAIR
  - Add five additional mid-West states to reduce NOx during ozone season.

- **Tier II Tailpipe NO_x Emission Standards – 5% reduction in fleet emissions per year over 2002 to 2010.**

Contributed by Ken Pickering

Ozone Monitoring Instrument (OMI)



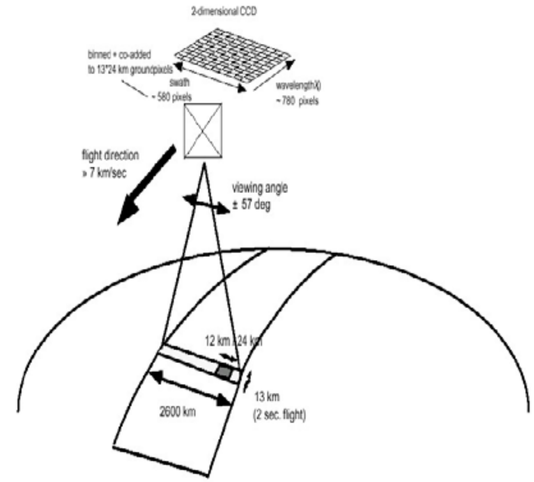


Figure 2.1 Measurement principle of OMI. *Courtesy of Fokker Space*

One of four sensors on the EOS-Aura platform (OMI, MLS, TES, HIRDLS)

Courtesy of OMAR Torres

Launched on 07-15-04

Instrument Characteristics

-Nadir solar backscatter spectrometer

-Spectral range 270-500 nm (resolution~0.6 nm)

-**Spatial resolution: 13X24 km footprint**

-**Swath width: 2600 km (global daily coverage)**

-**13:45 (+/- 15 min) Local equator crossing time (ascending node)**

Data Quality Control

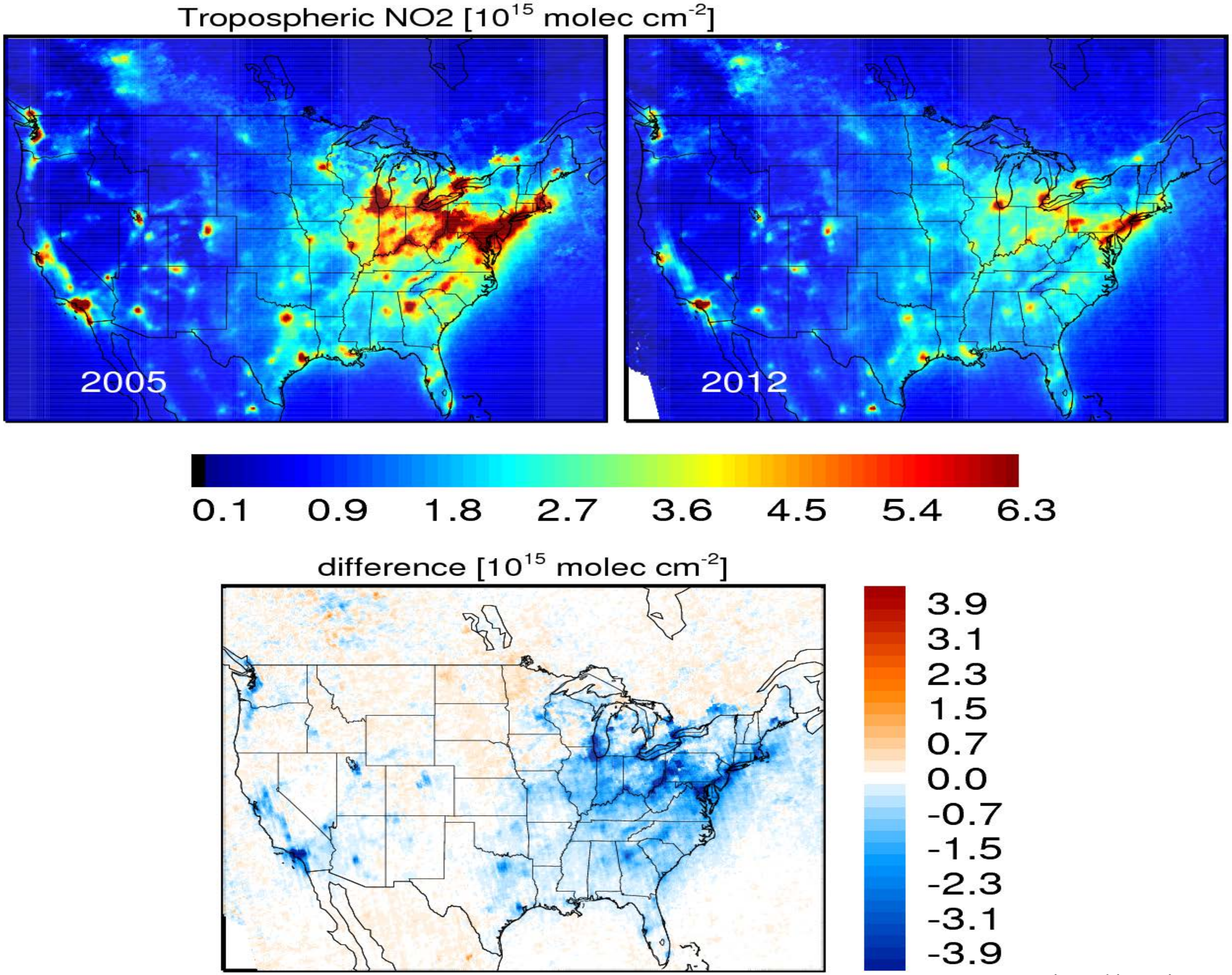
- VCD quality flag;

- Cloud fraction;

- **Row Anomaly;**

- **Outliners (5% at each end)**

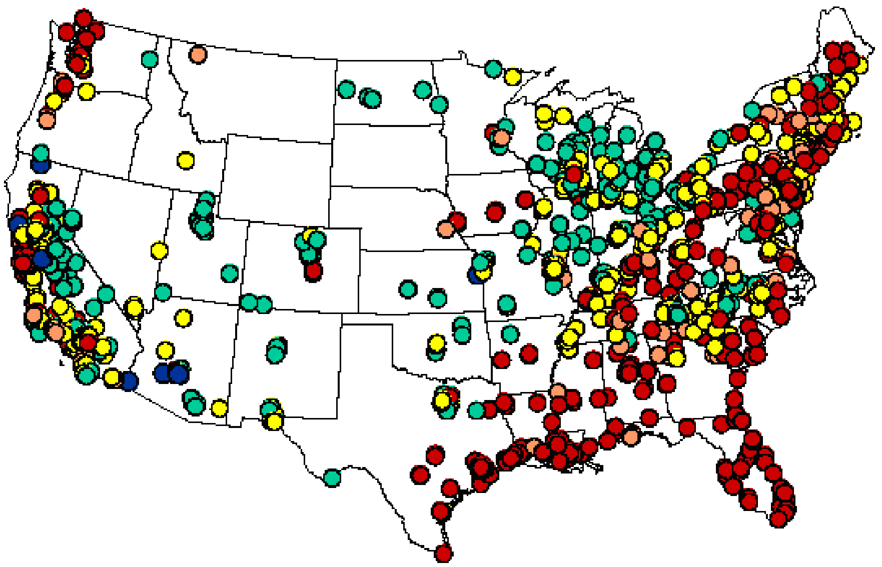
OMI Observed NOx Change (July)



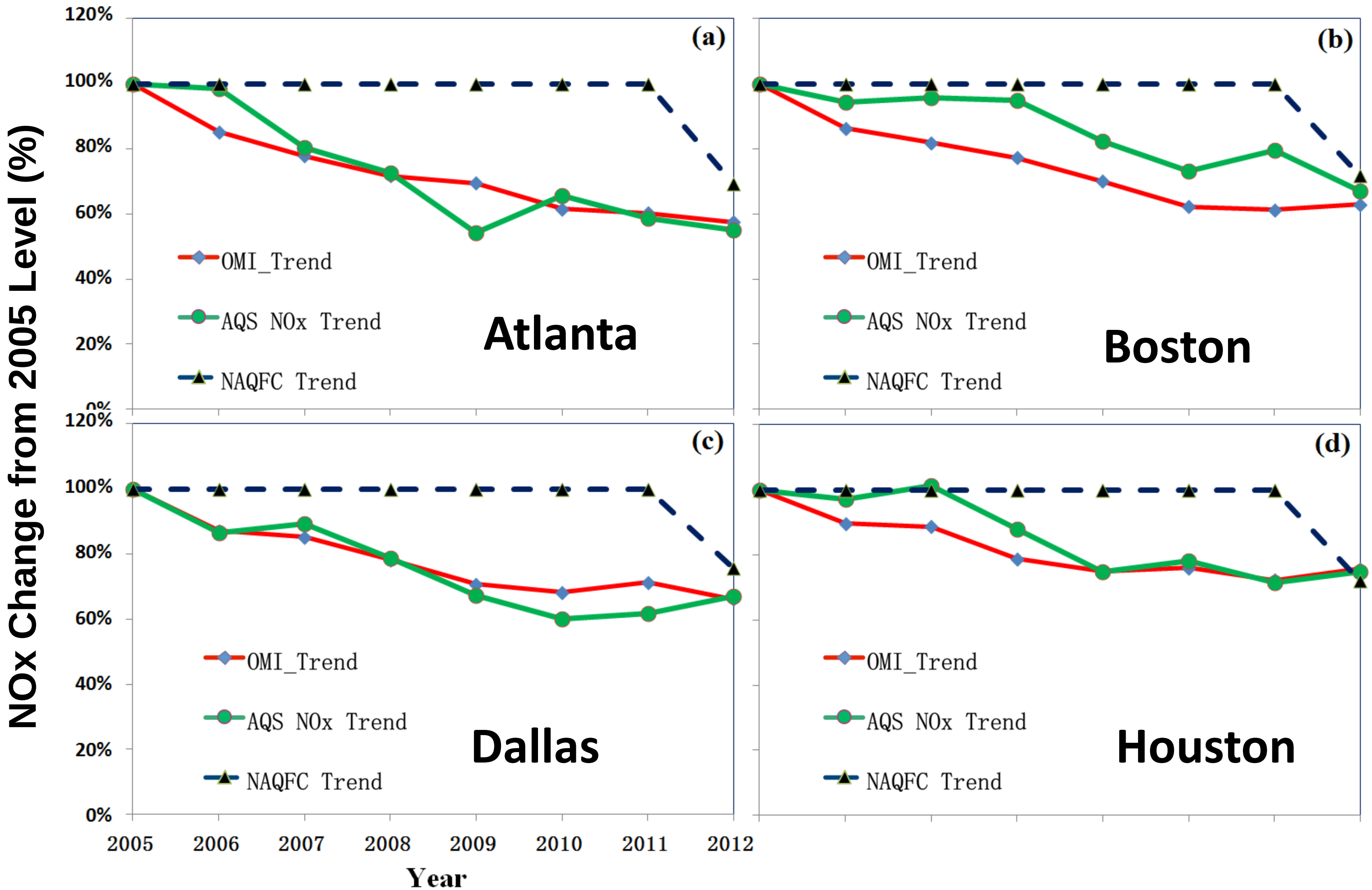
Contributed by Lok Lamsal

AQS: EPA Ambient NO2 Monitoring

- **Method: Chemiluminescence**
  - **Interferences with PAN, O3 and alkyl nitrates**
  - **Uncertainty higher at lower end**
- **Select early morning rush hours (6-9AM): higher values and less photochemistry**

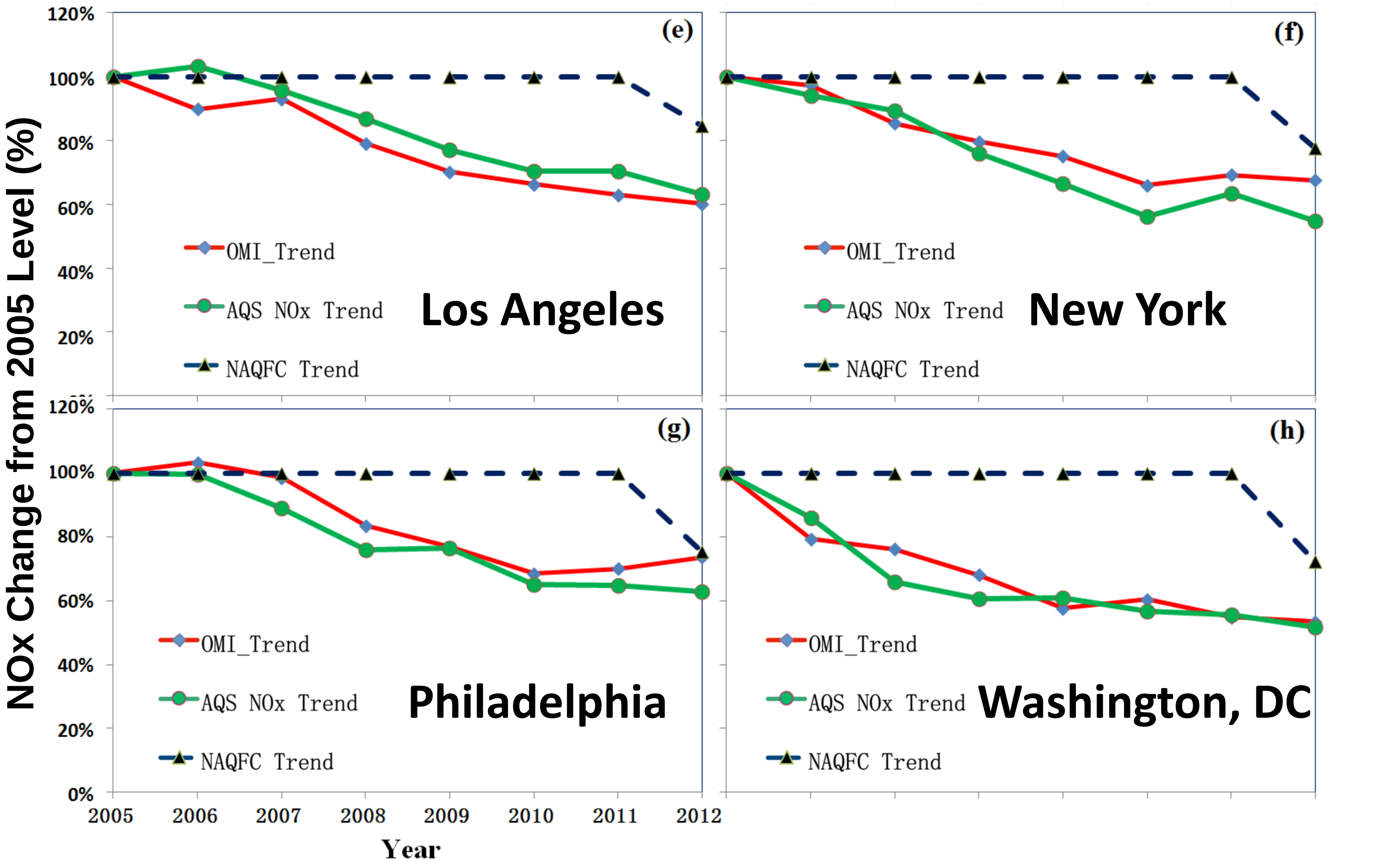


Inter-Comparison of OMI, AQS and NAQFC



(Source: Tong et al., 2015)

Inter-Comparison of OMI, AQS and NAQFC (Continued)



(Source: Tong et al., 2015)

Morning Rush Hours vs Early Afternoon

Atlanta

Boston

Dallas

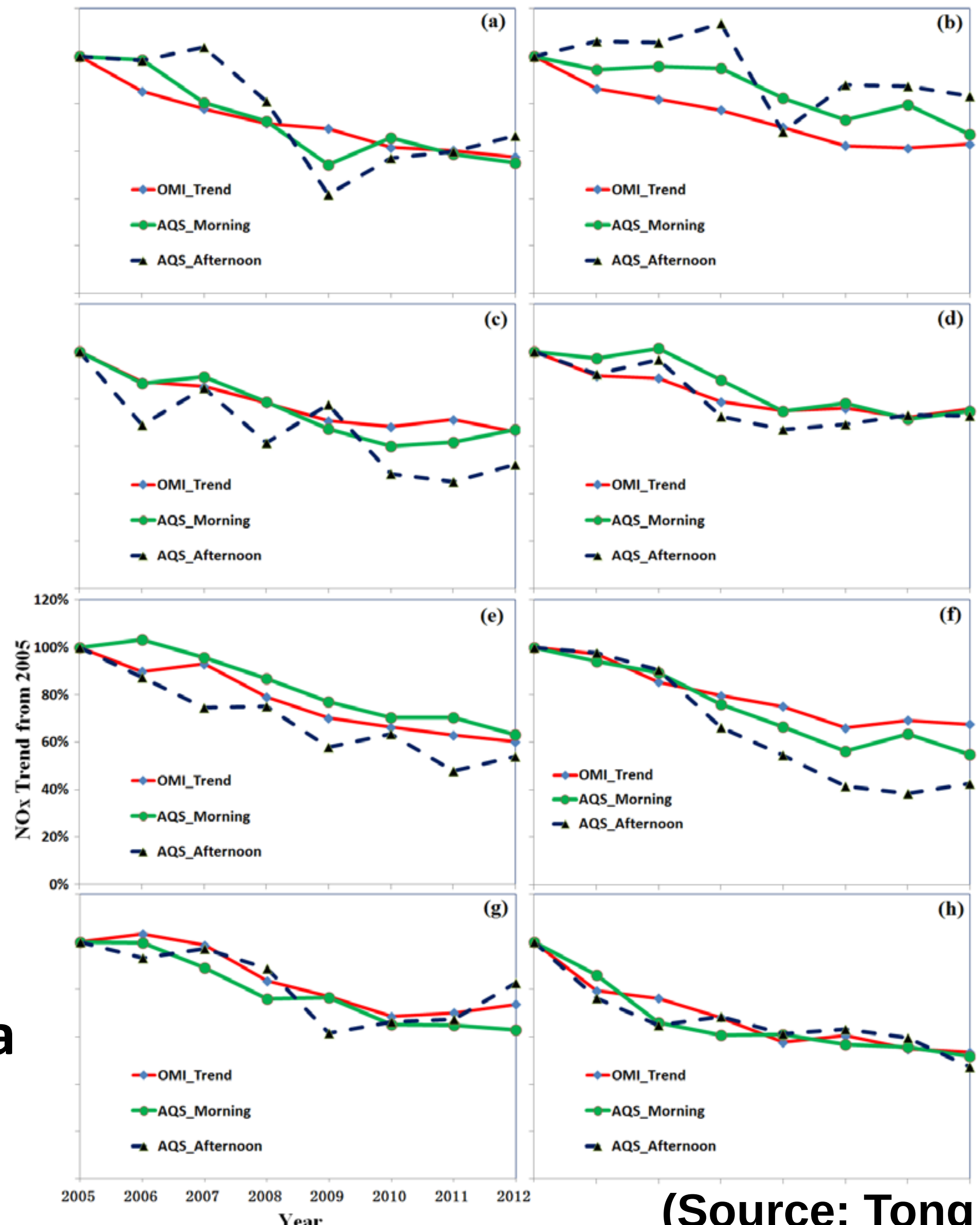
Houston

Los Angeles

New York

Philadelphia

Washington, DC



(Source: Tong et al., 2015)

Seven-year NOx Changes

City	Atlanta	Boston	Dallas	Houston	Los Angeles	New York	Philadel-phia	Washing-ton, DC	Mean
OMI	-42%	-37%	-34%	-24%	-40%	-32%	-26%	-47%	-35%
AQS	-45%	-33%	-33%	-25%	-37%	-45%	-37%	-48%	-38%
NAQFC	-31%	-28%	-24%	-28%	-15%	-22%	-25%	-28%	-25%

- **Both observations (OMI and AQS) revealed -5%/yr reduction rate;**
- **NAQFC adopted change corresponds to -3.5%/yr;**

NOx Changes
Prior to, during and after the Recession

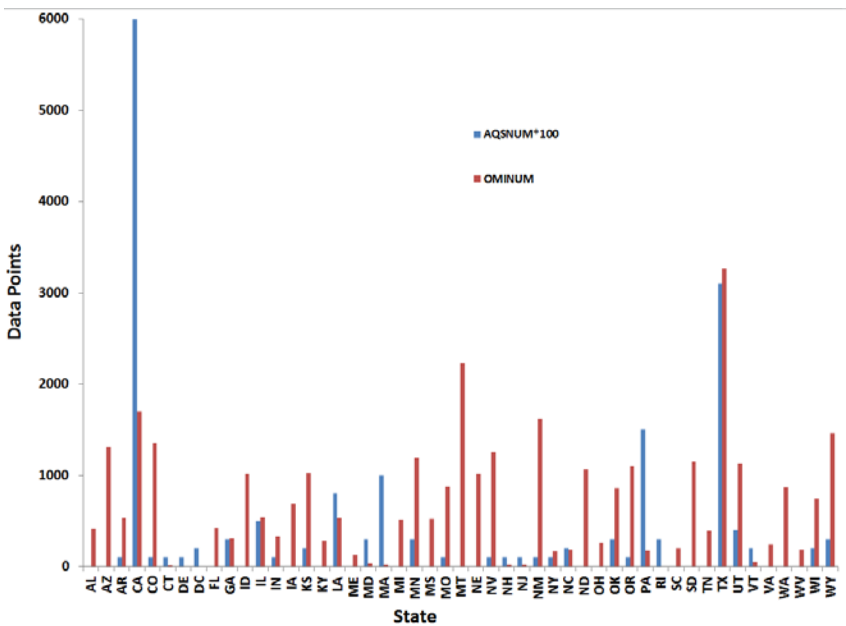
Stage	Sources	Atlanta	Boston	Dallas	Houston	Los Angeles	New York	Philadel-phia	Washing-ton, DC	Mean
Before	OMI SP	-11.7	-9.4	-7.5	-5.7	-3.3	-7.5	-0.6	-12.3	-7.3
	AQS	-9.9	-2.1	-5.2	0.7	-2.0	-5.5	-5.5	-18.7	-6.0
During	OMI SP	-5.5	-7.5	-8.9	-7.9	-13.1	-6.2	-11.7	-13.0	-9.2
	AQS	-17.5	-7.0	-13.0	-14.0	-10.3	-13.6	-7.0	-3.7	-10.8
After	OMI SP	-6.0	-3.3	-2.1	0.4	-5.0	-3.2	-1.2	-2.3	-2.8
	AQS	1.4	-6.1	0.1	0.2	-6.4	-5.4	-6.1	-5.3	-3.4

- **Distinct regional difference;**
- **Average NOx changes are consistent for OMI and AQS data;**
- **-6%/yr - -7%/yr prior to Recession;**
- **-9%/yr - -11%/yr during Recession;**
- **-3%/yr after Recession (Recovery?).**

(Source: Tong et al., 2015)

Rapid Refresh of NO_x Emissions

Question: Can satellite and ground data be used to rapidly refresh NOx emissions?

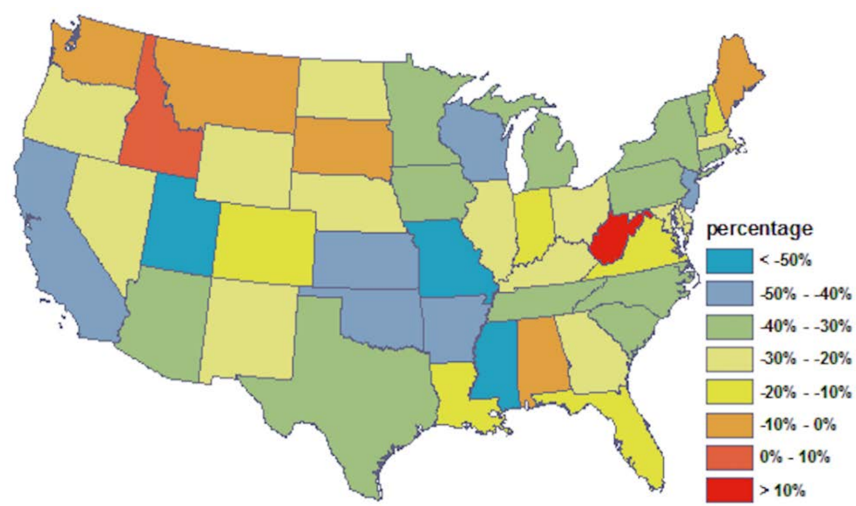


Comparison of OMI and AQS (x100) Samples

Fusing AQS & OMI

$$AF = \frac{\Delta S \times N_S \times f_S + \Delta G \times N_G \times f_G}{N_S \times f_S + N_G \times f_G}$$

State-level Projection

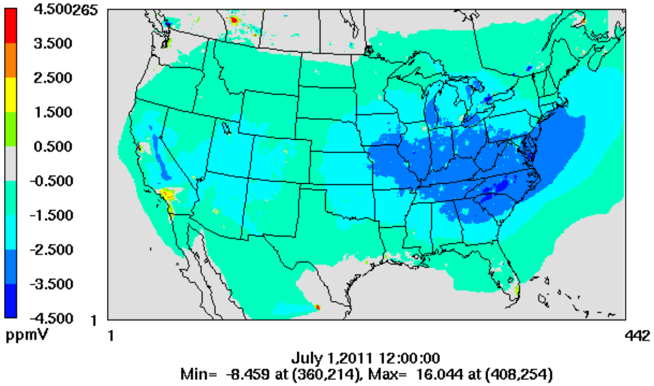


(2005 to 2012)

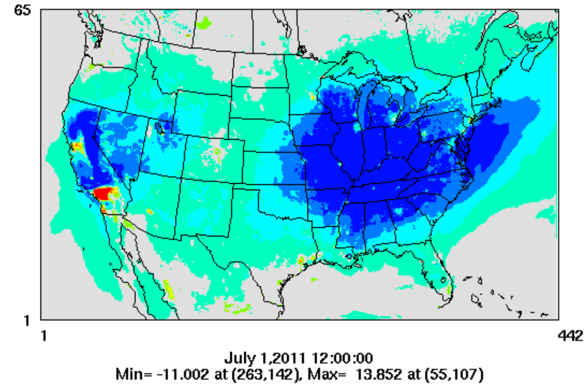
(Source: Tong et al., GRL, 2016)

Effect on O_3 Forecast

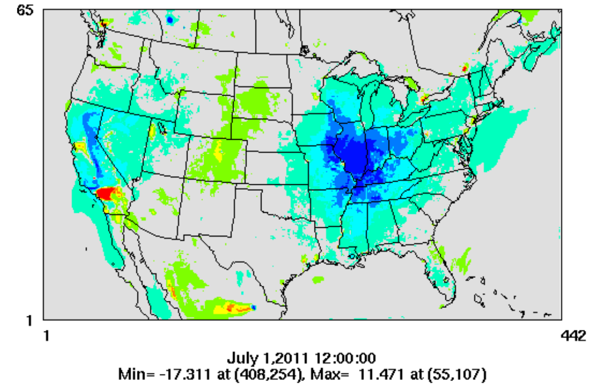
Effect of Using EPA Projection



Effect of Using Fused Obs.



Difference



Performance Metrics (July 2011 over CONUS)

	MB (ppbv)		NMB (%)		RMSE (ppbv)	
	Hourly	Max8	Hourly	Max8	Hourly	Max8
Op. NAQFC	11.9	9.9	29.7	20.3	23.1	21.5
Fused Obs	11.5	9.7	28.7	20.1	22.7	21.4

(Source: Tong et al., GRL, 2016)

Summary

- **Revealed consistent NOx responses to the 2008 Economic Recession by OMI and AQS (-6%, -10%, and -3% reduction per year before, during and after the Recession);**

- **Demonstrated how to use space and ground observations to 1) evaluate emission updates; and 2) rapidly update NOx emissions to support national air quality forecasting.**

References:

Tong, D.Q., L. Pan, W. Chen, L. Lamsal, P. Lee, Y. Tang, H. Kim, S. Kondragunta, I. Stajner, 2016. Impact of the 2008 Global Recession on air quality over the United States: Implications for surface ozone levels from changes in NO_x emissions. Geophysical Research Letter, Accepted.

Tong, D.Q., L. Lamsal, L. Pan, C. Ding, H. Kim, P. Lee, T. Chai, and K.E. Pickering, and I. Stajner, 2014. Long-term NO_x trends over large cities in the United States during the 2008 Recession: Intercomparison of satellite retrievals, ground observations, and emission inventories, Atmospheric Environment, 107,70-84, doi:10.1016/j.atmosenv.2015.01.035.

JPSS and Marine Isoprene

- SNPP-VIIRS, MODIS and SeaWiFS was used to produce marine isoprene emissions for use in NAQFC and other NOAA models