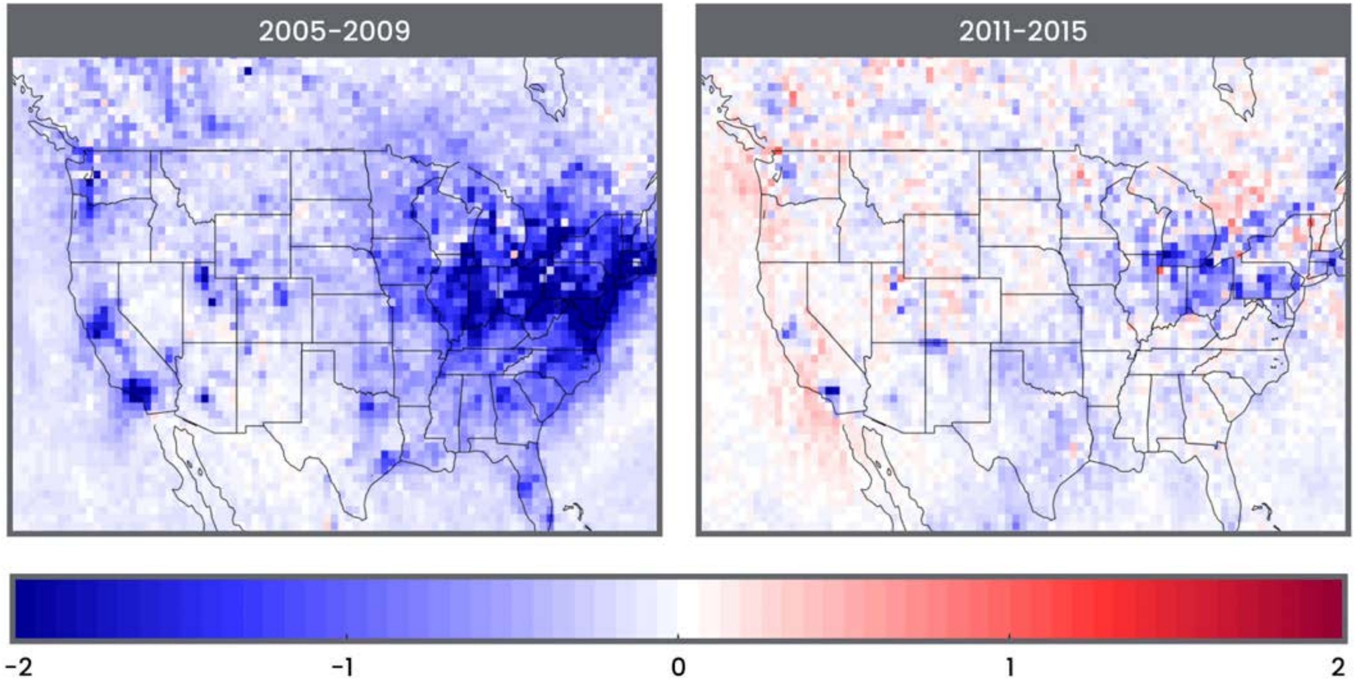
Slowing Declines in U.S. NOx Emissions Reductions Detected With OMI

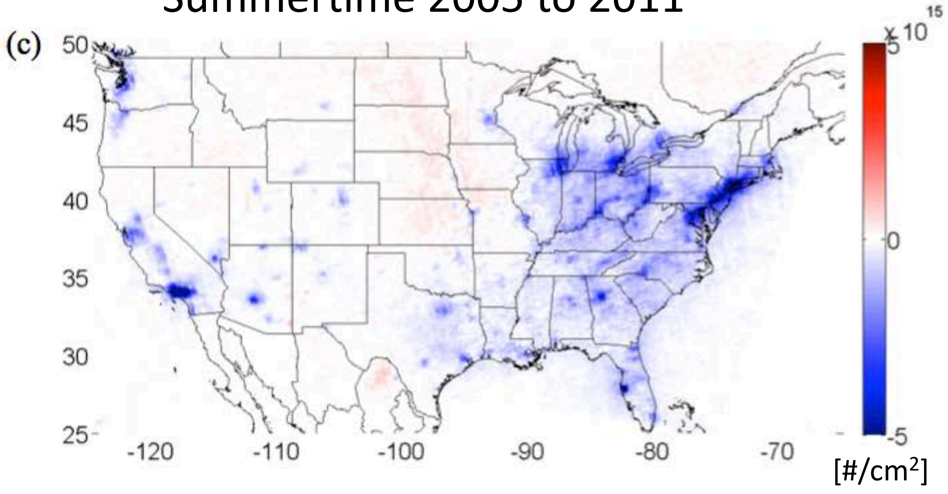


Zhe Jiang[a,b,1], Brian C. McDonald[c,d], Helen Worden[a], John R. Worden[e], Kazuyuki Miyazaki[f], Zhen Qu[g], Daven K. Henze[g], Dylan B. A. Jones[h], Avelino F. Arellano[i], Emily V. Fischer[j], Liye Zhu[j,2], and K. Folkert Boersma[k,l]
[a]NCAR; [b]University of Science and Technology of China; [c]NOAA; [d]CIRES; [e]JPL; [f]JAMSTEC; [g]CU Boulder; [h]Univ. Toronto; [i]University of Arizona; [j]CSU; [k]Wageningen University; [l]KNMI

Funding from NASA HAQAST, EOSP, NSF, COMDEV, ABB BOMEM, Canadian Space Agency

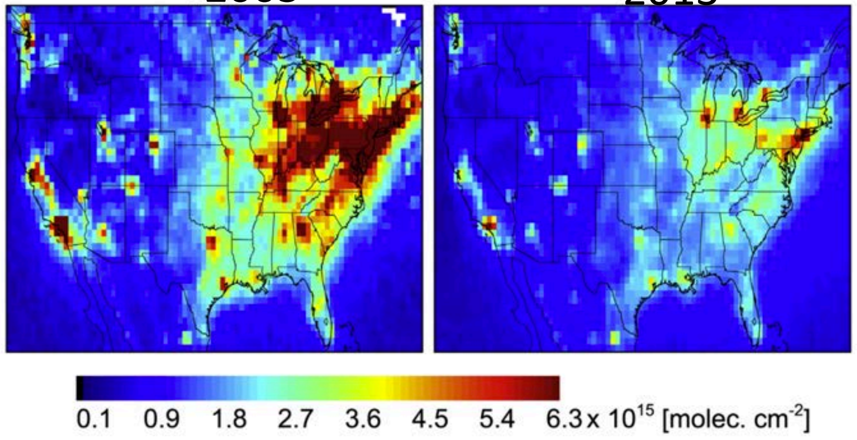
Mapping NO_2 trends with OMI

Summertime 2005 to 2011



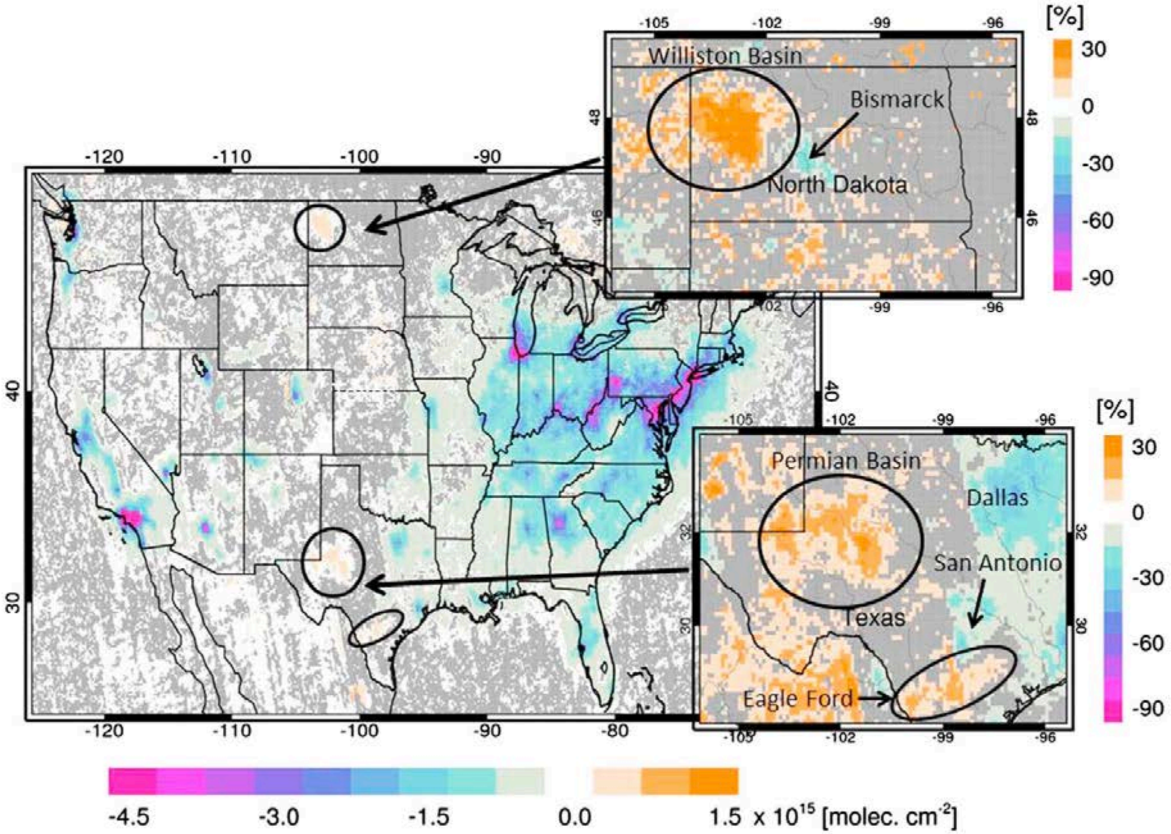
Russell et al. 2012

2005 2013



Lamsal et al. 2015

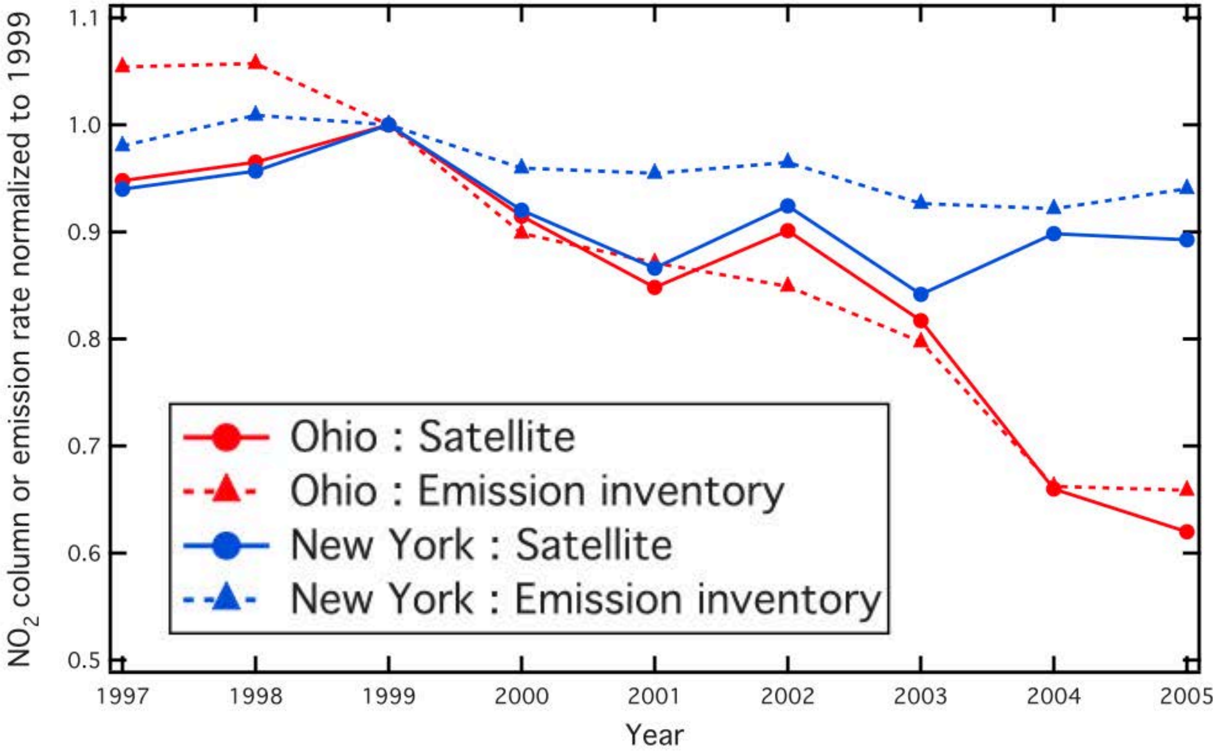
2005 to 2014



Duncan et al. 2016

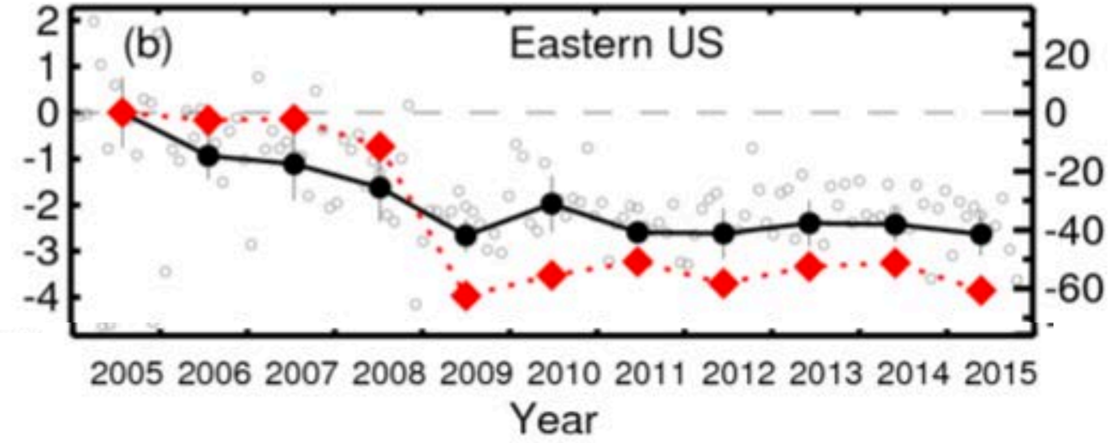
Corroborating satellite NO_2 trends with bottom-up inventories

NO_2 column (summer) from GOME & SCIA, and bottom-up NOx emissions



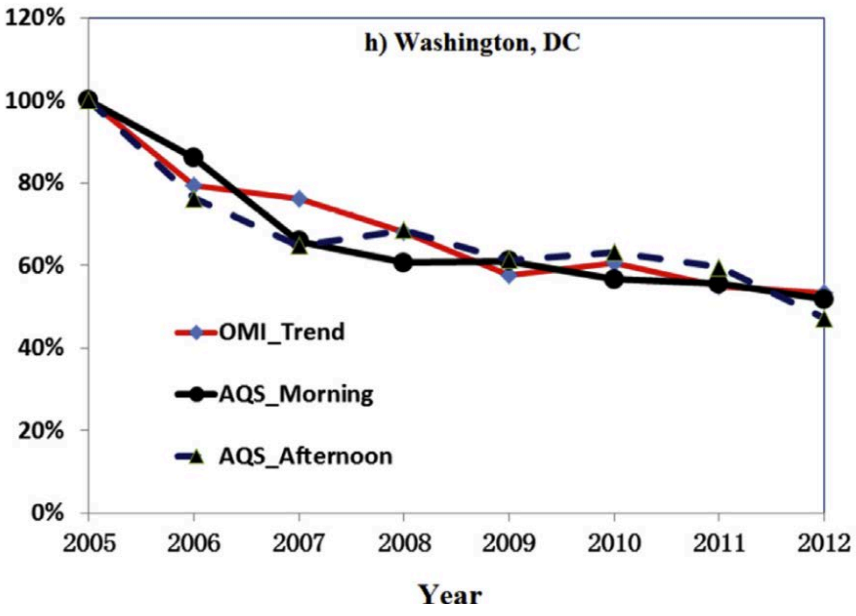
Kim et al., 2006

NO_2 column (black) from OMI, and bottom-up power-plant emissions (red)

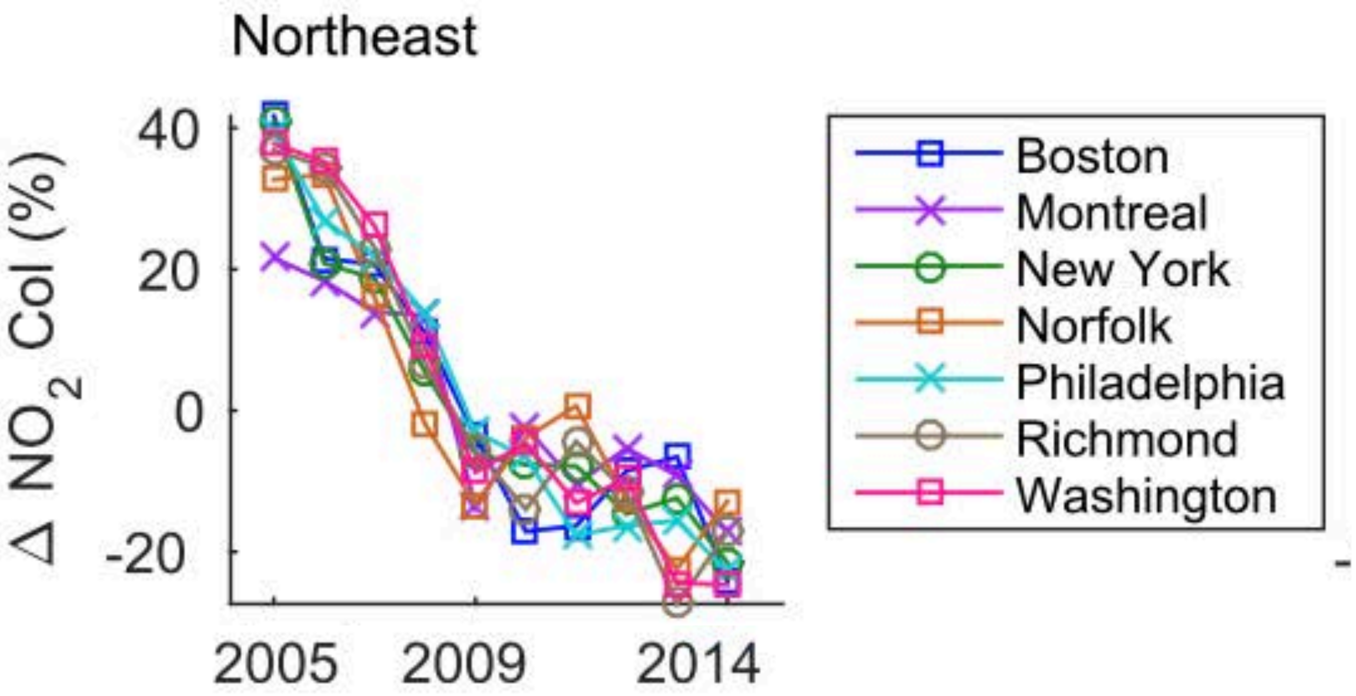


Krotkov et al., 2016

Changes in trends observed in OMI and AQS data



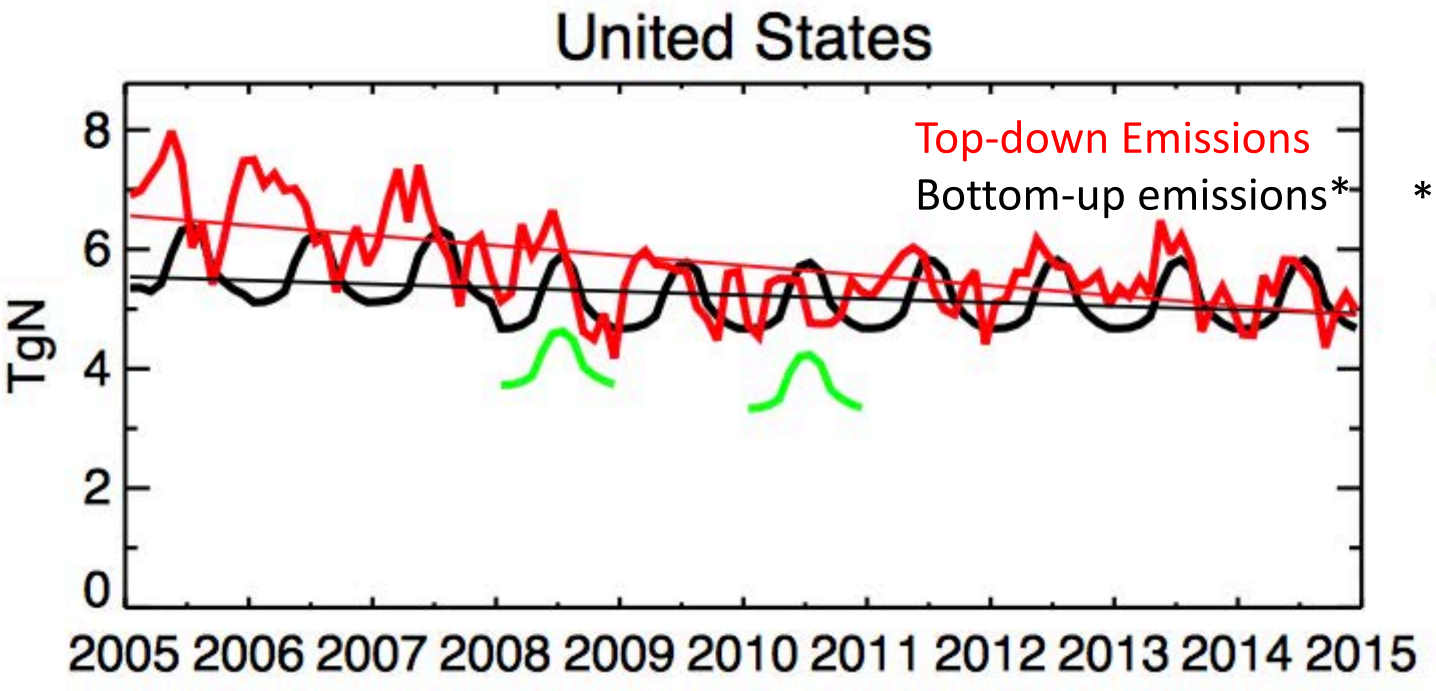
Tong et al., 2015



de Foy et al., 2016

Top-down constraints from chemical data assimilation

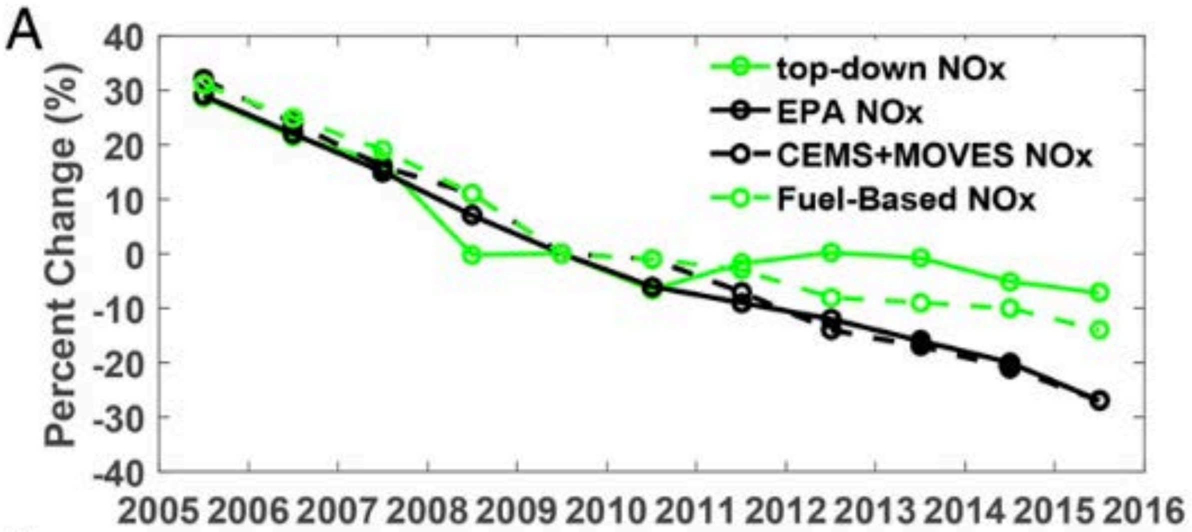
Global chemical data assimilation using OMI NO2 from Miyazaki et al. (2017) included results over the U.S.



*EDGAR (constant after 2008)

Results also show a decline in the rate of NOx emissions reductions post 2009

Declining trends have been decreasing, in contrast to inventories



“top-down NOx” from inverse modeling study of Miyazaki et al., ACP, 2017

“EPA NOx” from EPA trends report

“CEMS+MOVES” is EPA trends report but using CEMS and MOVES for egu and transport, respectively.

“Fuel-Based NOx” our bottom-up estimate (see SI)

Jiang et al., PNAS, 2018

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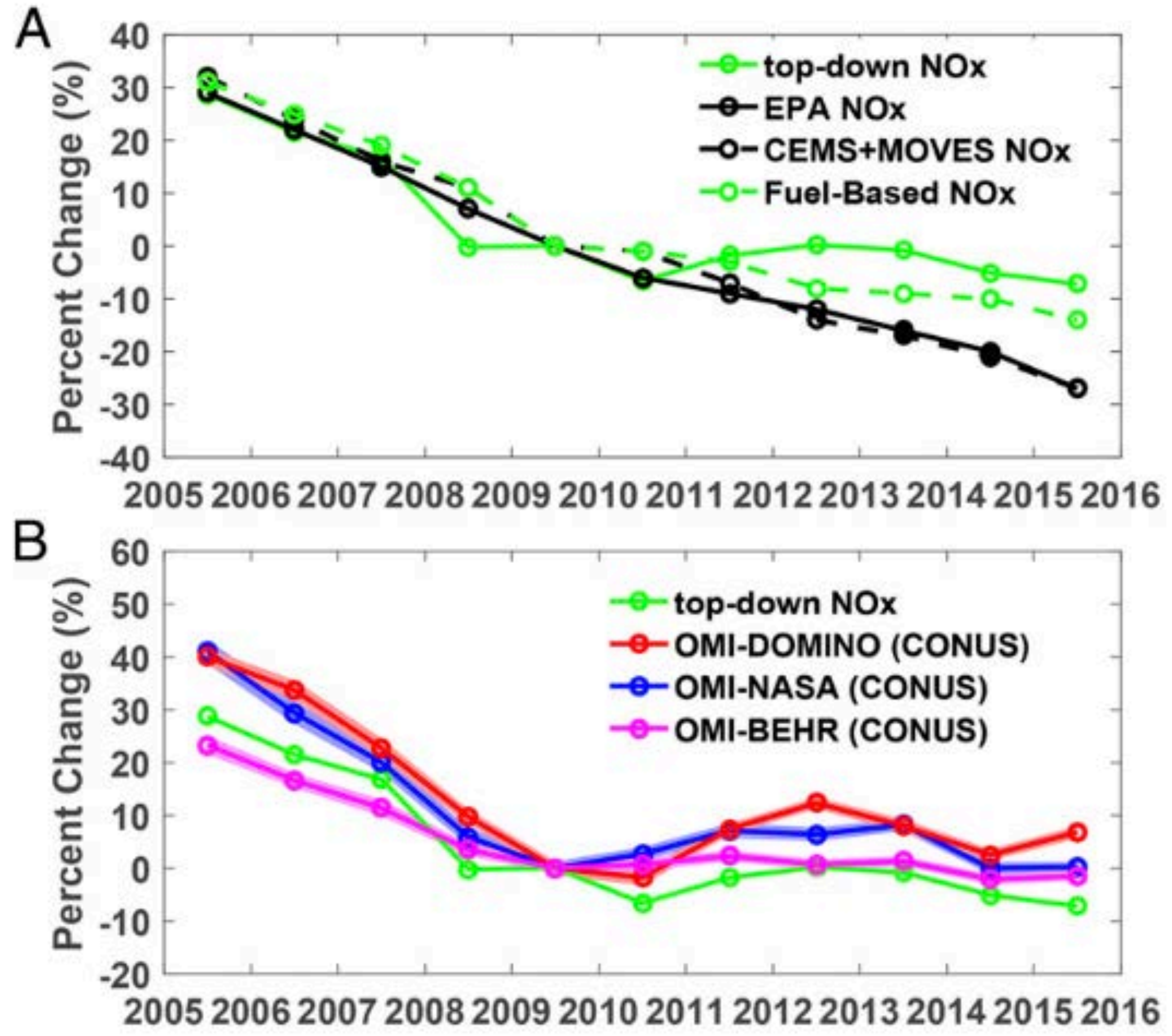

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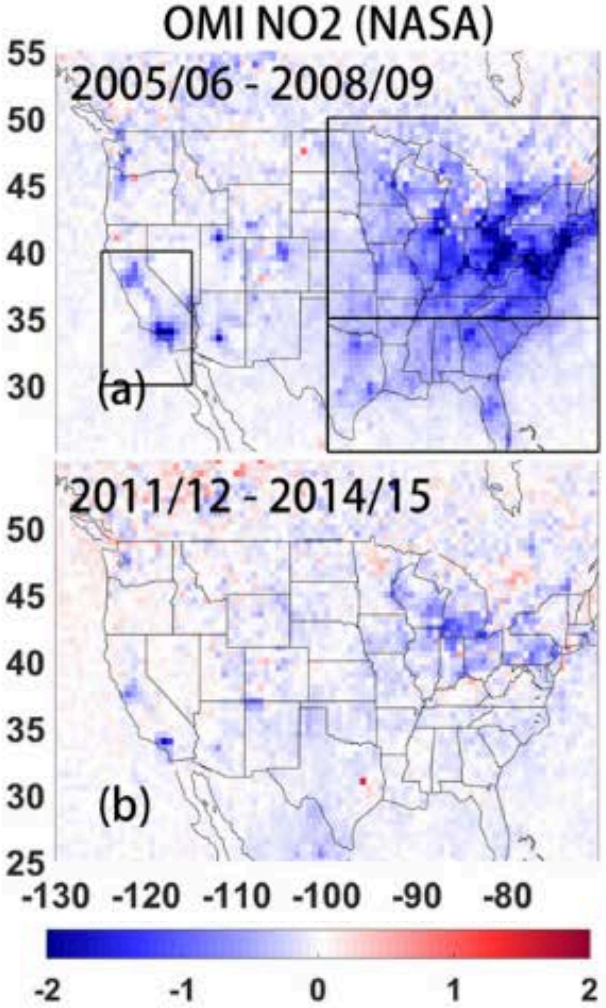
"Fuel-Based NOx" our bottom-up estimate (see SI)

DOMINO, NASA, and BEHR are different satellite retrievals (the process of converting OMI's spectroscopic measurements to column concentrations of NO2) processed by different groups.
They can differ owing to assumptions about clouds, vertical distributions of gases and aerosols in the atmosphere, etc.

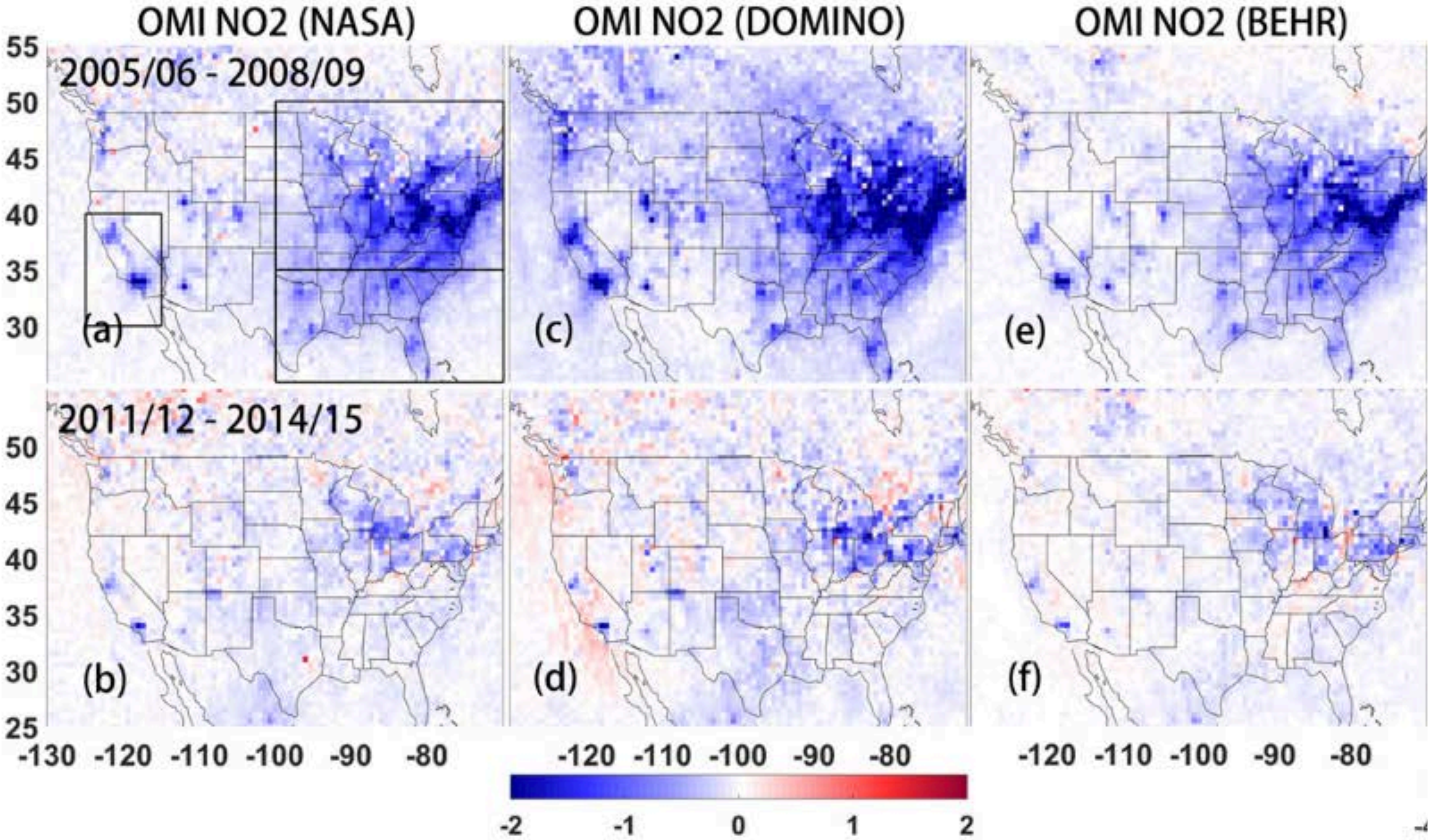
OMI NO_2 column and MOPITT CO trends



Retrieval variability at the 10 km scale makes it difficult to evaluate trends in many individual locations (and hence associate trends with particular sectors), but the broader trends are consistent.

Jiang et al., PNAS, 2018

OMI NO_2 column and MOPITT CO trends



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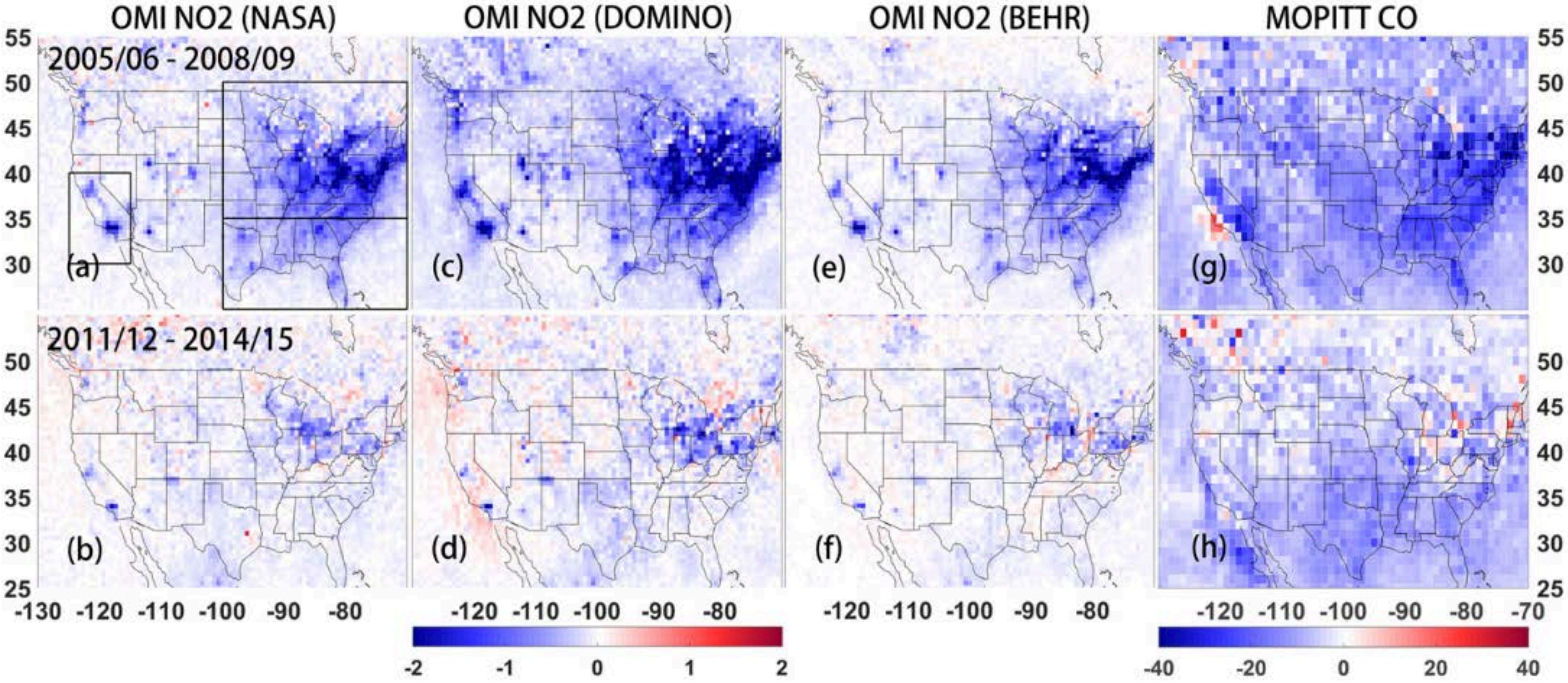
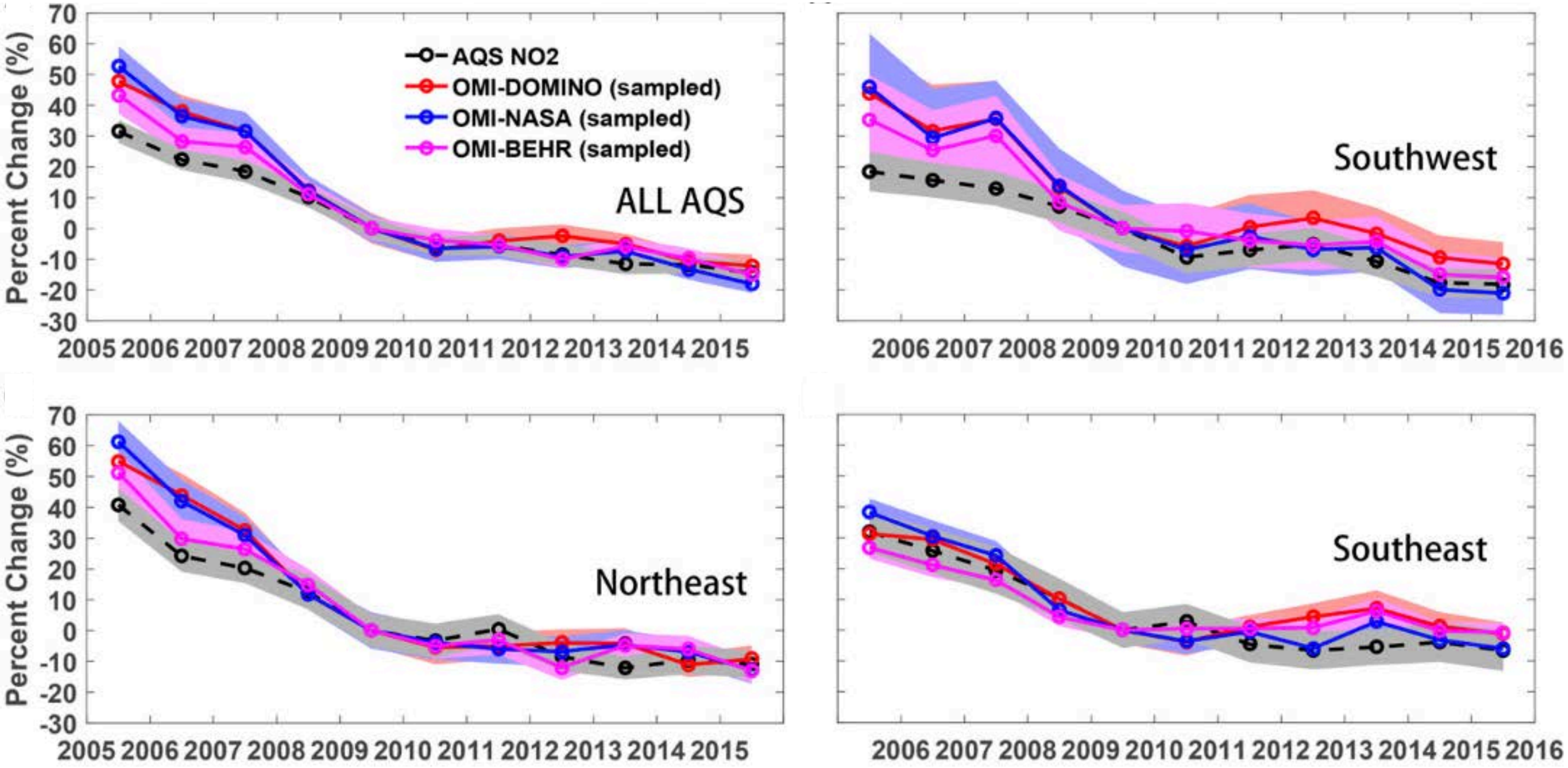


Retrieval variability at the 10 km scale makes it difficult to evaluate trends in many individual locations (and hence associate trends with particular sectors), but the broader trends are consistent.

Jiang et al., PNAS, 2018

OMI NO_2 column trends at AQS sites



Urban vs rural? The declining trends are similar if we look CONUS wide, rural, or just urban sites that have AQS measurements.

Summary

The decades-long decline in NOx and CO emissions is slowing.

- NOx concentrations dropped by 7 percent yearly from 2005 to 2009 but just 1.7 percent yearly from 2011 to 2015—a 76% slowdown.
- EPA emission inventories put the slowdown at only 16% for same period.

Slowdown likely caused by a number of reasons:

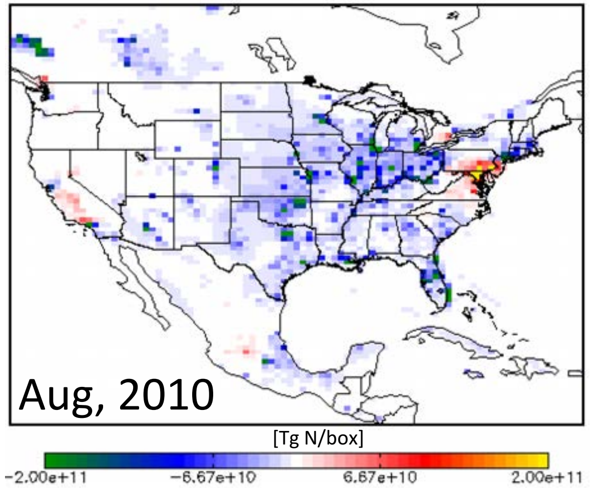
- The decreasing relative contributions of gasoline cars, due to the ongoing effectiveness of three-way catalytic converters
- The increasing relative emissions of nitrogen oxides from such sources as off-road vehicles and industrial, residential, and commercial boilers, and off-road vehicles
- Slower-than expected reductions in emissions by heavy-duty diesel trucks that have newer (and still maturing) catalytic converter technologies

•*Note:* The study concluded that emissions from China not playing a role

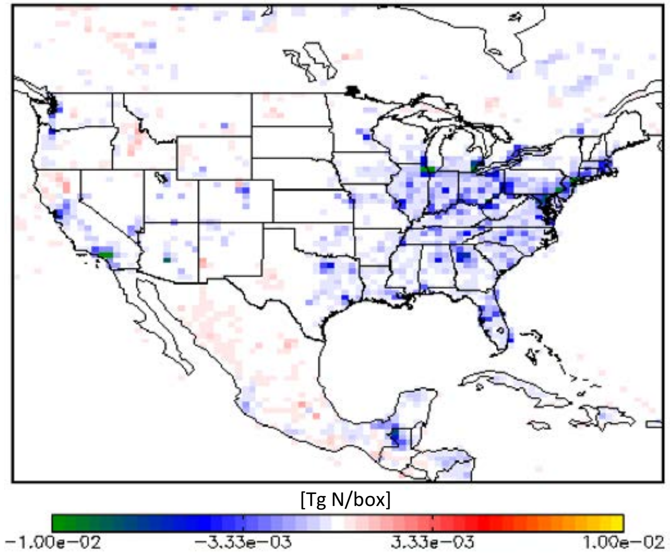
Jiang et al., PNAS, 2018

Next Steps: Constraints on NOx emissions from OMI and GEOS-Chem 4D-Var

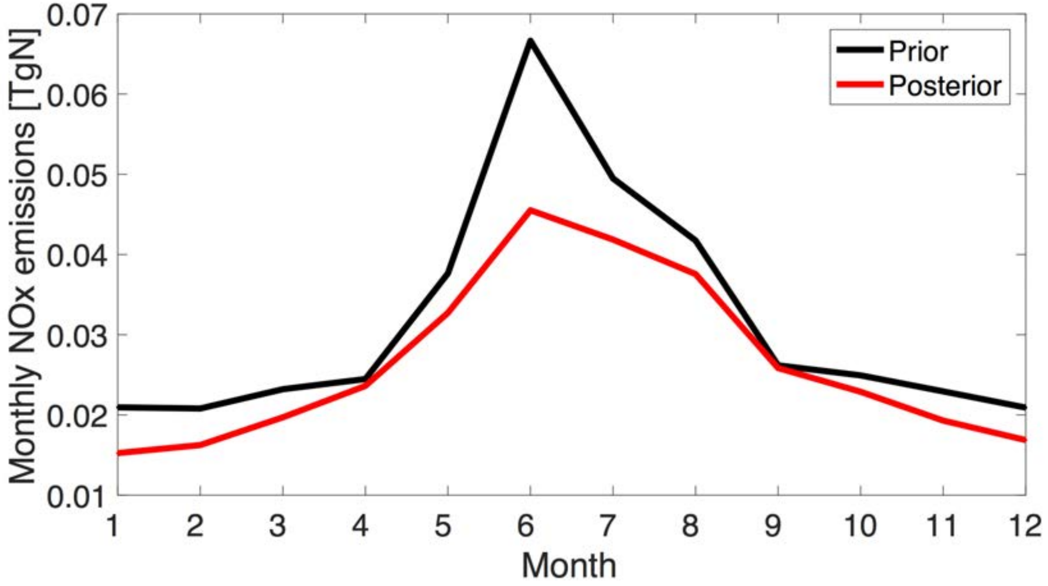
Posterior – Prior NOx Emissions



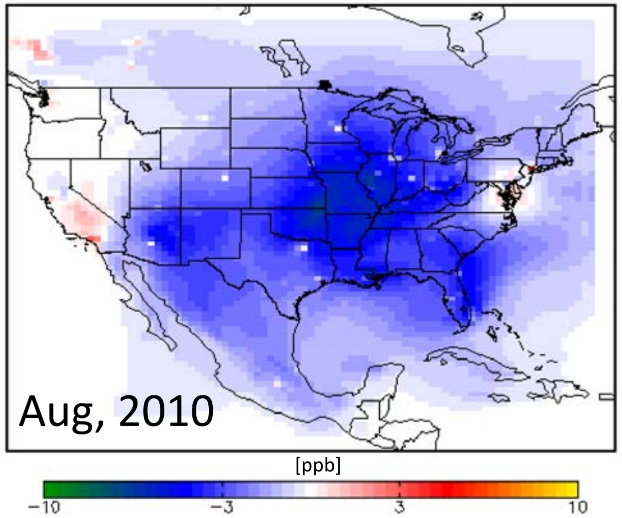
2012 – 2005 Posterior NOx Emissions



Monthly NOx emissions over entire domain (2010)



Impact on surface O_3



- Extending analysis to the entire OMI record using combination of mass-balance and 4D-Var techniques (aka “hybrid inversion” Qu et al., 2017)
- Global (2°x2.5°) and NA (0.5° x 0.67°) inversions of NO_2 and SO_2
- Examining sensitivity of inversions to satellite retrievals

Year 2 Progress Update, PI Henze, Co-I's Anenberg, Kinney

Supporting health impact assessment tools using remote sensing and earth system models

- Source-receptor (SR) coefficients for $PM_{2.5}$ and O_3 to CCAC impact toolkit (LEAP-IBC)
  - $PM_{2.5}$ SR coefficients delivered to CCAC for all countries in Asia, Africa, most countries in Caribbean, Central & South America.
  - O_3 coefficients for each CCAC member nation
  - LEAP-IBC applied in Nepal (Nakarmi et al., submitted)
  - Impacts of cookstoves (Lacey et al., 2017) and fugitive diesel NOx (Anenberg et al., 2017)
- High-resolution SR calculations for urban regions
  - In progress for Africa, West Africa
- Expand health impacts
  - Global burden of ambient air pollution on asthma (Anenberg et al., submitted)

Tiger Team Participation

- Hi-Res $PM_{2.5}$ (Kinney, Tong)
  - Health impacts of different $PM_{2.5}$ estimates (**Anenberg**)
  - Low-cost monitors deployed in NYC, Boston, SF (**Kinney**)
- NOx constraints (Pierce, Tong)
  - US July 2011 0.5x0.667 NOx emissions, comparison to CMAQ DA (Pierce) and impact of retrieval choice (SP vs DOMINO)
- SIPs (Fiore)
  - Contribute to / review technical guidance documents
  - NO_2 trends from OMI (Zhang et al., 2018)
  - Review of background O_3 (Jaffe et al., 2018) and satellite $PM_{2.5}$ (Diao et al, in prep.)
- Trends (Duncan, West)
  - SO_2 and NO_x emission constraints from OMI and associated $\Delta PM_{2.5}$ and O_3 in progress
- Long-range pollution transport (AQAST TT)
  - Contributed to 6 papers in ACP special issue

Extra slides

Table 1. Trends and uncertainties for all NO_x datasets

Period	EPA NO_x	Top-down NO_x	OMI (NASA)	OMI (DOMINO)	OMI (BEHR)	AQS NO_2
2005–2009 (CONUS)	−6.4%	−7.0 ± 1.4%	−8.8 ± 1.0%	−8.6 ± 0.9%	−5.4 ± 1.0%	
2011–2015 (CONUS)	−5.3%	−1.7 ± 1.4%	−1.9 ± 0.8%	−1.0 ± 0.9%	−1.0 ± 0.8%	
2005–2009 (sampled)			−10.2 ± 1.8%	−9.6 ± 1.7%	−8.5 ± 1.8%	−6.6 ± 1.4%
2011–2015 (sampled)			−3.2 ± 1.6%	−2.6 ± 1.8%	−2.1 ± 1.6%	−2.6 ± 1.5%

All trends are relative to the average of each data period (2005–2009 and 2011–2015) cover the whole US and based on a linear trend model. Uncertainties represent 1 σ and include the error budget discussed in *SI Appendix*. OMI (sampled) represents OMI NO_2 measurements sampled at AQS NO_2 measurement locations and times based on monthly averages.