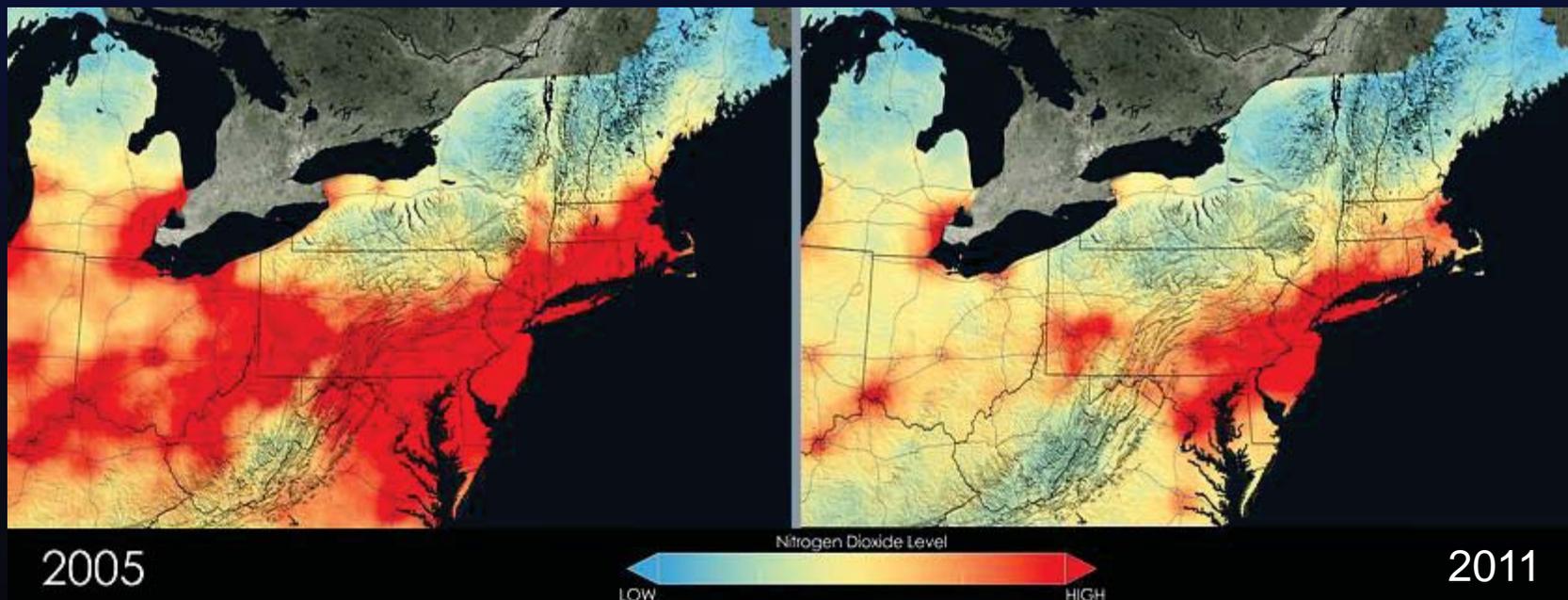


# Nitrogen dioxide trend over the United States: The view from the ground, the view from space

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## Federal NO<sub>x</sub> reduction program

- 1998 NO<sub>x</sub> State Implementation Plan (SIP) Call
- 2005 Clean Air Interstate Rule (CAIR)
- 2011 Cross-State Air Pollution Rule (CSAPR)
  - ~68% decrease in NO<sub>x</sub> emissions from EGU since late 1990s
- Clean Air Act Amendments (CAAA) of 1990
  - ~43% decrease in NO<sub>x</sub> emissions from mobile sources since late 1990s

Duncan, B.N., Y. Yoshida, B. de Foy, L.N. Lamsal, D. Streets, Zifeng Lu, K. E. Pickering, and N. A. Krotkov, the observed response of the Ozone Monitoring Instrument (OMI) NO<sub>2</sub> column to NO<sub>x</sub> emission controls on power plants in the United States: 2005–2011, *Atmos. Environ.*, 81, 102–111, 2013.

Tong, D., L.N. Lamsal, L. Pan, H. Kim, P. Lee, T. Chai, K.E. Pickering, Long-term NO<sub>x</sub> trends over large cities in the United States: Intercomparison of satellite retrievals, ground observations, and emission inventories, *Atmos. Env.*, 2014, under review.

Lamsal, L.N., B.N. Duncan, Y. Yoshida, N.A. Krotkov: U.S. regional and urban nitrogen dioxide trends (2005–2013): Linking high-resolution satellite tropospheric column data to AQS surface observations, 2014, in preparation.

## Research questions

- How do NO<sub>2</sub> trends from OMI and surface monitors (EPA/AQS) compare?
- How is the pace of NO<sub>2</sub> reduction?
- Do we expect NO<sub>2</sub> column and surface concentration exhibit same trend?
- Do AQS (molybdenum converter) monitors offer actual NO<sub>2</sub> trend?
- How do a-priori NO<sub>2</sub> profiles used in retrievals affect satellite-derived trend?
- What are the trends over major metro areas and power plants?

# Analysis of time series: 2005–2013

$$Y_t = Y_0 + Bt + A1 \cdot \cos(2\pi t) + A2 \cdot \sin(2\pi t) + N_t$$

= **constant + trend + seasonal + residual**

$Y_t$ : monthly mean of tropospheric  $\text{NO}_2$

$t$ : months

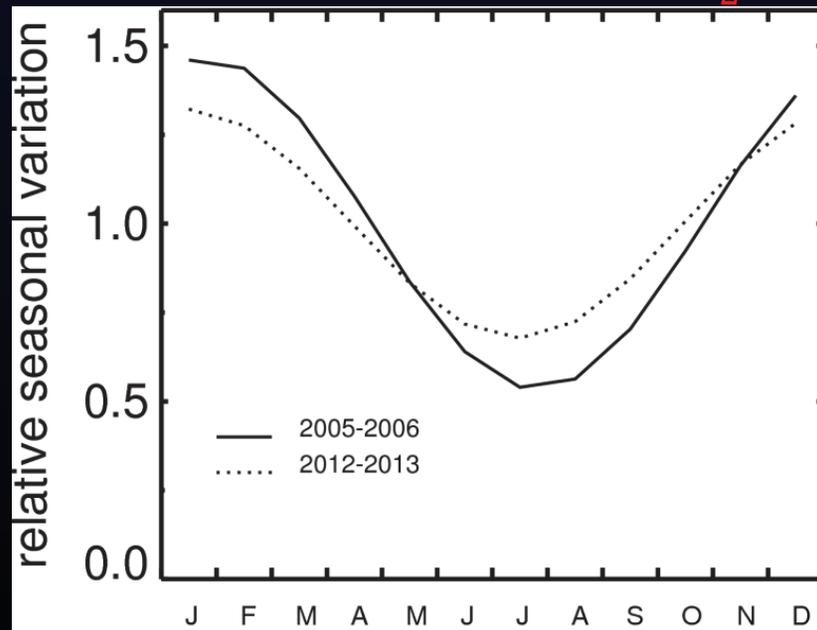
$Y_0$ : constant

$B$ : monthly trend

$A1, A2$ : constant defining seasonal variability

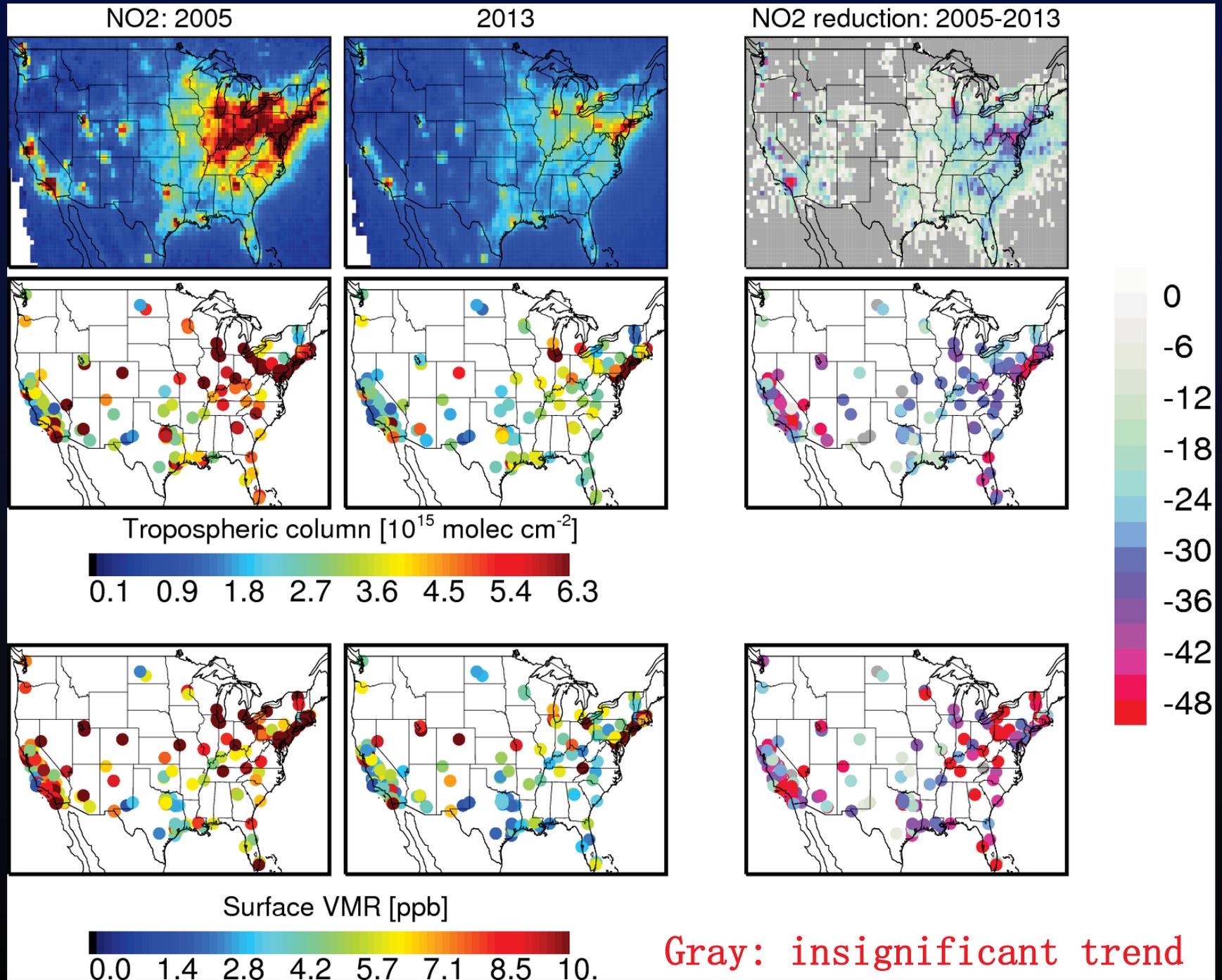
$N_t$ : residual

OMI tropospheric  $\text{NO}_2$

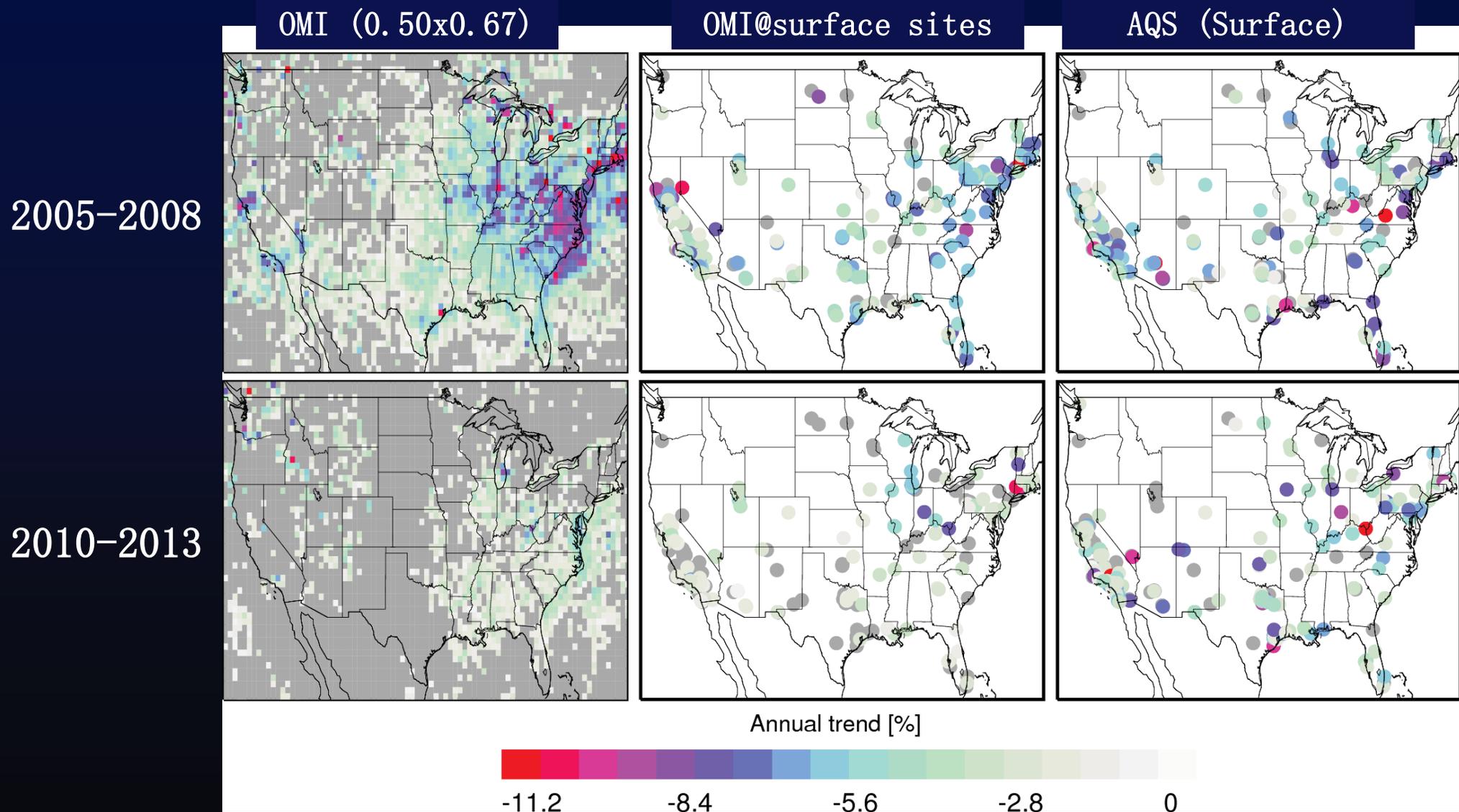


$$Y_t = \text{constant} + \text{trend} + \text{seasonal} + \text{seasonal amplitude change} + \text{residual}$$

# OMI and surface (AQS) measurements show consistent trend



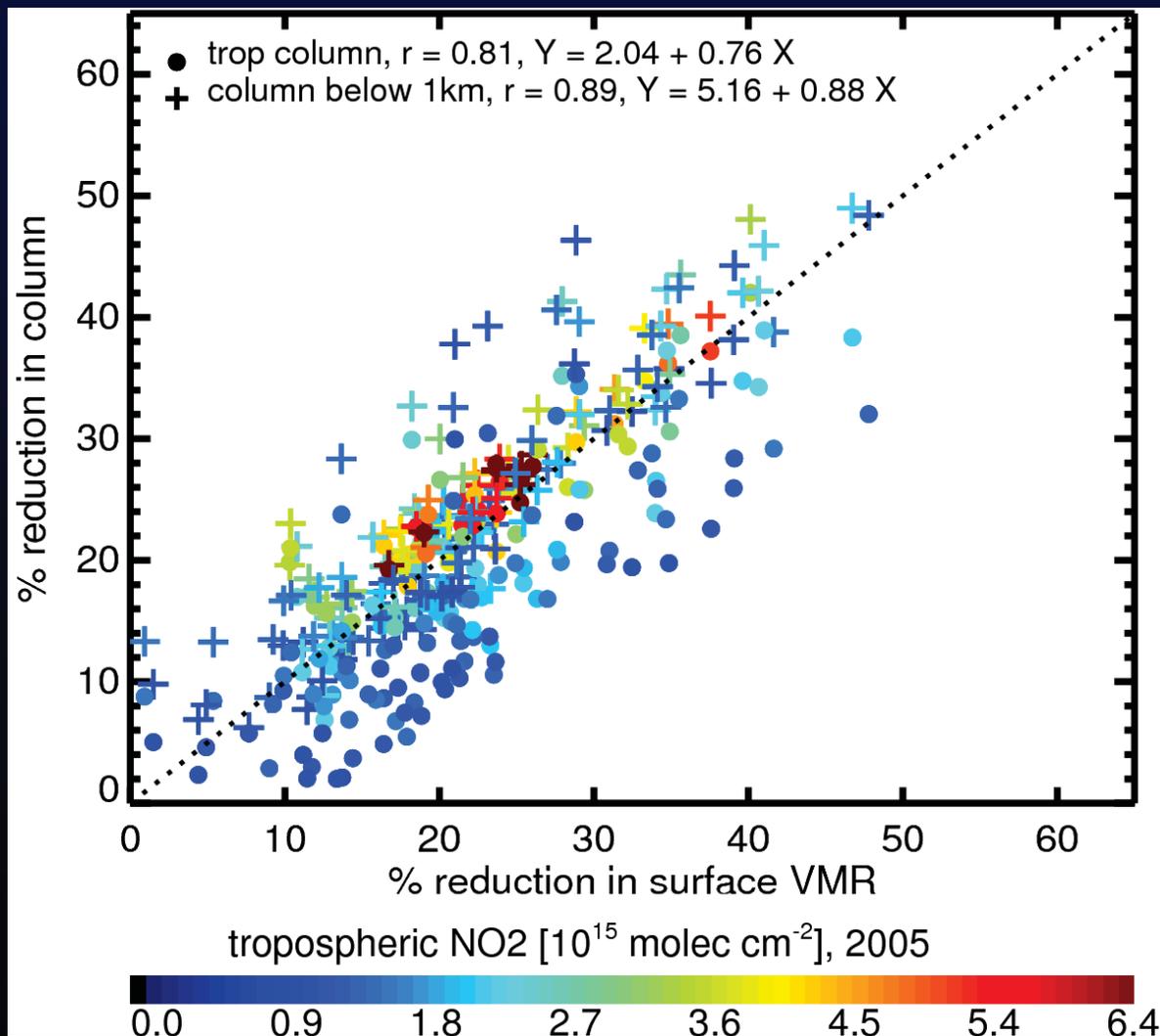
# Pace of NO<sub>2</sub> reduction is slowing down lately



- a) OMI shows complex spatial trend that surface monitors cannot provide,
  - b) For 2005–2008, large and significant trend,
  - c) Pace of reduction is slowing down
- Gray: insignificant trend

# Causes for the difference: (A) Do we expect NO<sub>2</sub> column and surface concentration exhibit same trend?

Results from model simulation  
2005–2010

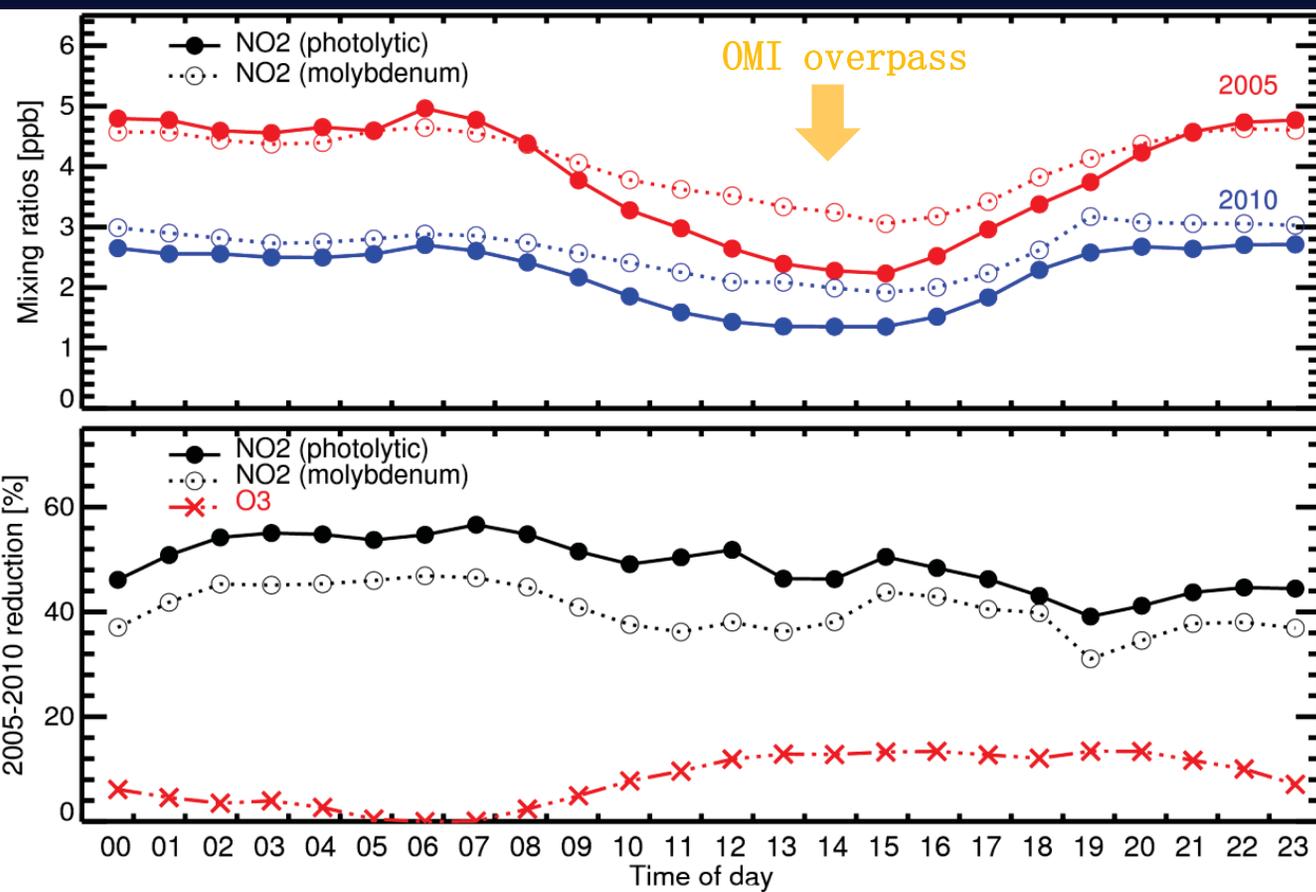


- NO<sub>2</sub> column and surface concentration don't necessarily feel same trend
- In less polluted areas, trend in surface concentration are higher than in column
- In highly polluted areas, trends are similar

# Causes for the difference: (B) Do AQS monitors offer actual $\text{NO}_2$ trend?

$\text{NO}_2$  measurements at Yorkville, GA  
2005-2010

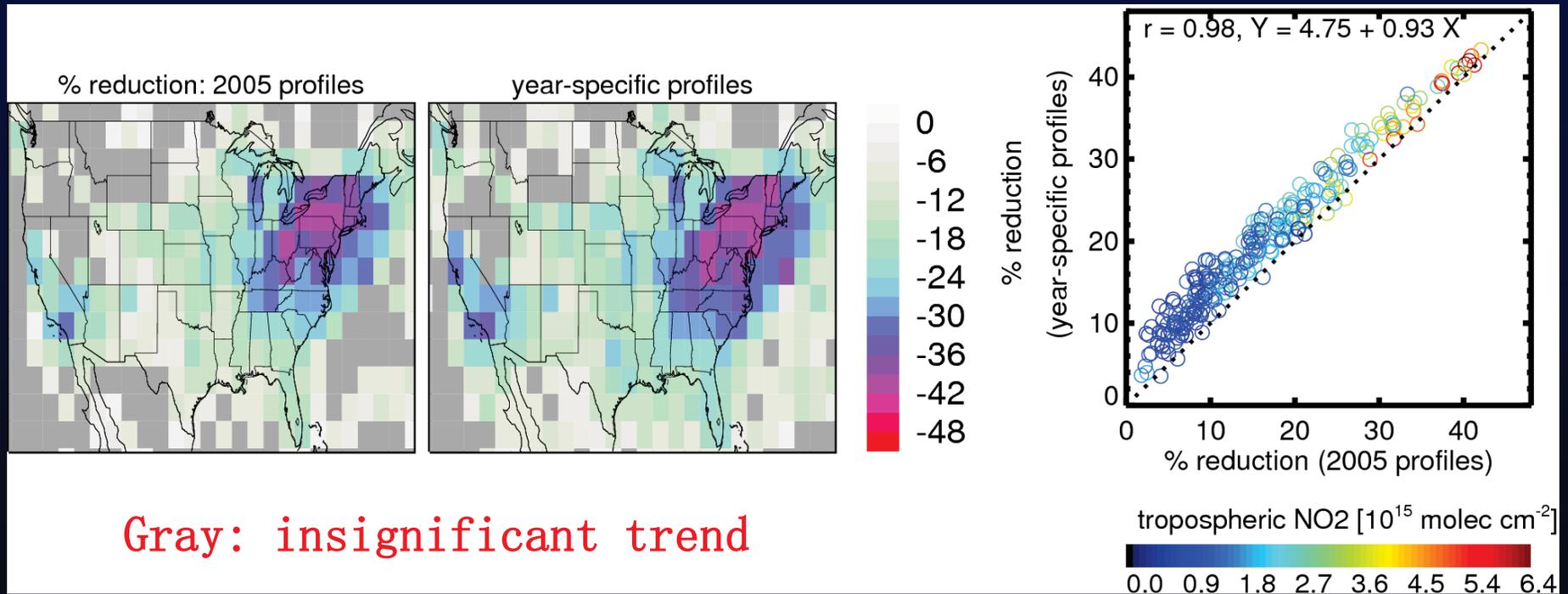
Photolytic  $\text{NO}_2$  (SEARCH): True  $\text{NO}_2$   
Molybdenum  $\text{NO}_2$  (AQS):  $\sim \text{NO}_z$   
(reactive nitrogen species)



- Strong interference around OMI overpass
- Interference is growing as  $\text{NO}_2$  levels going down
- AQS monitors likely underestimate true  $\text{NO}_2$  trend

# Causes for the difference: (C) How do a-priori NO<sub>2</sub> profiles used in retrievals affect OMI-derived trend?

Separate NO<sub>2</sub> retrievals with 2005 and year-specific monthly mean profiles: OMI NO<sub>2</sub> trend for 2005–2010



Gray: insignificant trend

- Profiles with updated emissions result in increase in both magnitude and areas of significant trend
- Trends are less sensitive to a-priori in highly polluted areas
- Satellite-observed NO<sub>2</sub> trends are likely underestimated due to the use of profiles with outdated emissions

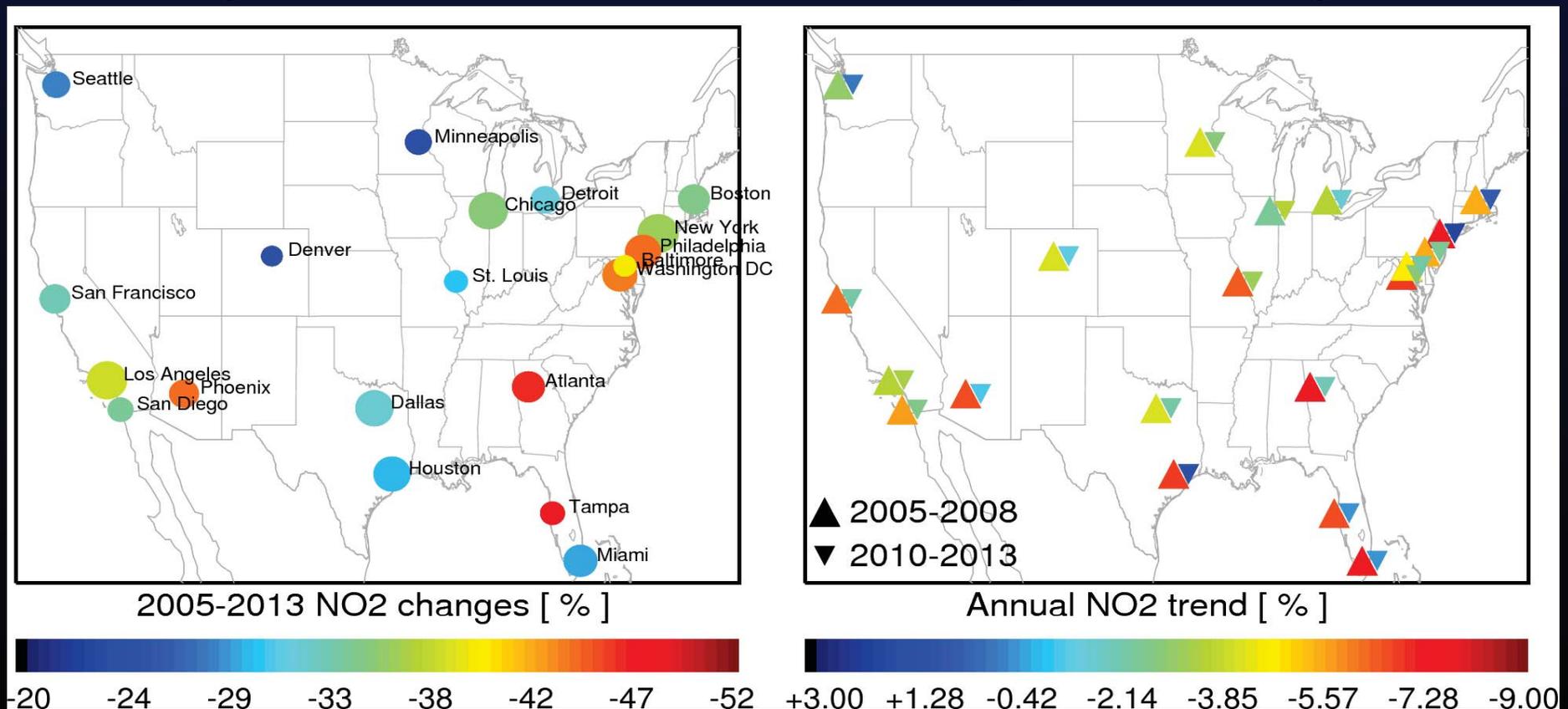
# Satellite-observed NO<sub>2</sub> trends over top-20 metro areas

In highly polluted areas, satellite-observed NO<sub>2</sub> trends  
[A] are least affected by a-priori,  
[B] are close to surface concentration trends,  
[C] offer true NO<sub>2</sub> trend

OMI trend  $\approx$  actual surface trend over metro areas and power plants

Change for 2005–2013

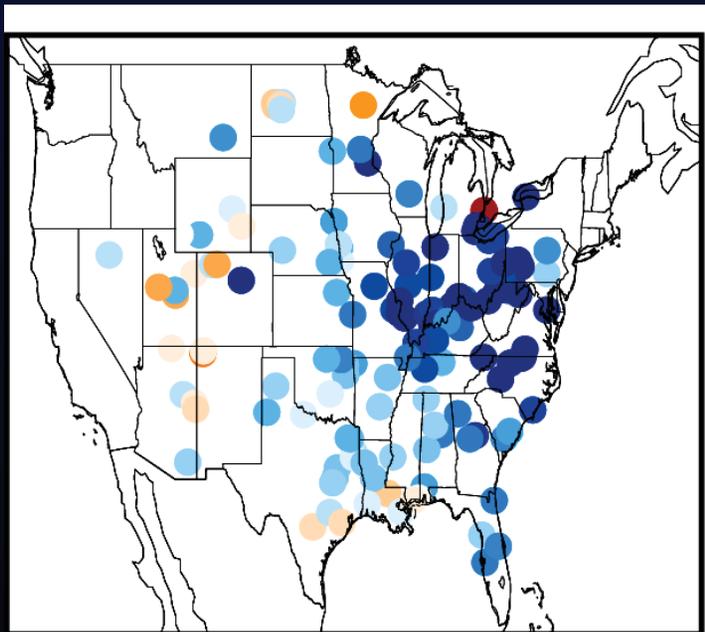
Annual pace of change



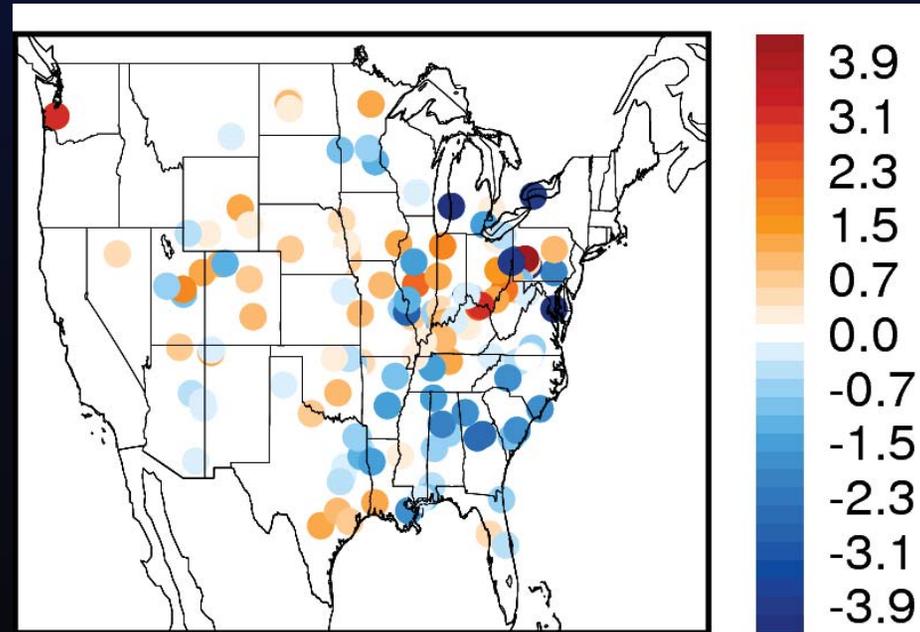
## Trends over top-100 power plants

Since ~2009, because of certain legal complications, many power plants could comply without running their control devices.

OMI annual  $\text{NO}_2$  trend ( $10^{14}$  molec  $\text{cm}^{-2}$ )  
2005–2009



2010–2014



Increasing trend confirmed by CEMS data

## Conclusions

- NO<sub>2</sub> trends from OMI and surface monitors (EPA/AQS) are generally consistent
- The pace of NO<sub>2</sub> reduction is slowing down in recent years
- NO<sub>2</sub> column and surface concentration unlikely feel similar trend, except in highly polluted areas
- AQS (molybdenum converter) monitors may not offer actual NO<sub>2</sub> trend
- Satellite-derived trends are sensitive to a-priori NO<sub>2</sub> profiles used in retrievals
- NO<sub>2</sub> reductions over major metro areas range 20–50% for 2005–2013, with annual rate of 3–8% for 2005–2008 and  $\pm 3\%$  for 2010–2013

### Acknowledgements:

NASA, ACAST

Thank you for your attention

# Analysis of time series: 2005–2013

