Evaluation of NO_x Emissions in the Western US using WRF-Chem Model Simulations and Satellite Observations

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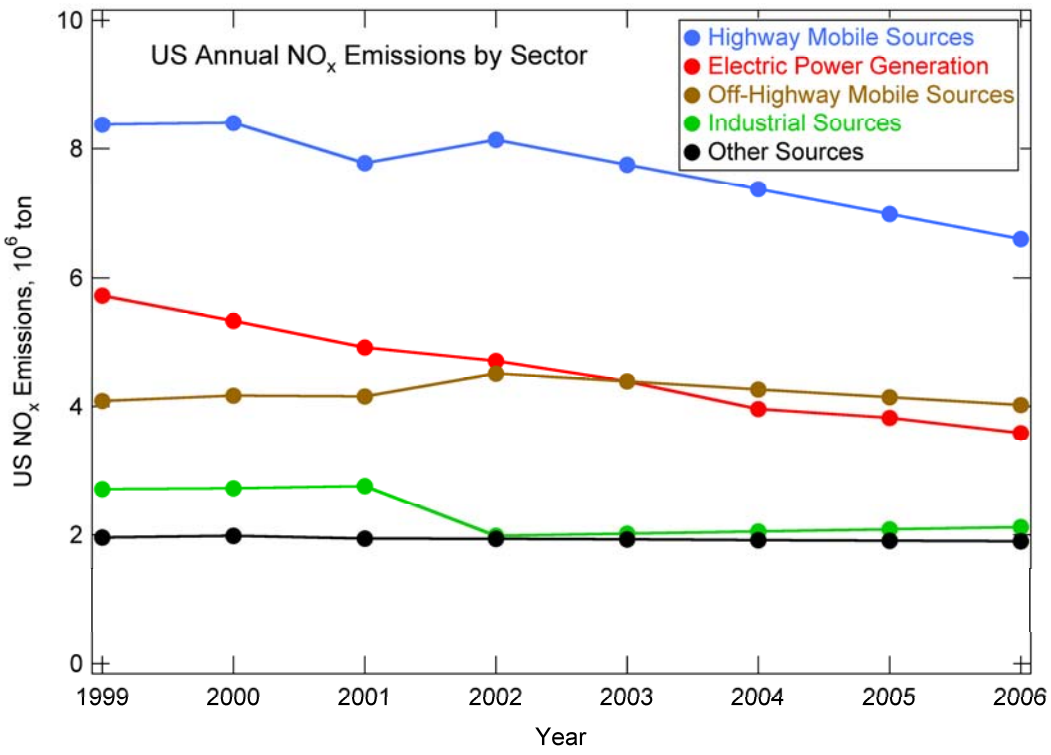
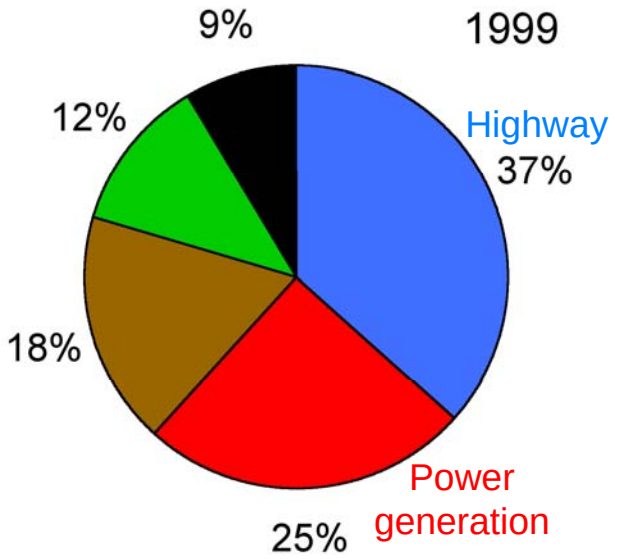
Outline

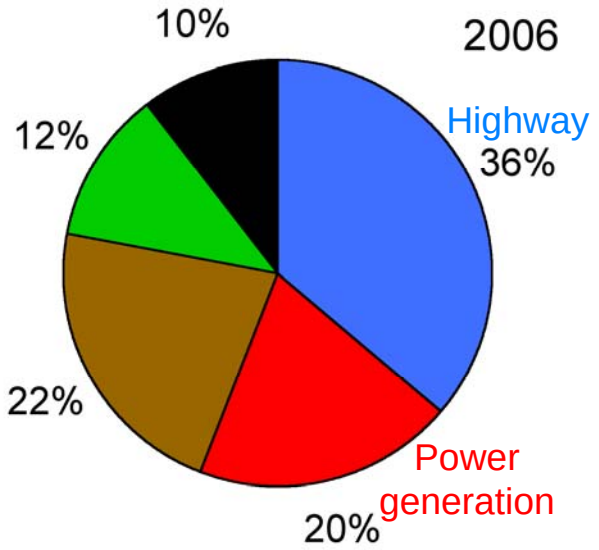
- Bottom-up assessment of NO_x emissions
- Satellite and model determination of atmospheric NO_2 columns
- Review previous work: NO_x emission controls at Eastern US power plants
- Analysis of NO_x emissions from Western US power plants and urban areas

EPA 17th International Emission Inventory Conference, June 3-5, 2008

EPA Assessments of US NO_x Emission Trends







EPA assessments of NO_x emission trends based on bottom-up inventories

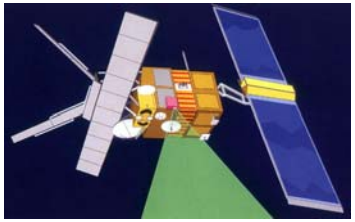
- US NO_x emissions have decreased 20% since 1999
- Largest decreases in two biggest sectors
  - Highway mobile sources: *emission models*
  - Electric power generation: *stack measurements*
- Power generation now smaller contributor

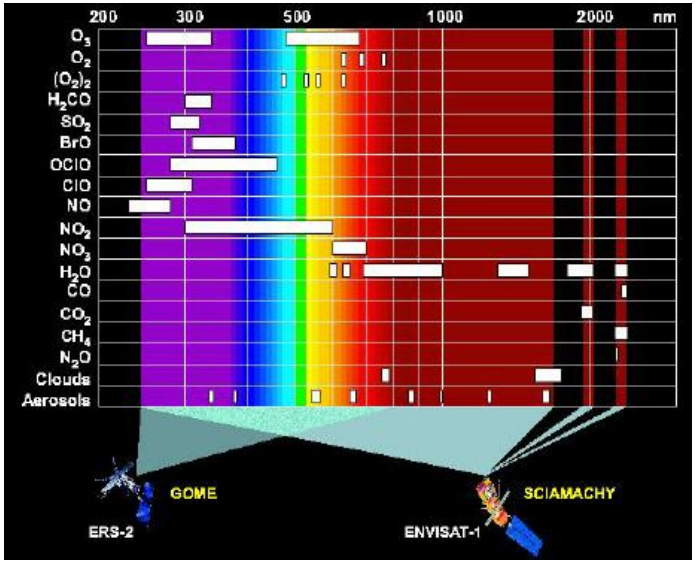
EPA National Emissions Inventory (NEI) Air Pollutant Emissions Trends Data
http://www.epa.gov/ttn/chief/trends/index.html

Satellite Measurements of NO_2 Vertical Columns

NO_x emissions ∝ NO_2 columns (summer day ⇒ short NO_x lifetime)

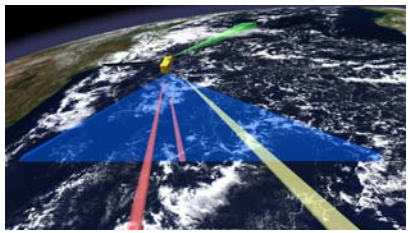
GOME
***G**lobal **O**zone **M**onitoring **E**xperiment*
- On ERS-2
- August 1995 - June 2003
- Horizontal resolution: 320 × 40 km^2
- Global coverage: 3 days
- Overpass time: 10:30 am local solar





SCIAMACHY
SC**anning **I**maging **A**bsorption spectro**M**eter for **A**tmospheric **CH**artograph**Y
- On ENVISAT
- March 2002 ~
- Horizontal resolution: 60 × 30 km^2
- Global coverage: 6 days
- Overpass time: 10:30 am local solar

OMI
***O**zone **M**onitoring **I**nstrument*
- On EOS-Aura
- November 2004 ~
- Horizontal resolution:13 x 24 km^2
- Global coverage: 1 day
- Overpass time: 1:30 pm local solar



Extracting NO_2 vertical columns
- Measure NO_2 absorption: DOAS
- Remove stratospheric component
- Cloud filtering: cloud fraction < 0.15
- Convert tropospheric residual to vertical column
  - vertical sensitivity: radiative transfer model
  - air mass factor: chemical transport model

WRF-Chem Modeling of NO_2 Vertical Columns

Weather ***R***esearch and ***F***orecasting - ***Chem***istry model

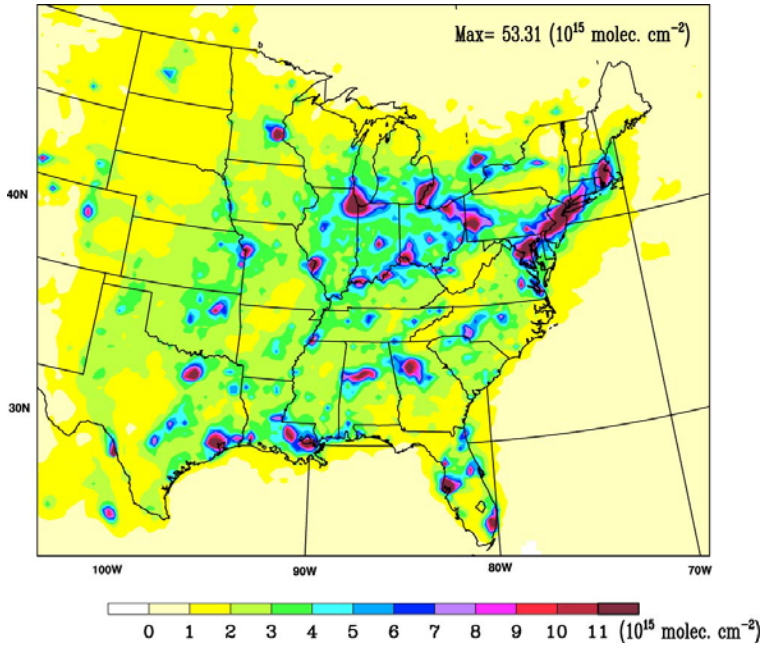
- www.wrf-model.org/WG11
- Simulates atmospheric chemistry online within WRF meteorological model
- Various chemical mechanisms, aerosol modules
- Variety of treatments of planetary boundary layer, microphysics, radiation, and convection

Setup for these case studies

- Eastern US
  - Summer 2004 simulation period
  - 27 x 27 km^2 horizontal resolution
- Western US
  - Summer 2005 simulation period
  - 15 x 15 km^2 horizontal resolution
- Emissions
  - EPA NEI1999 updated with 2004/2005 CEMS power plant data

NOAA ESRL High Performance Computing System

WRF-Chem Summer 2004 Average NO_2 Vertical Columns



Previous Work: NO_x Controls at Eastern US Power Plants

Examine effects of NO_x controls on large point sources in the Eastern US beginning in the late 1990s

- National and regional pollution control programs
- Focus on coal-burning power plants
- Improved burner technology, post-burner ammonia scrubbers

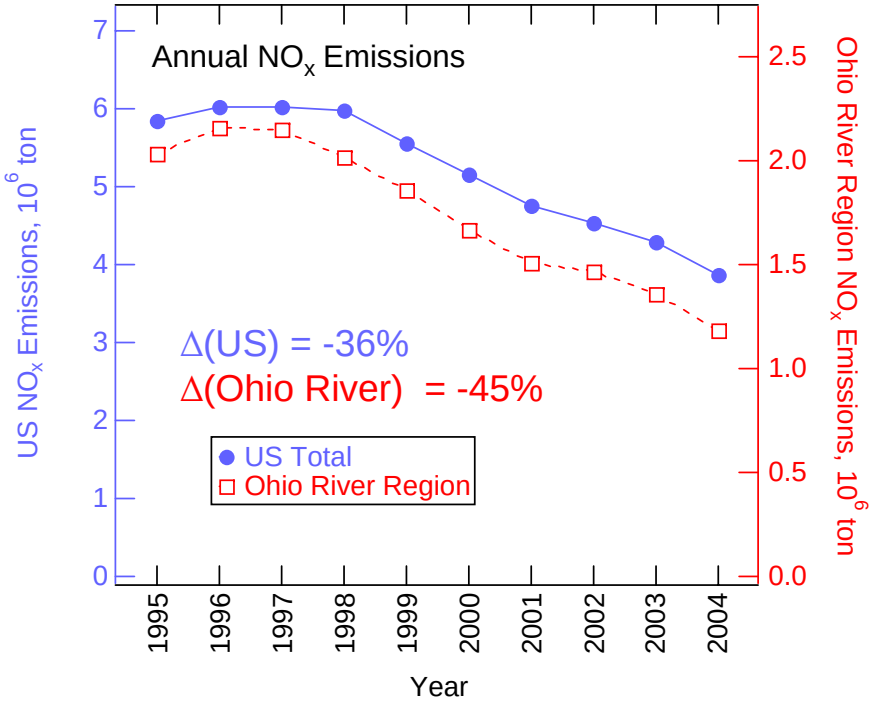
S.-W. Kim et al. (2006), Satellite-observed US power plant NO_x emission reductions and their impact on air quality, Geophys. Res. Lett., 33, L22812, doi:10.1029/2006GL02774

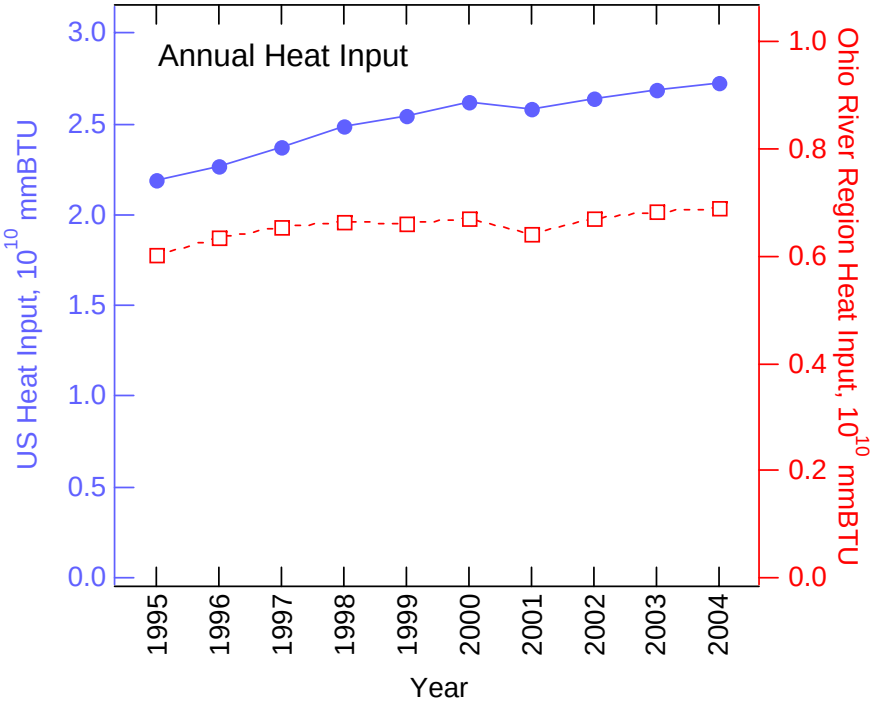
Power Plant NO_x Emission Decreases Measured by CEMS

Continuous Emission Monitoring Systems (CEMS)

- *Stack measurements of hourly NO_x, SO_2, and CO_2 emissions made by utility companies*
- *Data for 966 facilities in 1999 and 1427 facilities in 2004*

Annual trends ➢ Substantial NO_x emission reductions since late 1990's while maintaining amount of electric power generated



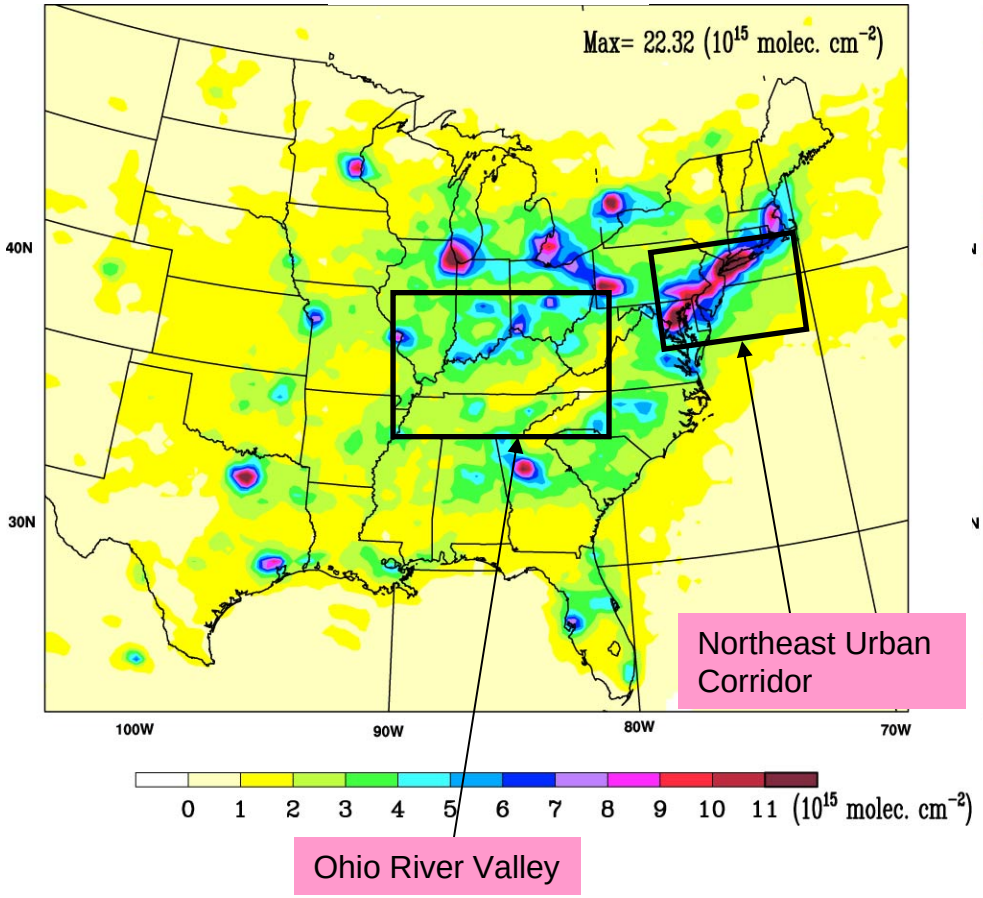


EPA Clean Air Markets Division Emissions Query Wizard
http://camddataandmaps.epa.gov/gdm/index.cfm?fuseaction=emissions.wizard

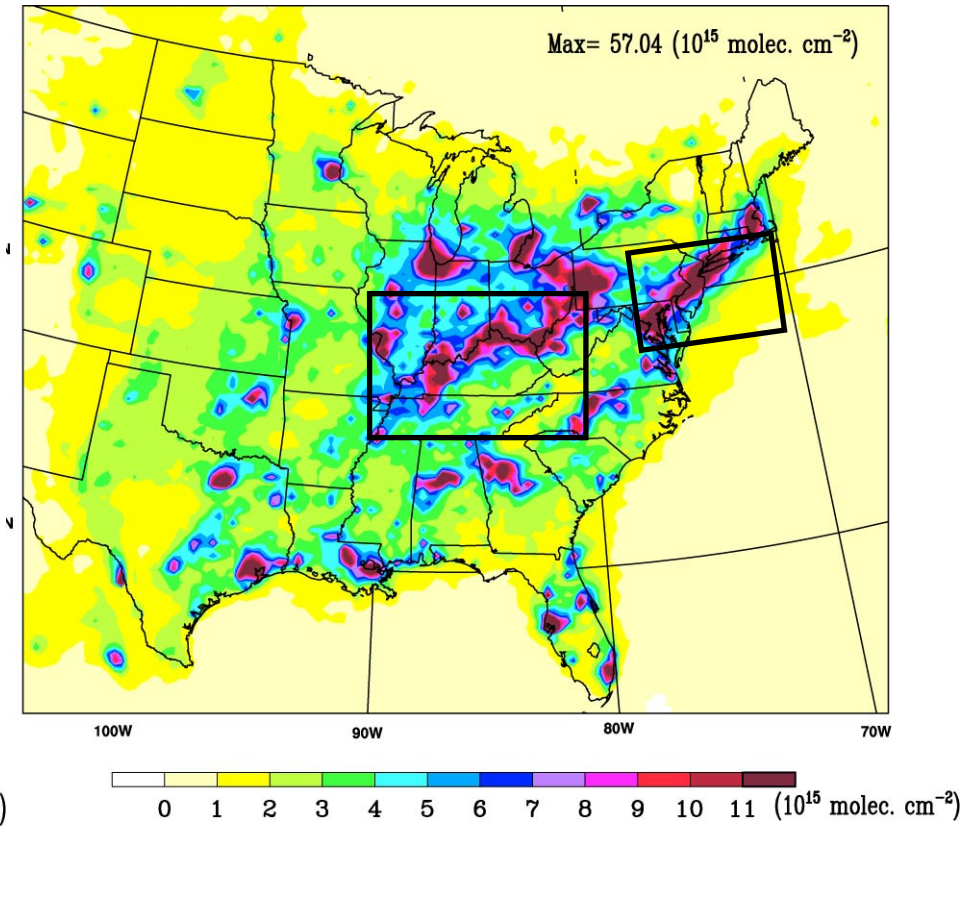
Eastern US Power Plant NO_x Emission Reductions Detected by Satellite

Summer 2004 Average NO_2 Vertical Columns

SCIAMACHY



WRF-Chem, Reference Emissions (NEI 99)



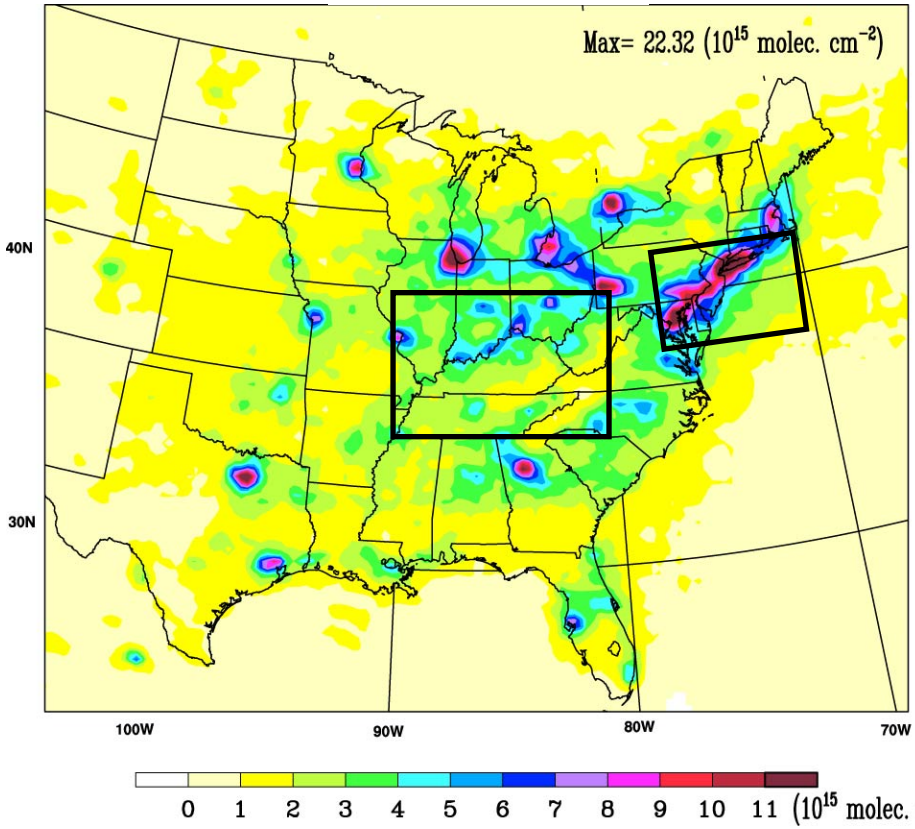
- Model reproduces satellite NO_2 vertical columns over urban areas
- Model NO_2 columns too large over power plants using 1999 emissions

S.-W. Kim et al. (2006), Satellite-observed US power plant NO_X emission reductions and their impact on air quality, Geophys. Res. Lett., 33, L22812, doi:10.1029/2006GL027749

Eastern US Power Plant NO_x Emission Reductions Detected by Satellite

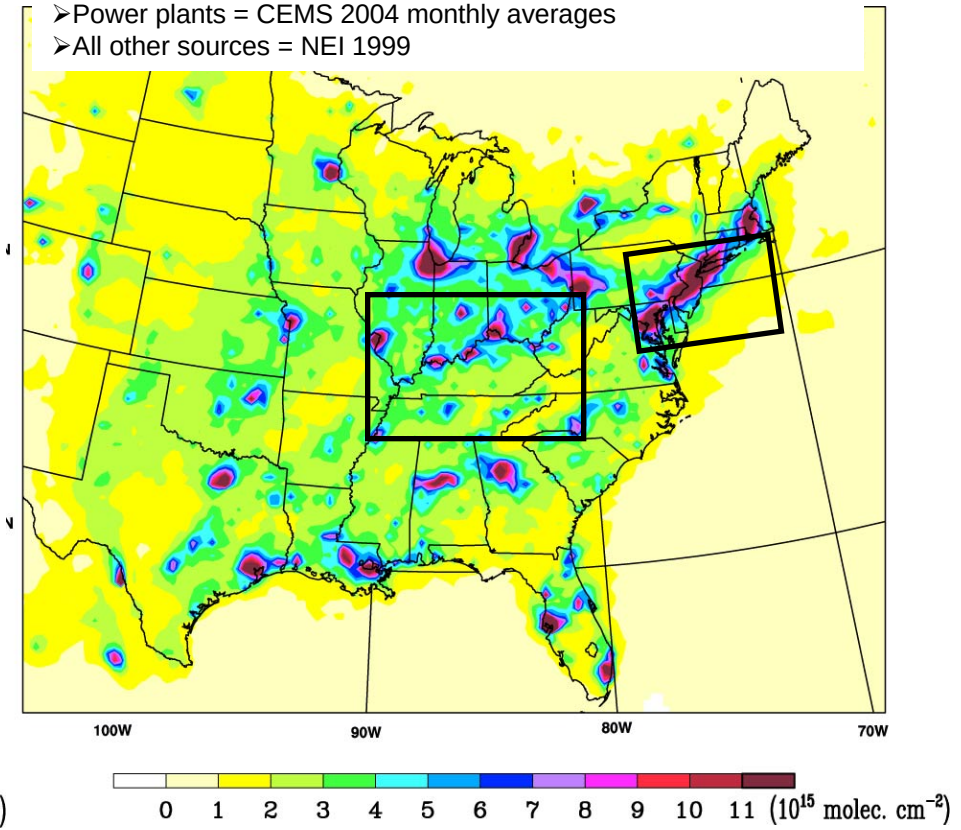
Summer 2004 Average NO_2 Vertical Columns

SCIAMACHY



WRF-Chem, Updated Power Plant Emissions

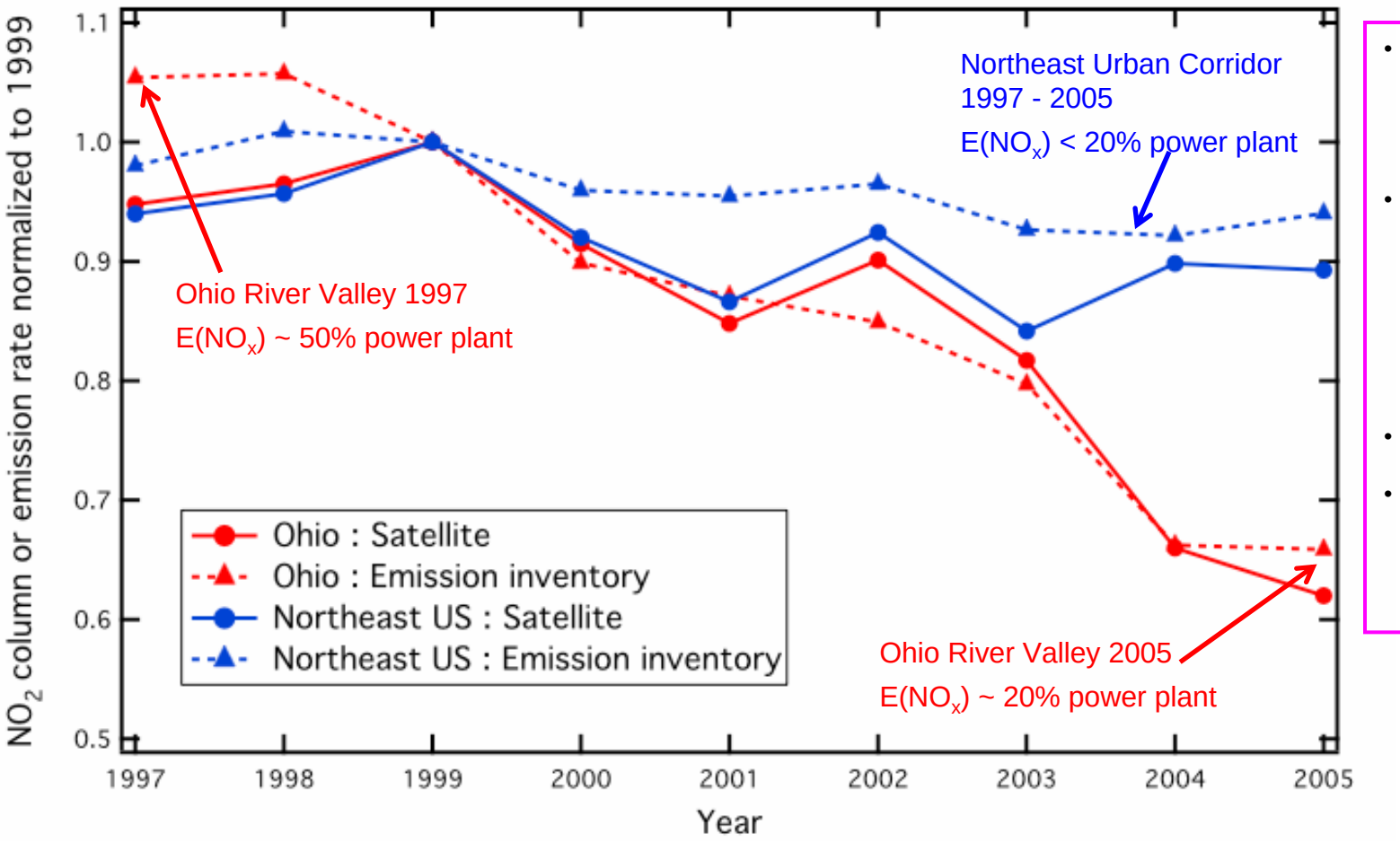
- Power plants = CEMS 2004 monthly averages
- All other sources = NEI 1999



- Model with summer 2004 power plant emissions agrees much better with satellite NO_2 columns over power plants
- *Satellite detects changes in Ohio River Valley from recent power plant NO_x emission controls*

S.-W. Kim et al. (2006), Satellite-observed US power plant NO_X emission reductions and their impact on air quality, Geophys. Res. Lett., 33, L22812, doi:10.1029/2006GL027749

Year-to-Year Trends in Eastern US Satellite NO_2 and Emissions



- **Satellite NO_2 columns**: GOME (1997-2002) & SCIAMACHY (2003-2005)
- **Bottom-up NO_x emissions** trend derived from monthly CEMS reports assuming all other NO_x sources constant at summer 1999
- June-August averages
- 1997-2005 trends normalized to 1999 value

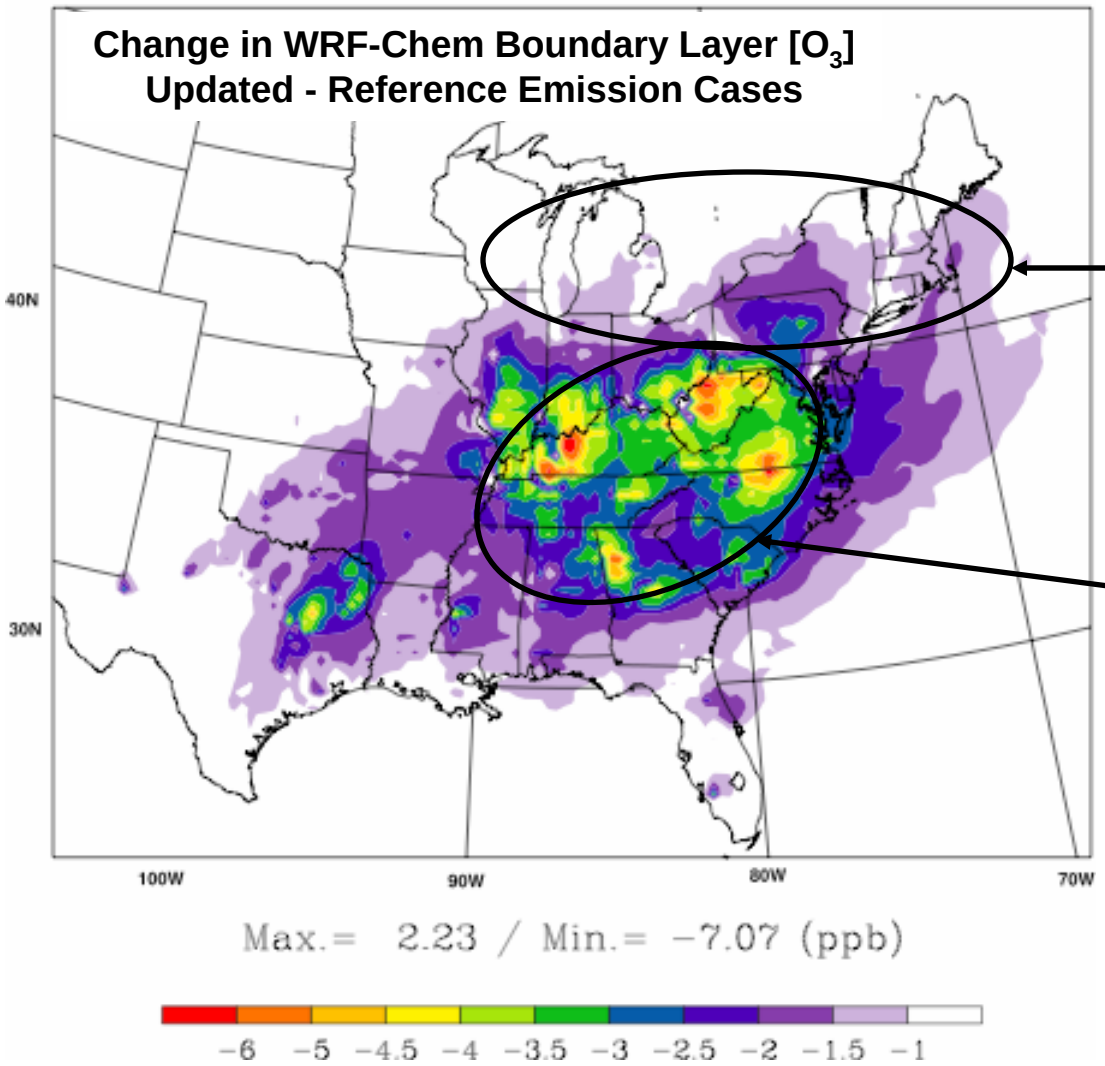
•Similar trends in satellite NO_2 columns and NO_x emissions

➢*Power plant NO_x controls have decreased NO_2 columns*

➢*Mobile NO_x emission changes smaller than those from power plants*

S.-W. Kim et al. (2006), Satellite-observed US power plant NO_X emission reductions and their impact on air quality, Geophys. Res. Lett., 33, L22812, doi:10.1029/2006GL027749

Boundary Layer O_3 Response to NO_x Emission Reductions



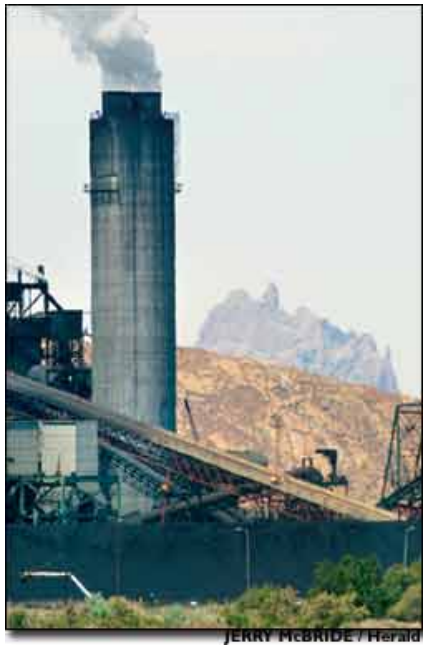
- *O_3 generally decreases in response to power plant NO_x emission reductions*
- *Small $\Delta[O_3]$ in northern US*

  $\Rightarrow$ persistent cold fronts and unusually cold conditions in summer 2004
- *Up to 10% $[O_3]$ decreases in Ohio River Valley, VA, NC, and GA*

Average of all model output between 0 & 1 km at 20 UTC (1500 EST) for all days June-August 2004

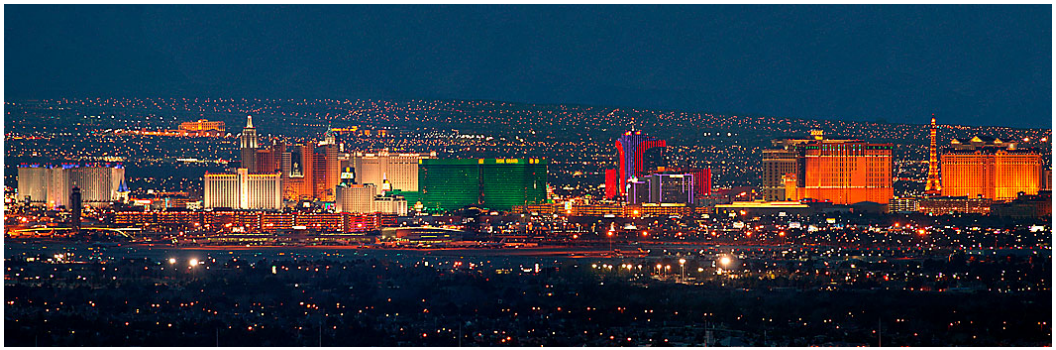
S.-W. Kim et al. (2006), Satellite-observed US power plant NO_X emission reductions and their impact on air quality, Geophys. Res. Lett., 33, L22812, doi:10.1029/2006GL027749

NO_x Emissions from Western US Power Plants and Cities



Use discrete satellite signals in Western US to evaluate NO_x emissions from individual power plants and urban areas

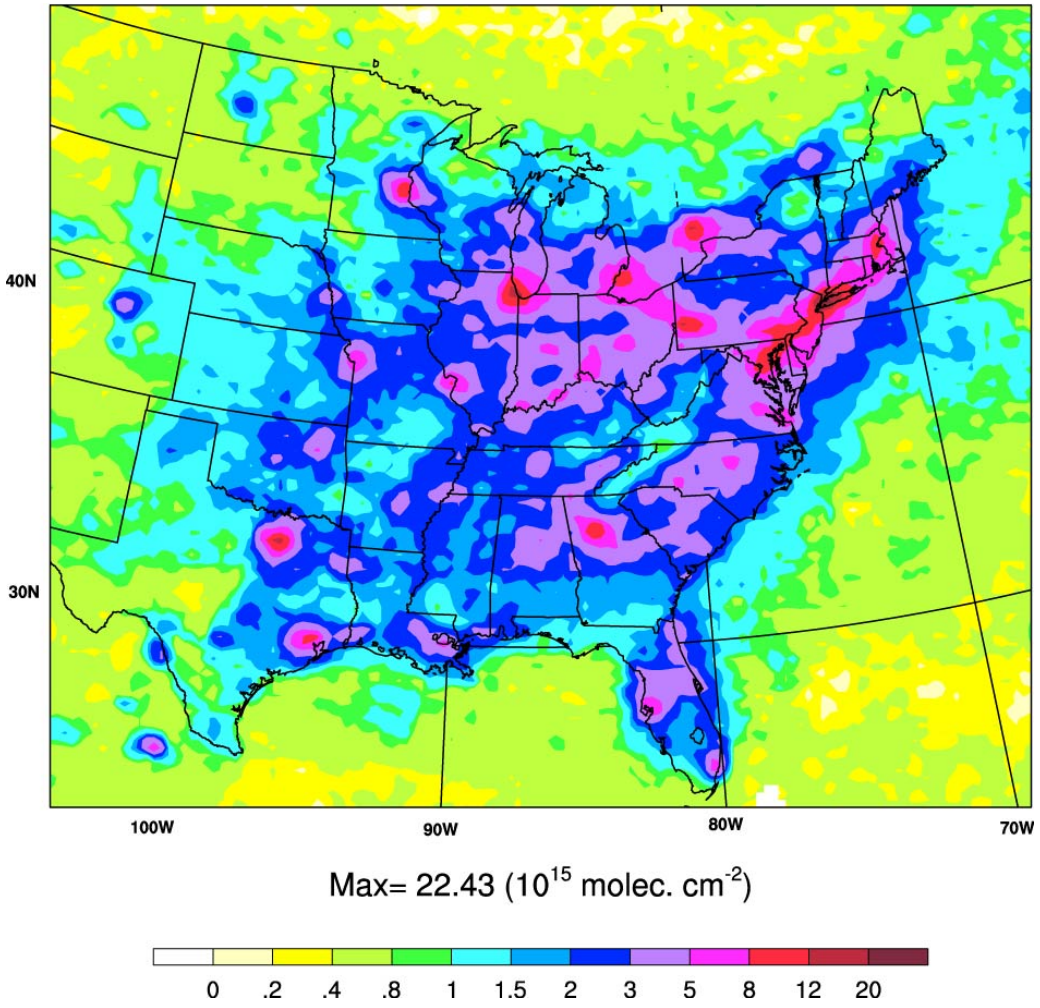
- Steady, well-known power plant emissions
  - "Calibrate" satellite and model algorithms
- Rapidly growing urban areas with lots of motor vehicles
  - How well are mobile source NO_x emissions understood?
  - Are overall NO_x emissions declining?



Isolating NO_x Emissions from Different Source Sectors

SCIAMACHY, Eastern US

Summer 2004 Average



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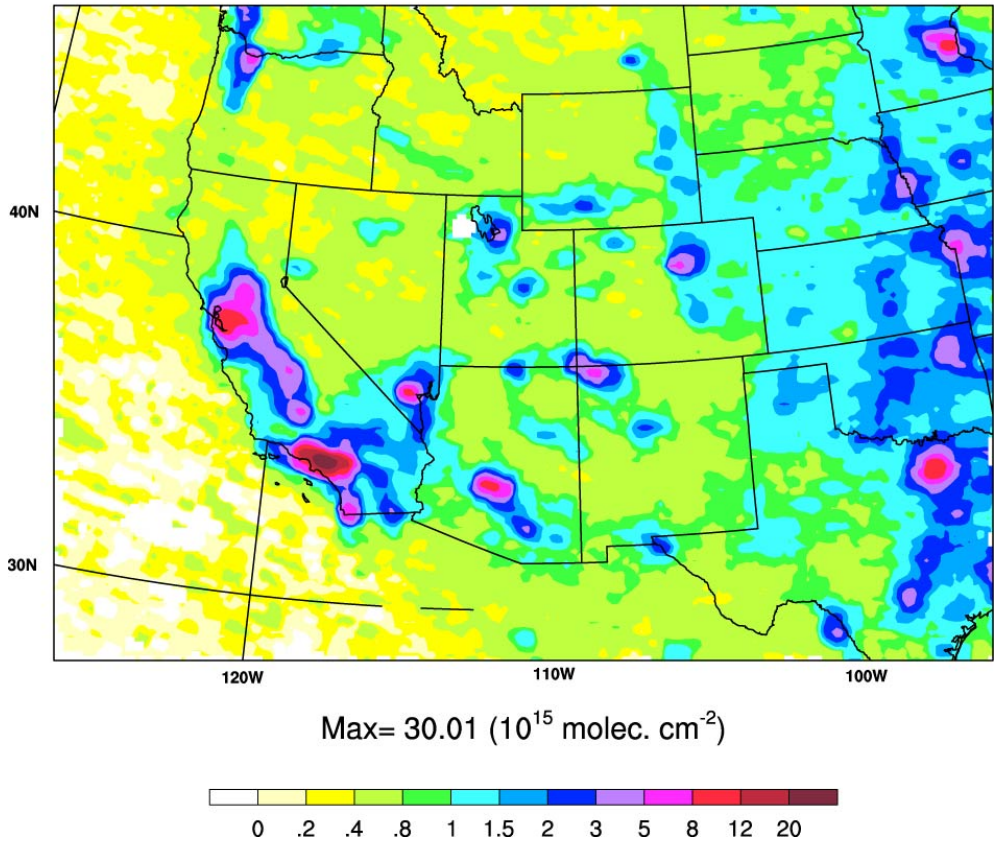
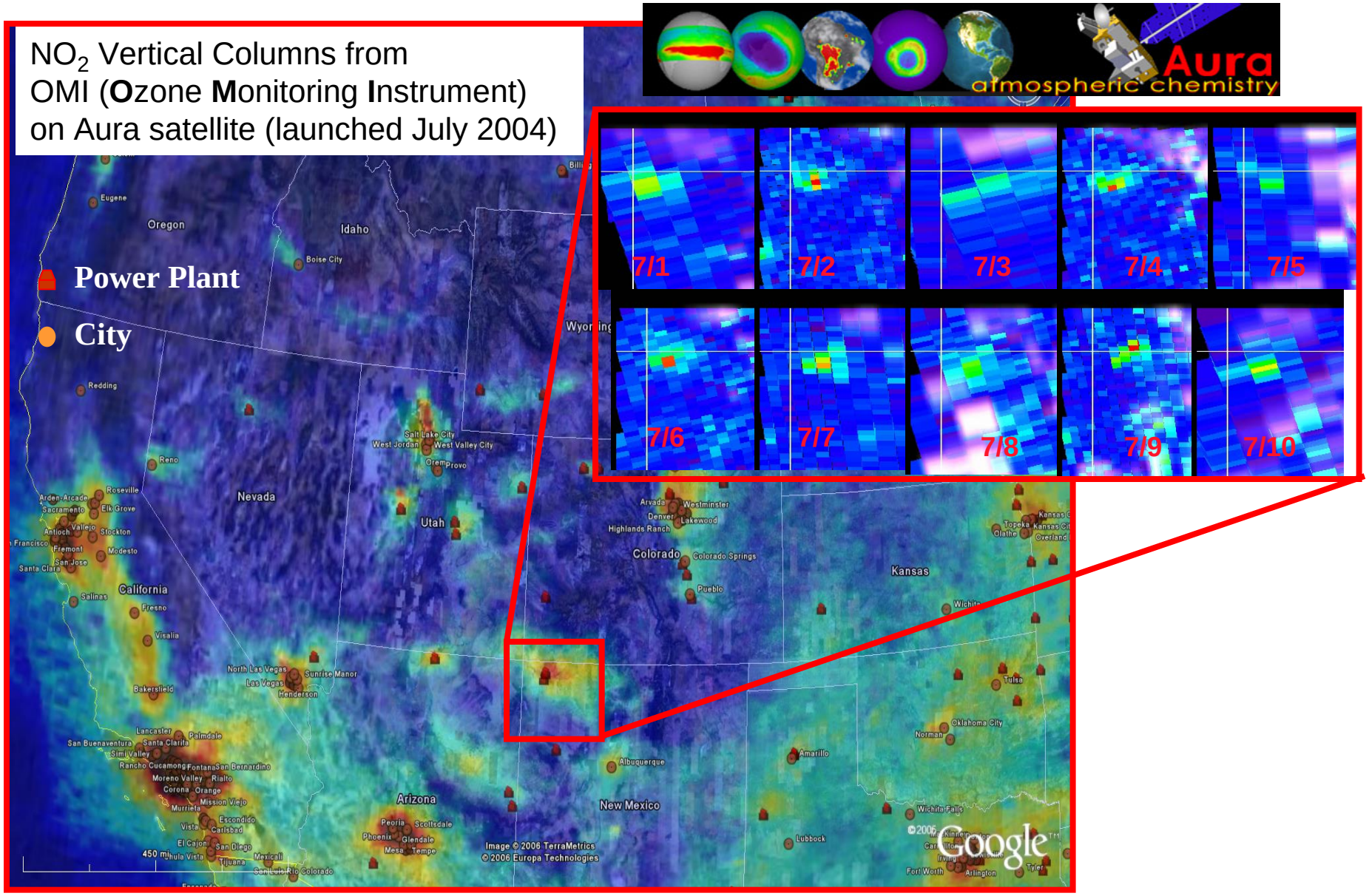
Summer 2005 Average



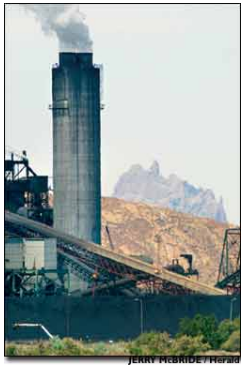
Satellite signals from Western US NO_x sources more distinct than in Eastern US

➢*Isolate and assess different emission sources*

Isolating NO_x Emissions from Different Source Sectors

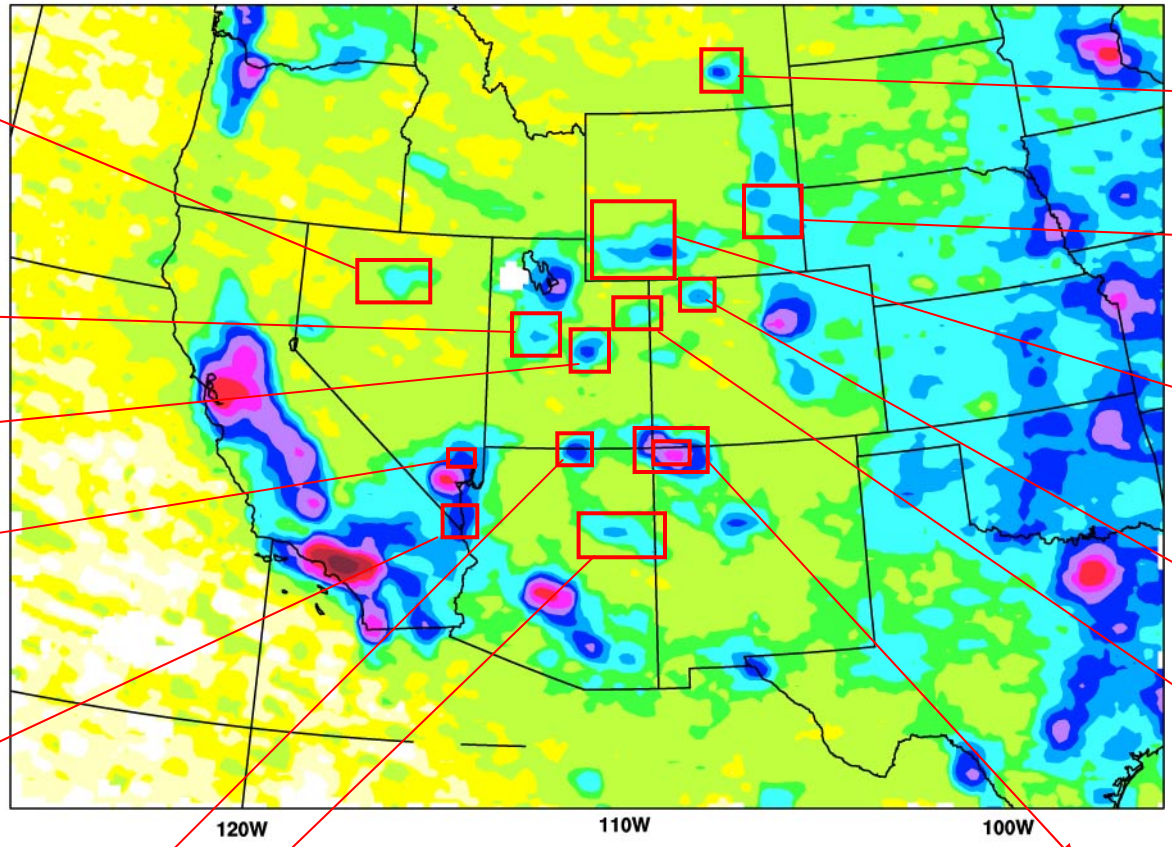


OMI images courtesy of James Gleason (NASA)



NO_x Emissions from Western US Power Plants

- *Isolated plants have discrete signatures in satellite retrievals*
- *Power plant emissions are measured continuously at each stack*
- *Currently no NO_x pollution controls on large coal-burning plants*
- ➢ *"Calibration" for satellite-model comparison*



North Valmy

Colstrip

Dave Johnston/
Laramie River

Intermountain

Jim Bridger/
Naughton

Hunter /
Huntington

Craig/Hayden

Reid Gardener

Bonanza

Mohave

Navajo

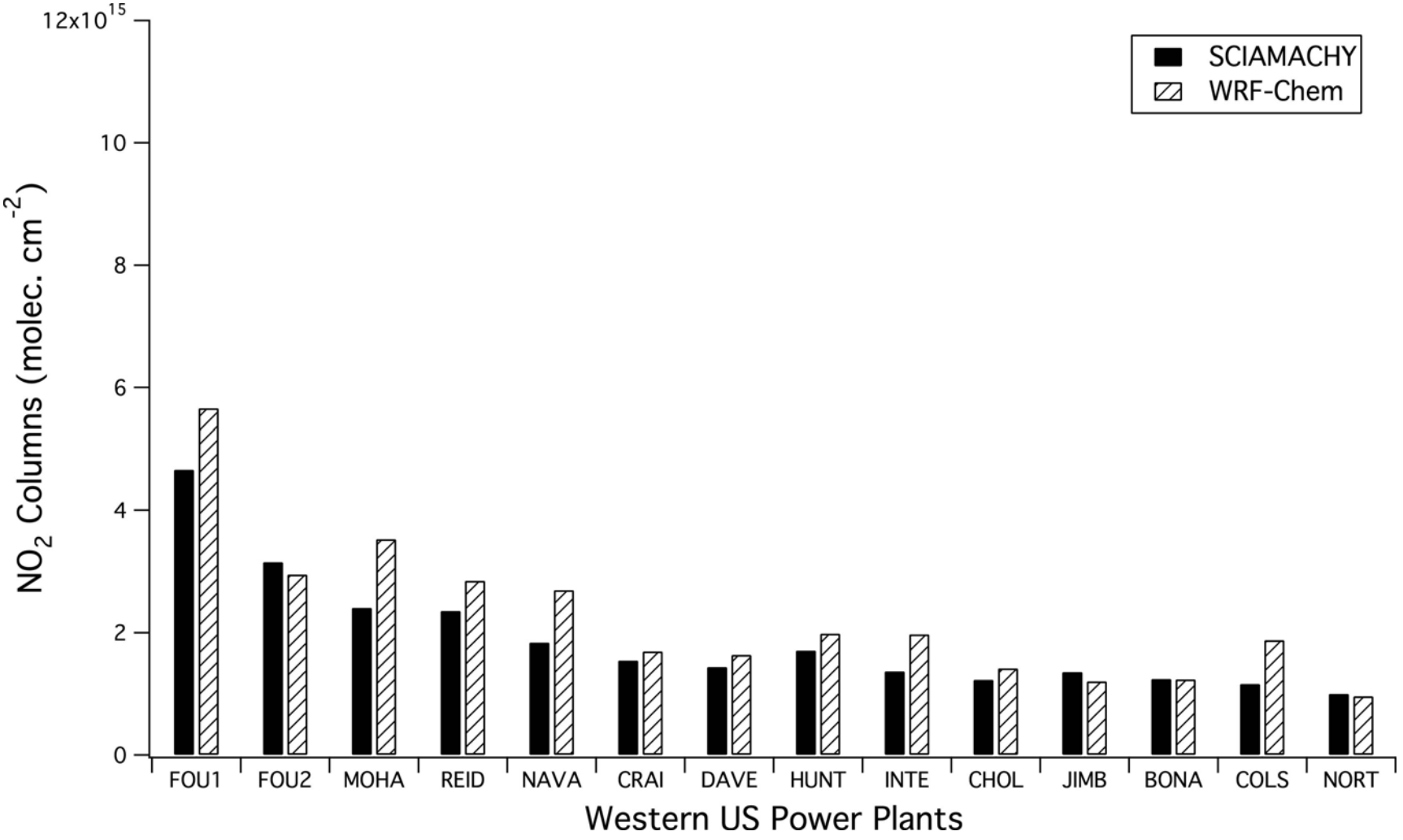
Four Corners/
San Juan

Cholla/Coronado/
Springerville

SCIAMACHY, Summer 2005

Satellite - Model NO_2 Column Comparison: Power Plants

Summer 2005 average NO_2 columns over boxes shown on previous map



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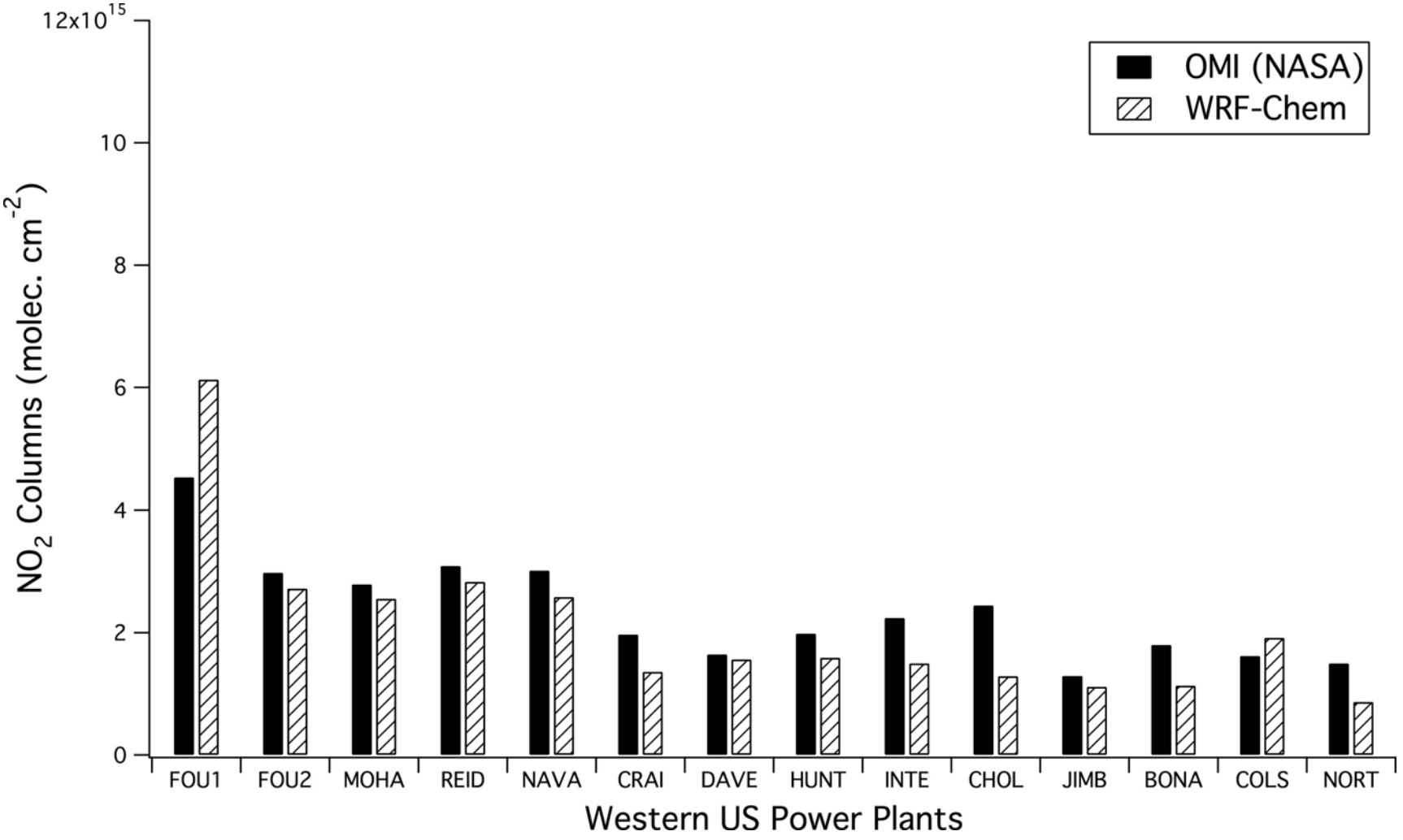

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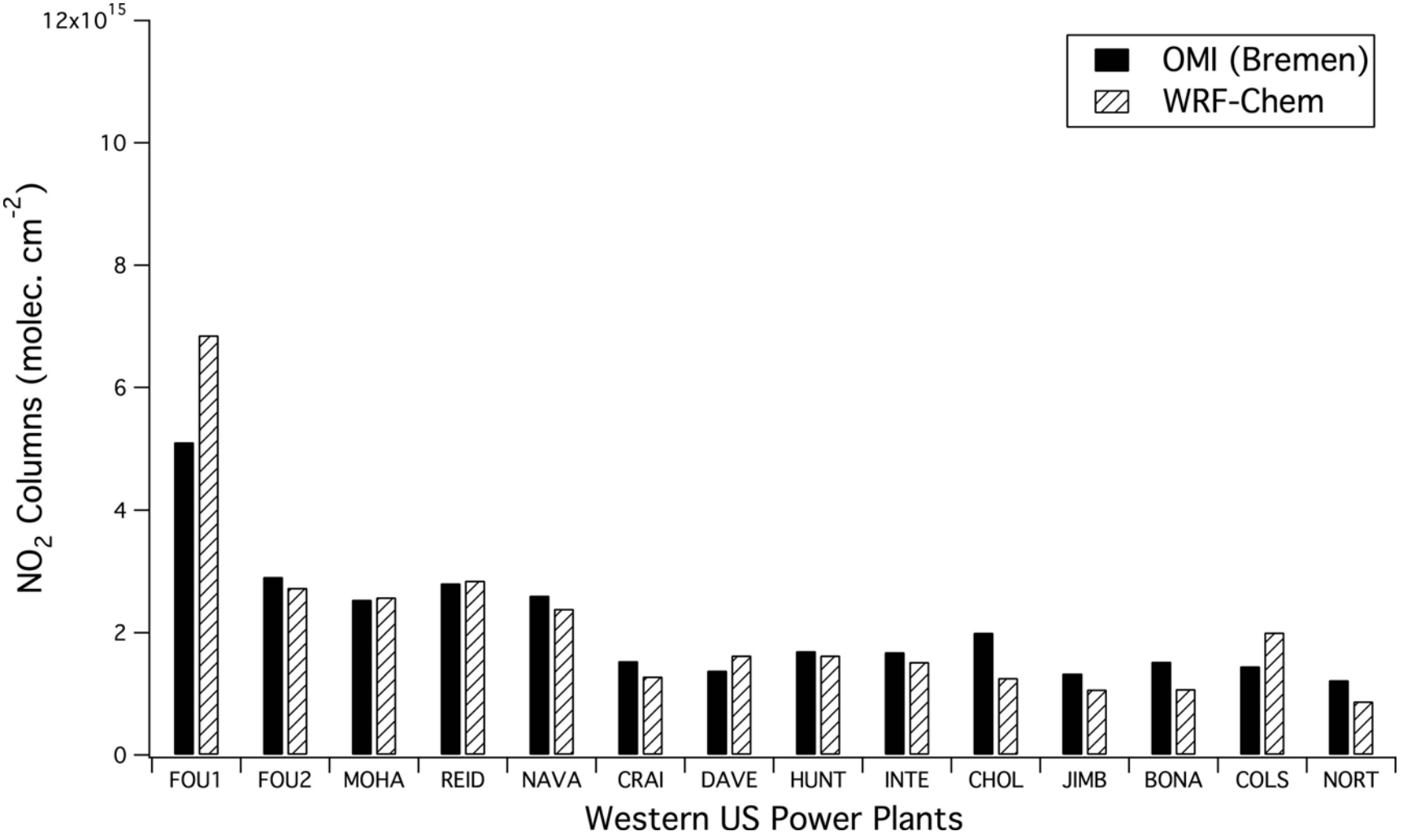
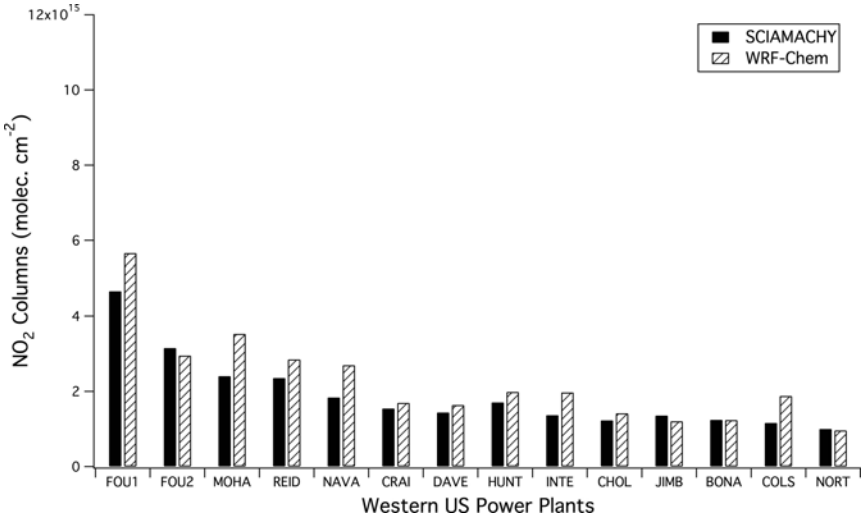
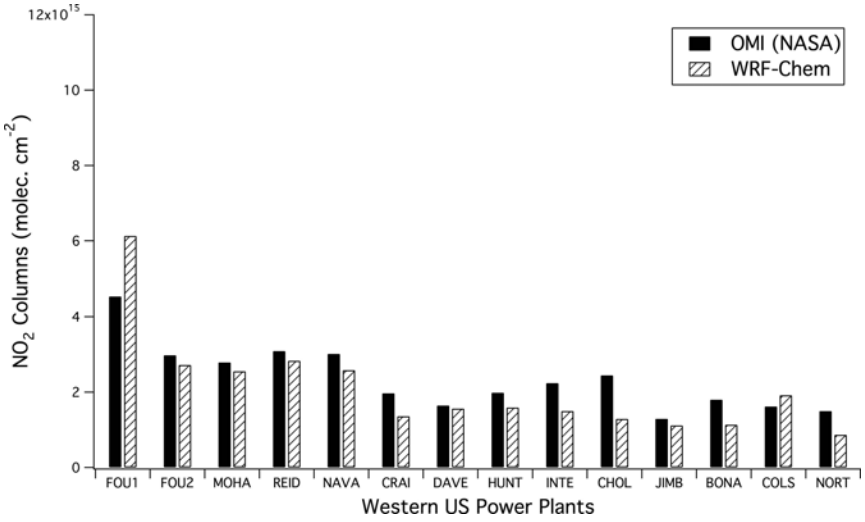


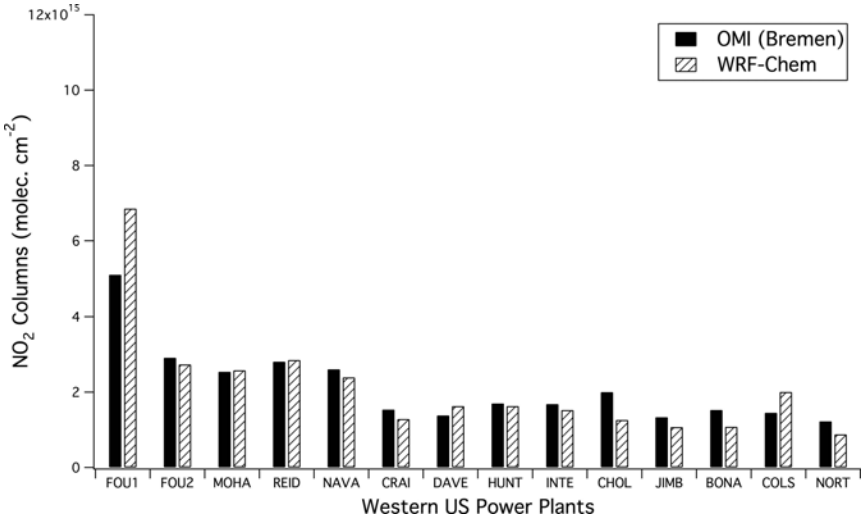
Satellite - Model NO_2 Column Comparison: Power Plants

Good agreement between satellite and model NO_2 columns over Western US power plants

- Optimize satellite column retrievals and model parameterizations
- Model enables comparison of different satellite retrieval approaches
- Consistency for different retrievals gives confidence in conclusions about emissions



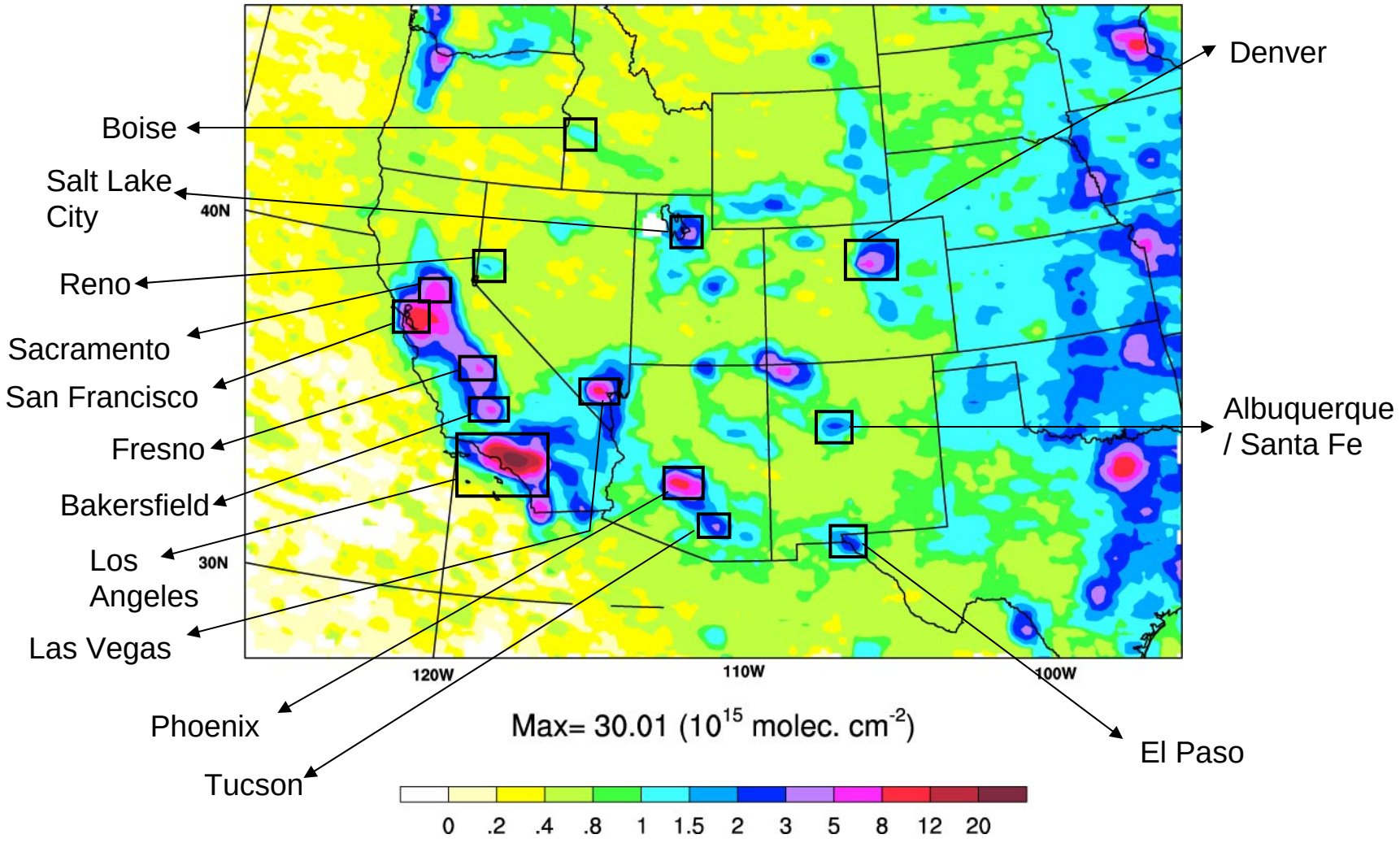




NO_x Emissions from Western US Urban Areas

Build on satellite-model comparisons for power plants

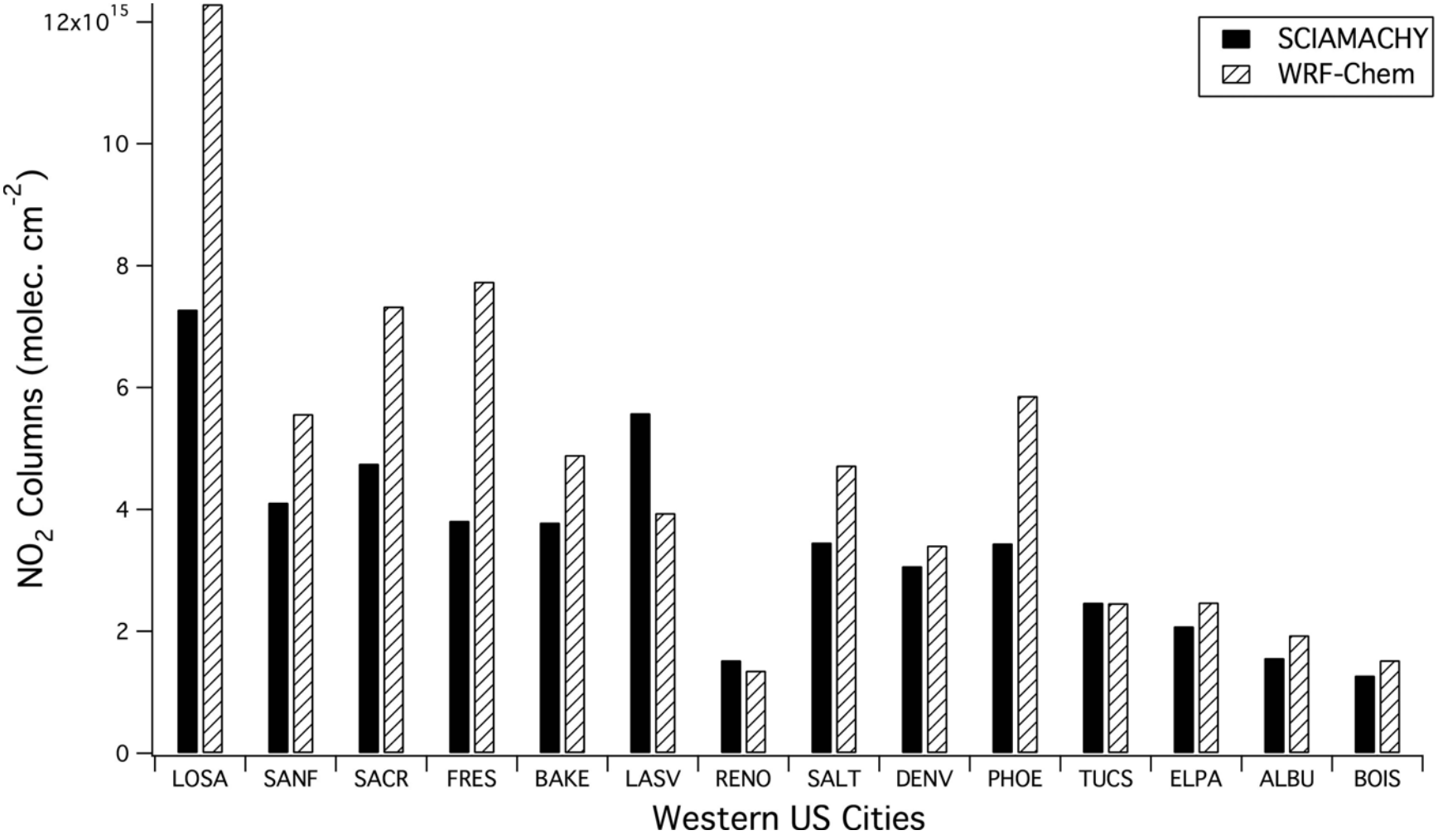
➢*Evaluate urban area emission inventories and monitor changes*



SCIAMACHY, Summer 2005

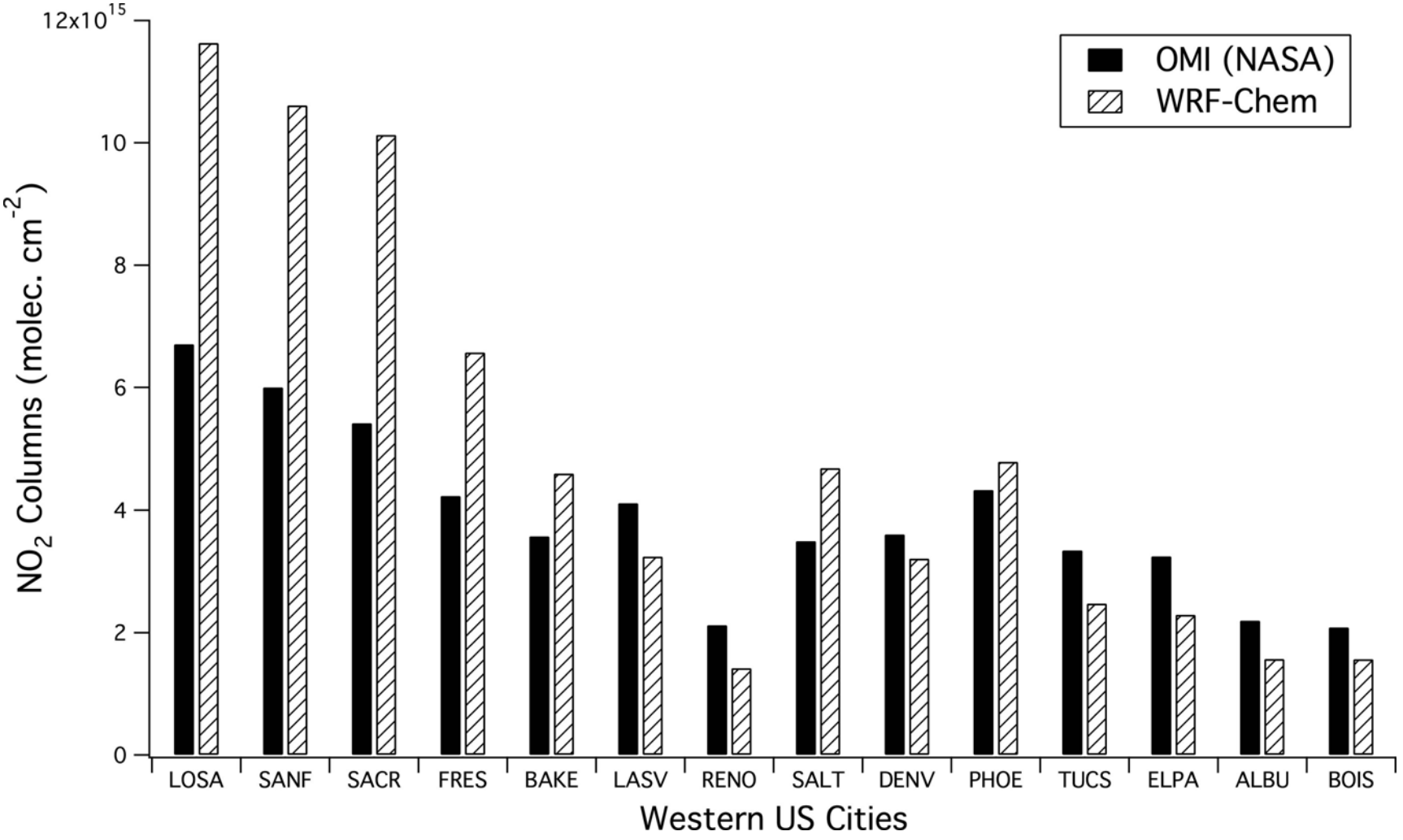
Satellite - Model NO_2 Column Comparison: Urban Areas

Summer 2005 average NO_2 columns over boxes shown on previous map



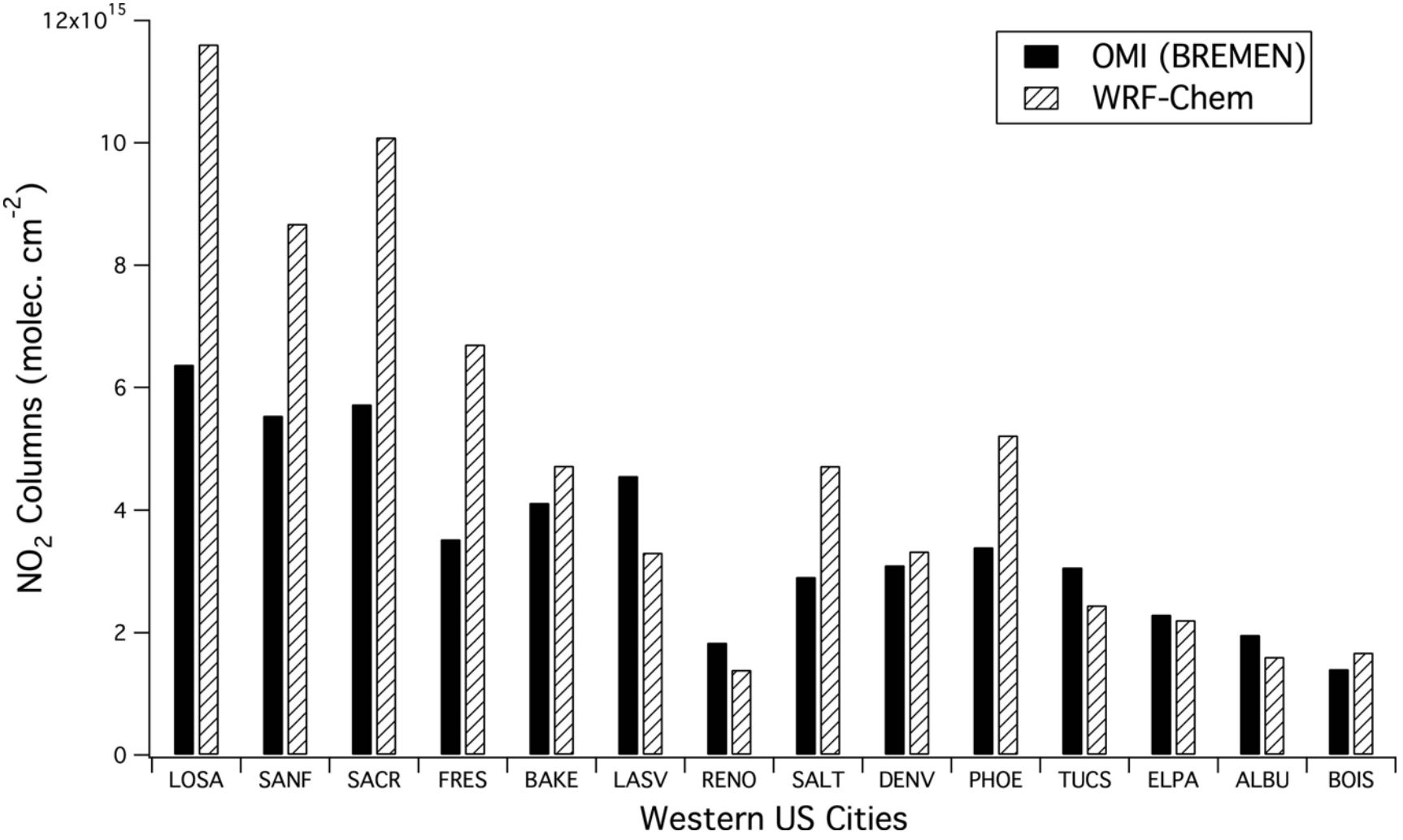
Satellite - Model NO_2 Column Comparison: Urban Areas

Summer 2005 average NO_2 columns over boxes shown on previous map

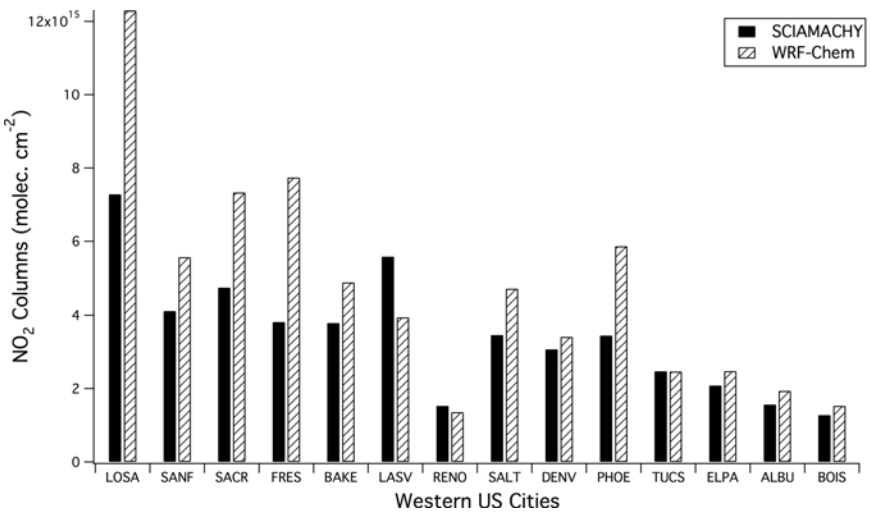


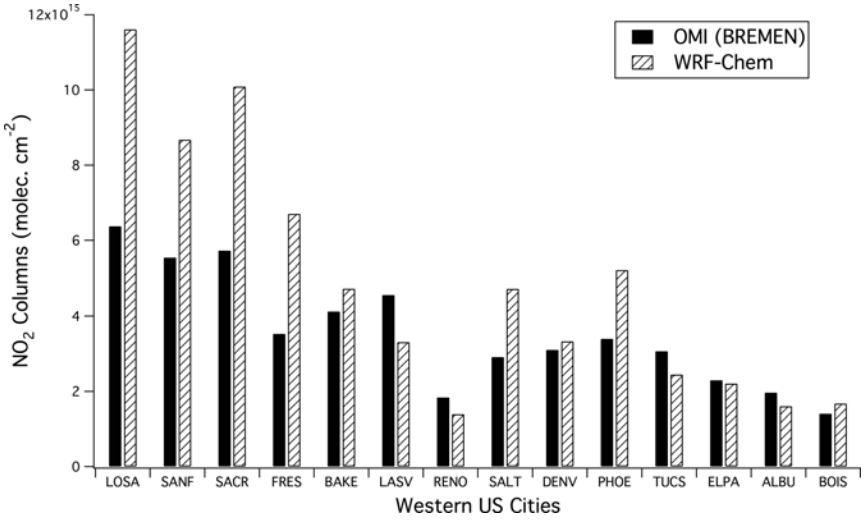
Satellite - Model NO_2 Column Comparison: Urban Areas

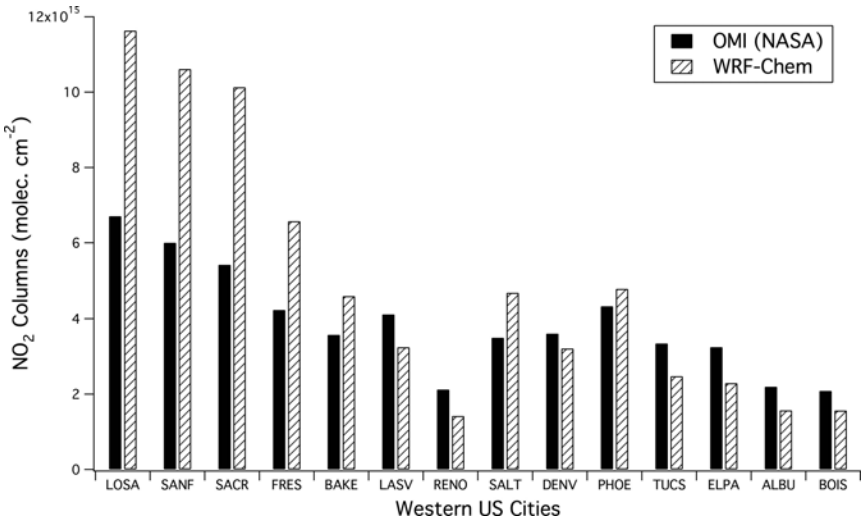
Summer 2005 average NO_2 columns over boxes shown on previous map



Satellite - Model NO_2 Column Comparison: Urban Areas



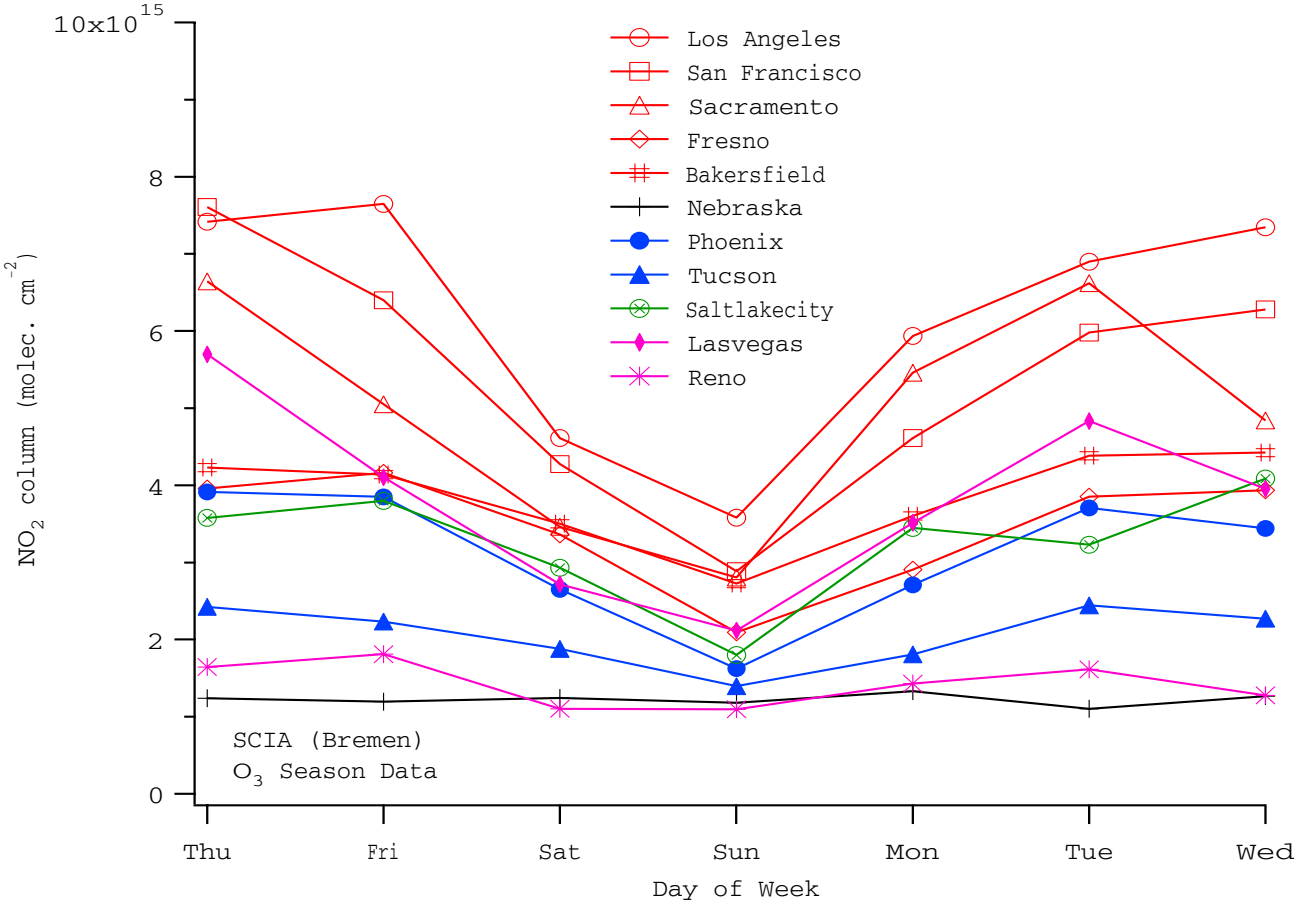




Large differences between satellite and model NO_2 columns over many Western US cities

- Urban emissions not well represented by 1999 inventory
- Trends in NO_x emissions since 1999?
- Are emission changes mostly due to motor vehicles?

Day of Week Trends in Satellite NO_2 Columns over Urban Areas



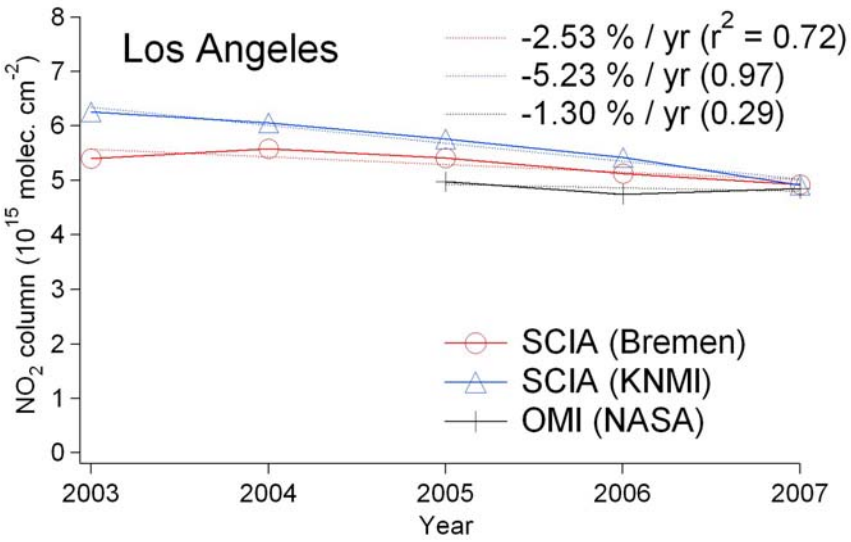
OMI shows weekend decline in urban NO_2 columns

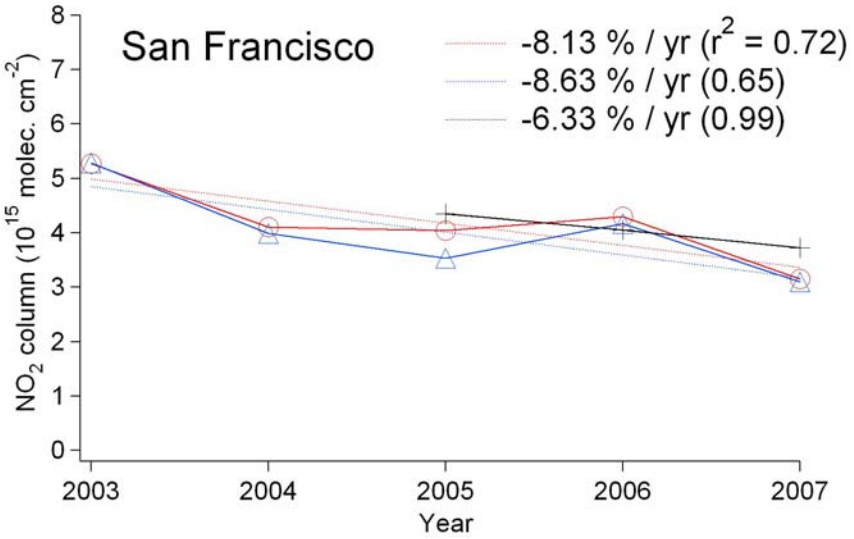
- Reduced traffic, particularly heavy-duty diesel vehicles
- Lower mobile source NO_x emissions on weekends

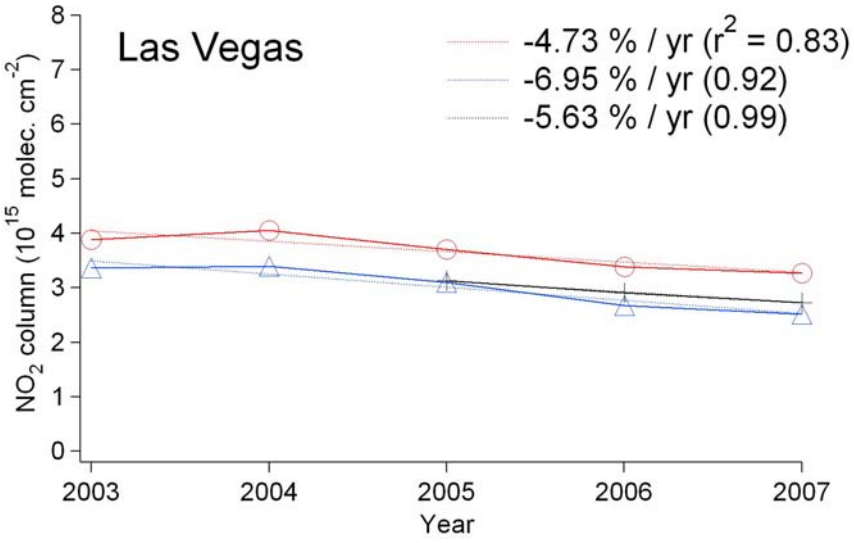
Day of week changes in satellite NO_2 columns first reported by:

S. Beirle et al. (2003), Weekly cycle of NO_2 by GOME measurements: a signature of anthropogenic sources, Atmos. Chem. Phys., *3*, 2225-2232

Year-to-Year Trends in Satellite NO_2 Columns over Urban Areas







Satellites demonstrate decline in NO_2 columns over many Western US cities in recent years

- Urban NO_x emissions appear to be decreasing
- Increasing population and motor vehicle fuel use
  - ➢ Effect of cleaner engines, especially light-duty gasoline vehicles

Conclusions

- Combination of space-based instruments and regional air quality model
  - ➢ Useful evaluation of NO_x emission inventories and trends
- Effects of major NO_x emission reductions at Eastern US power plants
  - ➢ Point source pollution control strategies have resulted in widespread, measurable changes to atmospheric pollutant levels
- Relative contributions from Western US NO_x sources and their long-term trends
  - ➢ Power plants serve as calibration for NO_2 vertical columns
  - ➢ Impact of cleaner motor vehicles on urban to regional scale appears to be measurable by space-based instruments