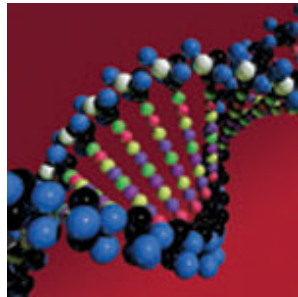


Acid Deposition and Sulfate Concentration Trends



March 2010

Lynsey Parker, Till Stoeckenius, Lan Ma
ENVIRON International Corp.

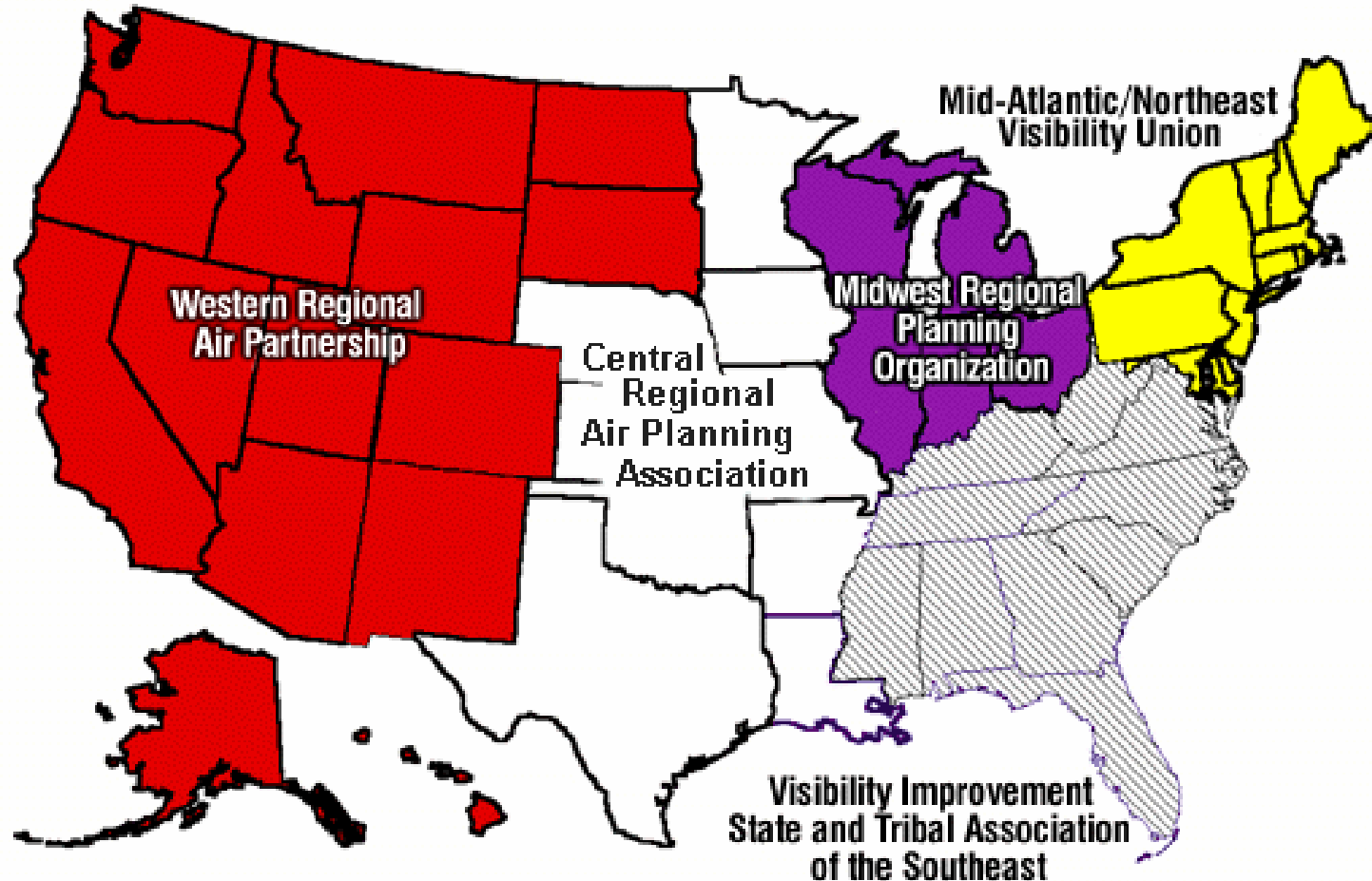


Scope

- Compute, summarize and display acid deposition and sulfate concentration trends for the continental U.S. for the period 1999 – 2008.
- Create a spreadsheet database of annual total acid deposition and annual average sulfate concentrations at each monitoring site for additional analyses.



Regional Planning Organizations

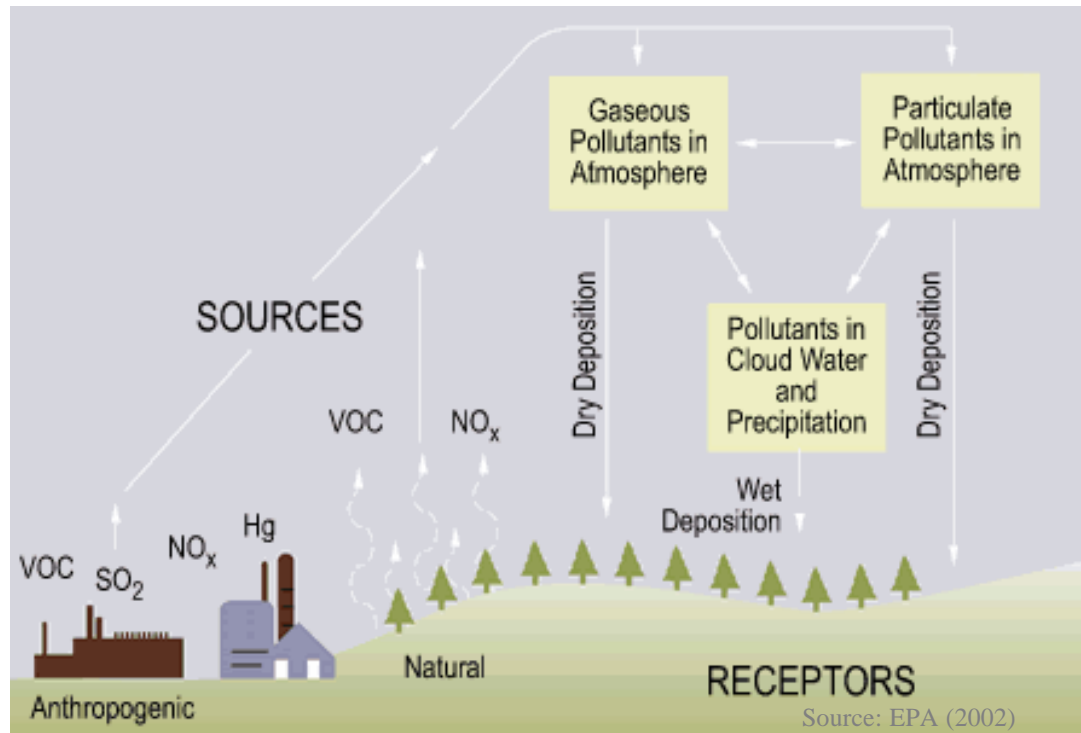




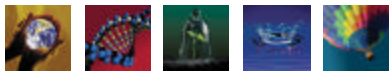
Part I: Sulfur and Nitrogen Deposition Trends



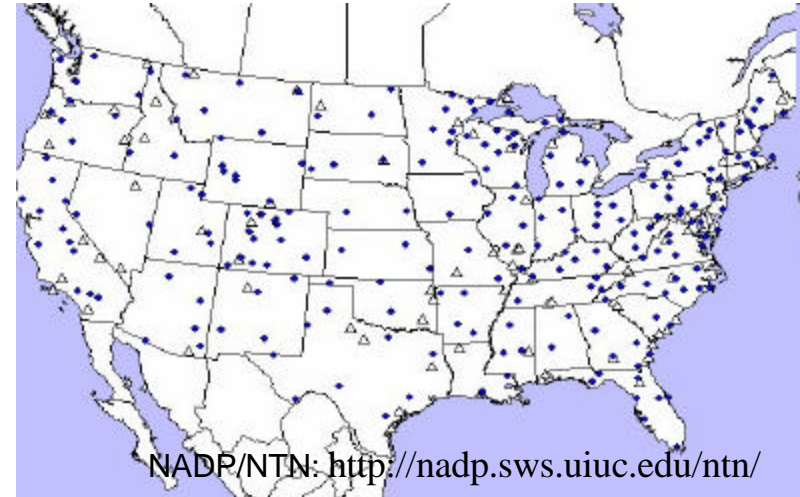
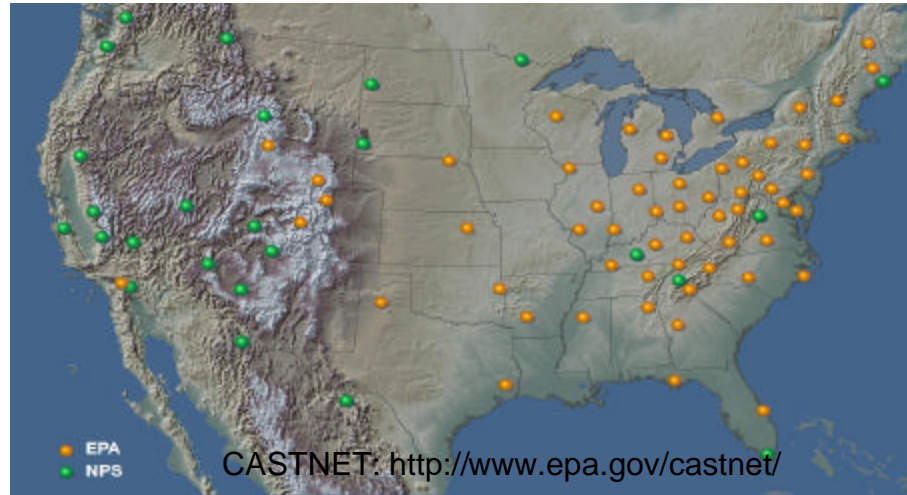
Acid Deposition



- SO₂ and NO_x emissions transform in the atmosphere and result in deposition of sulfur and nitrogen pollutant species (including “acid rain”)
- Wet and dry deposition of pollutants impacts natural ecosystems



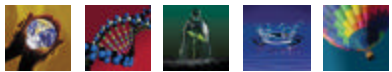
Monitoring Data



CASTNET

NADP/NTN

- Clean Air Status and Trends Network (CASTNET) monitoring network
 - Regional, long-term environmental monitoring at locations away from major population centers or pollutant sources
 - Measures pollutant concentrations in air and calculates resulting dry deposition
- Combine CASTNET dry deposition with wet deposition values from NADP/NTN precipitation sample data collected at co-located or nearby monitoring site(s) to estimate total (wet + dry) deposition



Summary Statistics

- Annual total sulfate and nitrate deposition (wet plus dry)
 - Dry deposition based on weekly average measurements of SO_2 , SO_4^{2-} , HNO_3 , NO_3^- , NH_4^+ concentrations converted to deposition using the Multi-Layer Model
 - Wet deposition based on sulfur and nitrogen compound concentrations in precipitation samples
 - Total deposition dominated by wet deposition in eastern U.S. for both sulfur and nitrogen

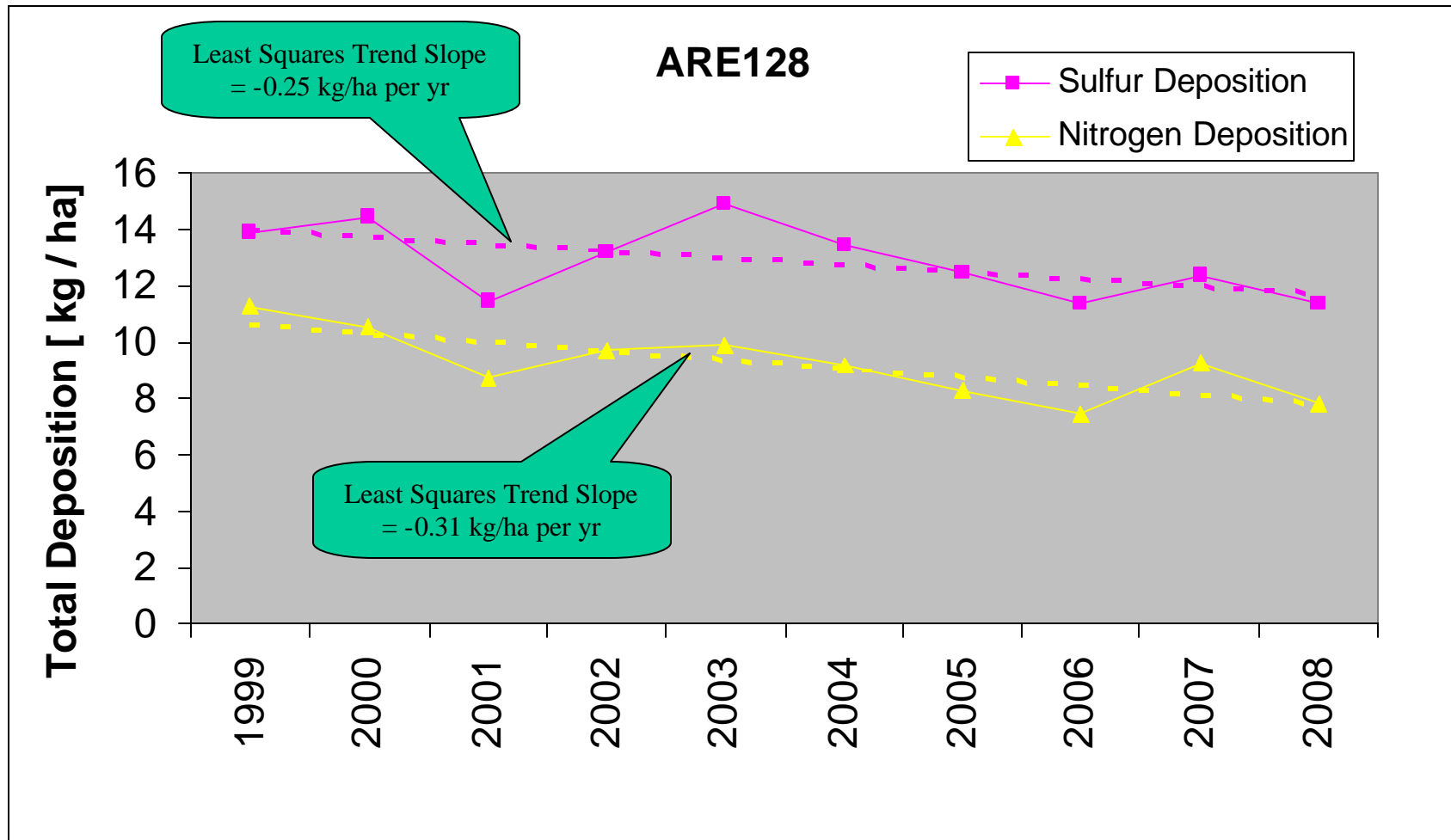


Data Handling Procedures

- All sites with at least 8 years of data are included in the 10 year trend analysis (1999-2008).
- Missing years filled by linear interpolation for years with data in both previous and following years, filled with adjacent year values otherwise.
- Trend represented by slope of linear regression line calculated for each site

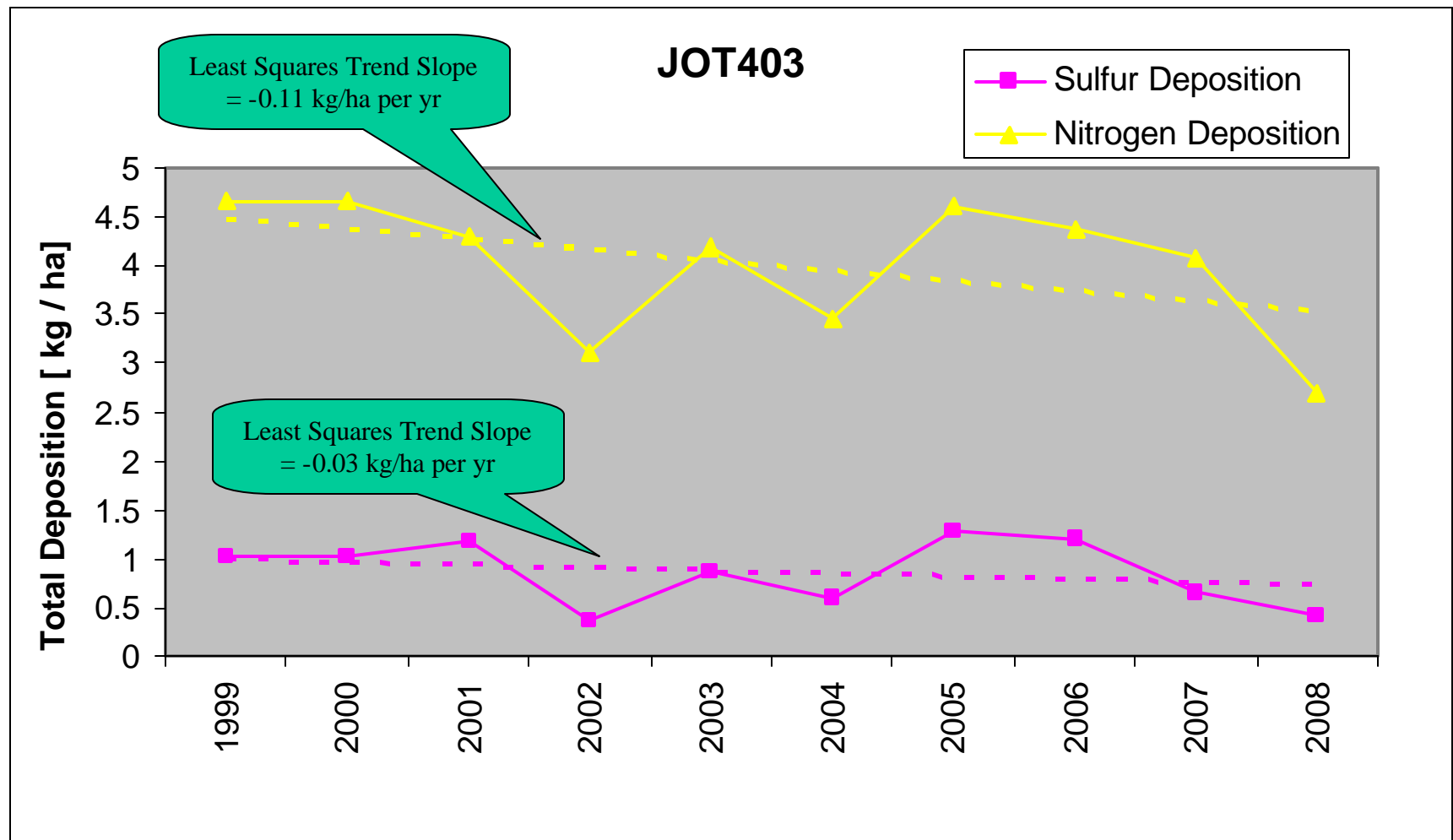


Example 1999-2008 Acid Deposition Trends for Single Site (ARE128: Arendtsville, PA)



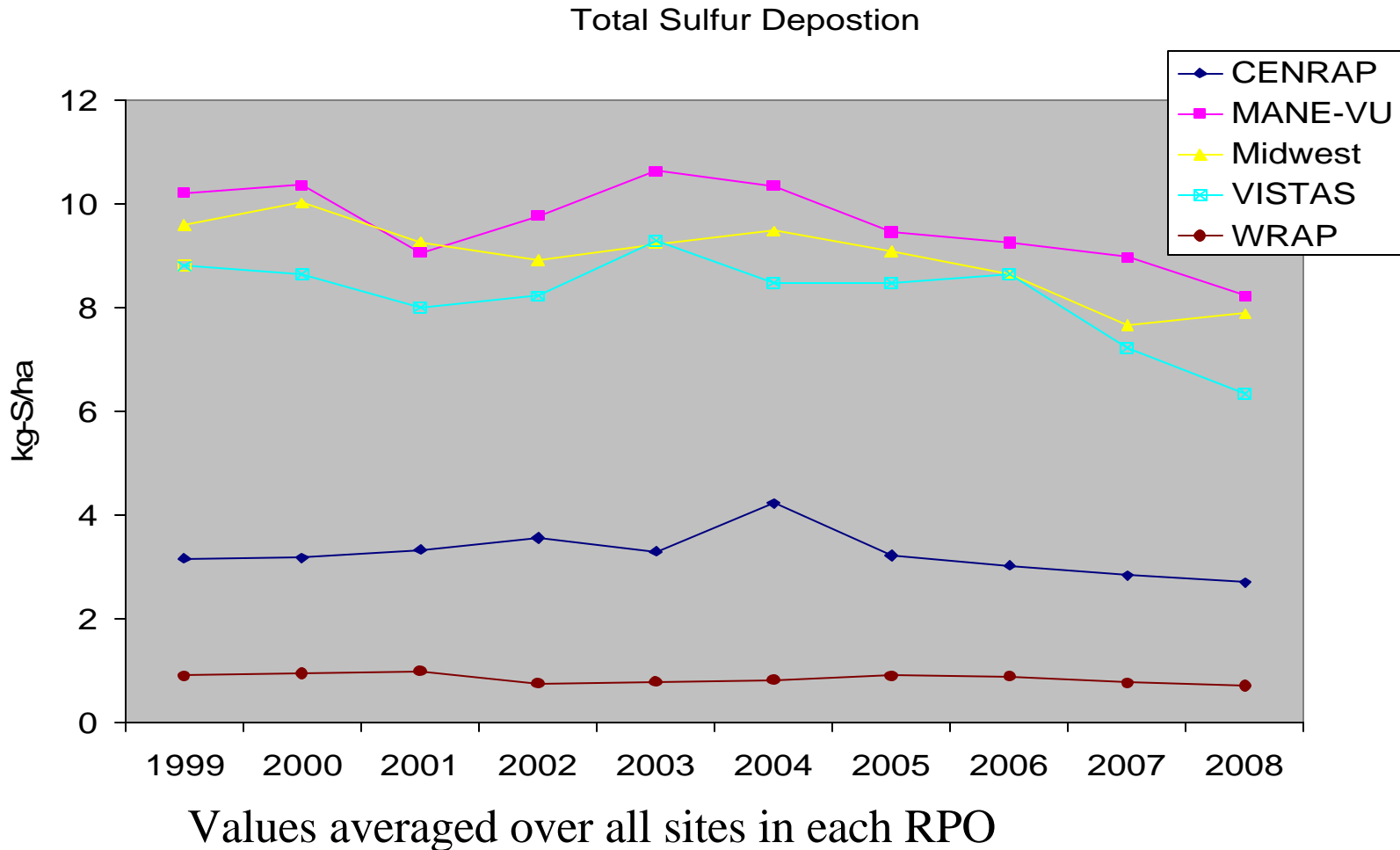


Example 1999-2008 Acid Deposition Trends for Single Site (JOT403: Joshua Tree NM, CA)



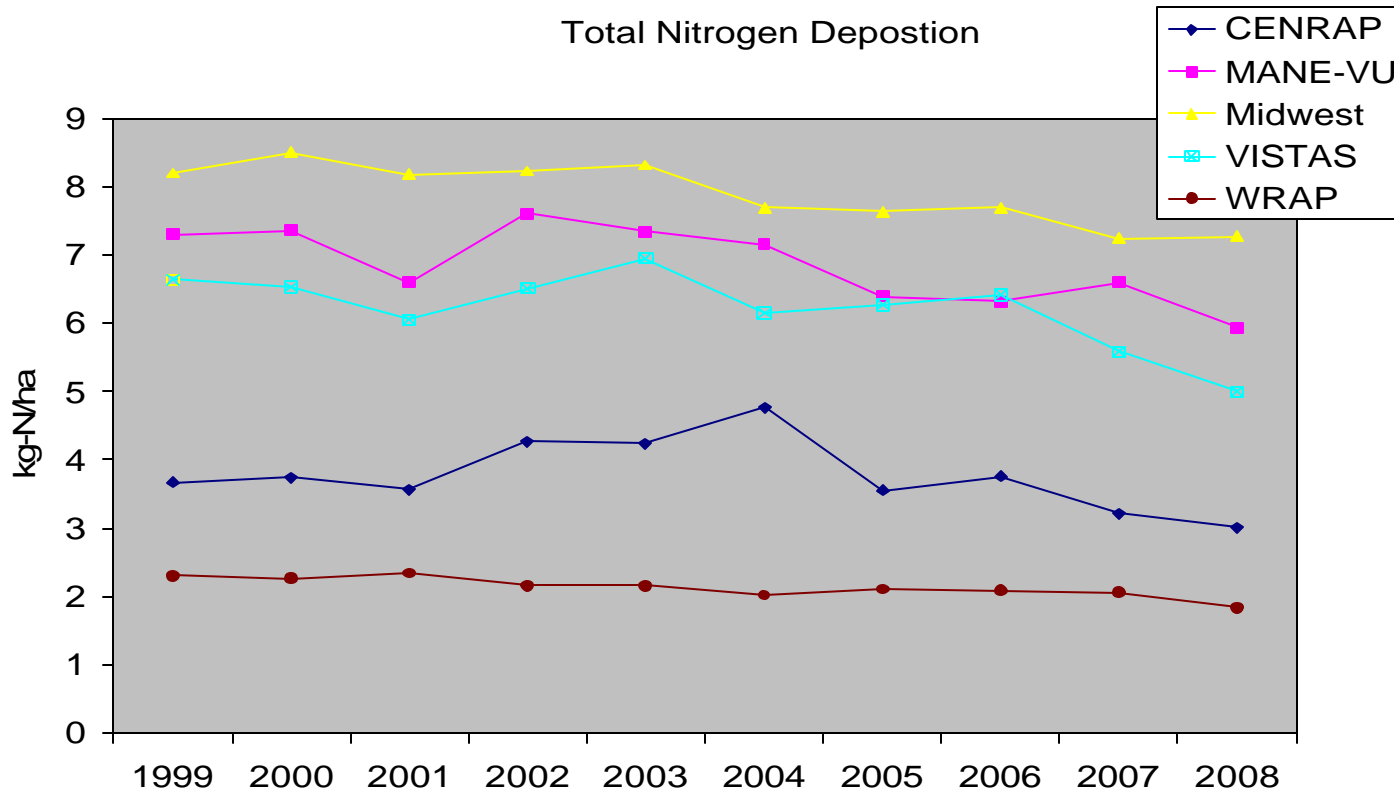


Total Sulfur Deposition Trends





Total Nitrogen Deposition Trends



- Values averaged over all sites in each RPO
- Decreasing deposition since 2001 (WRAP), 2002 (MANE-VU), 2003 (Midwest and VISTAS) and 2004 (CENRAP)

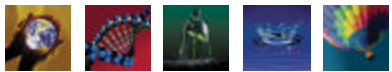


Total Deposition Trends

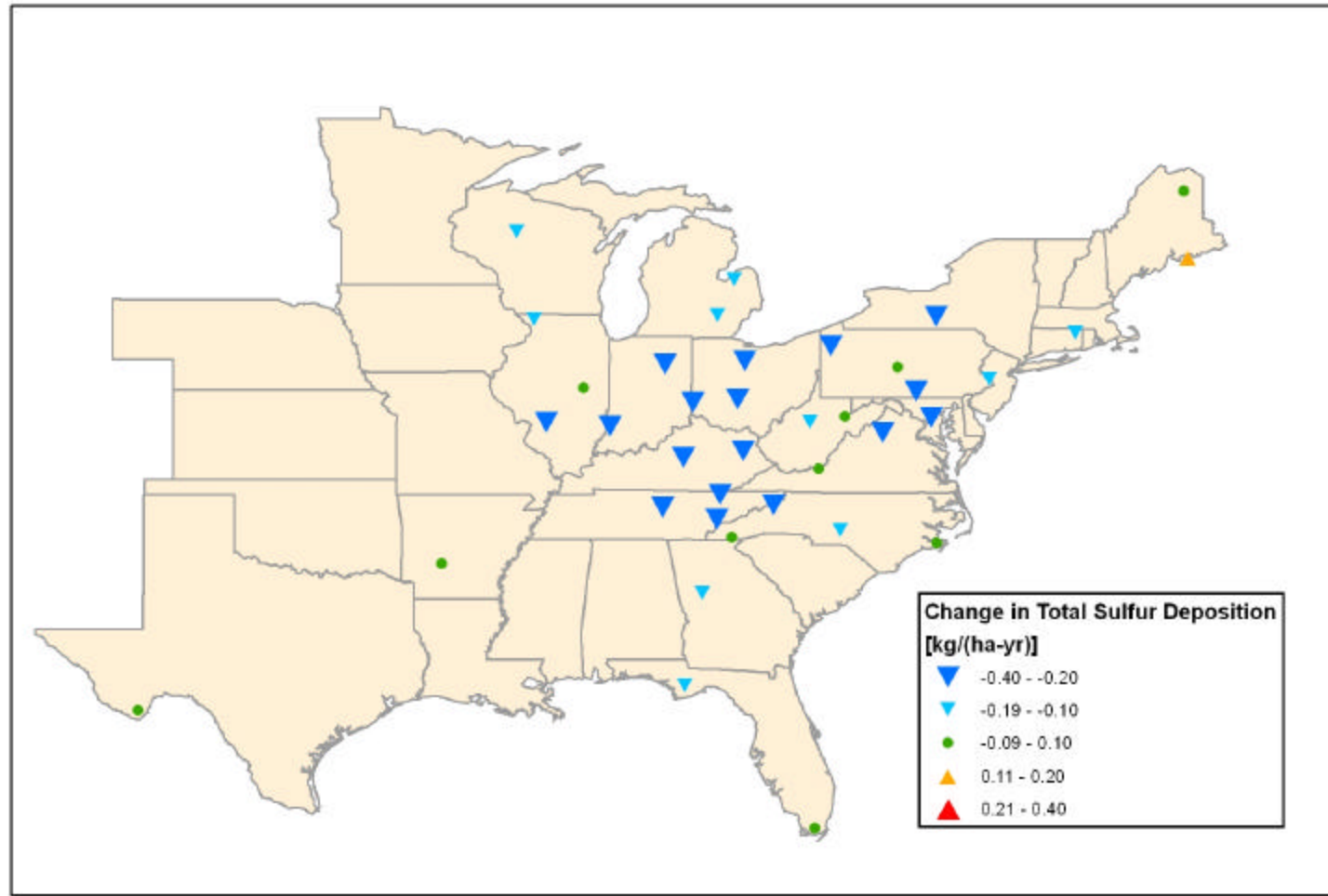
Values averaged over all sites in each RPO

Region	Sulfur Trend		Nitrogen Trend	
	kg/ha	% Change 1999 - 2008	kg/ha	% Change 1999 - 2008
CENRAP	-0.049	-14%	-0.062	-15%
MANE-VU	-0.169	-16%	-0.139	-19%
Midwest	-0.208	-21%	-0.134	-16%
VISTAS	-0.175	-19%	-0.128	-19%
Eastern Avg.	-0.177	-19%	-0.129	-18%
WRAP Avg.	-0.02	-20%	-0.04	-19%

- Reductions in all RPOs
- WRAP percent reductions similar to eastern US trends



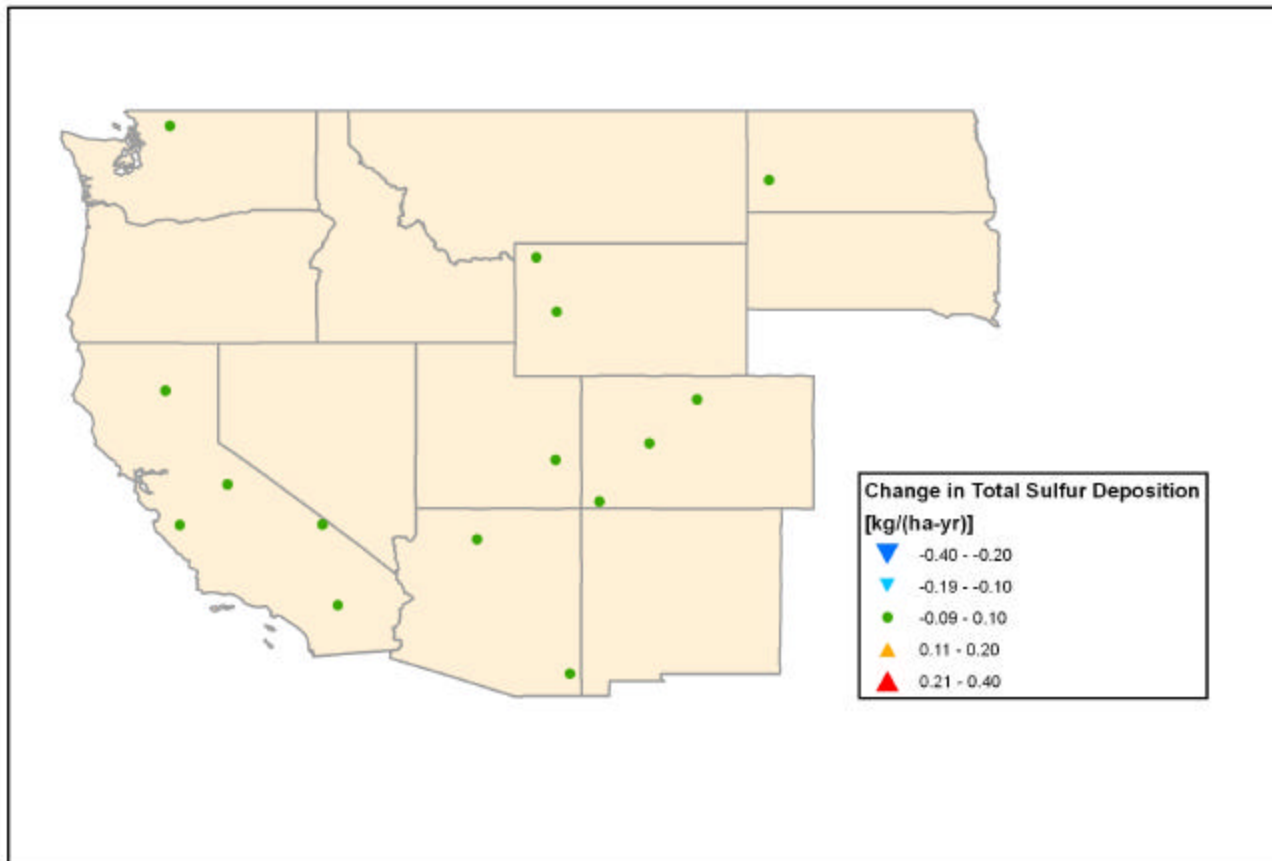
Total Sulfur Deposition Trends: 1999-2008 Eastern U.S.



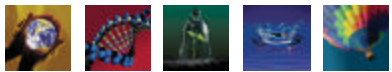
- Thirty seven of thirty nine sites show decreasing sulfur deposition



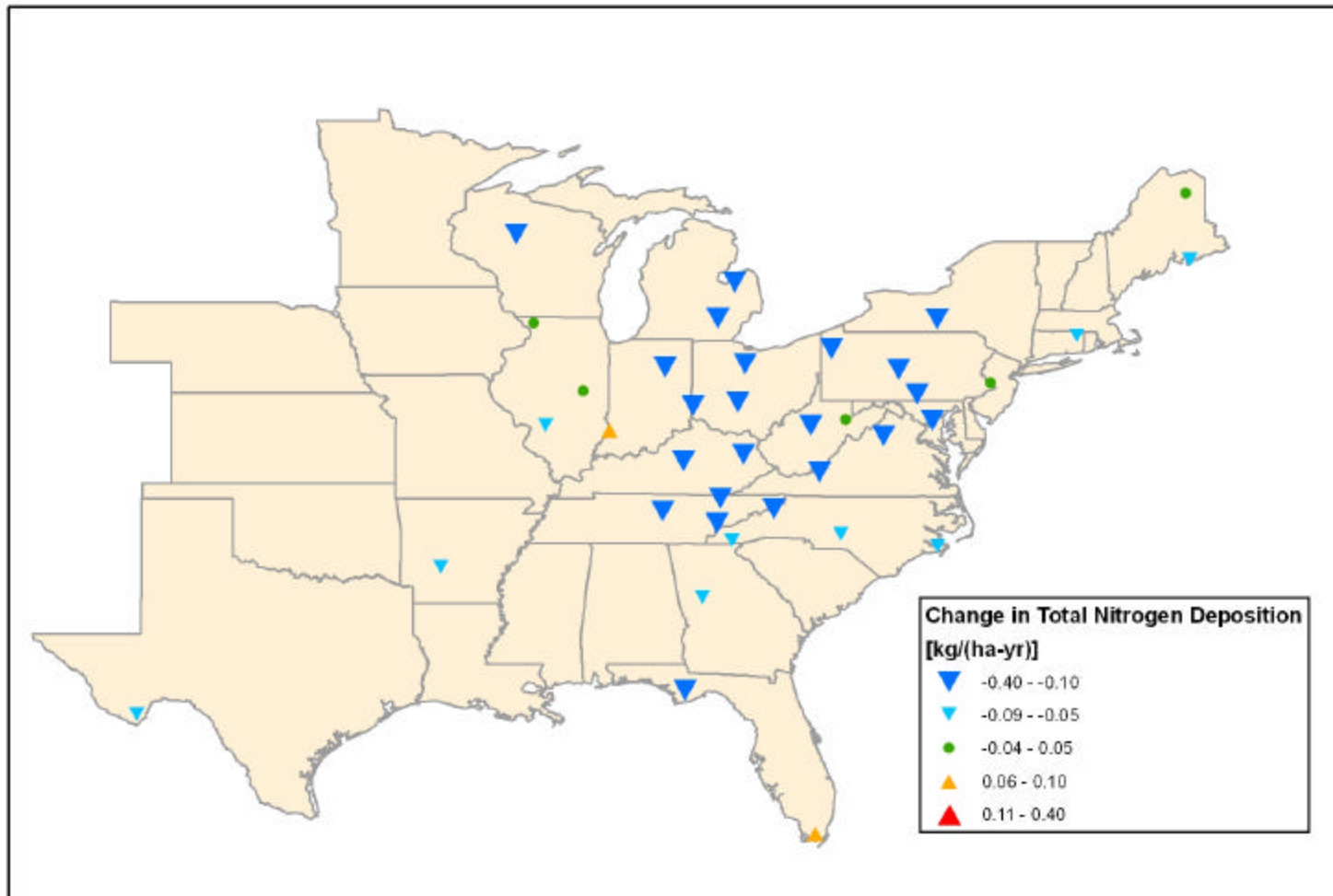
Total Sulfur Deposition Trends: 1999-2008 Western U.S.



- Concentrations are low so trend slopes are small
- Ten of fifteen sites show decreasing sulfur deposition



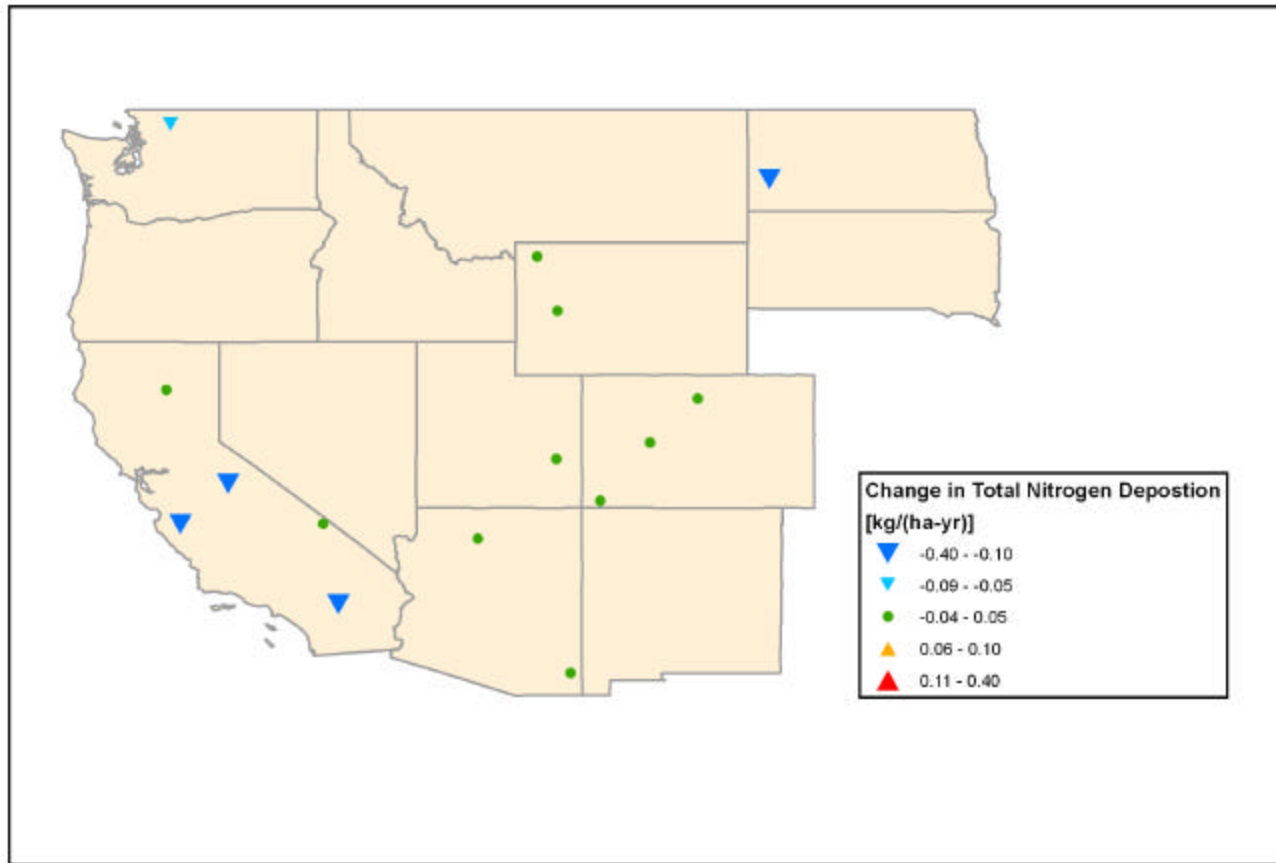
Total Nitrogen Deposition Trends: 1999-2008 Eastern U.S.



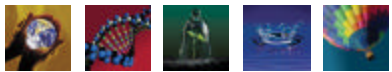
- Thirty five of thirty nine sites show decreasing nitrogen deposition



Total Nitrogen Deposition Trends: 1999-2008 Western U.S.

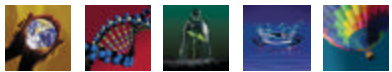


- Eight of fifteen sites show decreasing nitrogen deposition



Results – Eastern U.S.

- Reductions in sulfur and nitrogen deposition between 1999 and 2008 at nearly every monitoring site in eastern U.S.
- Average reduction was 19% (sulfur) and 18% (nitrogen)



Results – Western U.S.

- Average sulfur and nitrogen deposition much lower in WRAP than in other regions
- Percentage reductions in sulfur and nitrogen deposition in WRAP similar to that in eastern RPOs
- Majority of western sites exhibited reductions in sulfur and nitrogen deposition
 - Sulfur deposition very low but with 20% reduction overall
 - Largest nitrogen deposition reductions near urban areas in California



Part II: Sulfate Concentration Trends

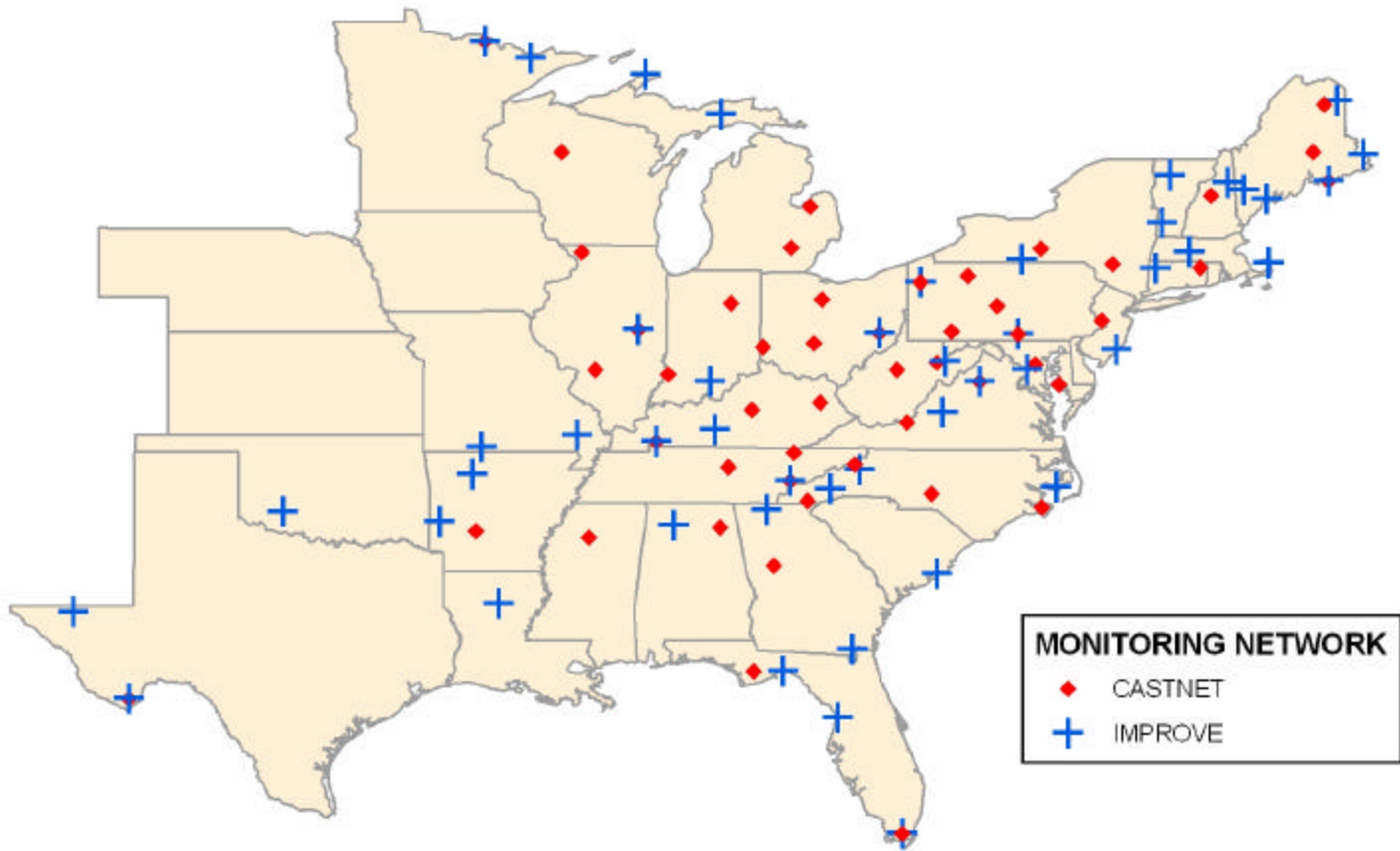


Sulfate Concentration Trends

- Total annual sulfur and nitrogen deposition strongly impacted by year-to-year changes in precipitation patterns
- Sulfate concentrations in air more directly related to trends in sulfur dioxide (SO_2) emissions than is total sulfur deposition

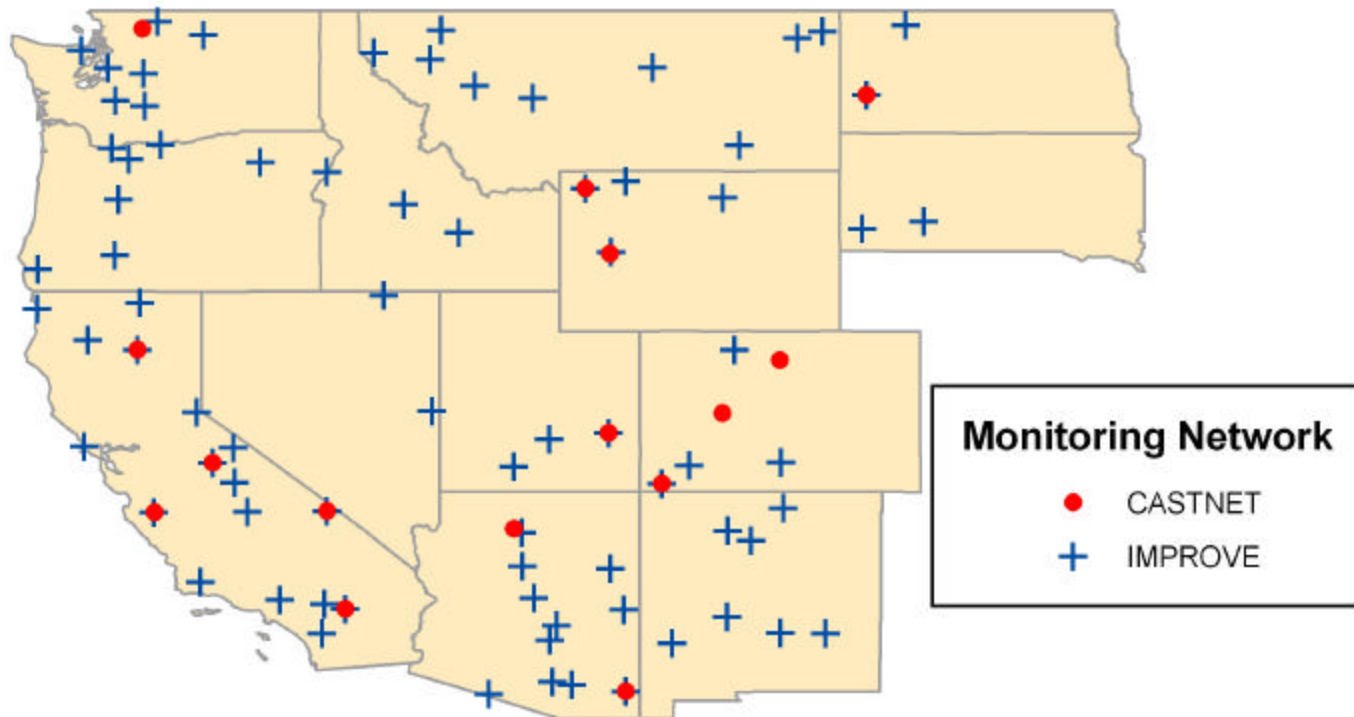


Monitoring Networks for Sulfate Concentration Analysis – Eastern U.S.





Monitoring Networks for Sulfate Concentration Analysis – Western U.S.



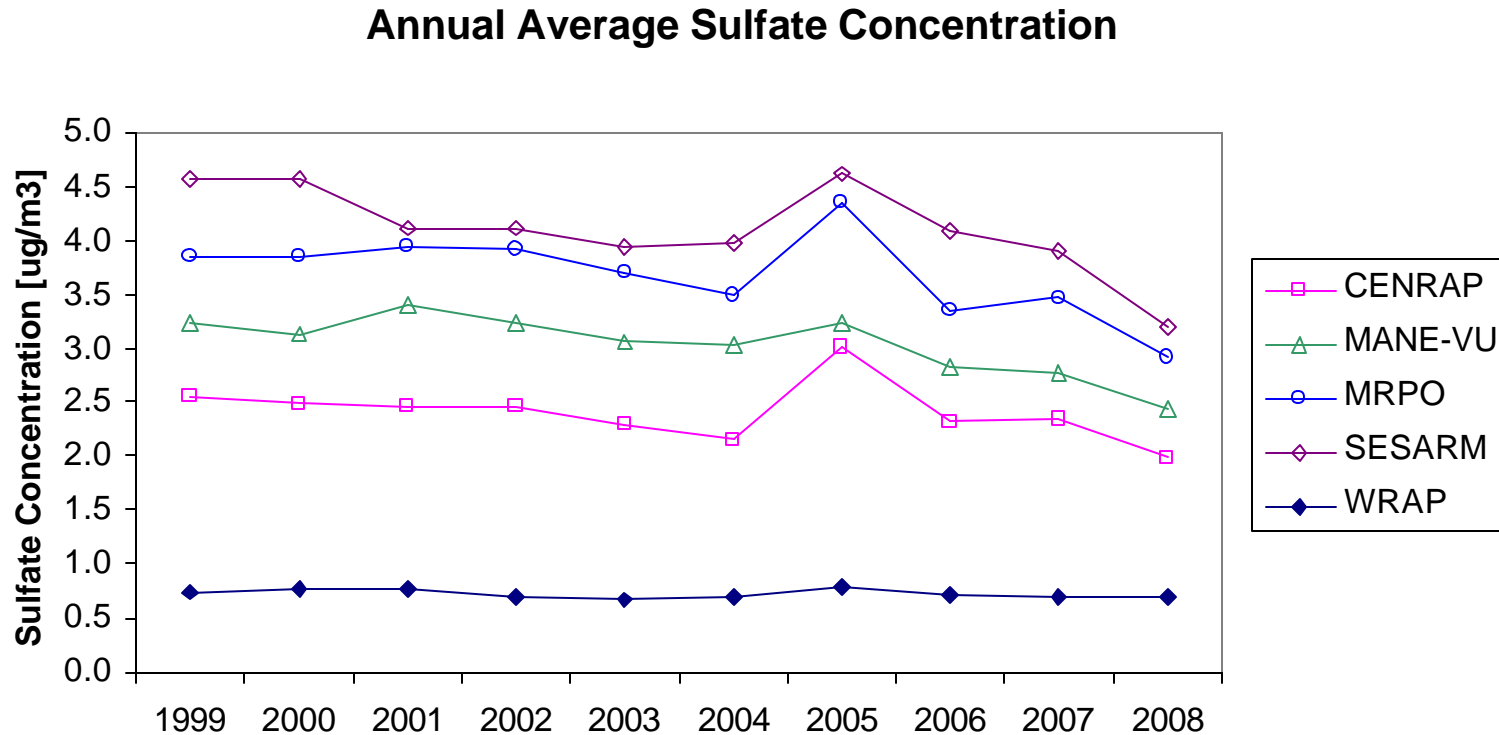


Sulfate Data Processing

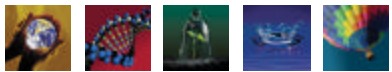
- CASTNET data represent weekly average sulfate. CASTNET sulfate data were filtered to include only those sites with at least 69% completeness (i.e. samples representing 69% of the hours in a year), as advised by CASTNET data processors.
- IMPROVE data are 24-hour samples measured once every 3 days, valid annual average required at least 50% data completeness (most sites achieved 70% or better data completeness).
- For both CASTNET and IMPROVE networks, sites with valid annual averages in at least 8 of the 10 years from 1999-2008 were included in trends analysis with missing years filled by linear interpolation for years with data in both previous and following years, filled with adjacent year values otherwise.
- Trend represented by slope of linear regression line calculated for each site



Annual Average Sulfate Averaged over monitoring sites within each RPO



- WRAP sulfate concentrations much lower than other RPOs
- 2005 discontinuity in sulfate trend also present in WRAP data

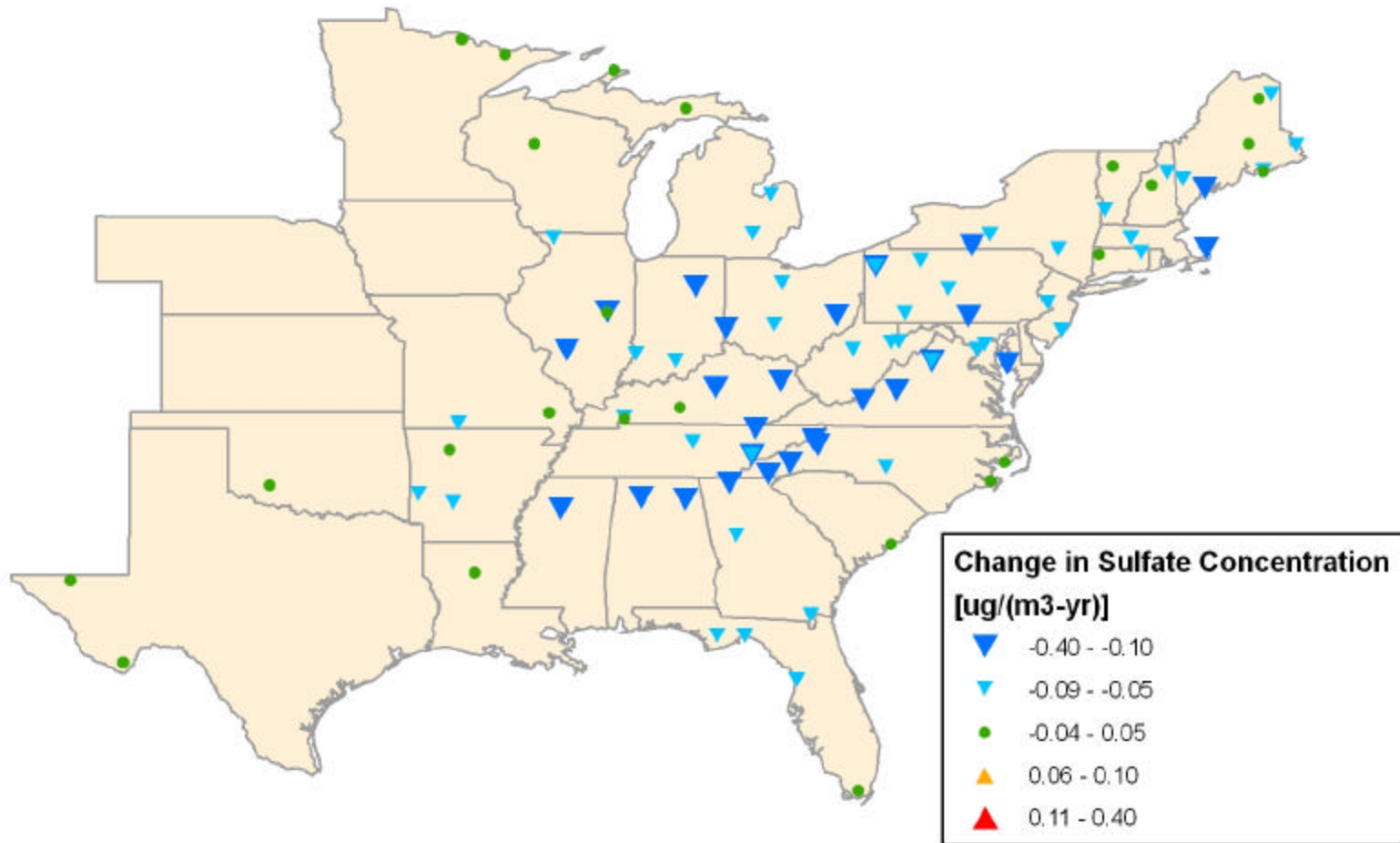


Annual Average Sulfate Trends

Region	Sulfate Trend	
	ug/m3-yr	% Change 1999 - 2008
CENRAP	-0.033	-12.9%
MANE-VU	-0.077	-22.8%
Midwest RPO	-0.079	-19.5%
VISTAS	-0.093	-20.6%
Eastern States	-0.078	-20.3%
WRAP	-0.005	-6.6%

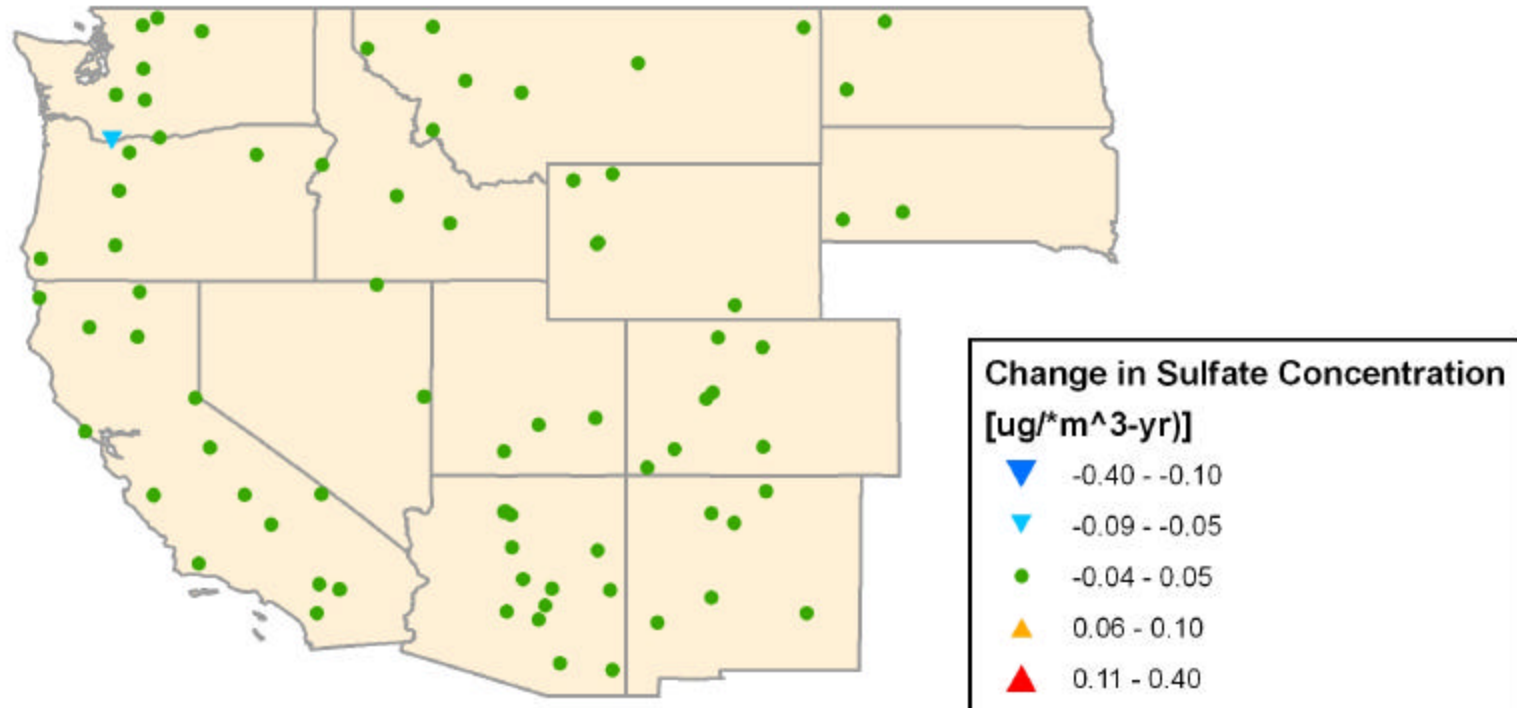


Change in Sulfate Concentration across the Eastern U.S. between 1999-2008





Change in Sulfate Concentration across the western U.S. between 1999-2008



- Sulfate trends and concentrations generally very small in the West ($<0.5 \mu\text{g}/\text{m}^3$ change over 10 years)
- Sulfate reductions occurred at 59 out of 92 sites



Results: Sulfate Concentrations

- Reductions in sulfate concentration between 1999 and 2008 throughout the eastern U.S.
 - Average reduction was 19%
 - Consistent with overall sulfur deposition trend
- Average sulfate concentrations much lower in western (WRAP) states
- Sulfate reductions occurred at about 2/3 of western U.S. sites between 1999 and 2008
 - Reductions were small (<0.5 $\mu\text{g}/\text{m}^3$ over 10 years) since concentrations are low