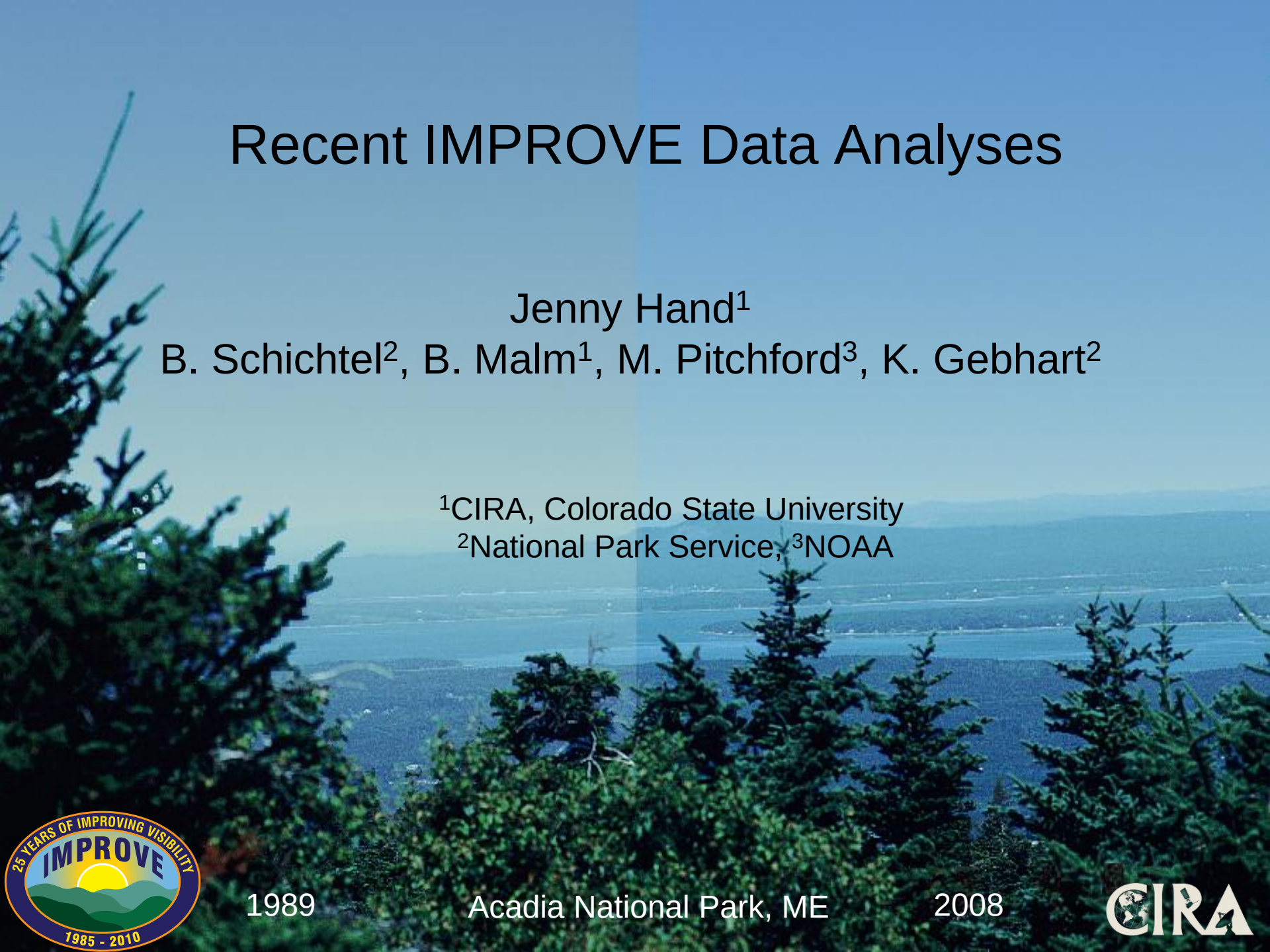
Recent IMPROVE Data Analyses

Jenny Hand[1]
B. Schichtel[2], B. Malm[1], M. Pitchford[3], K. Gebhart[2]

[1]CIRA, Colorado State University
[2]National Park Service, [3]NOAA



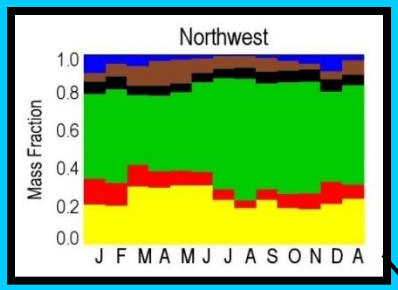
IMPROVE Report V Finalized

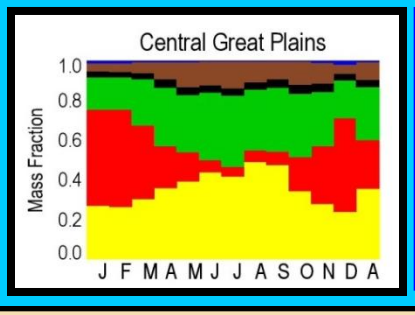
Executive Summaries are available:

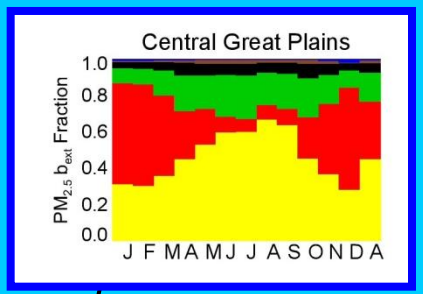
Email Helene at Bennett@cira.colostate.edu

http://vista.cira.colostate.edu/improve/Publications/Reports/2011/2011.htm

2005–2008 Annual Mean $PM_{2.5}$ Mass

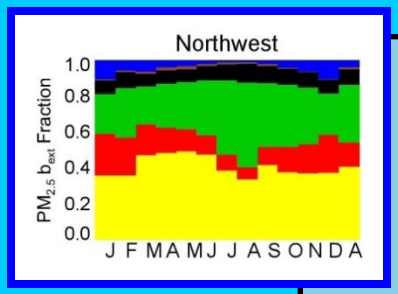


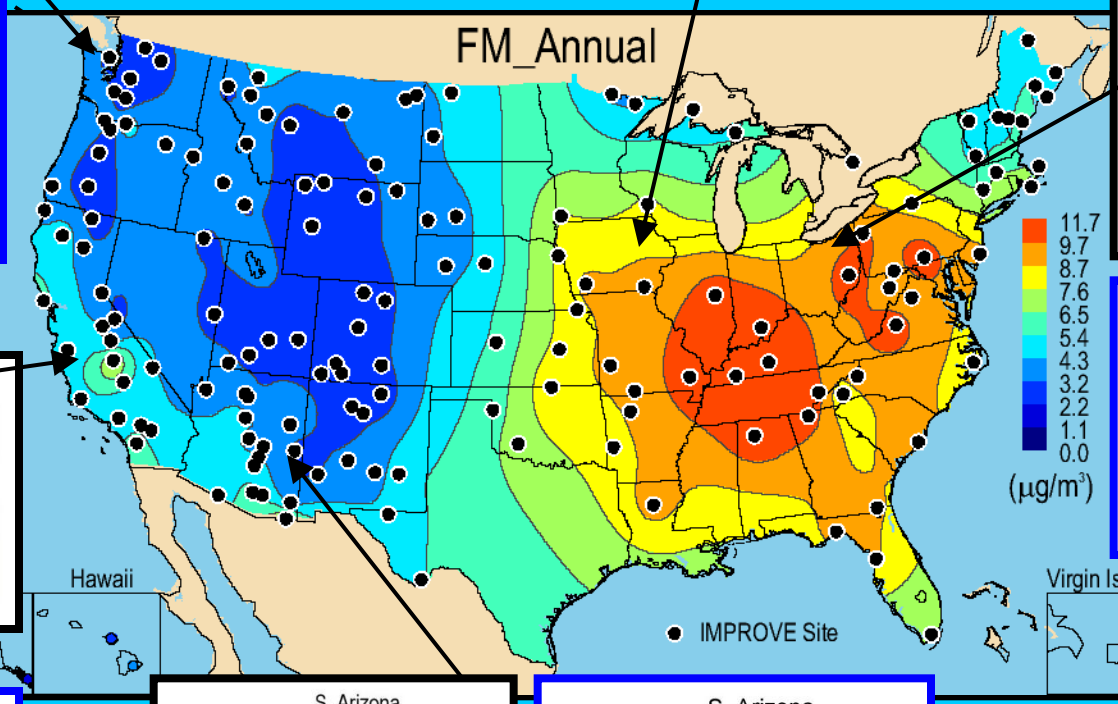


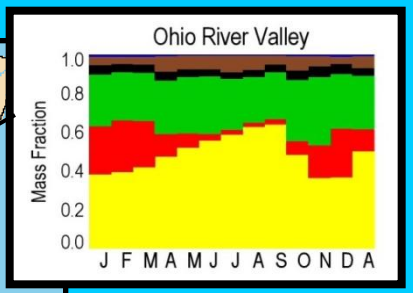


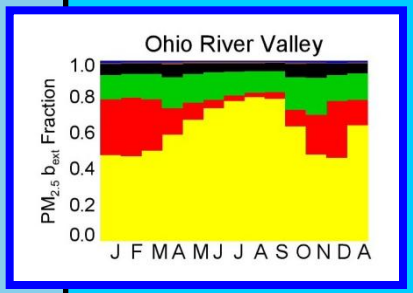
Mass Fraction

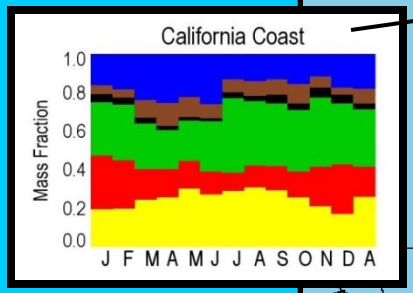
$PM_{2.5}$ b_{ext} fraction

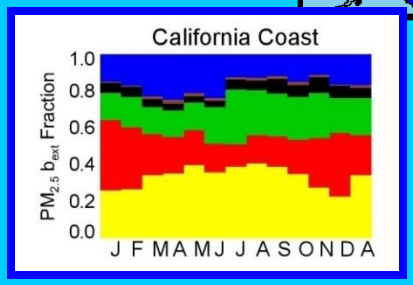


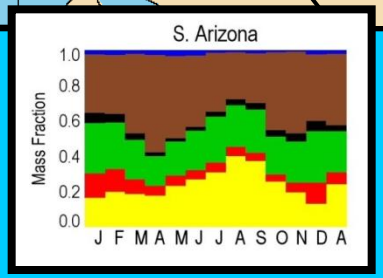


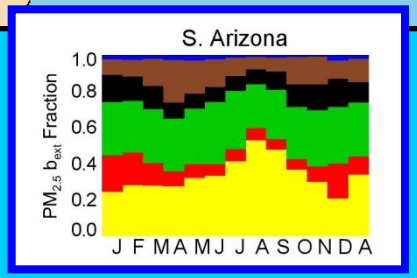












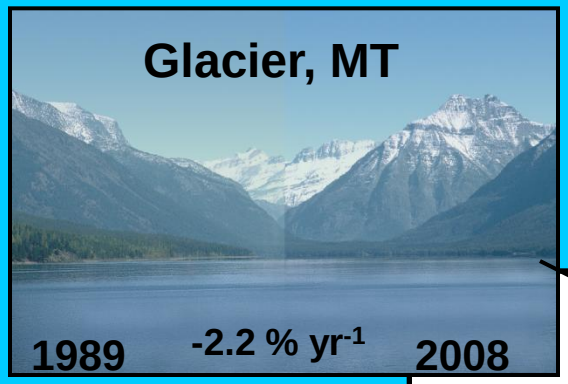
Ammonium sulfate
Ammonium nitrate
Particulate organic matter
Light absorbing carbon
Soil
Sea salt

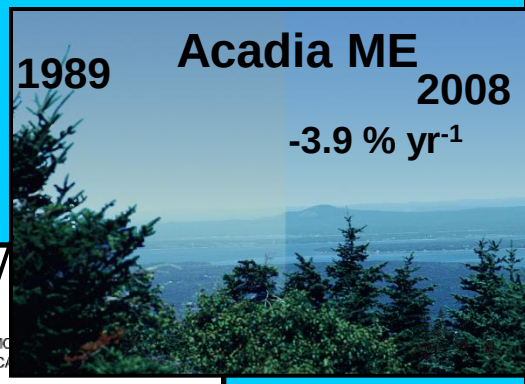
Recall from last year that we computed trends:

- Theil regression
- 1989–2008; 2000–2008; -2009; -2010
- Sulfate, nitrate, total carbon, soil, $PM_{2.5}$, PM_{10}, coarse mass
- 10^{th}, 50^{th}, 90^{th}, monthly, seasonal, and annual mean and medians

Trends for IMPROVE data generally show decreases in aerosol concentrations

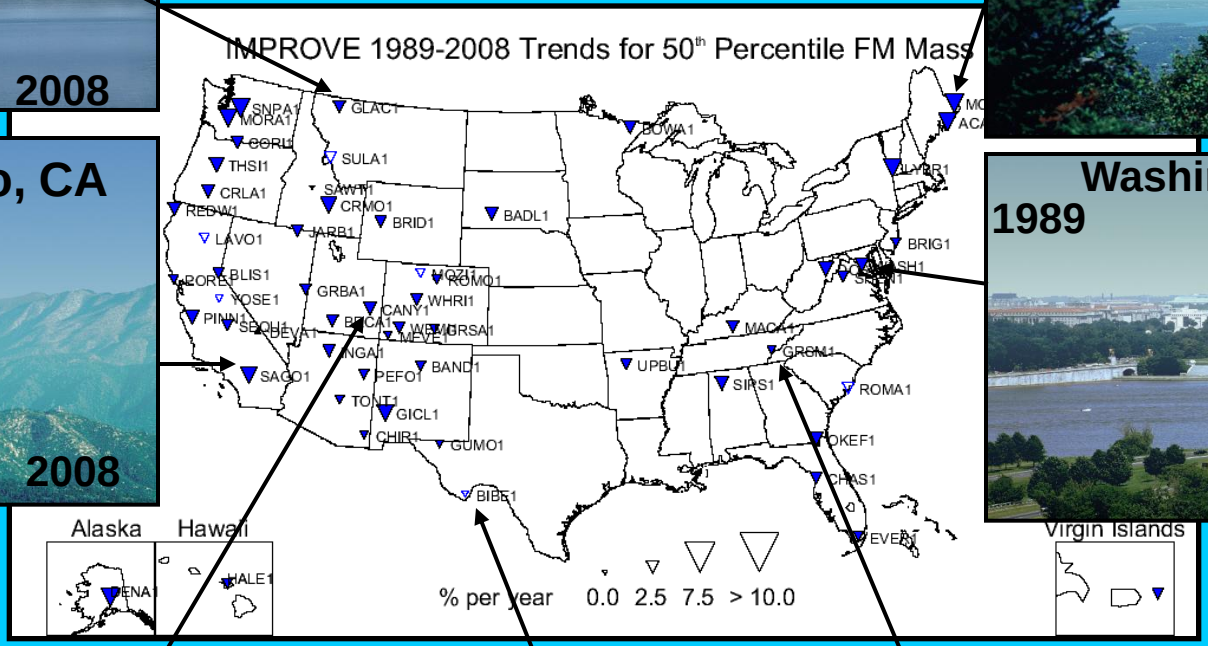
Trend Results $PM_{2.5}$ Mass





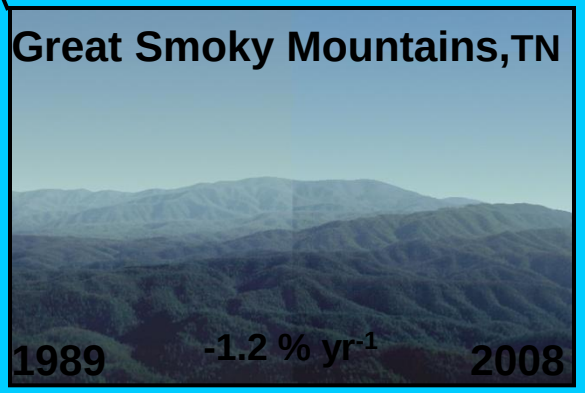




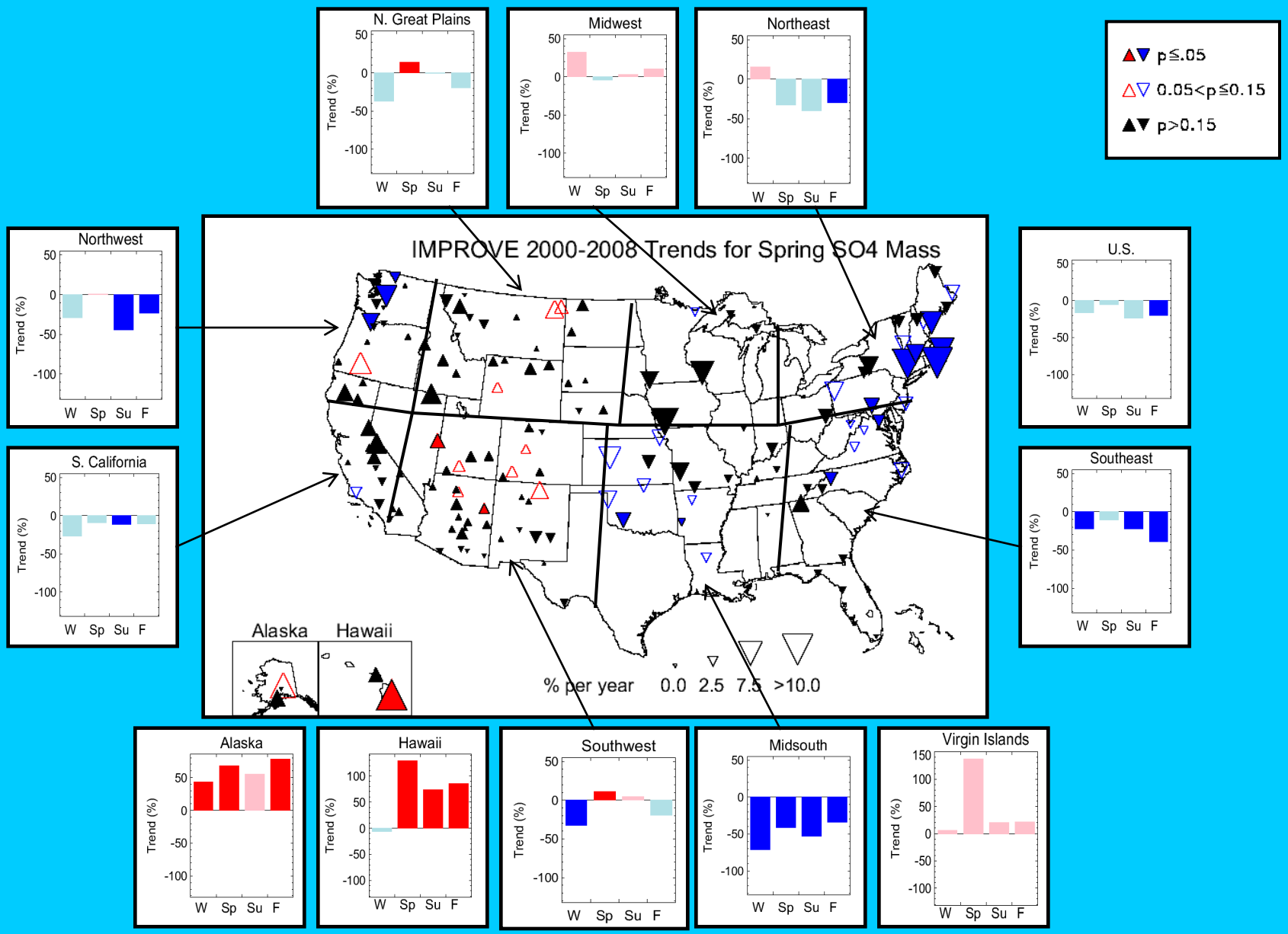






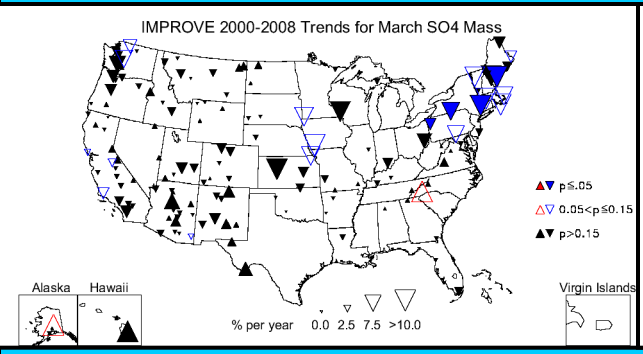


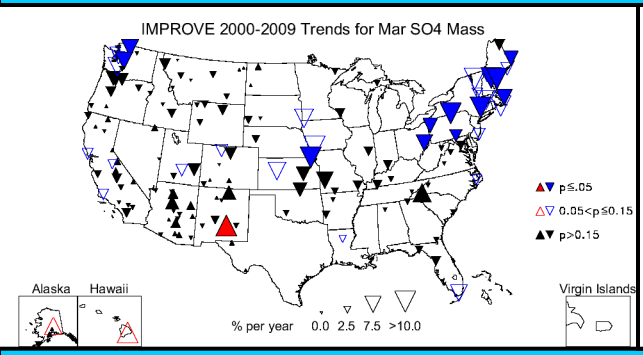
2000-2008 Spring (MAM) Sulfate Trends

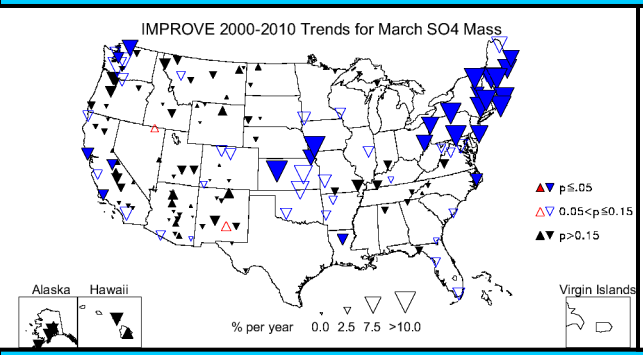


Monthly Mean Sulfate Trends

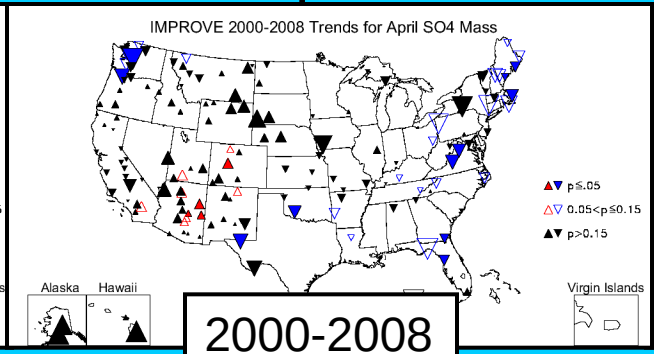
March



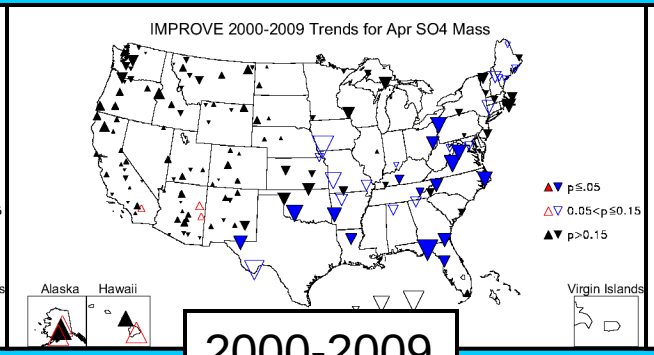




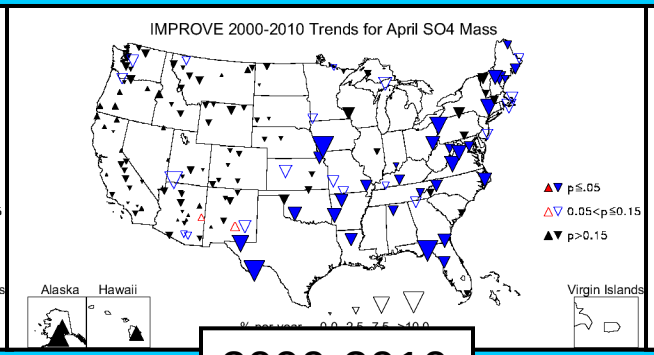
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2000-2008

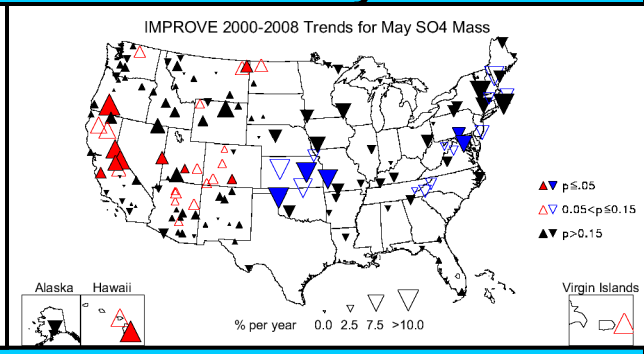


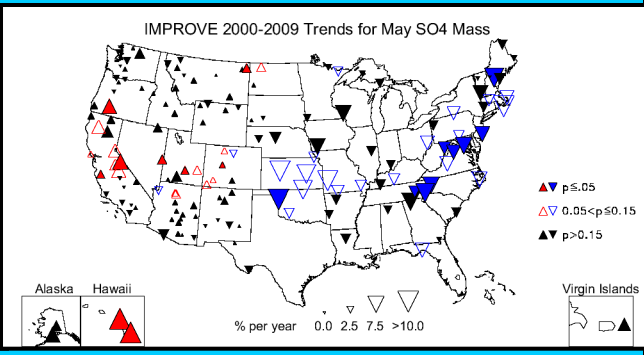
2000-2009

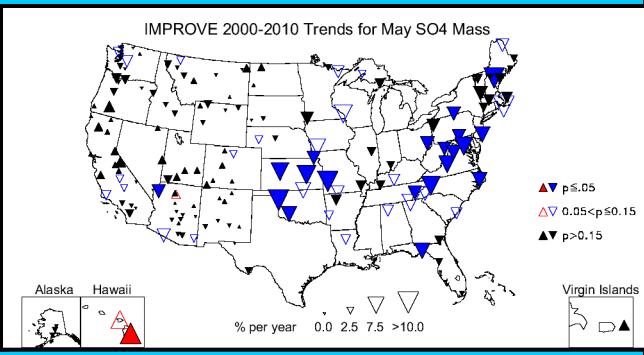


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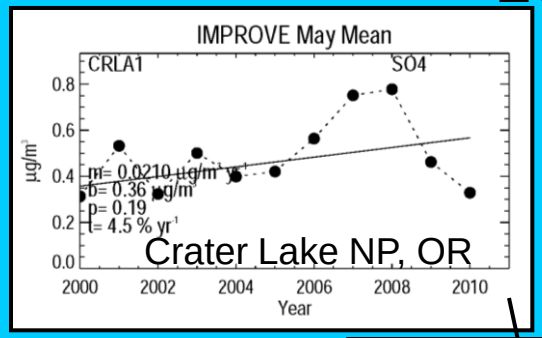
May

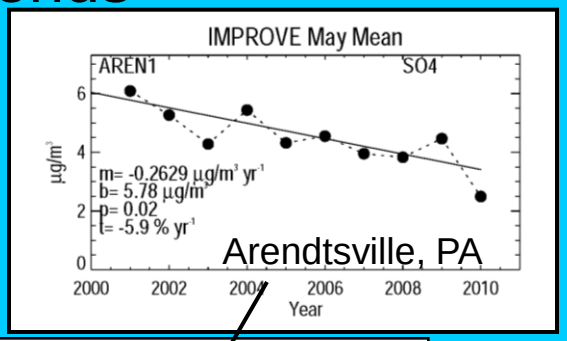


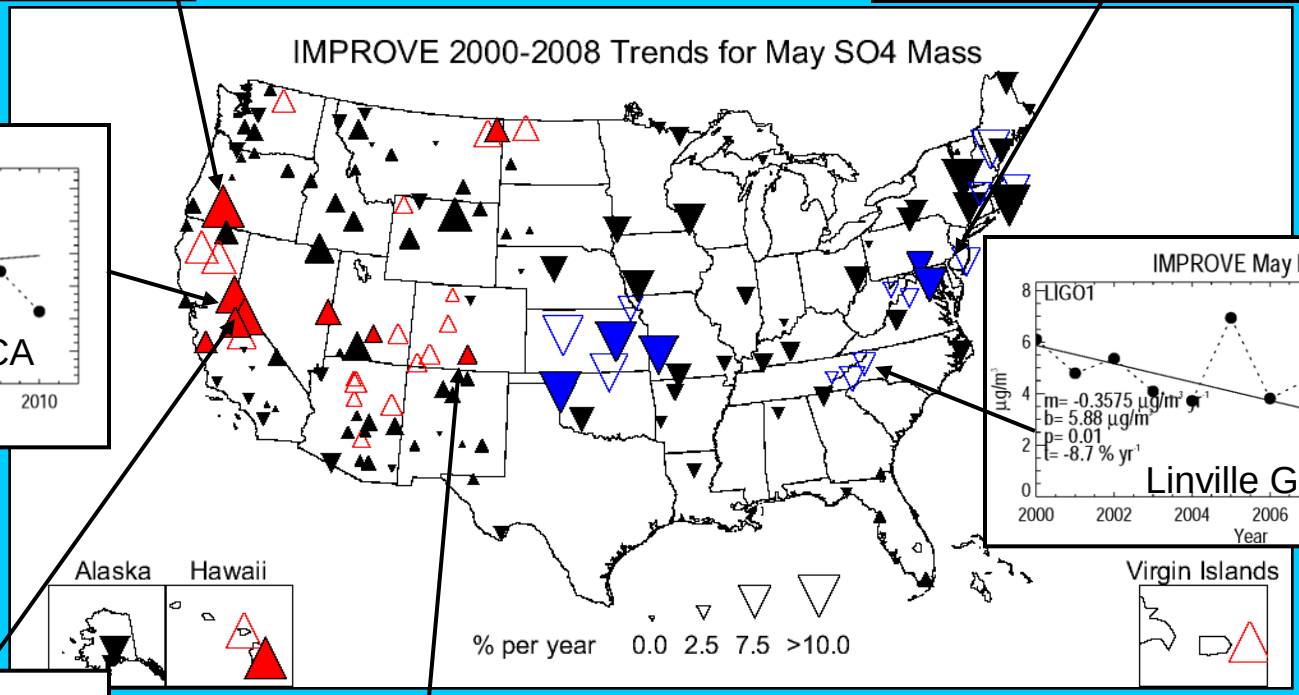


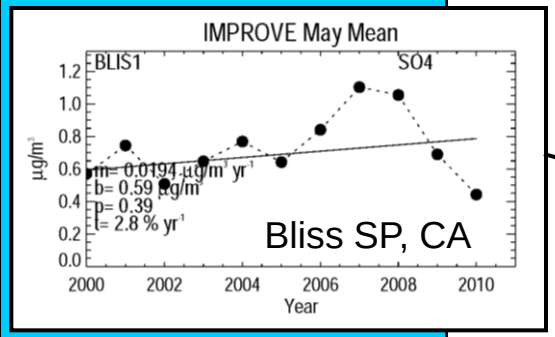


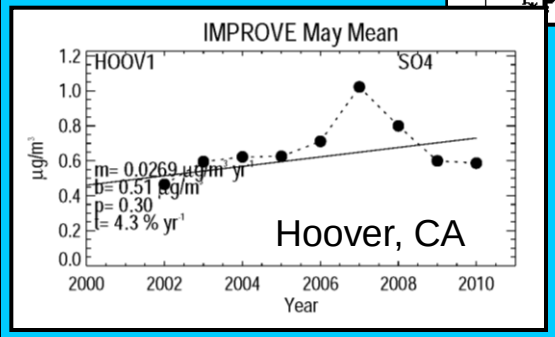
2000-2008 Mean May Trends

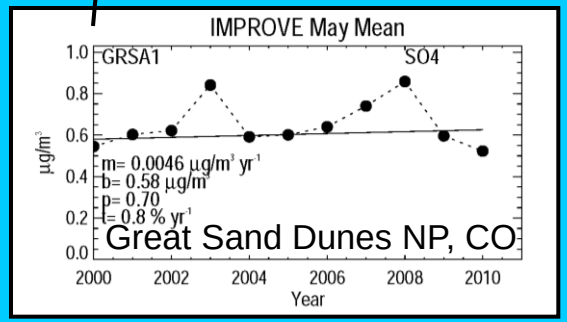




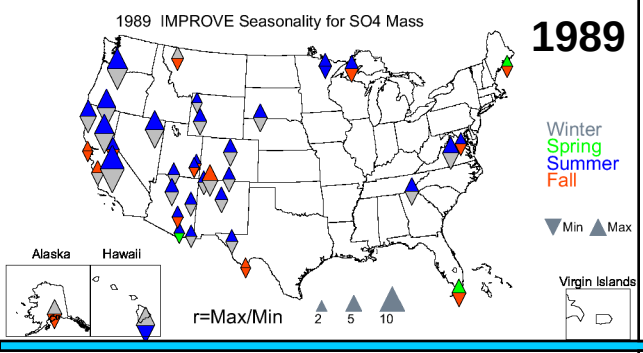


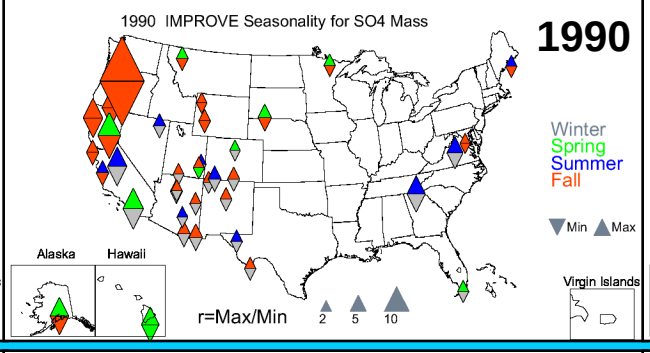


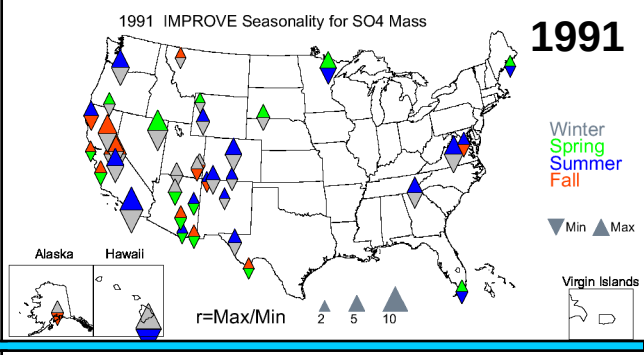


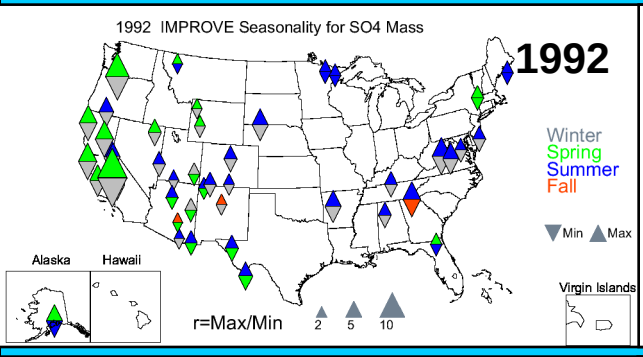


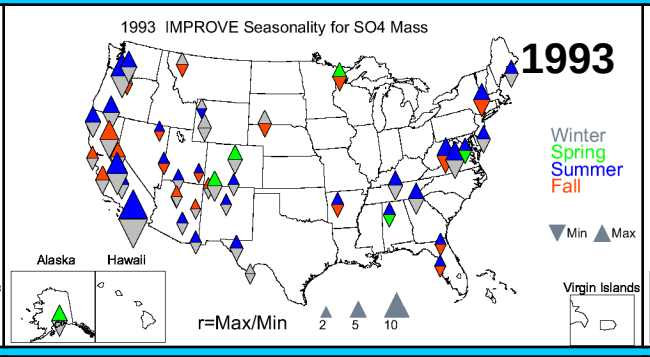
The seasonality of sulfate has been shifting from summer toward spring

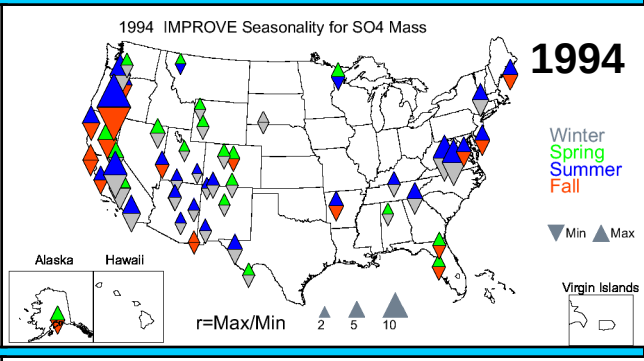


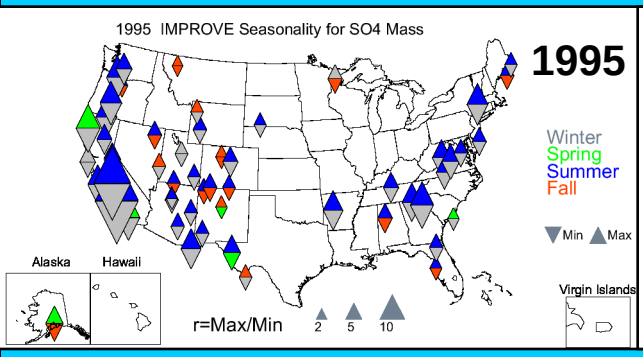


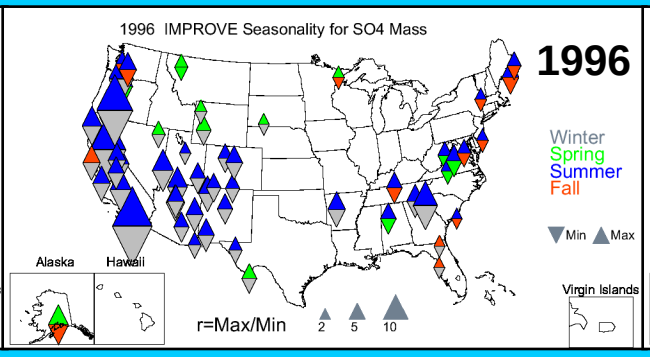


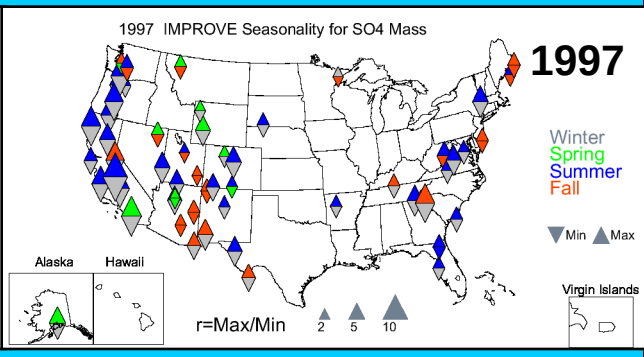


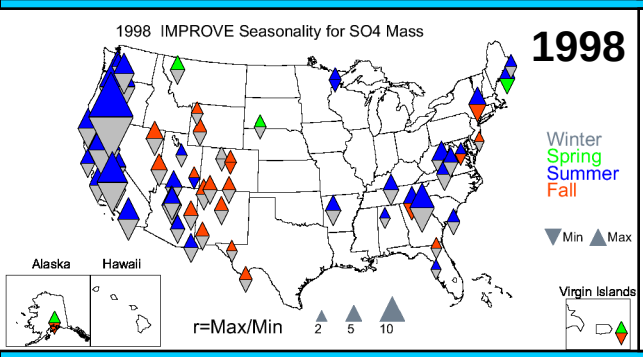


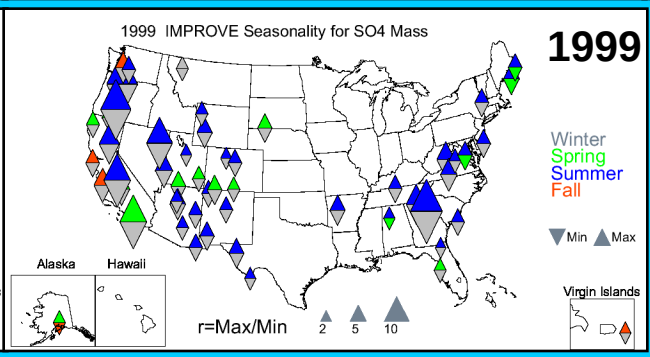






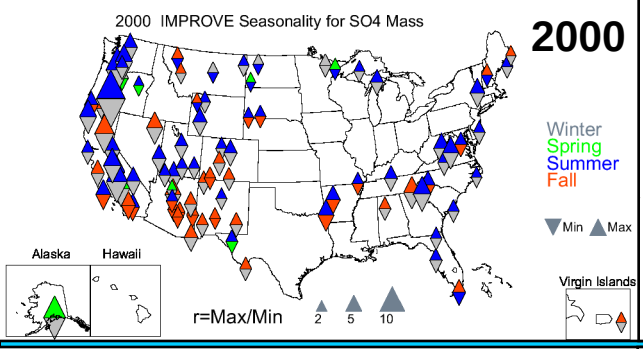


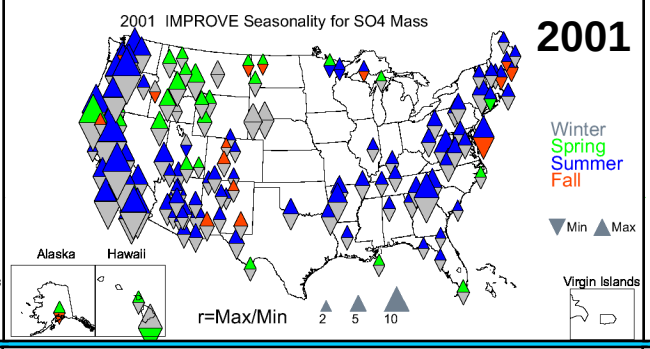


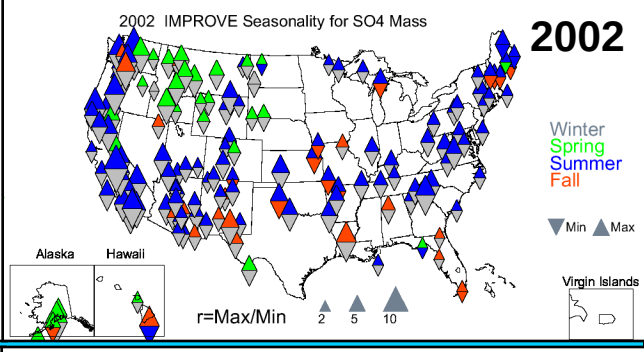


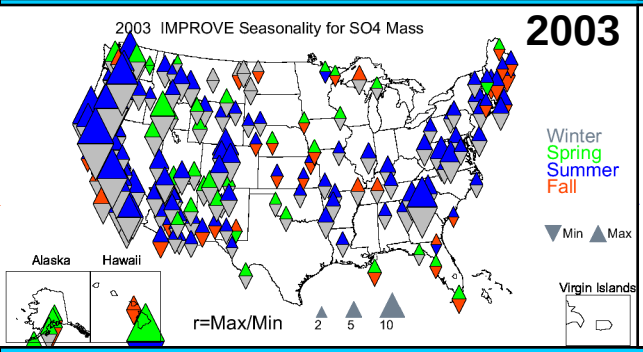
Sulfate Seasonality

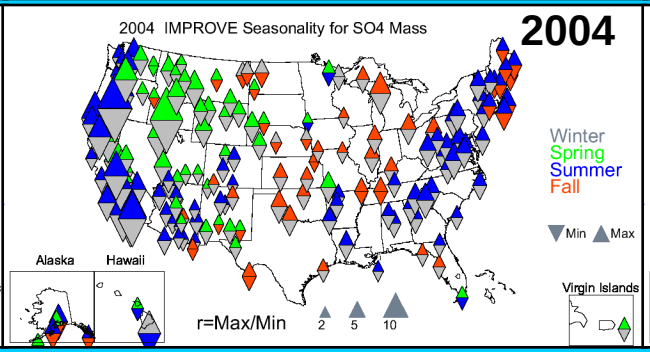
Winter Spring
Summer Fall

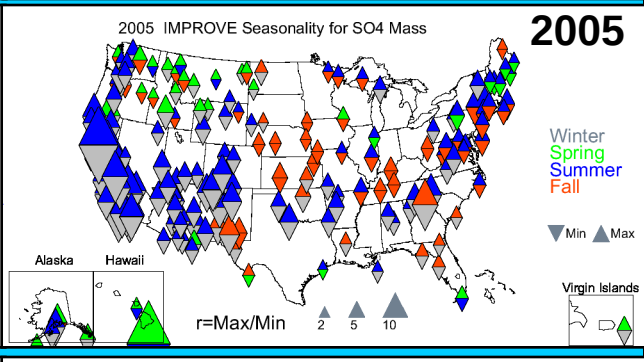


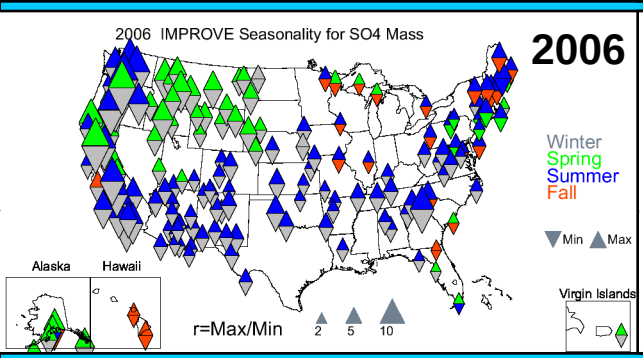


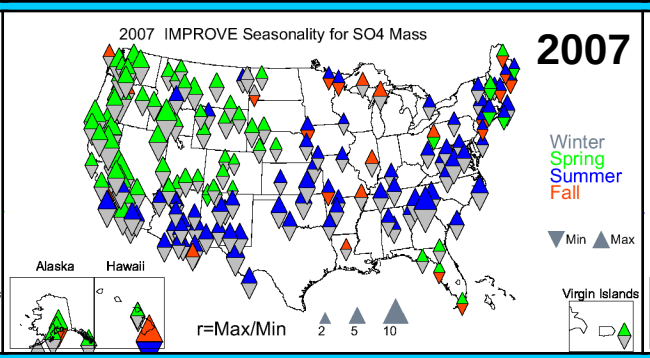


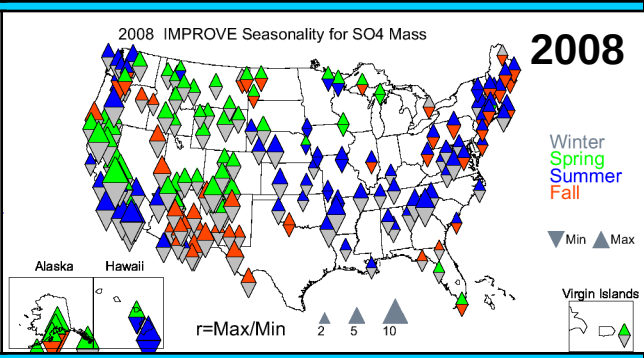


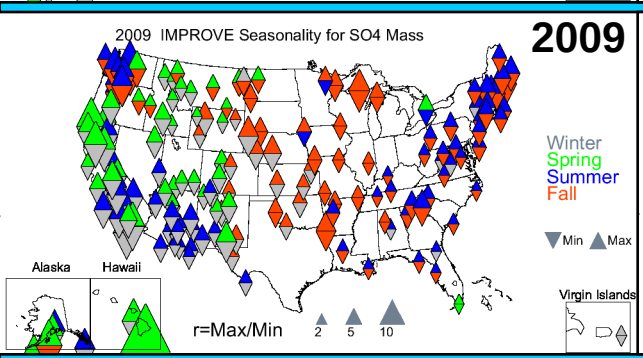


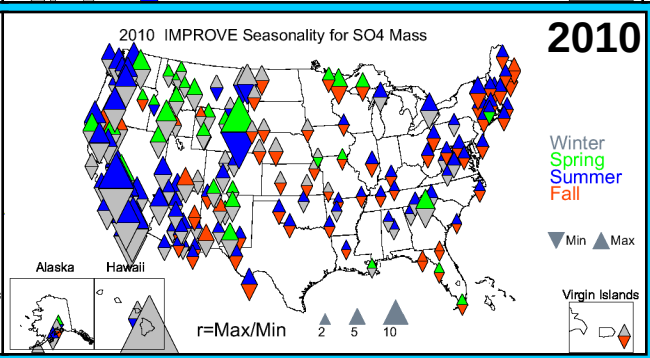










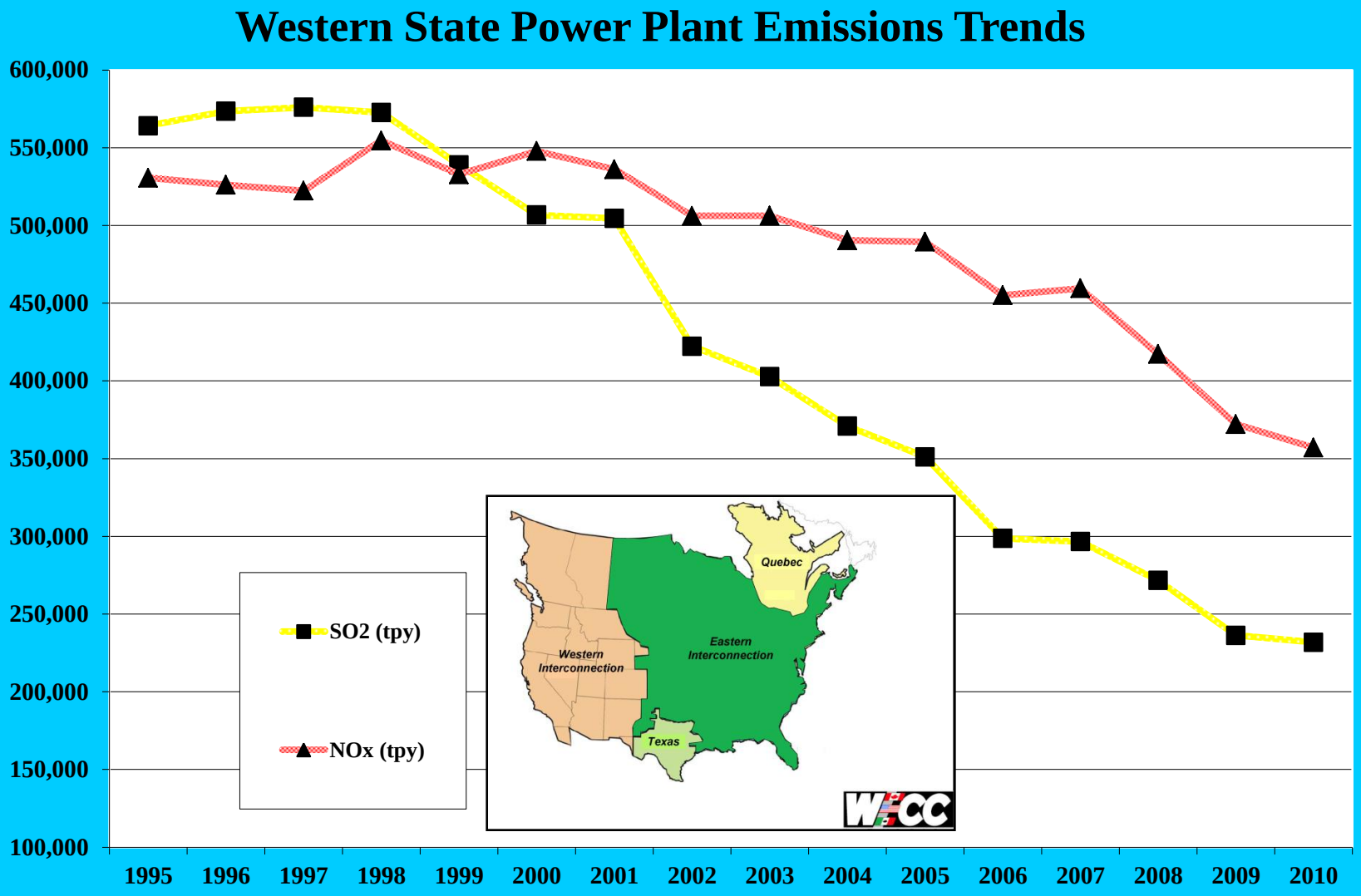


Sulfate Seasonality

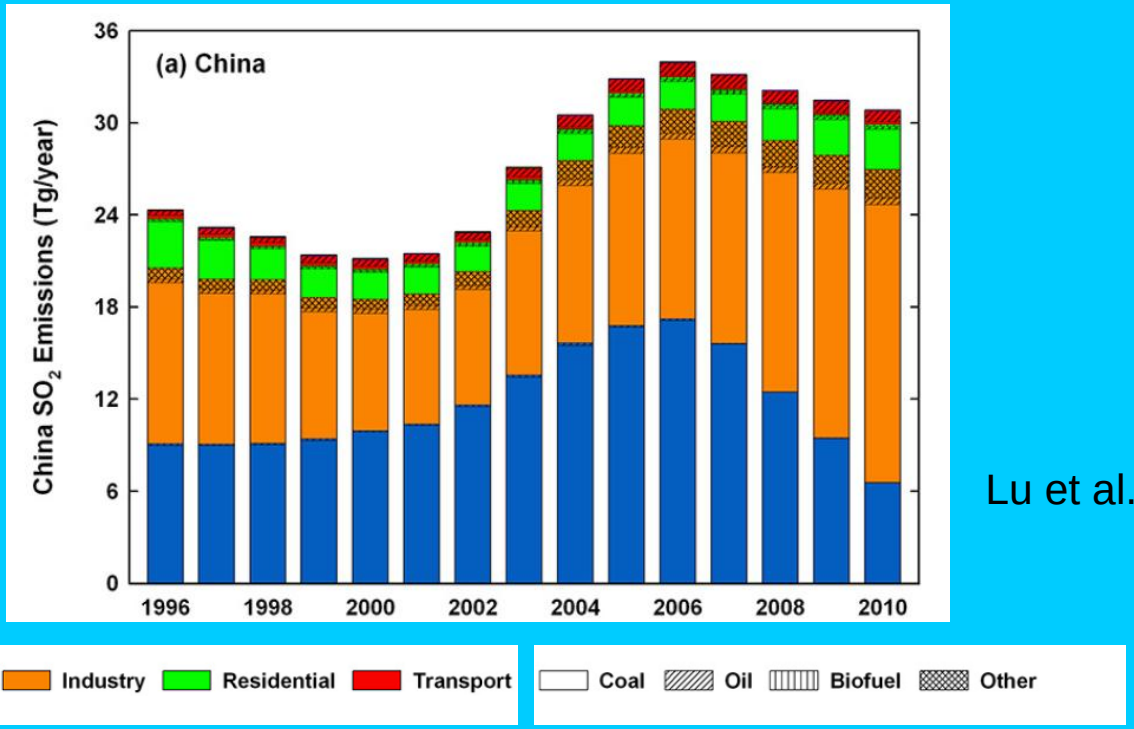
Winter Spring
Summer Fall

What is contributing to positive spring sulfate trends in the West?

Emissions: Local emissions are decreasing:



•International contributions (Asia, Mexico, Canada)?



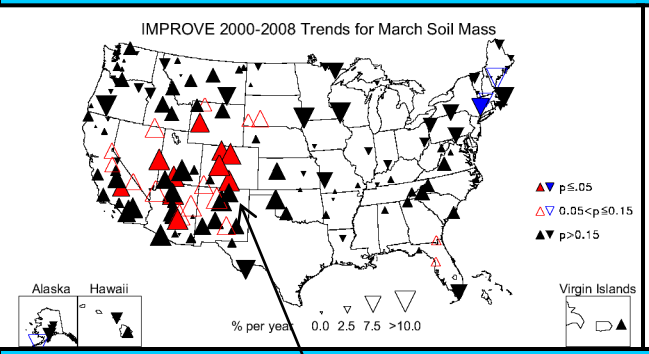
Lu et al., ACP, 2011

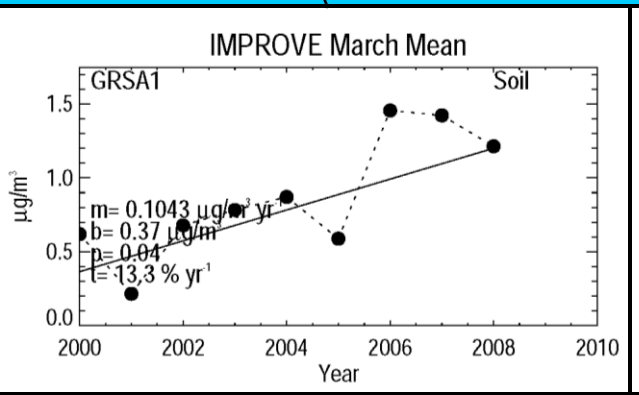
•Changes in atmospheric physical or chemical processes that favor sulfate formation/accumulation (changes in precursors/oxidants, clouds, precipitation, etc.)?

•Other?

2000-2008 $PM_{2.5}$ Soil Monthly Mean Trends (Real?)

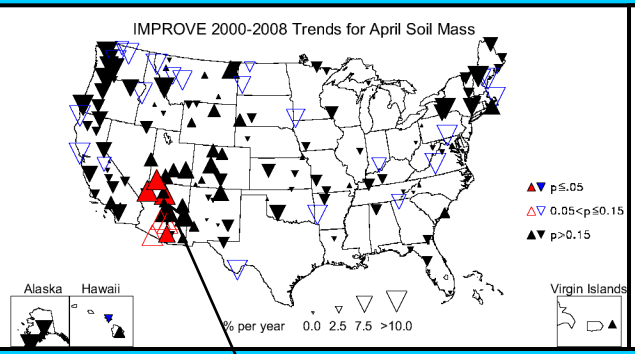
March

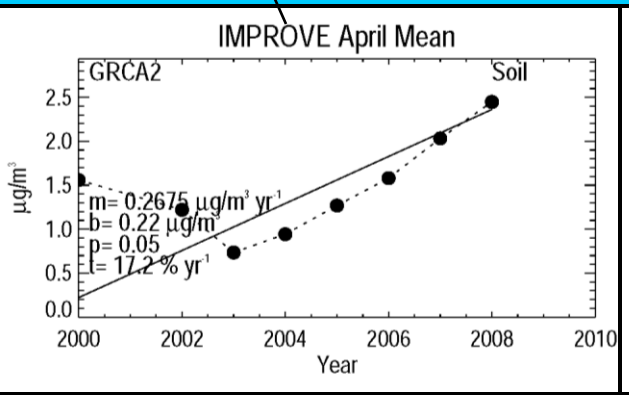




Great Sand Dunes NM, CO

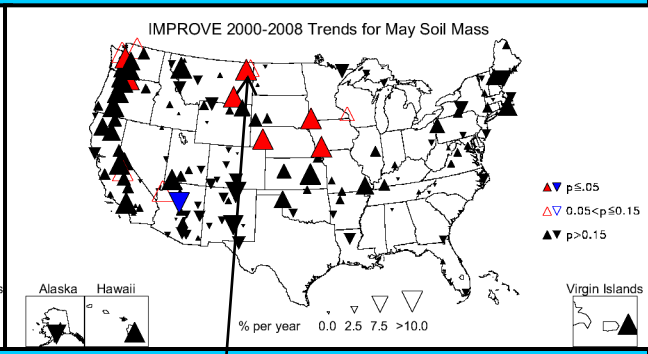
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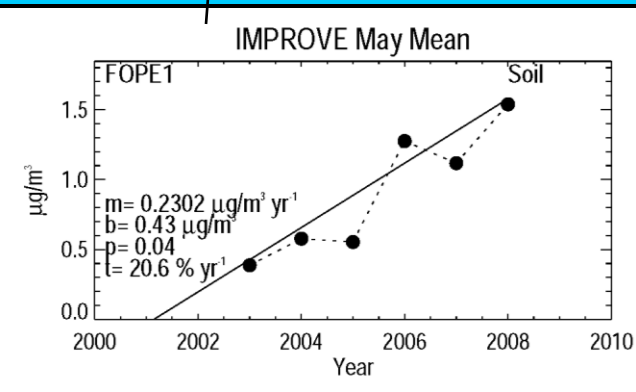




Grand Canyon NP, AZ

May

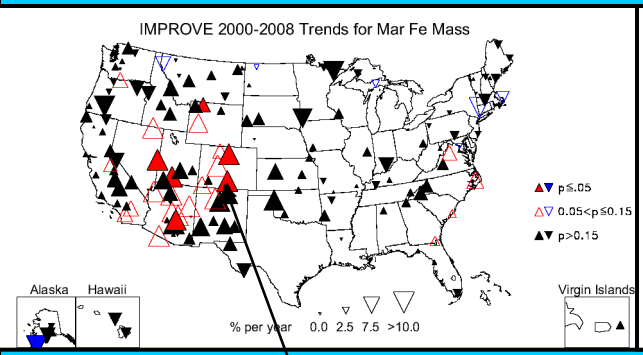


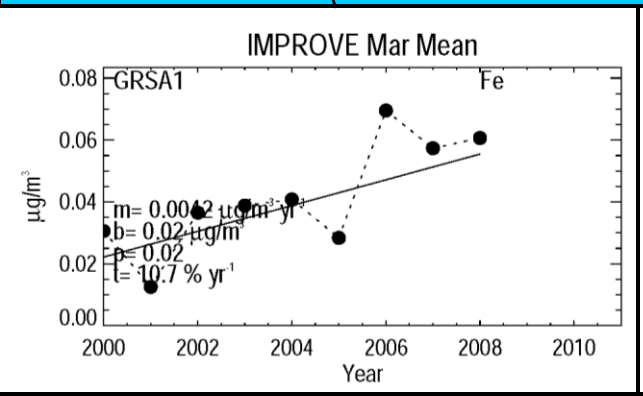


Fort Peck, MT

2000-2008 $PM_{2.5}$ Fe Monthly Mean Trends

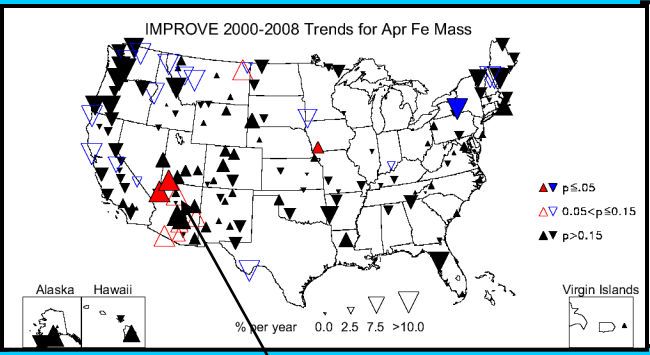
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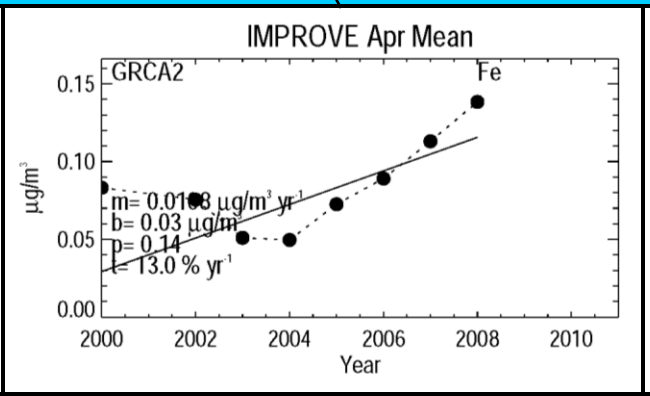




Great Sand Dunes NM, CO

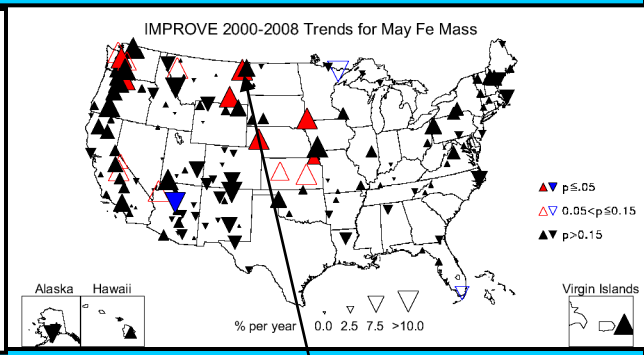
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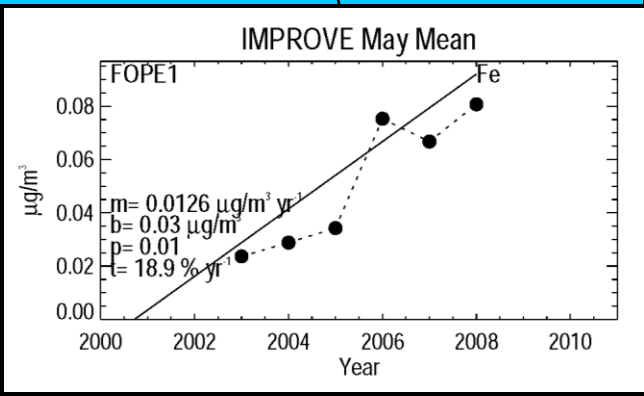




Grand Canyon NP, AZ

May

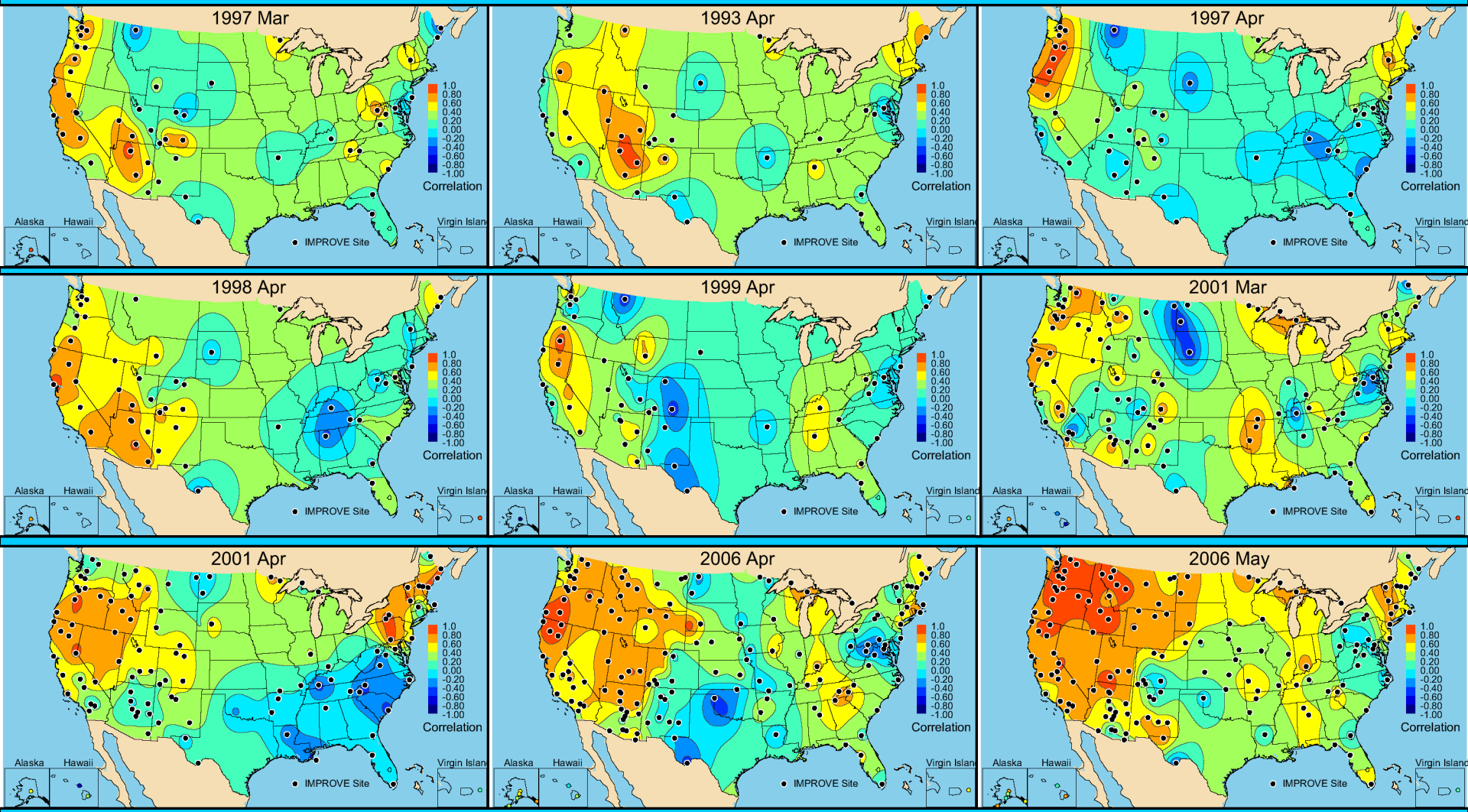




Fort Peck, MT

Correlation Between Sulfate and Iron:

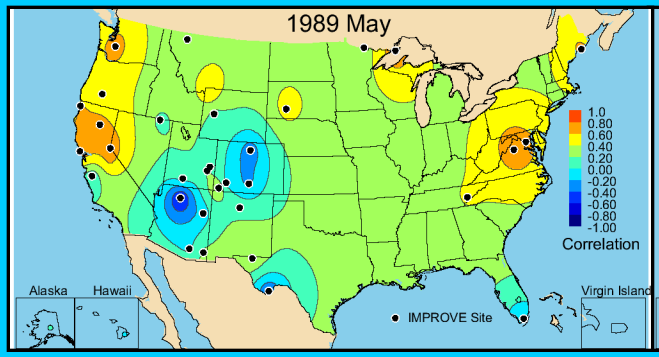
Known Asian Dust Events (Jaffe et al., 2003)

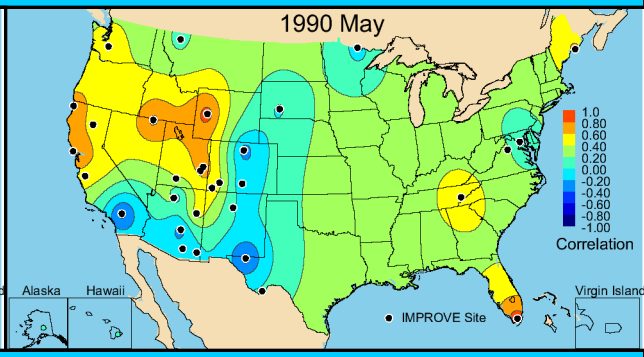


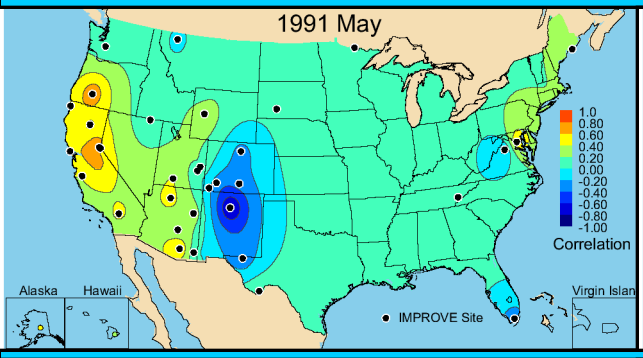
r = 0.8 corresponds to 90% confidence

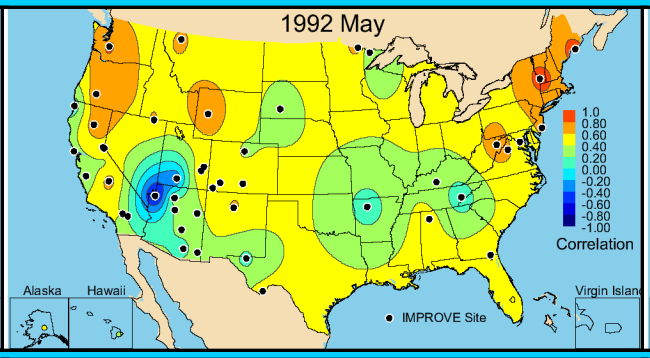
Sulfate and Iron Correlation

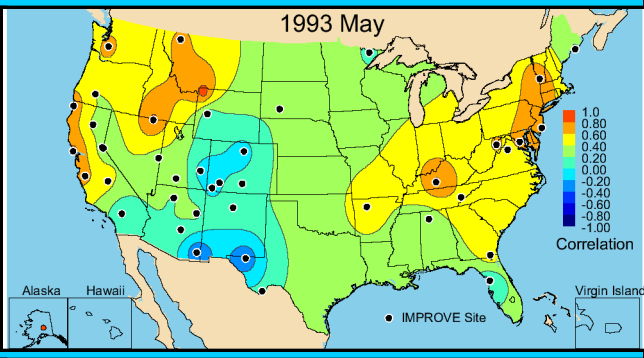
May 1989-1999

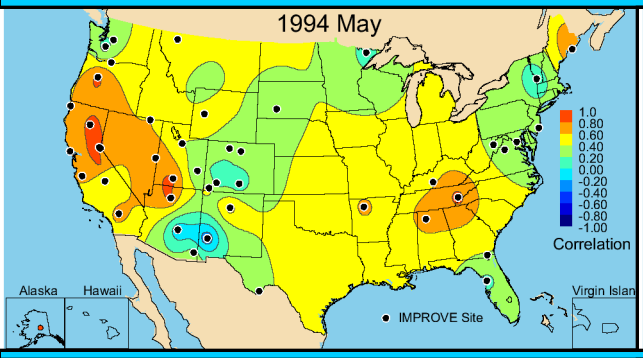


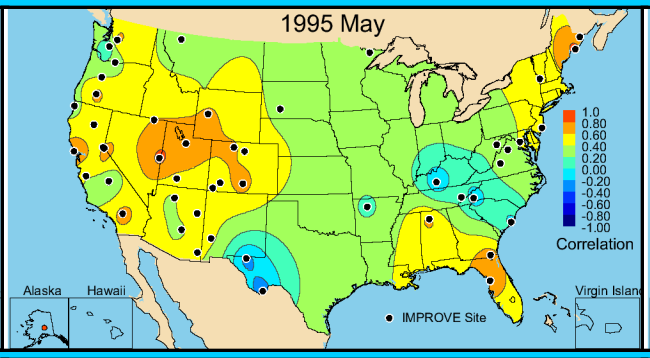


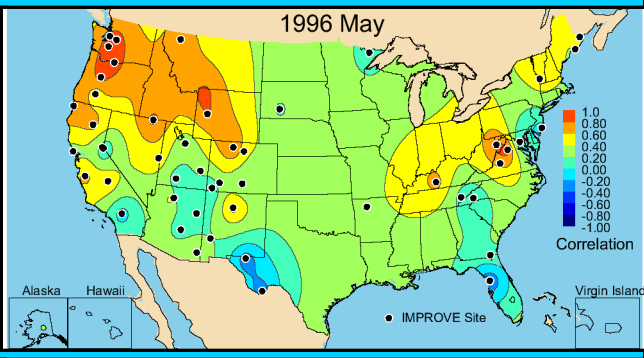


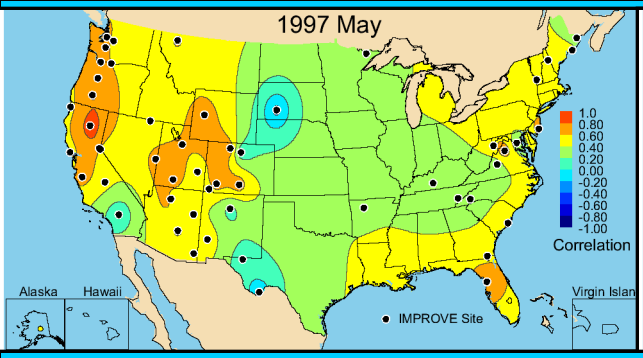


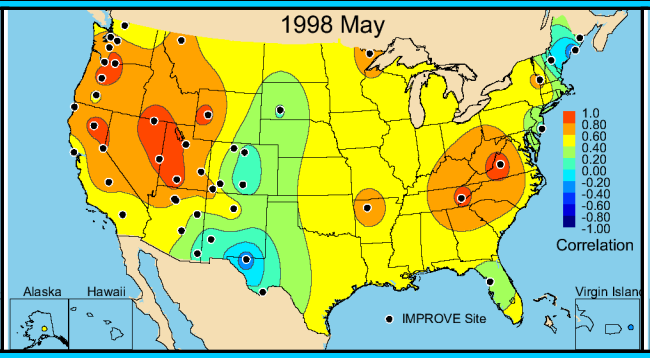


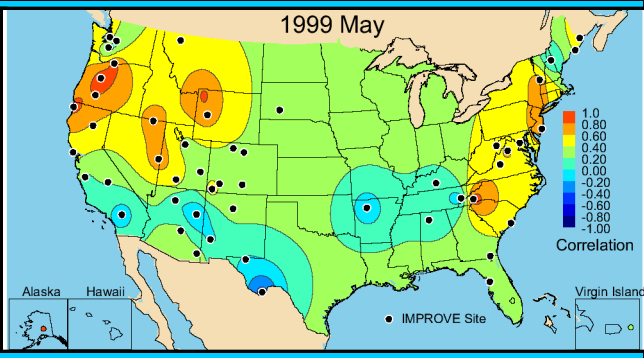






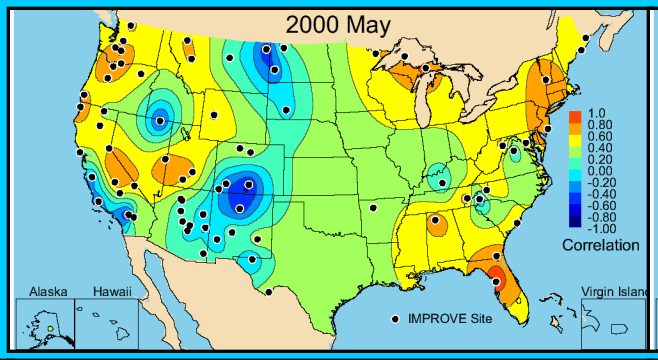


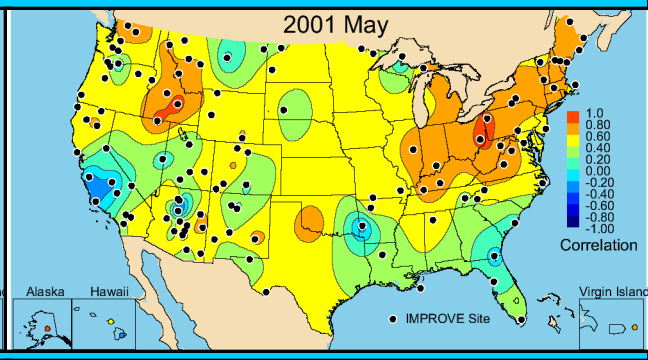


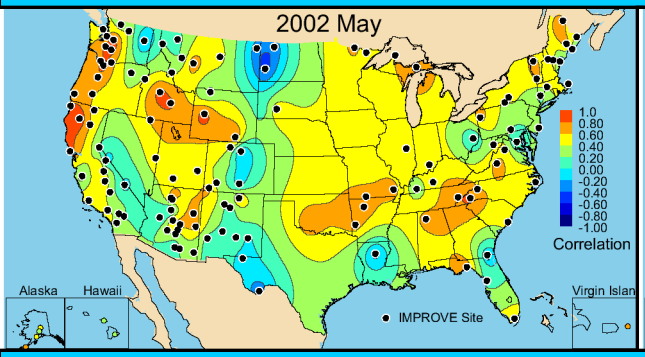


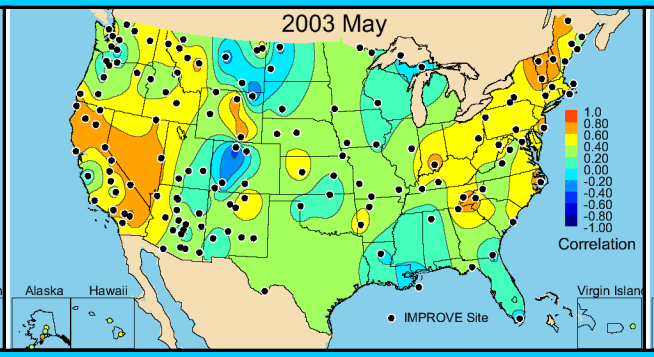
Sulfate and Iron Correlation

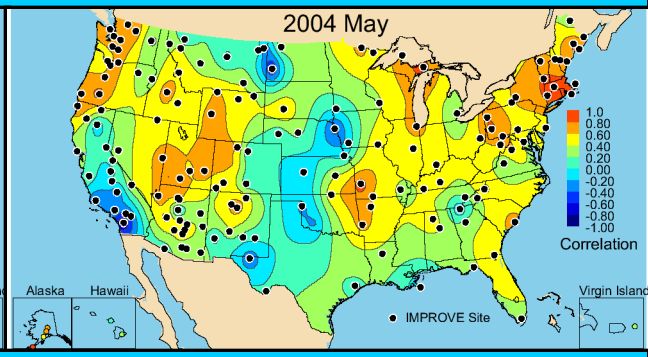
May 2000-2009

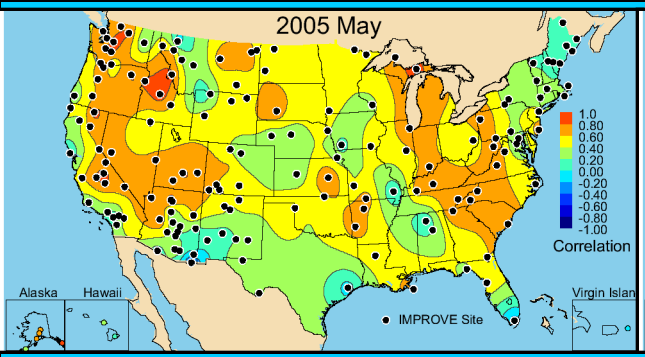


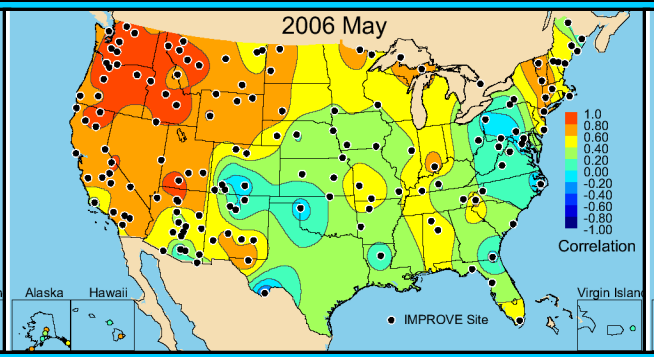


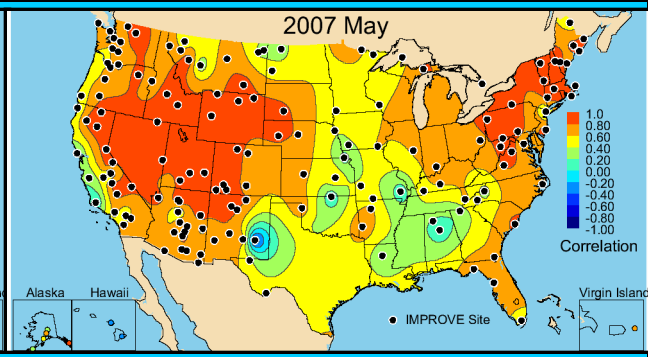


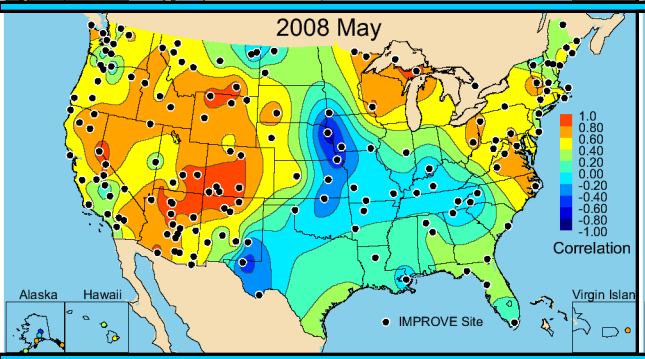


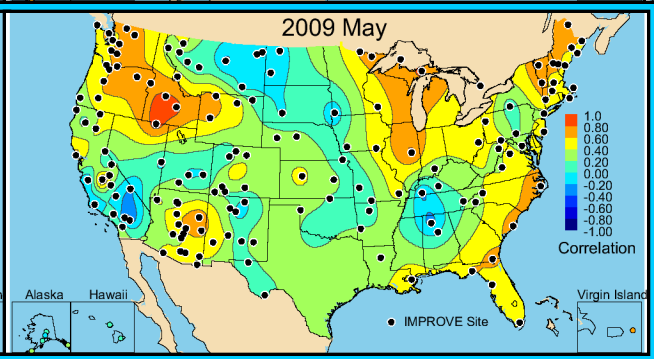












Are episodes significant?

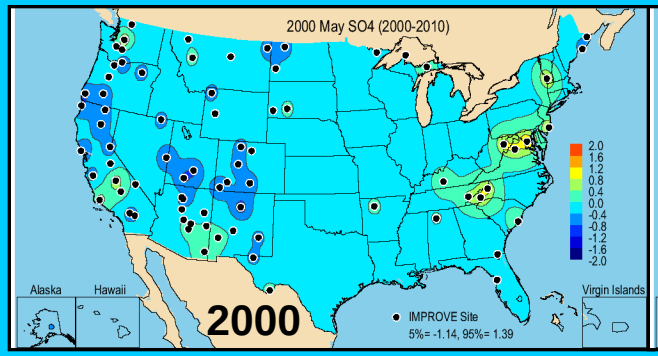
Standardized Anomaly

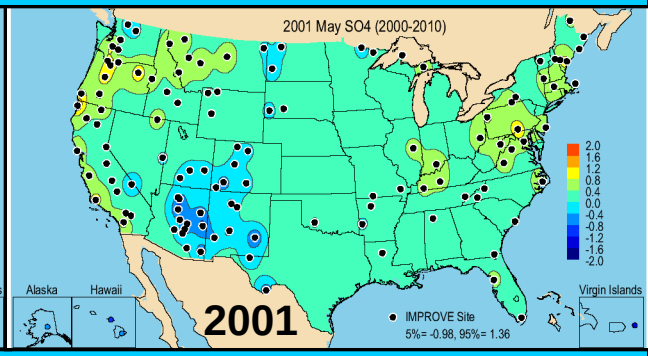
$$x' = \frac{x - \bar{x}}{s_x}$$

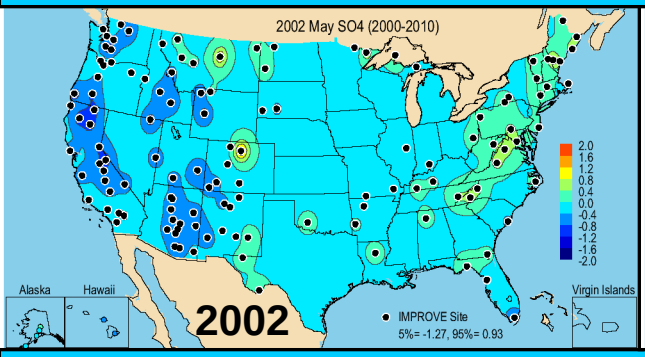
x' = standardized anomaly
x = data (monthly mean)
$\bar{x}$ = climatological monthly mean
s_x= climatological standard deviation

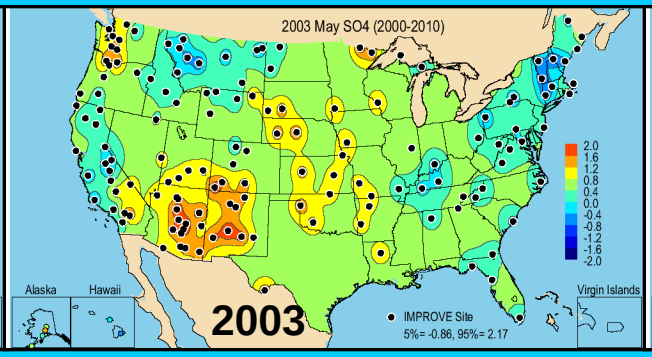
- Removes influences of location and spread
- x'= 0 for mean, x'=1 for 1 standard deviation

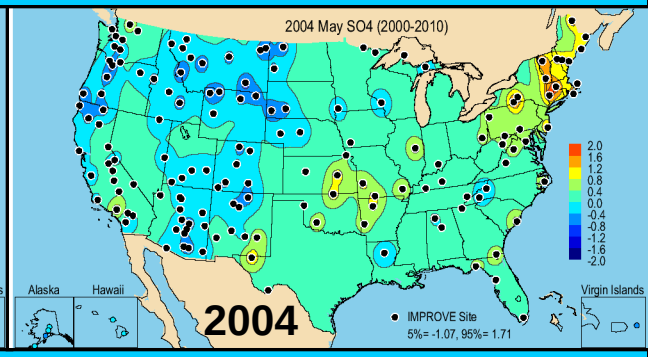
Sulfate 2000-2010 Standardized Anomaly for May

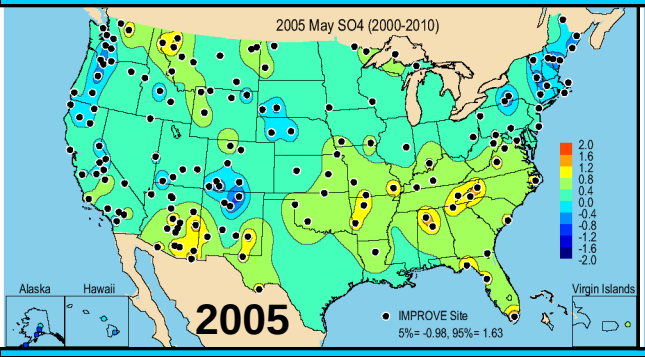


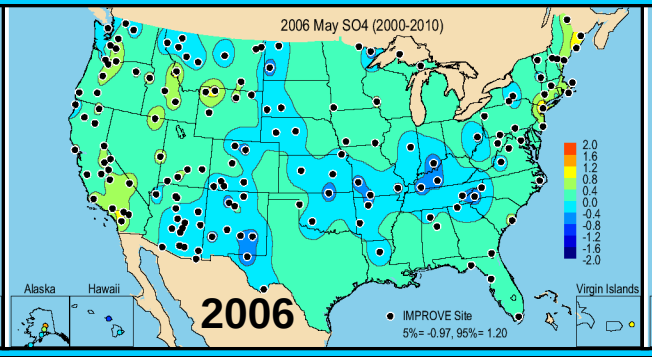


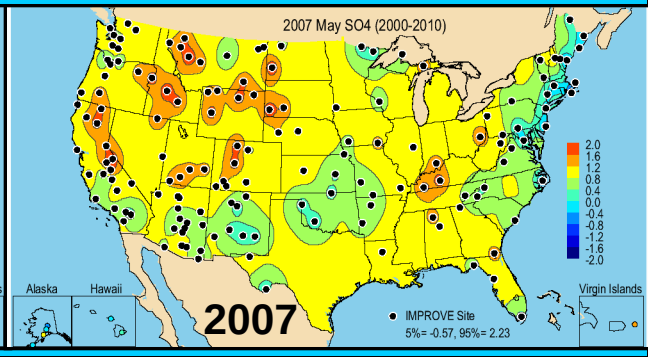


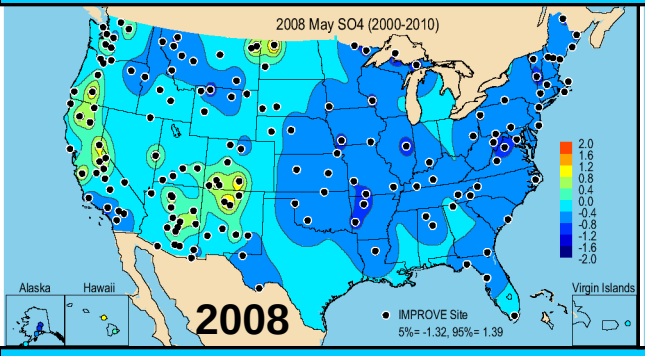


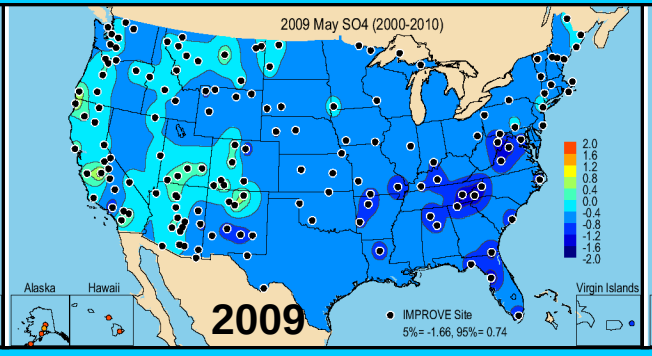


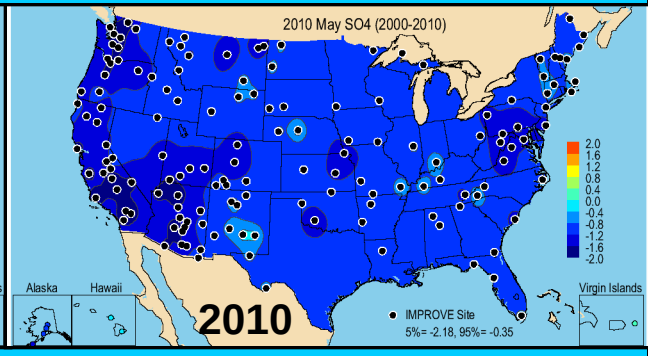




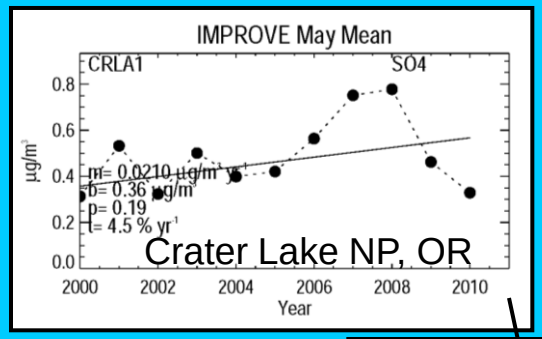


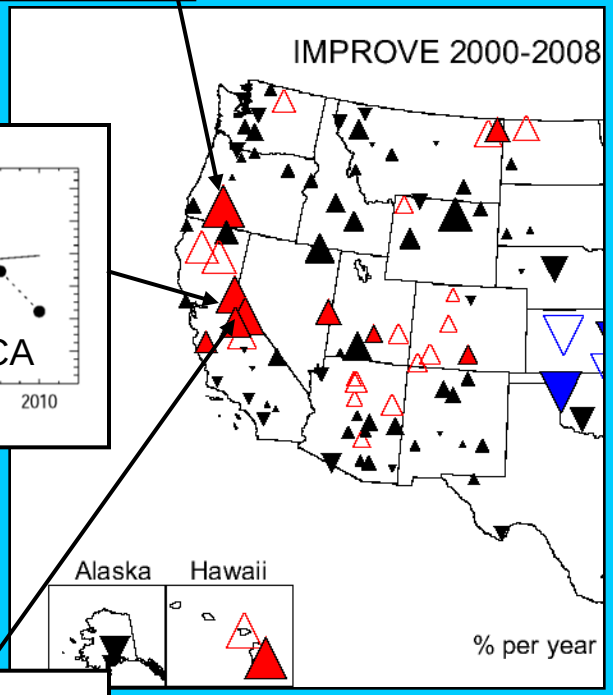


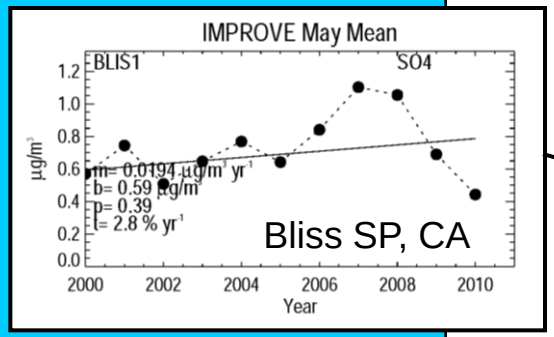


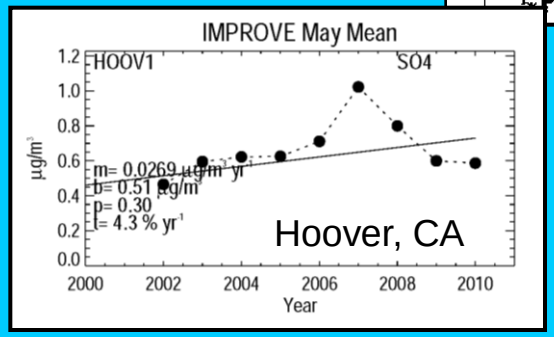


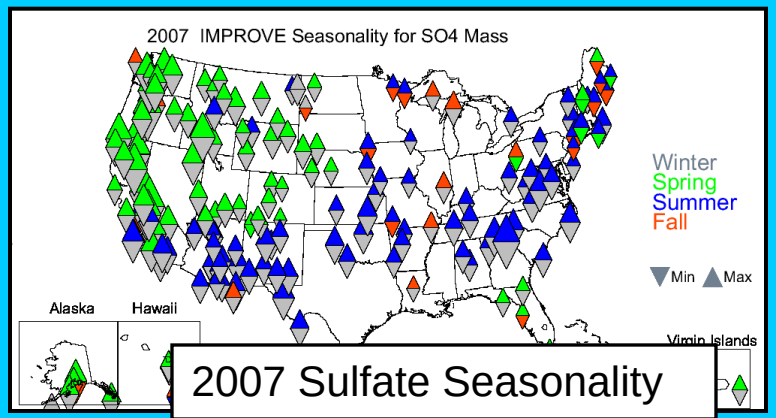
May Sulfate Patterns

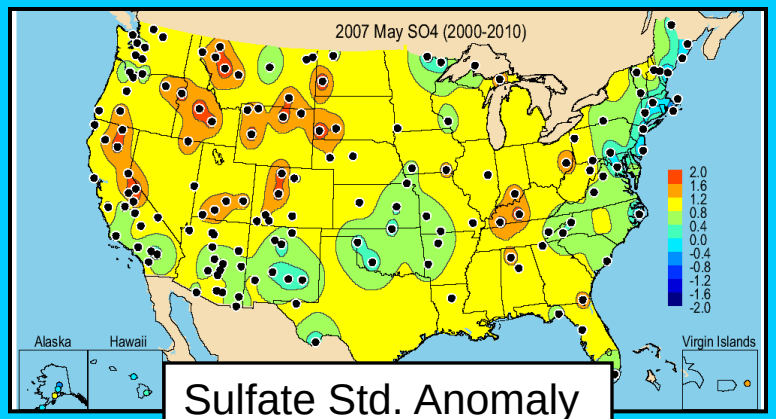


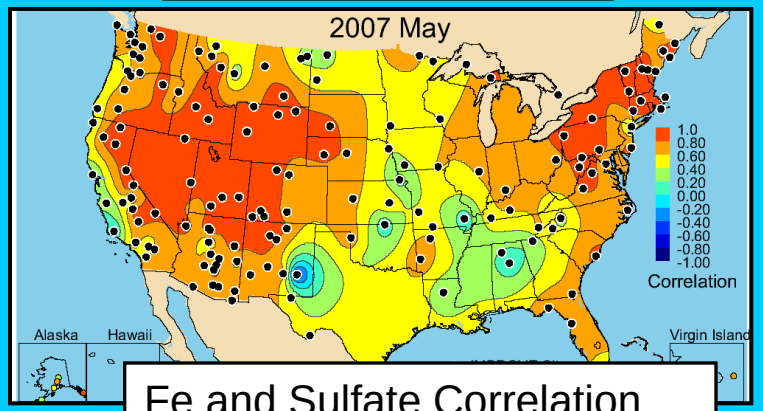




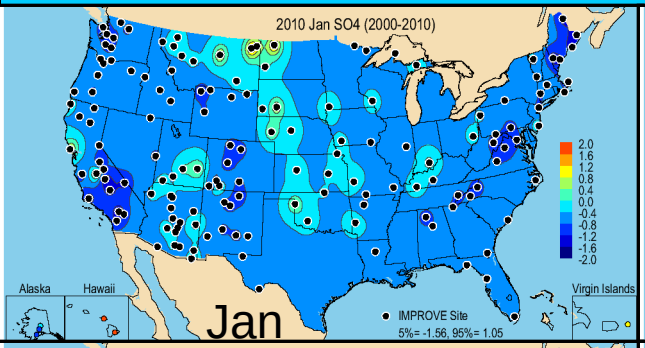


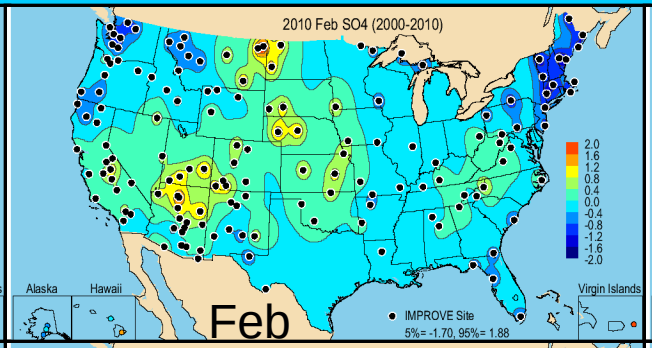


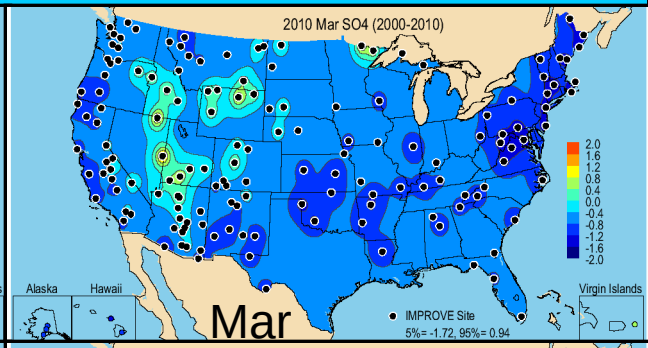


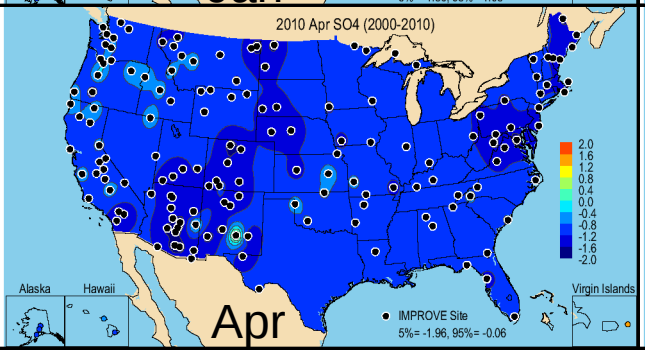


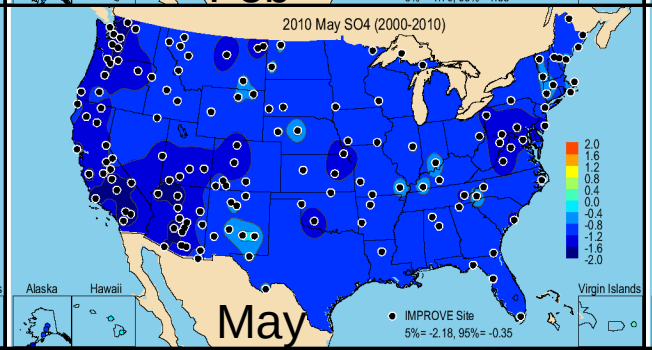
2010 Sulfate concentrations are significantly low

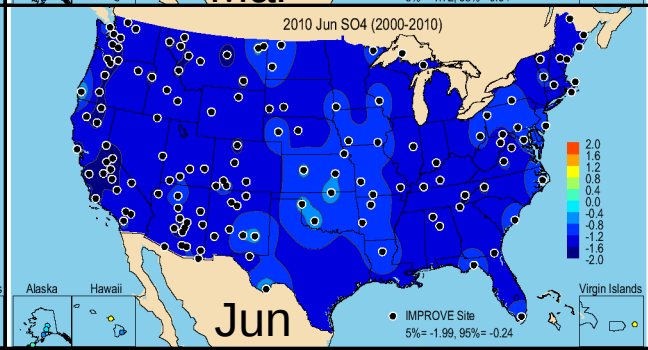


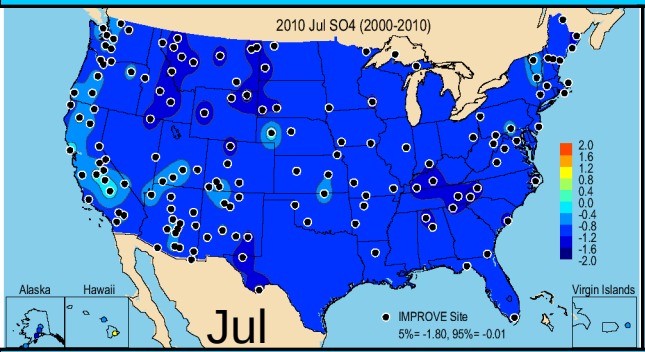


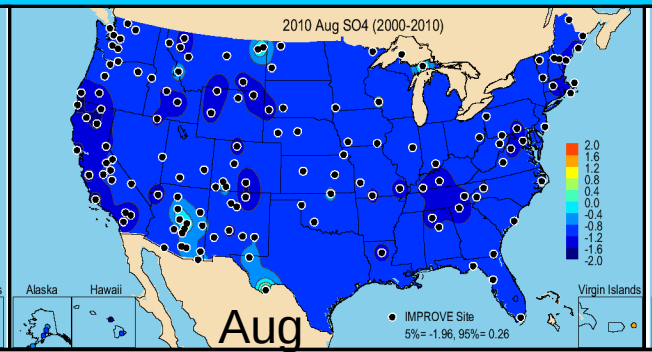


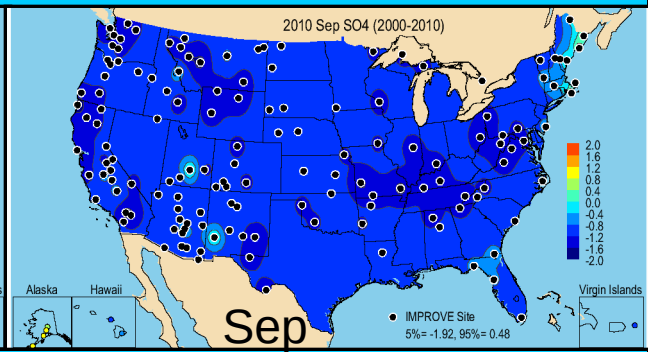


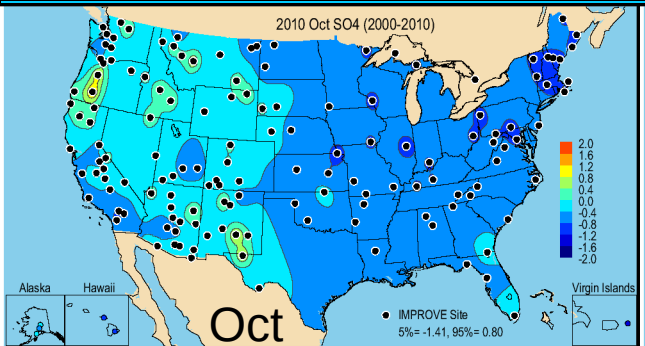


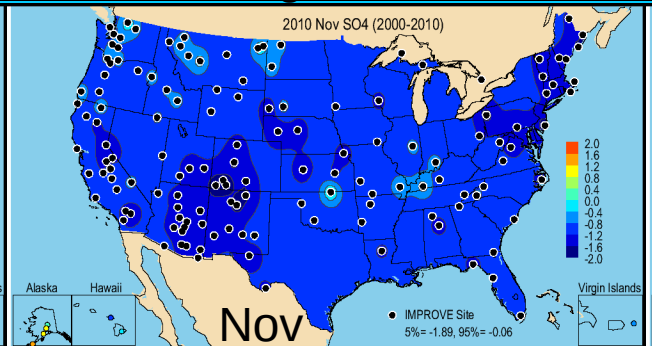


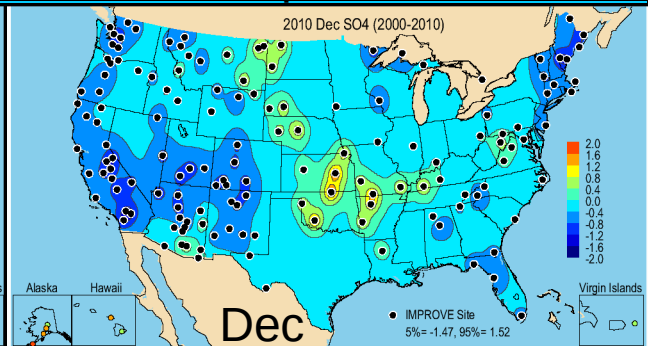




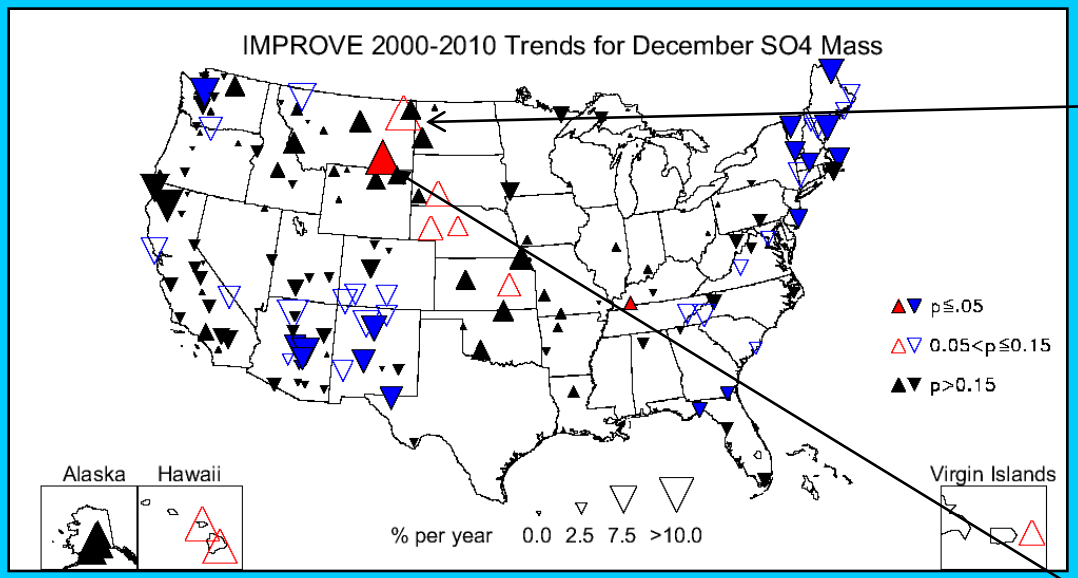


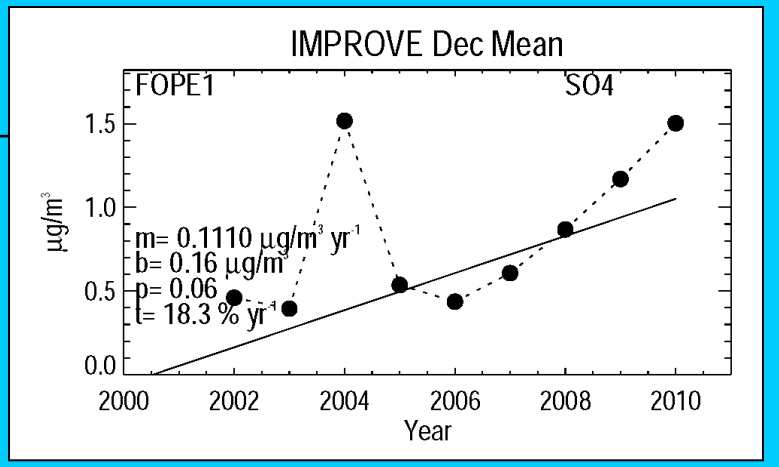




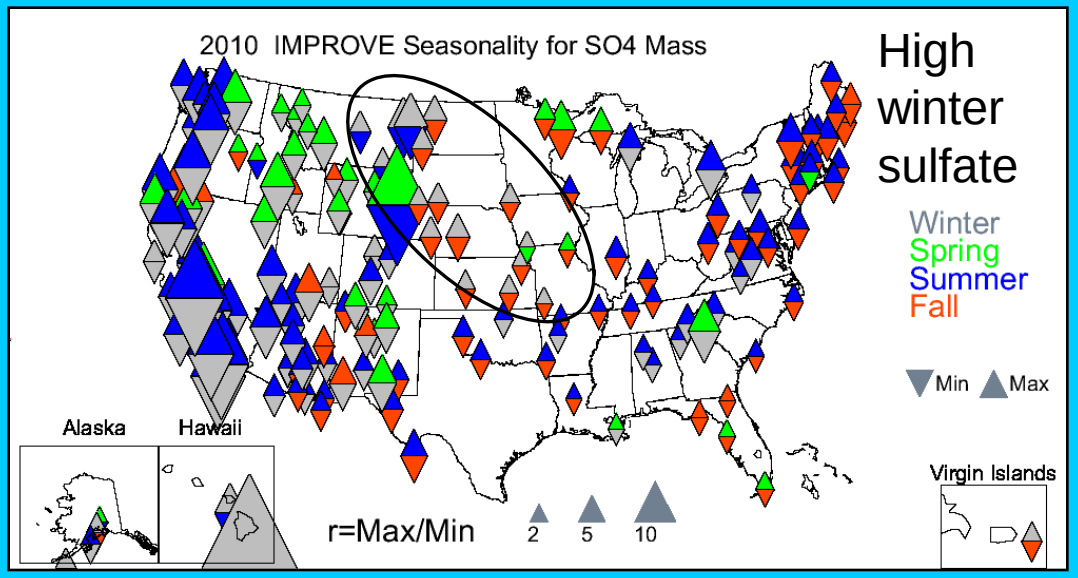


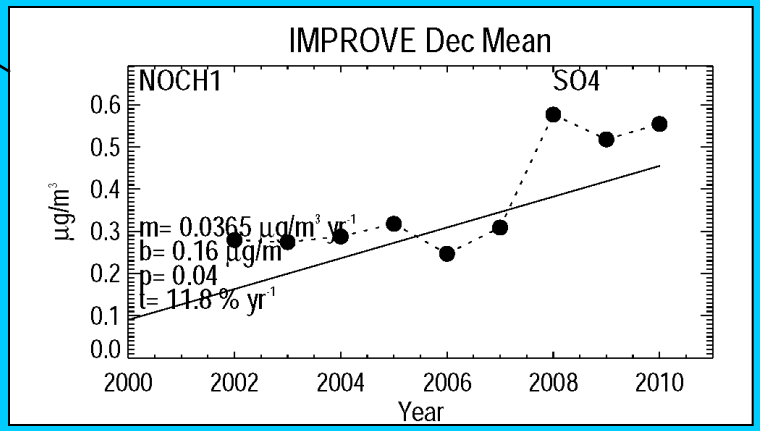
Winter Sulfate in the Midwest





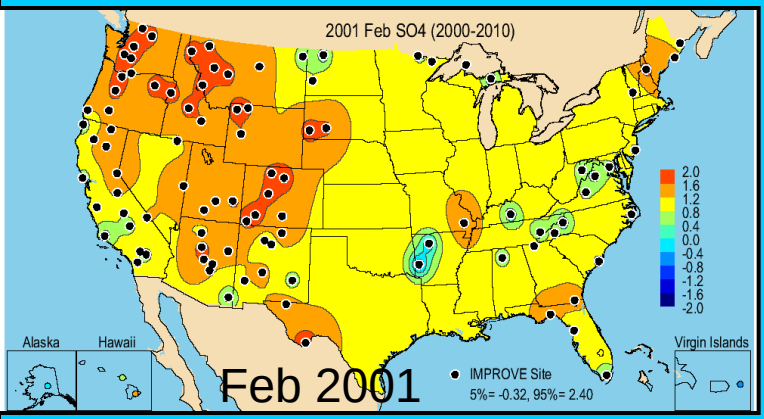
Fort Peck, MT

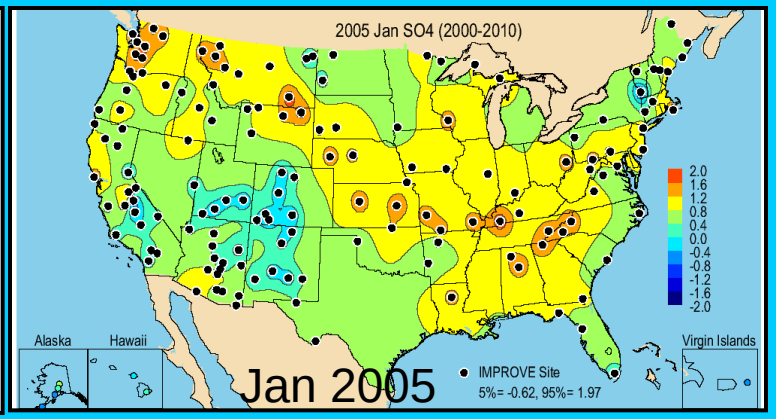


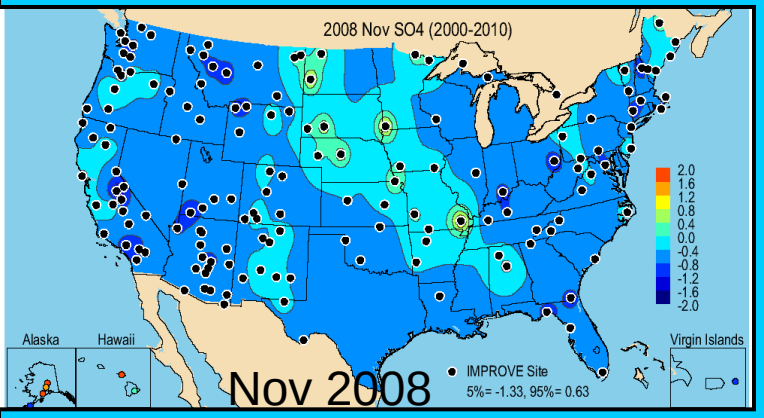


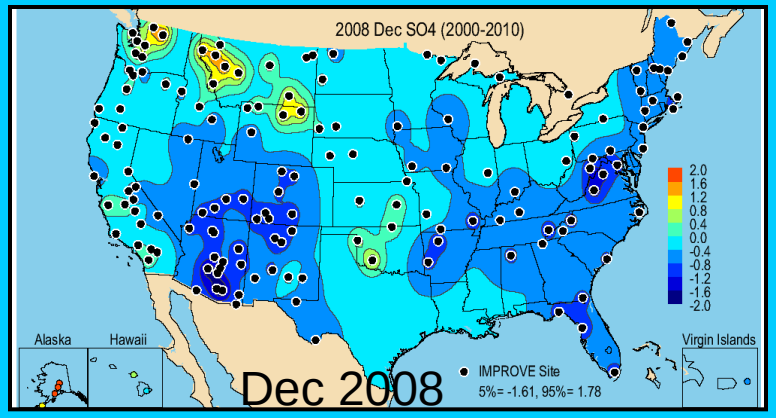
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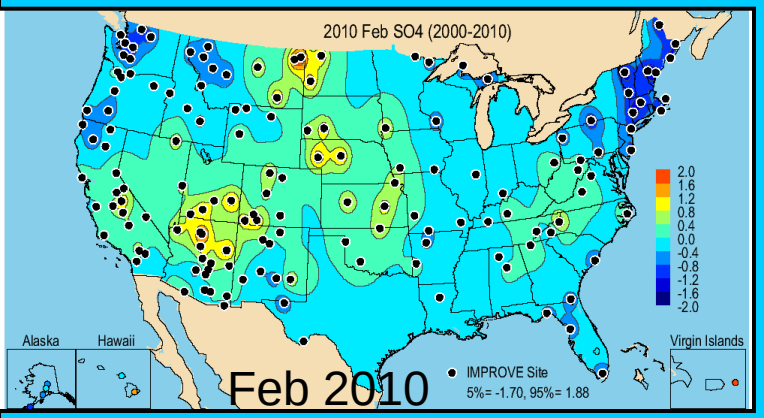
Winter Sulfate Standardized Anomalies

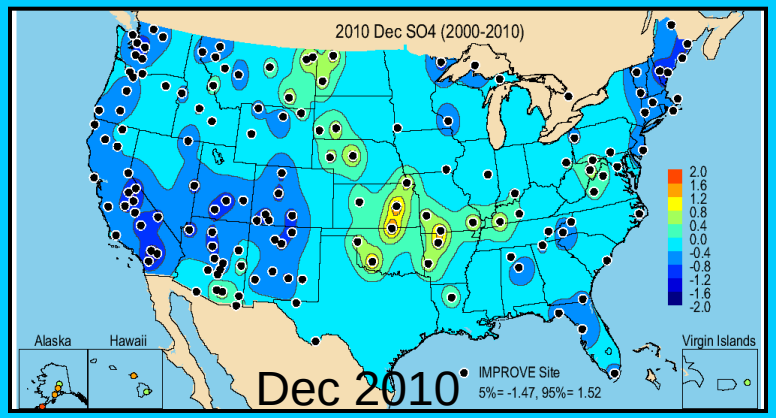








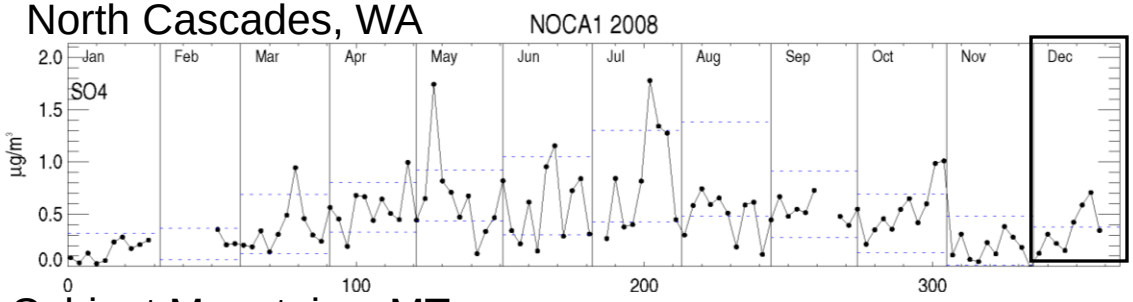




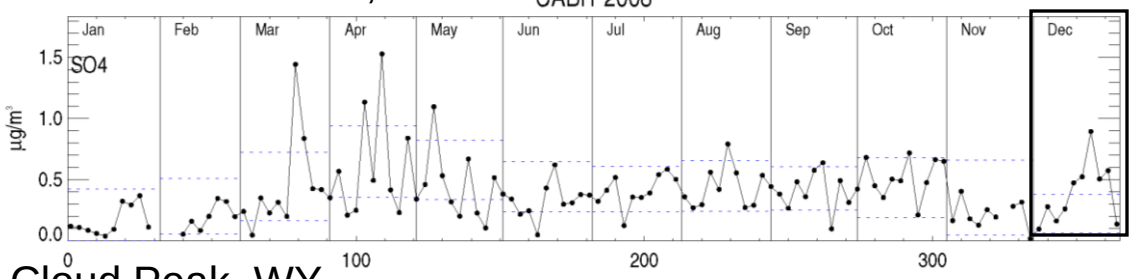
Examples of other periods with Midwestern winter episodes

December 2008

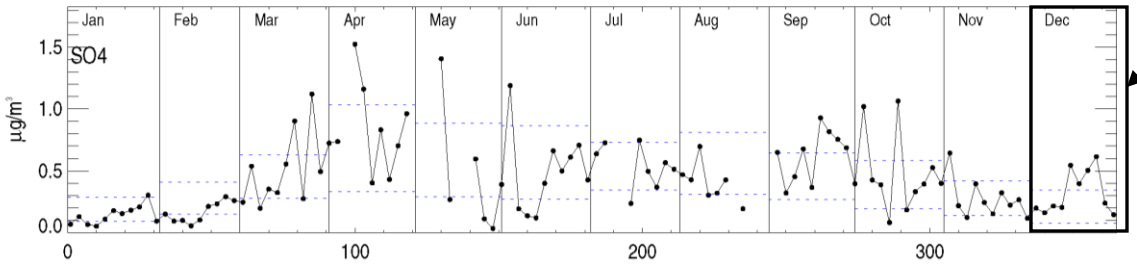
North Cascades, WA



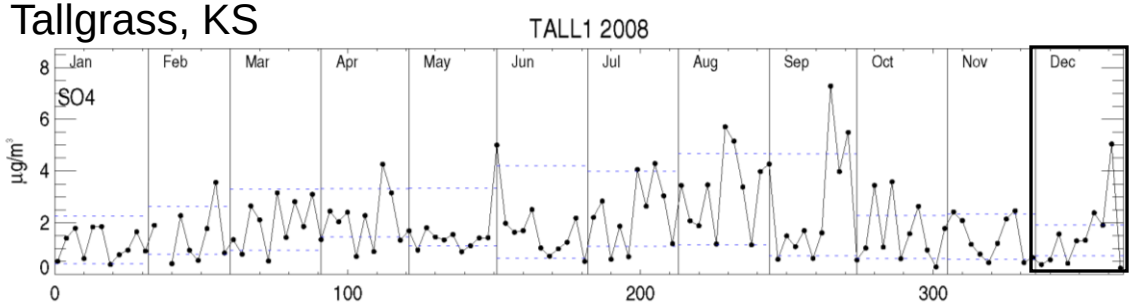
Cabinet Mountains, MT



Cloud Peak, WY

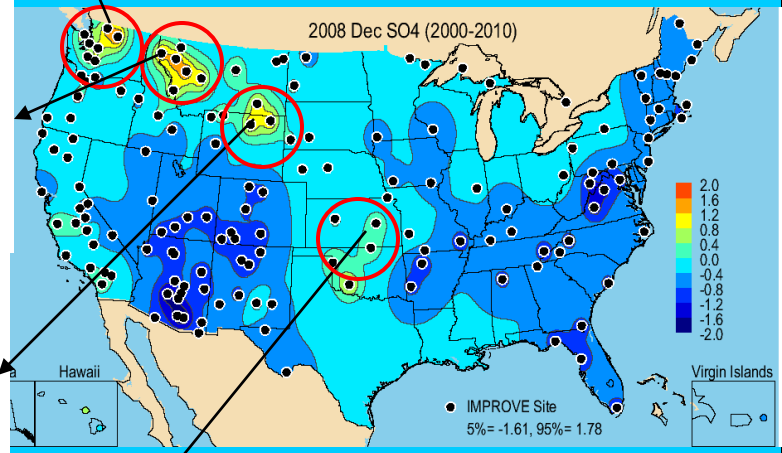


Tallgrass, KS

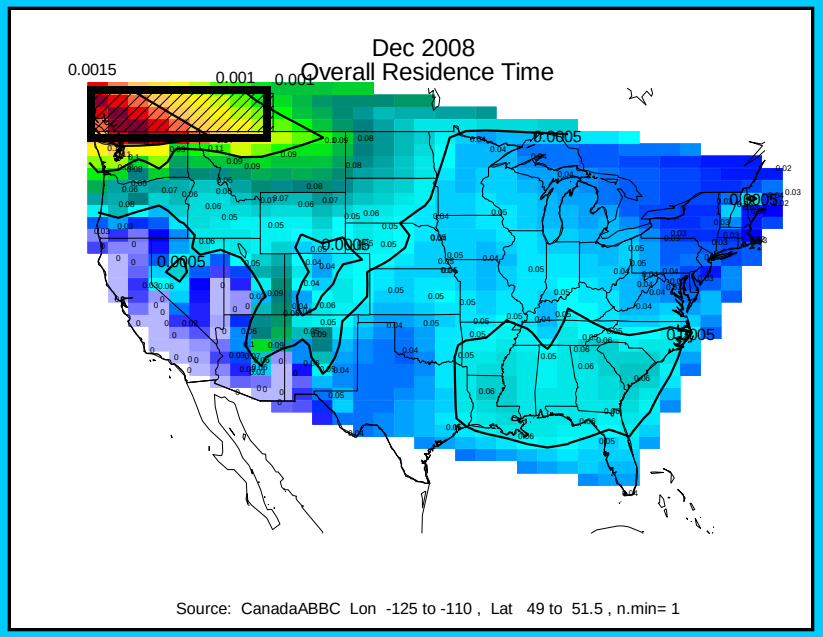


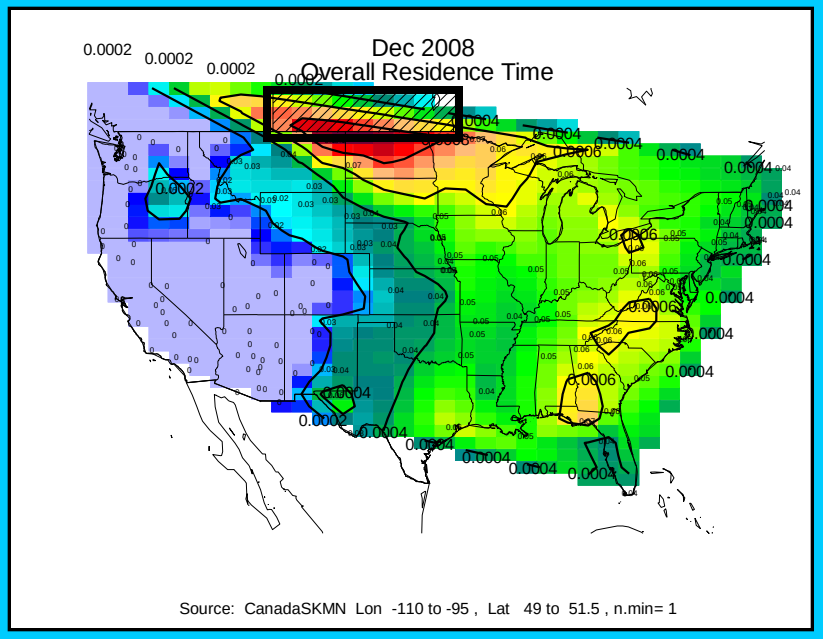
2008 Sulfate 24-hr concentrations

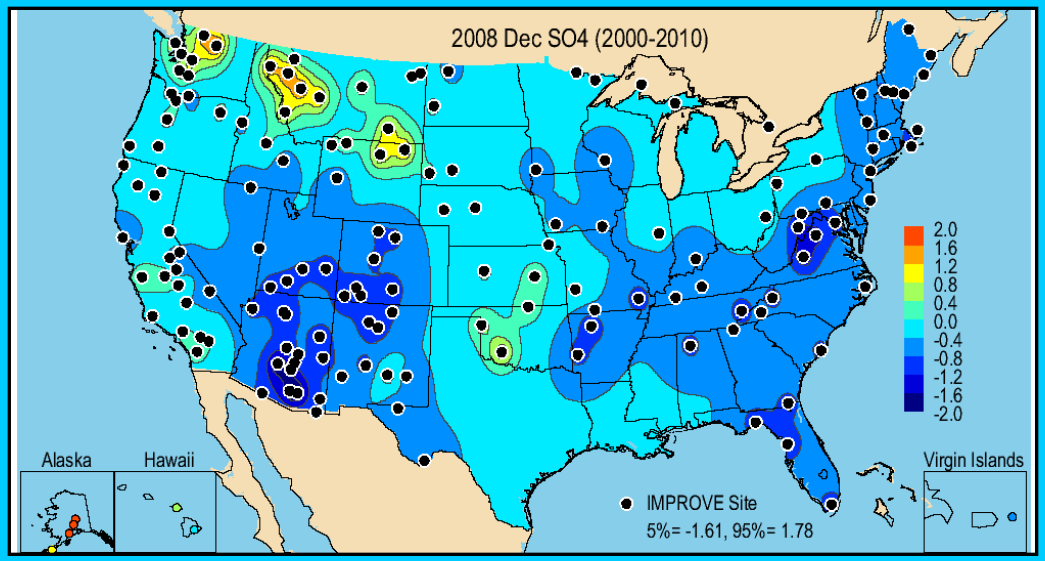
Sulfate Standardized Anomaly



ATAD Back trajectories



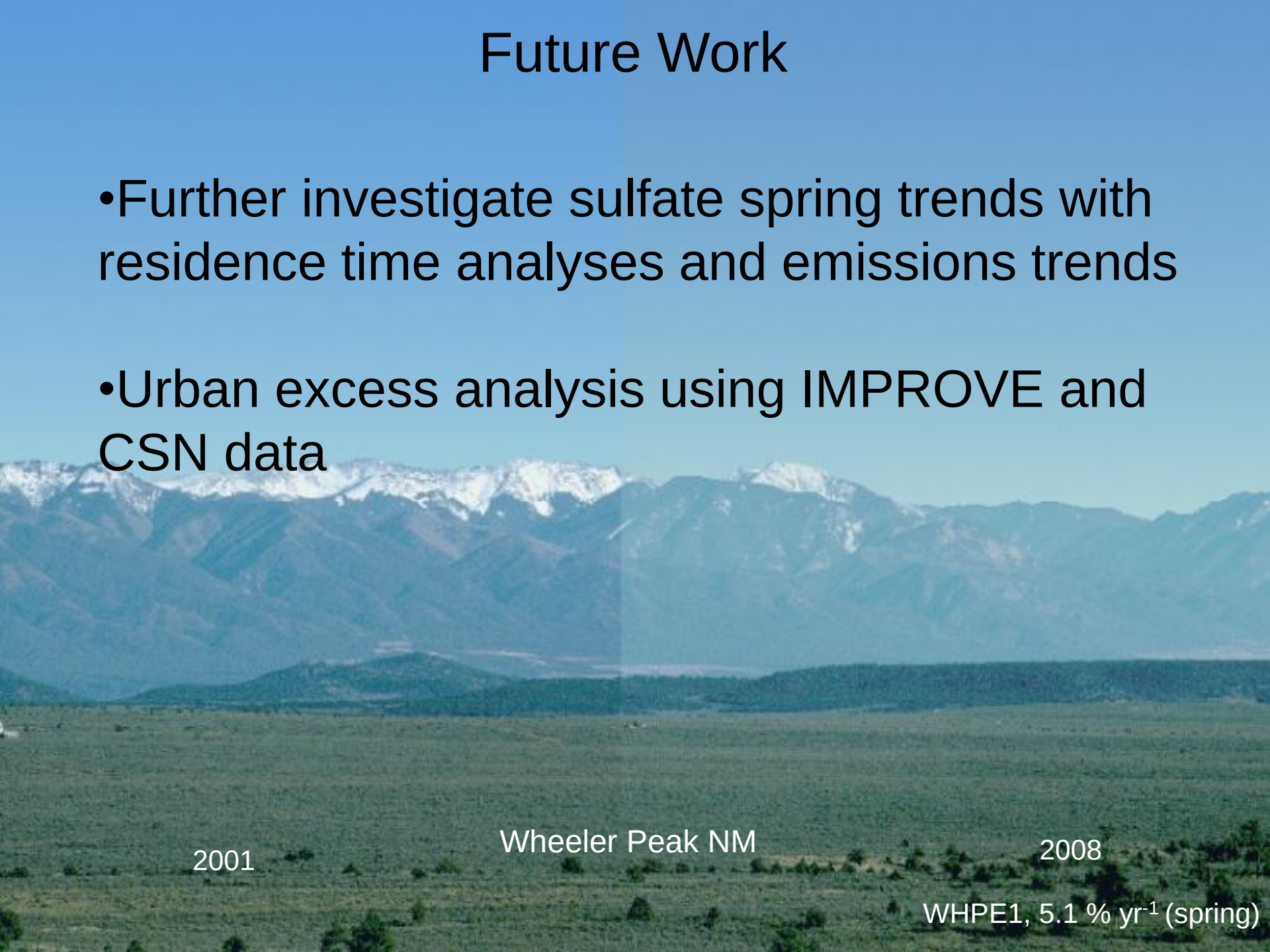




Future Work

- Further investigate sulfate spring trends with residence time analyses and emissions trends

- Urban excess analysis using IMPROVE and CSN data



Acknowledgements

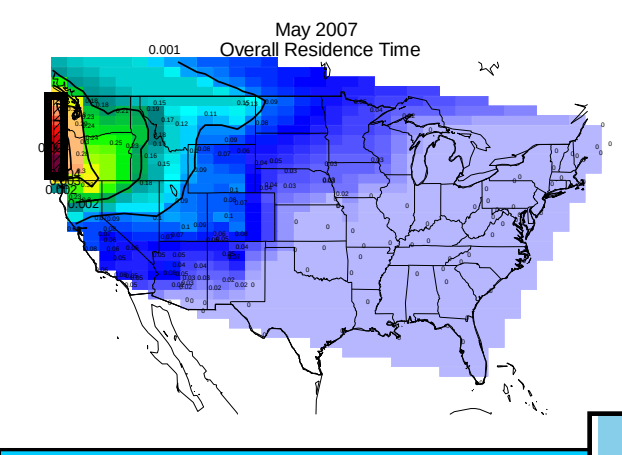
National Park Service

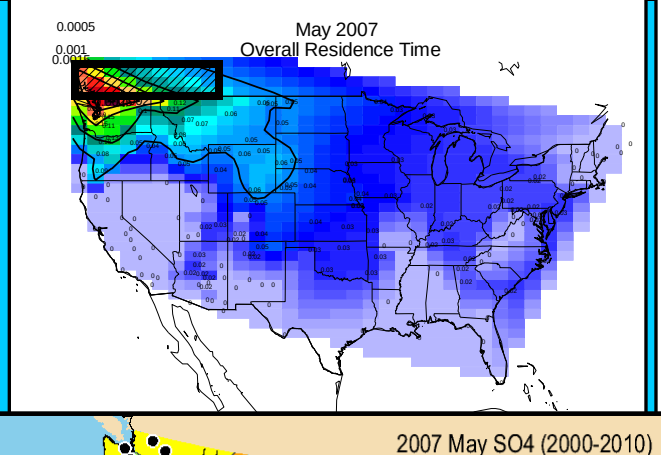
IMPROVE

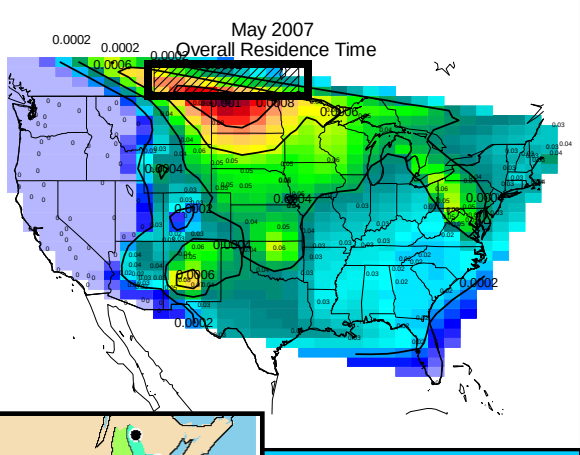
Visibility simulations performed with WinHaze version 2.9.9

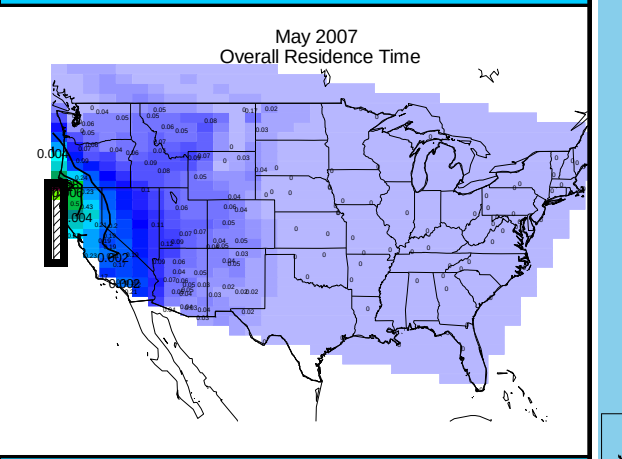
(www.air-resource.com/resources/downloads.html)

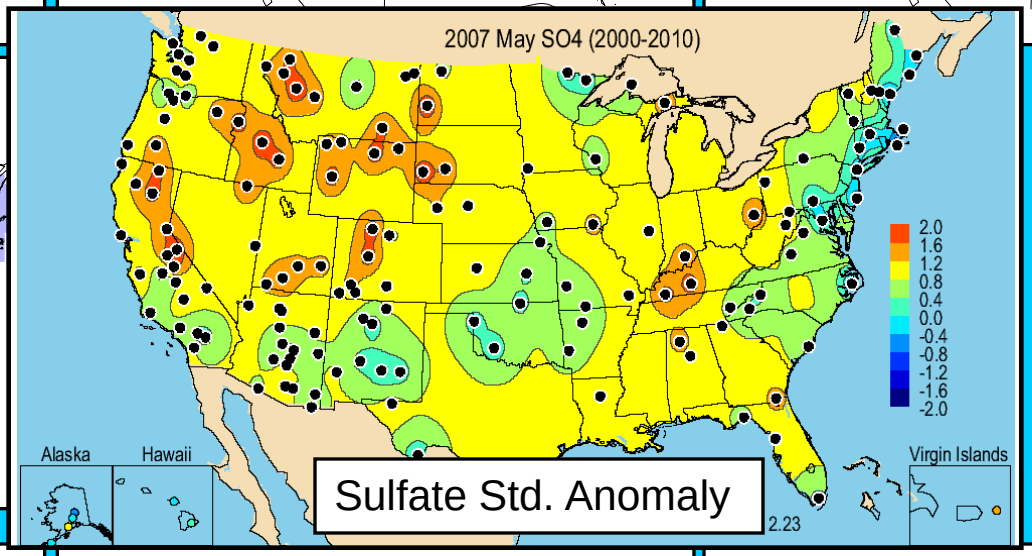
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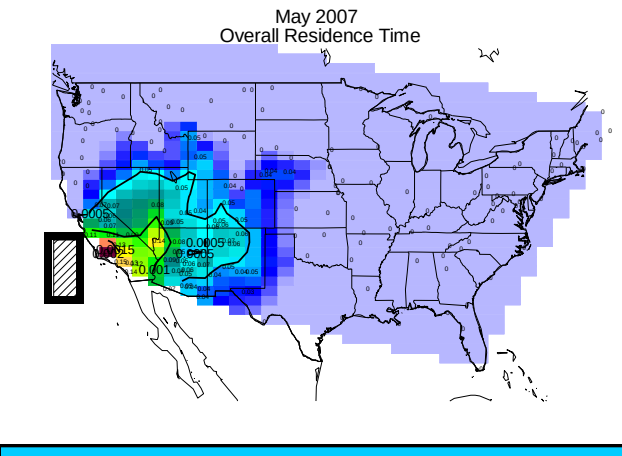


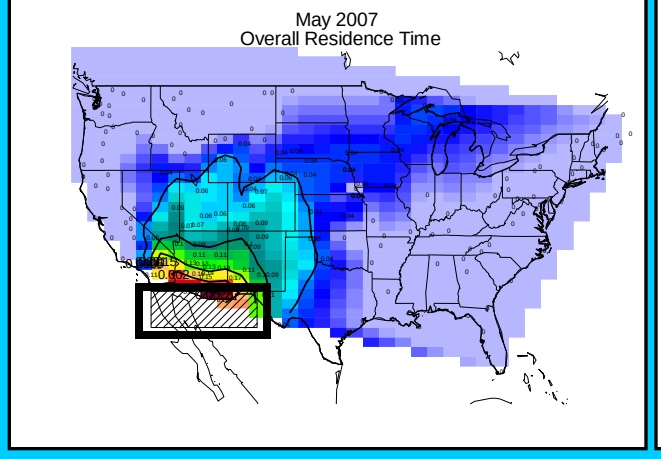


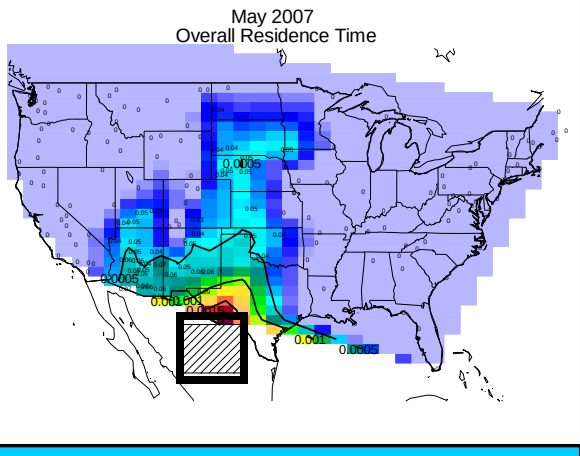




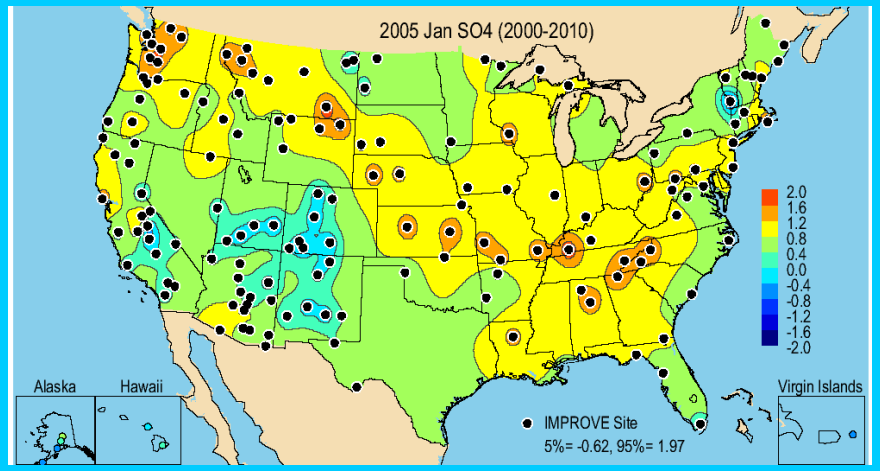
May 2007
ATAD back
trajectories

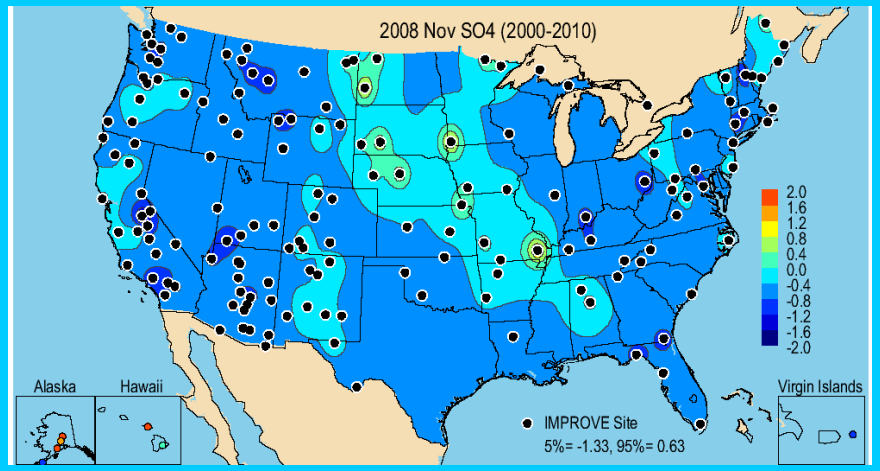


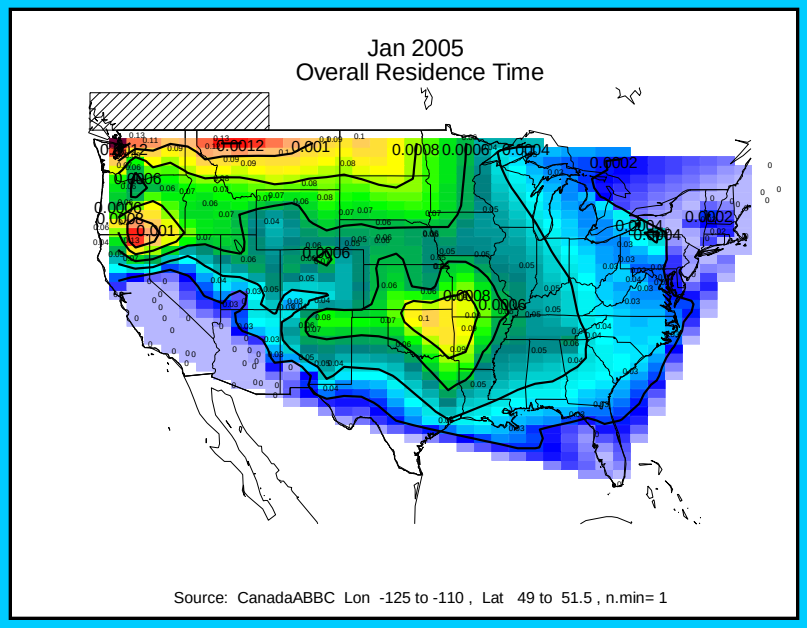


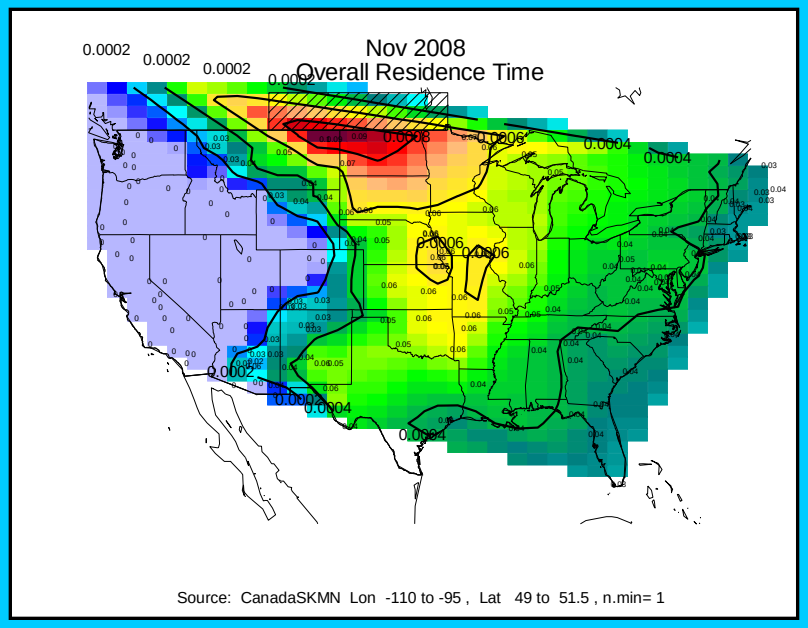


ATAD Residence Times

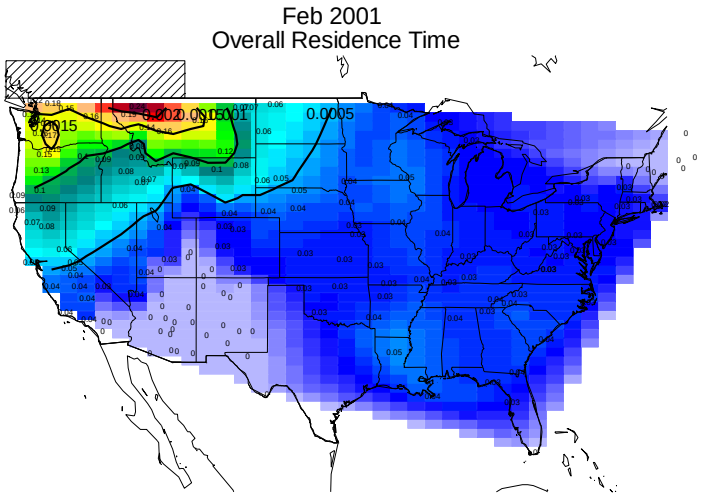




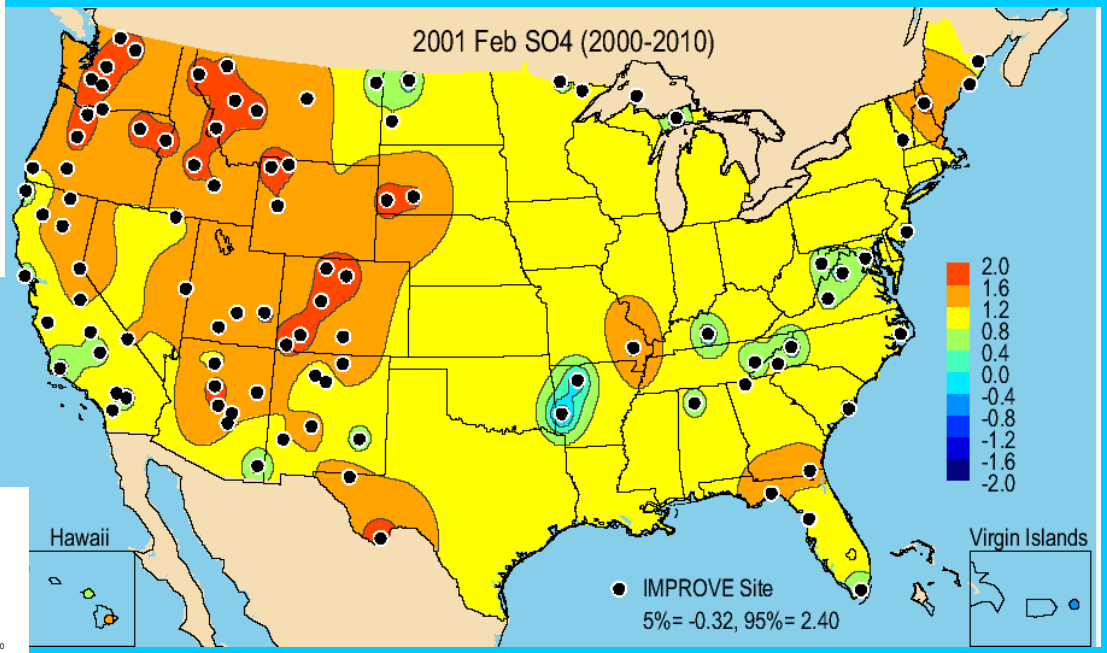


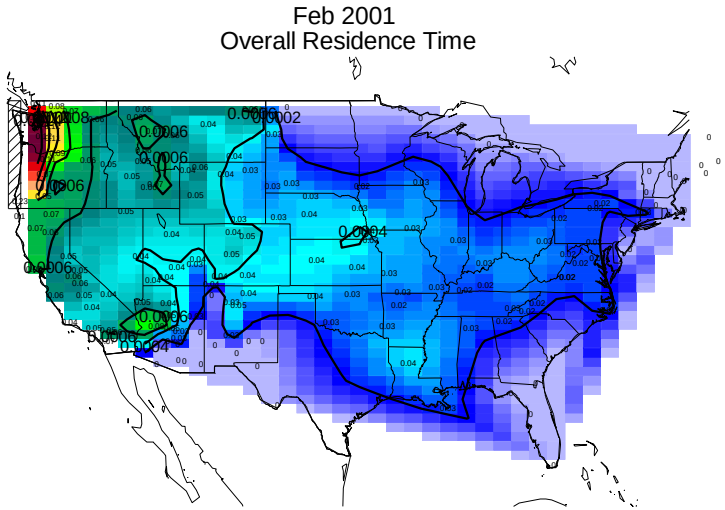


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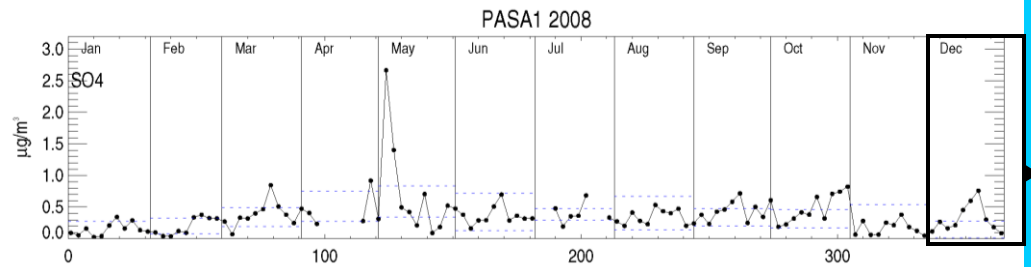


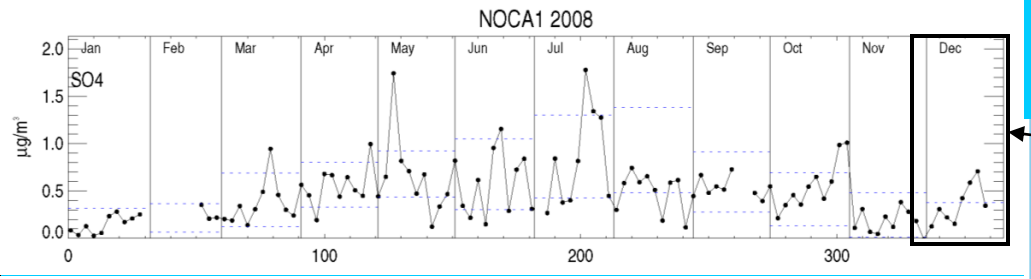
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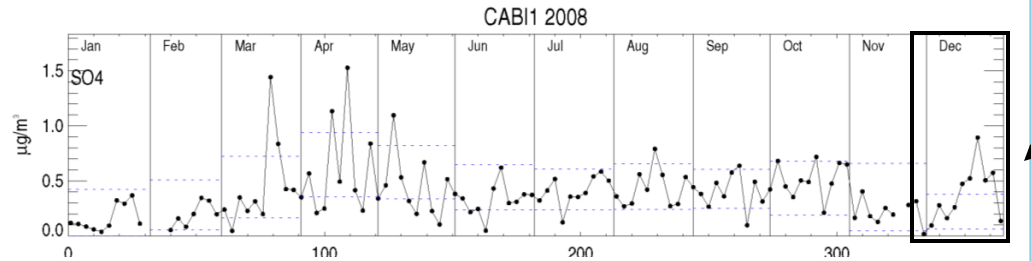


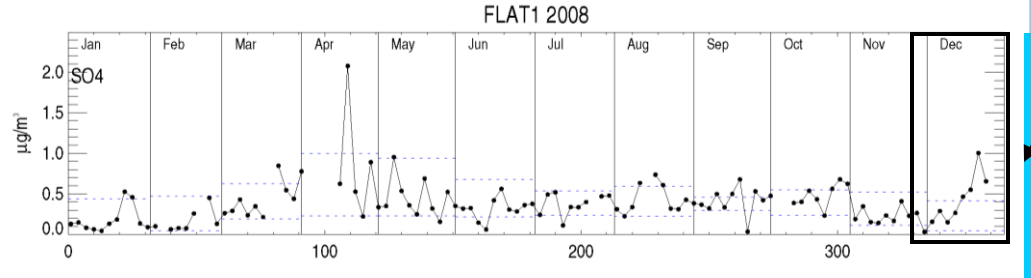


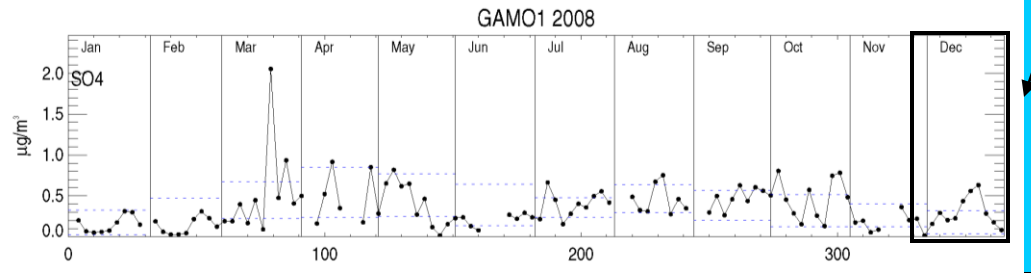
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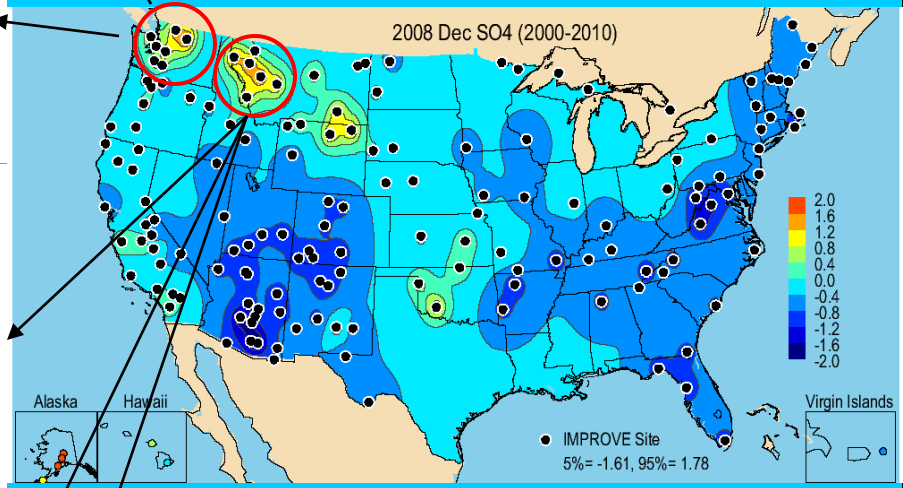


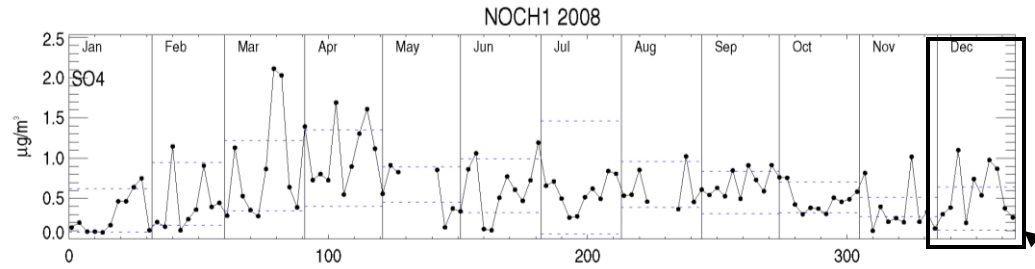


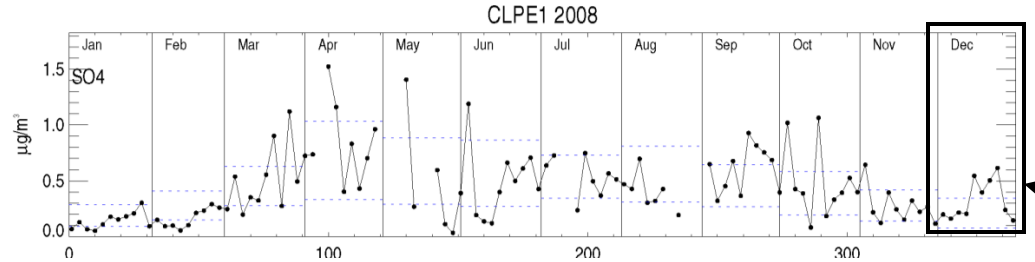


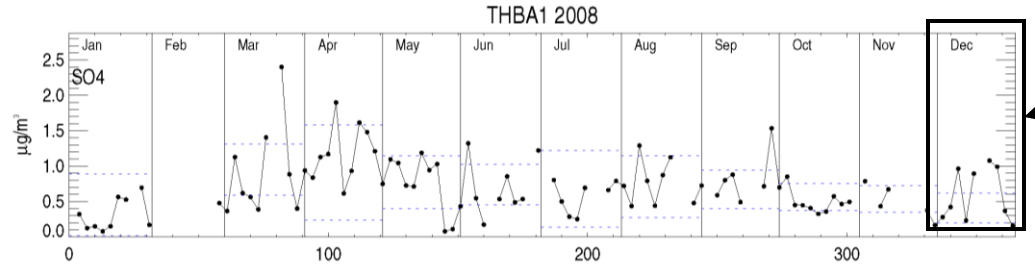


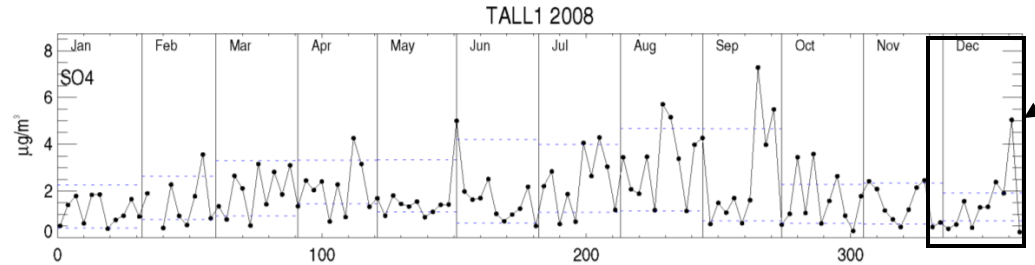
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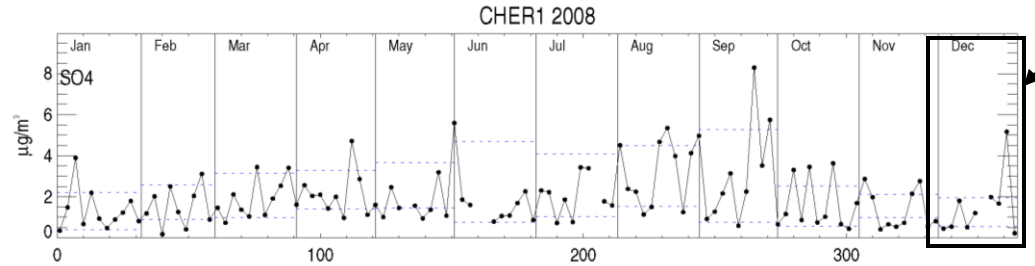




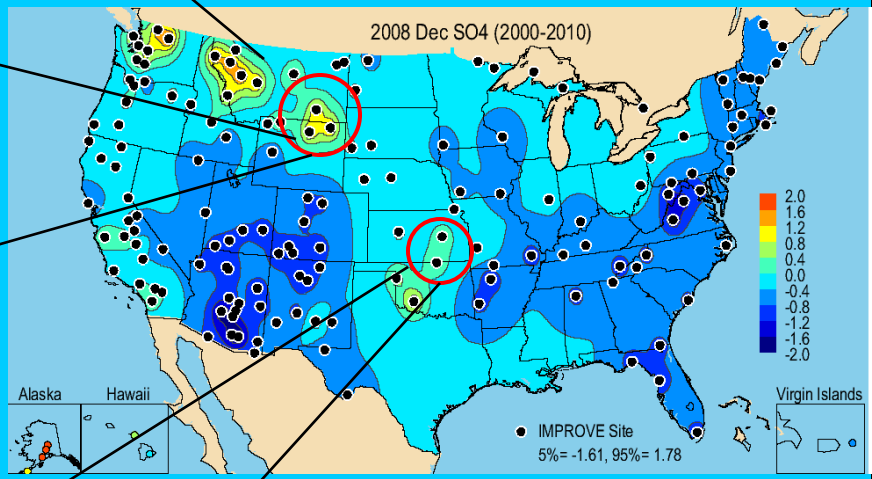




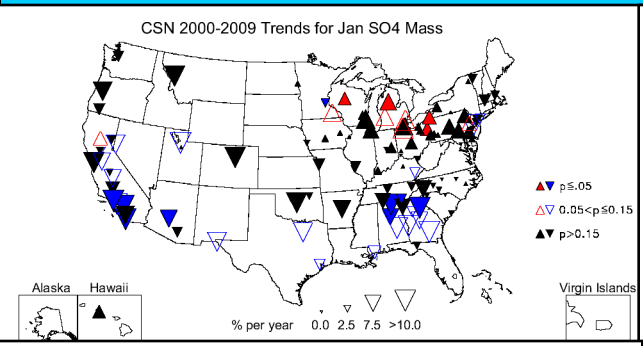


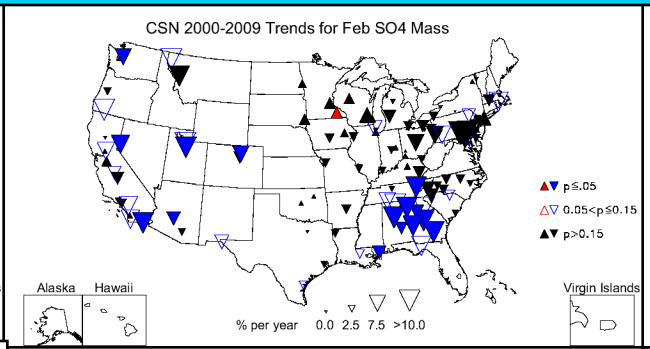


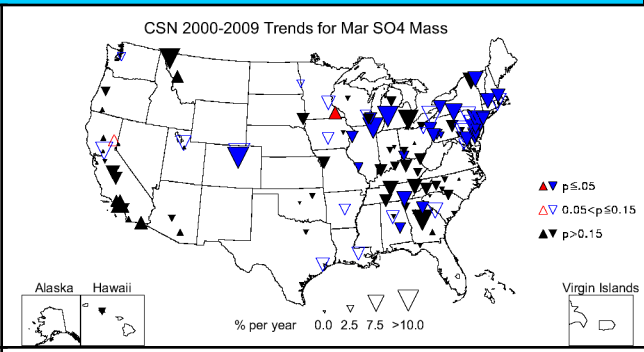
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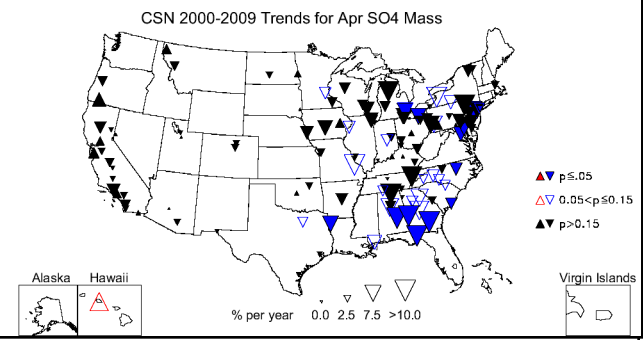


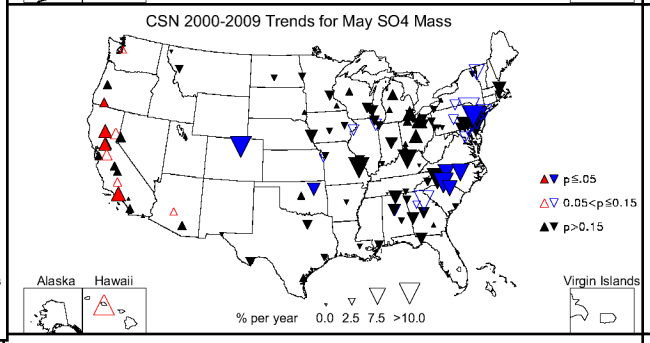
CSN 2000-2009 Monthly Mean Sulfate Trends

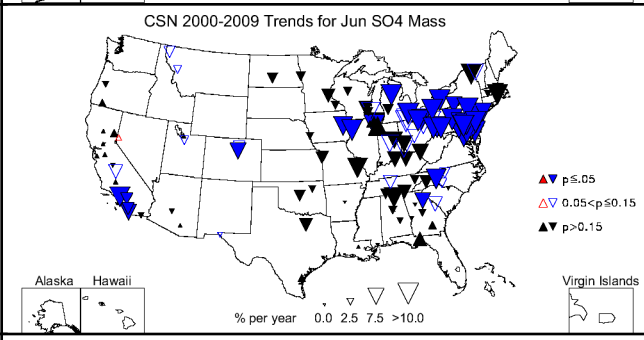


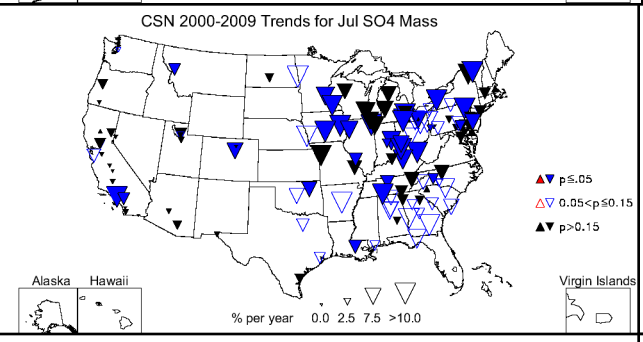


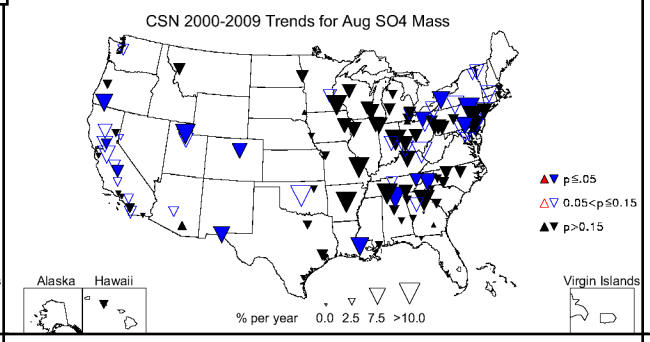


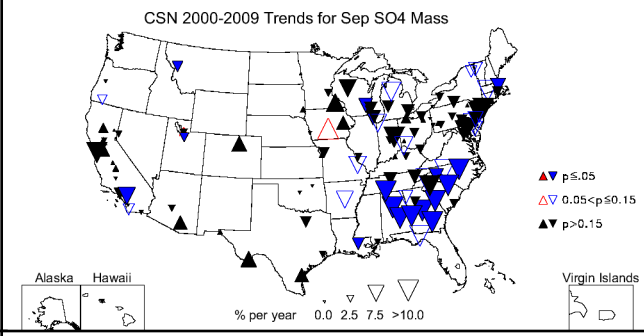


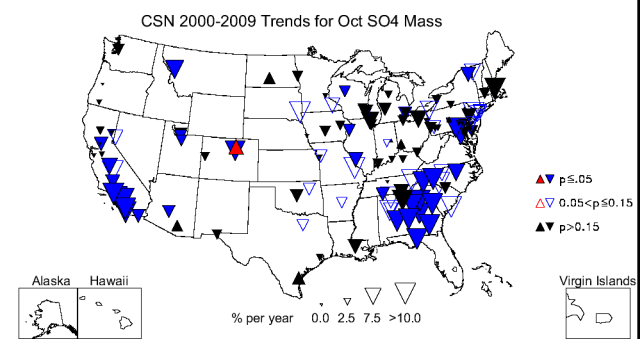


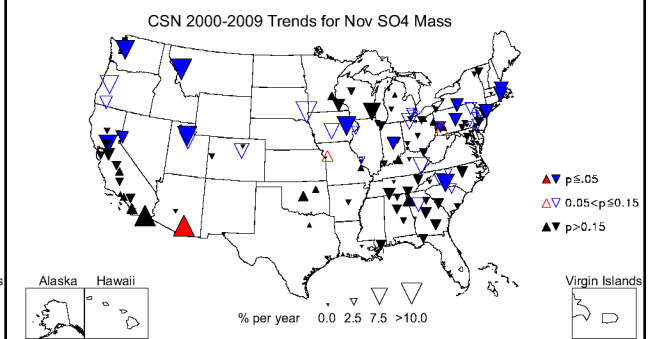


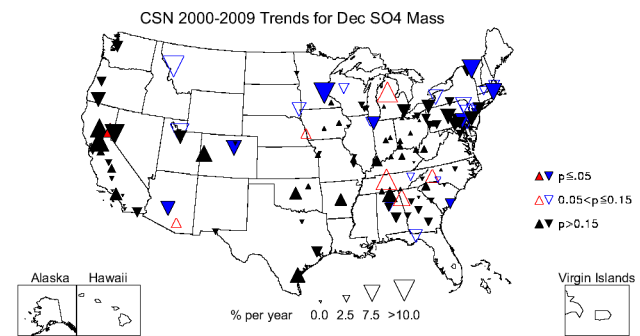


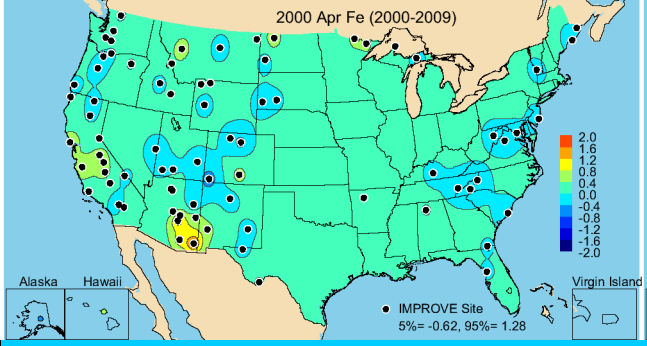


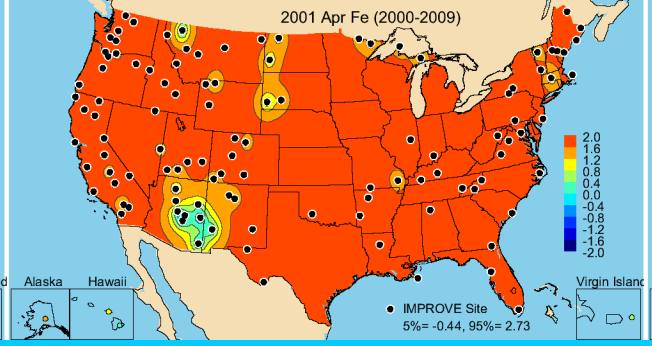


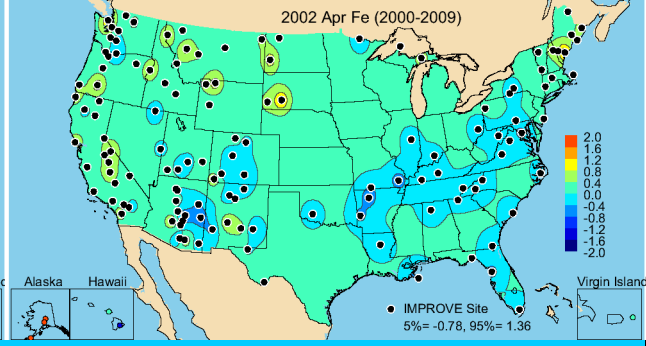


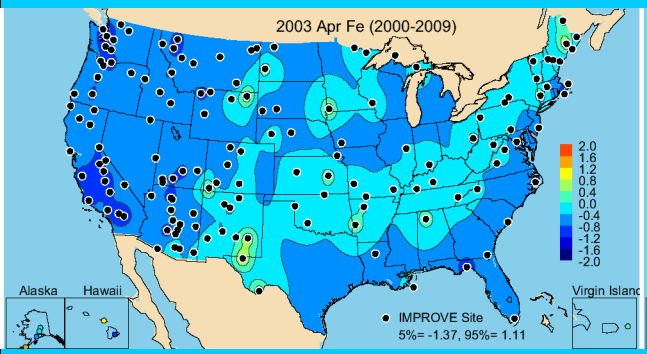


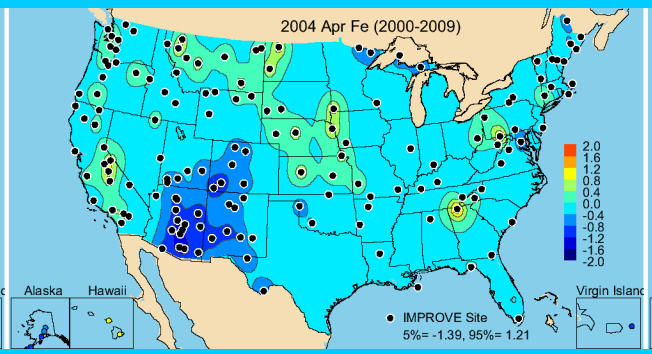


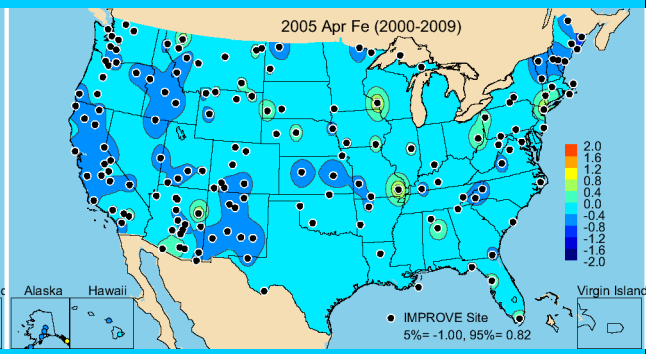


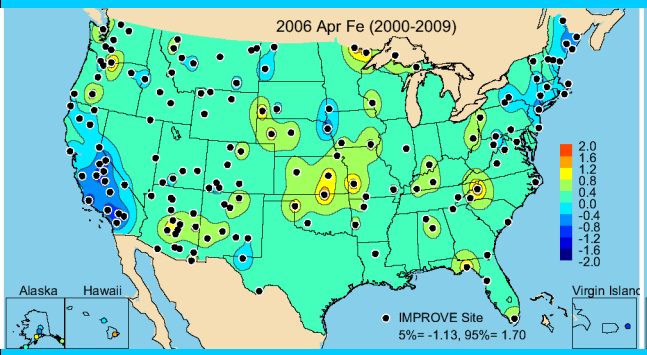


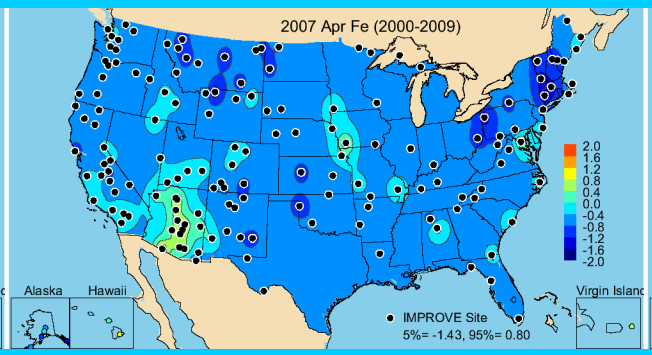


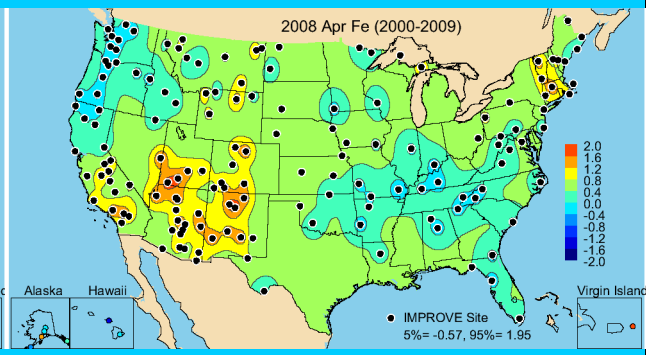


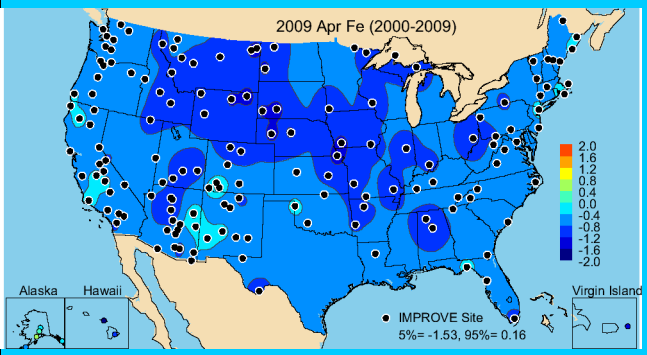




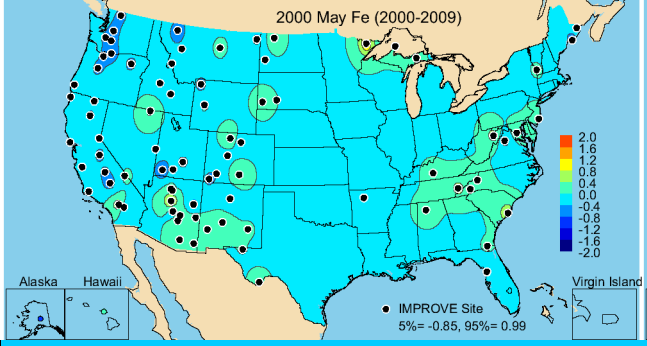


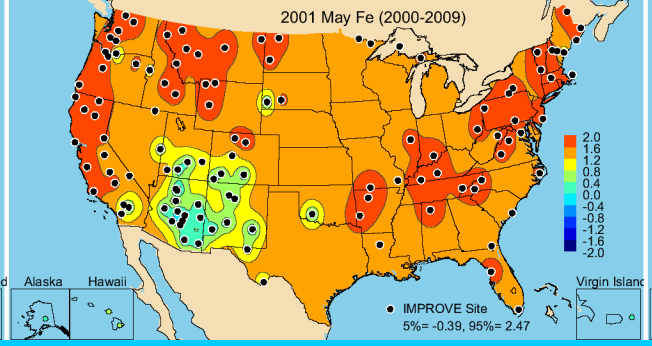


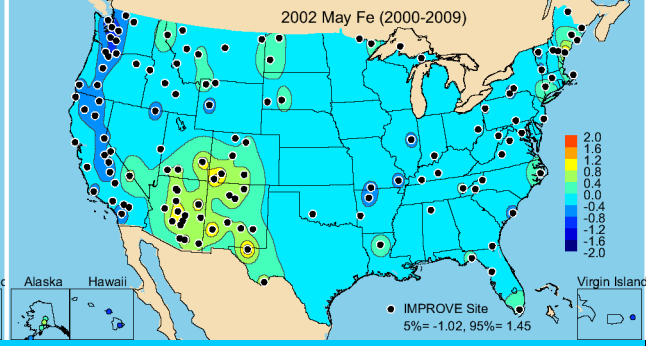


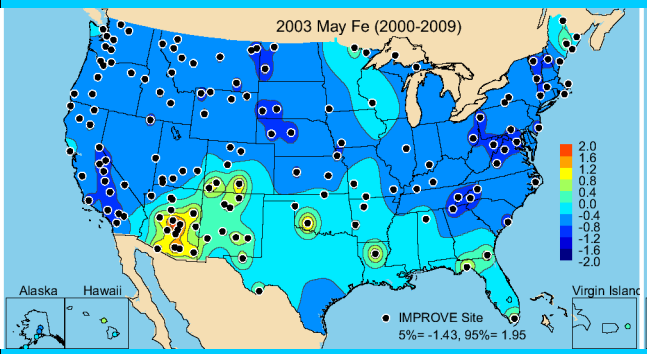


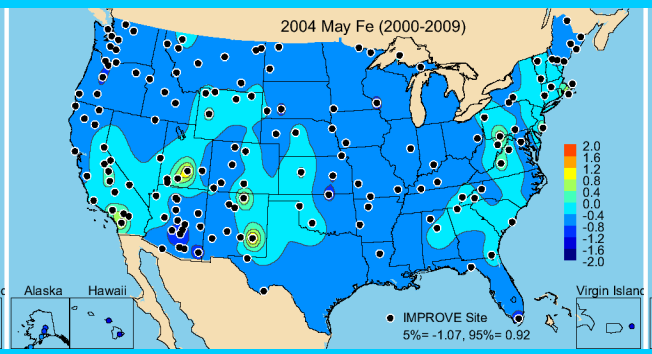
Iron Standardized Anomaly- April

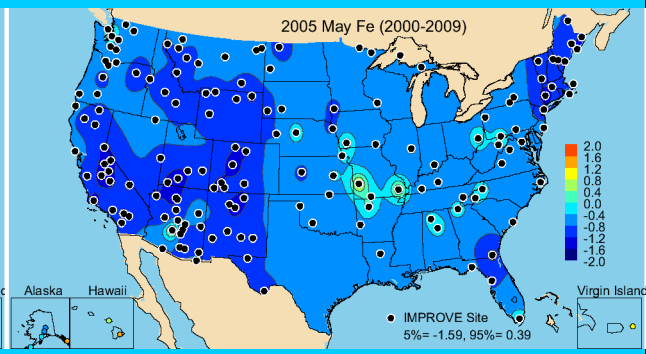


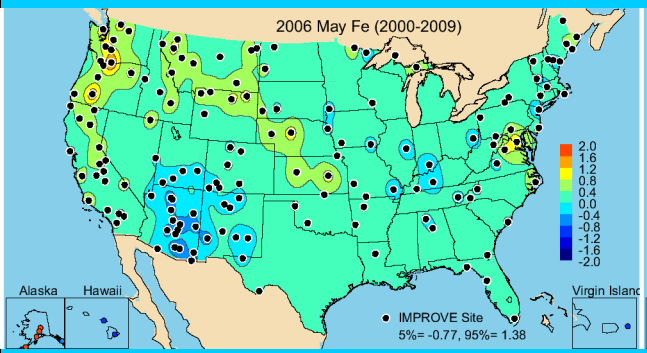


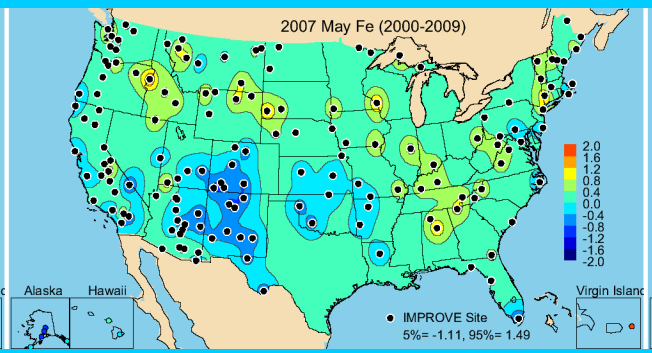


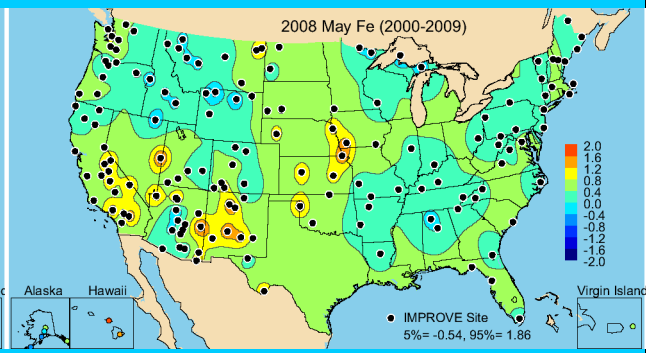


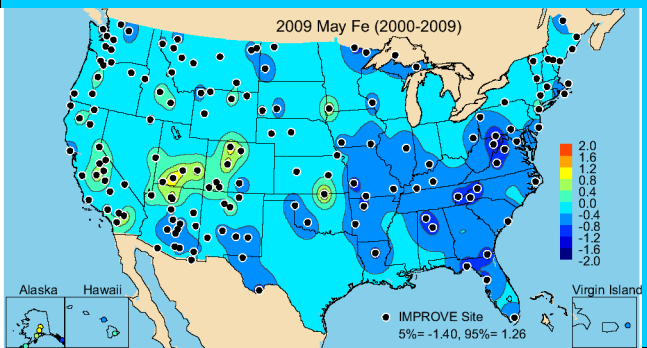




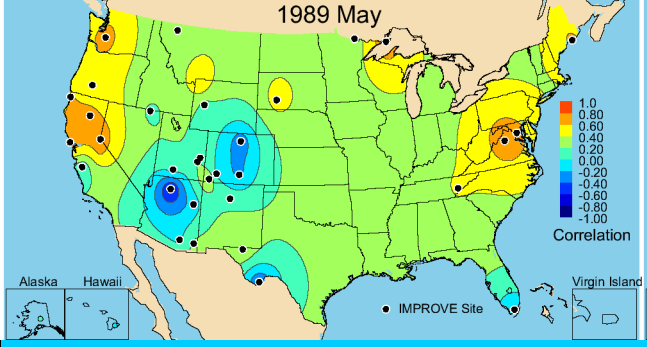


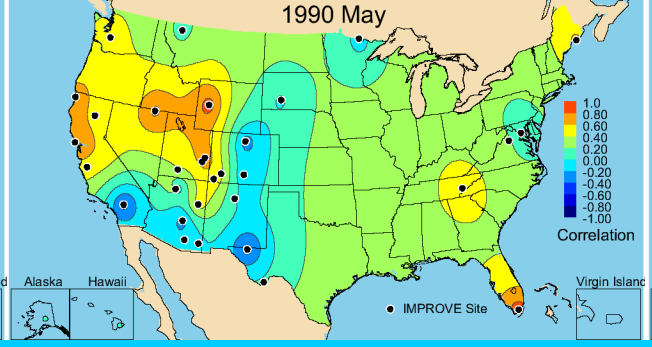


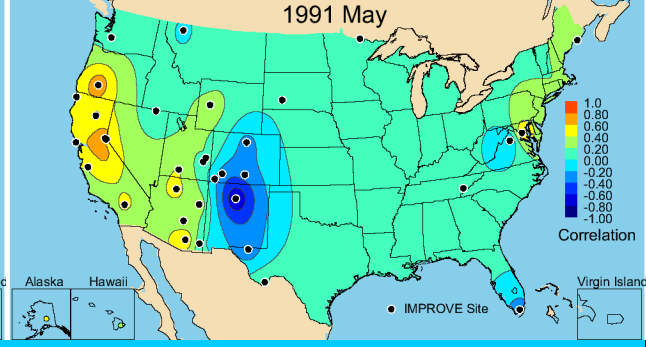


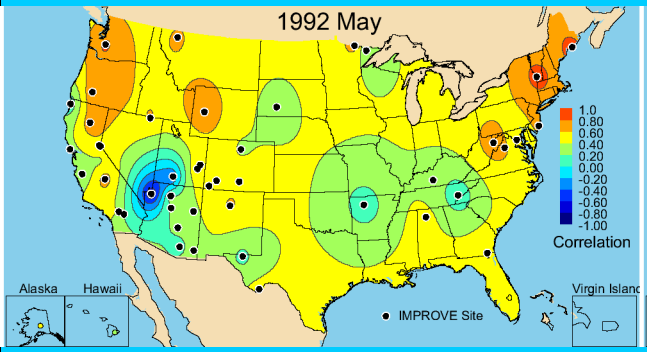


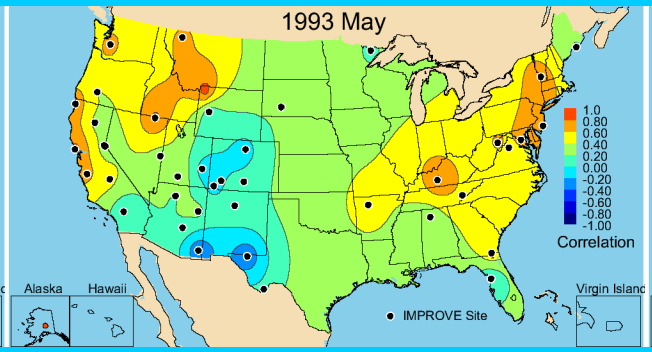
Iron Standardized Anomaly- May

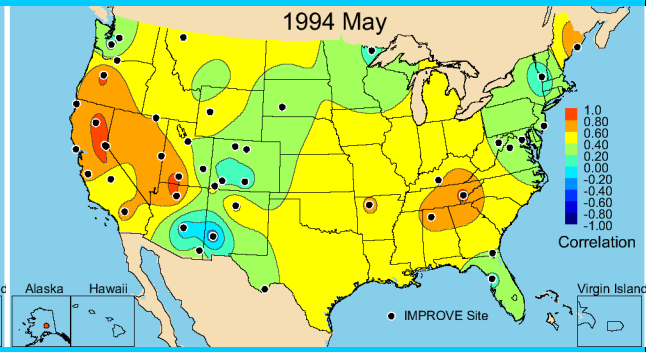


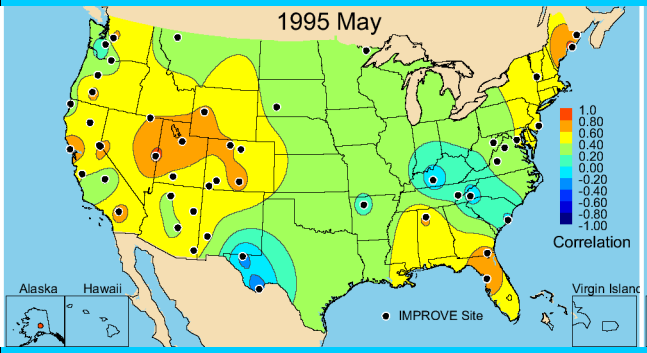


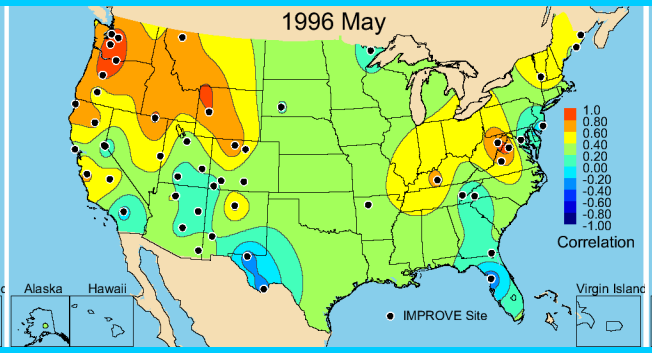


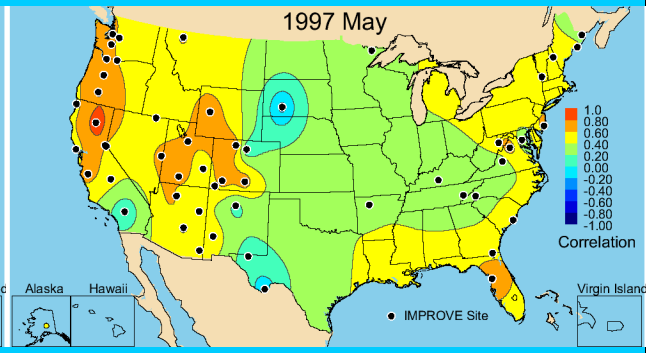


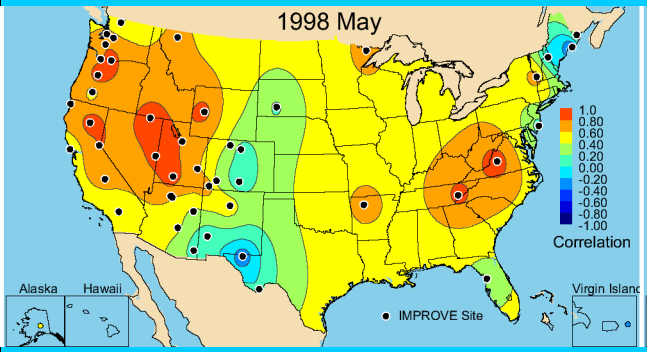


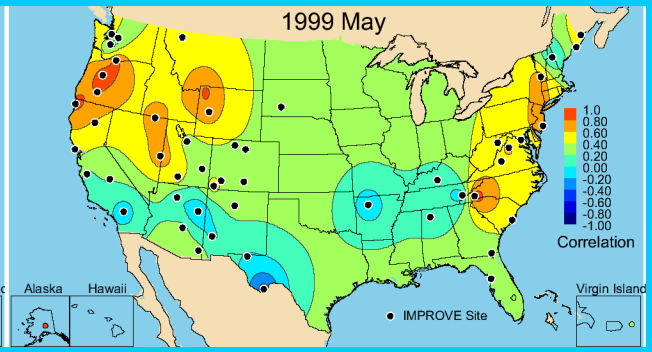






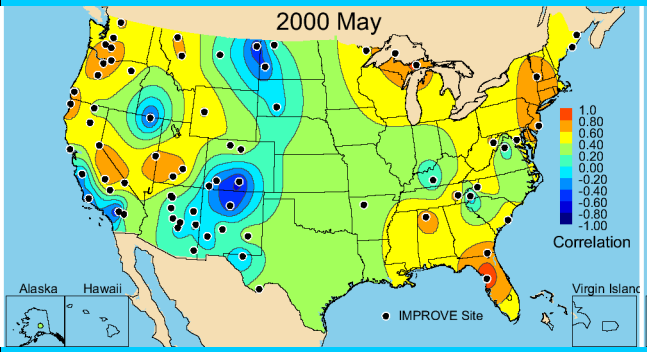


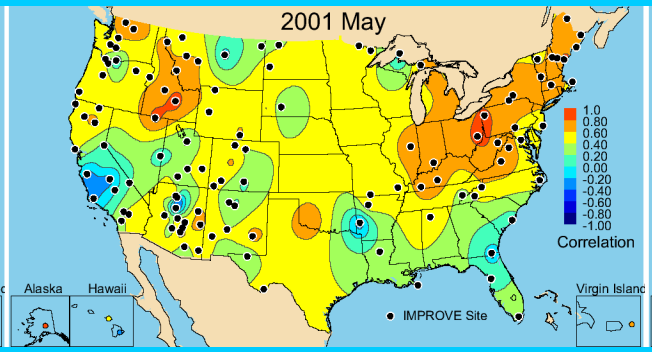


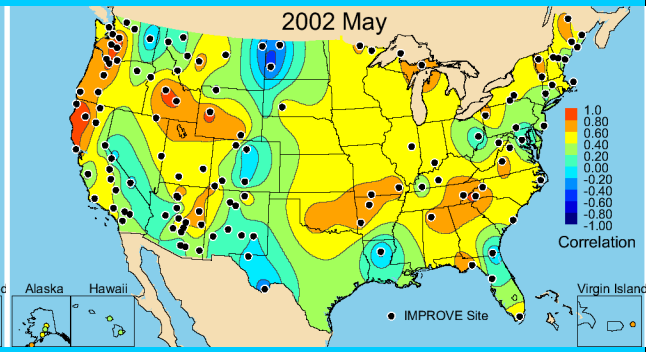


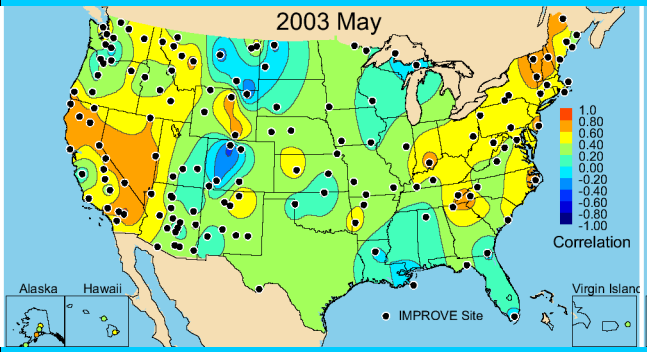
May 1989-1999

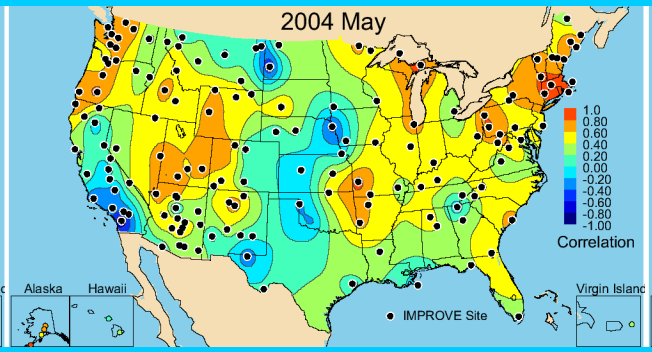
Iron and sulfate correlation

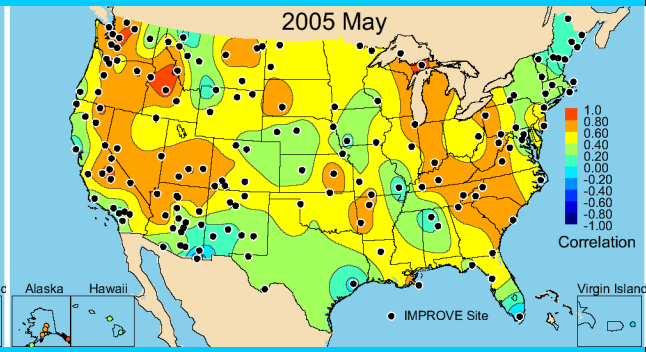


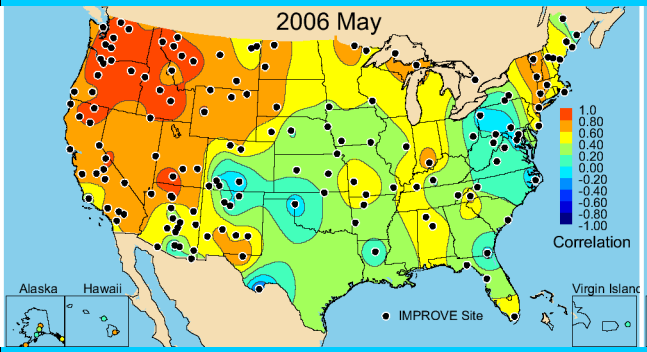


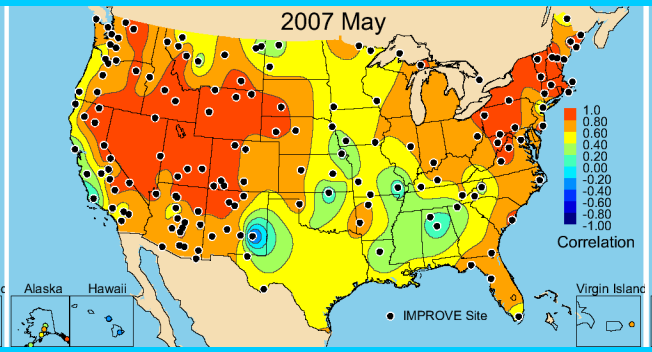


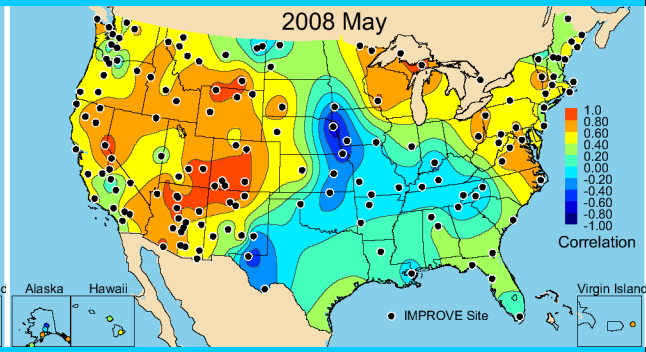


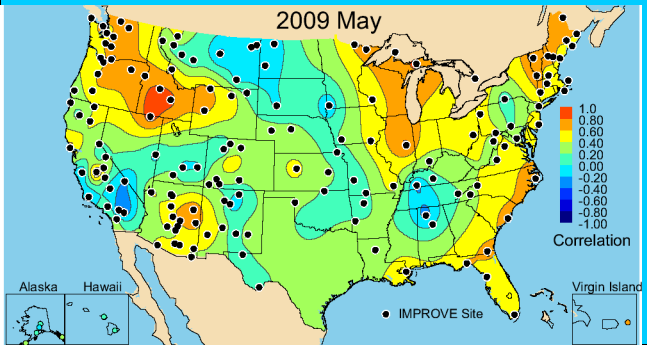






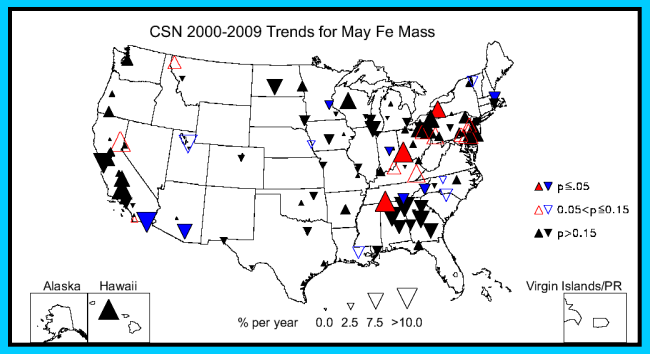


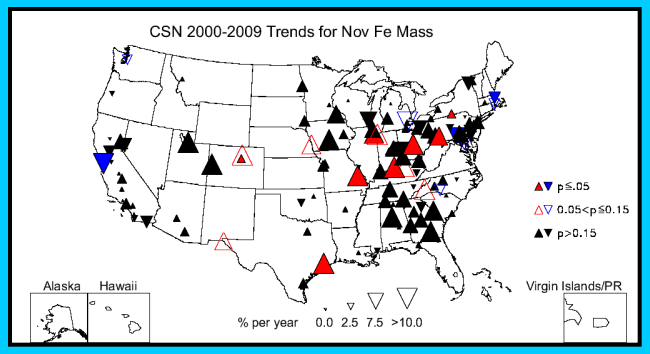


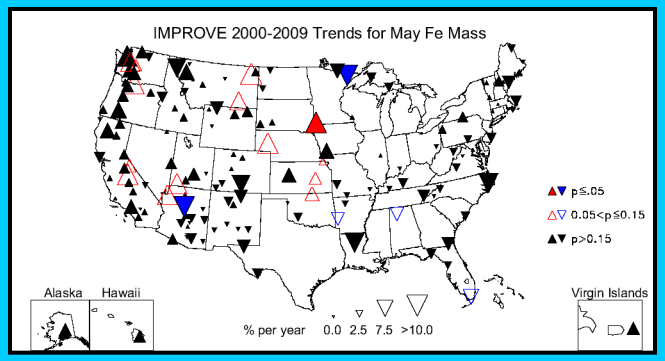


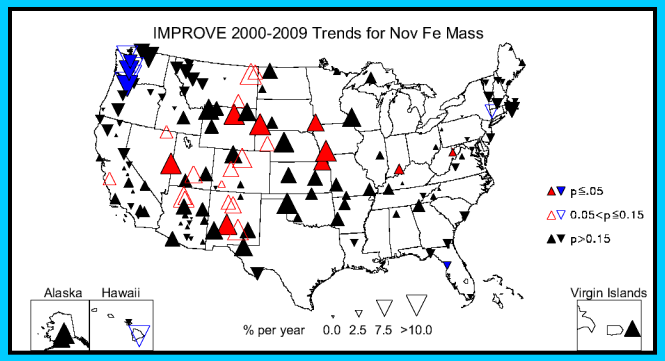
May 2000-2009

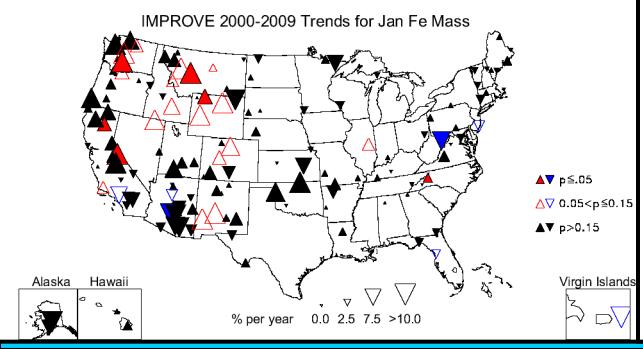
Iron and sulfate correlation

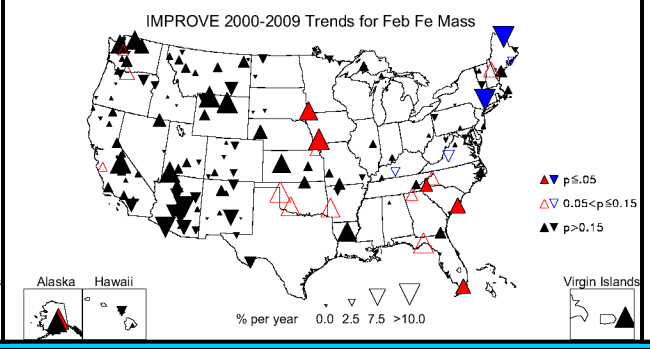

CSN 2000-2009 Trends for May Fe Mass
p≤.05
0.05<p≤0.15
p>0.15
Alaska
Hawaii
Virgin Islands/PR
% per year 0.0 2.5 7.5 >10.0

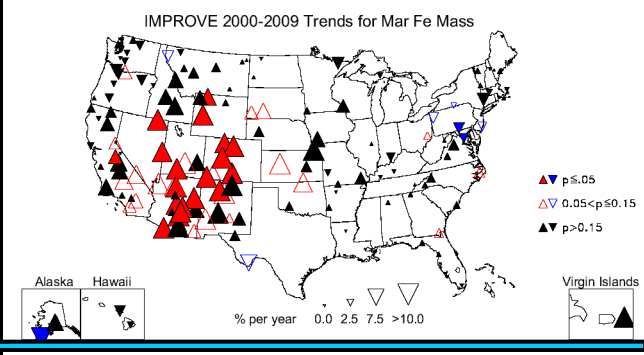

CSN 2000-2009 Trends for Nov Fe Mass
p≤.05
0.05<p≤0.15
p>0.15
Alaska
Hawaii
Virgin Islands/PR
% per year 0.0 2.5 7.5 >10.0

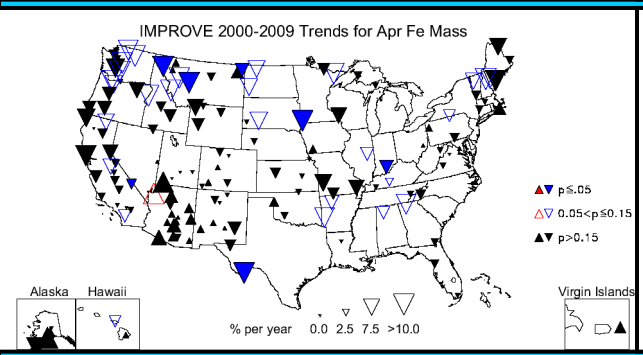

IMPROVE 2000-2009 Trends for May Fe Mass
p≤.05
0.05<p≤0.15
p>0.15
Alaska
Hawaii
Virgin Islands
% per year 0.0 2.5 7.5 >10.0

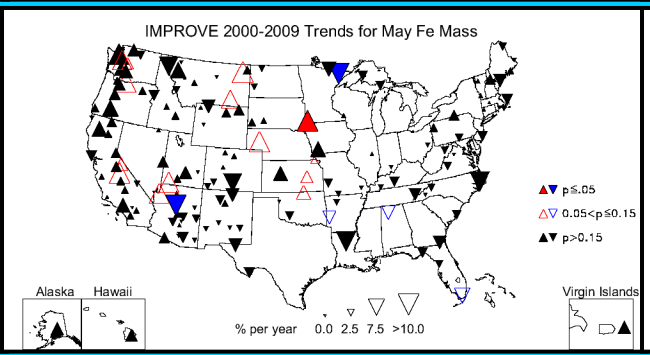

IMPROVE 2000-2009 Trends for Nov Fe Mass
p≤.05
0.05<p≤0.15
p>0.15
Alaska
Hawaii
Virgin Islands
% per year 0.0 2.5 7.5 >10.0

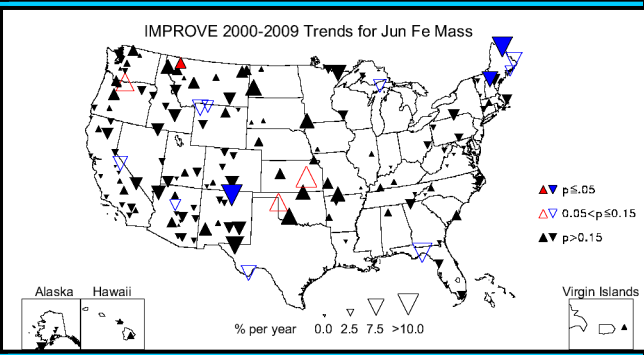

IMPROVE 2000-2009 Trends for Jan Fe Mass
p≤.05
0.05<p≤0.15
p>0.15
Alaska
Hawaii
Virgin Islands
% per year 0.0 2.5 7.5 >10.0

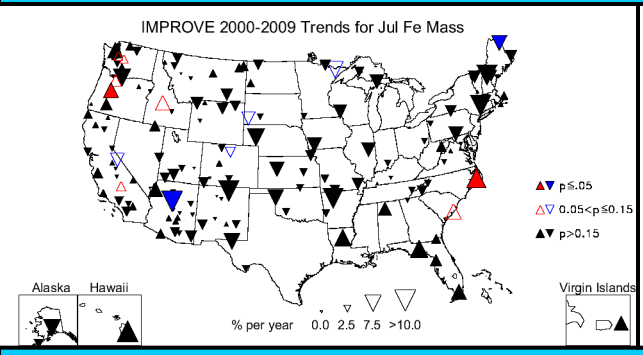

IMPROVE 2000-2009 Trends for Feb Fe Mass
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0.05<p≤0.15
p>0.15
Alaska
Hawaii
Virgin Islands
% per year 0.0 2.5 7.5 >10.0

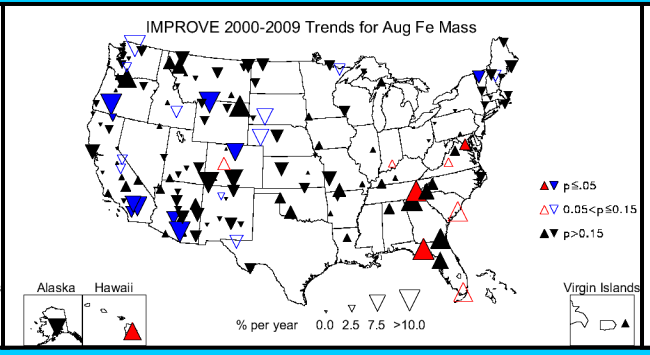

IMPROVE 2000-2009 Trends for Mar Fe Mass
p≤.05
0.05<p≤0.15
p>0.15
Alaska
Hawaii
Virgin Islands
% per year 0.0 2.5 7.5 >10.0

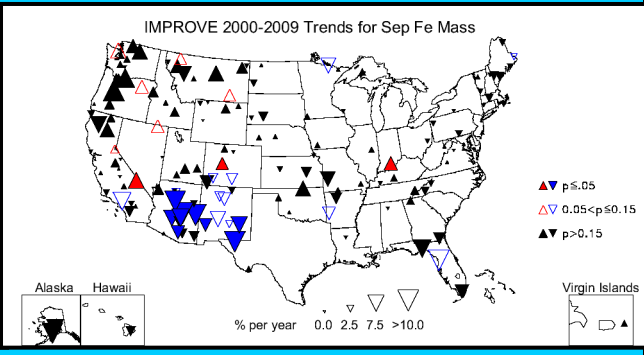

IMPROVE 2000-2009 Trends for Apr Fe Mass
p≤.05
0.05<p≤0.15
p>0.15
Alaska
Hawaii
Virgin Islands
% per year 0.0 2.5 7.5 >10.0

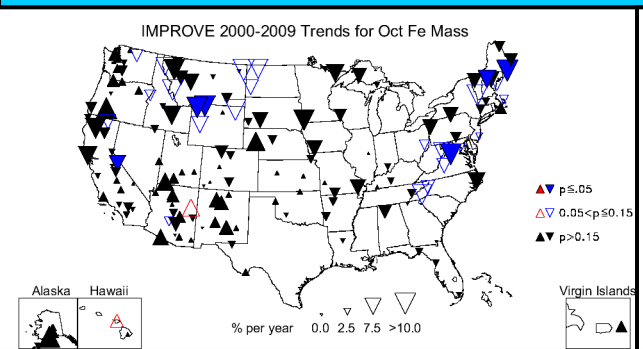

IMPROVE 2000-2009 Trends for May Fe Mass
p≤.05
0.05<p≤0.15
p>0.15
Alaska
Hawaii
Virgin Islands
% per year 0.0 2.5 7.5 >10.0

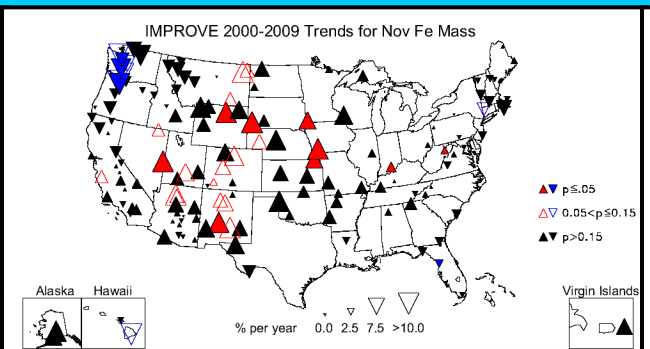

IMPROVE 2000-2009 Trends for Jun Fe Mass
p≤.05
0.05<p≤0.15
p>0.15
Alaska
Hawaii
Virgin Islands
% per year 0.0 2.5 7.5 >10.0

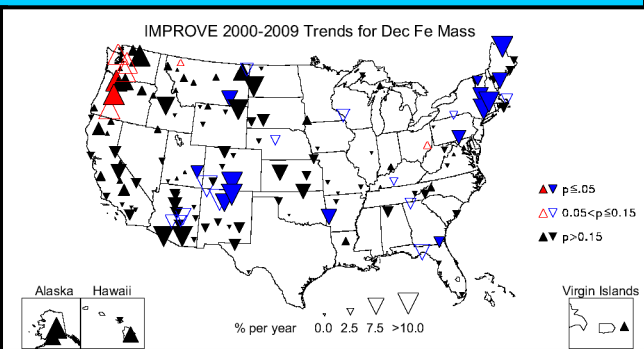

IMPROVE 2000-2009 Trends for Jul Fe Mass
p≤.05
0.05<p≤0.15
p>0.15
Alaska
Hawaii
Virgin Islands
% per year 0.0 2.5 7.5 >10.0


IMPROVE 2000-2009 Trends for Aug Fe Mass
p≤.05
0.05<p≤0.15
p>0.15
Alaska
Hawaii
Virgin Islands
% per year 0.0 2.5 7.5 >10.0

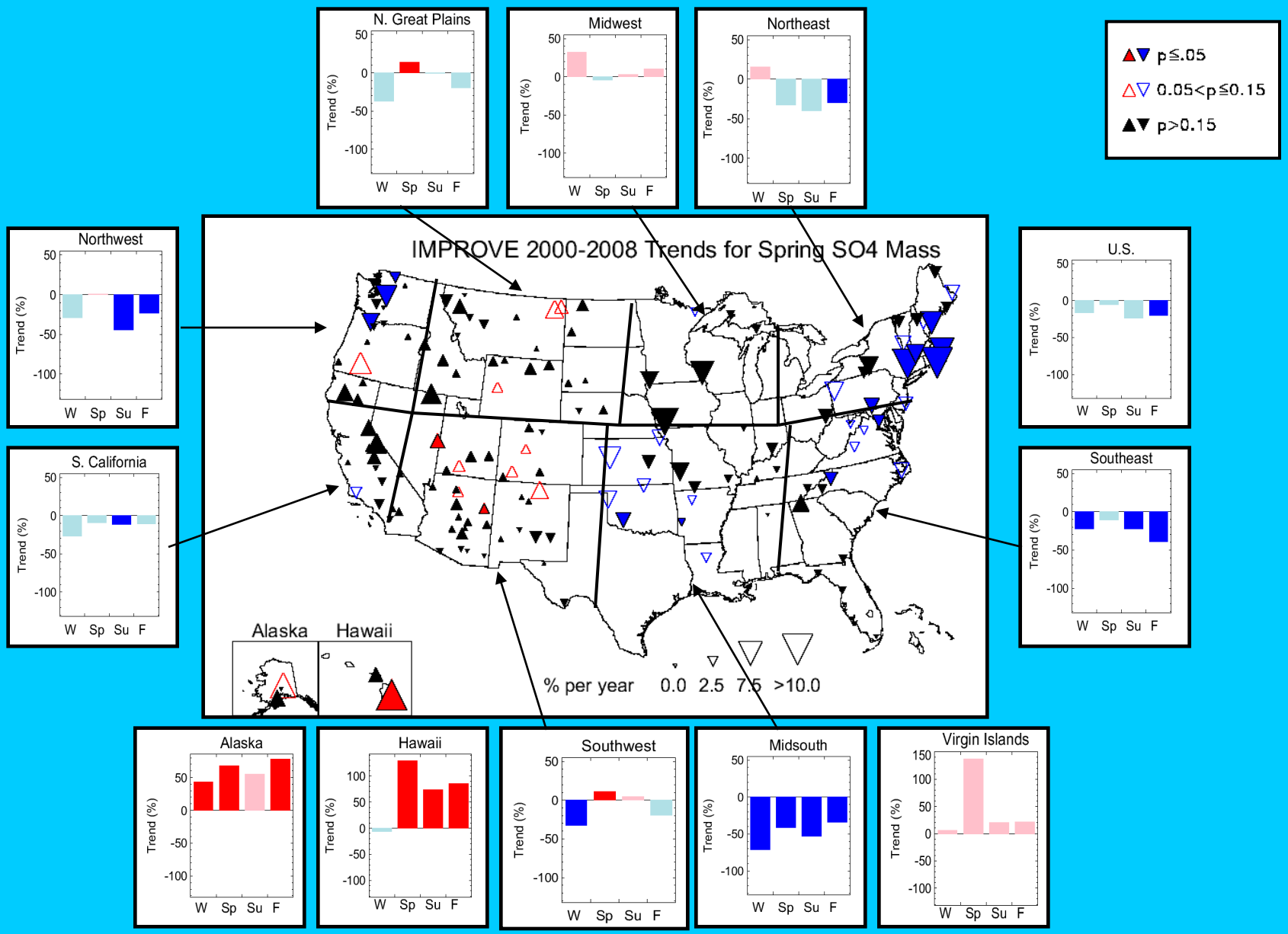

IMPROVE 2000-2009 Trends for Sep Fe Mass
p≤.05
0.05<p≤0.15
p>0.15
Alaska
Hawaii
Virgin Islands
% per year 0.0 2.5 7.5 >10.0


IMPROVE 2000-2009 Trends for Oct Fe Mass
p≤.05
0.05<p≤0.15
p>0.15
Alaska
Hawaii
Virgin Islands
% per year 0.0 2.5 7.5 >10.0


IMPROVE 2000-2009 Trends for Nov Fe Mass
p≤.05
0.05<p≤0.15
p>0.15
Alaska
Hawaii
Virgin Islands
% per year 0.0 2.5 7.5 >10.0


IMPROVE 2000-2009 Trends for Dec Fe Mass
p≤.05
0.05<p≤0.15
p>0.15
Alaska
Hawaii
Virgin Islands
% per year 0.0 2.5 7.5 >10.0

2000-2008 Spring Mean Sulfate Trends



2000-2008 Monthly Mean Sulfate Trends

