

Insights from the IMPROVE Network

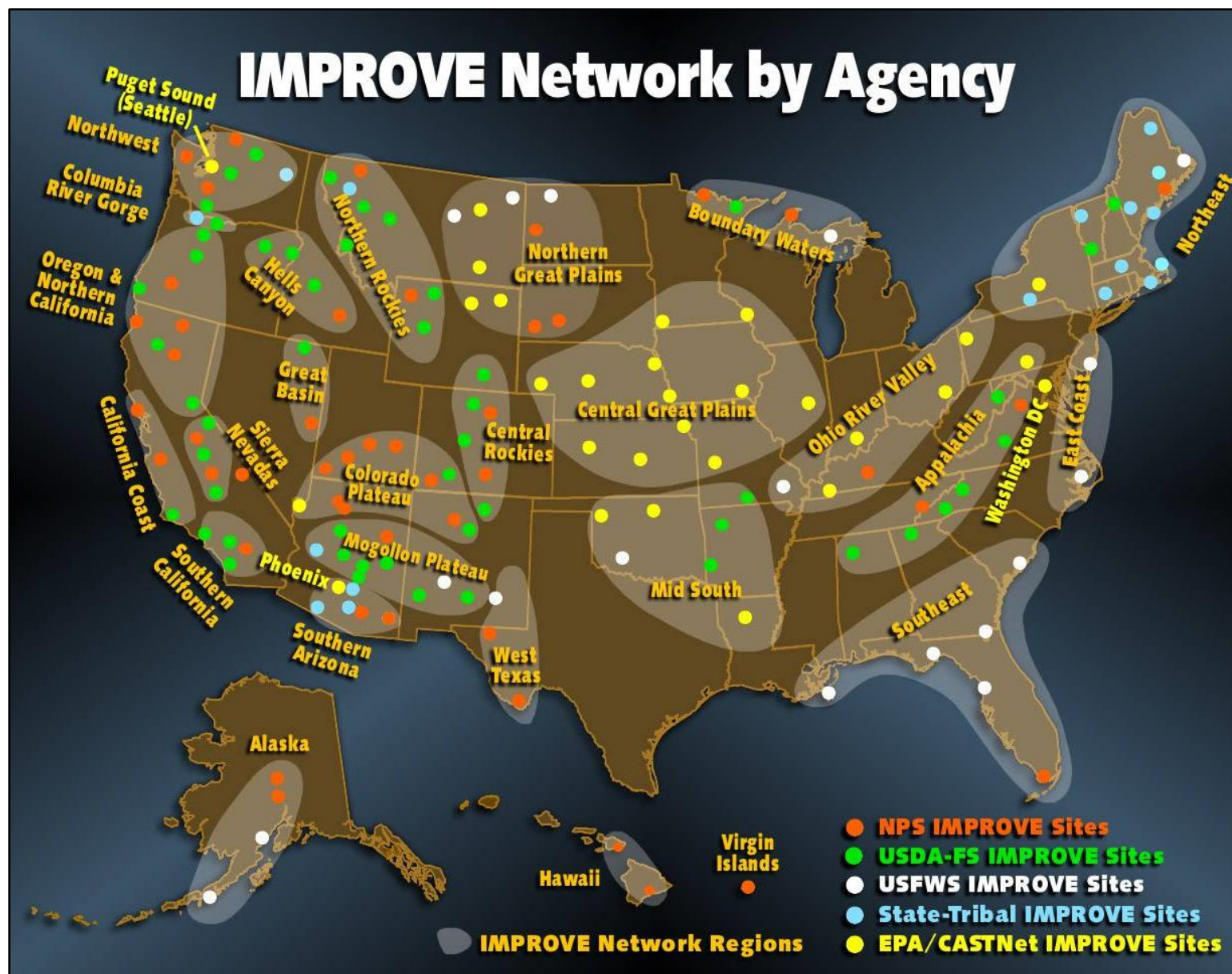
Jenny Hand

CIRA, Colorado State University, Fort Collins, CO

and others from CSU and NPS



Interagency Monitoring of Protected Visual Environments



Routine monitoring: aerosol chemical properties



IMPROVE Site in Capitol Reef, UT



Photo credit: Derek Day

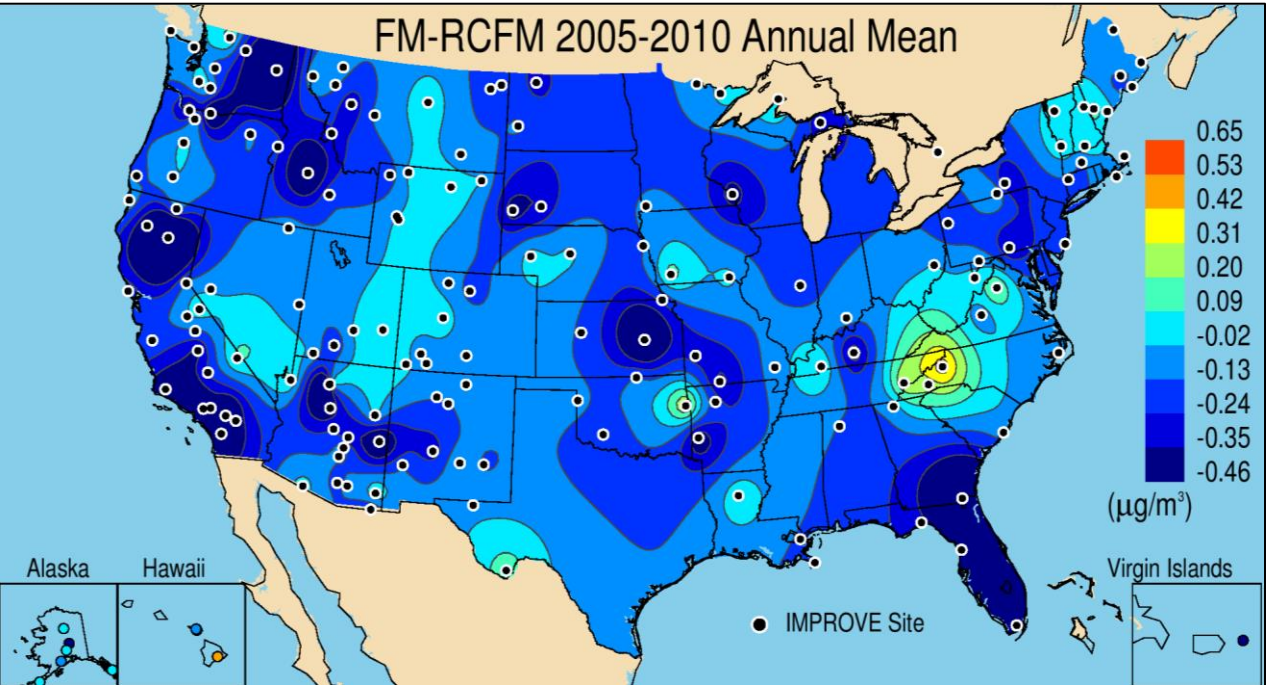
- 24-hr samples collected every 3rd day
- PM_{2.5} inorganic anions, carbonaceous aerosols
- PM_{2.5} elemental species by XRF
- Gravimetric PM_{2.5} and PM₁₀ mass
- Coarse Mass (PM₁₀ – PM_{2.5})

Aerosol mass concentration and PM_{2.5} mass budget

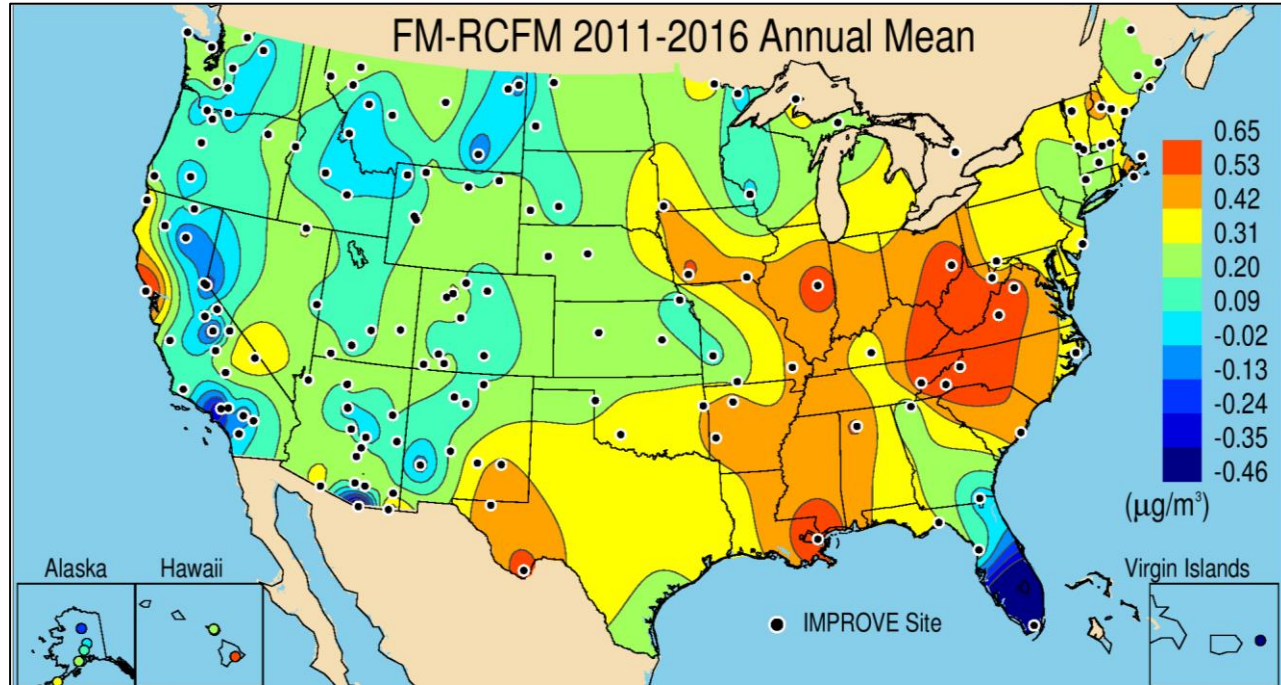


Species	Formula
Ammonium sulfate	AS = 1.375*sulfate ion
Ammonium nitrate	AN = 1.29*nitrate ion
Organic carbon	OC = OC1+OC2+OC3+OC4+OP
Elemental carbon	EC = EC1+EC2+EC3-OP
Particulate organic mass	POM = (OM/OC)*OC OM/OC = 1.8 (historically) (monthly OM/OC)
Fine dust	FD = 1.15*(2.2[Al] + 2.49[Si] + 1.63[Ca] + 2.42[Fe] + 1.94[Ti])
Sea salt	SS = 1.8*chloride ion
Reconstructed fine mass	RCFM = AS + AN + POM + EC + FD + SS
Gravimetric mass (PM _{2.5})	FM
Residual	FM – RCFM

Trends in Residual (FM-RCFM): 2005-2010 versus 2011-2016



FM < RCFM



FM > RCFM

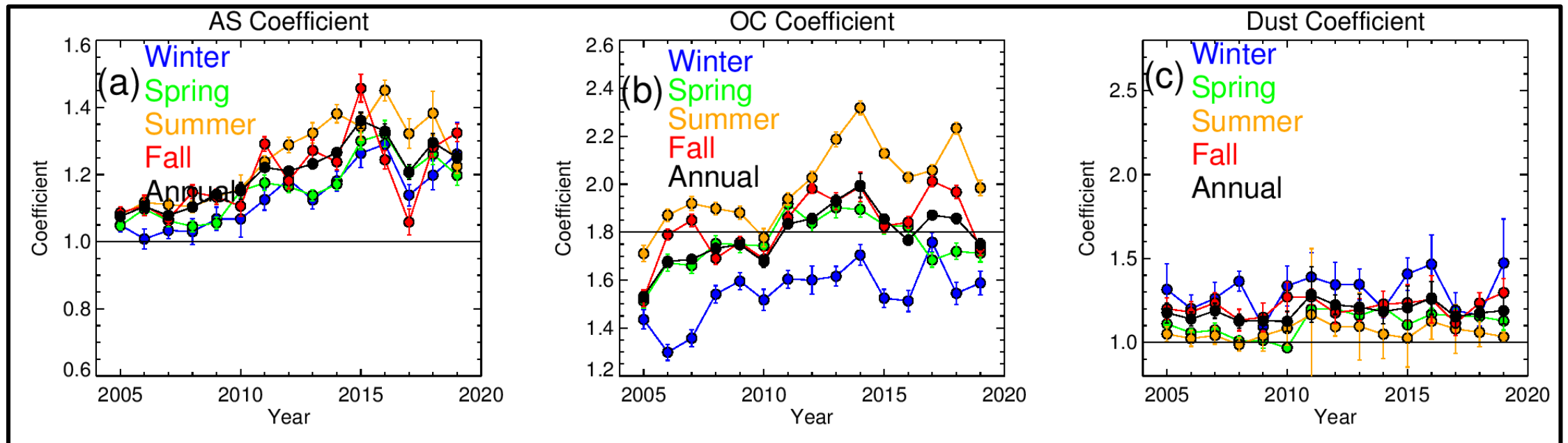
Residual increased $\sim 0.3 \mu\text{g m}^{-3}$ from 2005-2019

FM ↓ 36%
RCFM ↓ 45%

Multiple linear regression

$$FM - EC - SS = a_{AS}AS + a_{AN}AN + a_{OC}OC + a_{dust}dust$$

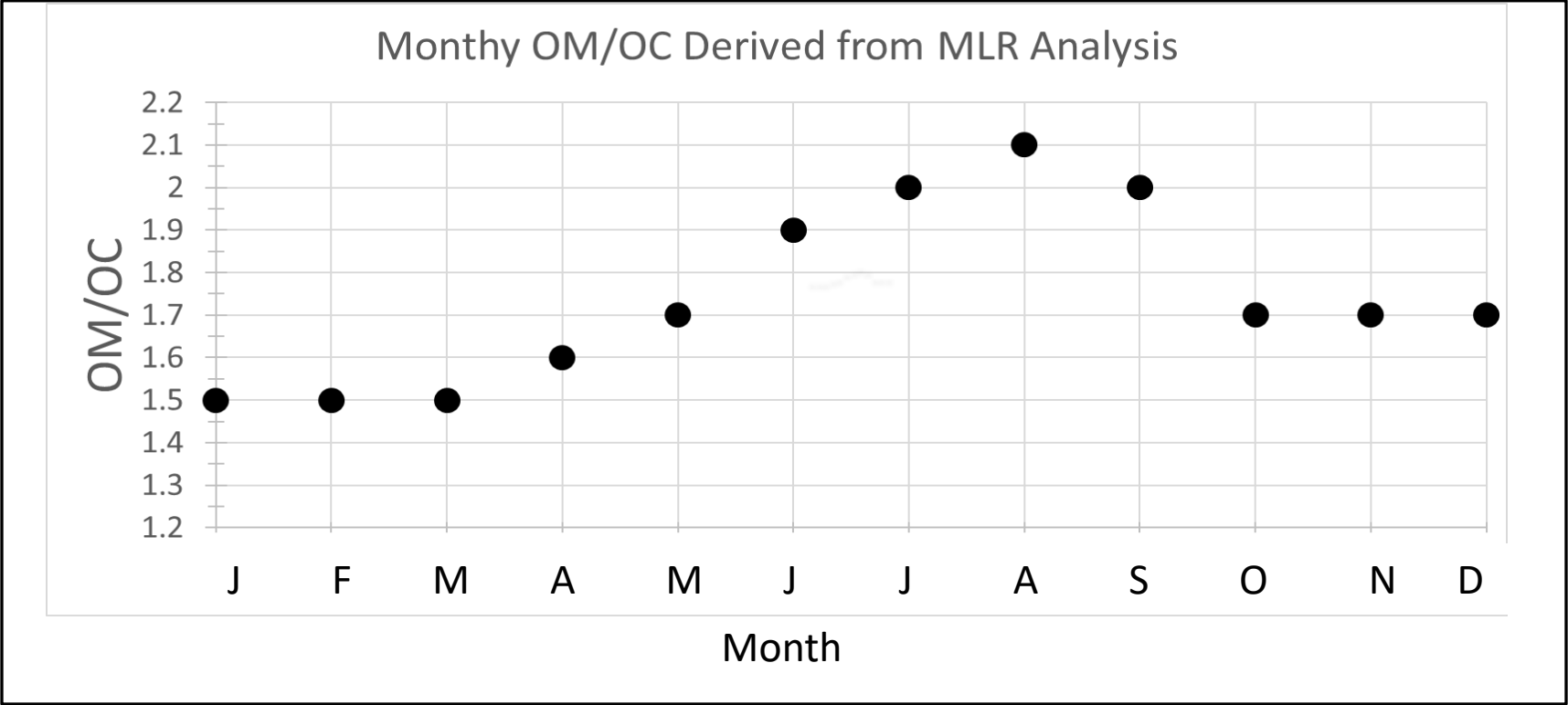
Seasonal mean coefficients



Assumptions about OC are increasingly important as it is now the major contributor to $PM_{2.5}$

Multiple linear regression: monthly mean

IMPROVE:
monthly
varying,
regionally
constant



Annual
mean: 1.7

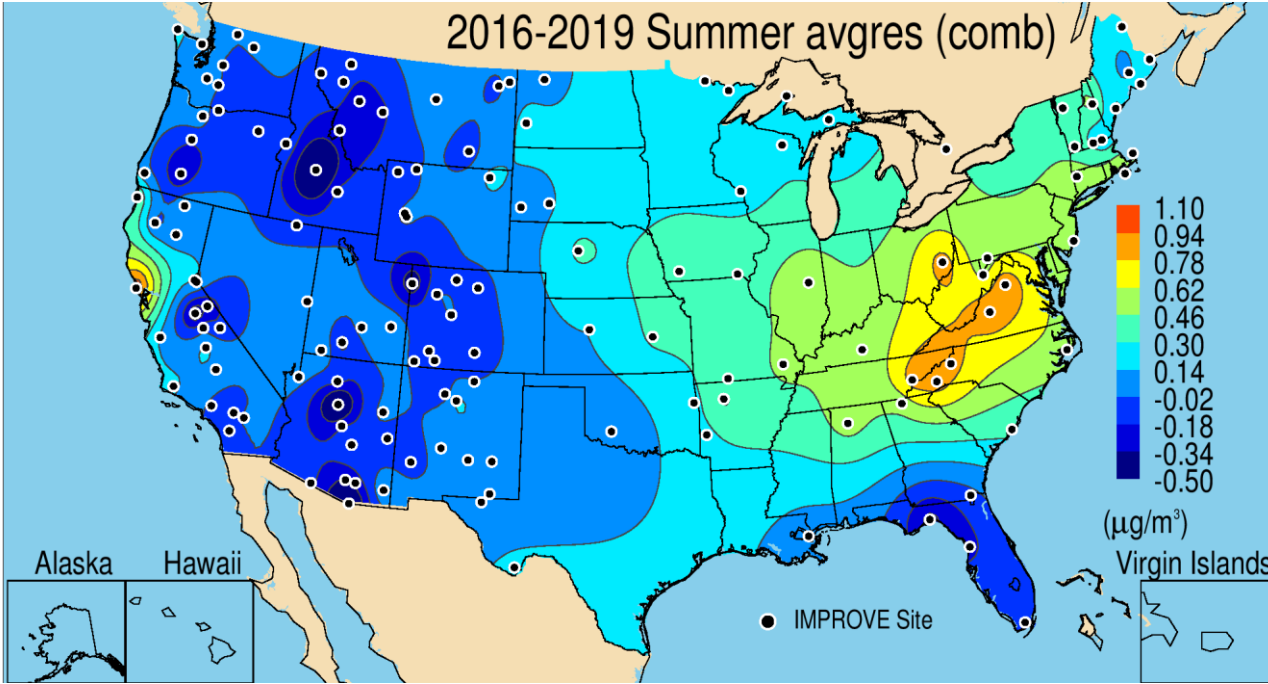
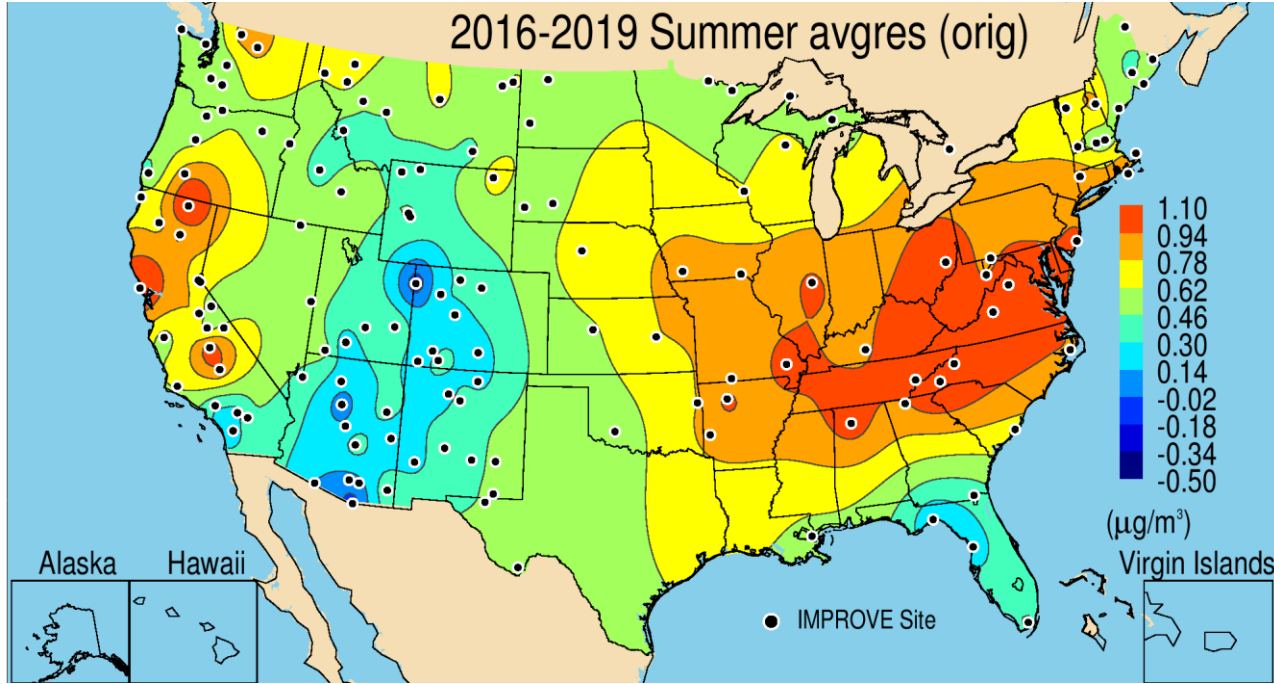


Residual: Constant OM/OC vs Monthly varying OM/OC

FM - RCFM

Summer Residual 2016-2019
Constant OM/OC (1.8)

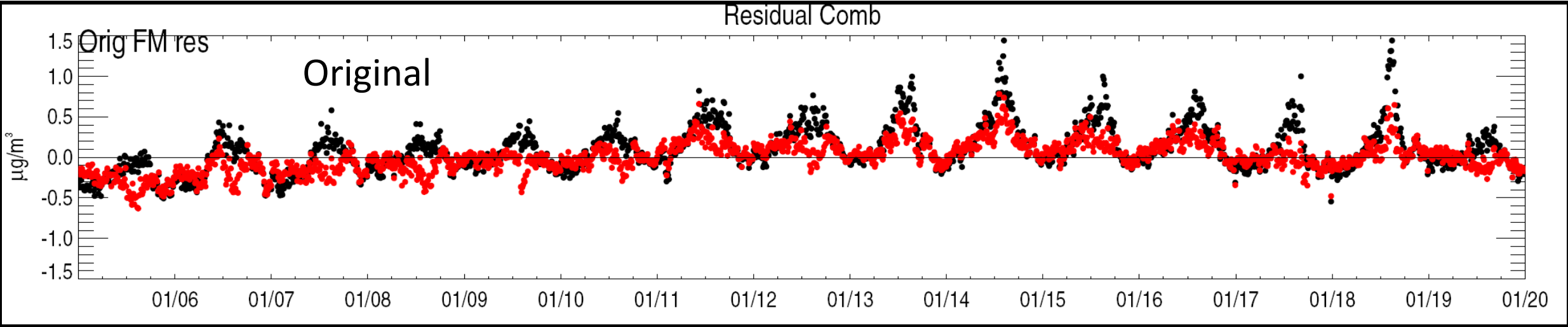
Summer Residual 2016-2019
New Monthly OM/OC, higher dust



FM > RCFM

FM ~ RCFM

Impacts on residual: Daily Network Median Residual



Red: New residual (monthly OM/OC, increased dust)
Also: weigh chamber – most samples in 2019!



IMPROVE Network Charter: Subcommittees

Network Operations and Sample Analyses: Joann Rice (EPA)-

Ensure procedures outlined in the SOP and QAPP are being followed and help resolve issues. Oversees QA/QC procedures.

Data Compilation, Analysis, and Reporting: Jenny Hand (CSU)-

Developing policies for generating and distributing data, metadata, and data products. Oversees QC assessments, irregular/suspect data, generation of routine reports and data products.

Outreach and Communication: Jay Baker (WESTAR)-

Keep broader IMPROVE community informed about IMPROVE activities and monitoring data analyses. Includes site operators, scientists, federal and state regulators, and the public.

Previous Reports available on the IMPROVE website:
<http://vista.cira.colostate.edu/Improve/improve-reports/>

Check out the new IMPROVE report draft:
<https://vader.cira.colostate.edu/files/improve/reports/>

Acknowledgments

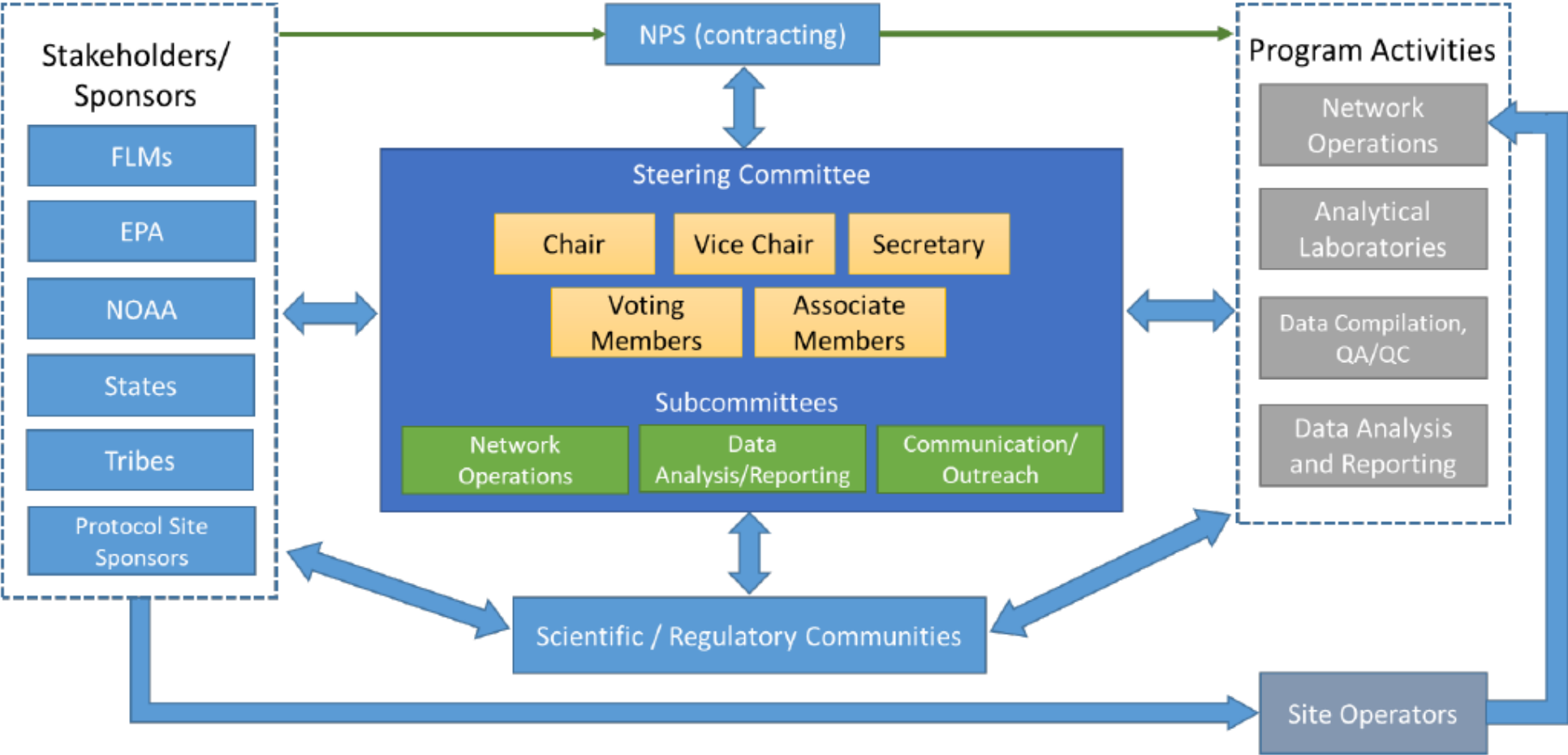
National Park Service Air Resources Division

contact:

jlhand@colostate.edu



IMPROVE Network Charter

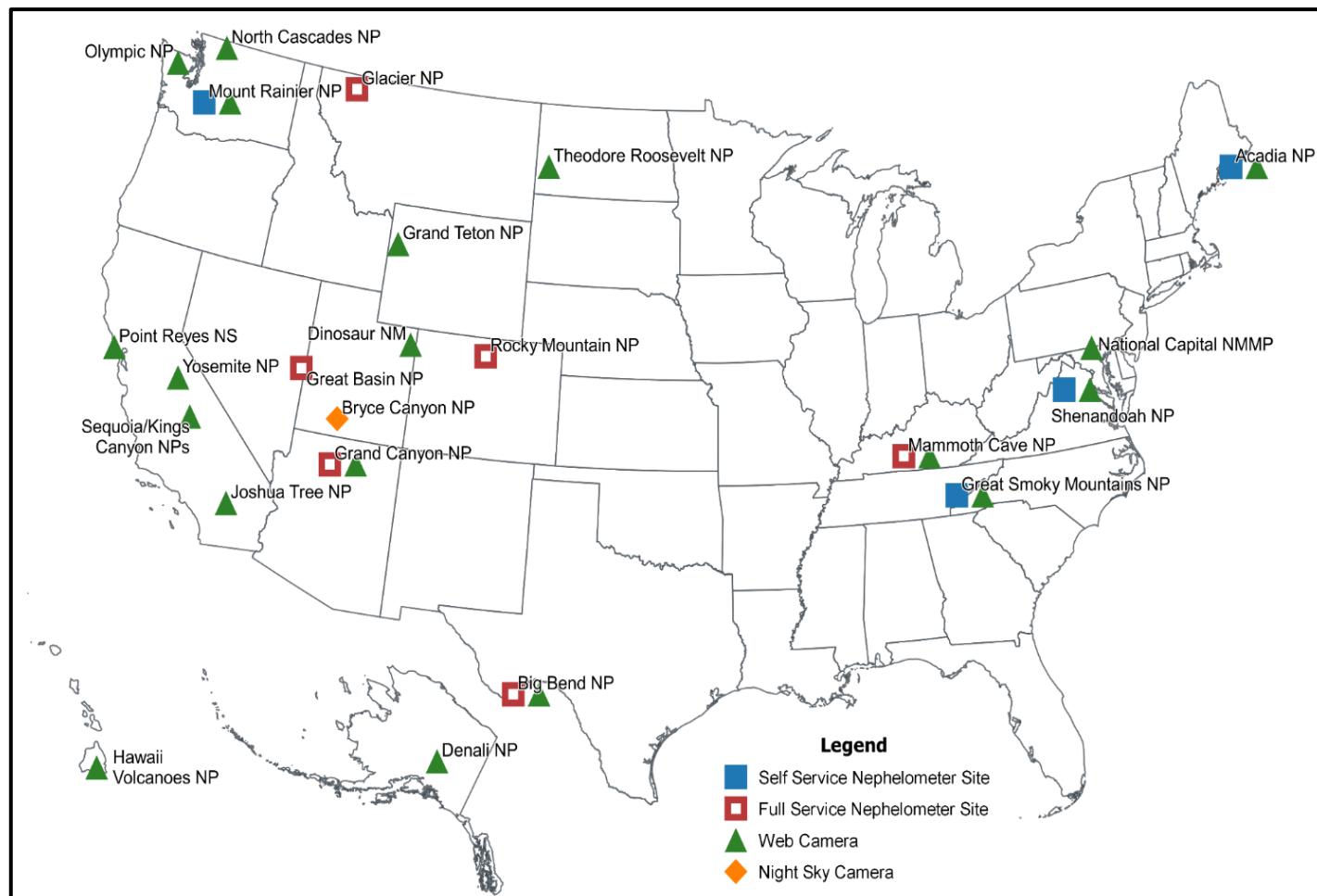


Routine monitoring: aerosol optical properties

Nephelometers are collocated at IMPROVE sites to measure ambient light scattering coefficients with finer time resolution and to provide data for evaluation of algorithms



Optical Monitoring



Error Metrics (seasonal and annual basis)

Normalized Root Mean Square: NRMSE =
$$\frac{\sqrt{\frac{1}{N} \sum (RCFM_i - FM_i)^2}}{\overline{FM}}$$
 $i = \text{daily sample, 2016-2019, entire network}$

Mean Absolute Error : MAE=
$$\frac{\sum |RCFM_i - FM_i|}{N}$$

Mean Absolute Bias: MAB=
$$\frac{\frac{1}{N} \sum (RCFM_i - FM_i)}{\overline{FM}}$$

Mean Absolute Deviation: MAD= $MEDIAN(|Res_i - MEDIAN(Res_i)|)$ $Res_i = FM_i - RCFM_i$

Total Residual =
$$\sum Res_i$$

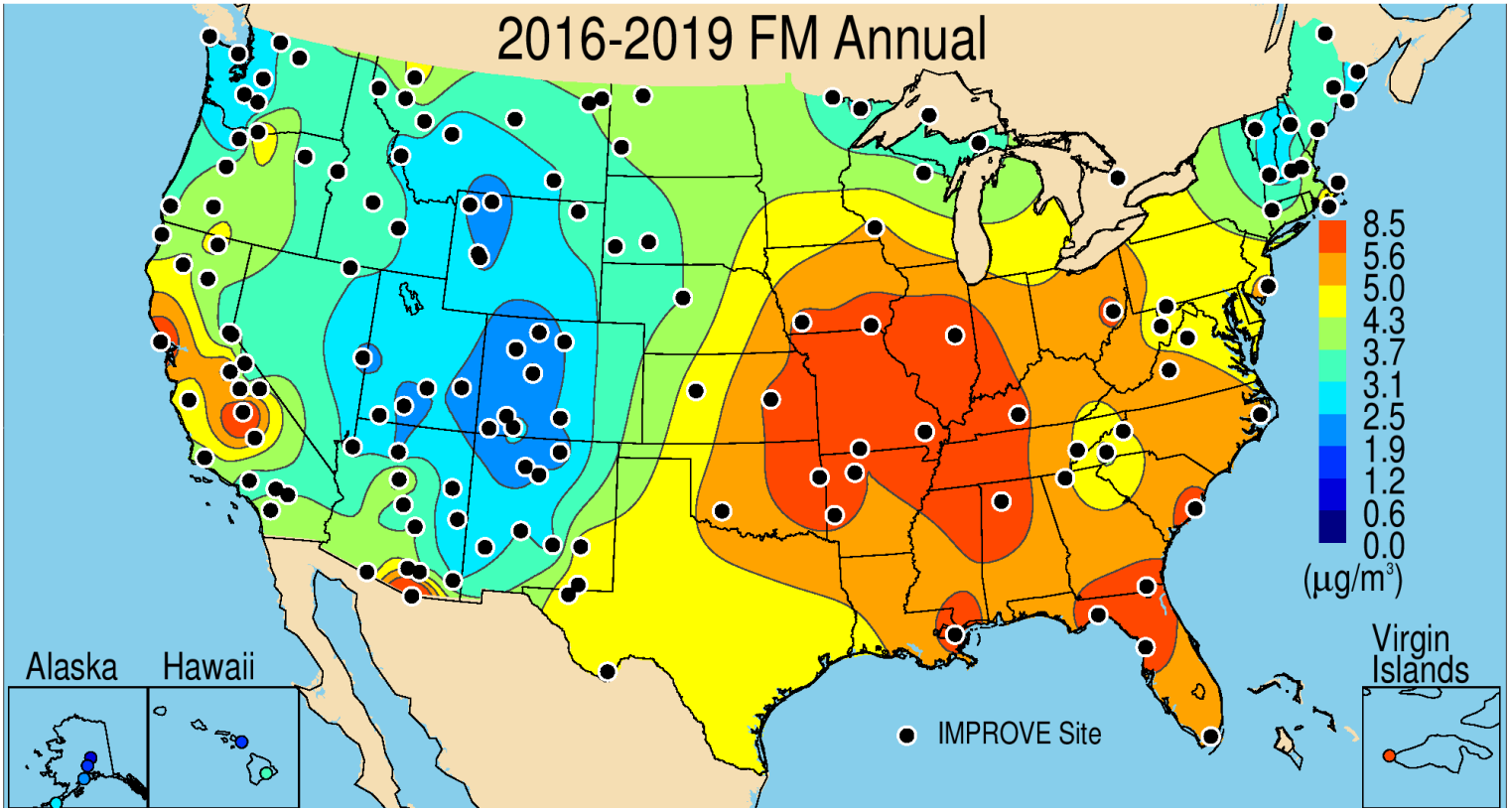
Mean Residual =
$$\overline{Res}$$

Slope (x,y) = (RCFM,FM)

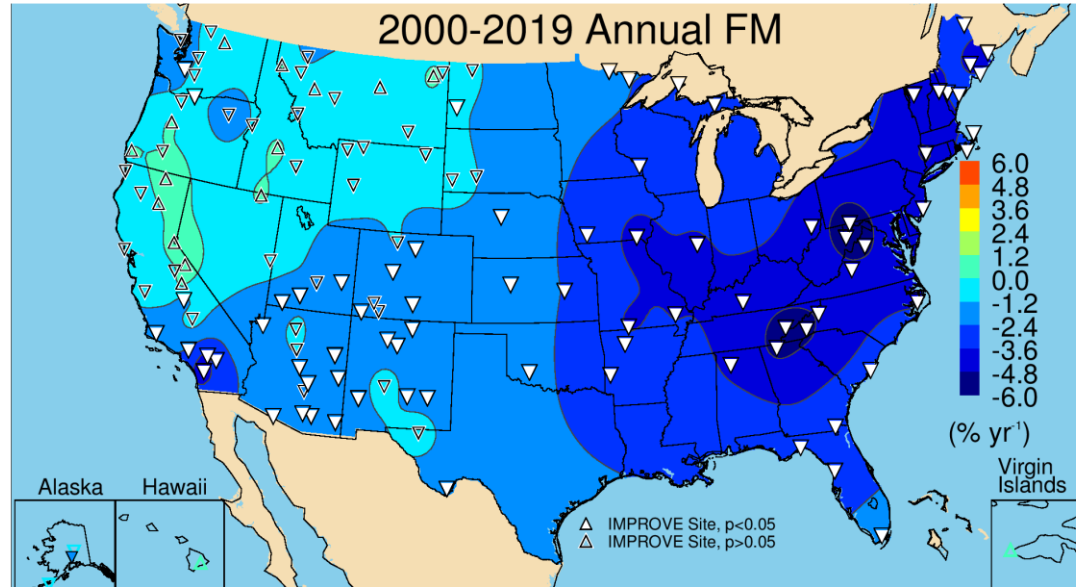
Intercept

R2

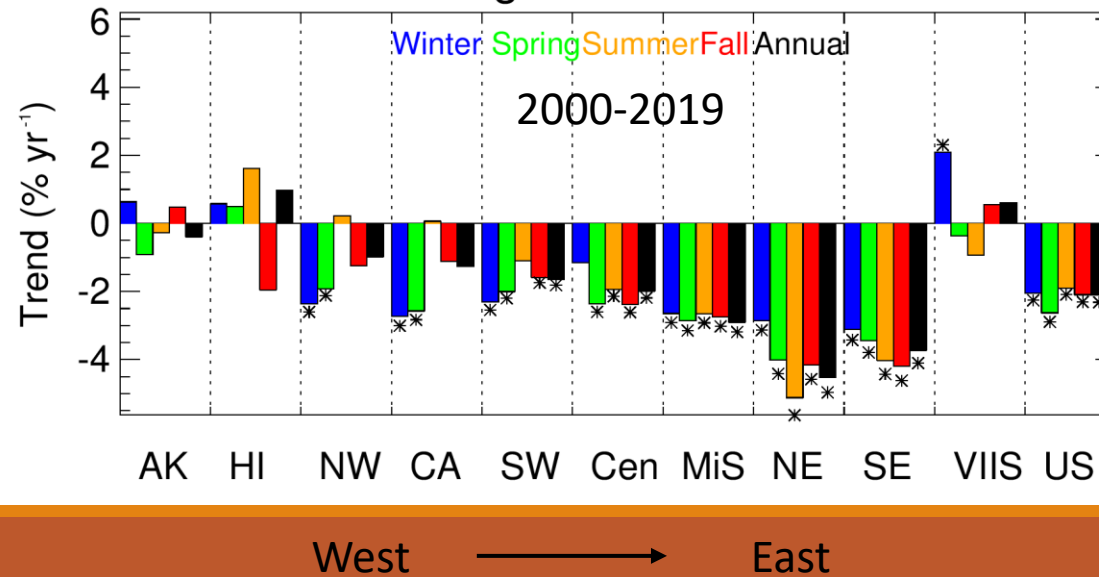
2016-2019 Annual mean gravimetric PM_{2.5} mass (FM)



Short-term FM annual mean trends

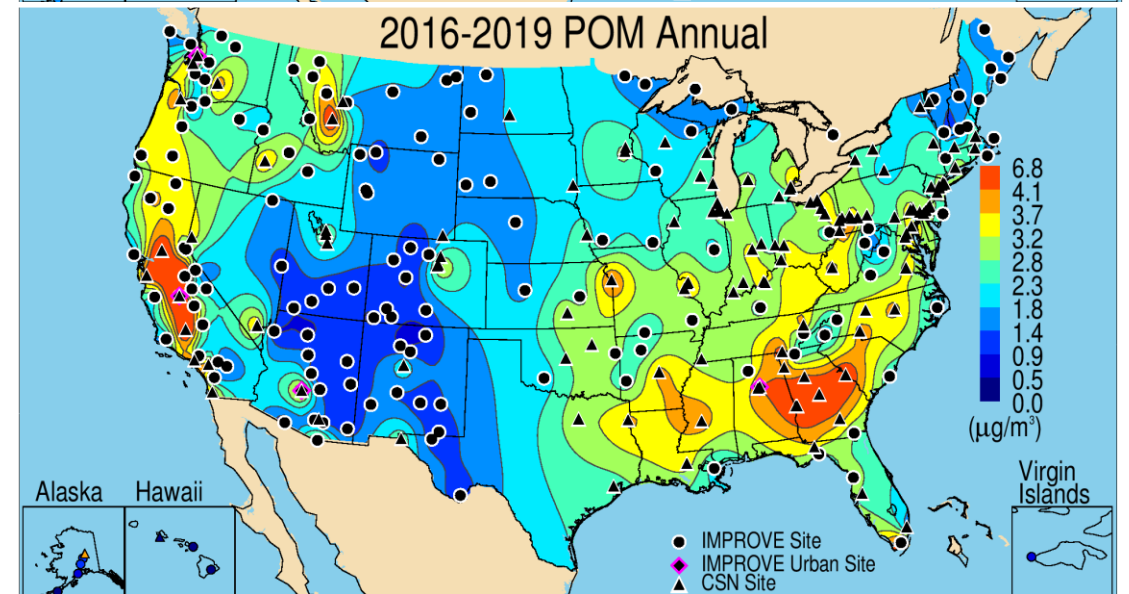
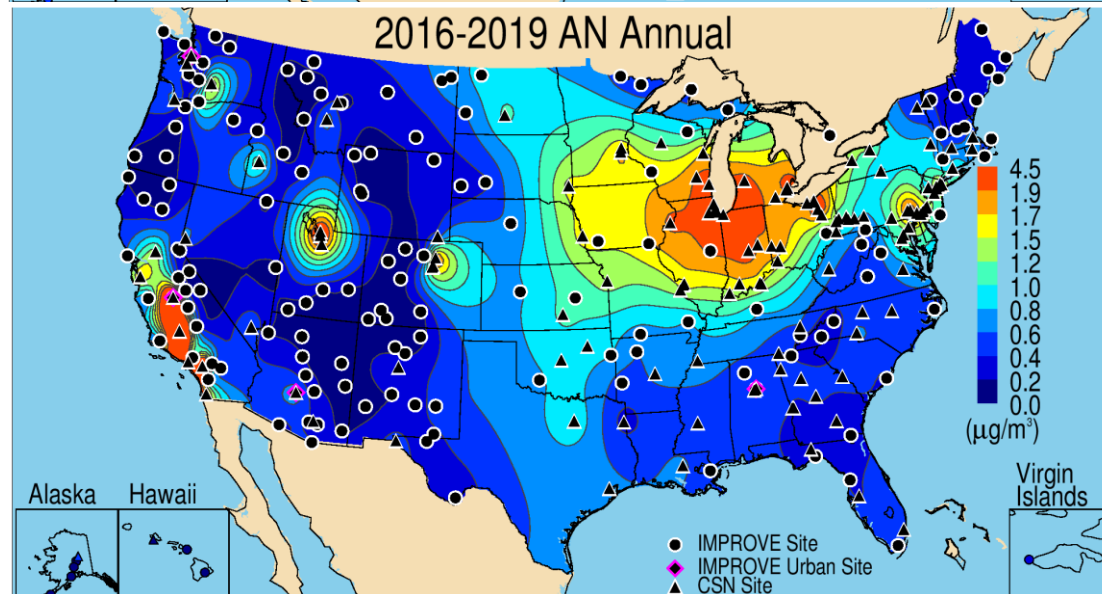
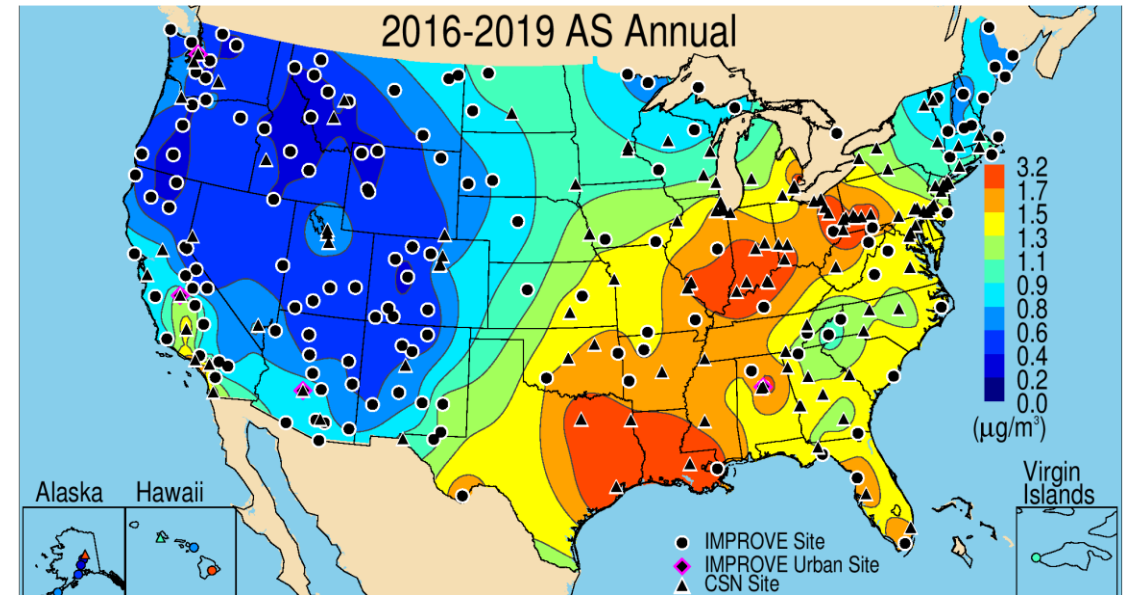
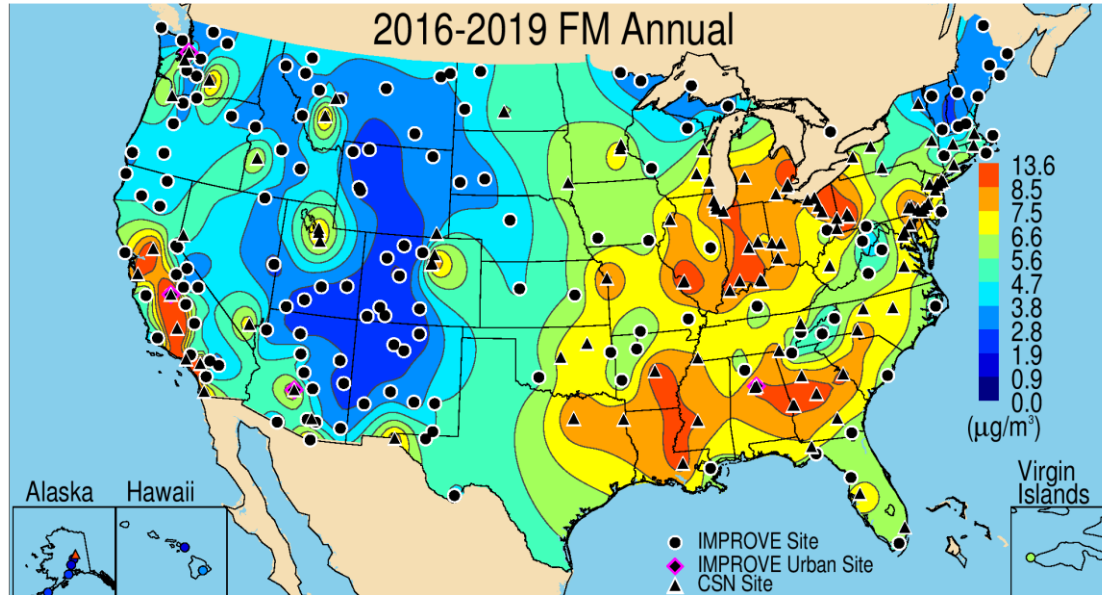


FM Regional Mean Trend

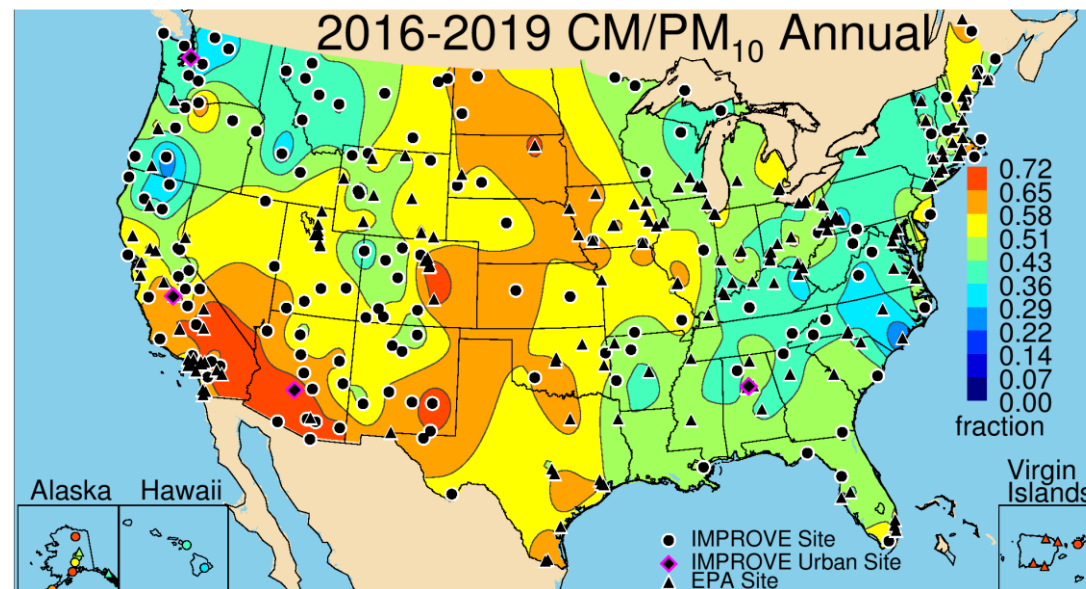
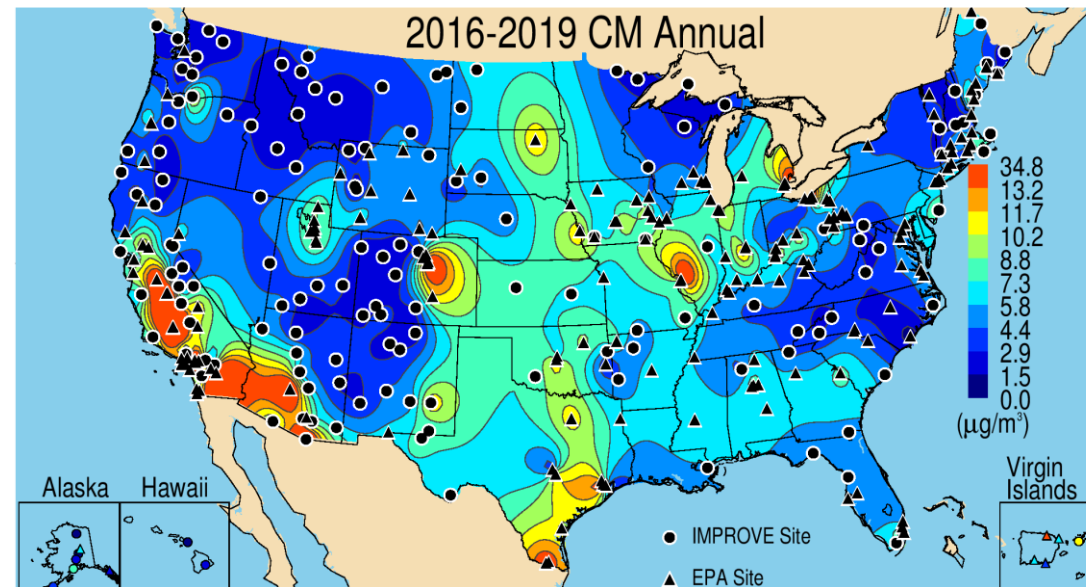
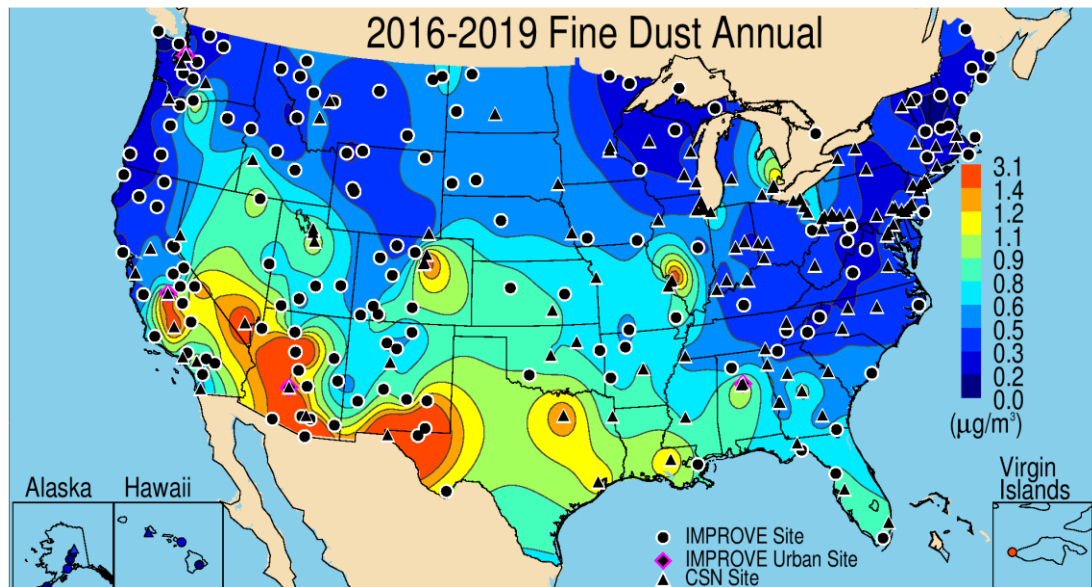


* $p \leq 0.05$

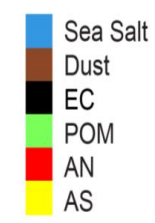
2016-2019 Annual mean mass: AS, AN, POM (IMPROVE and CSN)



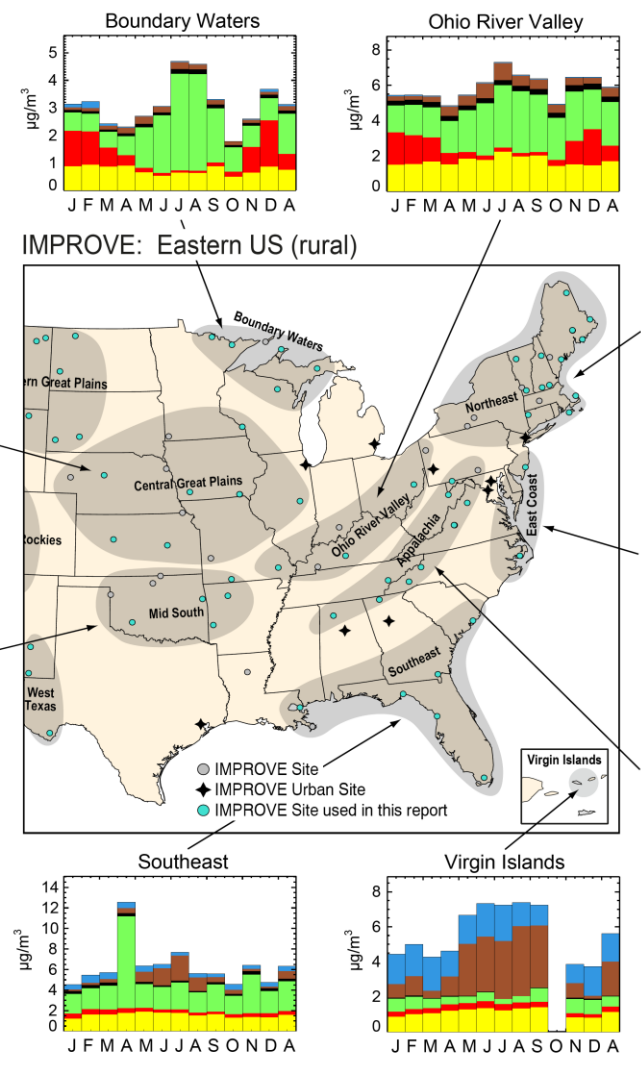
2016-2019 Annual mean mass: FD & CM (IMPROVE and EPA)



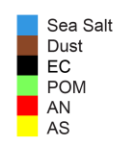
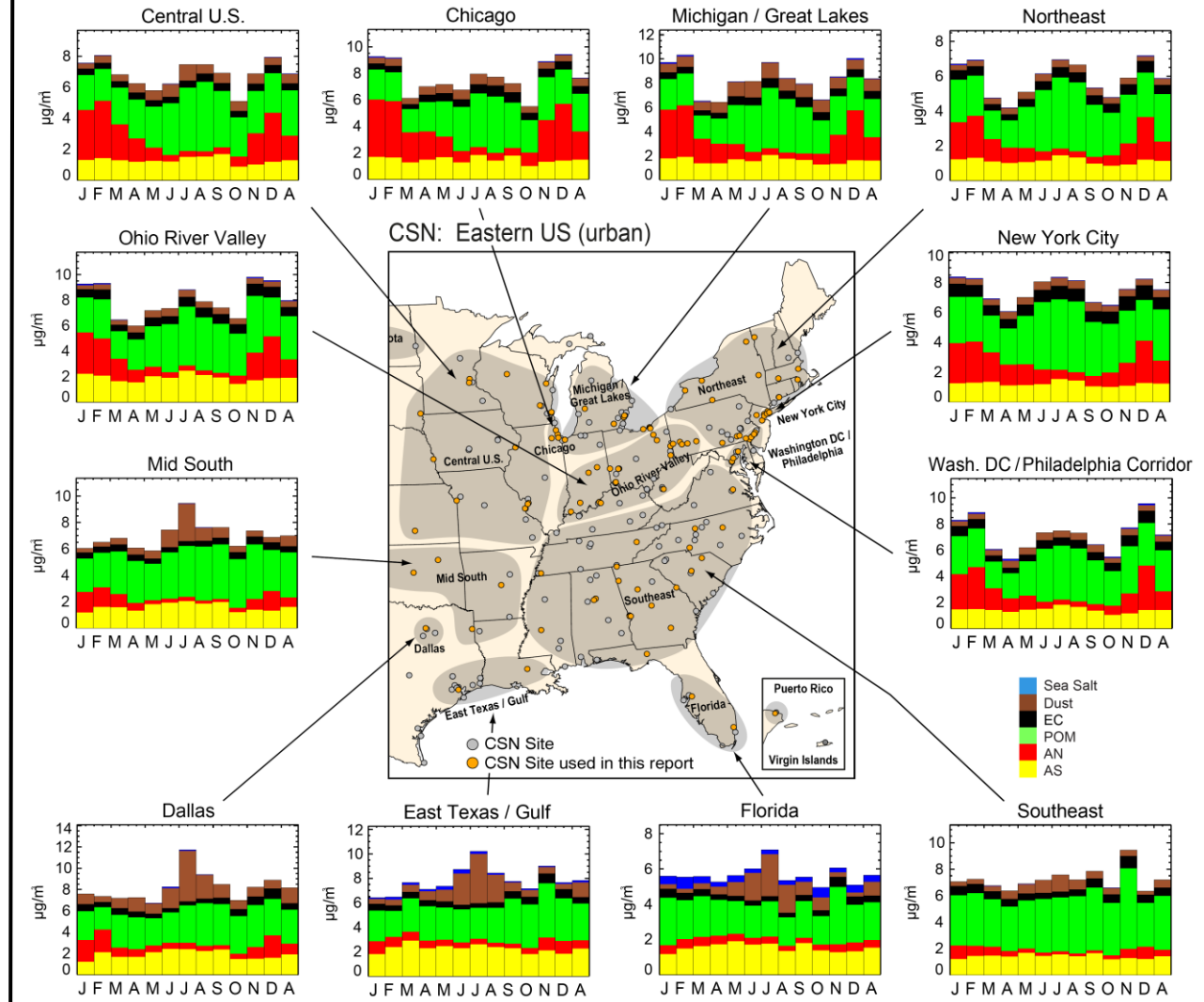
Eastern U.S. mass concentration ($\mu\text{g m}^{-3}$)



IMPROVE



CSN



Impacts on residual: errors

	NRMSE		MAB		MAE		MAD		Slope		Avg Res	
	Orig	New	Orig	New	Orig	New	Orig	New	Orig	New	Orig	New
Winter	0.22	0.21	0.05	0.02	0.35	0.33	0.22	0.20	0.97	1.00	-0.14	-0.04
Spring	0.17	0.17	-0.02	<i>-0.03</i>	0.35	0.35	0.22	0.21	1.03	1.06	0.05	<i>0.09</i>
Summer	0.23	0.17	-0.10	-0.02	0.68	0.47	0.34	0.28	1.12	0.99	0.59	0.12
Fall	0.23	0.22	-0.03	-0.01	0.42	0.38	0.25	0.23	1.07	1.01	0.13	0.02
Annual	0.23	0.19	-0.04	-0.01	0.45	0.38	1.03	0.70	1.09	1.00	0.17	0.05

“New” = monthly OM/OC, 15% increase in dust

Italics: errors higher

NRMSE= normalized root mean square error

MAB = Mean Absolute Bias

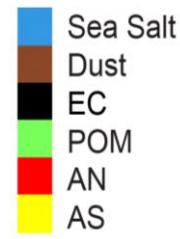
MAE = Mean Absolute Error

MAD = Mean Absolute Deviation of residual

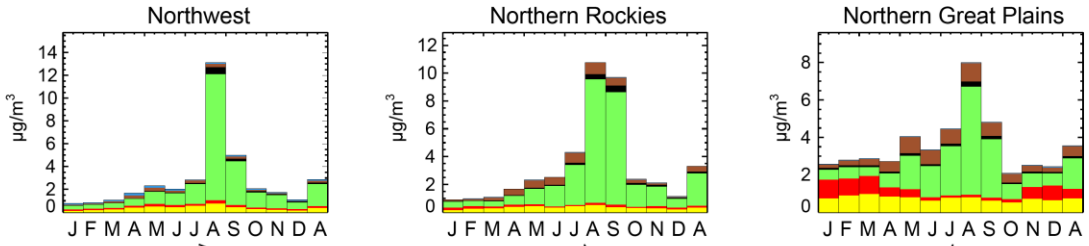
Slope (x=RCMF, y = FM)

Average Residual = mean(FM-RCFM)

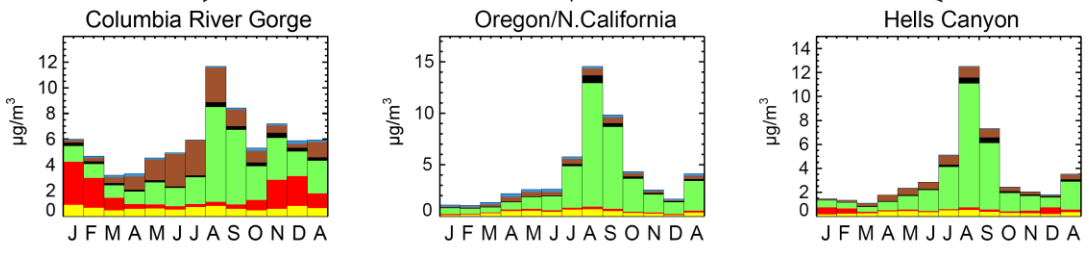
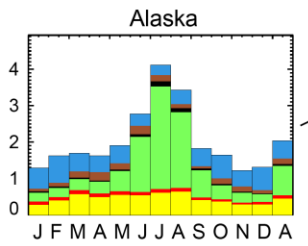
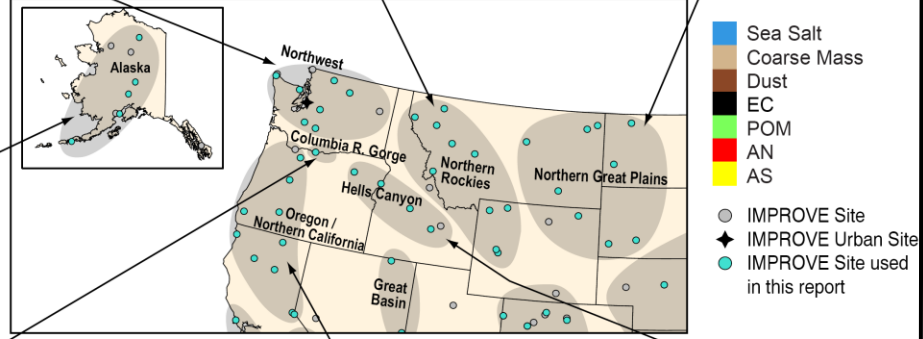
Northwestern U.S. mass concentration ($\mu\text{g m}^{-3}$)



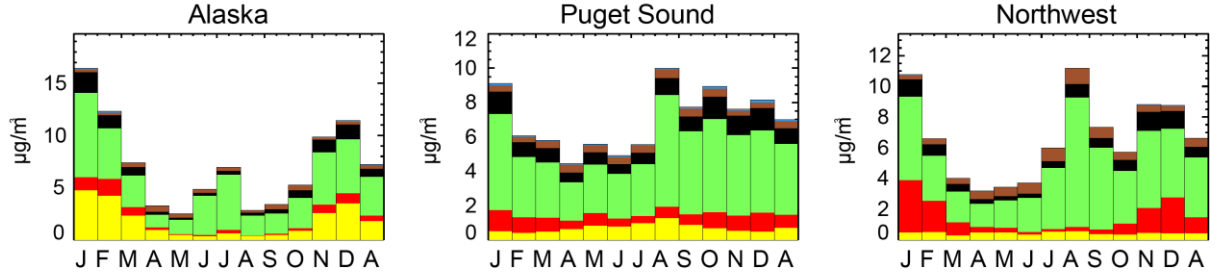
IMPROVE



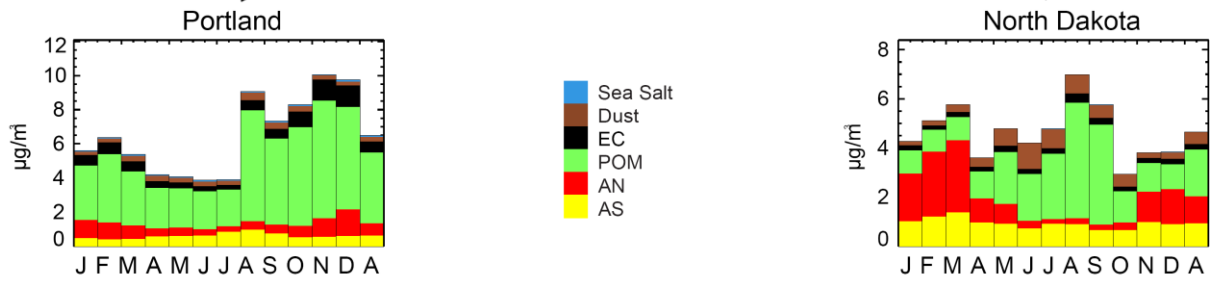
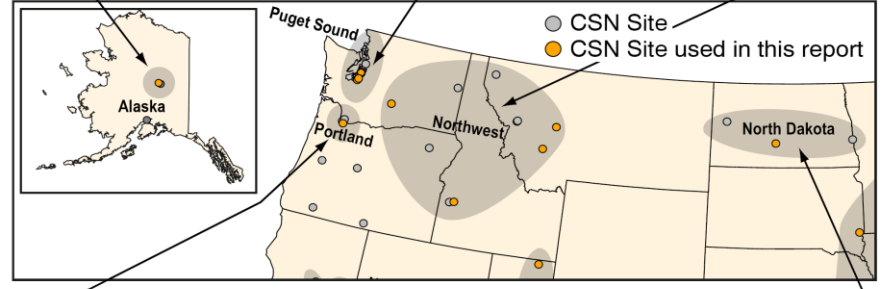
IMPROVE: Northwestern US (rural)



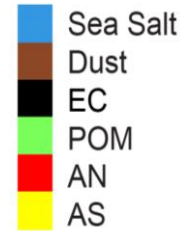
CSN



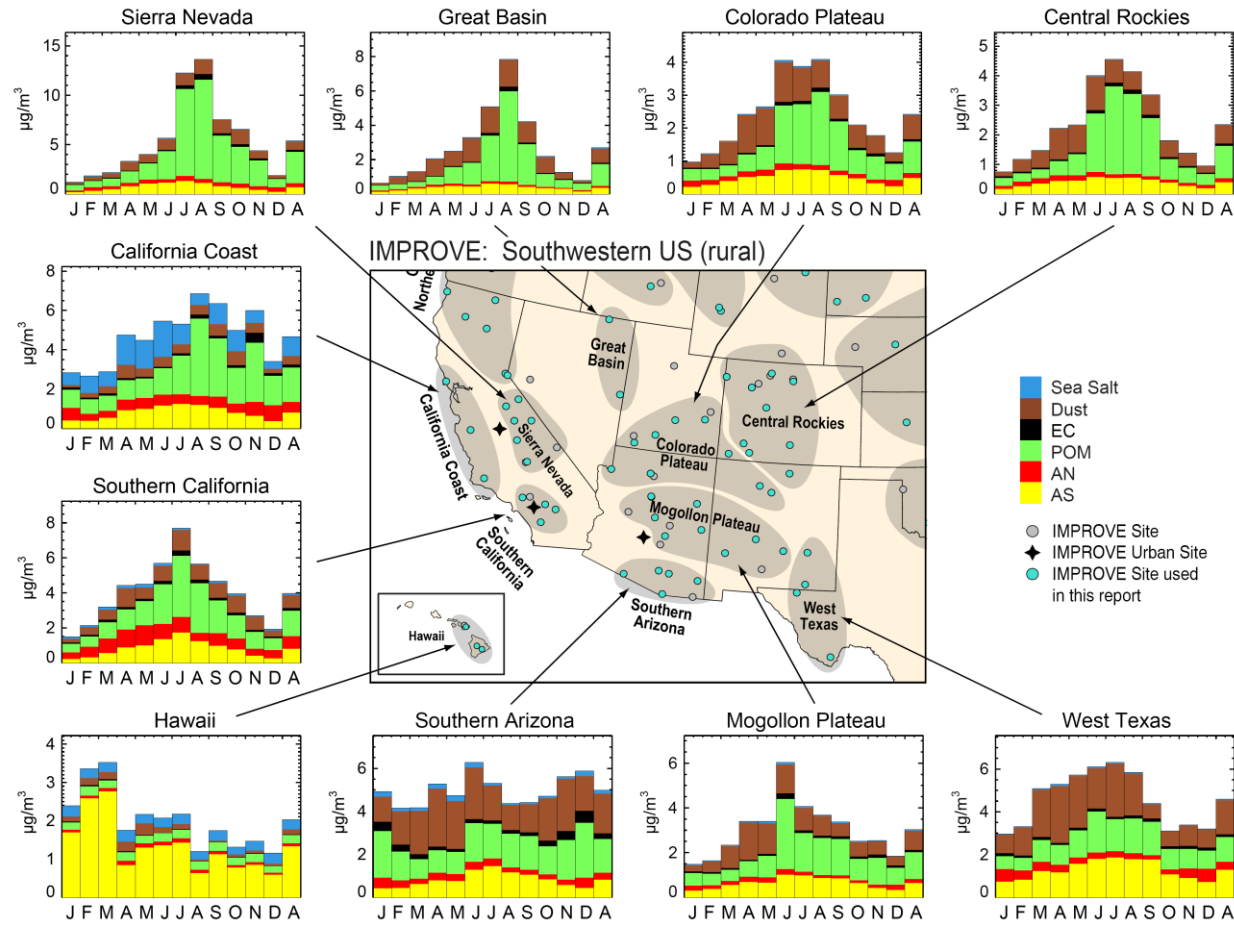
CSN: Northwestern US (urban)



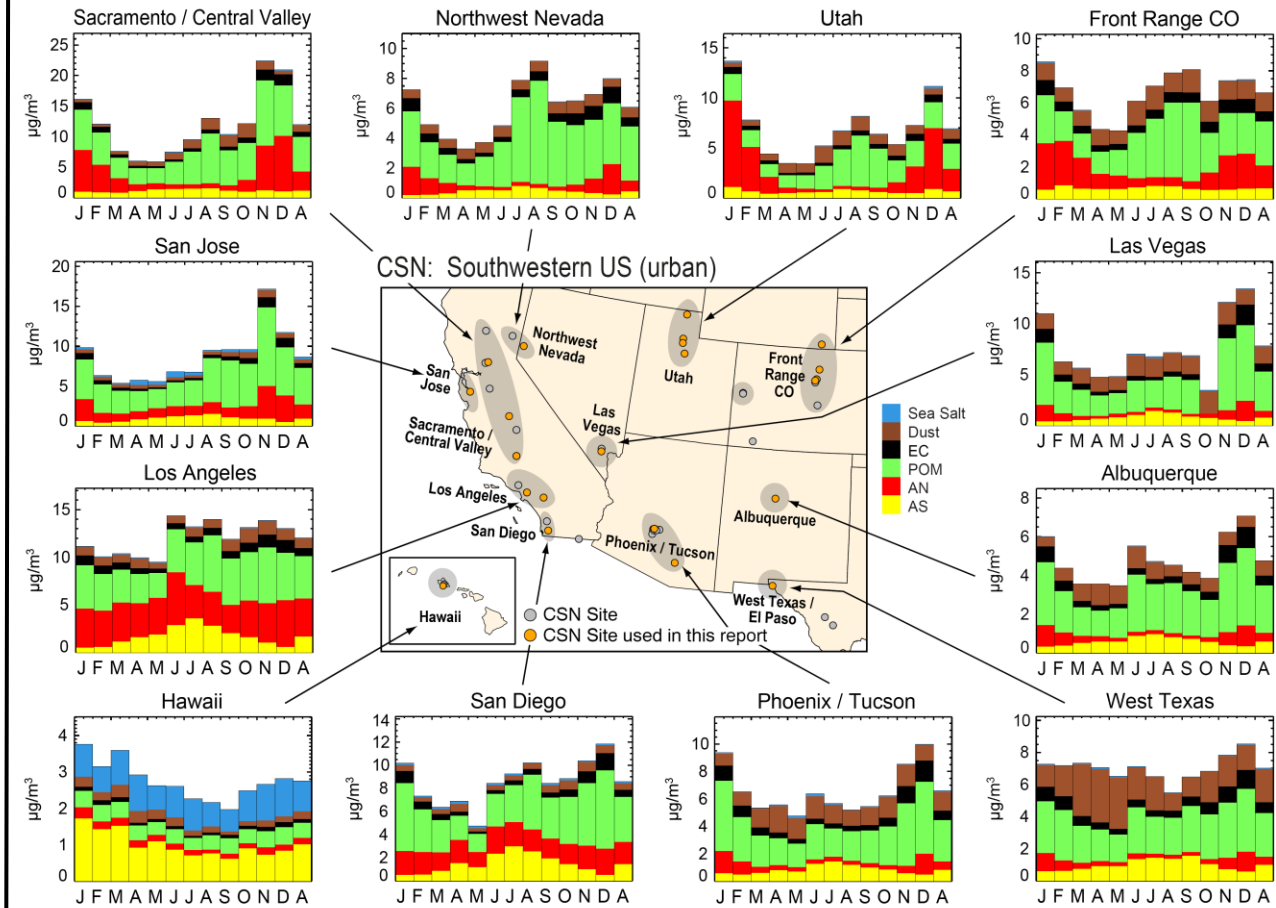
Southwestern U.S. mass concentration ($\mu\text{g m}^{-3}$)



IMPROVE



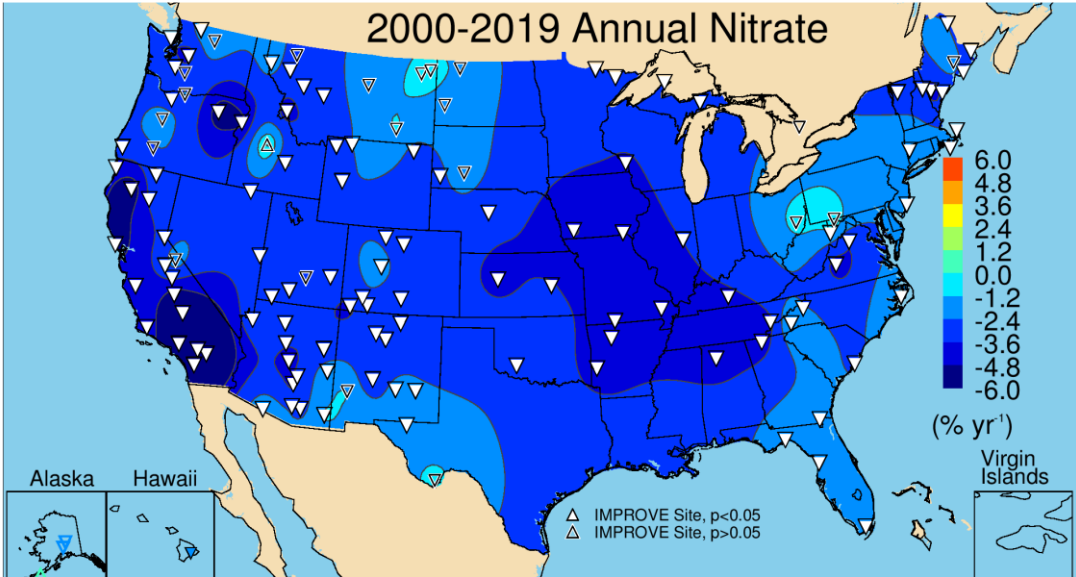
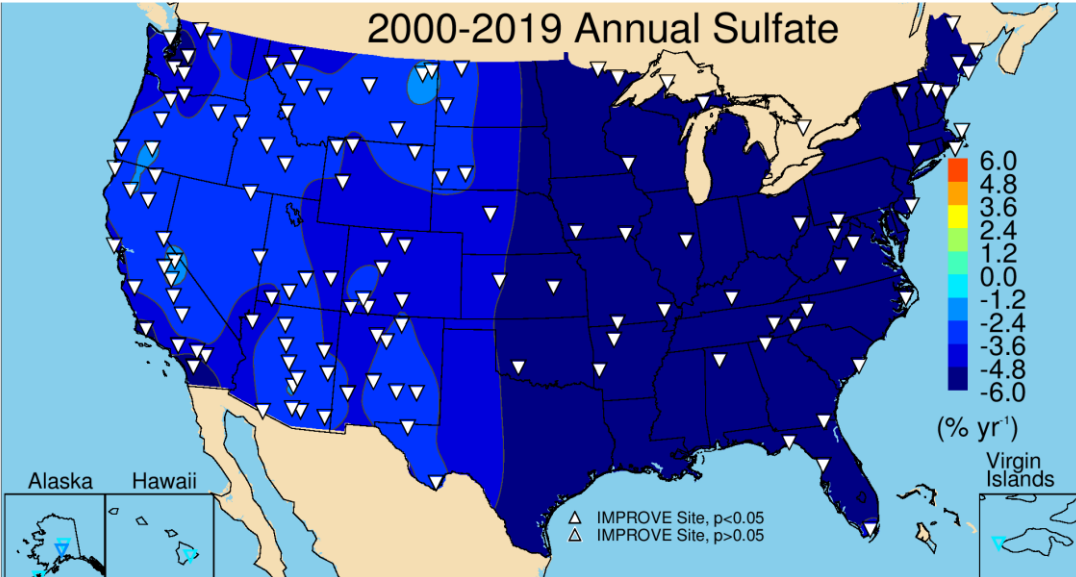
CSN



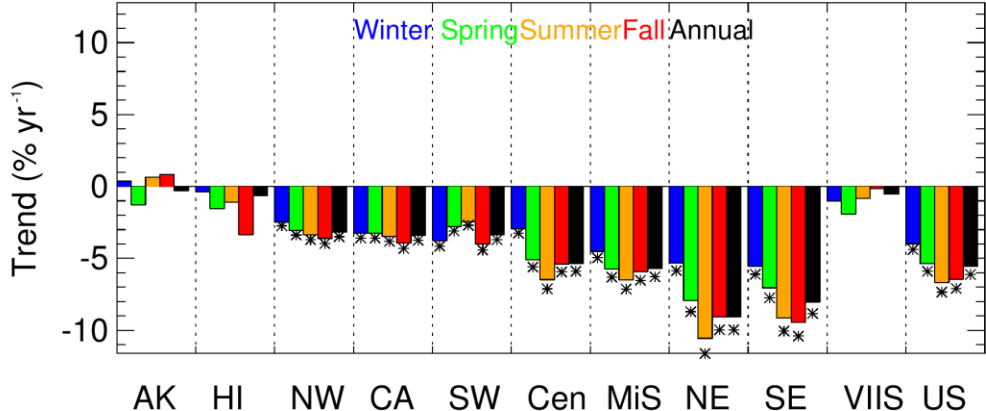
Short-term sulfate and nitrate trends (2000-2019)

Sulfate

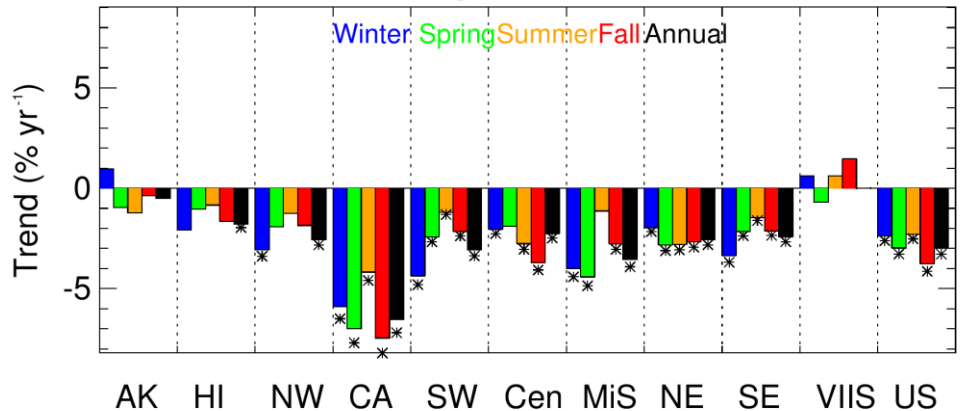
Nitrate



Sulfate Regional Mean Trend



Nitrate Regional Mean Trend

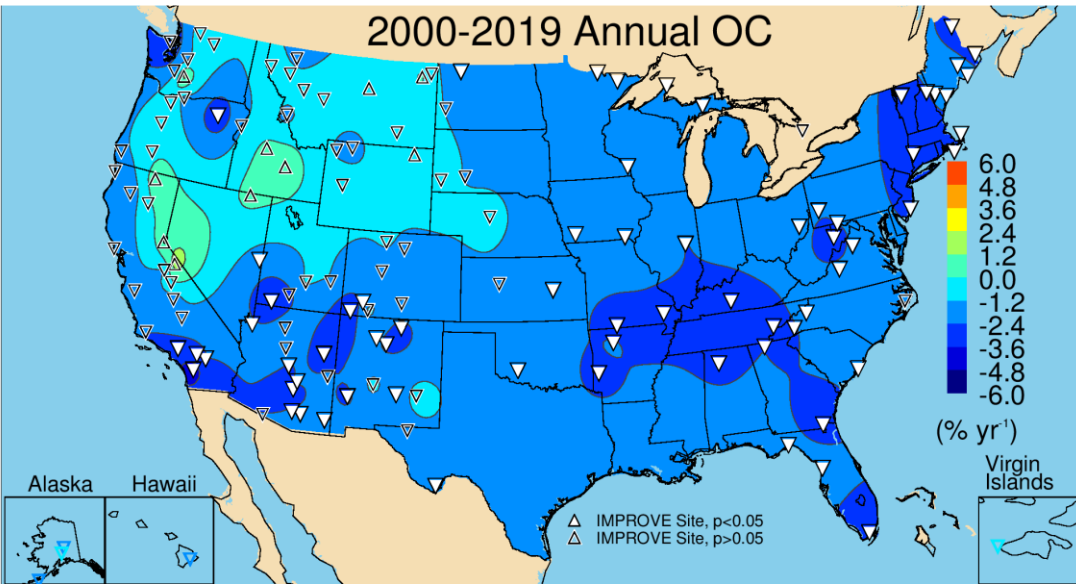


* p < 0.05

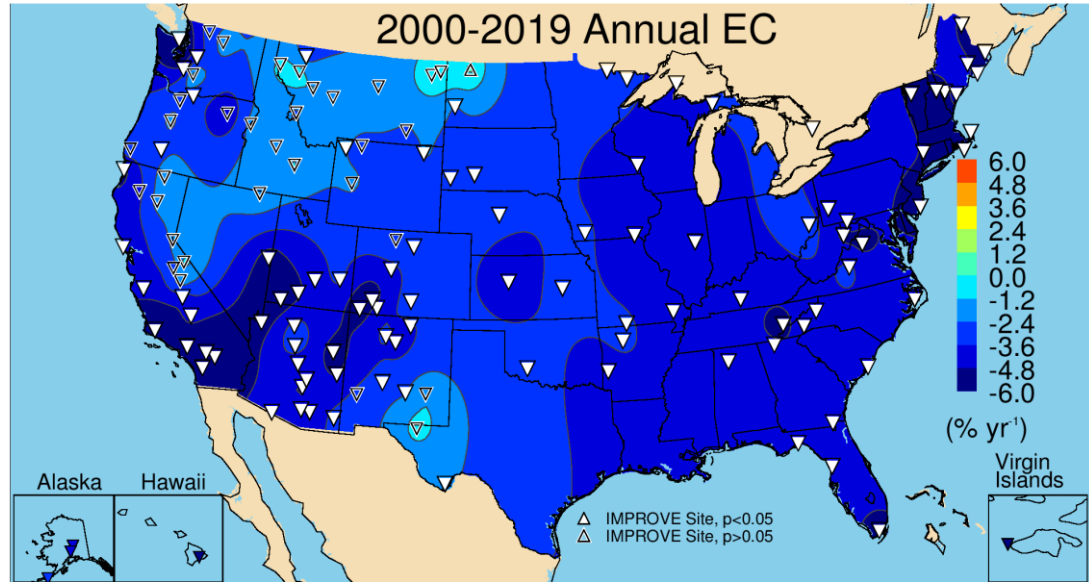
West → East

Short-term trends OC and EC trends (2000-2019)

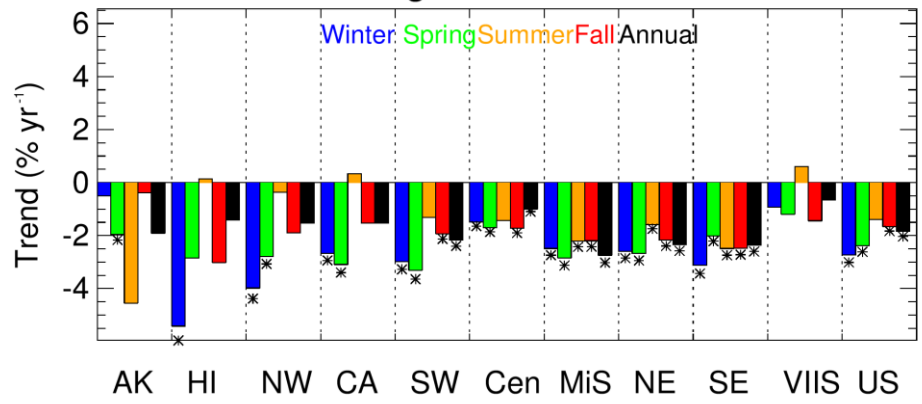
Organic Carbon



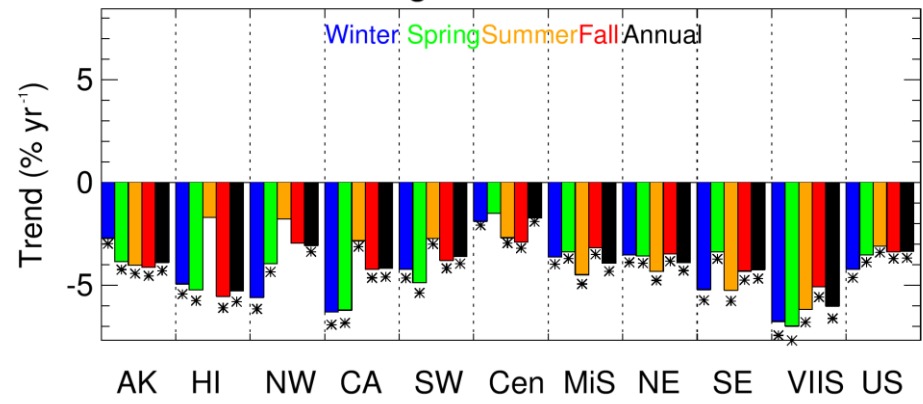
Elemental Carbon



OC Regional Mean Trend



EC Regional Mean Trend



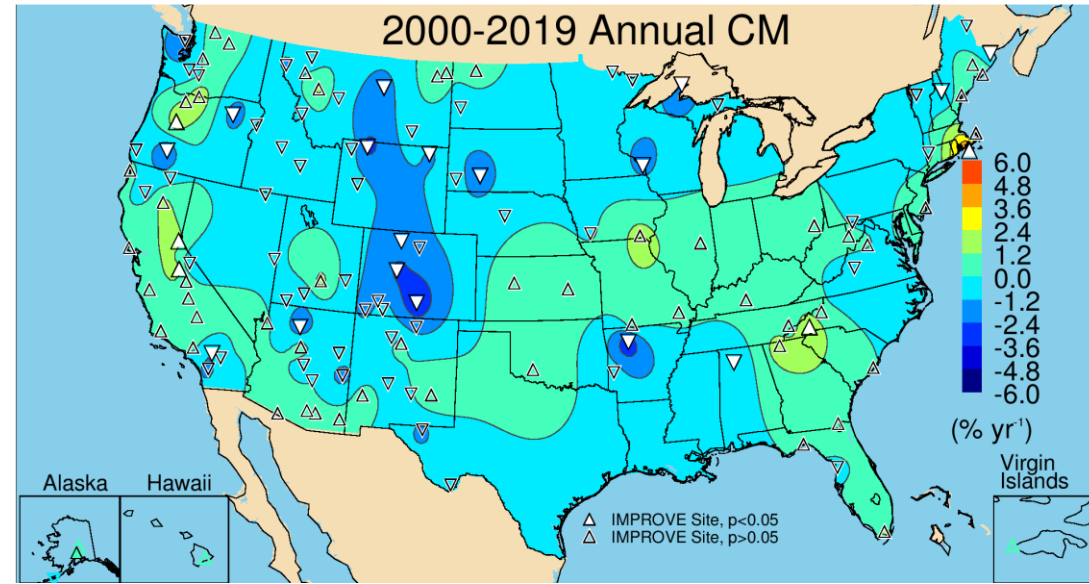
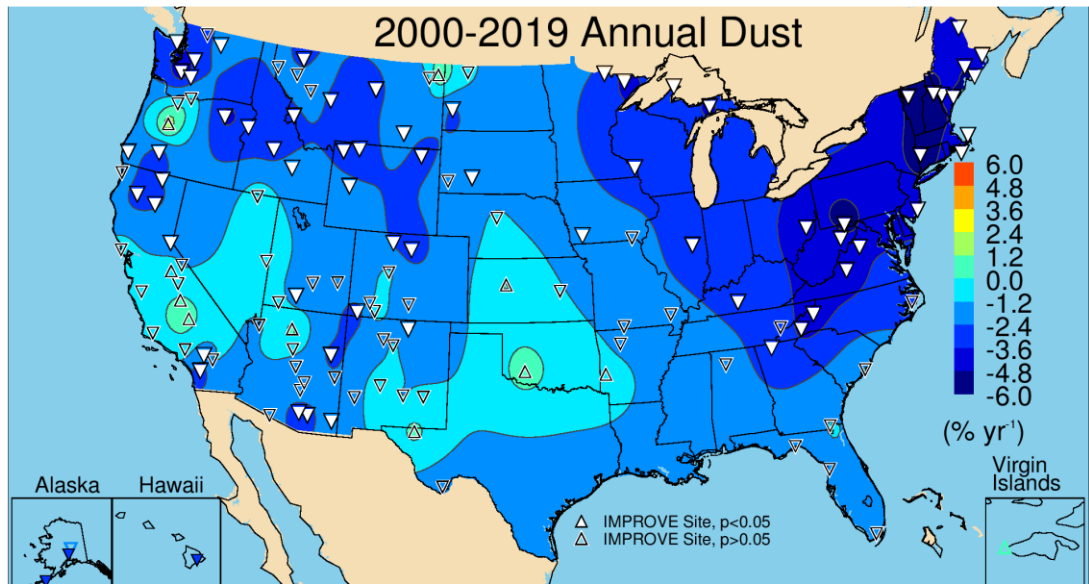
* p ≤ 0.05

West → East

Annual mean short-term trends (2000-2019)

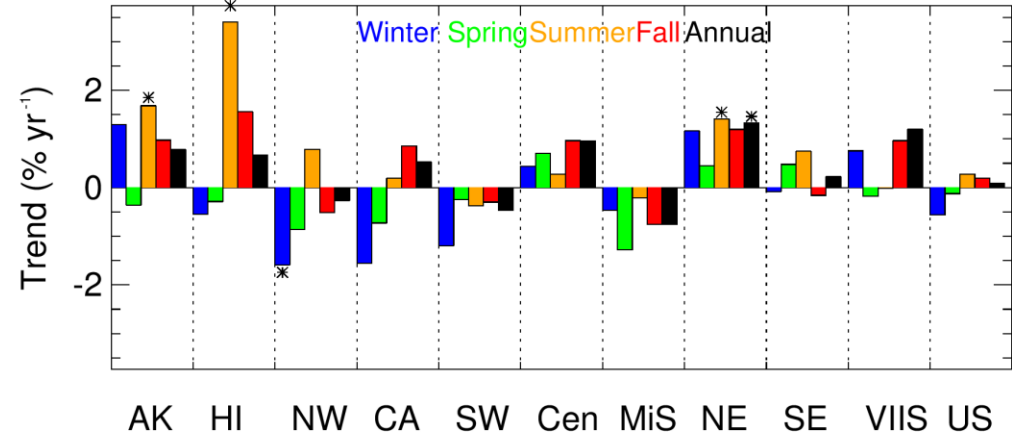
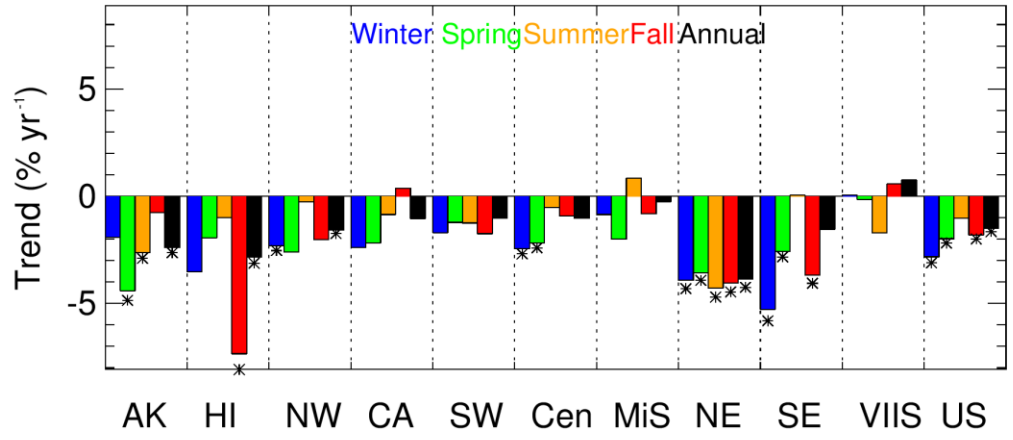
Fine Dust

Coarse Mass



Dust Regional Mean Trend

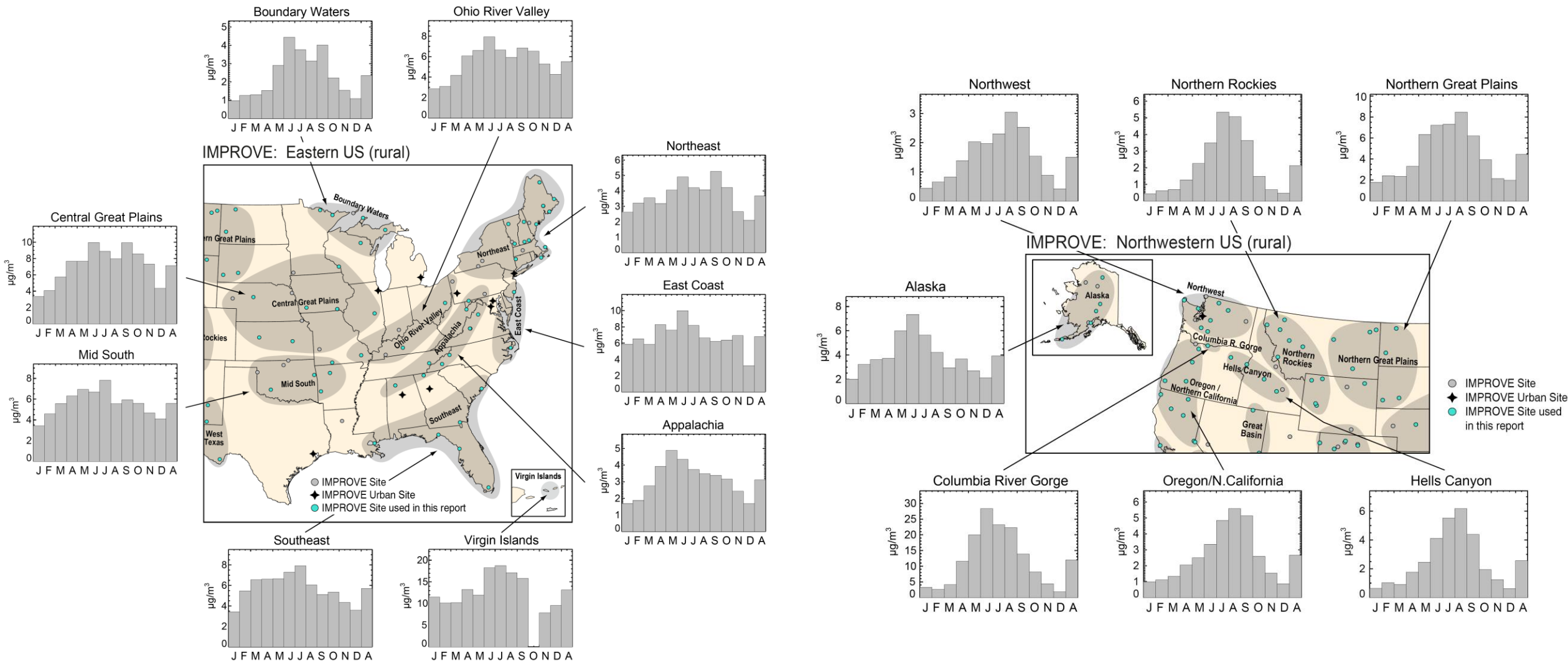
CM Regional Mean Trend



* p < 0.05

West → East

Coarse Mass- IMPROVE



Coarse Mass- IMPROVE

