Evaluation of Methods to Estimate Natural Visibility Conditions

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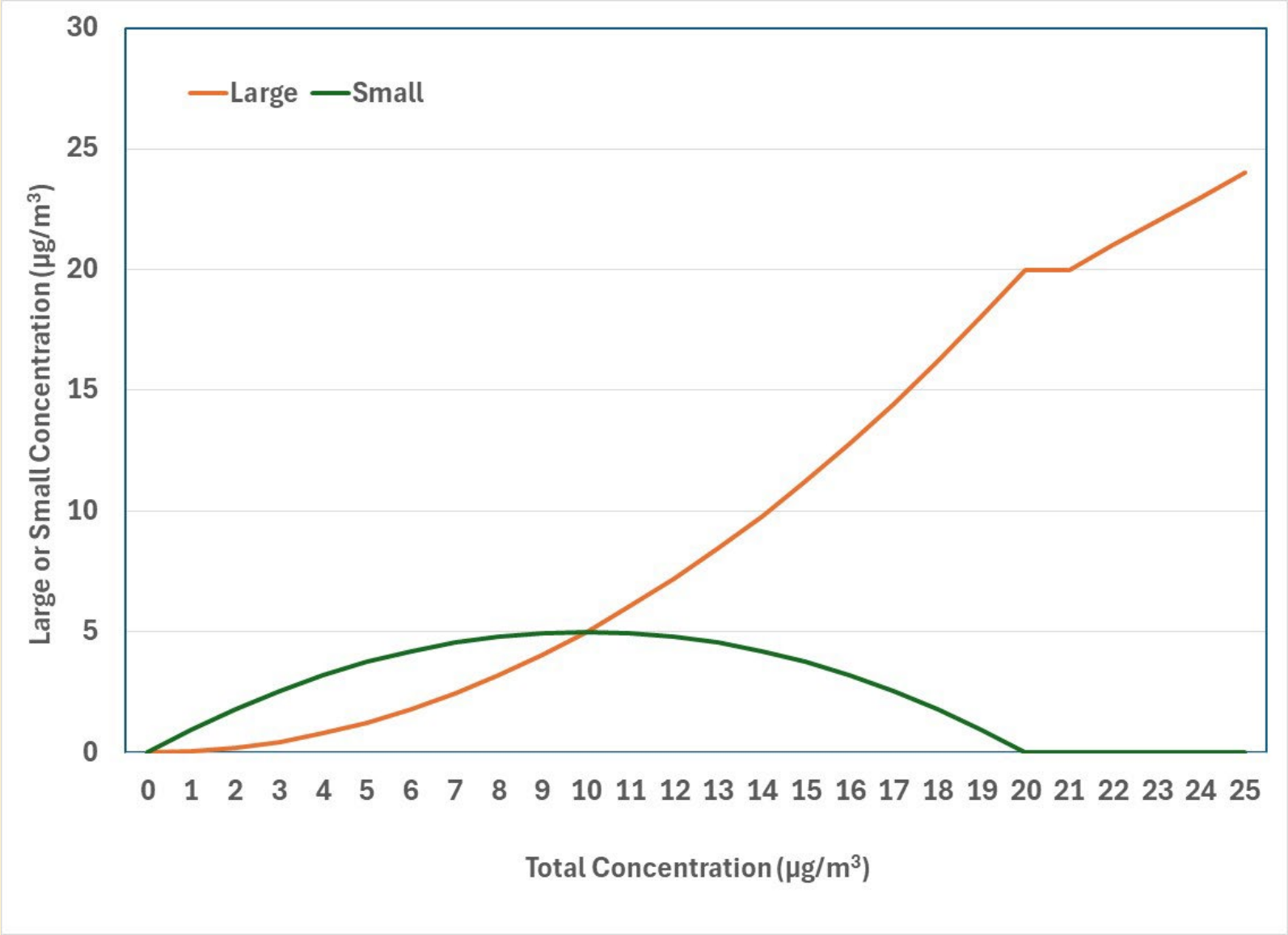
Objectives

- **Describe evolution of natural condition estimates applicable to the regional haze rule.**
- **Identify and summarize recent measurements of light extinction at remote locations.**
- **Summarize and evaluate modeling approaches to determine non-US influences.**
- **Provide recommendations for future natural condition estimates.**

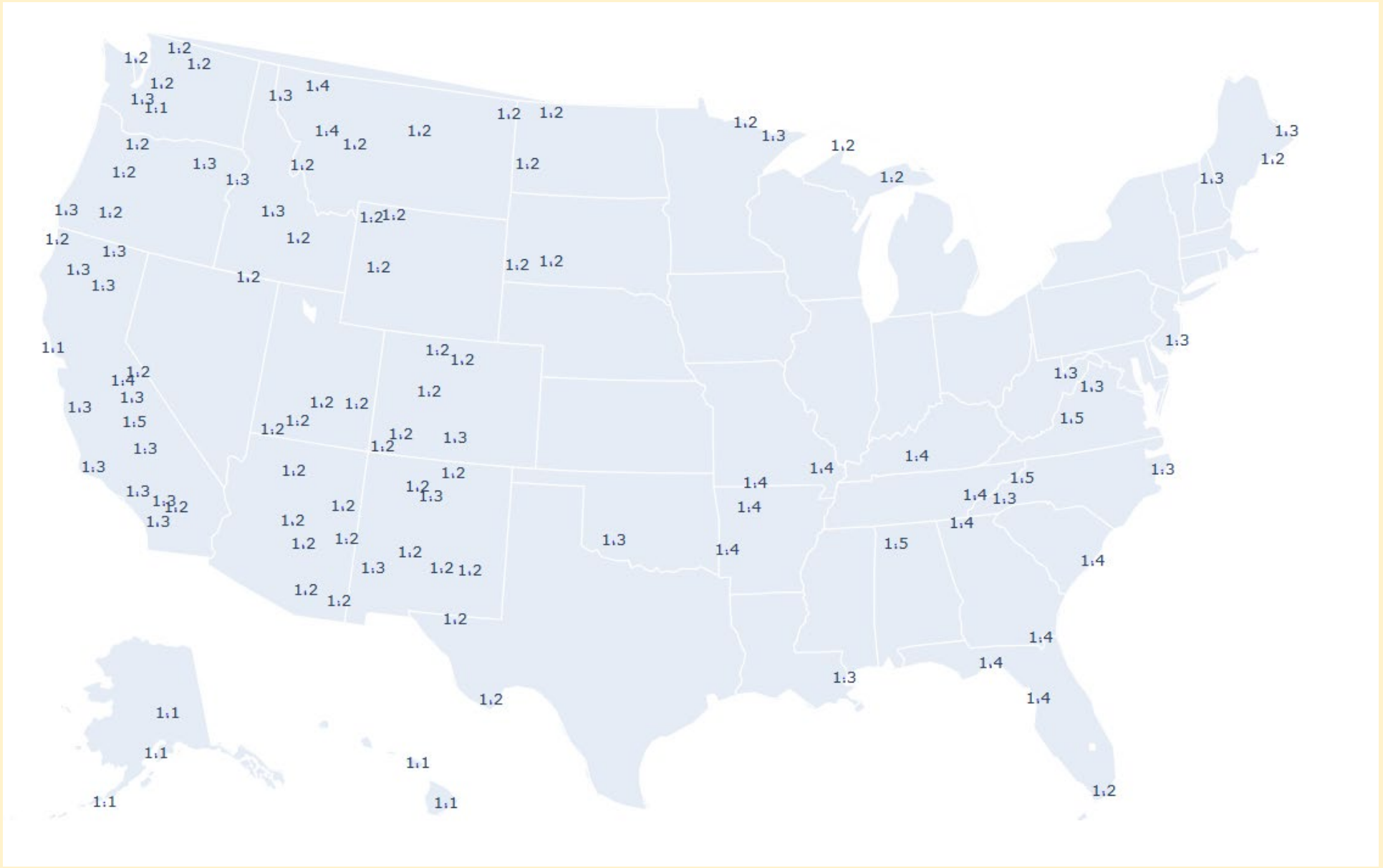
Natural conditions method evolution

- **1990 NAPAP estimates.** Average natural visibility levels (including water) were 27 Mm^{-1} for the eastern US and 17 Mm^{-1} for the western US. Factors of 2 and 3 uncertainty levels
- **2003 Guidance.** Rayleigh =10 Mm^{-1}, 1.4 OC multiplier, f(rh) curves for SO4 and NO_3, Integral extinction efficiencies, same NAPAP natural levels
- **2006 Assessment.** Add sea salt, 1.8 OC multiplier, site/month rh for f(rh), large and small SO_4, NO_3, OC extinction efficiencies, site specific Rayleigh, same f(rh)
- **2017/2018 Guidance.** Separate episodic natural, recurring natural, non-US from US anthropogenic contributions. Use minimum 95th%tile from 2000-2015 as threshold for Carbon and Dust events. Allocate recurring natural based on fraction of average for 1990 NAPAP background concentrations. Regional modeling to estimate non-US influences. Track chemical b_{ext} instead of deciviews

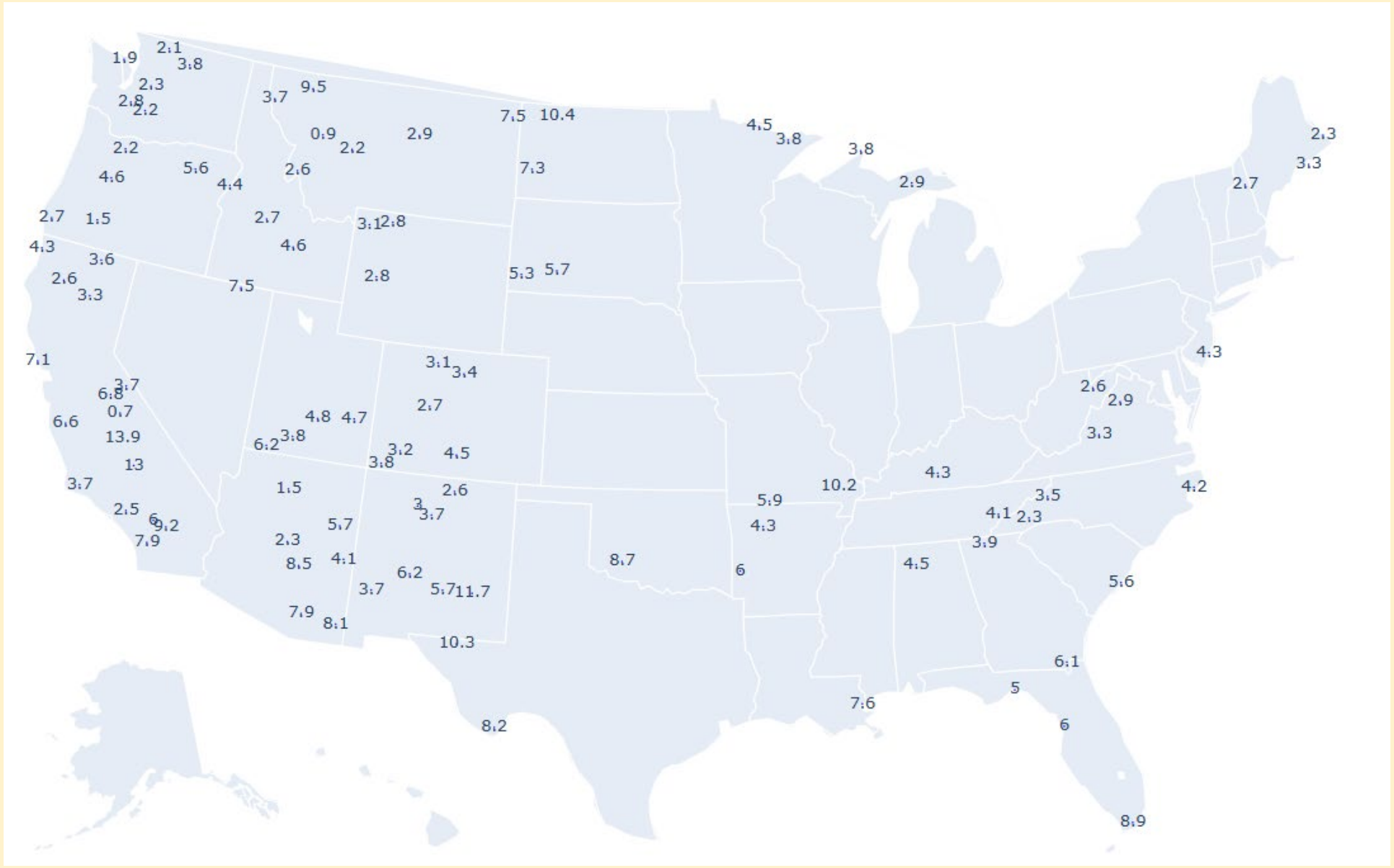
The current chemical extinction formula is dominated by the small fraction at normal levels, except for high carbon concentrations during wildfires



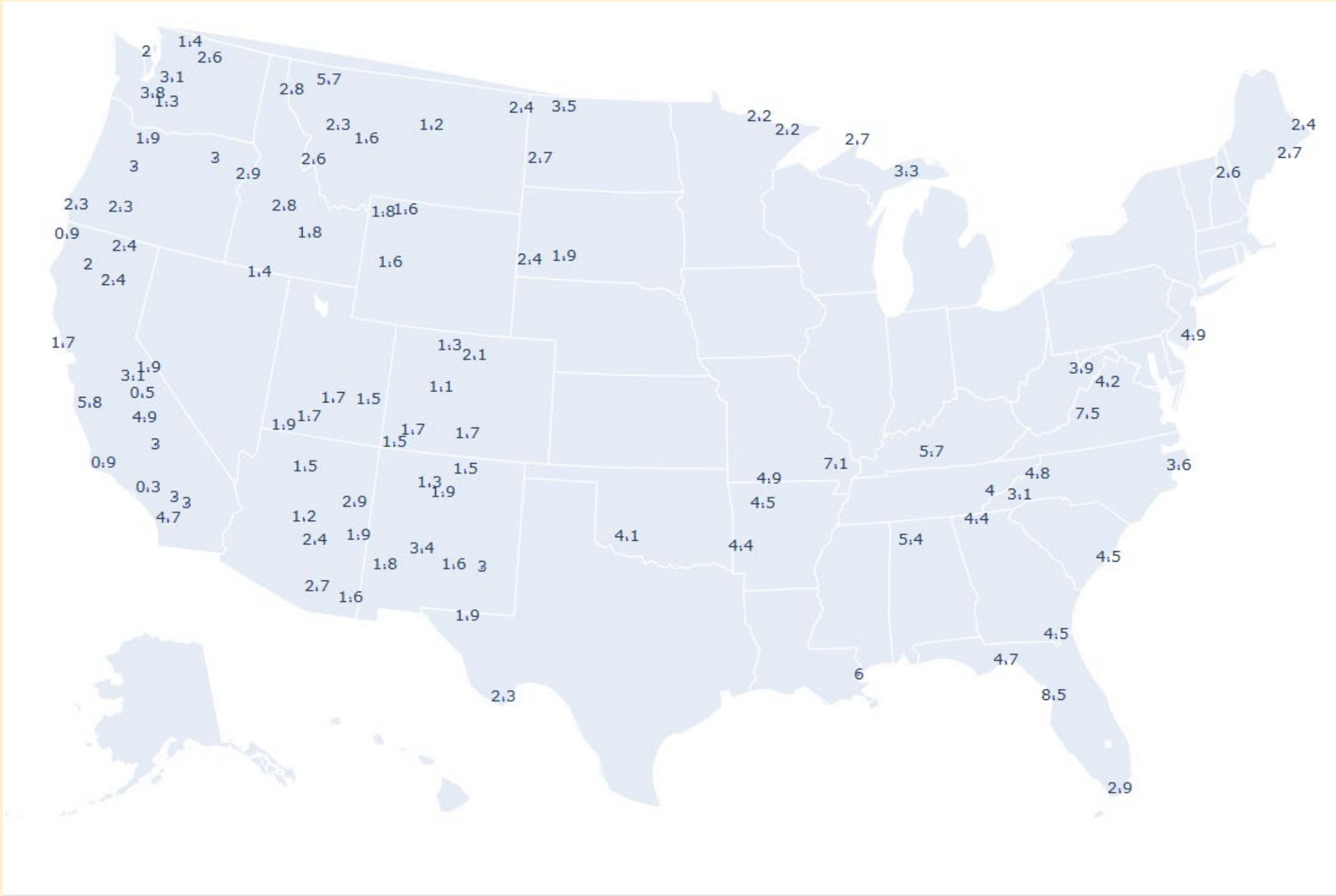
Ratio of old to new chemical b_{ext} (Mm^{-1}) for 2015-2024



Dust Thresholds (Mm^{-1}) for 2015-2024



Carbon Thresholds (Mm^{-1}) for 2015-2024



Conditions at Remote Locations

Global Atmospheric Watch (GAW) includes global scale background locations, but only a few report recent light scattering data in EBAS date base

Heated inlets, dry scattering

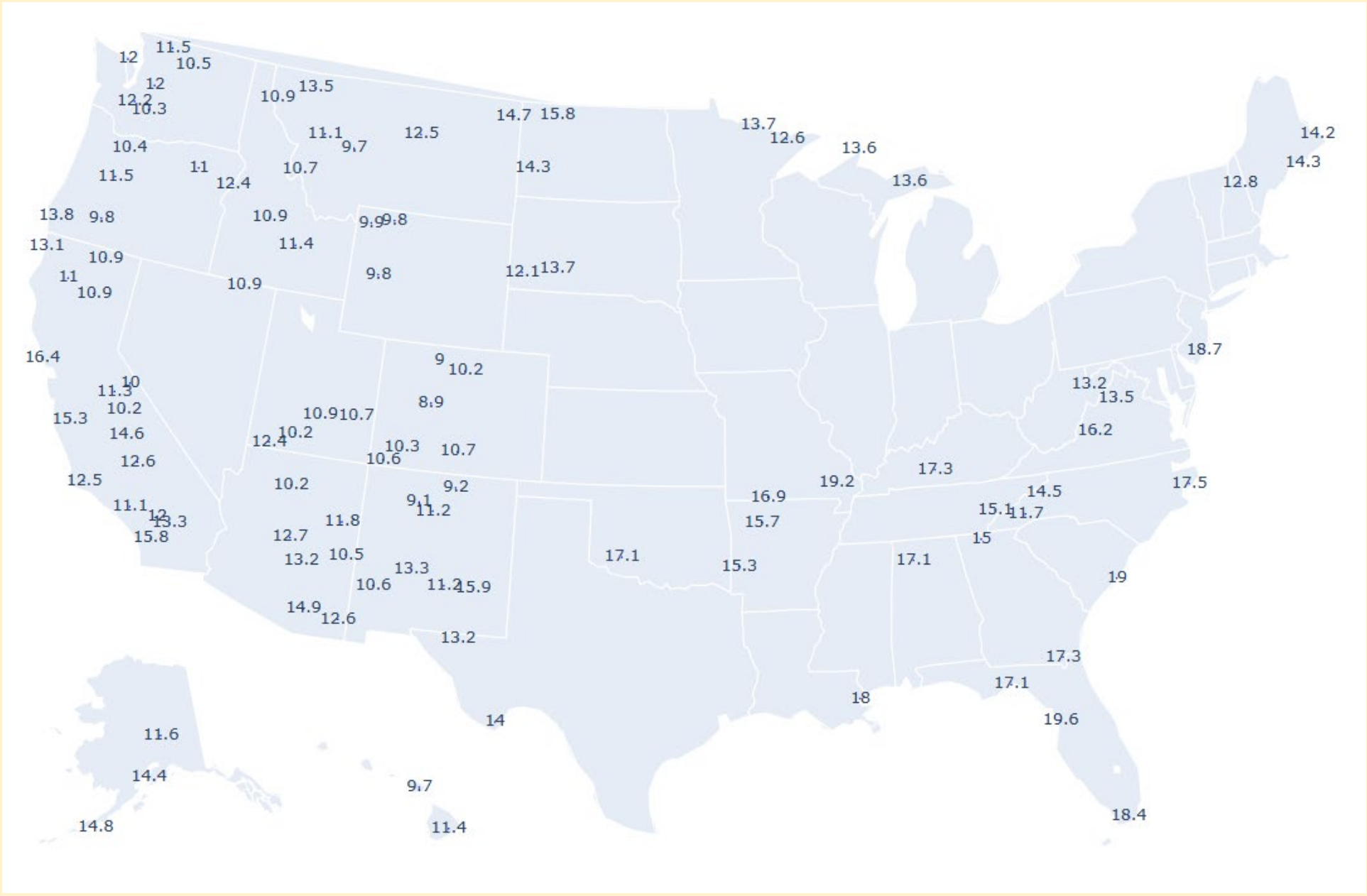
Multiple wavelengths

No absorption

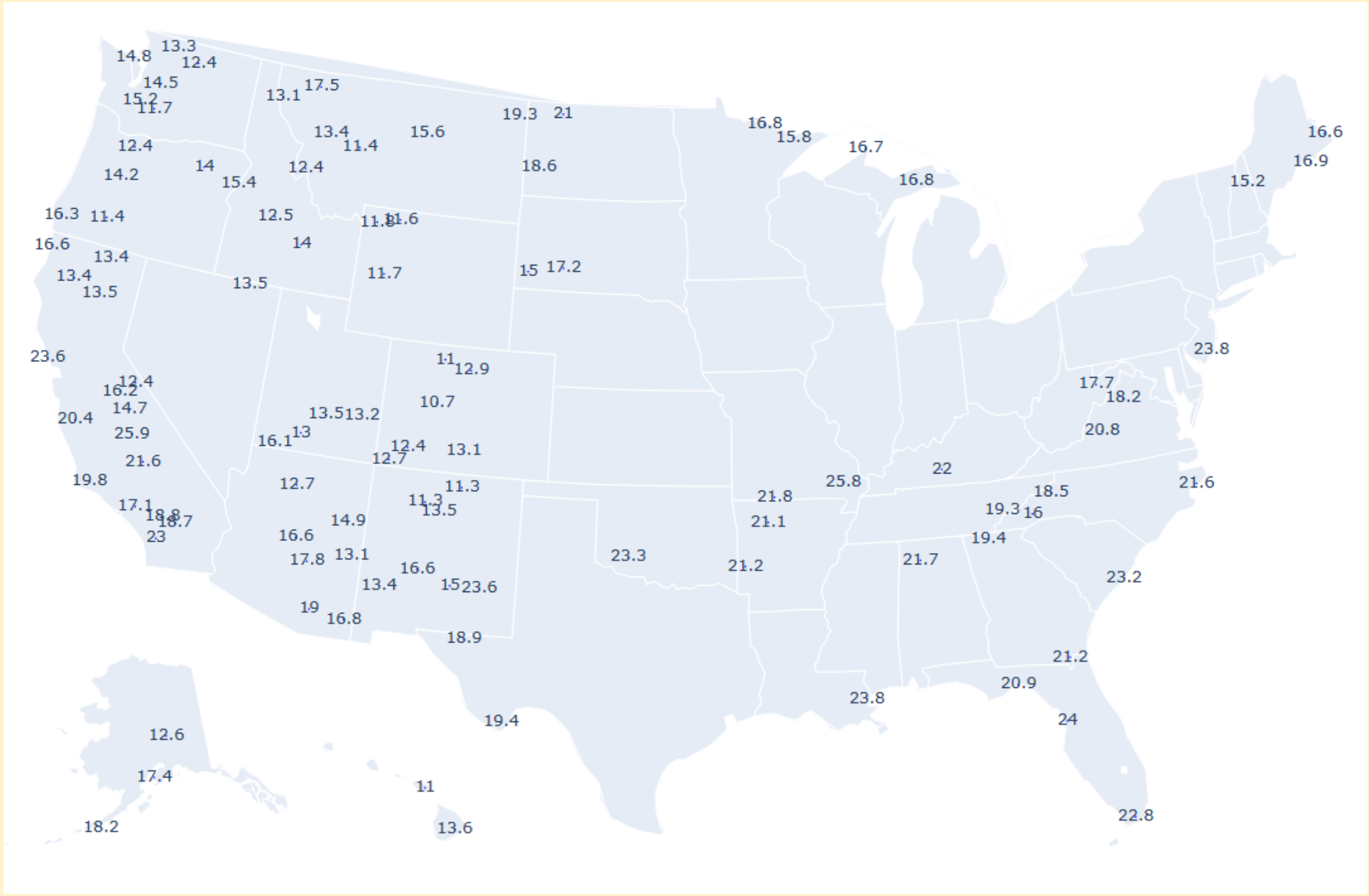
Particle scattering from 0 to ~10 Mm^{-1}

NILU, (2025). Welcome to EBAS. https://ebas-data.nilu.no/
https://ebas-data.nilu.no/Default.aspx
https://ebas.pages.nilu.no/ebas-io/fileformat_netcdf/index.html

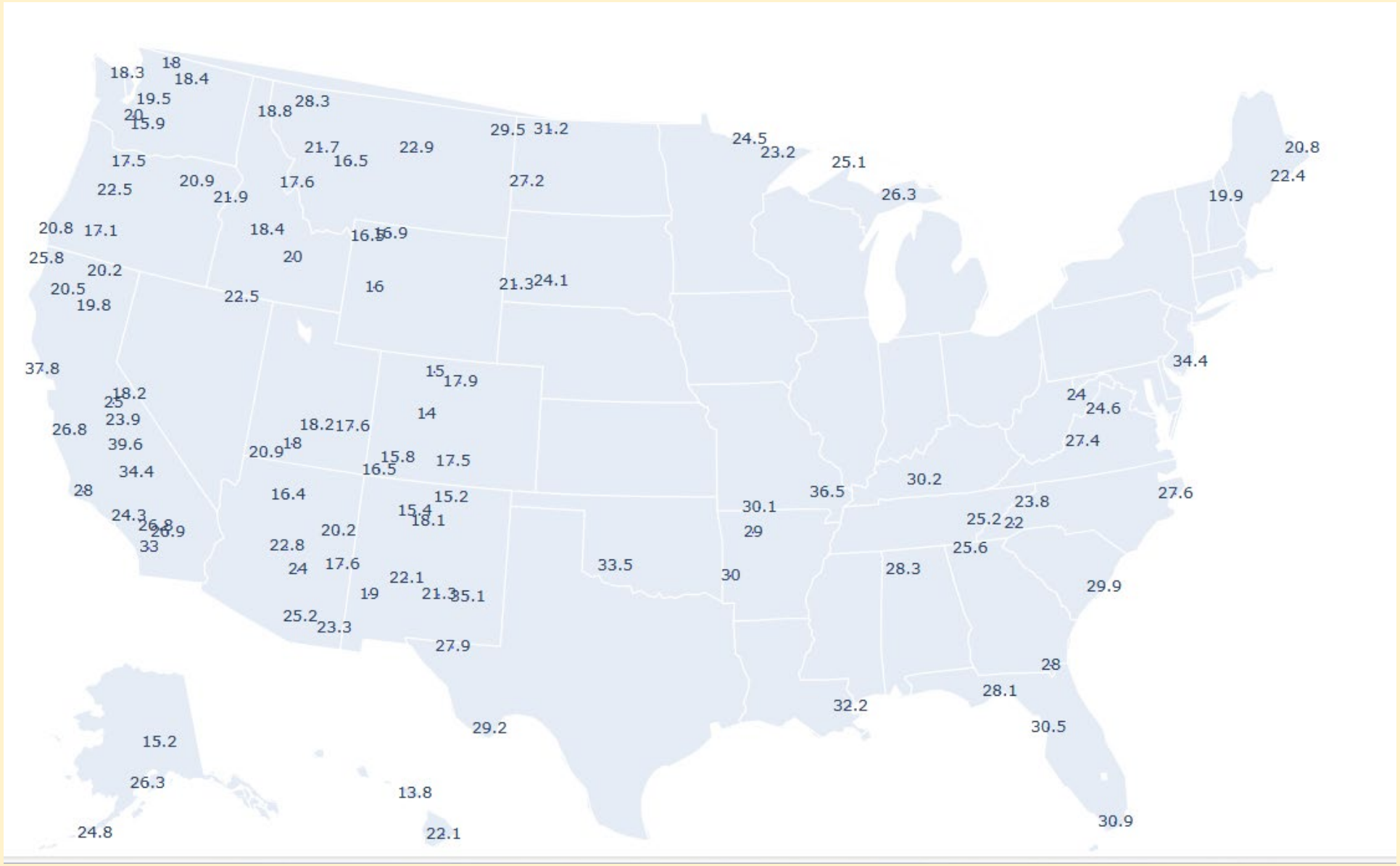
10^{th}% b_{ext} (Mm^{-1}) for 2015-2024



50th% b_{ext} (Mm^{-1}) for 2015-2024



$90^{th}\%\ b_{ext}\ (Mm^{-1})$ for 2015-2024



Modeling approaches

Table 1
Background and natural aerosol concentrations in the USA[a]

	Ammonium sulfate[b]		Ammonium nitrate		Elemental carbon		Organic carbon mass[c]	
	West	East	West	East	West	East	West	East
Background	0.50	0.86	0.06	0.12	0.04	0.03	0.54–0.68	0.41–0.77
Natural	0.17	0.17	0.01	0.01	0.01	0.01	0.39–0.58	0.22–0.65
Transboundary pollution	0.33	0.71	0.05	0.11	0.02	0.03	0.10	0.12
Canada & Mexico	0.22	0.53	0.04	0.09	0.01	0.02	0.08	0.10
Rest of world	0.11	0.15	0.01	0.02	0.01	0.01	0.02	0.02
EPA natural defaults[d]	0.12	0.23	0.10	0.10	0.02	0.02	0.47	1.40

[a]Concentrations are in $\mu g\,m^{-3}$. Values are annual means averaged at the ensemble of IMPROVE sites from the sensitivity simulations described in Section 2. Partitioning between west and east is at 95 °W. Background and natural concentrations are obtained from the sensitivity simulations without US and global anthropogenic emissions, respectively. Transboundary pollution influences from Canada and Mexico are determined by difference between two sensitivity simulations with anthropogenic emissions shut off in the USA versus in all of North America. Pollution influences from the rest of the world are determined by difference between two sensitivity simulations with anthropogenic sources shut off in all of North America versus globally. The ranges given for natural OMC aerosol concentrations correspond to the low and high limits discussed in Section 5.

[b]Sulfate concentrations computed by the model are converted here to equivalent ammonium sulfate mass concentrations for consistency with the formulation of the Regional Haze Rule (Eq . (2)).

[c]Organic carbon mass concentrations are derived by multiplying simulated OC concentrations by a factor of 1.4 (Malm et al., 1994).

[d]"Default average natural concentrations" recommended by US EPA (2003) for estimating natural visibility conditions as 2064 endpoint in the application of the EPA Regional Haze Rule.

- GEOS-CHEM Model for 2000
- US 1999 emissions inventory, 1999-2000 Global Emissions
- Natural emissions from volcanoes, lightning, biogenics, fires
- 4 x 5 degree global, 1x1 degree North America
- Mechanisms for anthropogenic and biogenic SOA formation

Park, R.J., Jacob, D.J., Kumar, N.K., Yantosca, R.M., (2006). Regional visibility statistics in the United States: Natural and transboundary pollution influences, and implications for the Regional Haze Rule. Atmospheric Environment, 40, 5405–5423.

2016 Modeling

- Intended to determine O_3 background levels, but aerosol components come along for the ride
- CAMx 7.2, Carbon Bond 6 chemistry
- 2016 Global and US gridded emissions of primary and precursor emissions
- Natural emissions from wildfires and biogenics
- 12 x 12 km spatial resolution
- Example non-US and natural sources to total for YOSE1

DatePST	PSO4	PNO3	PCL	FPRM	PFE	OM
10th	0.77	0.04	0.05	0.25	1.00	0.48
20th	0.84	0.05	0.08	0.37	1.00	0.60
50th	0.93	0.09	0.21	0.63	1.00	0.83
80th	0.98	0.19	0.52	0.84	1.00	0.93
90th	0.99	0.25	0.71	0.93	1.00	0.97

Hu, Y., Odman, M.T., Russell, A.G., Kumar, N., Knipping, E., (2022). Source apportionment of ozone and fine particulate matter in the United States for 2016 and 2028. Atmospheric Environment, 285, 10.1016/j.atmosenv.2022.119226.
Tran, T., Kumar, N., Knipping, E., (2023). Investigating sensitivity of ozone to emission reductions in the New York City (NYC) metropolitan and downwind areas. Atmospheric Environment, 301, 10.1016/j.atmosenv.2023.119675.

CAMx (µg/m^3)	IMPROVE (µg/m^3)	Definition
PSO4	SO4f	Sulfate
PNO3	NO3f	Particulate Nitrate
PNH4		Particulate Ammonium
PH2O		Aerosol Water Content
NA	NAf	Sodium
PCL	CLf	Particulate Chloride
PEC	ECf	Primary Elemental Carbon
FPRM		Fine Other/Unspecified Primary
FCRS	SOILf	Fine Crustal
CPRM	CM_calculated	Coarse Other/Unspecified Primary
CCRS	CM_calculated	Coarse Crustal
PFE	FEf	Iron
PMN	MNf	Manganese
PMG	MGf	Magnesium
PCA	CAf	Calcium
PAL	ALF	Aluminum
PK	Kf	Potassium
PSI	SIf	Silicon
PTI	TIf	Titanium
POA		Primary Organic Aerosol (direct emissions)
SOA1		Secondary Organic Aerosol from anthropogenic VOCs (low volatility bin)
SOA2		Secondary Organic Aerosol from anthropogenic VOCs (medium volatility bin)
SOA3		Secondary Organic Aerosol from anthropogenic VOCs (higher volatility bin)
SOA4		Secondary Organic Aerosol from biogenic VOCs (isoprene, monoterpenes)
SOPA		Semi-volatile Organic Aerosol from anthropogenic precursors
SOPB		Semi-volatile Organic Aerosol from biogenic precursors
POA+SOA1+SOA2+SOA3+SOA4+SOPA+SOPAB	OM (1.8xOC)	

Findings

- Recent data show that many sites are attaining dry b_{ext} close to or less than twice Rayleigh at the 90th percentile
- The lowest 10th percentiles indicate that lower levels than current natural estimates can be achieved
- Episodic events appear to be identifiable, but thresholds should be updated with more recent data
- 2016 model results seem to show bias toward non-US and natural emissions, site dependent