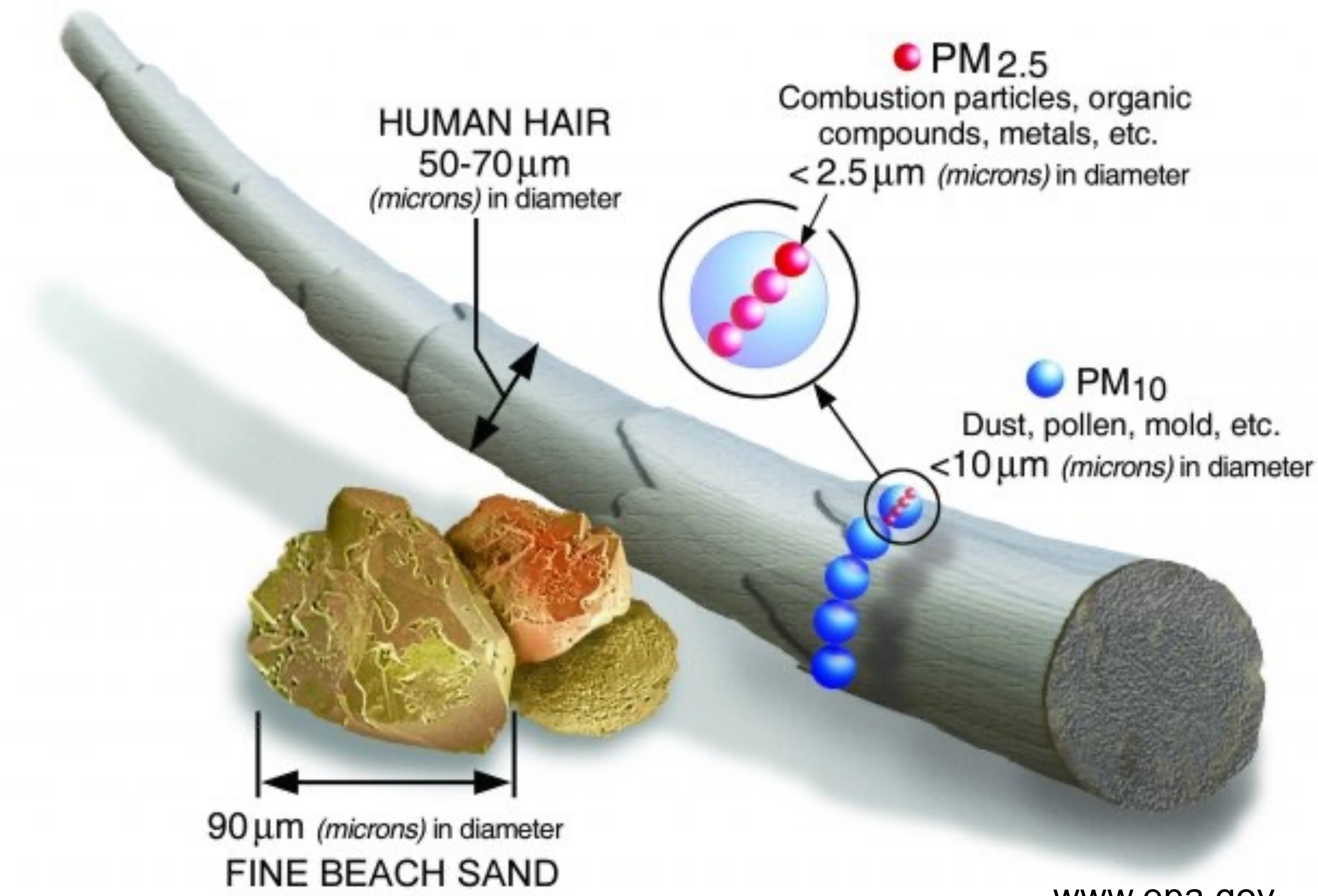
Estimates of submicron particulate matter (PM_1) concentrations for 1998-2022 across the contiguous United States

[Scan to read the paper]

Chi Li (chili@wustl.edu), Randall V. Martin, Aaron van Donkelaar, Jose L. Jimenez, Qi Zhang, Jay R. Turner, Xuan Liu, Mark Rowe, Jun Meng, Wuyue Yu, George D. Thurston

Is the widely used 2.5 µm cut-off size *too precise*?

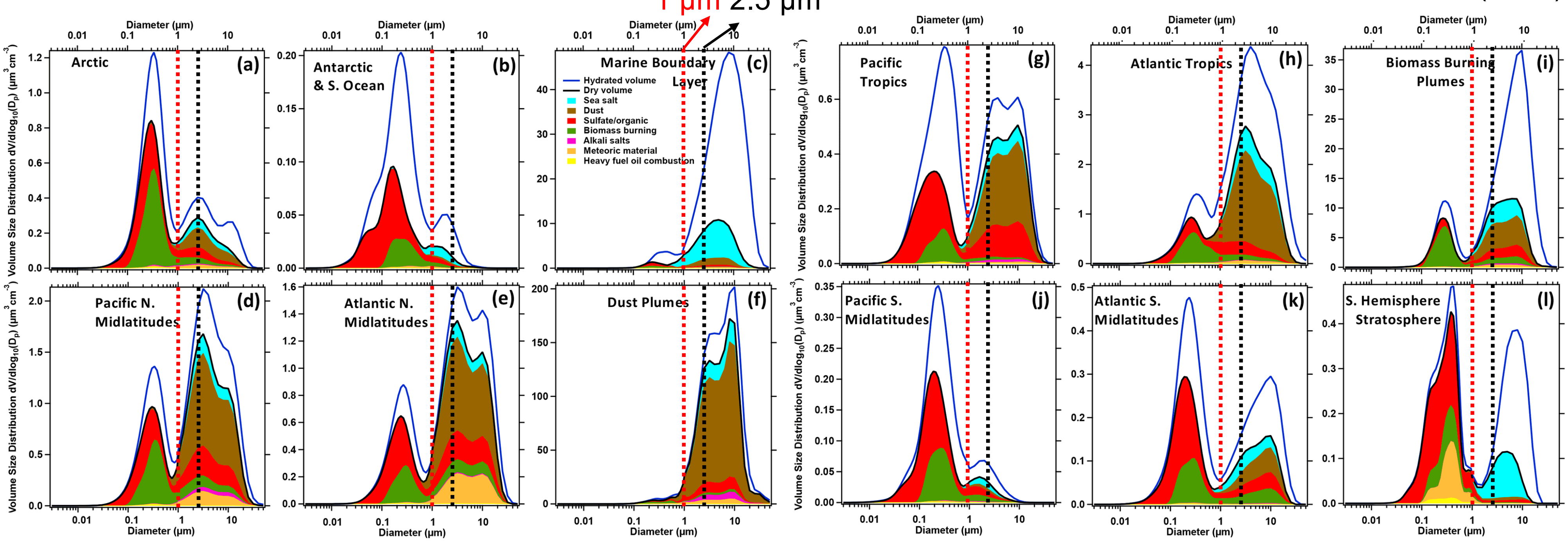


www.epa.gov

$PM_{2.5}$ includes significant coarse mass

ATOM observations of remote aerosols suggest smaller diameter as the division between fine and coarse modes.

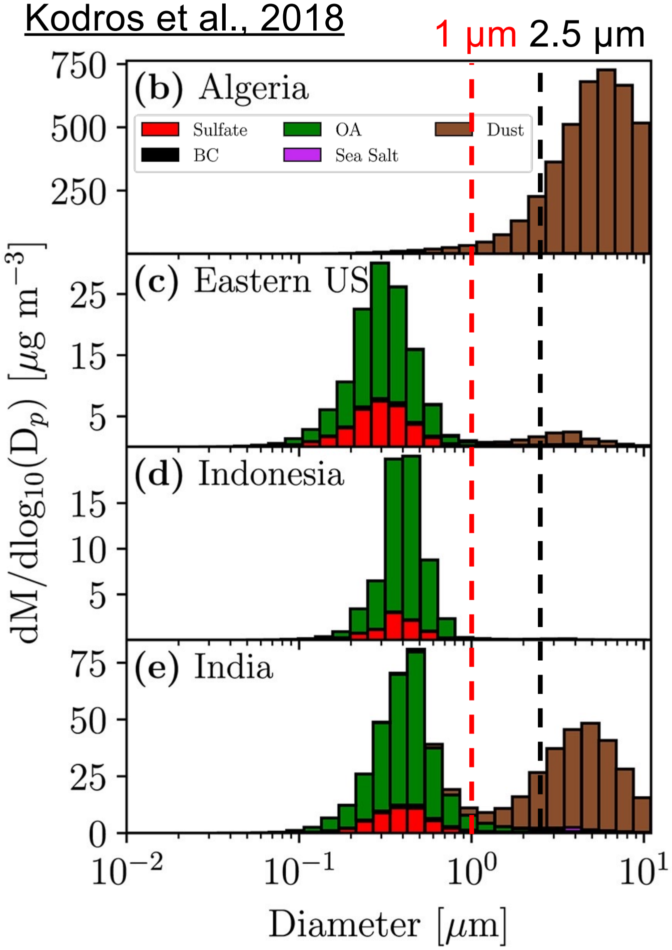
Brock et al. (2021)



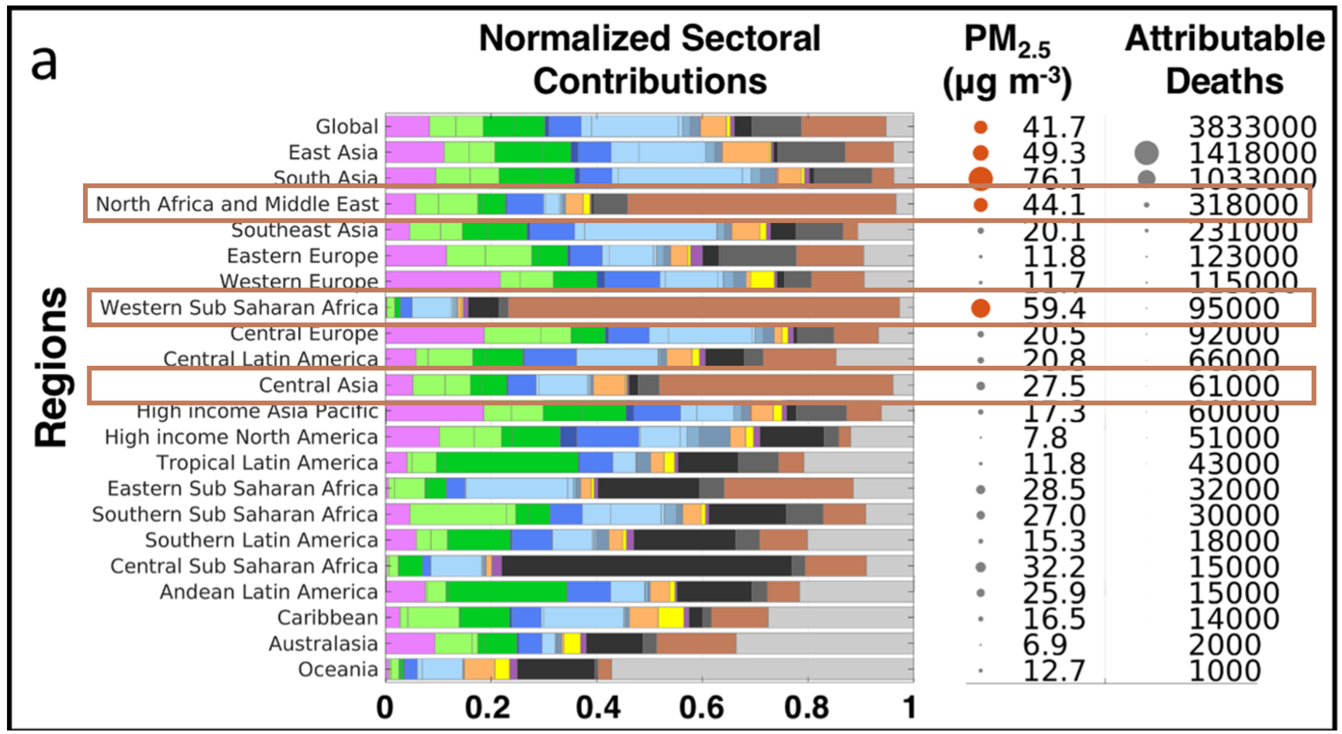
Similar conclusions from AERONET inversions of columnar aerosol (Mukhopadhyay et al., 2025)

Coarse-mode $PM_{2.5}$ is usually hard to regulate

Kodros et al., 2018



McDuffie et al. (2021)



PM_1 is a tentative leverage of mitigation efficiency, toxicity, and cost

PM_1

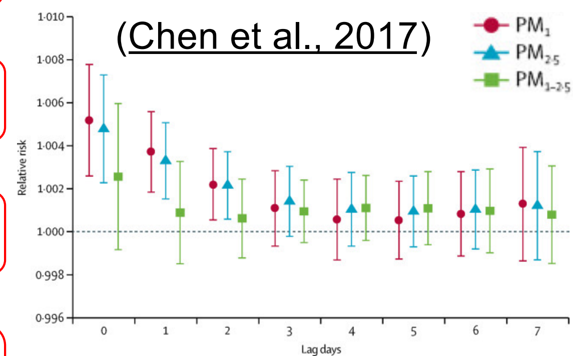
$PM_{2.5}$

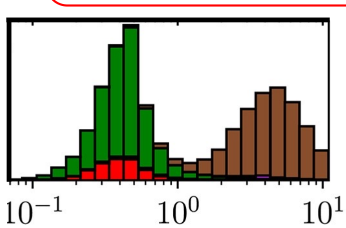
Similar/stronger interaction with satellite signal

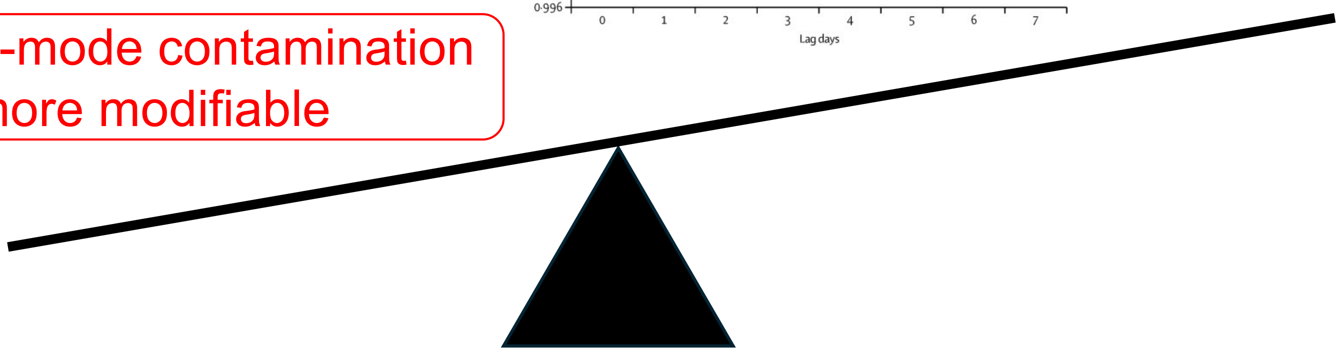
Similar ground monitoring cost

Possibly stronger toxicity

Less coarse-mode contamination and more modifiable





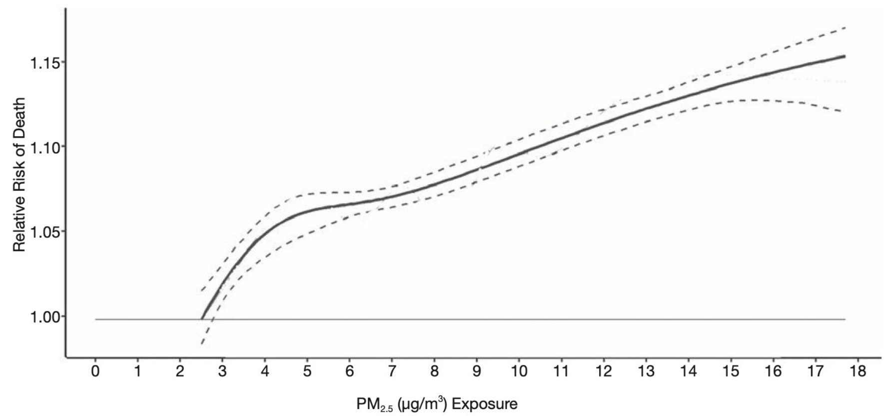


Can we follow the successful $PM_{2.5}$ research story?

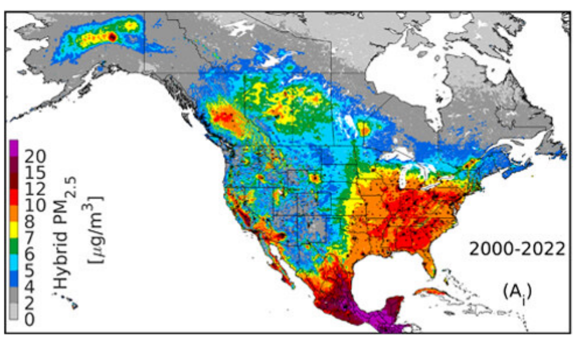
HAQAST

$PM_{2.5}$ monitoring

Health and AQ studies



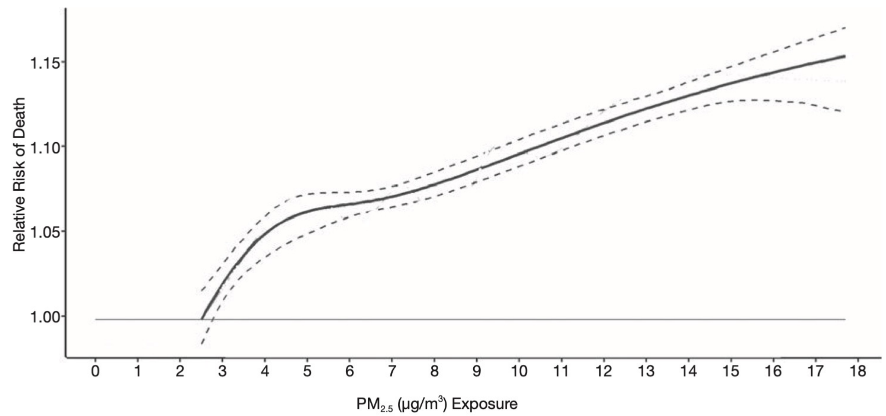
$PM_{2.5}$ estimates



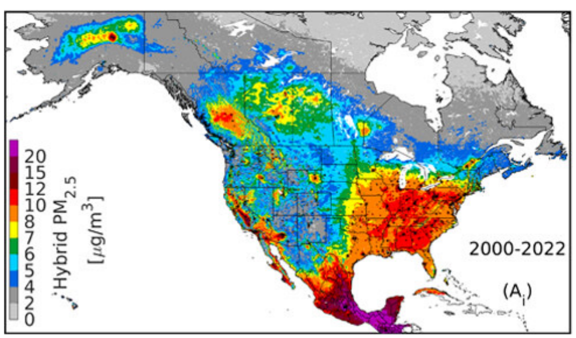
Can we follow the successful $PM_{2.5}$ research story?

$PM_{2.5}$ monitoring

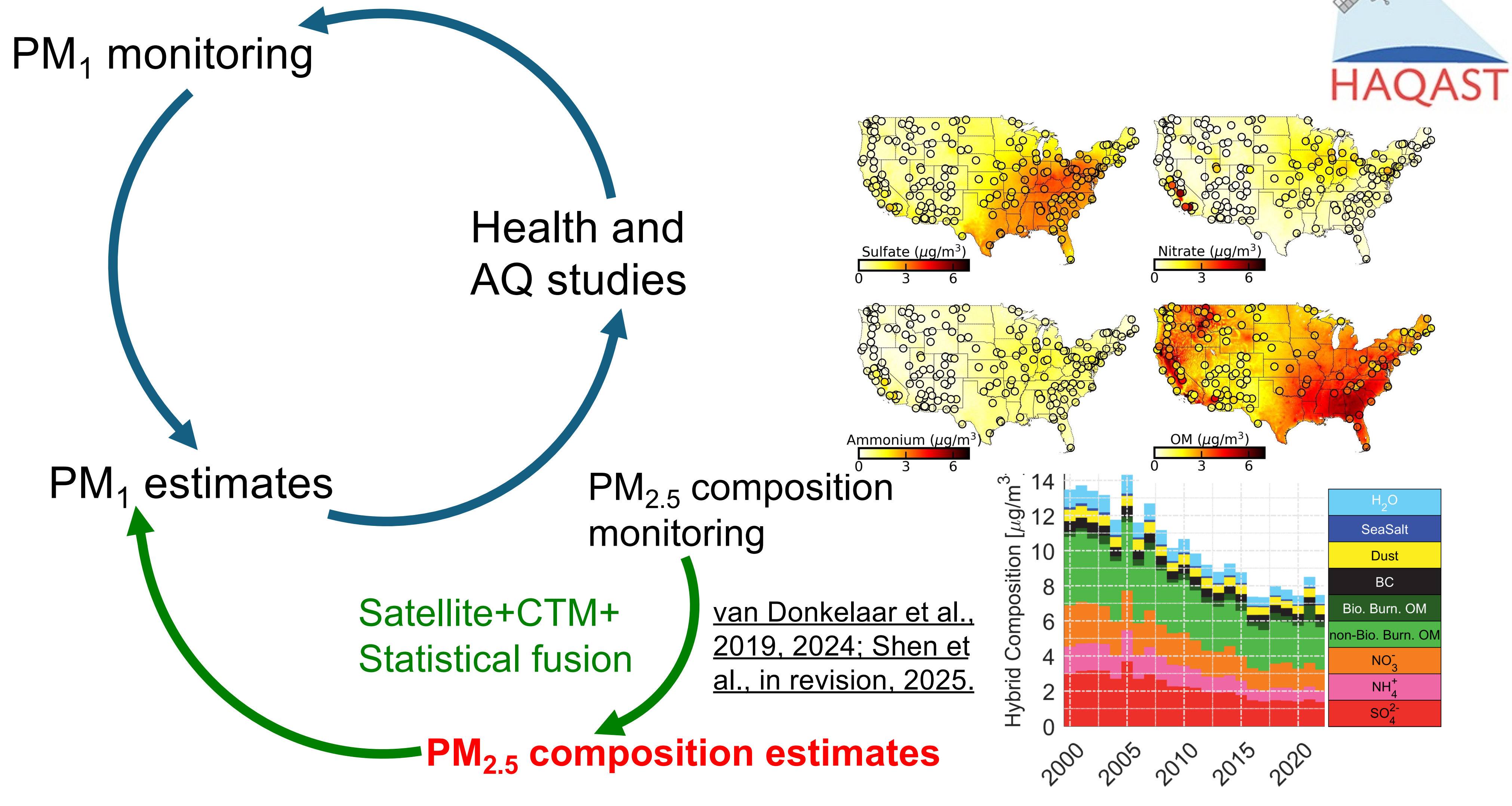
Health and AQ studies



$PM_{2.5}$ estimates



Gear up PM_1 research with $PM_{2.5}$ composition



Estimate PM_1 from $PM_{2.5}$ composition

$$[PM_1] = \sum_S k_S \times [S]$$

S: $PM_{2.5}$ component

k_s: fraction of mass in PM_1 for each $PM_{2.5}$ component

HAQAST

Li et al., *LPH*, 2025

Estimate PM_1 from $PM_{2.5}$ composition

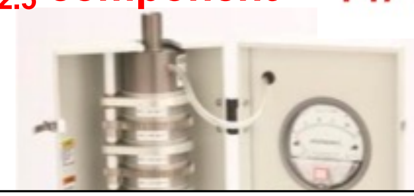
$$[PM_1] = \sum_S k_S \times [S]$$

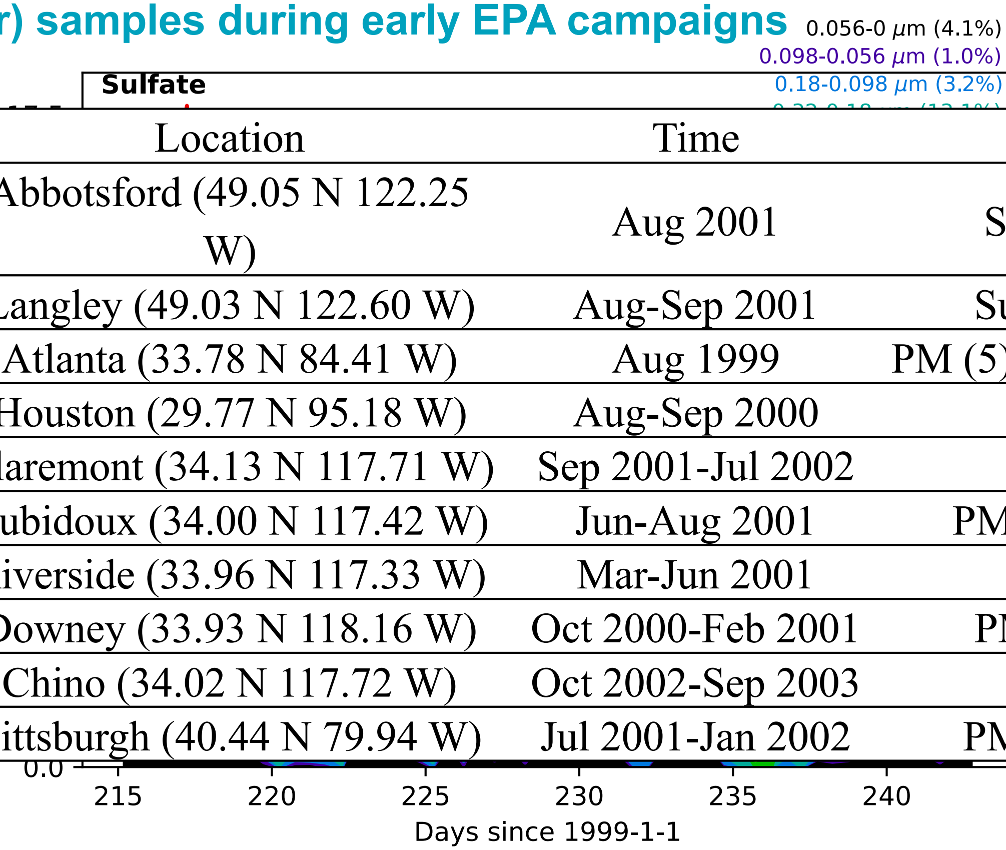
S: $PM_{2.5}$ component

k_S: fraction of mass in PM_1 for each $PM_{2.5}$ component

HAQAST

Source 2: Chemical analysis of MOUDI (microorifice uniform deposit impactor) samples during early EPA campaigns

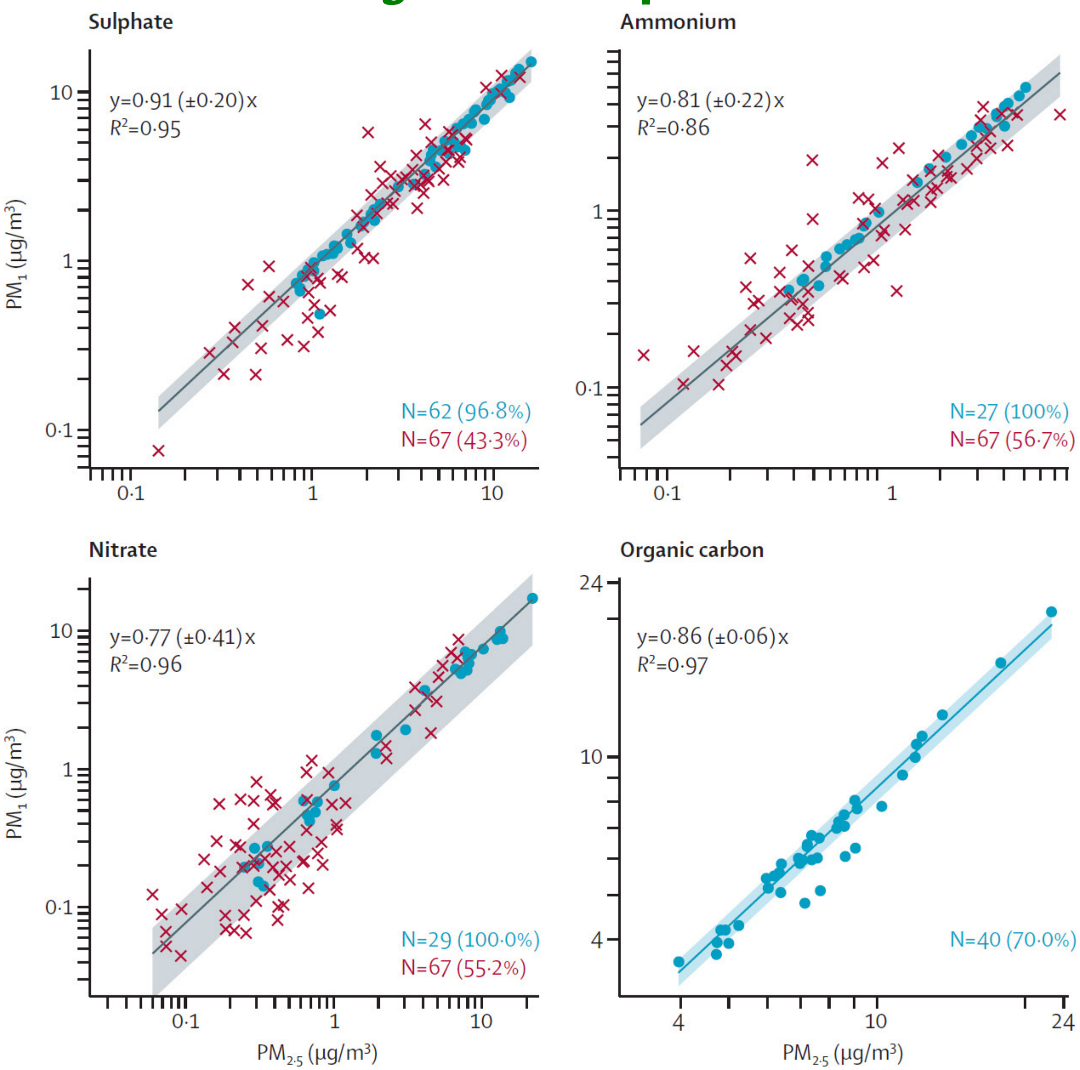




Location	Time	Measured components (# days)
Abbotsford (49.05 N 122.25 W)	Aug 2001	Sulfate (6), Ammonium (5), Nitrate (1)
Langley (49.03 N 122.60 W)	Aug-Sep 2001	Sulfate (11), Ammonium (9), Nitrate (9)
Atlanta (33.78 N 84.41 W)	Aug 1999	PM (5), Sulfate (24), Ammonium (13), Nitrate (2)
Houston (29.77 N 95.18 W)	Aug-Sep 2000	PM (28)
Claremont (34.13 N 117.71 W)	Sep 2001-Jul 2002	OC (8)
Rubidoux (34.00 N 117.42 W)	Jun-Aug 2001	PM (12), Sulfate (10), Nitrate (10), OC (3)
Riverside (33.96 N 117.33 W)	Mar-Jun 2001	PM (15), OC (9)
Downey (33.93 N 118.16 W)	Oct 2000-Feb 2001	PM (11), Sulfate (8), Nitrate (5), OC (5)
Chino (34.02 N 117.72 W)	Oct 2002-Sep 2003	PM (32), OC (13)
Pittsburgh (40.44 N 79.94 W)	Jul 2001-Jan 2002	PM (202), Sulfate (3), Nitrate (2), OC (2)

Li et al., *LPH*, 2025

Determine k_s for PM_1 estimation



$$[PM_1] = \sum_{S} k_S \times [S]$$

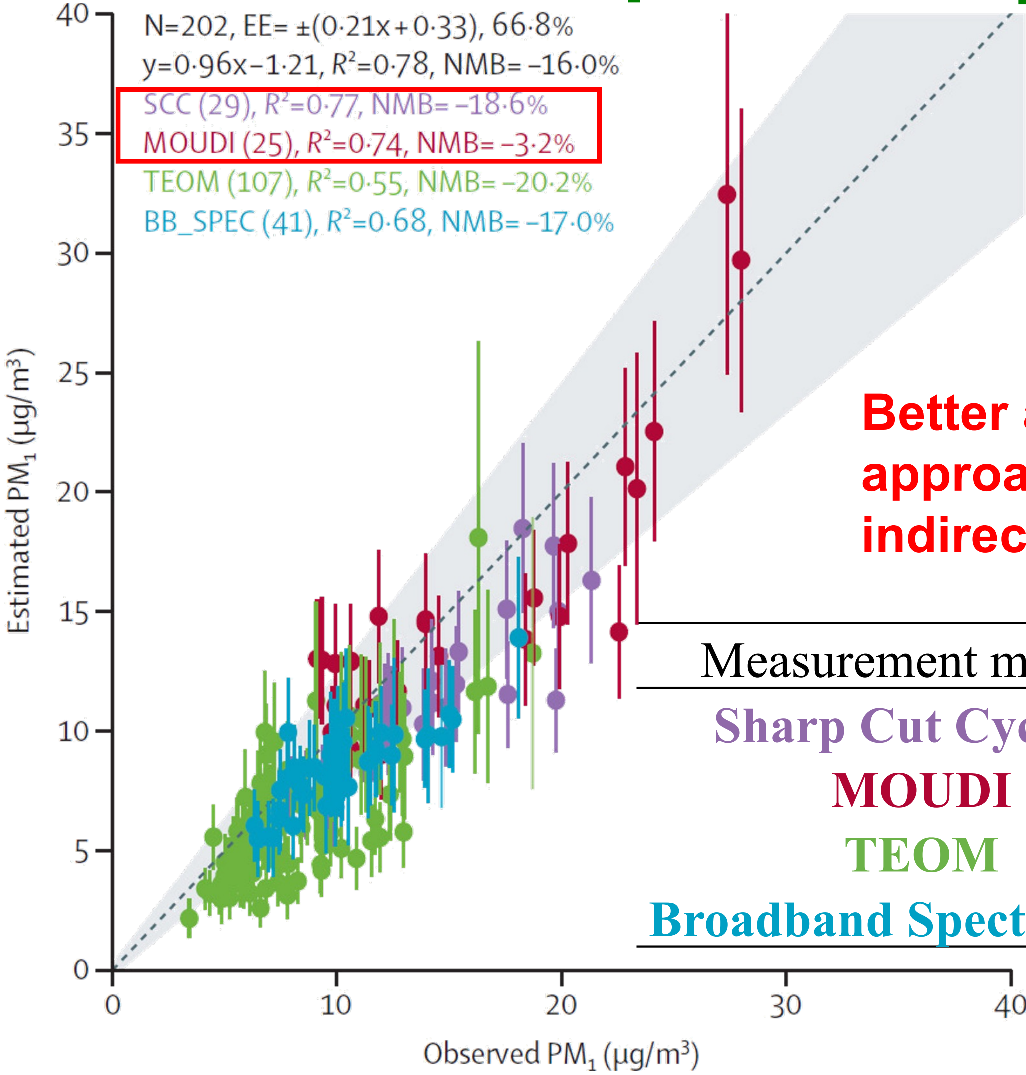
S	k_s	Source
Sulfate	0.91	Constrained from observations of PM_1 and $PM_{2.5}$ components (Left)
Ammonium	0.82	
Nitrate	0.77	
OM	0.86	
BC	1.00	State-of-science understanding and used in models
Dust	0.08	
Sea salt (f)	0.7	

IMPROVE/CSN $PM_{2.5}$ vs. AMS/ACSM PM_1

MOUDI

Li et al., *LPH*, 2025

Evaluation with independent PM_1 monitors



HAQAST

Better agreements with gravimetric analysis approaches (SCC and MOUDI) than with indirect methods (TEOM and BB_SPEC)

Measurement method	Location and time
Sharp Cut Cyclone	St. Louis (Apr, 2001-May, 2002)
MOUDI	Multiple locations
TEOM	Spokane (Jan, 1998-May, 2002)
Broadband Spectroscopy	Indianapolis (May, 2021-Dec, 2022)

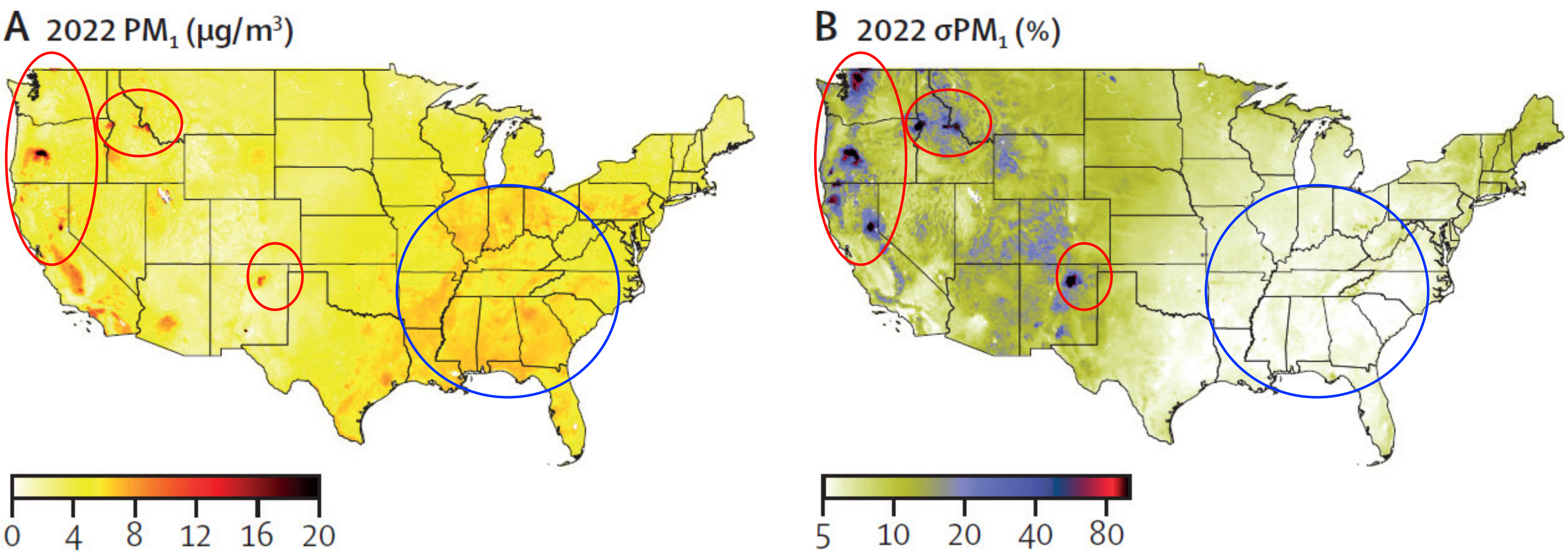
Li et al., *LPH*, 2025

First US-wide PM_1 and uncertainty maps

$$[PM_1] = \sum_S k_S \times [S]$$

$$\sigma^2_{PM1} = \sum_S \sigma^2_{k,S} \times [S]^2 + \sigma^2_S \times k^2_S$$

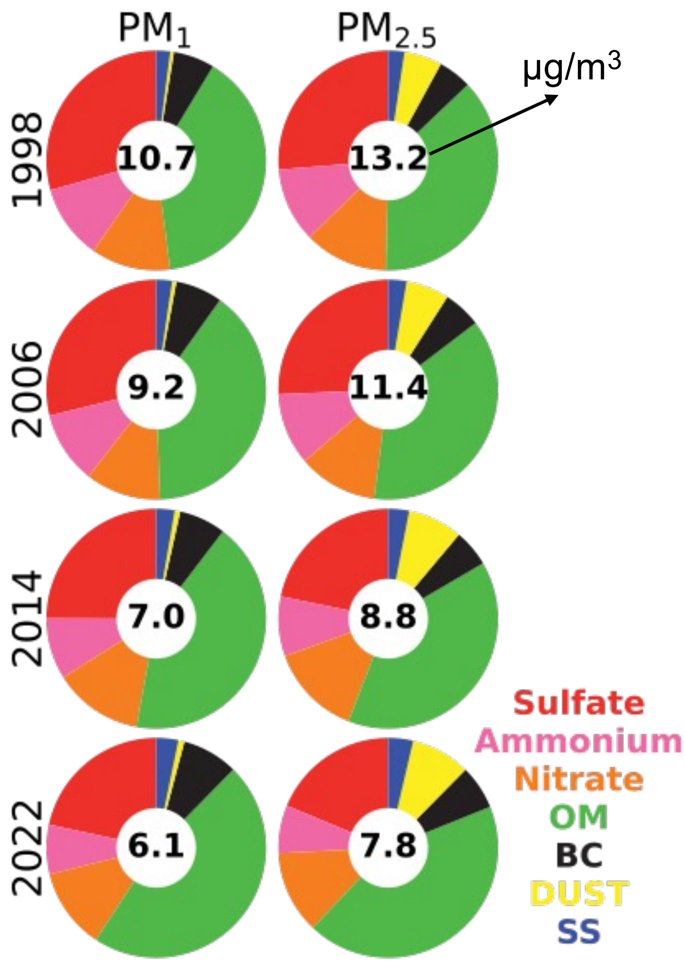
HAQAST

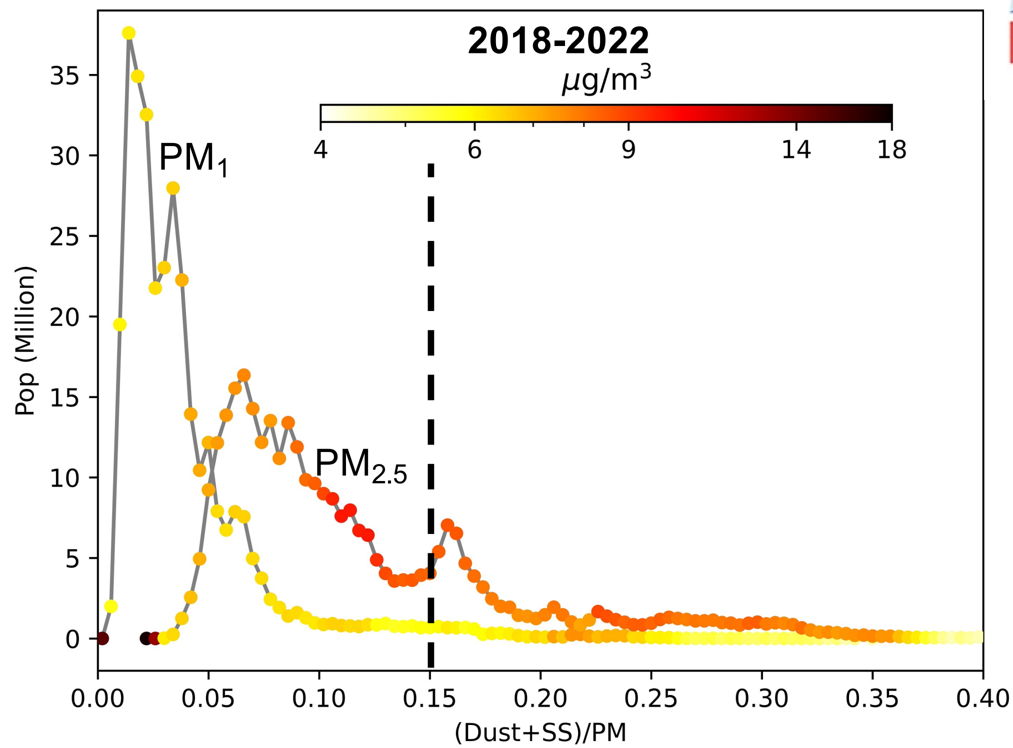


Reduced agreements vs. observations at higher concentrations for OM and BC.

[Li et al., *LPH*, 2025]

Dust and sea salt are increasingly critical for $PM_{2.5}$ mitigation, but not as much for PM_1



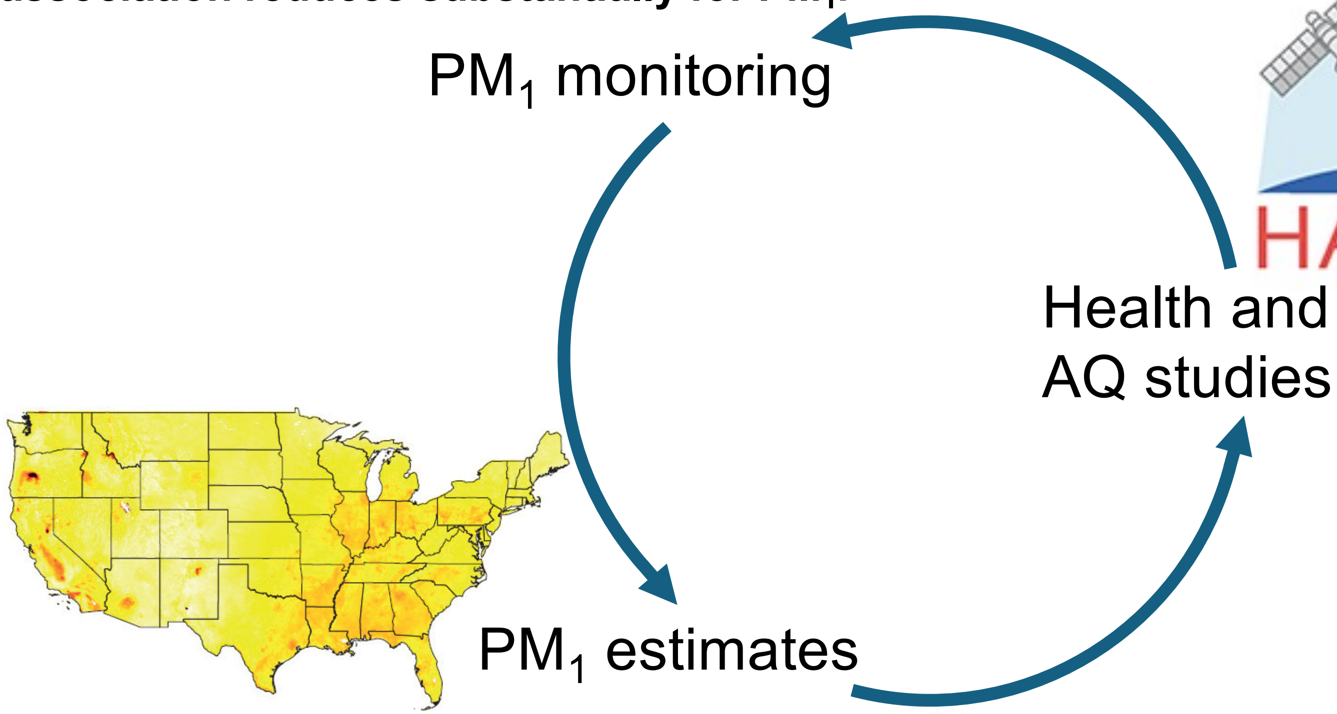


24% of populations associate with >15% of $PM_{2.5}$ mass from DUST + SS, which contribute >20% of PM_1 for 2% population.

Li et al., *LPH*, 2025

Concluding remarks

- Monitoring PM_1 could potentially identify stronger health relevance of "mitigable" particles.
- Observations reveal varying % of $PM_{2.5}$ in PM_1, enabling the first estimates of long-term CONUS-wide PM_1 to spin up the PM_1-related research cycle.
- Future $PM_{2.5}$ mitigation exhibits increasing relevance with dust and sea salt; such association reduces substantially for PM_1.



HAQAST

Scan to read the paper

The 2.5 μm cut-off size is a conventional heritage

Evolution of $PM_{2.5}$ Measurements and Standards in the U.S. and Future Perspectives for China

"The Harvard Six Cities Study (Spengler and Thurston, 1983; Chow and Spengler, 1986a, b; Dockery *et al.*, 1993) established this relationship using a dichotomous sampler (Evans and Ryan, 1983) with 15 and 2.5 μm 50% cut-points on its inlets for total (PM_{15}) and fine ($PM_{2.5}$) particle size fractions, respectively. Subsequent epidemiological studies (Chow *et al.*, 2006b; Pope and Dockery, 2006) used similar $PM_{2.5}$ inlets, and $PM_{2.5}$ was selected as the fine particle indicator for the U.S. $PM_{2.5}$ NAAQS (U.S. EPA, 1997a)."

(Cao et al., 2013)

AN ASSOCIATION BETWEEN AIR POLLUTION AND MORTALITY IN SIX U.S. CITIES

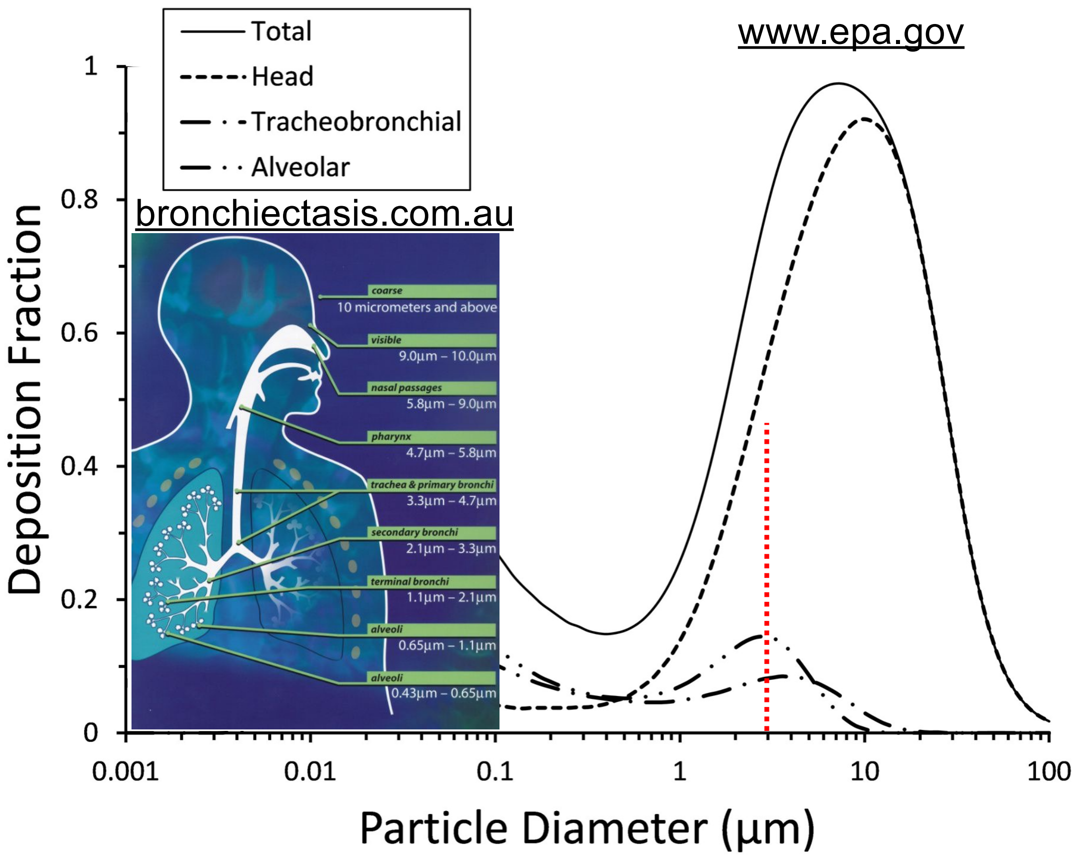
Douglas W. Dockery, Sc.D., C. Arden Pope III, Ph.D., Xiping Xu, M.D., Ph.D., John D. Spengler, Ph.D., James H. Ware, Ph.D., Martha E. Fay, M.P.H., Benjamin G. Ferris, Jr., M.D., and Frank E. Speizer, M.D.

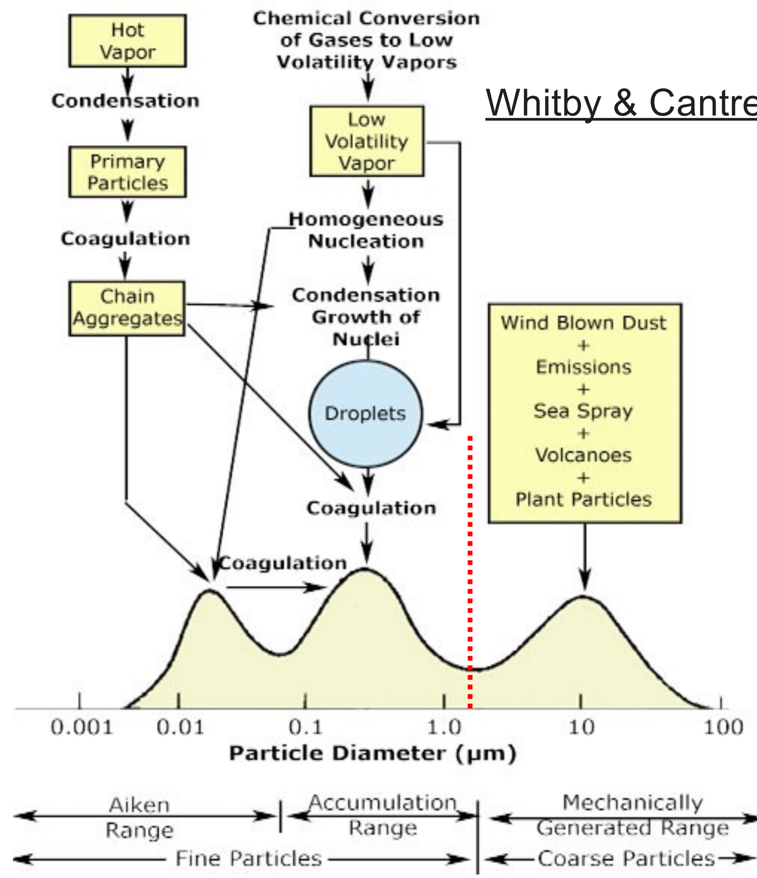
Fine-particulate air pollution includes particles with an aerodynamic diameter equal to or below 2.5 micrometers. Whereas larger particles are derived chiefly from soil and other crustal materials, fine particles are derived primarily from the combustion of fossil fuels in transportation, manufacturing, and power generation. Fine-particulate pollution typically contains a mixture of particles including soot, acid condensates, and sulfate and nitrate particles. Fine particles are thought to pose a particularly great risk to health because they are more likely to be toxic than larger particles and can be breathed more deeply into the lungs.[14]

(Dockery et al., 1993)

The *original* source of 2.5 µm cut-off size

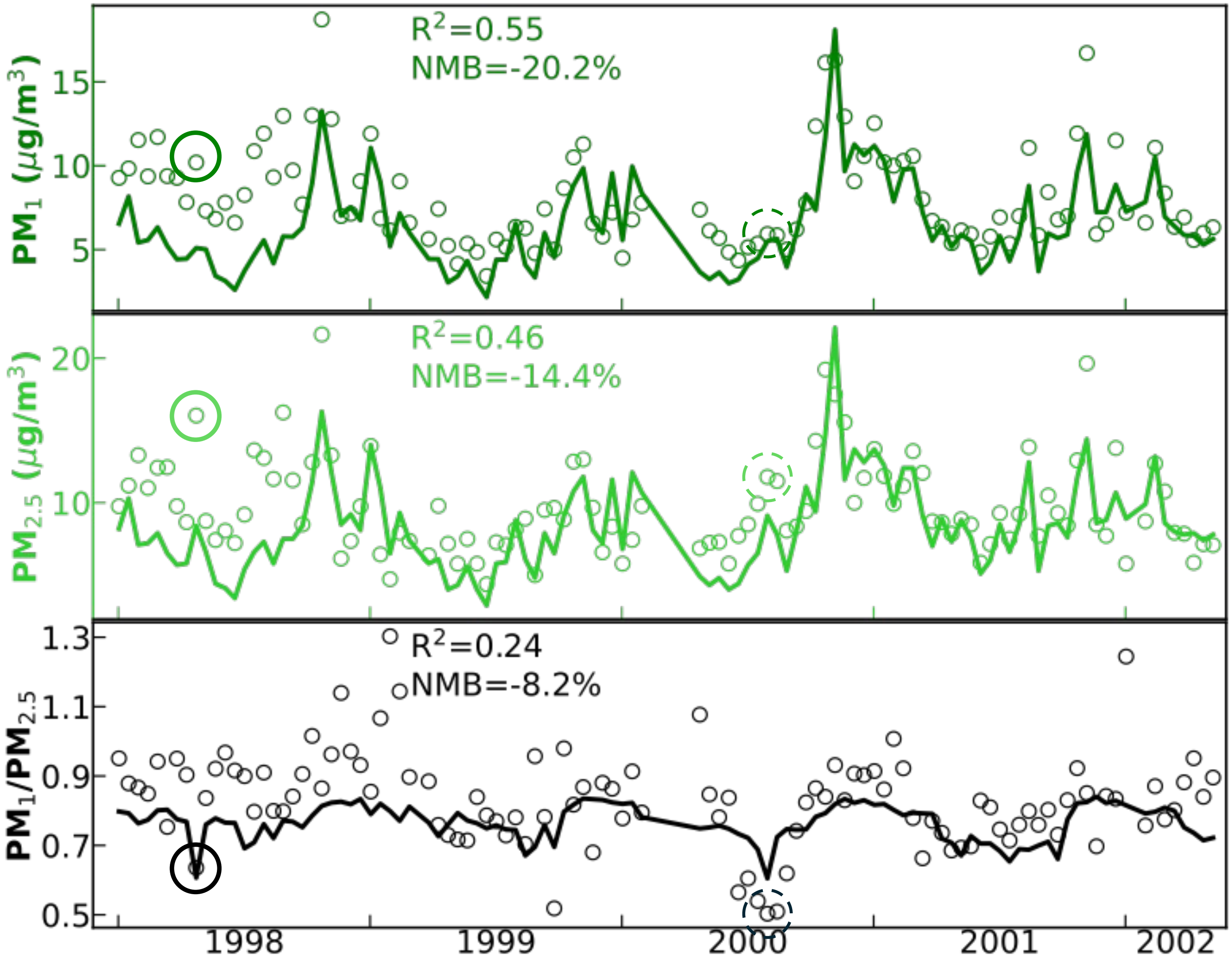
size considerations for establishing a standard for inhalable particles (Miller et al., 1979)



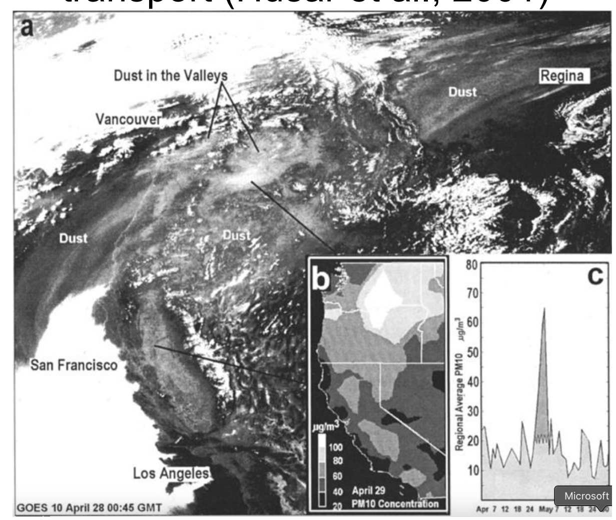


Whitby & Cantrell (1976)

Capture dust events in Spokane, WA



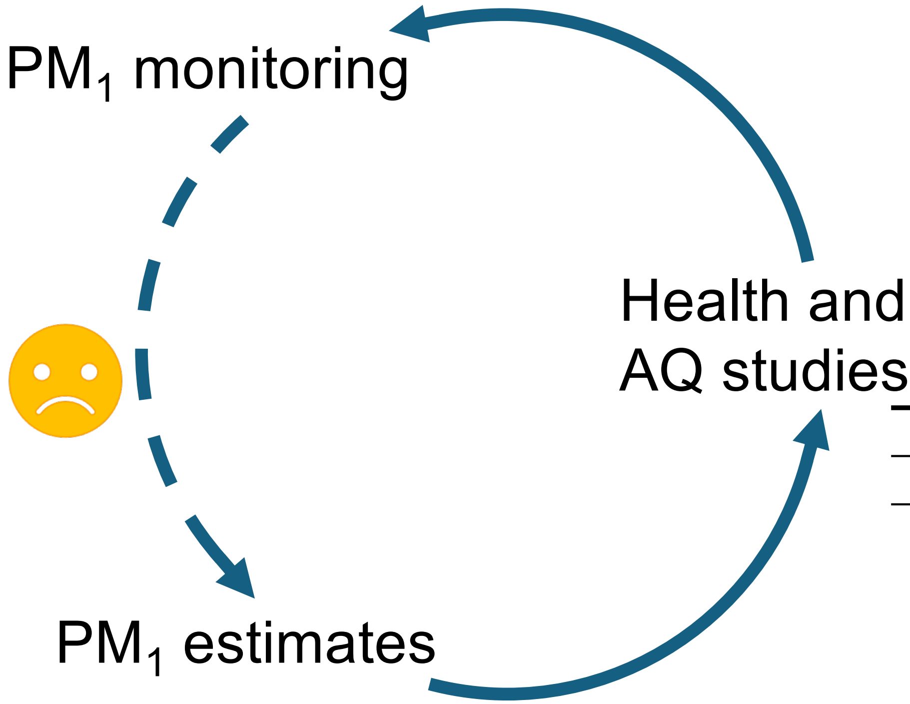
Apr-May 1998, Asian dust transport (Husar et al., 2001)



Indirectly validate the dust k_s (8%).

Li et al., *LPH*, 2025

Can we follow the successful $PM_{2.5}$ research story?



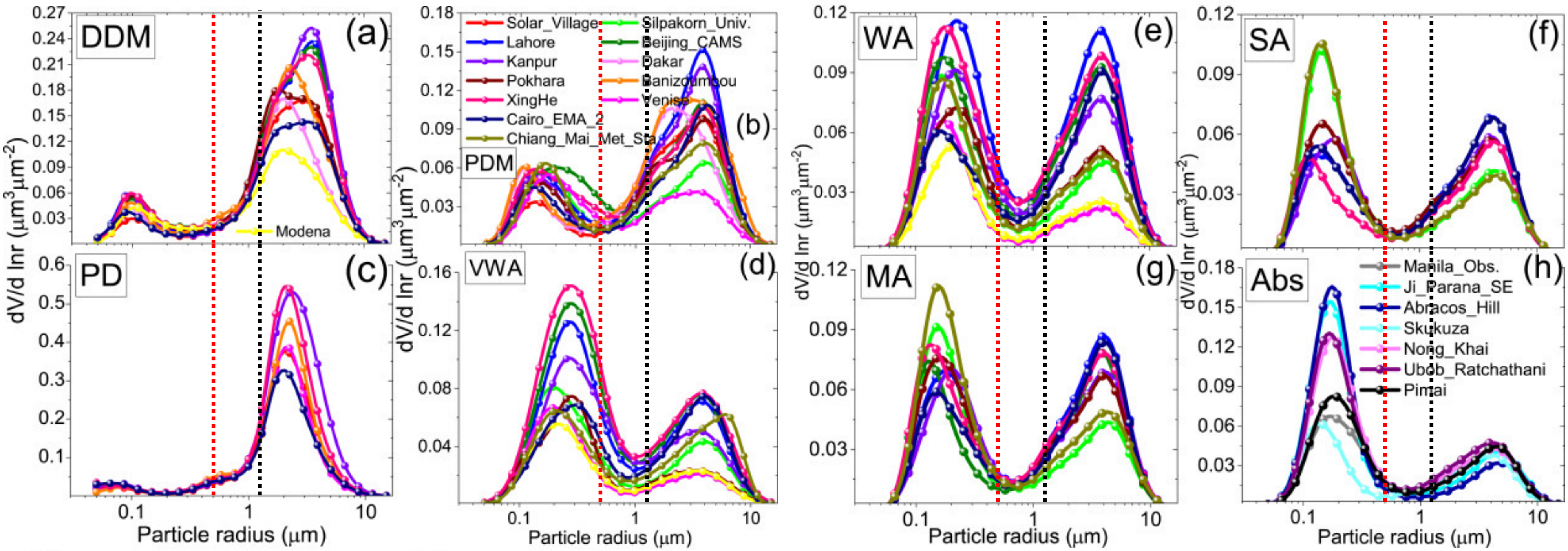
Sporadic PM_1 measurements

Measurement method	Location and time
Sharp Cut Cyclone	St. Louis (Apr 2001-May 2002)
Microorifice Uniform Deposit Impactor (MOUDI)	Atlanta, GA (Aug 1999) Houston, TX (Aug-Sep 2000) Rubidoux, CA (Jun-Aug 2001) Riverside, CA (Mar-Jun 2001) Downey, CA (Oct 2000-Feb 2001) Chino, CA (Oct 2002-Sep 2003) Pittsburgh, PA (Jul 2001-Jan 2002)
Tapered Element Oscillating Microbalance (TEOM)	Spokane (Jan 1998-May 2002)
Broadband Spectroscopy	Indianapolis (May 2021-Dec 2022)

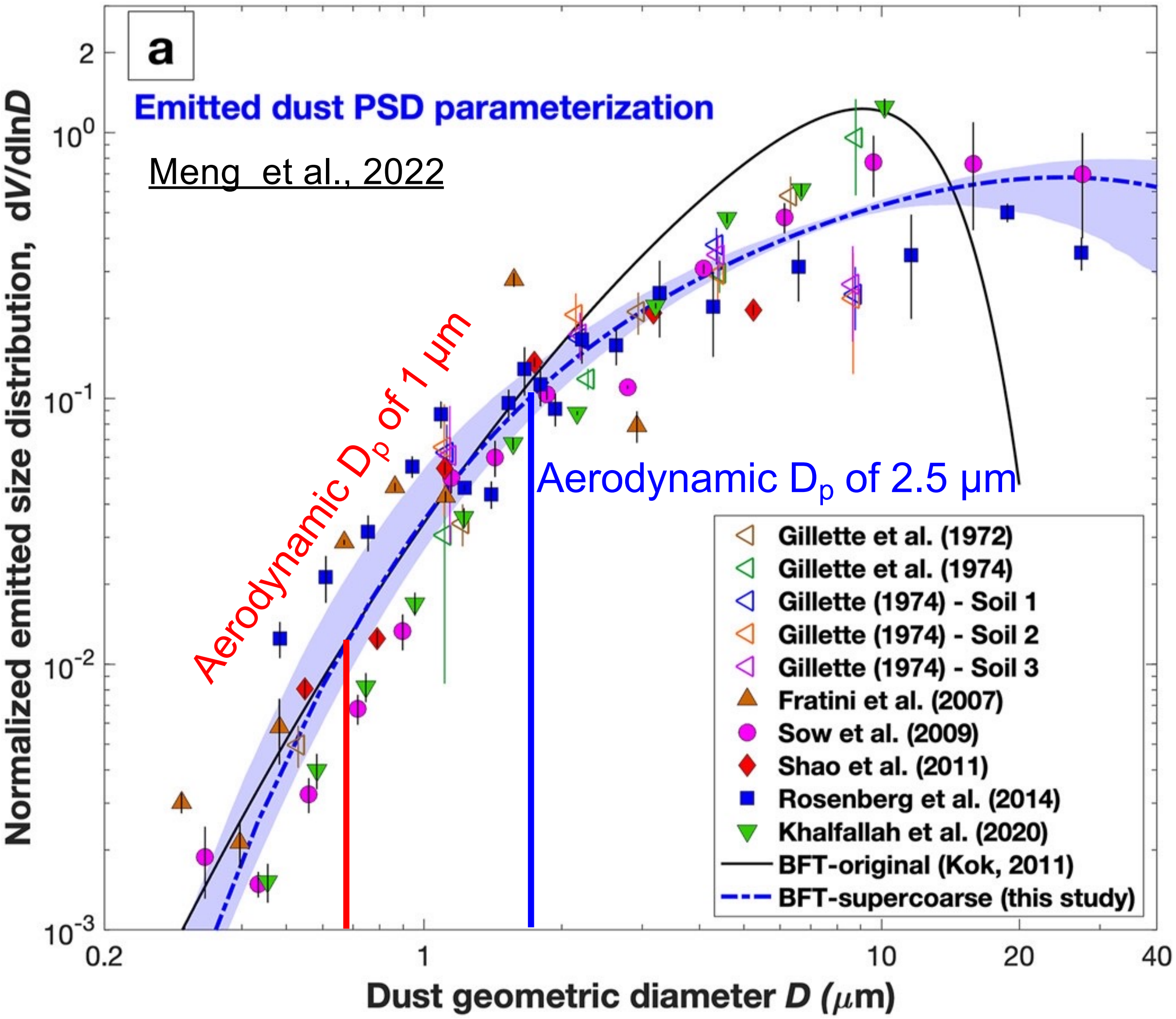
$PM_{2.5}$ includes significant coarse mass

AERONET retrievals also suggest consistently

Mukhopadhyay et al., 2025



Dust in $PM_{2.5}$ and PM_1



~8% of dust $PM_{2.5}$ mass (left of the blue line) is PM_1 (left of the red line)