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JIANGSU KEY LABORATORY OF ATMOSPHERIC ENVRONVENT MONTORNG&POLLUTION CONTROL

Predicting and Identifying Concentrations and Sources of Ultrafine Particulate Matter in California for Health Effect Studies

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2015.9.11, Nanjing

Acknowledgement

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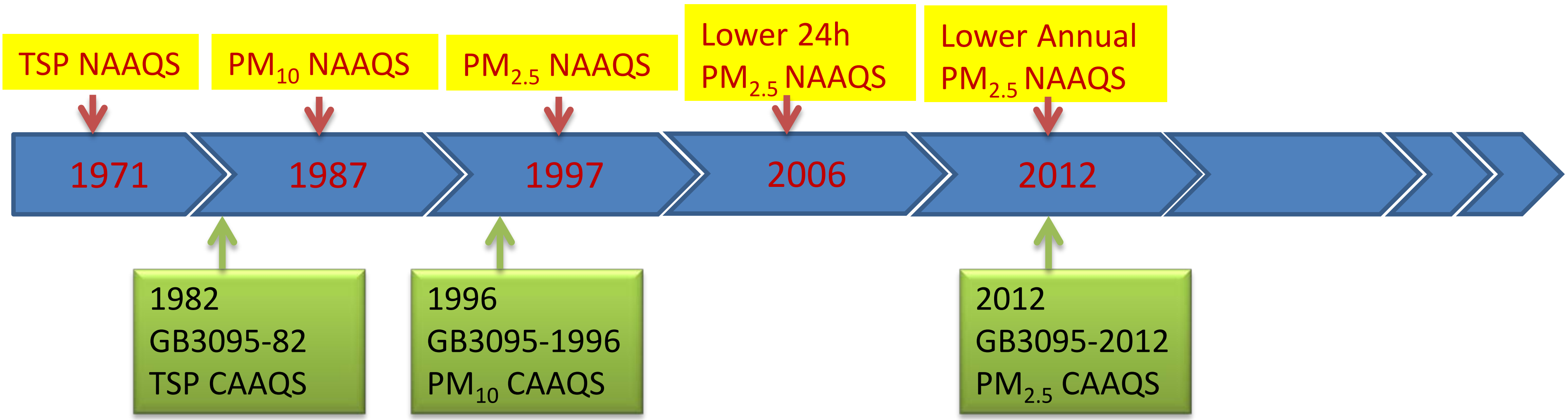
- Funding Support:
  - U.S. Environmental Protection Agency
  - California Air Resources Board
  - UC Atmospheric Aerosol and Health Grant

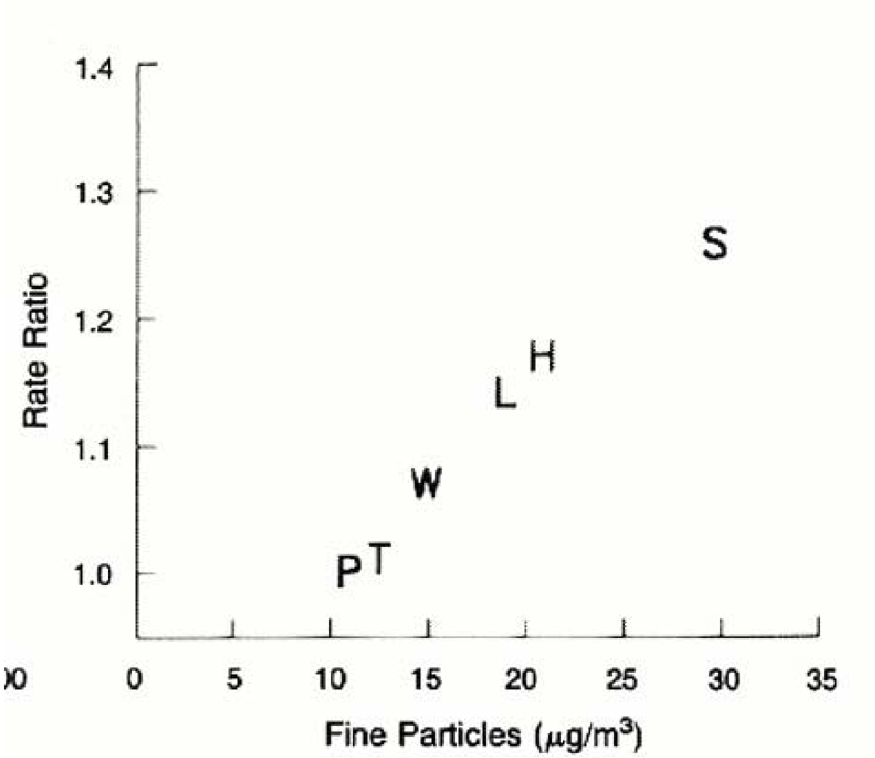
Evolution of Ambient Particulate Matter Standards

- TSP = total suspended particles
- NAAQS: National Ambient Air Quality Standards
- CAAQS: China Ambient Air Quality Standards



$PM_{2.5}$ Standards Based on Evidence from Epi. Studies

- consistent associations between outdoor PM concentrations and adverse health effects



Source: NEW ENGLAND JOURNAL OF MEDICINE 329 (24): 1753-1759 DEC 9 1993.

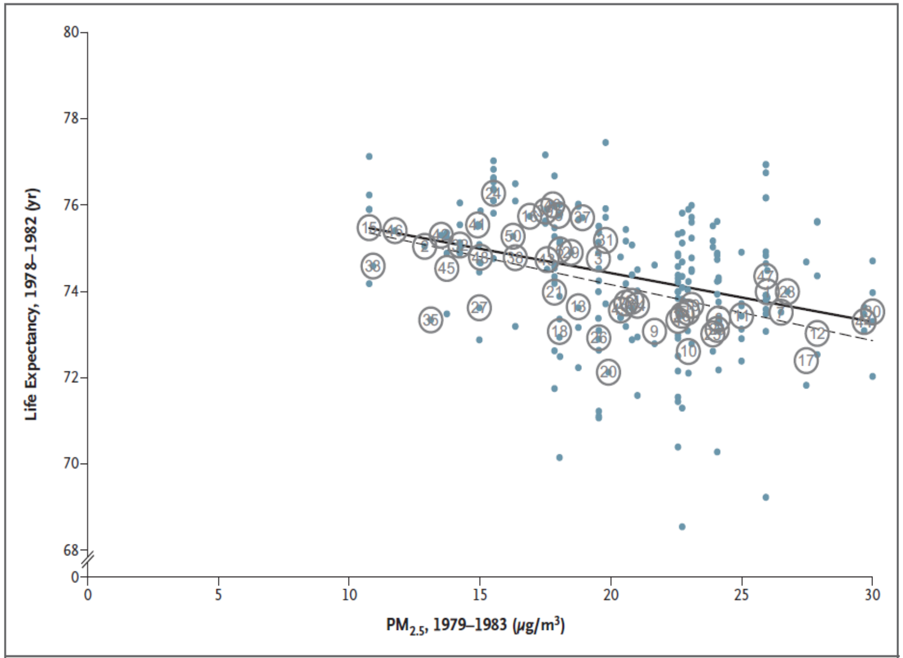


Figure 2. Cross-Sectional Life Expectancies for 1978–1982, Plotted against $PM_{2.5}$ Concentrations for 1979–1983.

Source:
1. NEW ENGLAND JOURNAL OF MEDICINE 360 (4): 376-386, 2009.
2. Epidemiology. 24(1): 23–31, 2013.

An increase of 10 $\mu g/m^3$ in the $PM_{2.5}$ concentration was associated with a reduction in life expectancy of 0.46±0.22 (p=0.039) in 1979-1983, 0.37±0.20 (p=0.091) in 1997-2001, and 0.35±0.16 (p=0.033) in 2000-2007

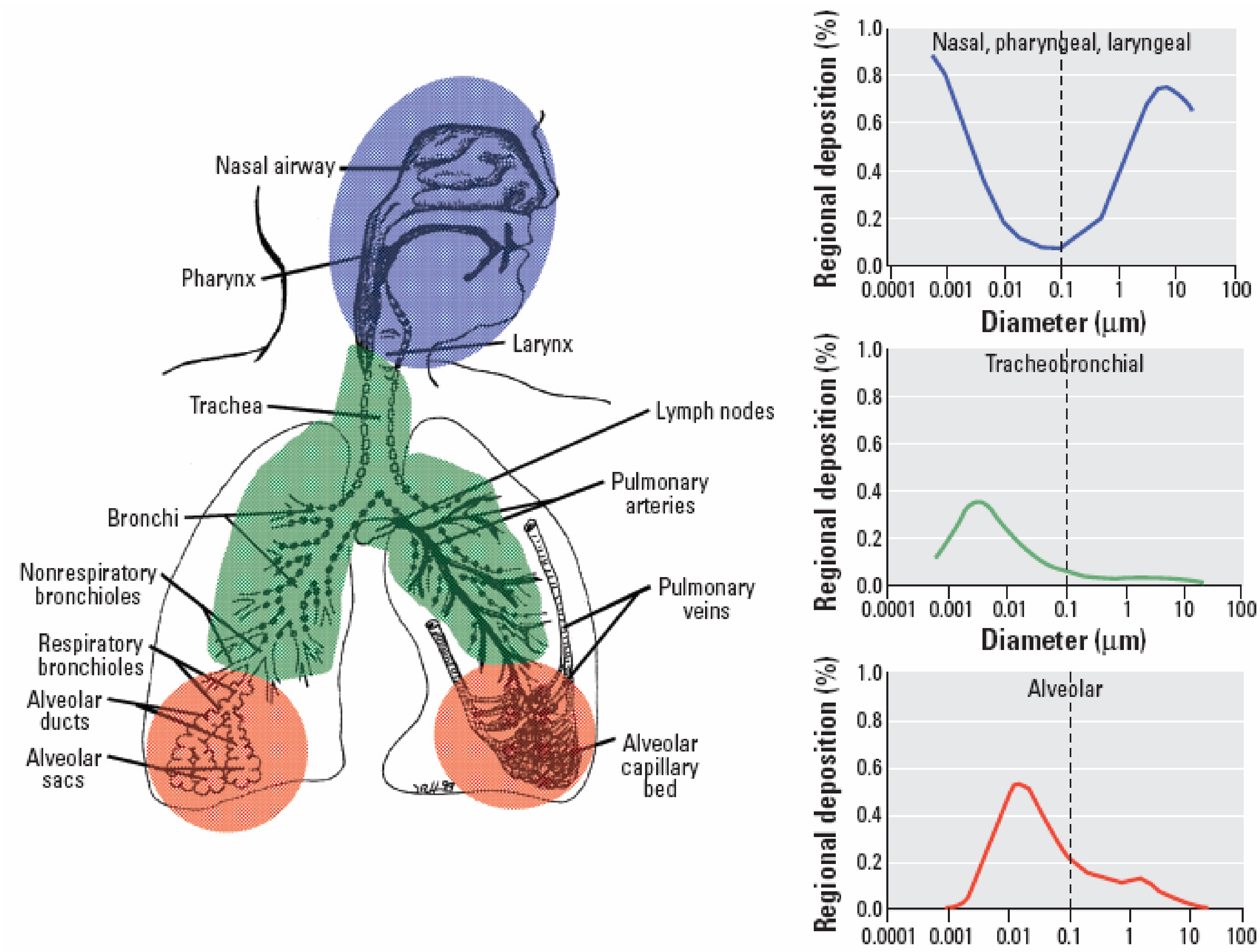
The Injury Mechanisms of PM Remains Unknown

- **Health Effects Associated with PM Exposure**
  - Autonomic nervous system
  - Development: Low birth weight/preterm birth
  - Increase in asthma and other respiratory disease in children
  - Decrease in lung development and function in children
  - Cardiovascular disease including atherosclerosis in adults
  - Cancer

- **All airborne PM is toxic to some degree; potency is based on physical and chemical characteristics**
  - What PM sizes
  - What PM compositions
  - What PM sources

  are responsible for observed health effects?

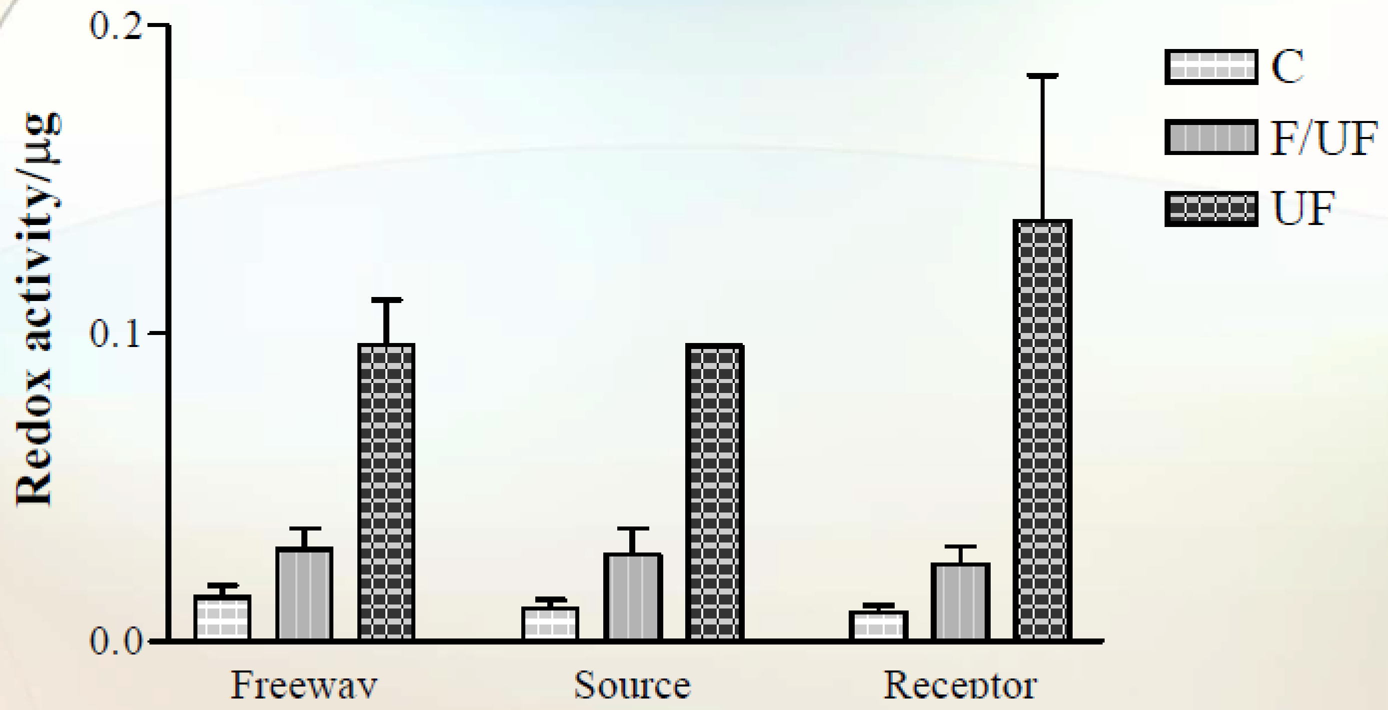
Ultrafine Particles Have an Important Role in Toxicity



Oberdorster et al., EHP, 2005

Ultrafine Particles Have an Important Role in Toxicity

Redox Activity

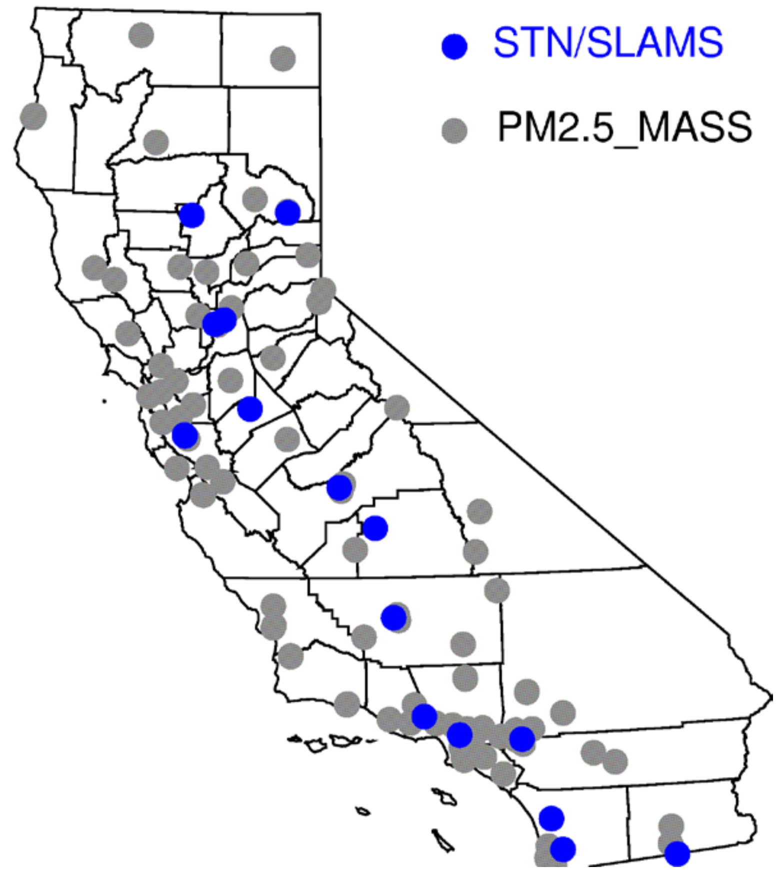


When activity is expressed per mass, the results reflect the potency of the sample

http://www.aqmd.gov/docs/default-source/technology-research/ultrafine-particles-conference/pre-conference_2_froines.pdf

Why No Ultrafine/PM0.1 Standards

- Because no consistent evidence from epidemiological studies
  - Due to limited scientific information about PM0.1 characteristics
    - PM0.1 number? Surface area? Mass?
    - PM0.1 chemical composition?
    - PM0.1 sources?



Ultrafines and Surface Area

- Ultrafine particles have the high surface area-to-volume ratio that can provide numerous sites for heterogeneous reactions. (Seaton and Macnee, 1995)

- Particle surface area may be most appropriate parameter to evaluate inflammatory potential and predict adverse effects of UFP (Stoeger, 2006)

- Most epidemiological studies have used particle number concentration as a surrogate for particle surface area

Challenges for Ultrafine Modeling

1. Sharp spatial gradient in particle number concentrations

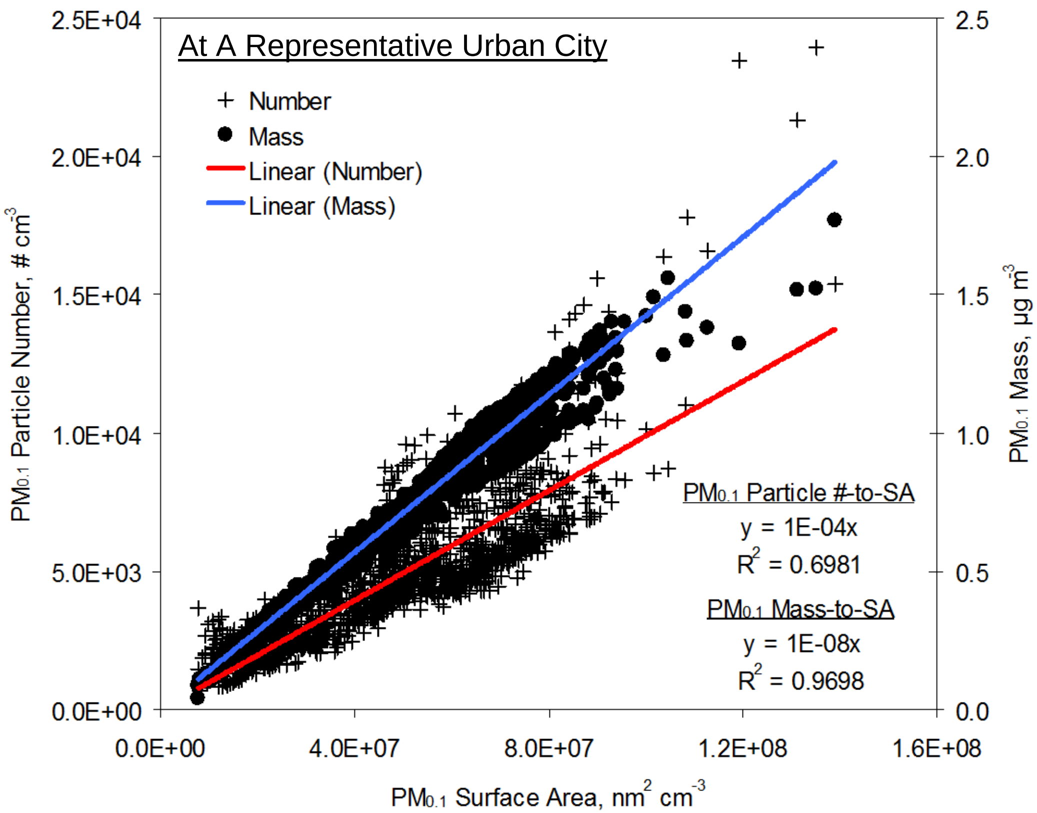
2. Incomplete theory about particle nucleation, coagulation

3. Limited source emission profiles about UFP

- California is an ideal place for developing UFP modeling studies
  - Long study history of air quality modeling
  - The richest ambient UFP measurement dataset available for model validation
  - The most accurate emissions inventories
  - The most health effect study groups of any state in the United States

UFP Mass vs. UFP numbers

- Recent study (Marheit et al. 2006) indicated that $PM_{0.1}$ mass is closely aligned with particle surface area



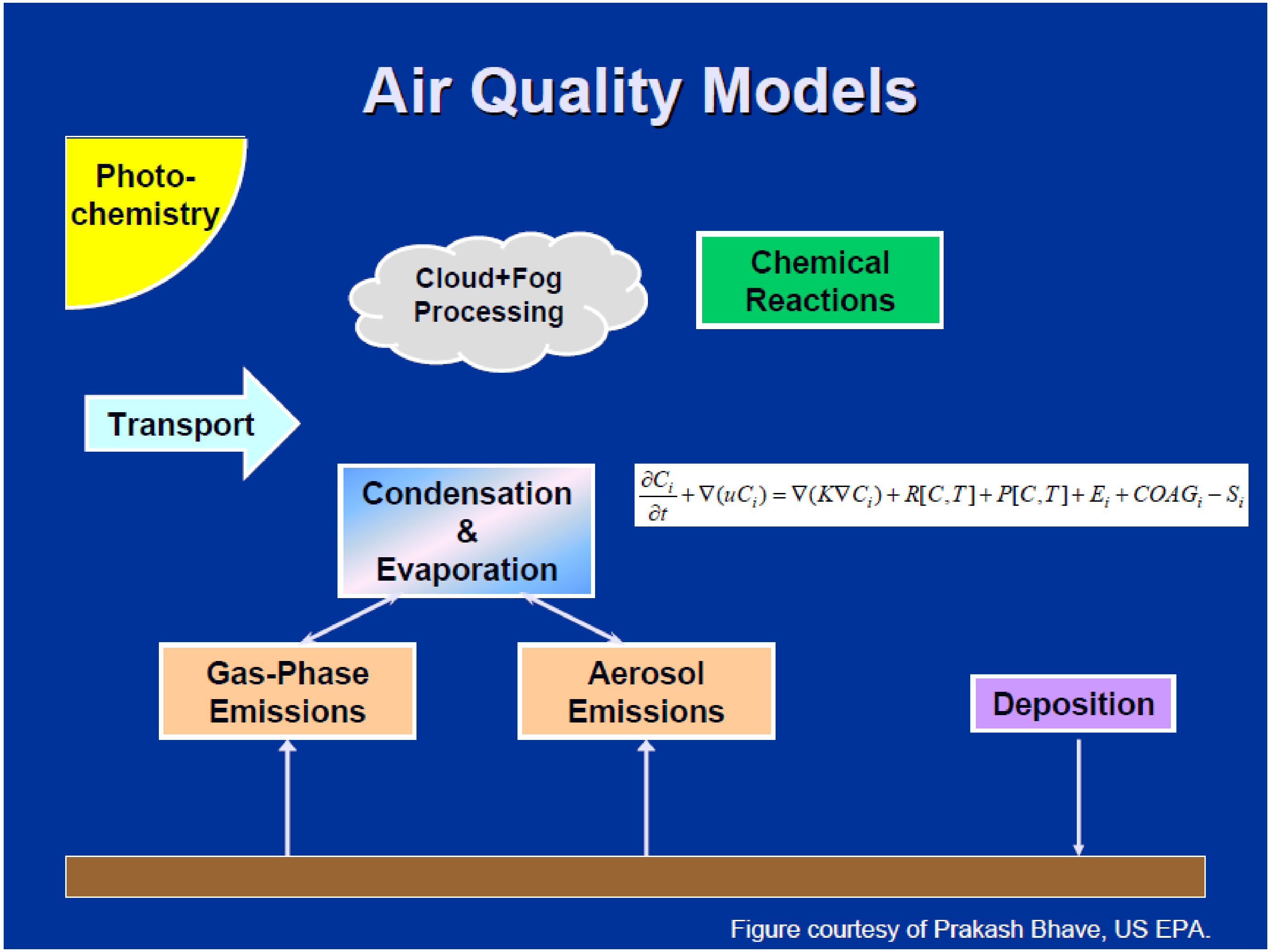
Source: Environ. Sci. Technol., 2013, *47* (24), pp 13957–13966

UFP Modeling Study for California

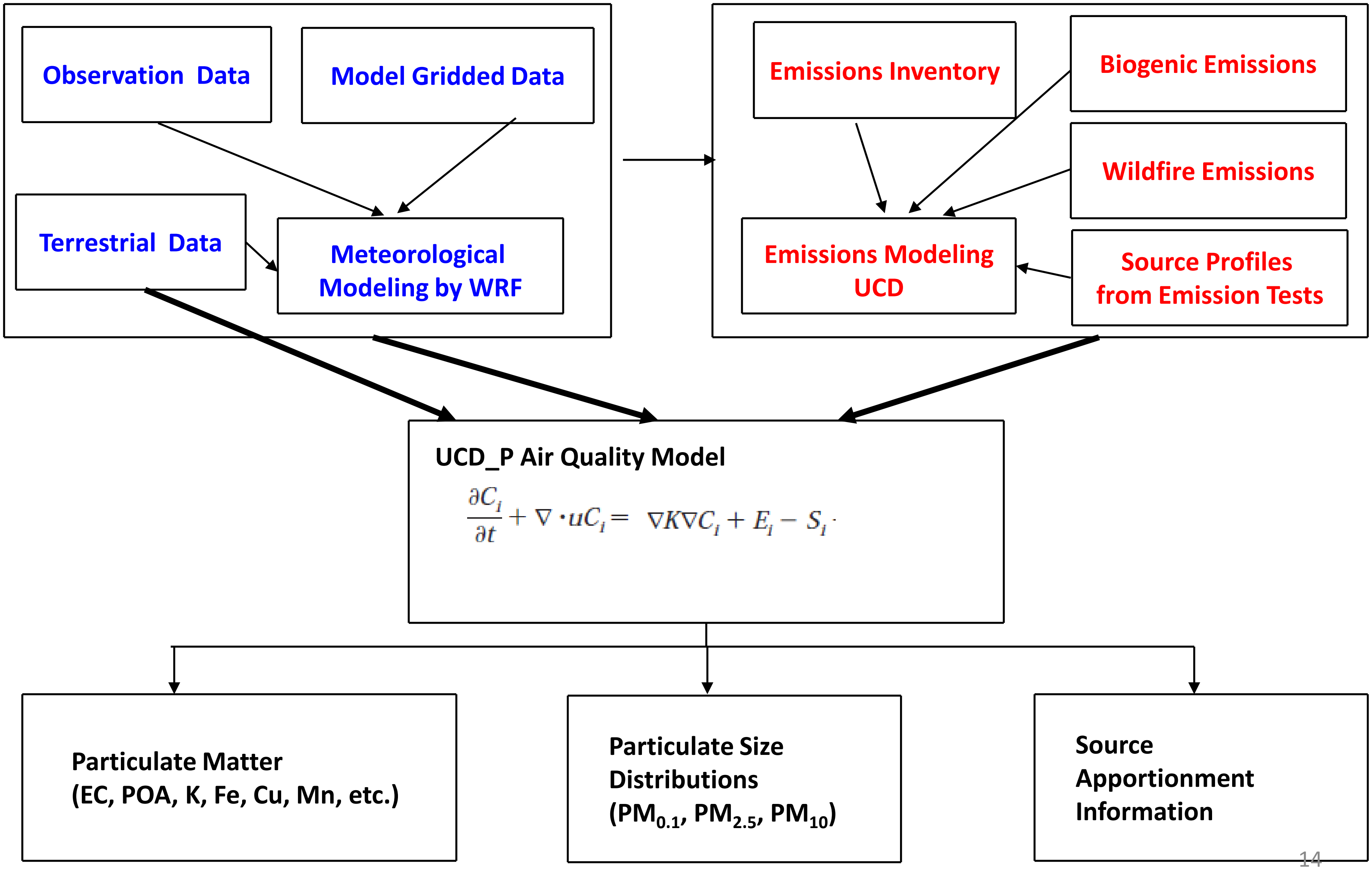
- UCD_Primary air quality model system for modeling UFP mass concentrations, chemical compositions, and sources
  - Track ~900 primary sources
  - No nucleation, no gas-particle conversion
  - 4 km resolution
  - 7 years, 2000-2006

- WRF for meteorology fields
- In-house tools for emission processing
  - ~300 UFP source profiles (size, composition)

Air Quality Models



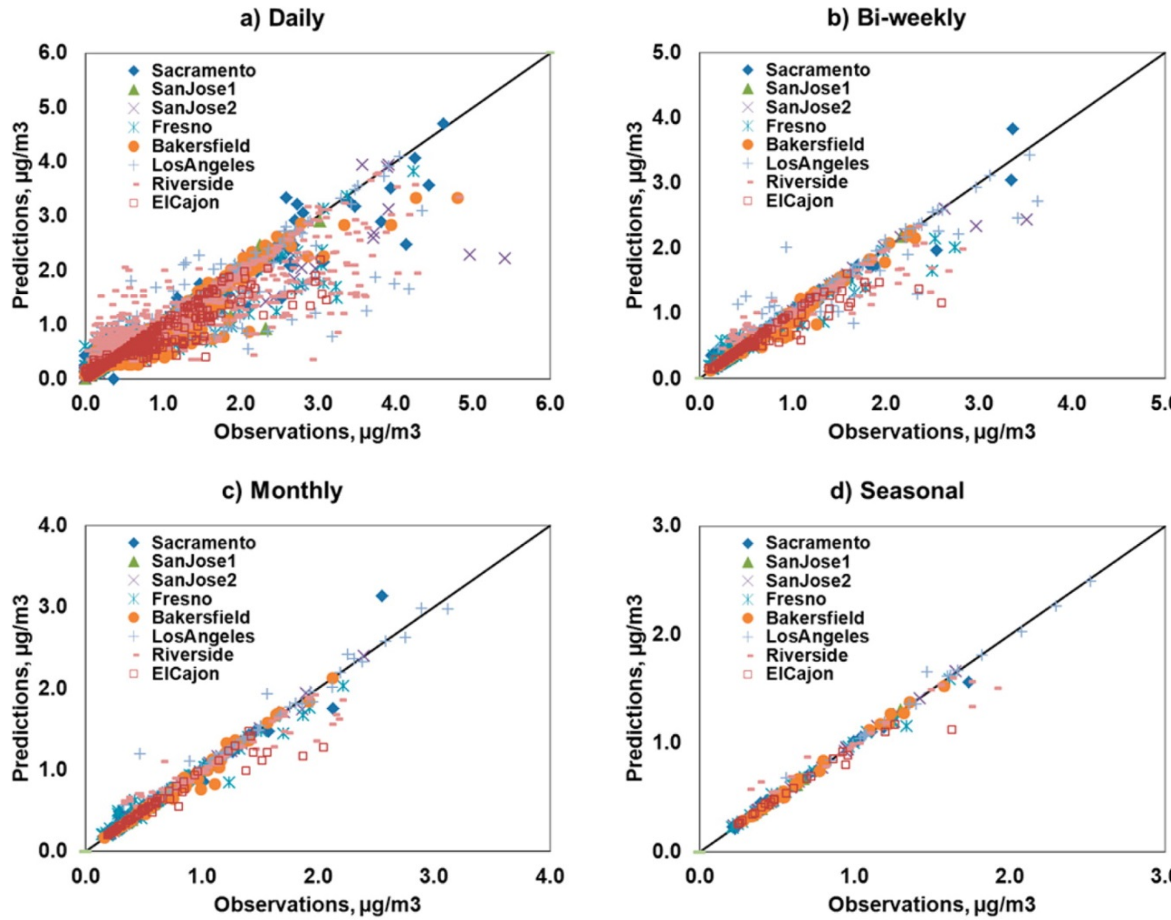
UCD_P Air Quality Model

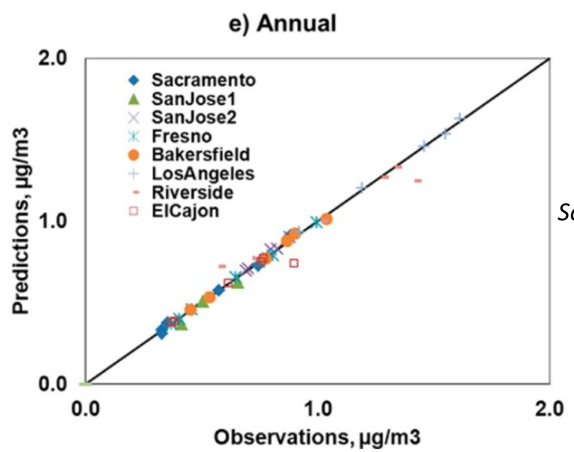


Our Cluster

$PM_{2.5}$ EC

Model works better with longer averaging time (>1 month)





Source: Environ. Sci. Technol., 2014, 48 (9), 4971-4979

Model Predicts well for Some Chemical Components, but not All

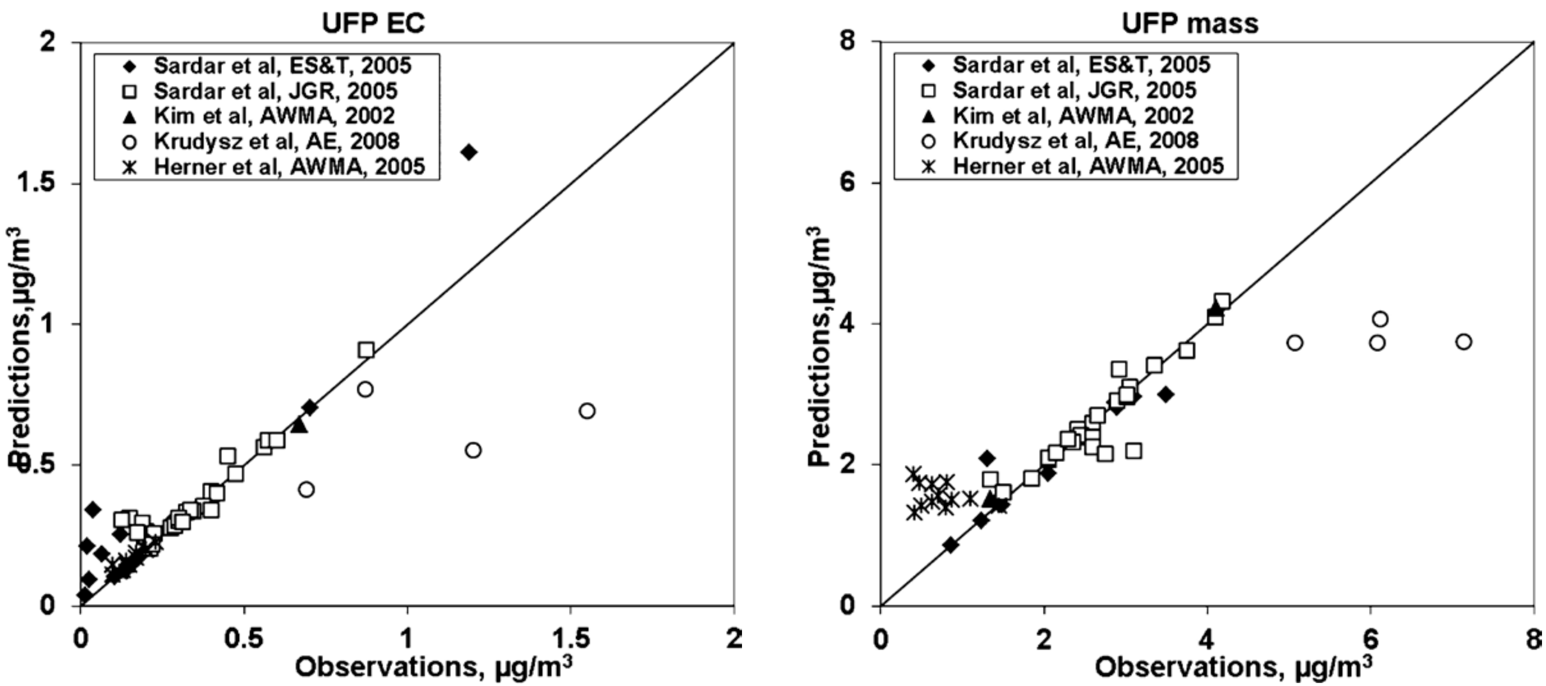
Species	Sacramento	SanJose1	SanJose2	Fresno	Bakersfield	LosAngeles	Riverside	ElCajon
EC	0.02	0.00	0.00	0.02	-0.02	0.03	0.04	-0.04
K	0.02	-0.04	-0.04	0.02	-0.11	-0.03	0.01	-0.14
CR	-0.22	0.08	-0.04	0.08	-0.07	0.02	0.03	-0.06
ZN	0.08	0.01	-0.01	-0.16	-0.03	-0.03	-0.35	0.00
FE	0.71	0.06	0.20	0.65	0.14	0.13	0.23	0.05
TI	0.33	-0.01	0.05	0.33	-0.01	0.03	0.02	0.01
AS	-0.14	-0.03	-0.01	-0.41	-0.81	0.01	-0.01	-0.03
CO	0.05	0.00	0.00	-0.64	0.09	0.55	0.56	-0.60
SR	0.04	-0.08	-0.05	-0.01	-0.13	-0.31	-0.10	-0.10
CA	0.35	-0.05	0.01	0.33	-0.01	-0.09	-0.07	-0.02
MN	0.49	0.01	0.22	0.58	0.20	0.03	0.07	0.00
AL	0.89	0.55	0.57	0.96	0.48	0.80	0.31	0.28
SI	0.84	0.15	0.42	0.78	0.34	0.27	0.10	0.12
CU	-0.47	-0.07	-0.24	-0.44	-0.68	-0.06	-0.03	-0.53
NI	-0.43	-0.97	-0.39	-0.16	0.02	0.02	0.03	-0.60
PB	-0.46	-0.24	-0.11	-0.73	-0.82	0.00	-0.02	-0.08
V	-0.43	-0.83	-1.02	-0.05	-0.21	-0.18	-0.12	-0.42
MO	-0.62	-1.33	-1.22	-0.79	-0.88	-0.75	-0.04	-1.79
RB	-0.36	-0.83	-0.68	-0.39	-0.57	-0.27	-0.16	-0.87
BA	-1.17	-1.17	-0.45	-0.75	-1.48	-0.58	-1.15	-1.15
CD	-1.80	-0.82	-1.00	-1.87	-1.42	-0.92	-0.69	-1.52
MG	-1.32	-1.55	-1.51	-1.47	-1.63	-1.45	-1.67	-1.54
NA	-1.71	-1.92	-1.87	-1.60	-1.61	-1.65	-1.64	-1.88

R	0.8~1	0.6~0.8	0.3~0.6	0~0.3	R≤0

- Mean Fractional Bias in numbers
- correlation coefficients in colors

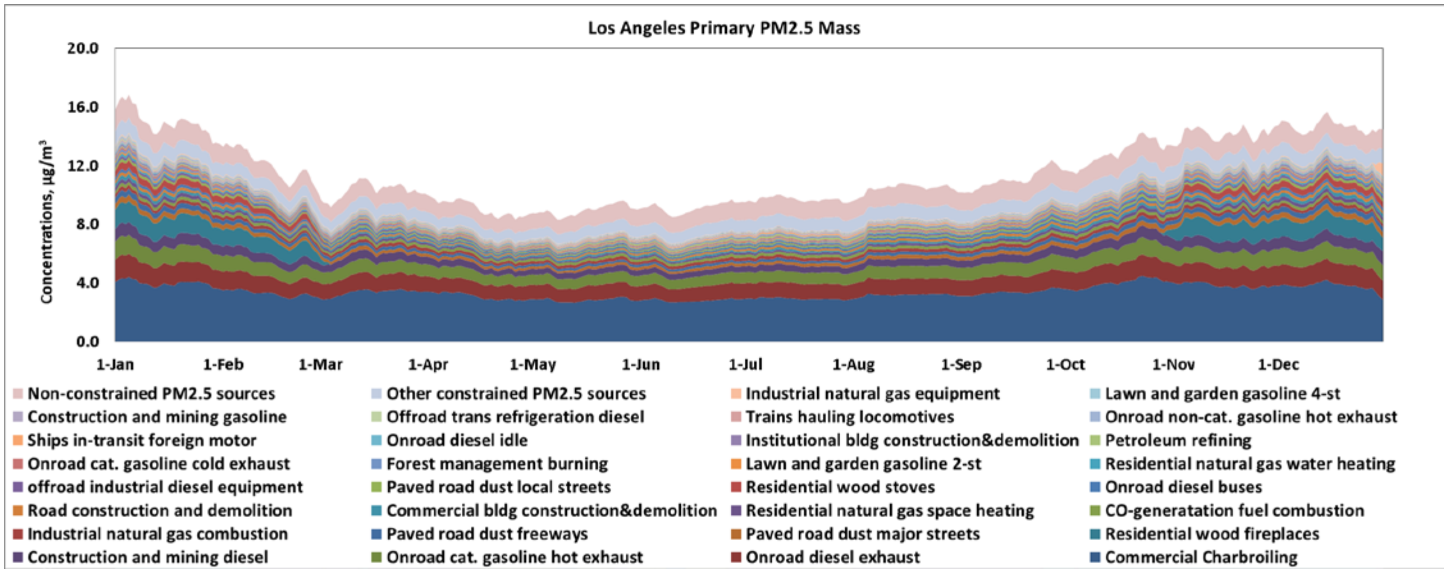
Source: Environ. Sci. Technol., 2014, 48 (9), 4971-4979

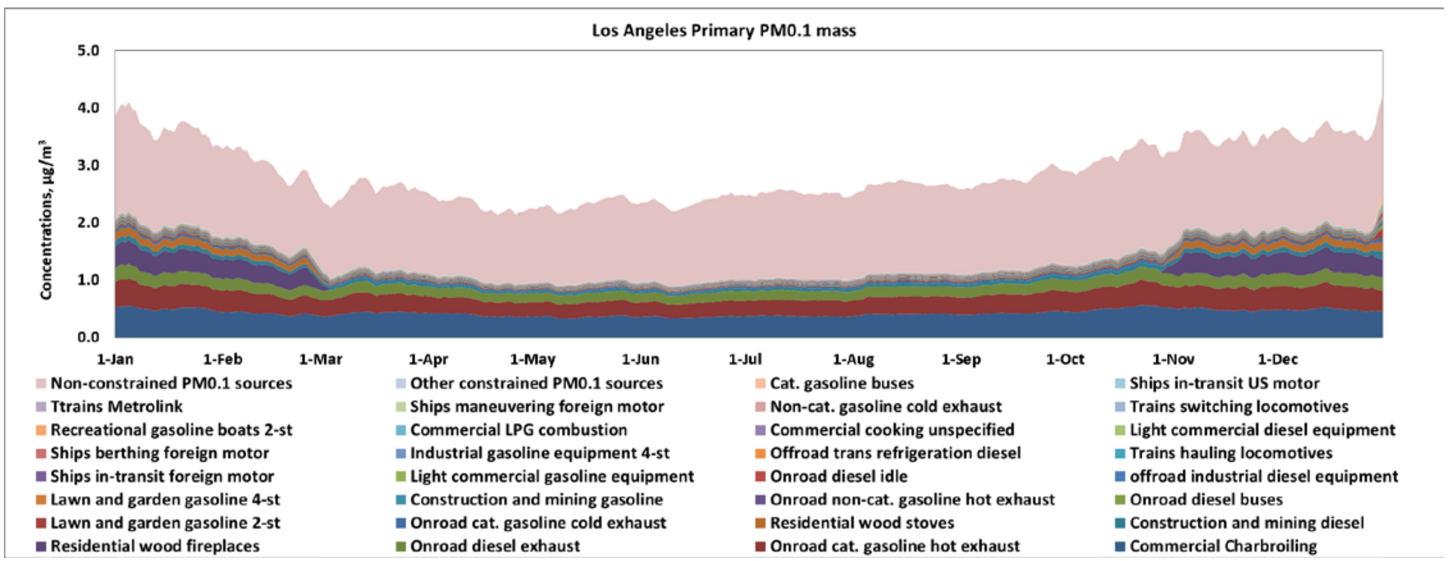
Overall Model Has Good Performance on $PM_{0.1}$ mass and $PM_{0.1}$ EC, but Not Perfect



Source: Environ. Sci. Technol., 2014, 48 (9), 4971-4979

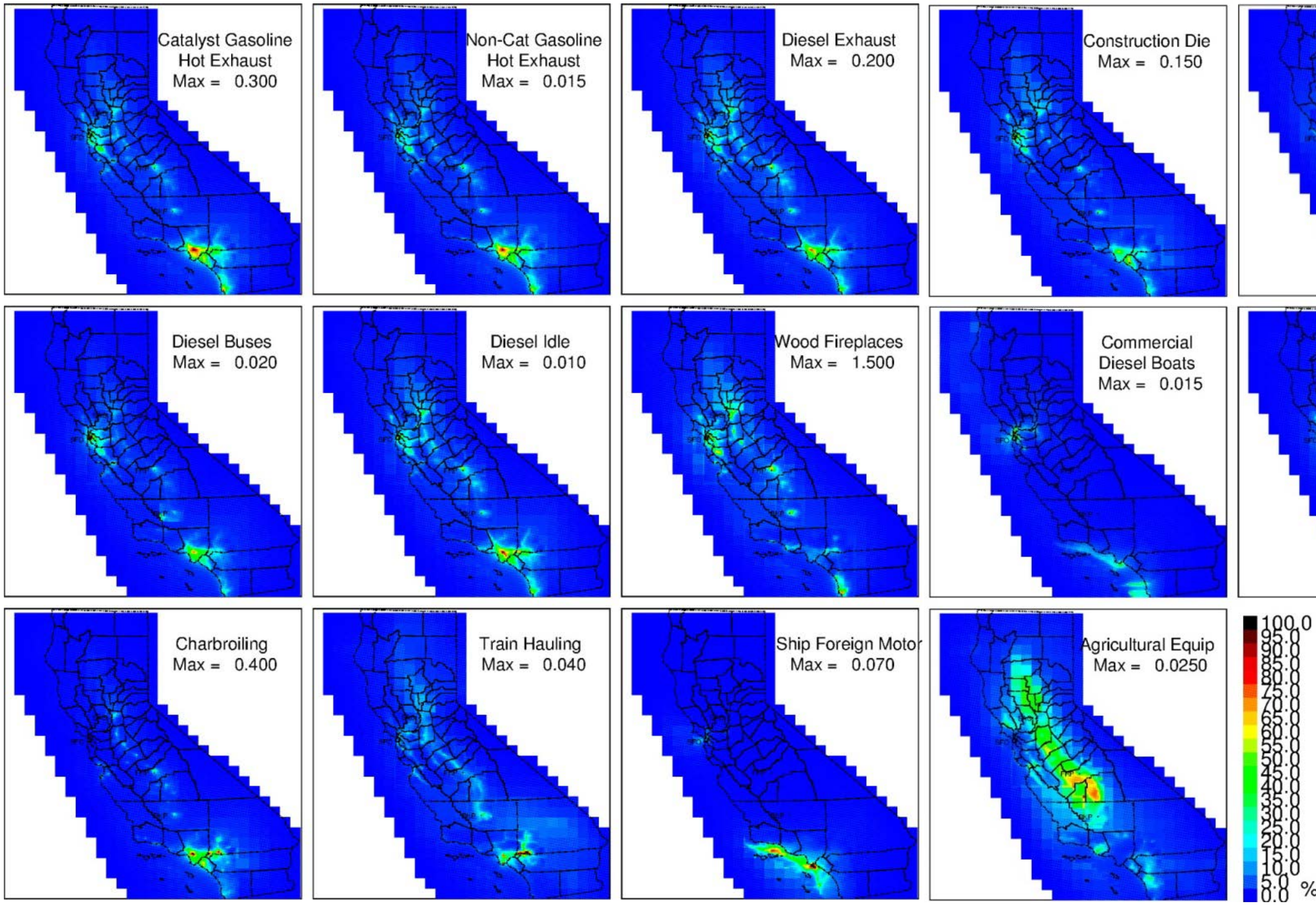
Sources of Primary $PM_{2.5}$ and $PM_{0.1}$





Source: Environ. Sci. Technol., 2014, 48 (9), 4980-4990

Regional Source Contributions of PM0.1

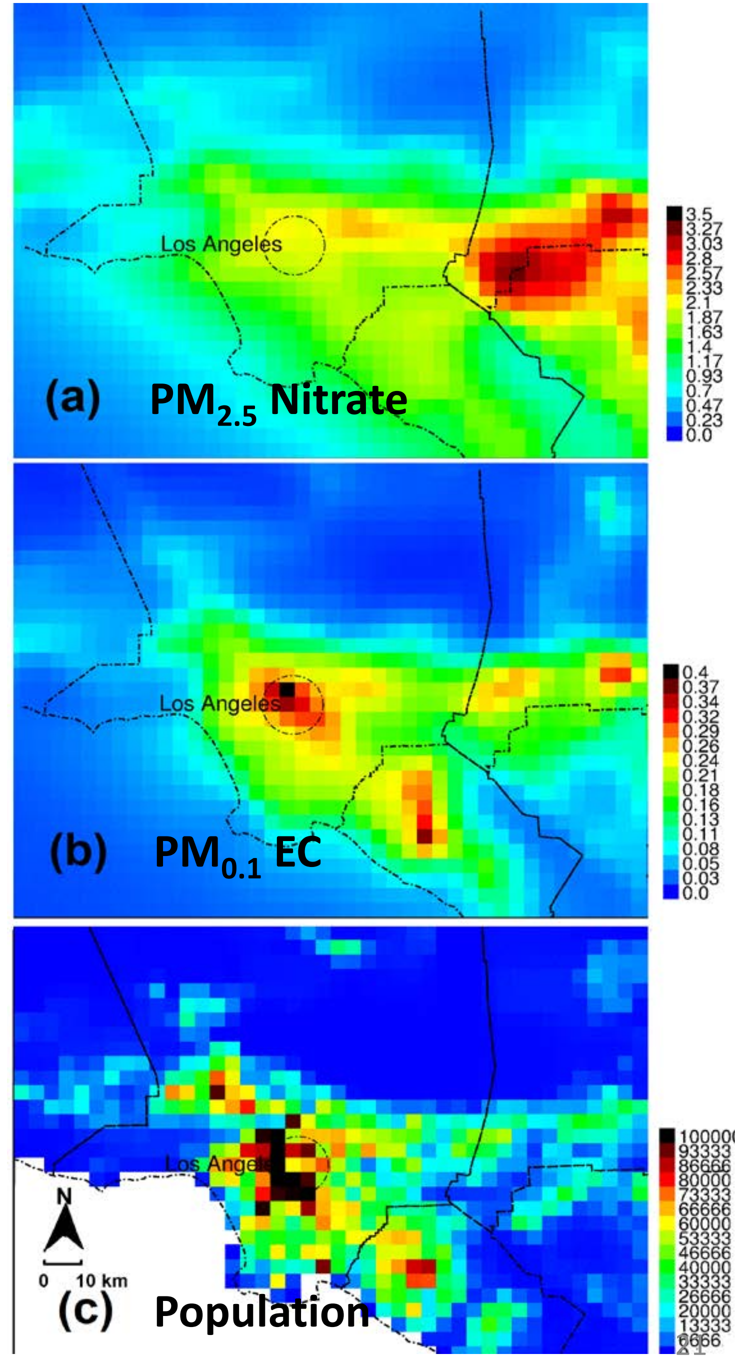


Source: Environ. Sci. Technol., 2014, 48 (9), 4980-4990

Air Pollution Exposure

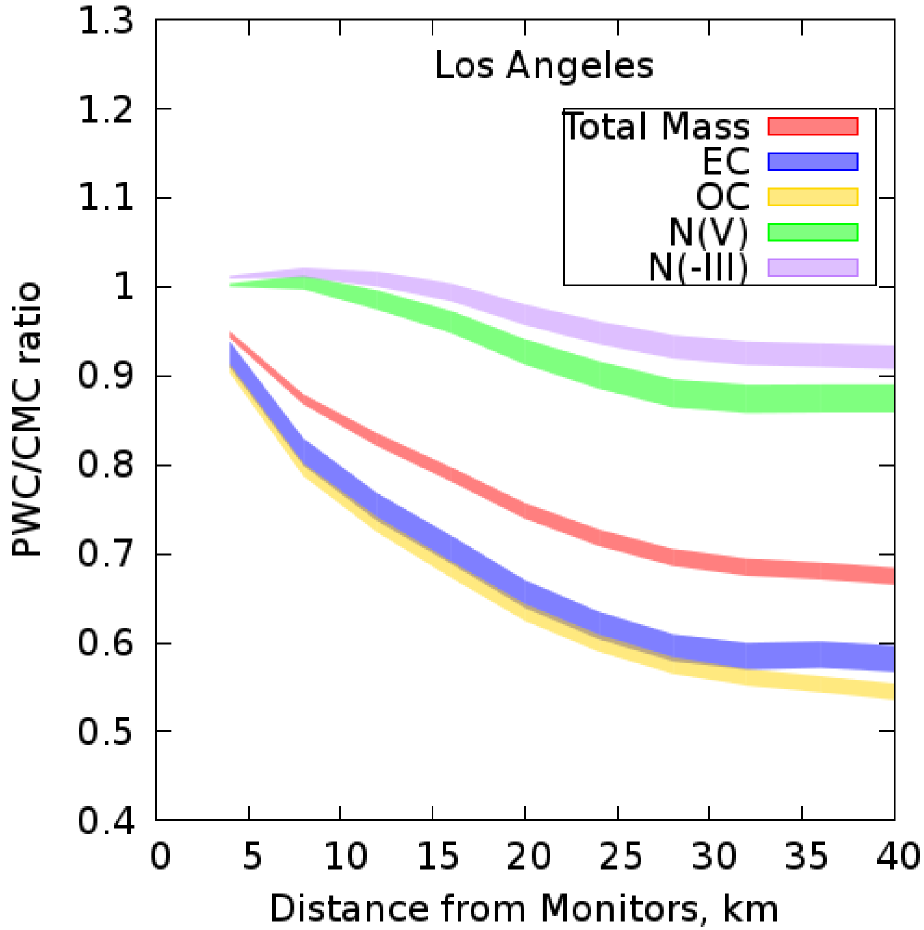
- Strong spatial heterogeneity in concentrations and population
- Use one or a few monitor sites to represent an entire county/air basin could lead to exposure misclassification
- Population weighted concentrations (PWC)

$$\text{PWC} = \frac{\sum_i C_i \times Pi}{\sum_i P_i}$$



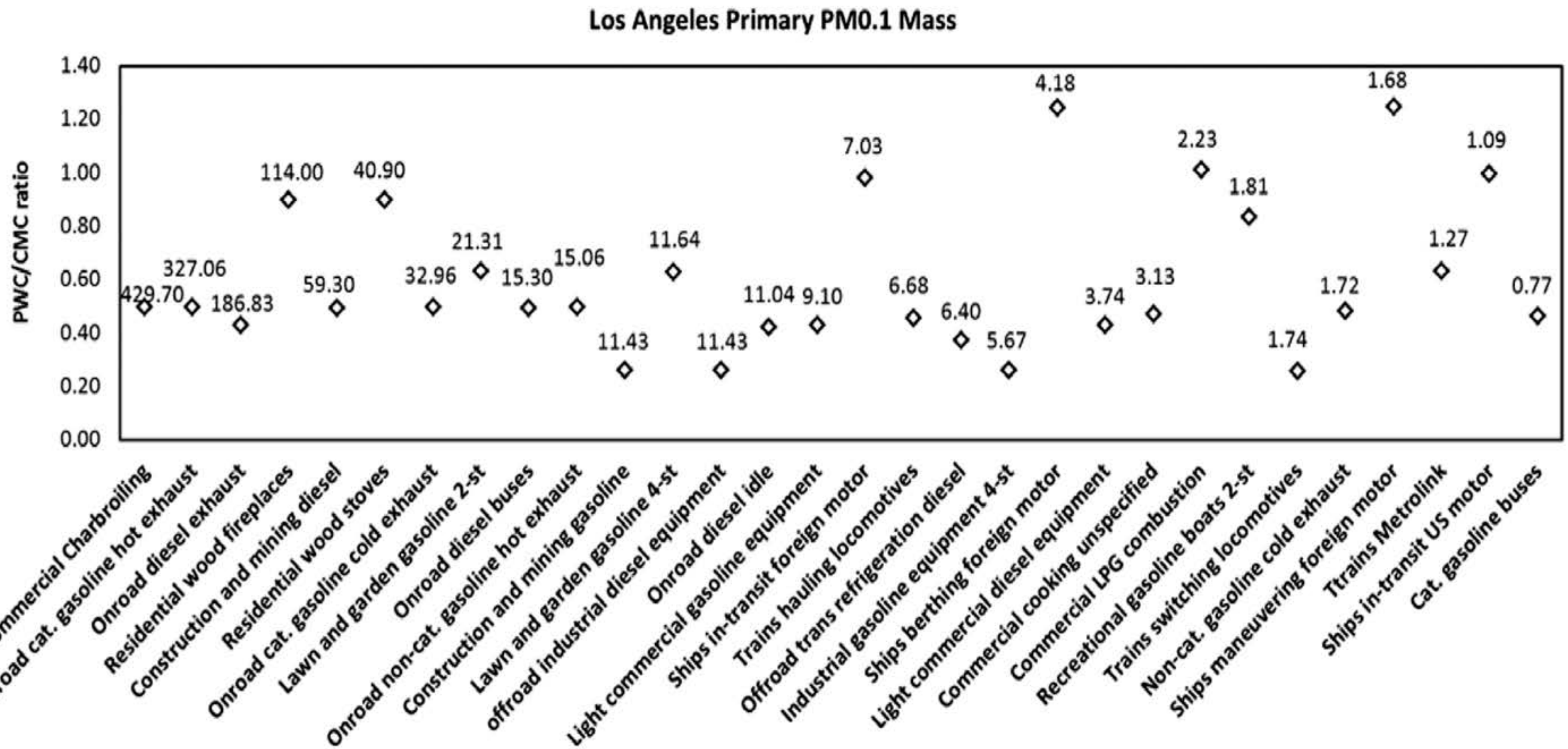
Source: *Environmental Health Perspective*, under review

Are We Under-Estimating the Health Effects of Particulate Matter?



Source: Manuscript in preparation.

Significant Difference Exists for PWC/CMC Ratios among Sources



Source: Environ. Sci. Technol., 2014, 48 (9), 4980-4990

Hazard Rates for UFP Mass and Constituents Associated with Ischemic Heart Disease

Table 5. Hazard ratios (HR) and 95% confidence interval (CI) for association of UF with Ischemic Heart Disease Mortality.

Pollutant	HR	Low CI	Upper CI	p-value
Mass	1.10	1.02	1.18	0.01
Cu	1.06	1.03	1.09	< 0.0001
Fe	1.03	1.00	1.06	< 0.05
Mn	1.00	0.99	1.01	0.62
Nitrate	-			
EC	1.15	1.06	1.26	< 0.001
OC	1.08	1.01	1.15	< 0.05
Other Compounds	1.10	1.04	1.16	< 0.001
Other Metals#	1.13	1.05	1.21	< 0.01
SOA biogenic	1.10	1.02	1.19	<0.01
SOA anthropogenic	1.25	1.13	1.39	< 0.001
S1: On-road gasoline	1.12	1.04	1.22	< 0.01
S2: Off-road gasoline	1.14	1.04	1.24	< 0.01
S3: On-road diesel	1.13	1.03	1.24	< 0.01
S4: Off-road diesel	1.14	1.05	1.23	< 0.01
S5:Wood smoke	0.95	0.89	1.02	0.20
S6: Meat cooking	1.11	1.03	1.20	< 0.01
S7: High sulfur fuel combustion	1.08	1.04	1.12	< 0.0001
S8: Other anthropogenic	1.06	1.01	1.10	0.01

Besides Cu, Fe, and Mn; S1-S8 indicate sources of primary particles

Source: Environ. Health Persp, 2015

Low Birth Weight (LBW, <2.5 kg) Is Associated With Air Pollution

- Odds Ratio of LBW per IQR associated with primary $PM_{2.5}$
  - Mass = 1.025 (1.017, 1.033)
  - Gasoline = 1.027 (1.018, 1.036)
  - Wood Burning = 1.020 (1.009, 1.031)
  - Com. meat cooking = 1.019 (1.013, 1.024)

- Odds Ratio of LBW per IQR associated with primary $PM_{0.1}$
  - Mass = 1.026 (1.018, 1.034)
  - Gasoline = 1.028 (1.019, 1.037)
  - Wood burning = 1.024 (1.013, 1.035)
  - Com. meat cooking = 1.019 (1.013, 1.024)

Source: Environmental Research, 2014

Summary

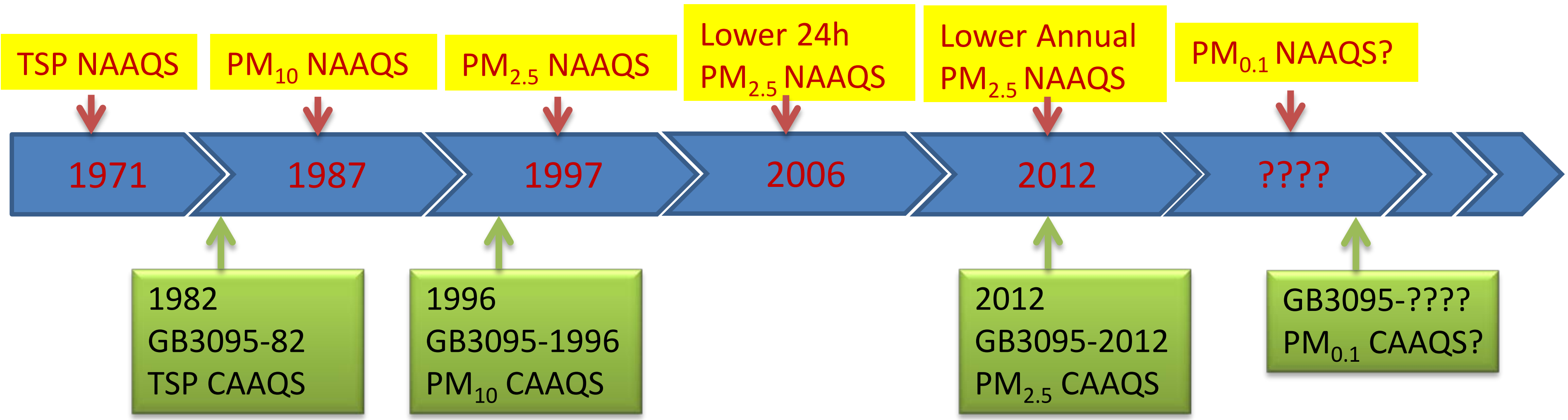
- 7-year UFP mass and sources modeling results for health effect studies in California
- Model generally captured concentrations of FP and UFP of certain compositions, but not all
- Model works better with longer averaging time
- Significant spatial heterogeneity of UFP among sources
- Large bias is expected if not considering the spatial heterogeneity
- UFP is found be associated with ischemic heart disease and low birth weight risks.

On-going and Future Studies

- Direct surface area modeling
- 1 km or less air quality modeling
- Full chemistry modeling

Evolution of Ambient Particulate Matter Standards

- TSP = total suspended particles
- NAAQS: National Ambient Air Quality Standards
- CAAQS: China Ambient Air Quality Standards



Thank You!