Enhanced Air Pollution Health Effects Studies Using Source-oriented Chemical Transport Models

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The 1st Regional GEOS-Chem Asia Meeting
May 21st – 23rd, 2015
Nanjing, China

Motivation

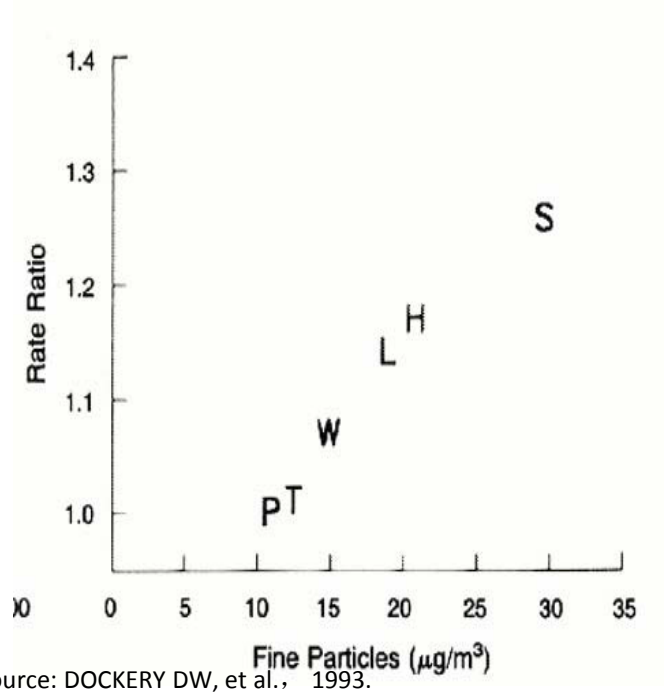
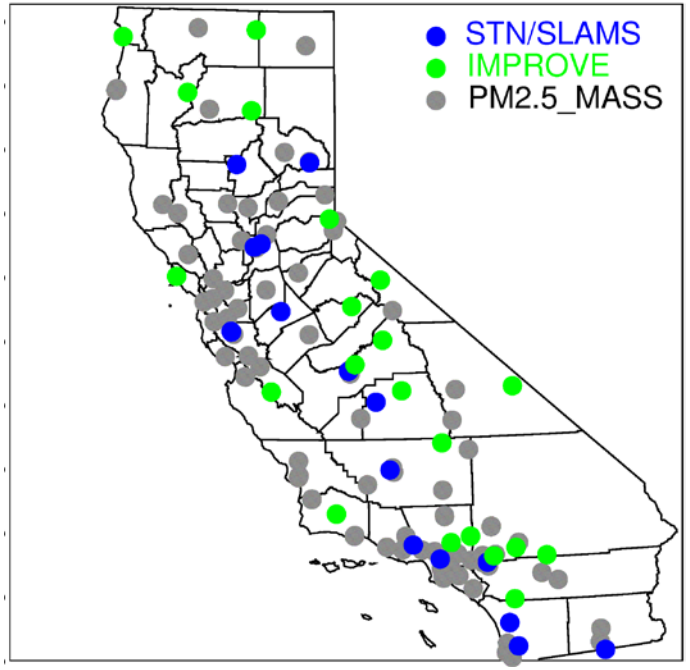


Figure Source: DOCKERY DW, et al., 1993.

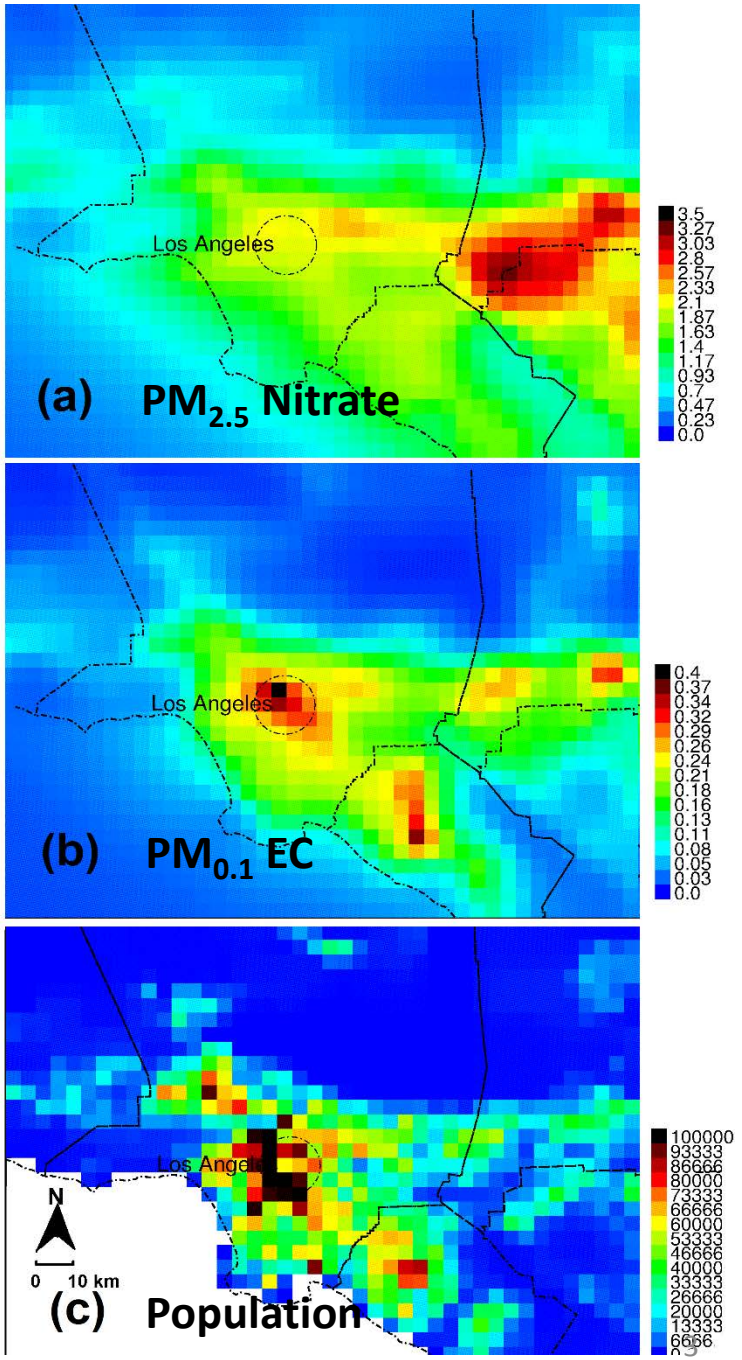


- Epidemiological and toxicological studies have shown positive associations between exposure to atmospheric particulate matter and adverse health effects
  - Can we target a specific set of sources / components / size fractions for less cost than the current PM2.5 control program?
- Fewer sites provide detailed PM chemical component measurements than total $PM_{2.5}$ mass
- Are central monitors providing poor exposure estimates that are masking the more detailed associations?

Population 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)

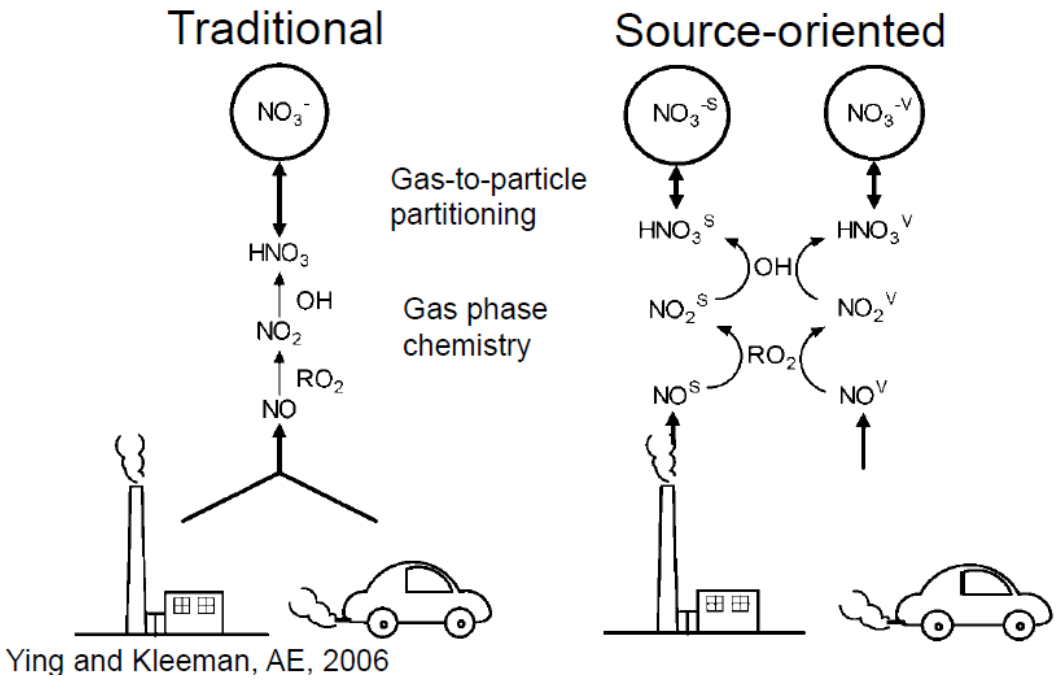
$$\text{PWC} = \frac{\sum_i C_i \times P_i}{\sum_i P_i}$$



Reference: Ostro et al., *EHP*, 2015

Source-Oriented Air Quality Models

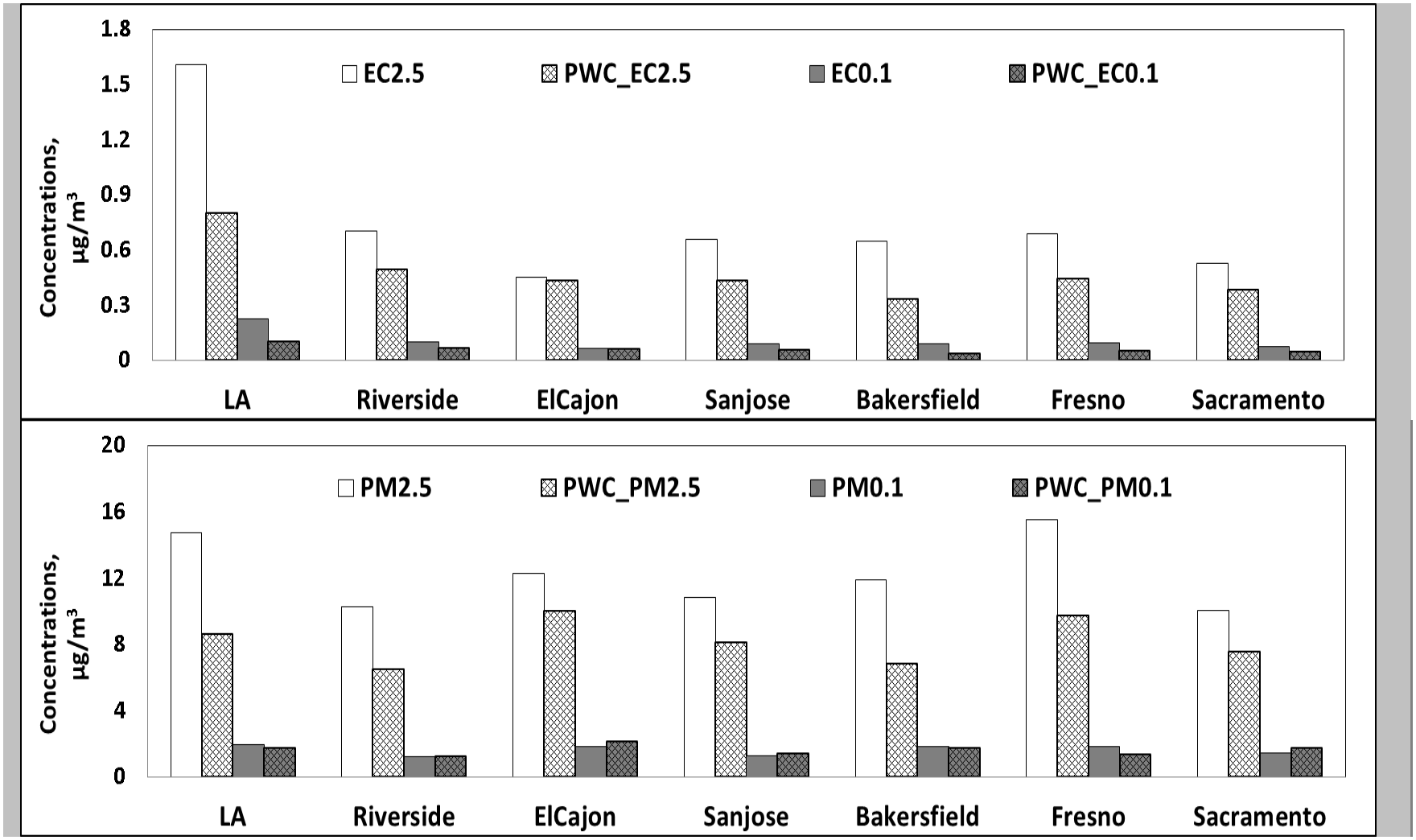
Source apportionment using Source-oriented air quality models



Ying and Kleeman, AE, 2006

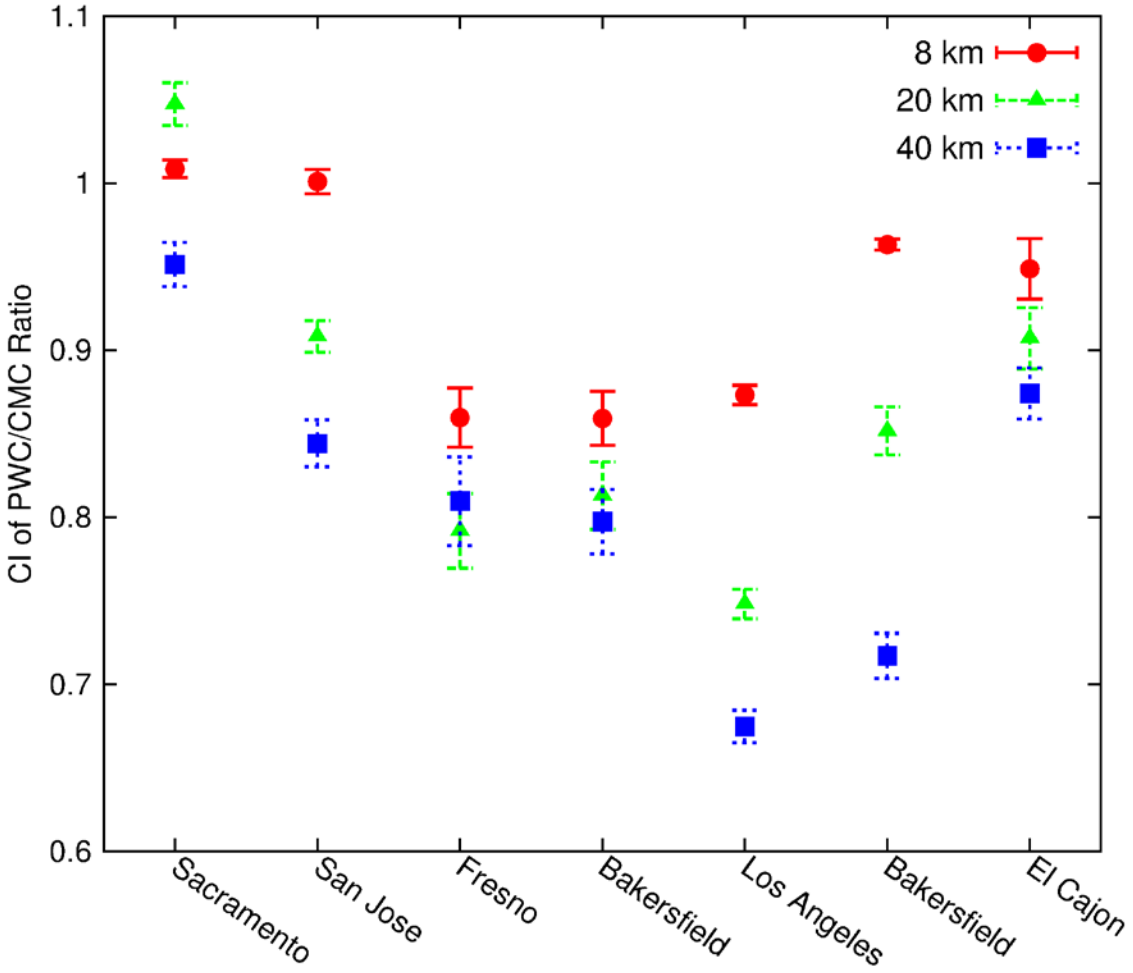
- Tag precursors from different sources
- Track the sources directly through all atmospheric processes
- Need to expand the gas and aerosol mechanisms

Central Site Concentrations vs. Population Weighted Concentrations of Total EC and Mass Concentrations

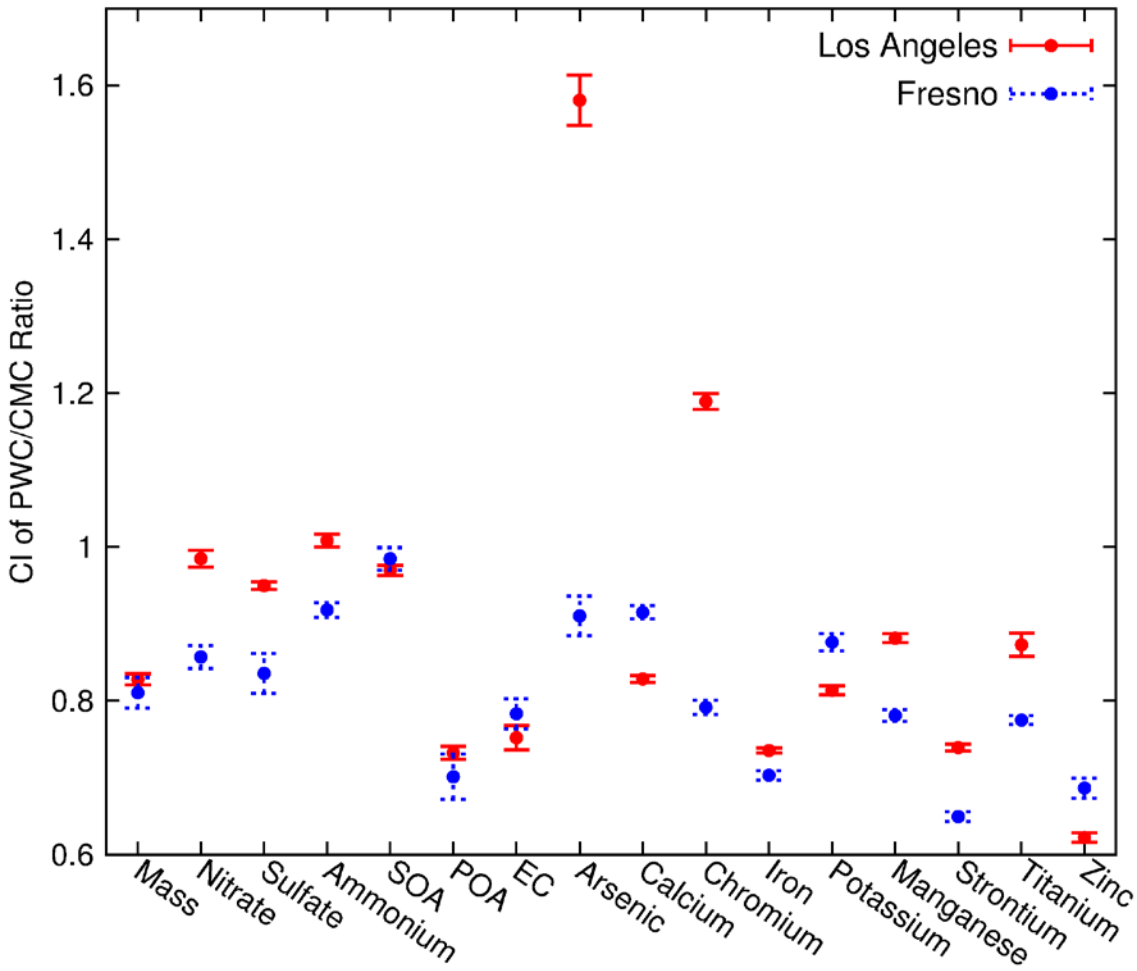


Reference: Hu et al., Environmental Science & Technology, 2014

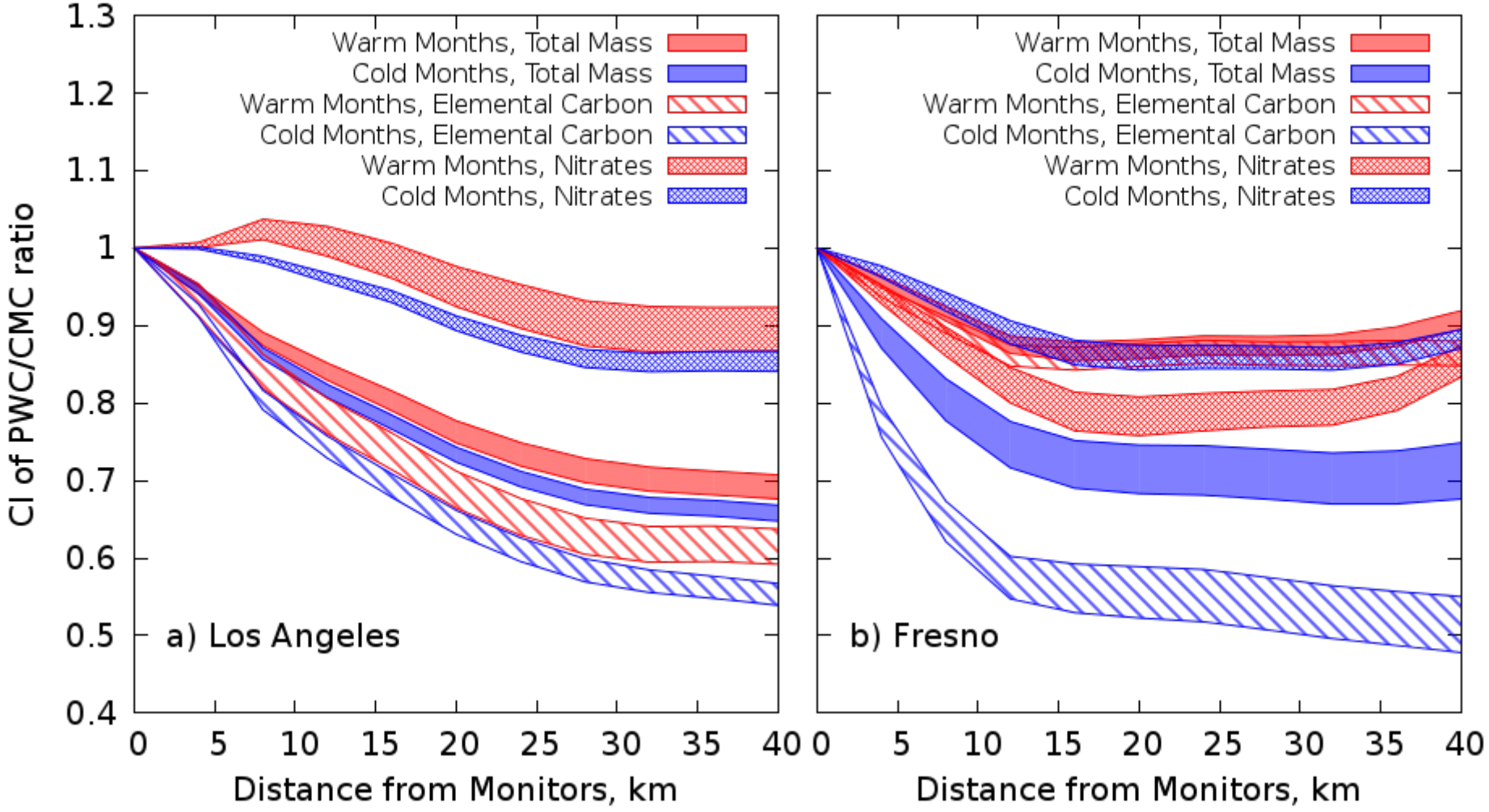
95% CIs when Choosing Different Spatial Representativeness of Central Monitors



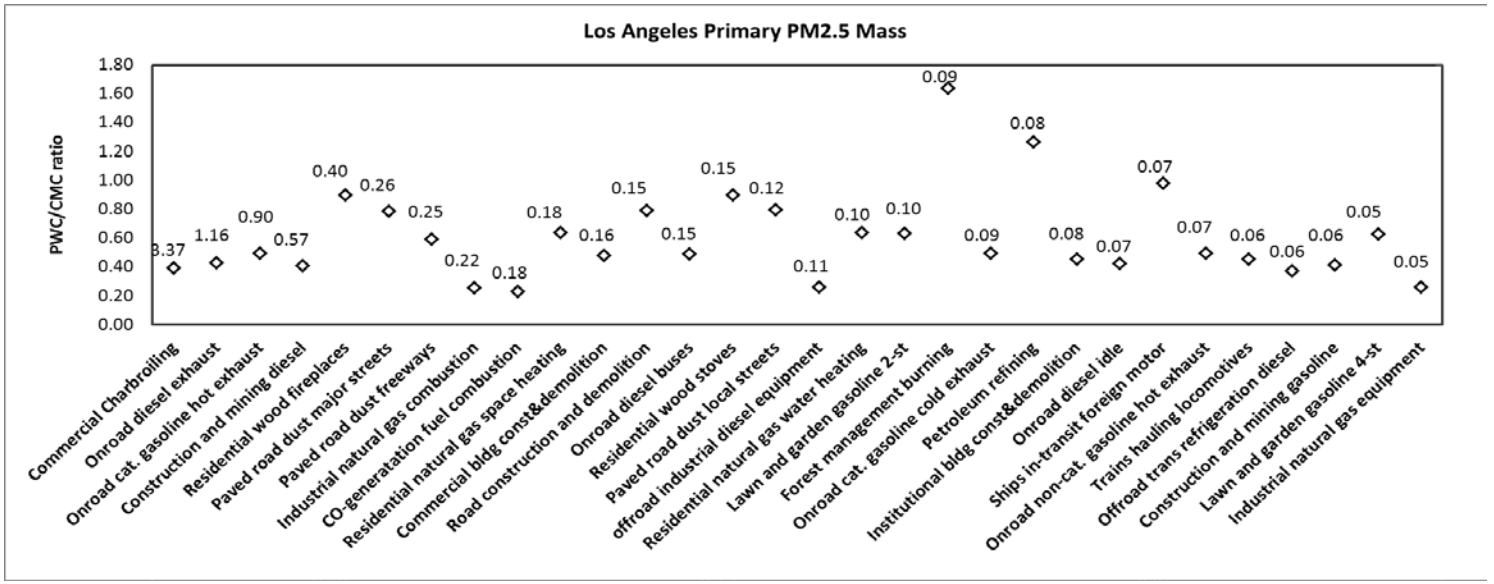
95% CIs for $PM_{2.5}$ Components with a 12 km buffer

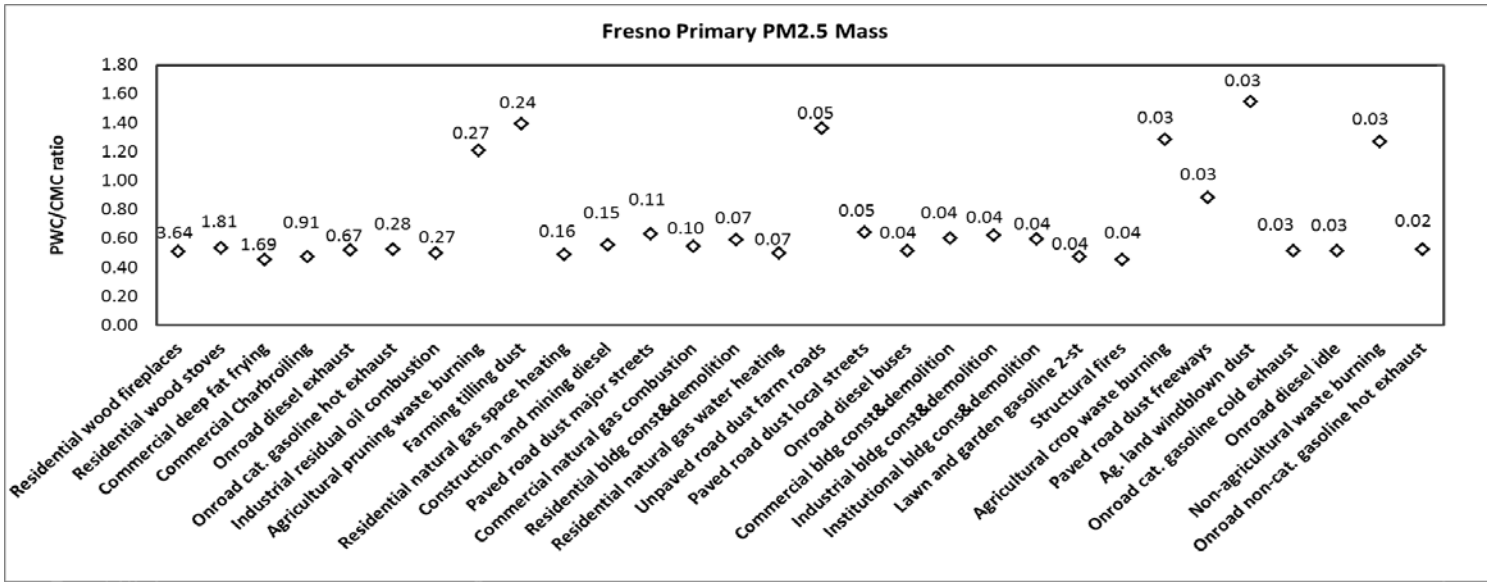


95% CIs for $PM_{2.5}$ Components in Warm (Apr-Sept) vs. Cold (Oct-Mar) Seasons



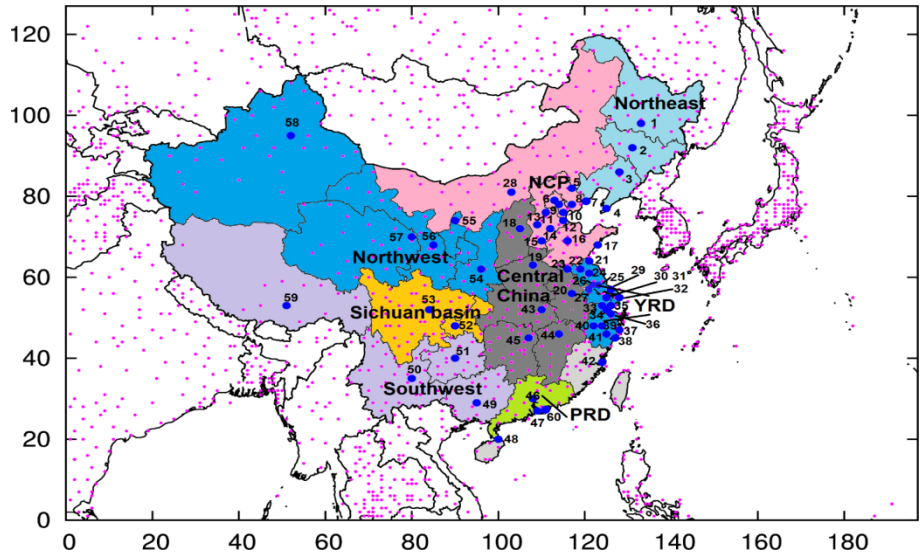
PWC/CMC ratios for Primary $PM_{2.5}$ Sources



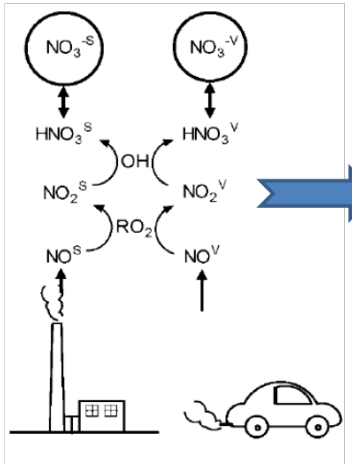


Reference: Hu et al., ES&T, 2014.

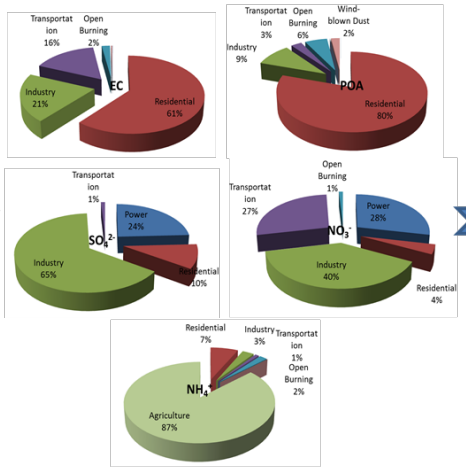
One Year Simulation in China



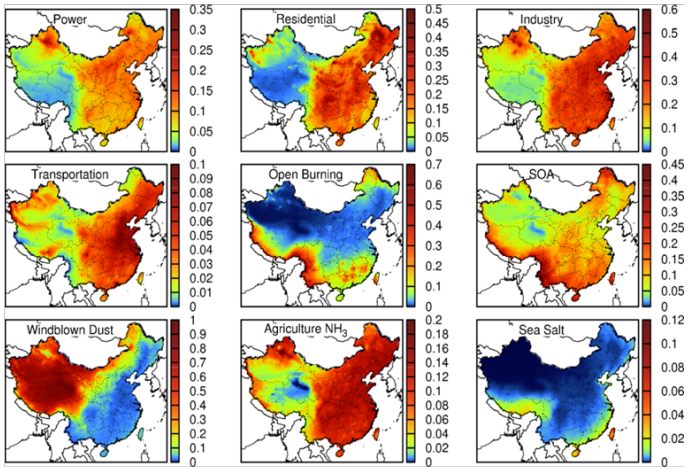
Source-oriented Chemical Transport Model



Source contributions to $PM_{2.5}$ components



Regional Source Apportionment of $PM_{2.5}$



Summary

- Strong spatial heterogeneity in concentrations in $PM_{2.5}$ components, sources and in different seasons.

- Population weighted concentrations of PM emitted from various sources calculated using the model spatial information differed from the central monitor estimates.

- CTMs provide more detailed information to help improve exposure assessment for health effect studies.

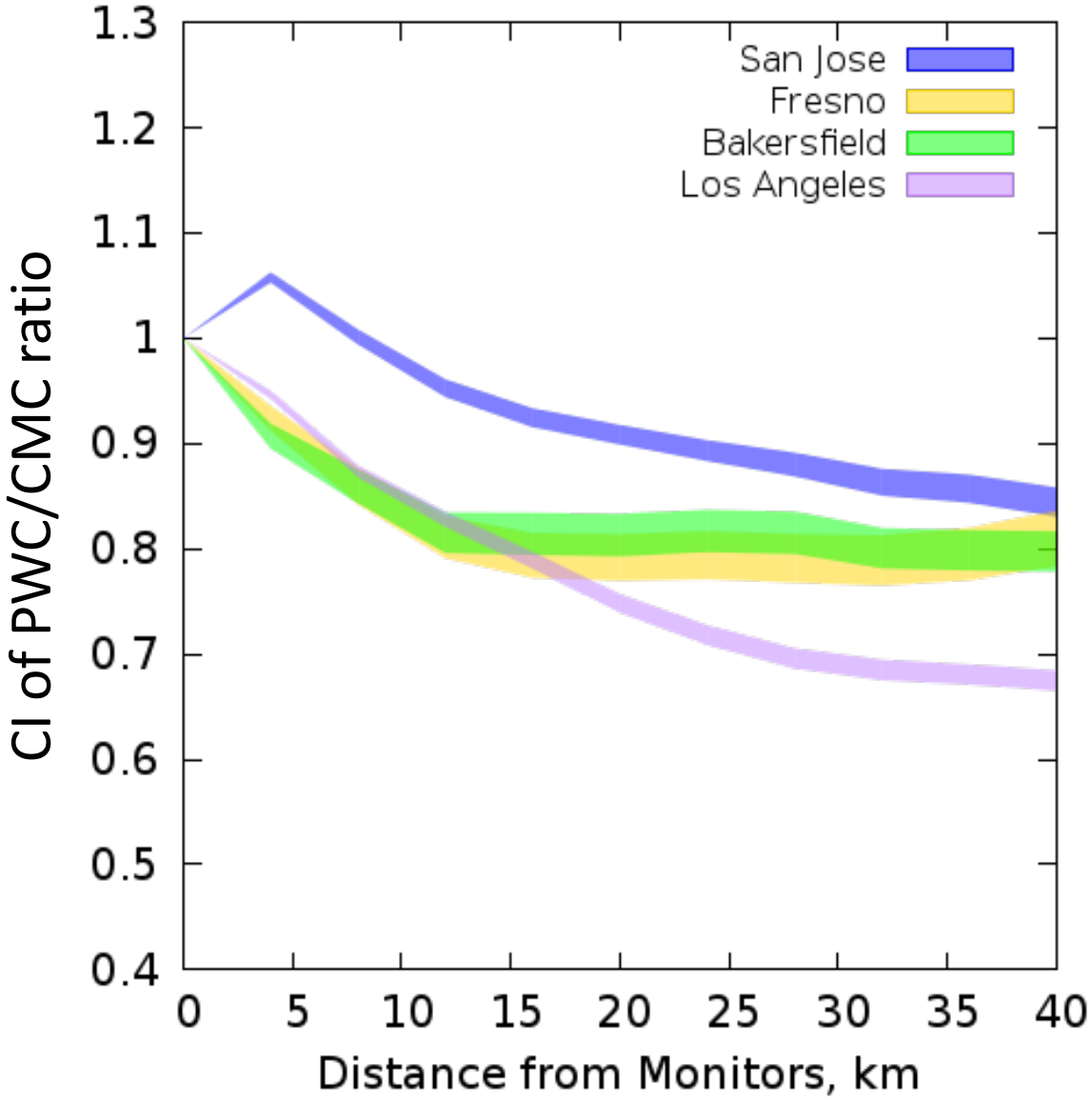
Acknowledgements

Disclaimer: Although the research described in the article has been funded wholly or in part by the U.S. Environmental Protection Agency's STAR program through grant (number), it has not been subjected to any EPA review and therefore does not necessarily reflect the views of the Agency, and no official endorsement should be inferred.

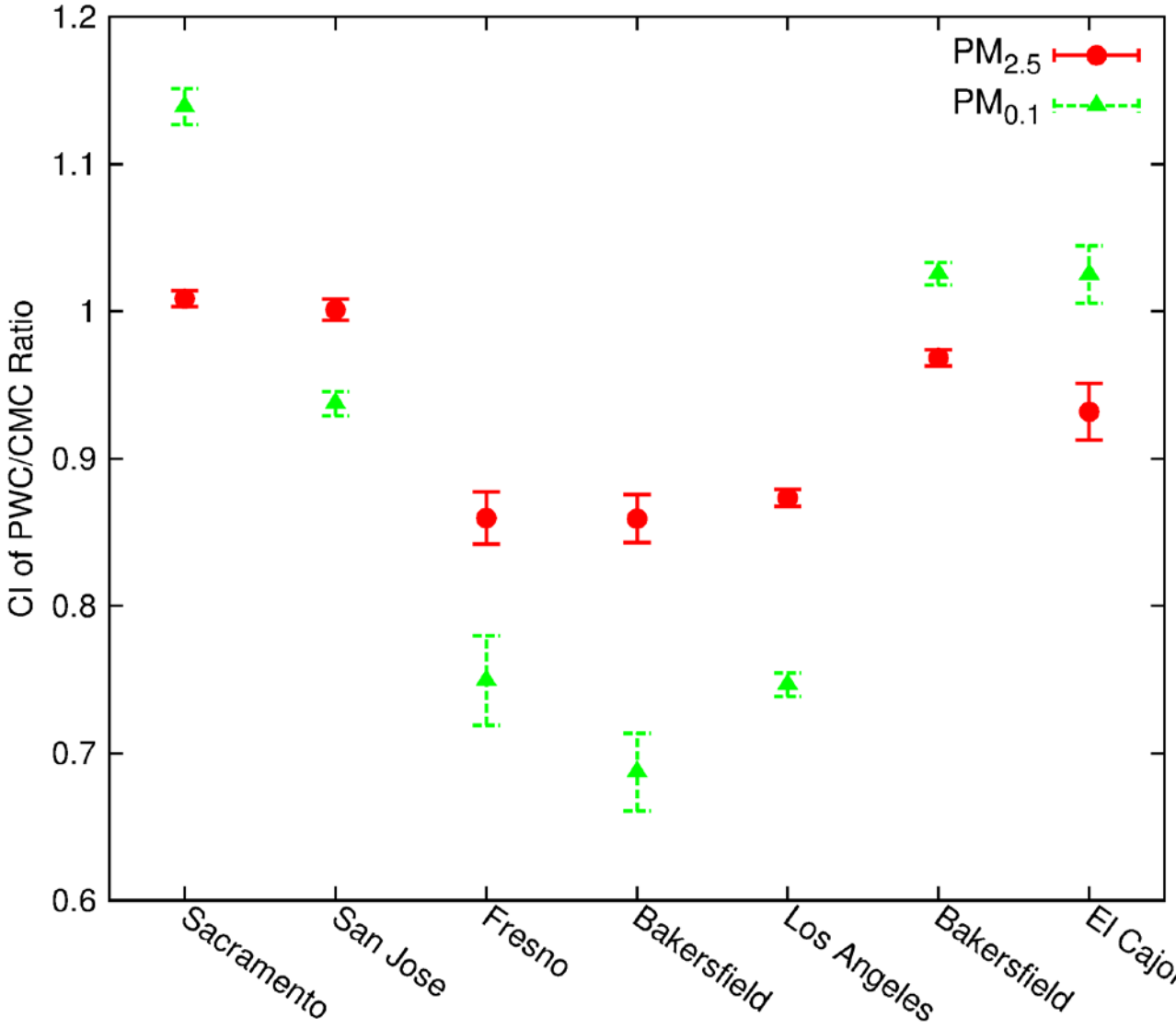
Data Availability: http://faculty.engineering.ucdavis.edu/kleeman/.

Supporting Slides

95% CIs for $PM_{2.5}$ Mass at Different Locations

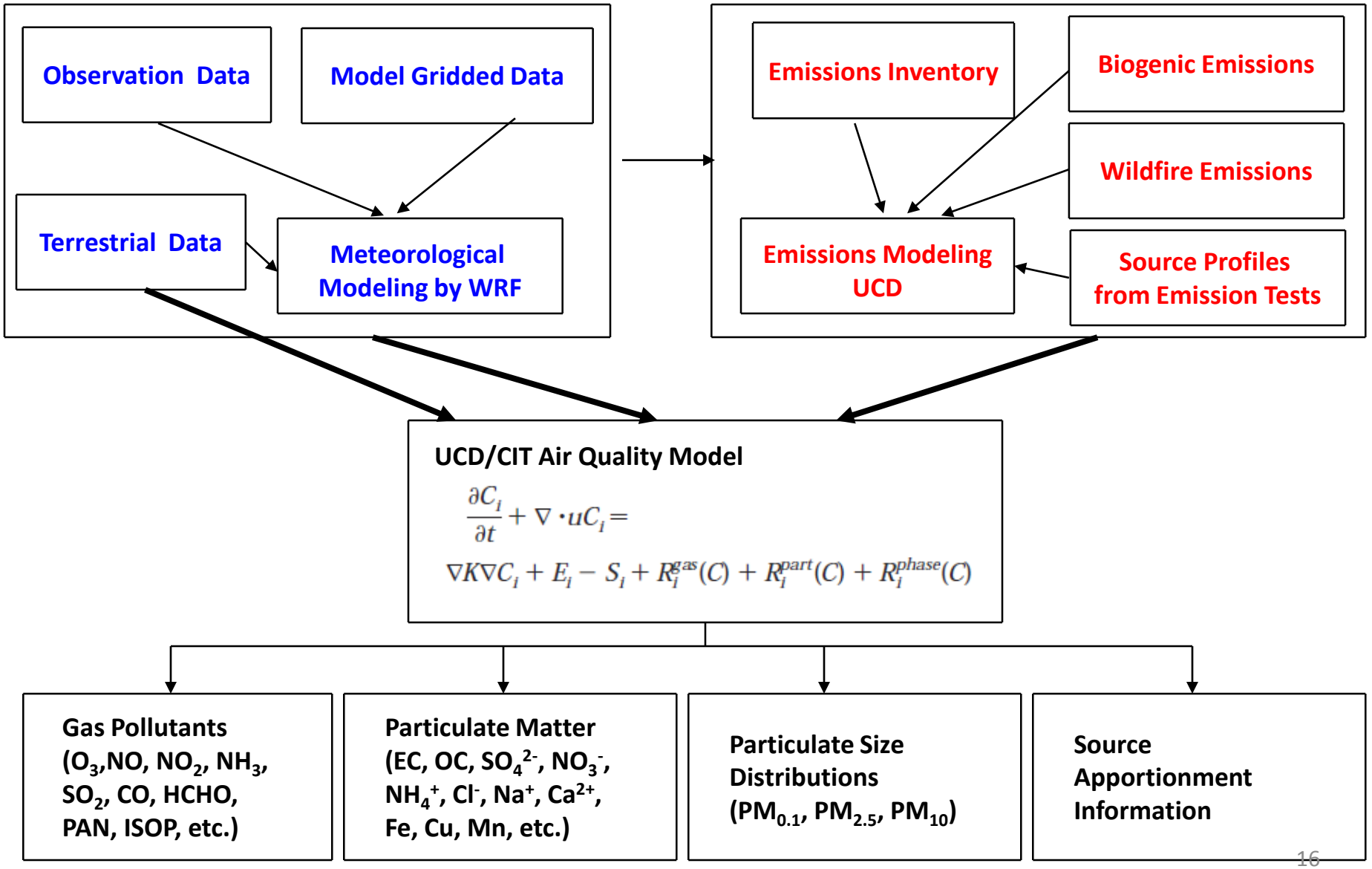


95% CIs of PWC/CMC ratios for $PM_{2.5}$ vs. $PM_{0.1}$



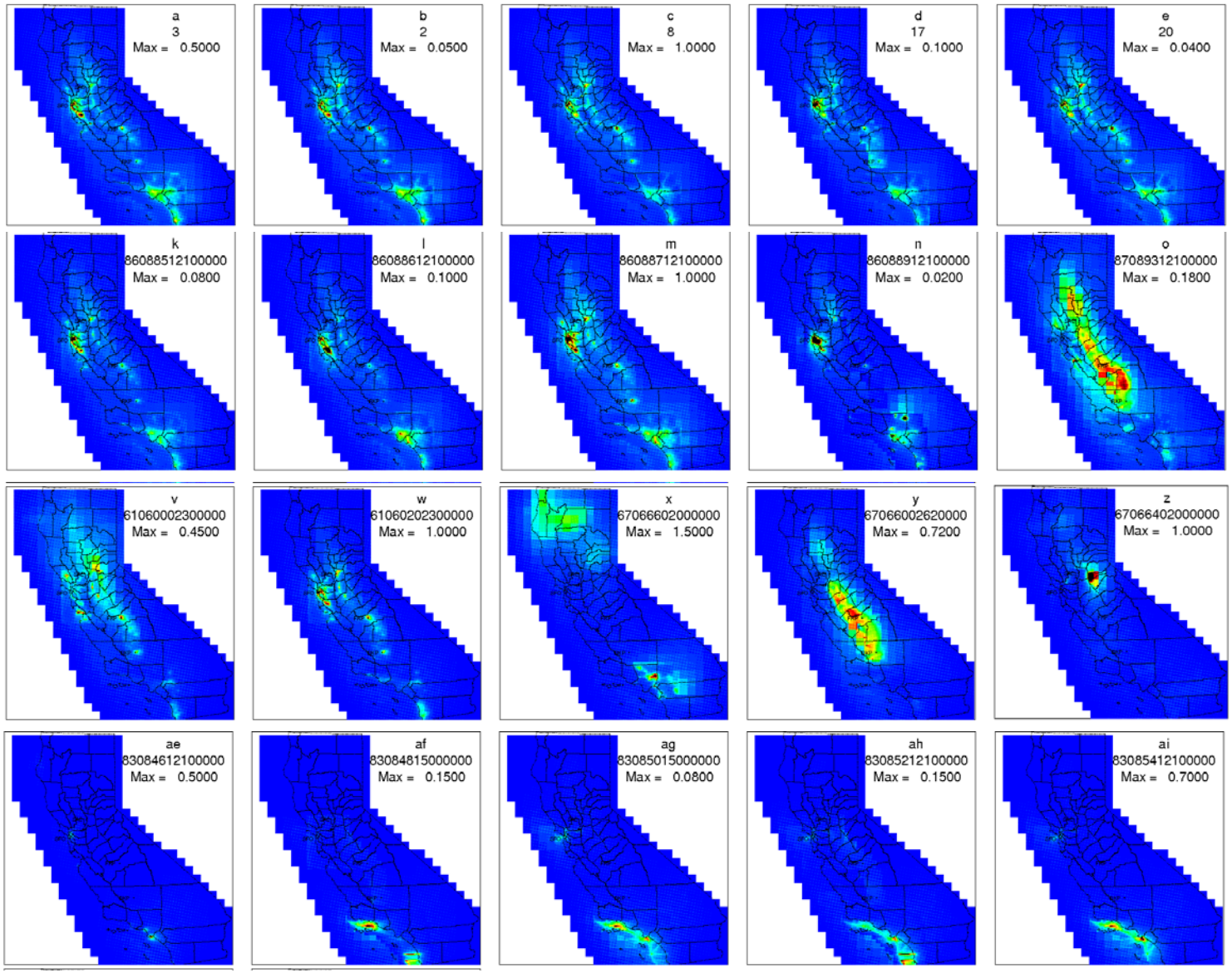
- Calculation is based on the distance from monitors of 8km
- $PM_{0.1}$ shows greater spatial variations of CIs than $PM_{2.5}$

Chemical Transport Model (CTM): UCD/CIT



Predicted Regional Distribution of $PM_{2.5}$ Sources

- on-road mobile sources
- off-road mobile sources
- wood burning sources
- shipping sources



Reference: Hu et al., Identifying Primary PM2.5 and PM0.1 Sources for Epidemiological Studies in California. ES&T, 2014.

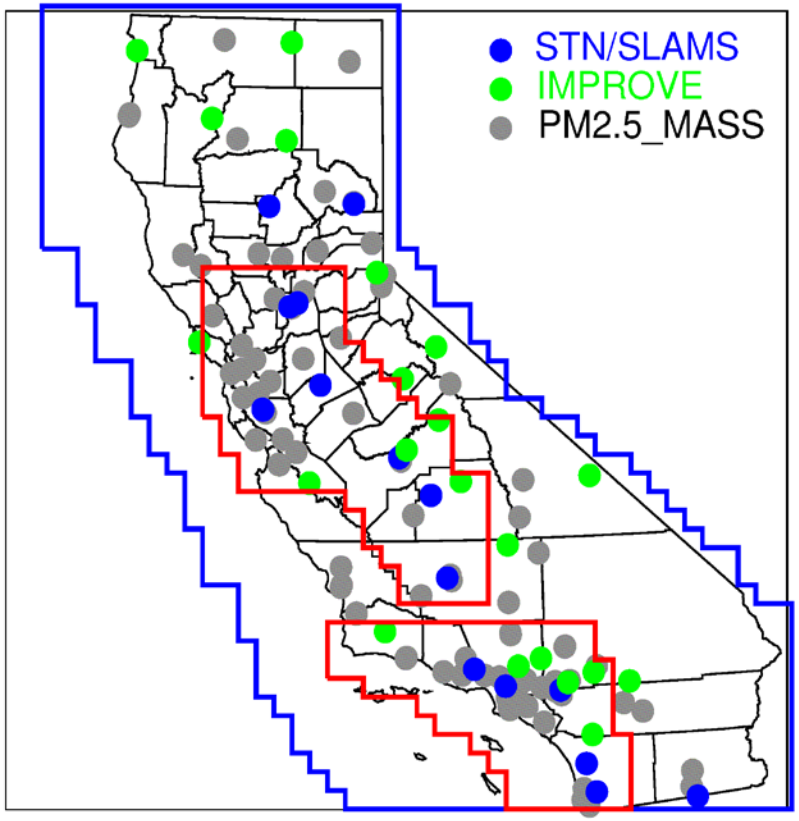
Model Configuration for California 2000-2008

- **Meteorology**
  - **WRFv3.1** with FDDA
  - Hourly average outputs
  - Increased surface friction velocity (u*) by 50% (Mass CF, 2010)

- **Emissions**
  - Emissions inventory from California Air Resources Board
  - EMFAC2007 for mobile emissions
  - 1kmX1km satellite wildfire emissions (http://bai.acd.ucar.edu/Data/fire/, Wiedinmyer C. et al., Geosci. Model Dev. Discuss., 3, 2439-2476, 2010)

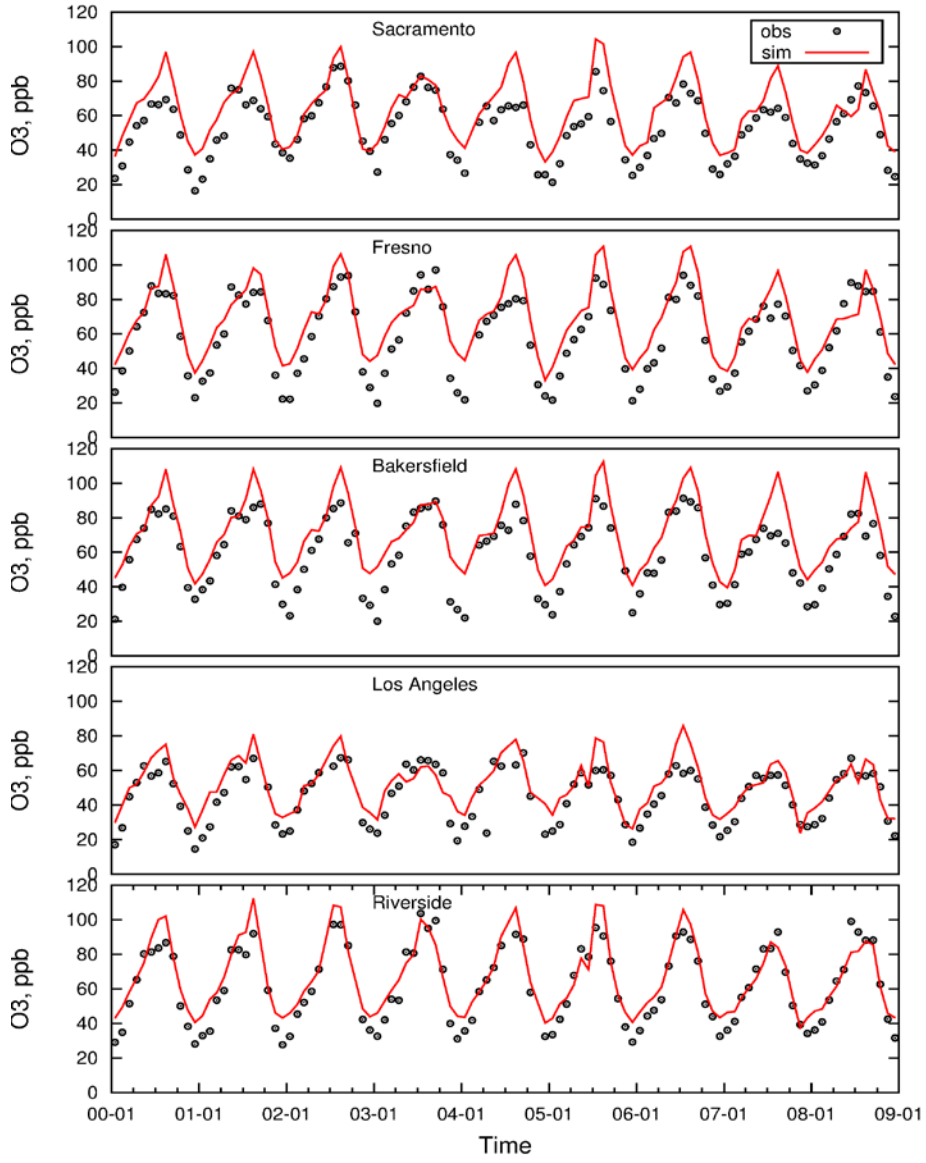
- **UC-Davis_Primary (UCD_P)**
  - ~900 sources of primary PM

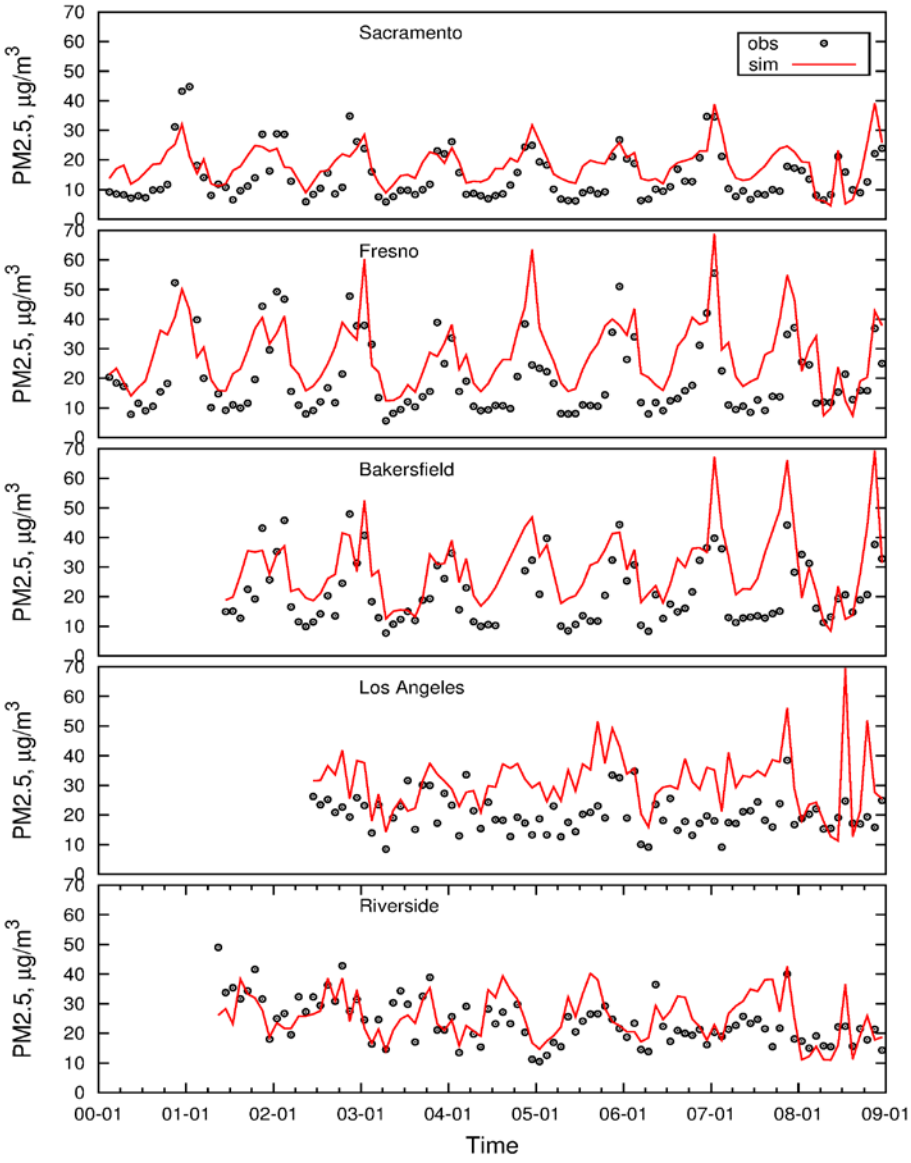
- **UCD/CIT**
  - gaseous pollutants,
  - secondary inorganic aerosols (nitrate, sulfate, ammonium, etc.)
  - secondary organic aerosol from
  - 10 sources
    - onroad/offroad gasoline, onroad/offroad diesel, wood burning, meat cooking, high sulfur content fuel combustion, other anthropogenic sources, biogenic sources, and IC/BCs



Reference: Hu et al., Long-term Particulate Matter Modeling for Health Effects Studies in California – Part I: Model Performance on Temporal and Spatial Variations. ACP, 2015.

Predicted vs. Measured O_3 and $PM_{2.5}$





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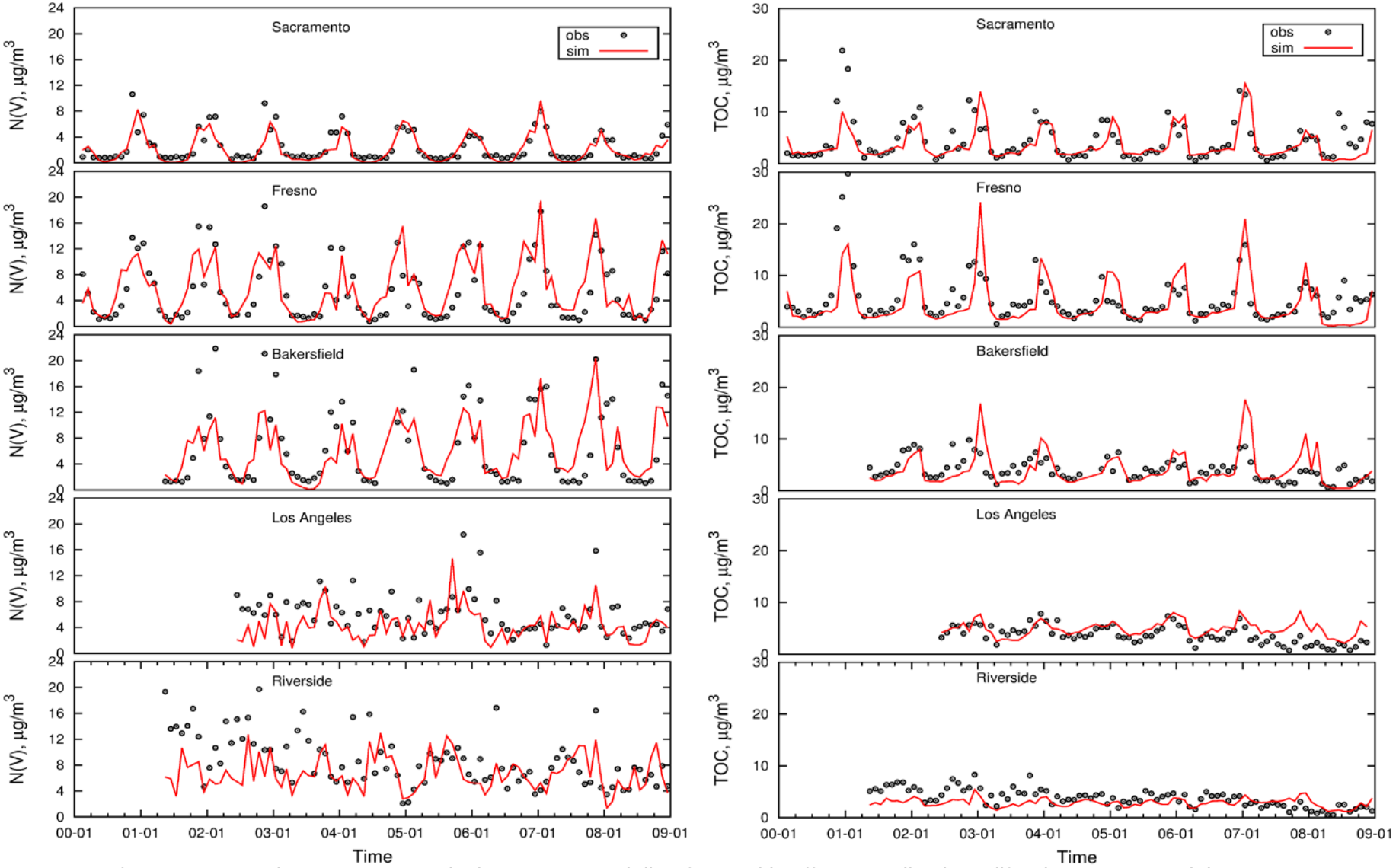
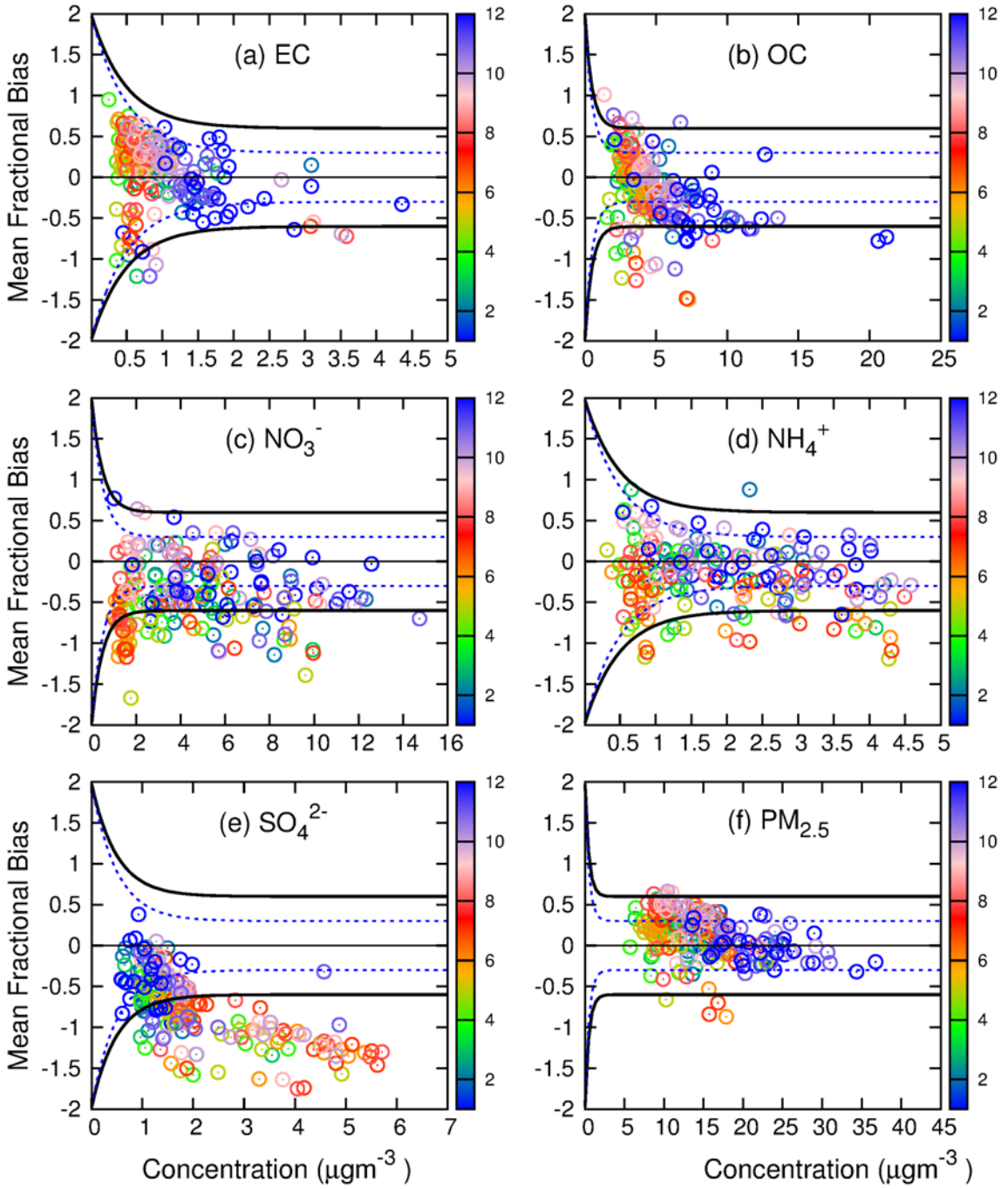
Predicted vs. Measured Nitrate and Total Organic Compounds



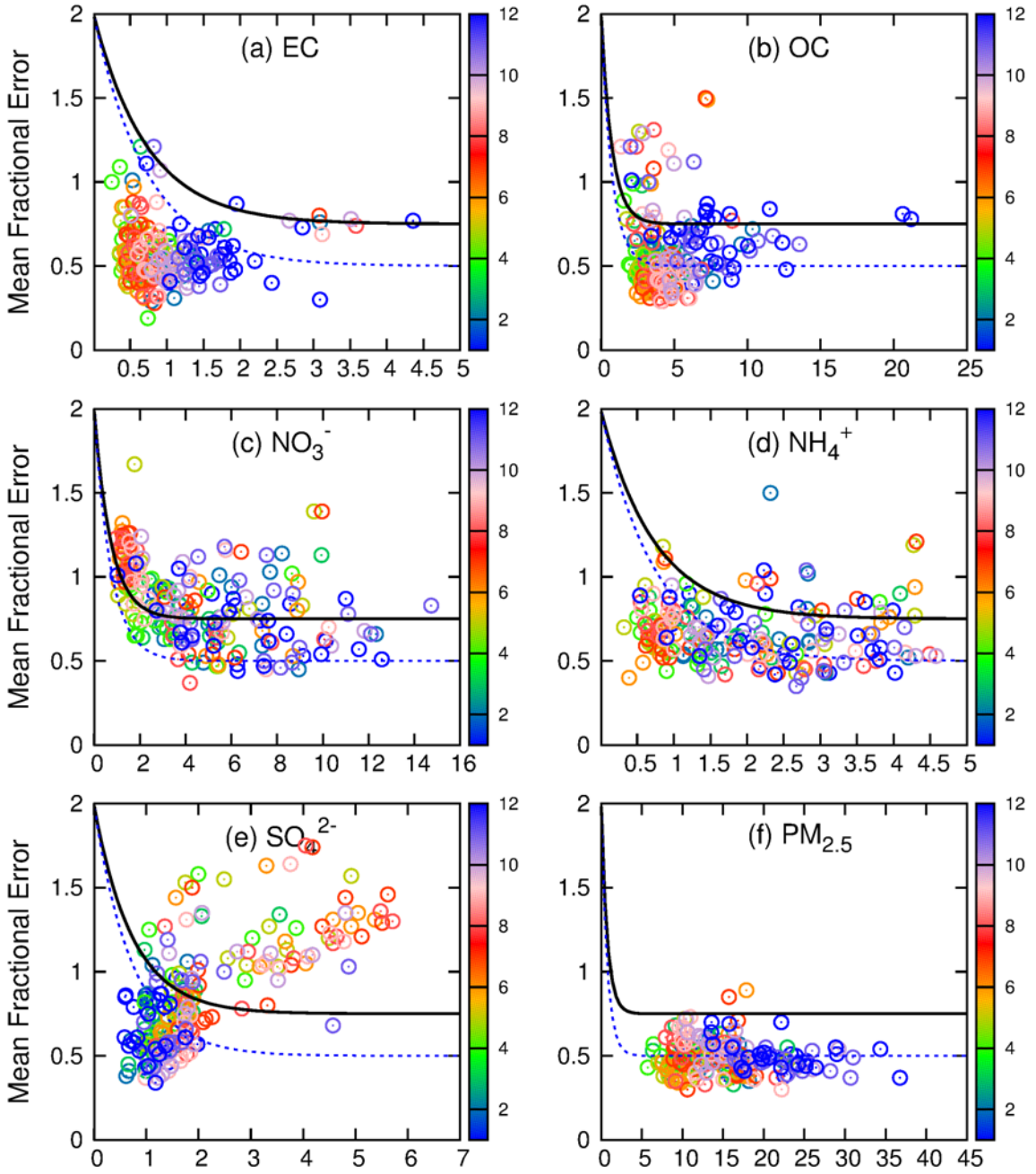
Reference: Hu et al., Long-term Particulate Matter Modeling for Health Effects Studies in California – Part I: Model Performance on Temporal and Spatial Variations. ACP, 2015.

Mean Fractional Bias



Reference: Hu et al., Long-term Particulate Matter Modeling for Health Effects Studies in California – Part I: Model Performance on Temporal and Spatial Variations. ACP, 2015.

Mean Fractional Error



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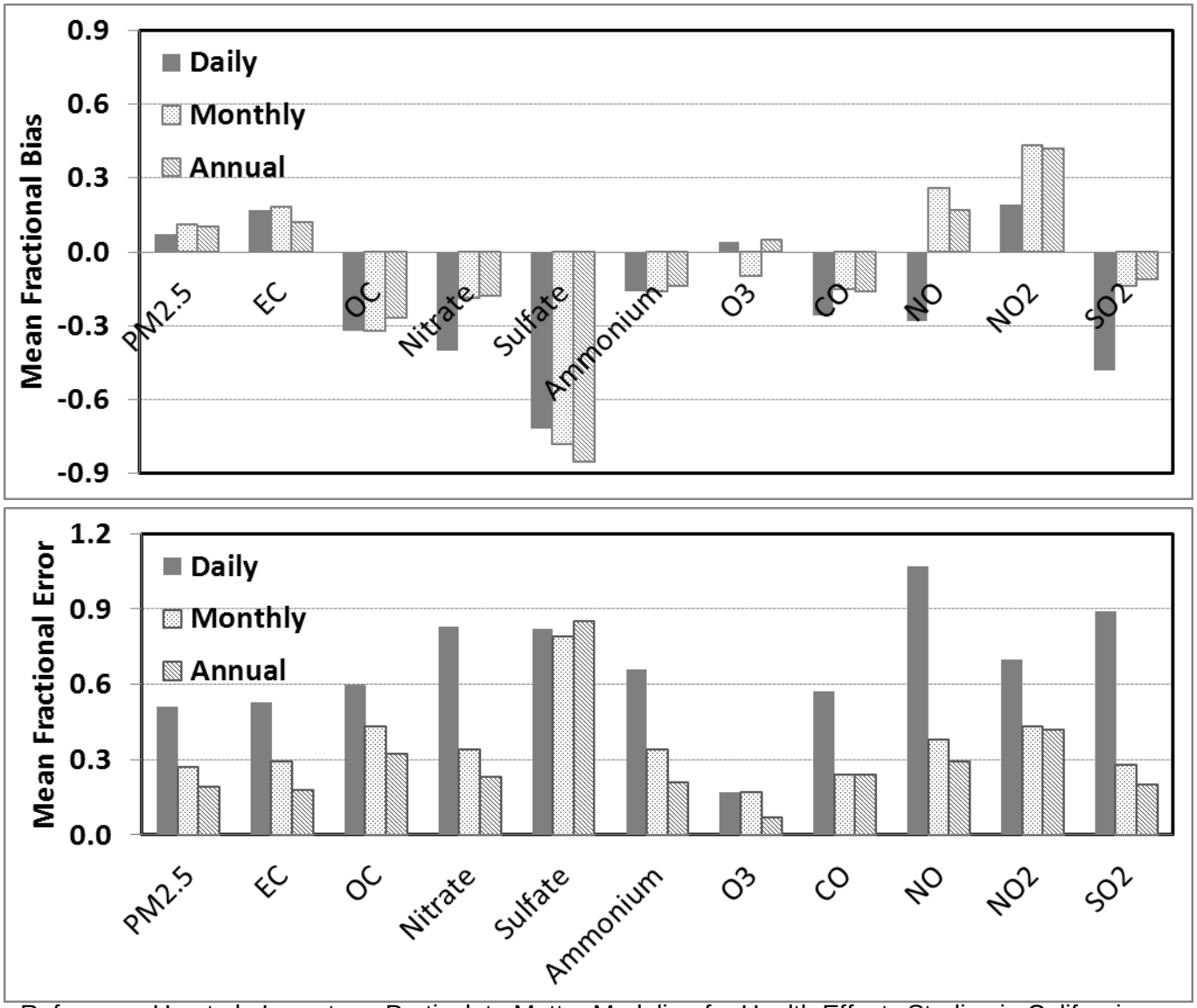
Model Evaluation Statistics



Reference: Hu et al., Long-term Particulate Matter Modeling for Health Effects Studies in California – Part I: Model Performance on Temporal and Spatial Variations. ACP, 2015.

Model Evaluation: MFB(numbers) and R (colors) of Monthly Average EC and Trace Elements at Individual Sites

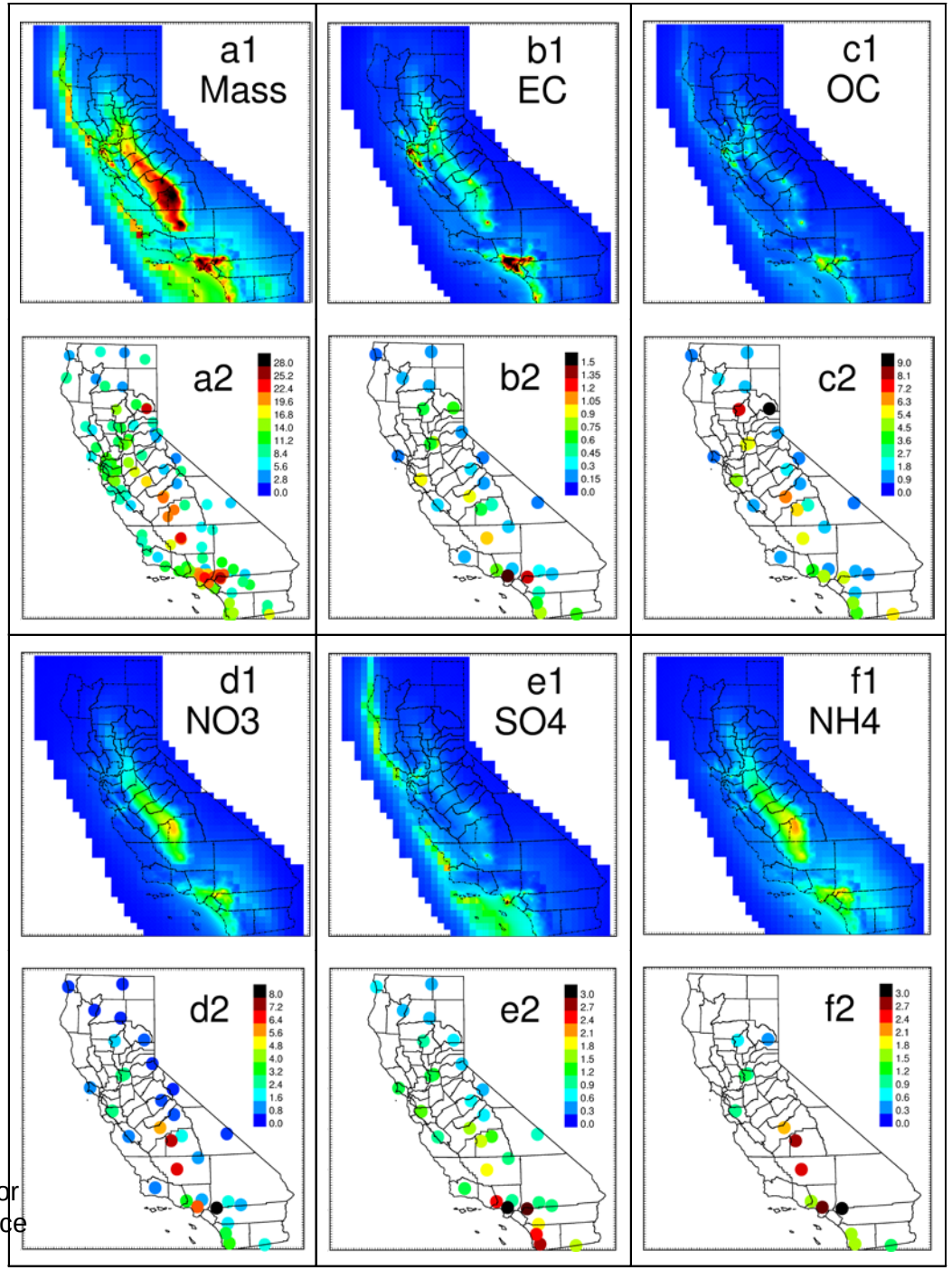
Species	Sacramento	SanJose1	SanJose2	Fresno	Bakersfield	LosAngeles	Riverside	ElCajon
EC	0.02	0.00	0.00	0.02	-0.02	0.03	0.04	-0.04
K	0.02	-0.04	-0.04	0.02	-0.11	-0.03	0.01	-0.14
CR	-0.22	0.08	-0.04	0.08	-0.07	0.02	0.03	-0.06
ZN	0.08	0.01	-0.01	-0.16	-0.03	-0.03	-0.35	0.00
FE	0.71	0.06	0.20	0.65	0.14	0.13	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

Reference: Hu et al., Predicting Primary PM2.5 and PM0.1 Trace Composition for Epidemiological Studies in California. ES&T, 2014.

Predicted Regional Distribution of $PM_{2.5}$ Components

- Model performance provides confidence in CTM predictions at locations with no measurement
- 1 - Predicted
  2 - measured
- 9-year average concentrations of PM2.5 total mass (a), EC (b), OC (c), nitrate (d), sulfate (e), and ammonium (f)



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