Fine Particulate Matter in the San Joaquin Valley: Introduction to Sources, Atmospheric Chemistry, and Transport

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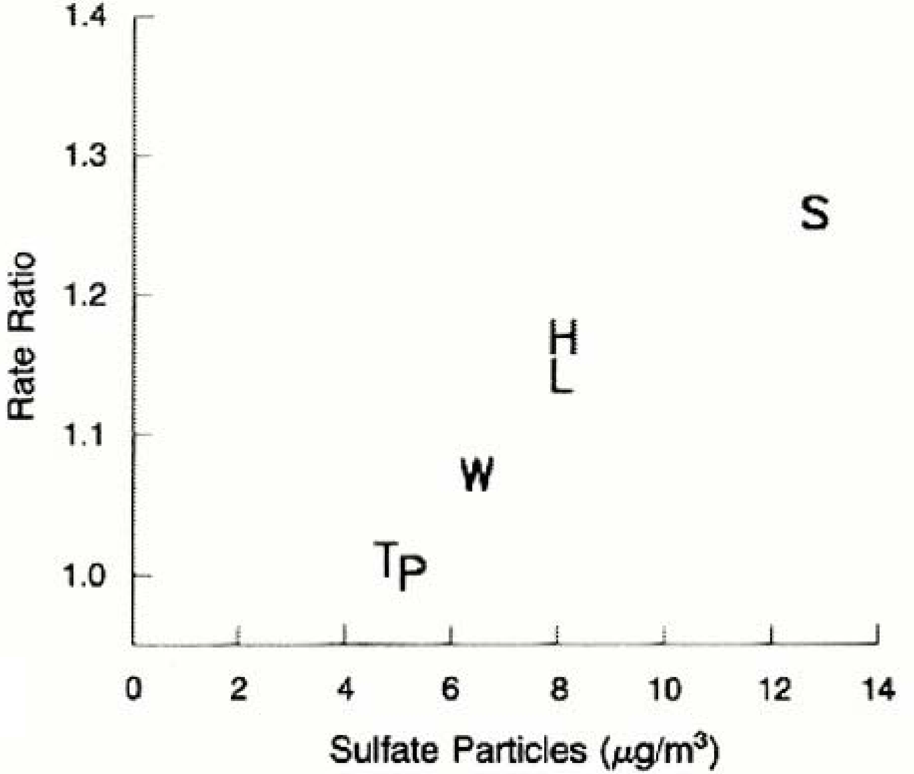
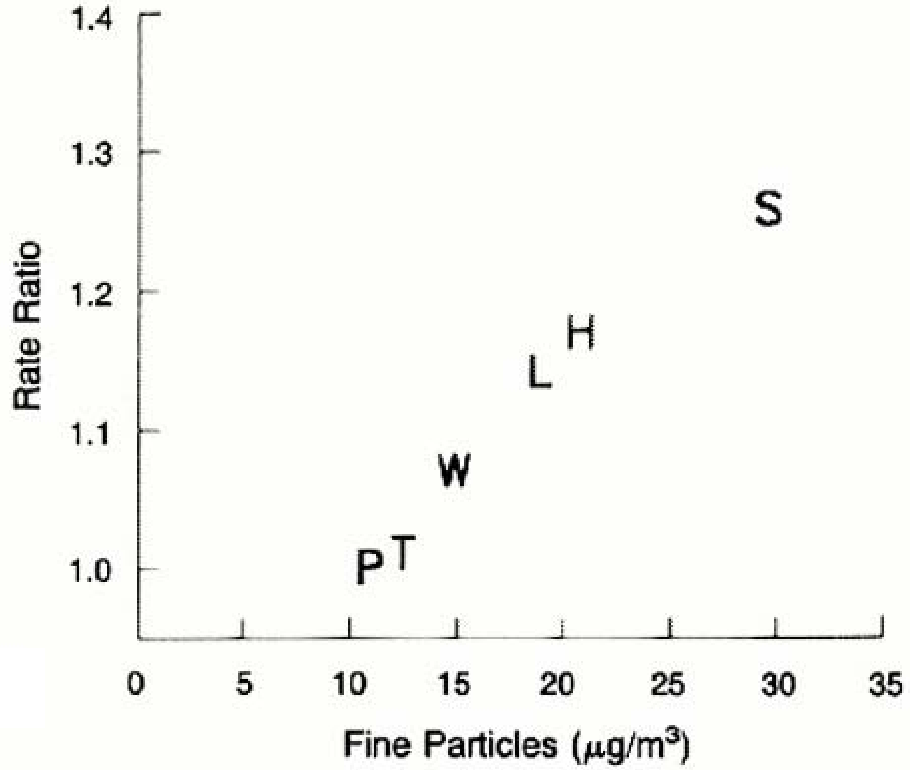
Civil and Environmental Engineering, UC Davis

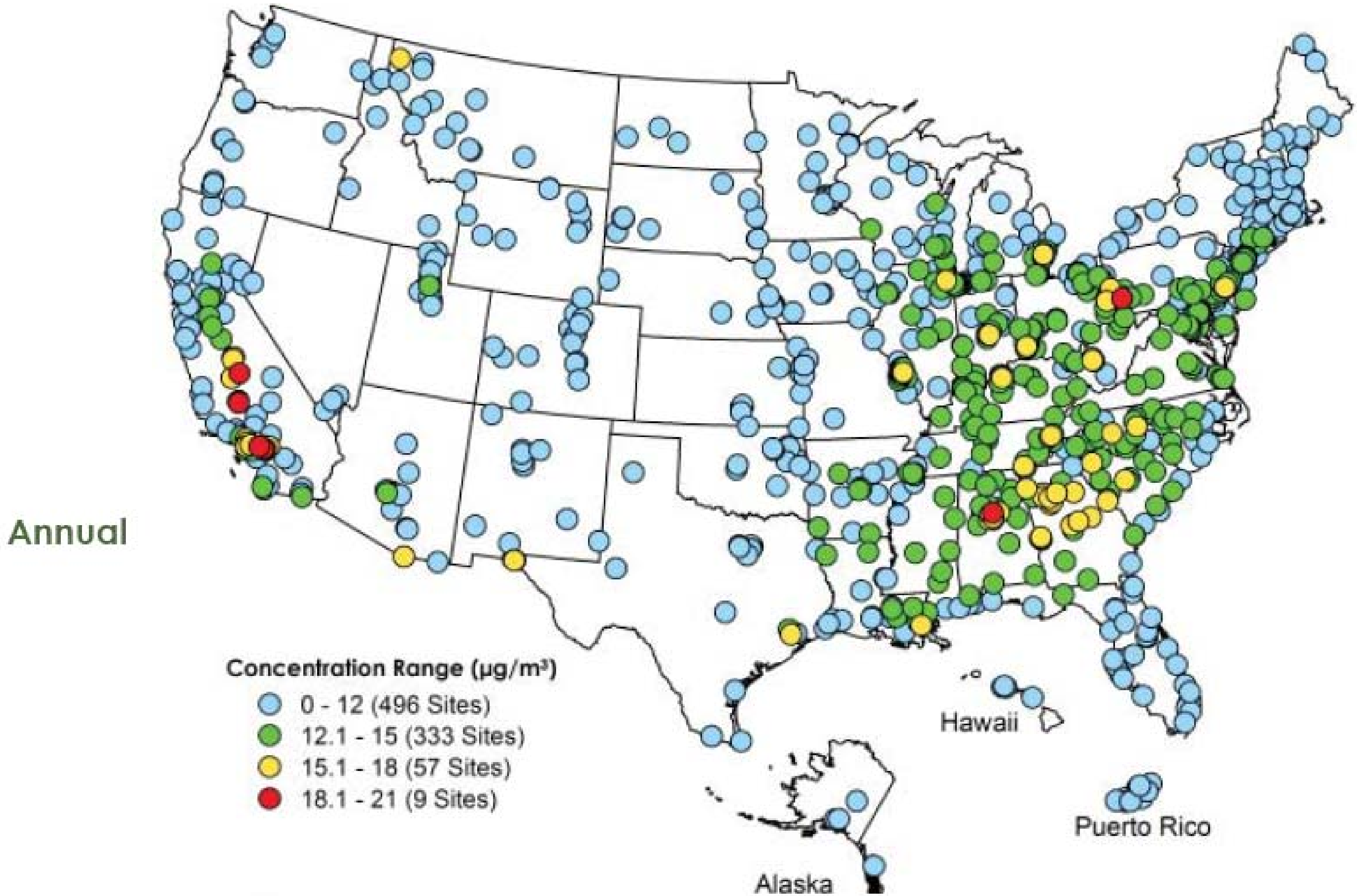
Health Effects of Airborne Particles





Source: DOCKERY DW, POPE CA, XU XP, et al. "AN ASSOCIATION BETWEEN AIR-POLLUTION AND MORTALITY IN 6 UNITED-STATES CITIES", NEW ENGLAND JOURNAL OF MEDICINE 329 (24): 1753-1759 DEC 9 1993.

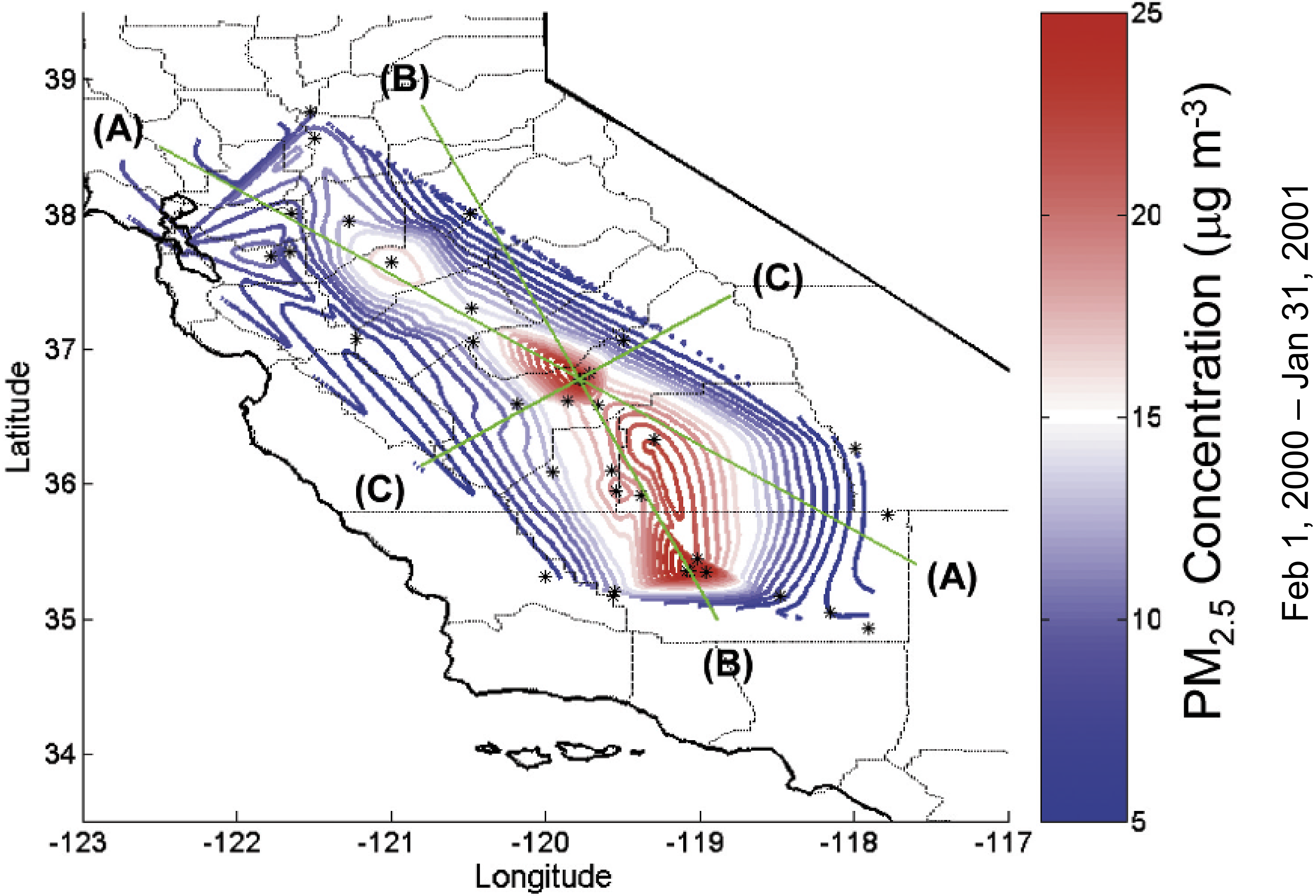
PM2.5 Concentrations in the US



Annual average and daily (98th percentile 24-hour concentrations) $PM_{2.5}$ concentrations in µg/m³, 2006.

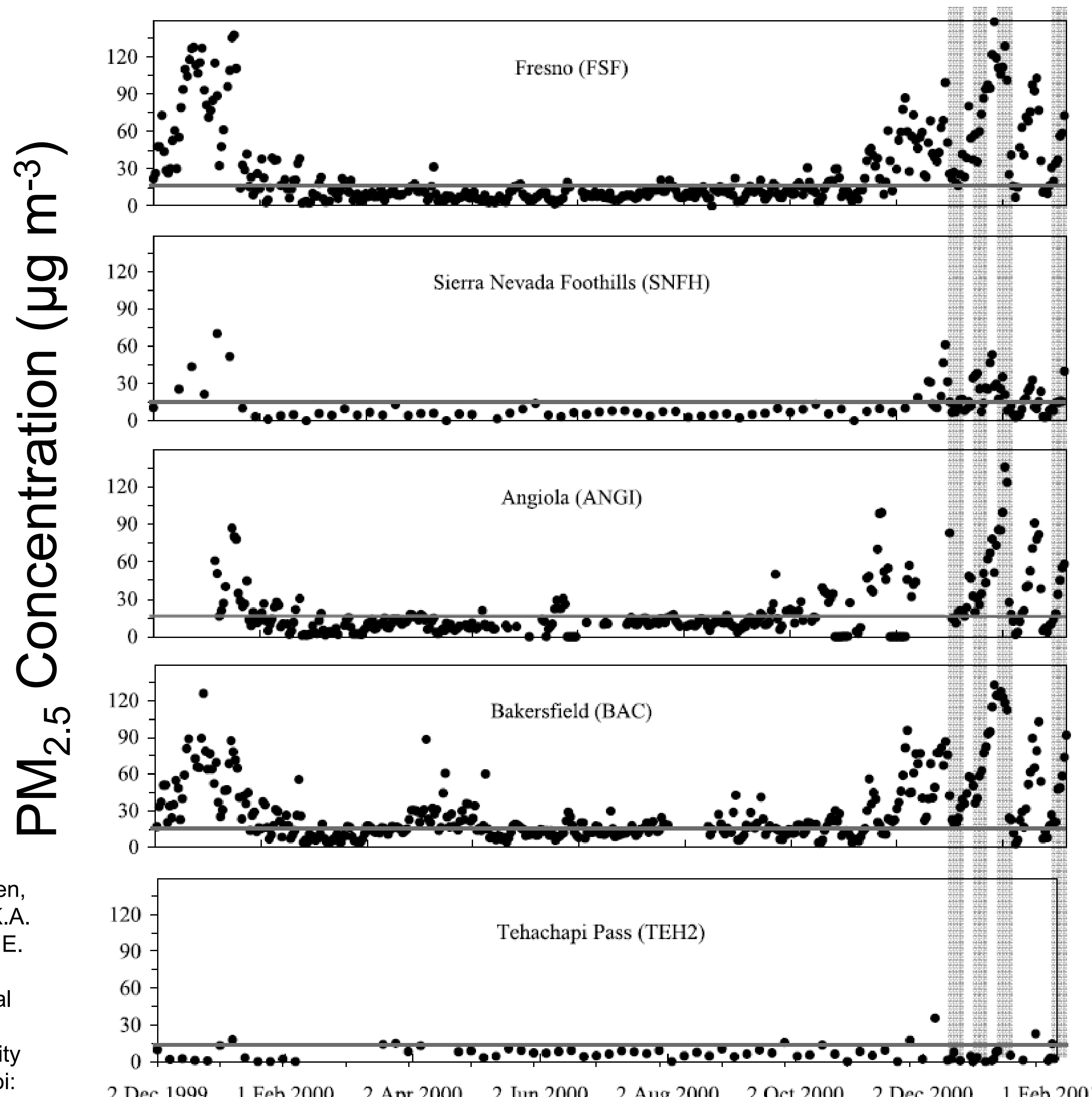
Source: US EPA (http://www.epa.gov/air/airtrends/2007/report/particlepollution.pdf).

PM2.5 Concentrations in the SJV



Source: J.C. Chow, L.W. A. Chen, J.G. Watson, D.H. Lowenthal, K.A. Magliano, K. Turkiewicz, and D.E. Lehrman, "PM2.5 Chemical Composition and Spatiotemporal Variability During the California Regional PM10/PM2.5 Air Quality Study (CRPAQS), JGR, 111, doi: 10.1029/2005JD006457, 2006.

PM2.5 Seasonal Variation in the SJV



Source: J.C. Chow, L.W. A. Chen, J.G. Watson, D.H. Lowenthal, K.A. Magliano, K. Turkiewicz, and D.E. Lehrman, "PM2.5 Chemical Composition and Spatiotemporal Variability During the California Regional PM10/PM2.5 Air Quality Study (CRPAQS), JGR, 111, doi: 10.1029/2005JD006457, 2006.

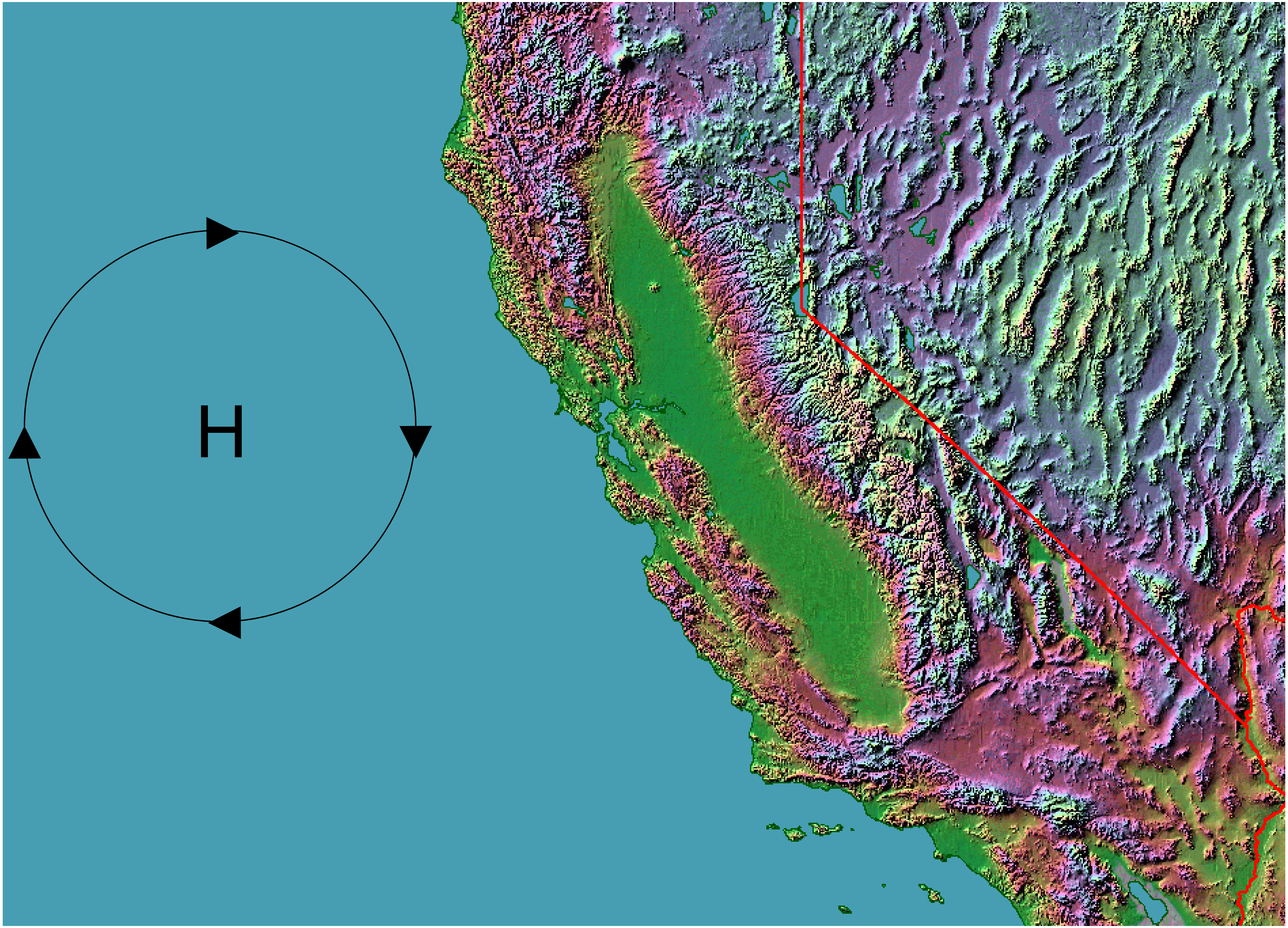
Questions

- *What are the sources of PM 2.5 in the region and why do they concentrate in winter?*
- *Primary vs. secondary PM 2.5 species;*
- *Where and when do PM 2.5 concentrations vary in the Valley?*
- *What types of control measures have been most successful?*

Overview of San Joaquin Valley (SJV)

- Includes Fresno, Kings, Madera, Merced, San Joaquin, Stanislaus, Tulare, and Kern counties
- Approximately 25,000 square miles
- 10% of California’s population and growing!

- Days exceeding 8-hr O3 standard in 2002:
  - LA = 100; SJV = 101
- Peak 24-hr PM2.5 concentration in 1999-2000:
  - LA = 121 $\mu g\ m^{-3}$; SJV = 160 $\mu g\ m^{-3}$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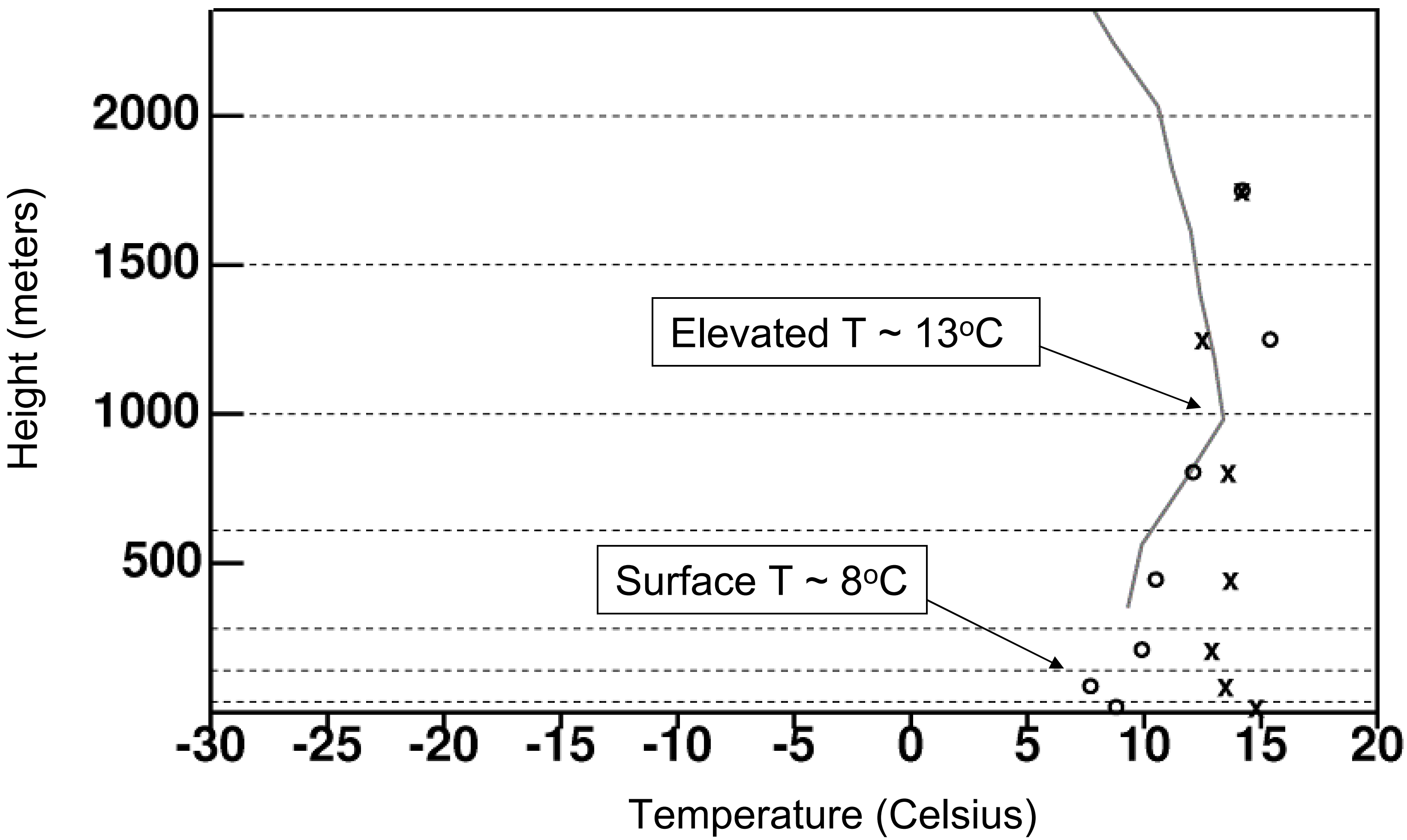
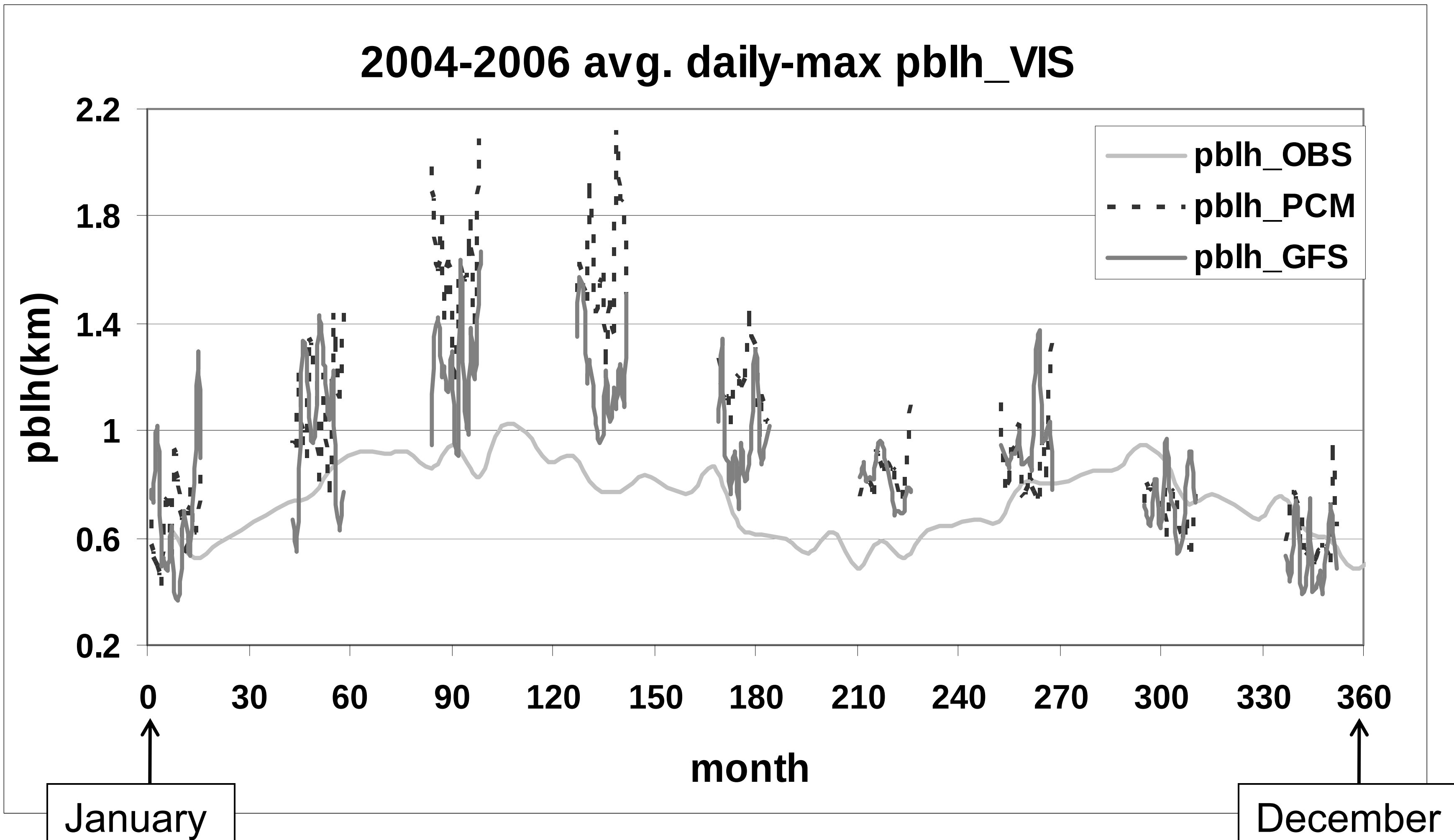
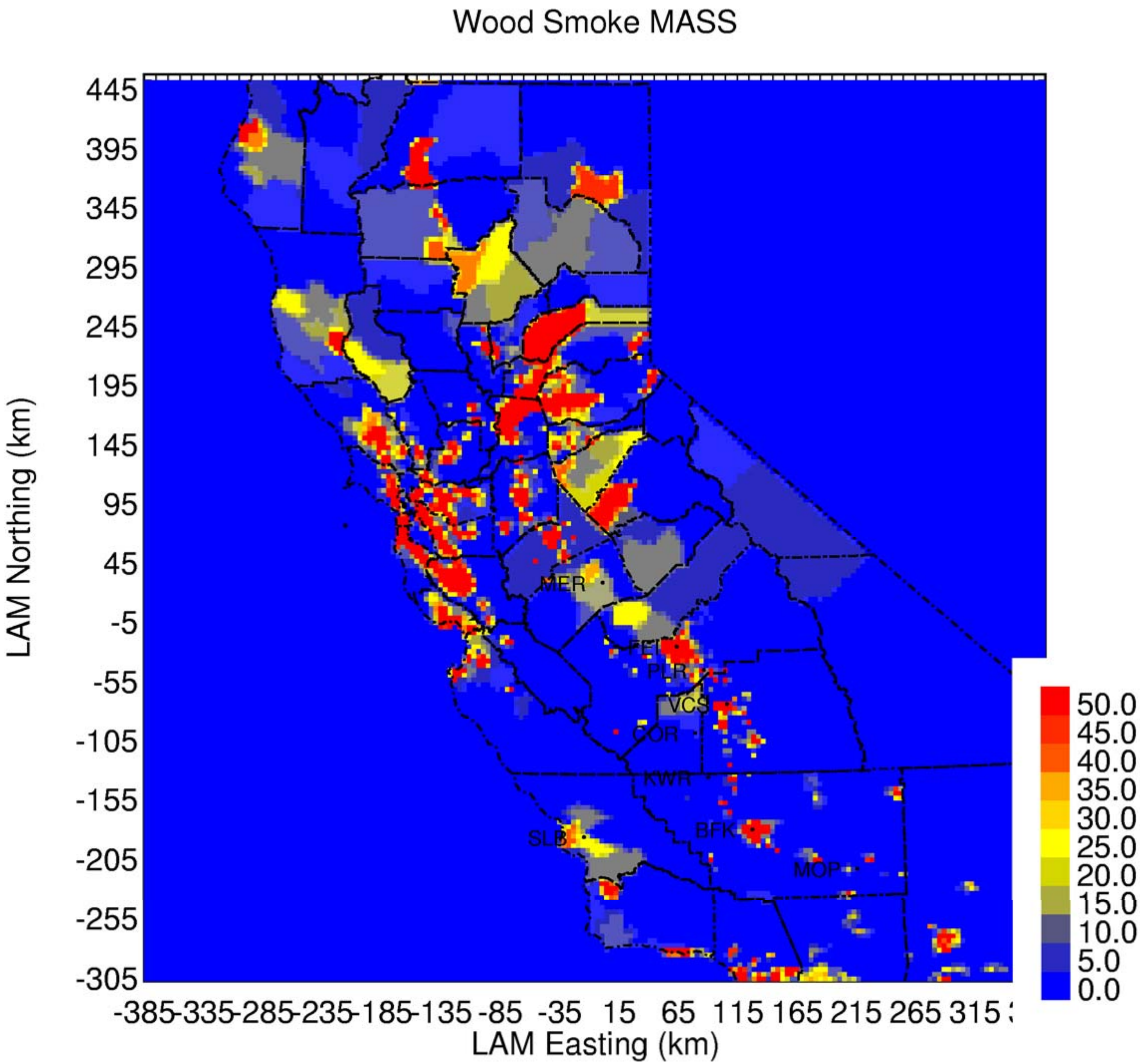
Vertical Temperature Profile
Fresno December 31 2000, 12PST



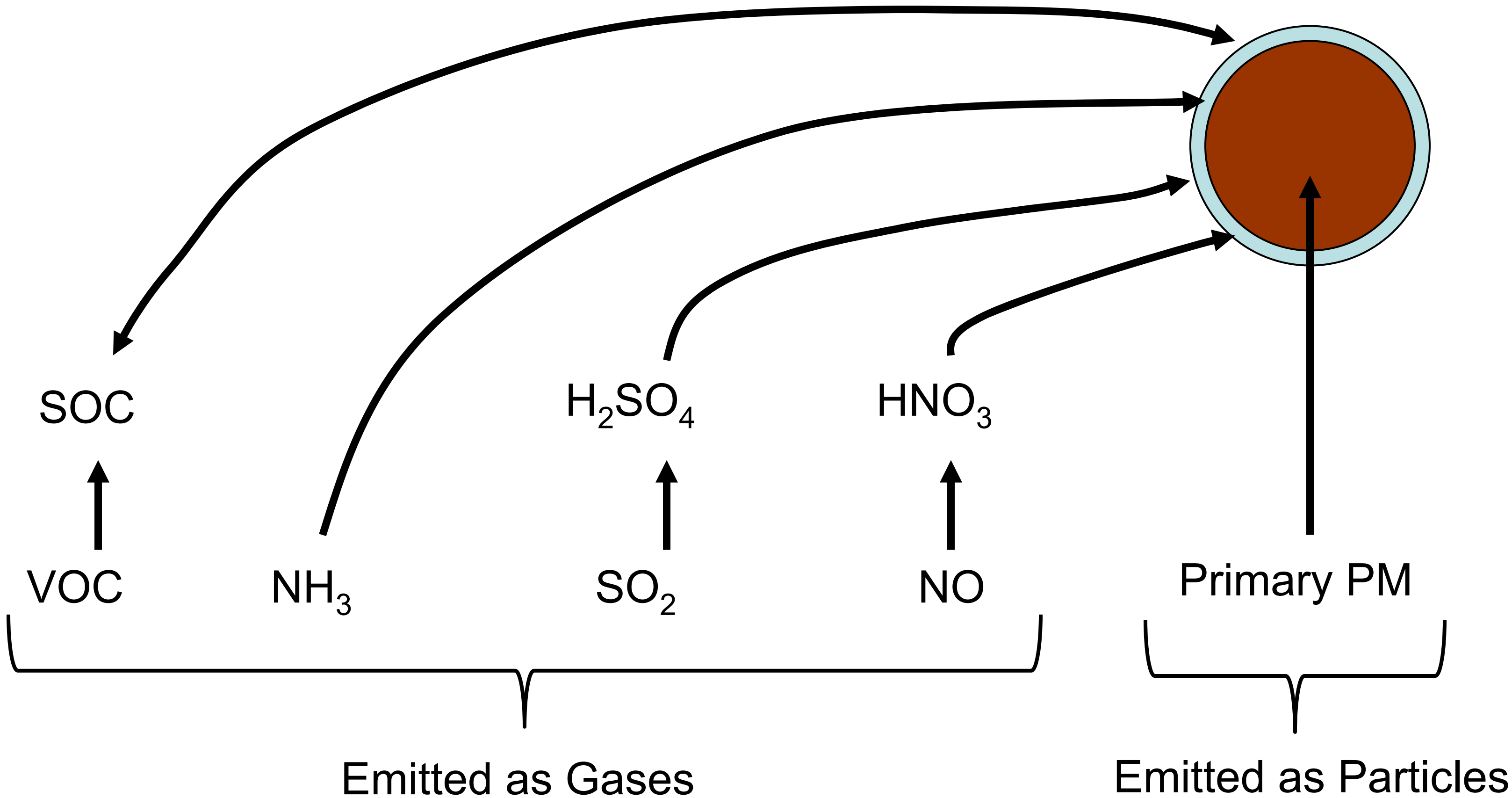
Mixing Depth Annual Cycle



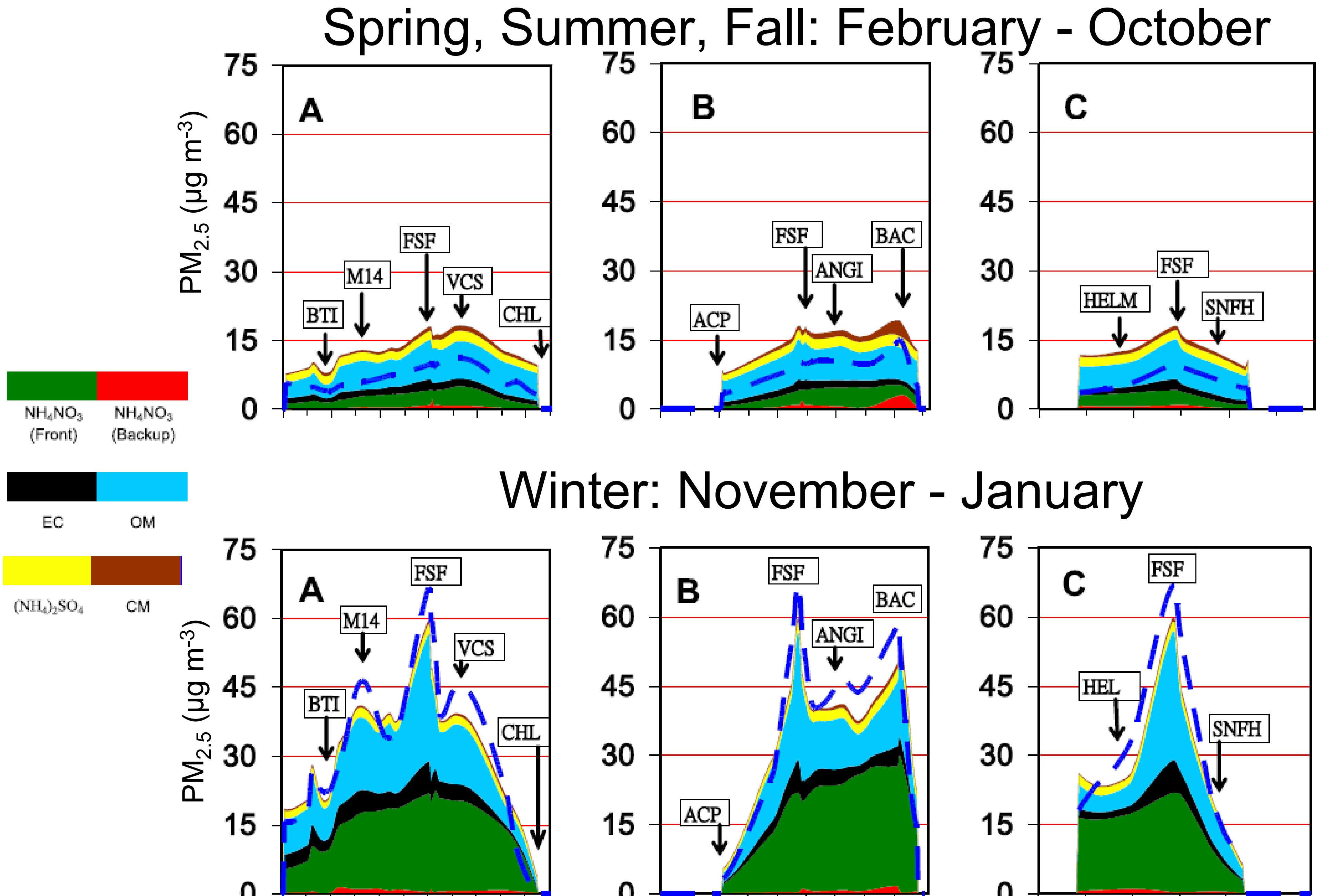


Wood Smoke MASS
LAM Northing (km)
LAM Easting (km)
445
395
345
295
245
195
145
95
45
-5
-55
-105
-155
-205
-255
-305
-385
-335
-285
-235
-185
-135
-85
-35
15
65
115
165
215
265
315
MER
FEI
PLR
VCS
COR
KWR
BFK
SLB
MOP
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0

Basic Particle Chemistry



VOC = Volatile Organic Compounds (benzene, ethanol, formaldehyde, …)
SOC = semi-volatile organic compounds (mostly unknown)
Primary PM = particulate matter emitted directly from sources (trace metals – aluminum, silicon, iron, nickel, etc, elemental carbon, organic carbon)

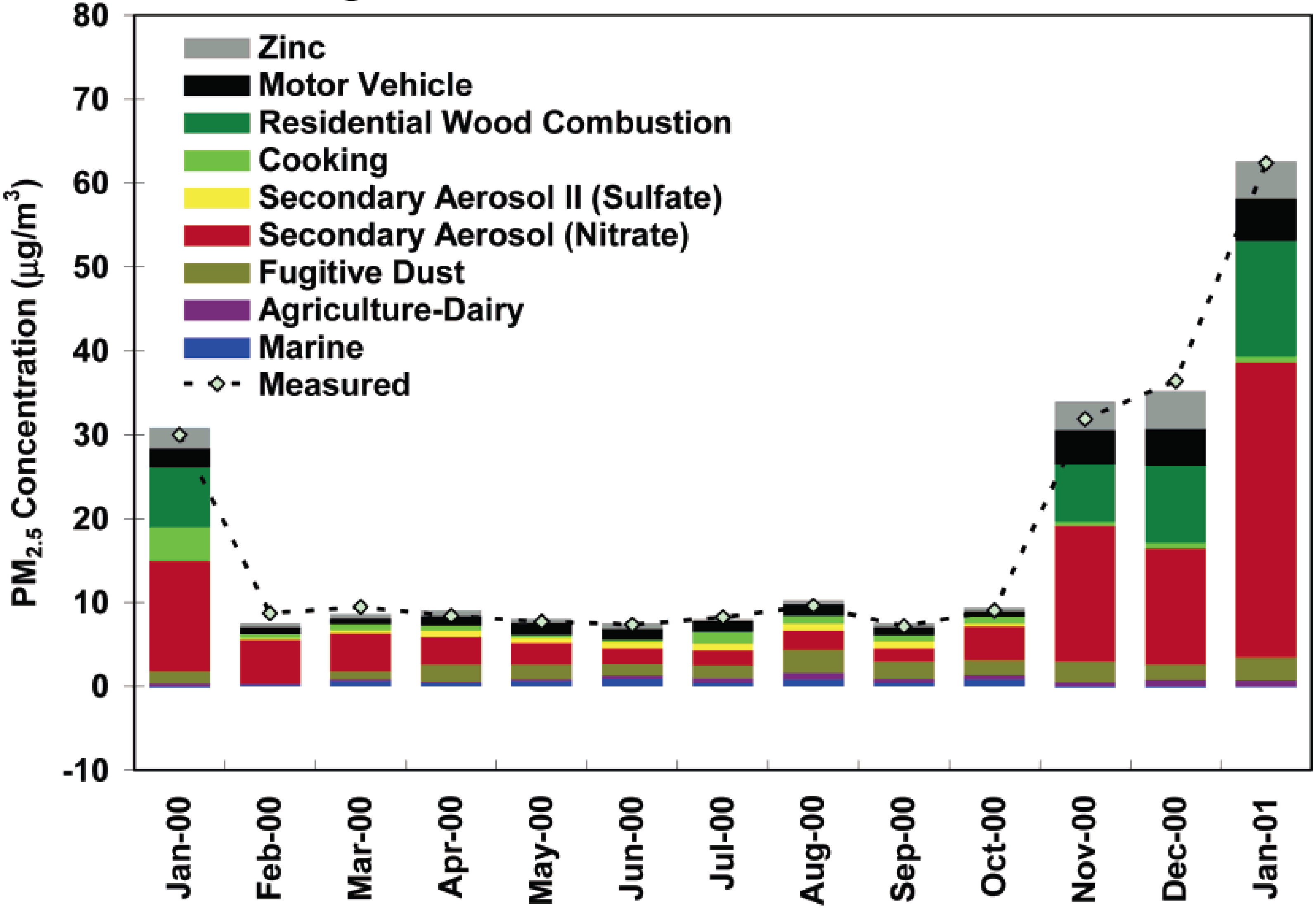


Source: J.C. Chow, L.W. A. Chen, J.G. Watson, D.H. Lowenthal, K.A. Magliano, K. Turkiewicz, and D.E. Lehrman, "PM2.5 Chemical Composition and Spatiotemporal Variability During the California Regional PM10/PM2.5 Air Quality Study (CRPAQS), JGR, 111, doi: 10.1029/2005JD006457, 2006.

Statistical Source-Receptor Models

- Measure the composition of the PM at a receptor site
- Calculate source contributions to PM
  - Chemical Mass Balance (CMB)
    - Use source profiles (chemical “fingerprints”)
  - Factor Analysis, PMF, UNMIX, …
    - Use patterns of variation in the measured signal at the receptor site
    - identifies factors that are “interpreted” as sources

PM2.5 Source Contributions Averaged Over CRPAQS Sites



Source: L.W. A. Chen, J.G. Watson, J.C. Chow, and K.A. Magliano, "Quantifying PM2.5 Source Contributions for the San Joaquin Valley with Multivariate Receptor Models", ES&T, 41, pg2818-2826, 2007.

Mechanistic Air Quality Models

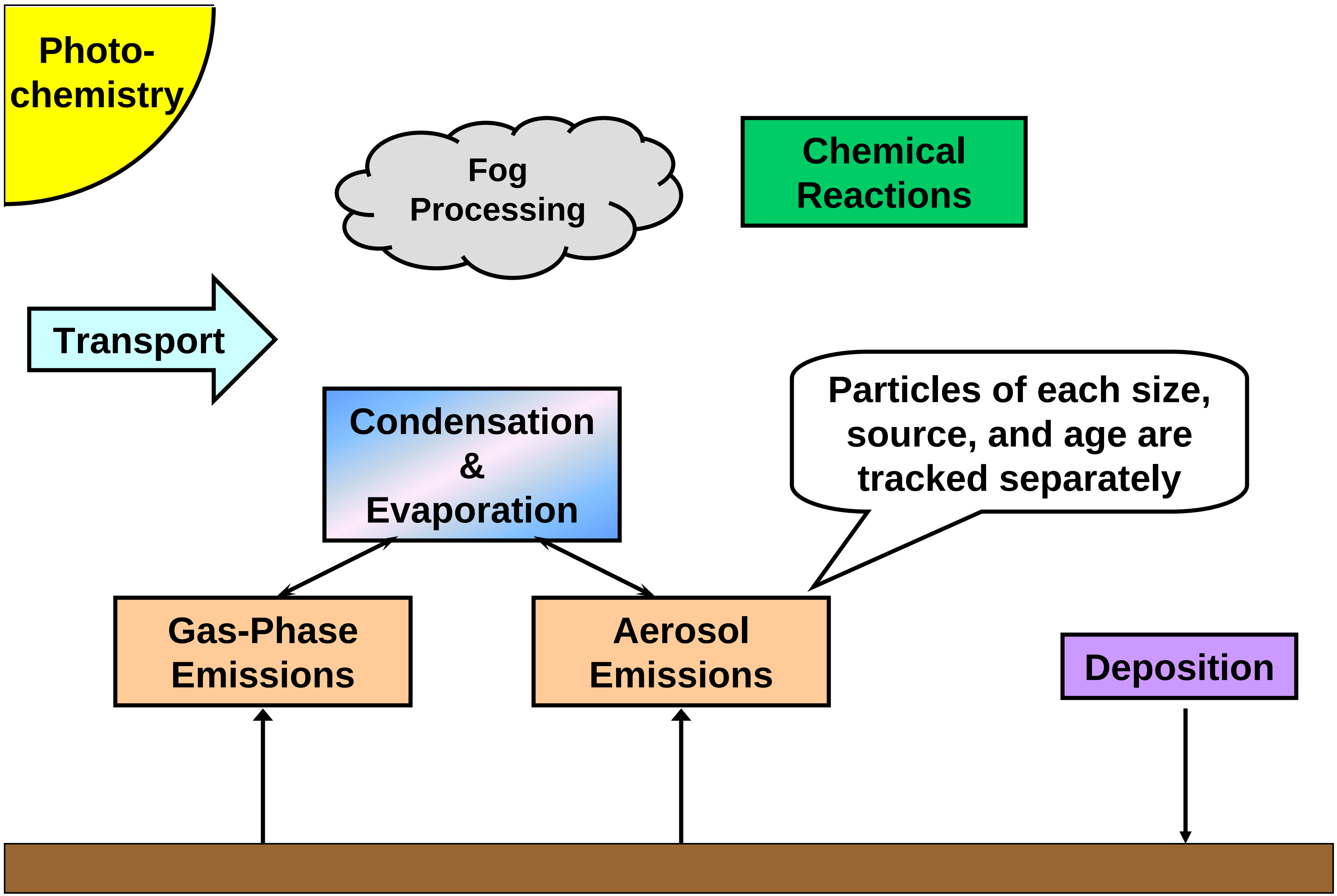
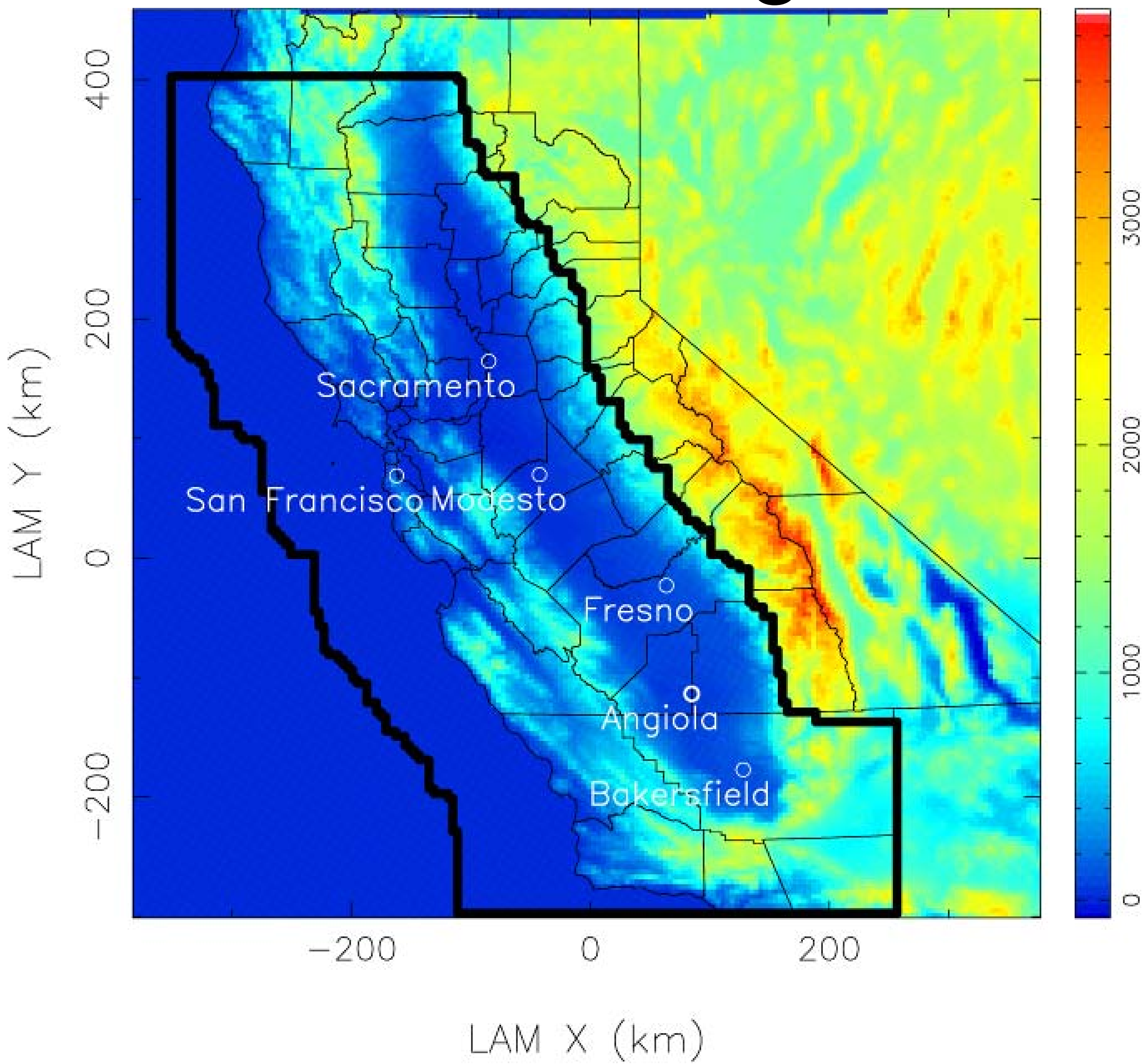


Figure courtesy of Prakash Bhave, U.S. EPA

CRPAQS Modeling Domain



CRPAQS PM2.5 Mass

Black Line – measurements

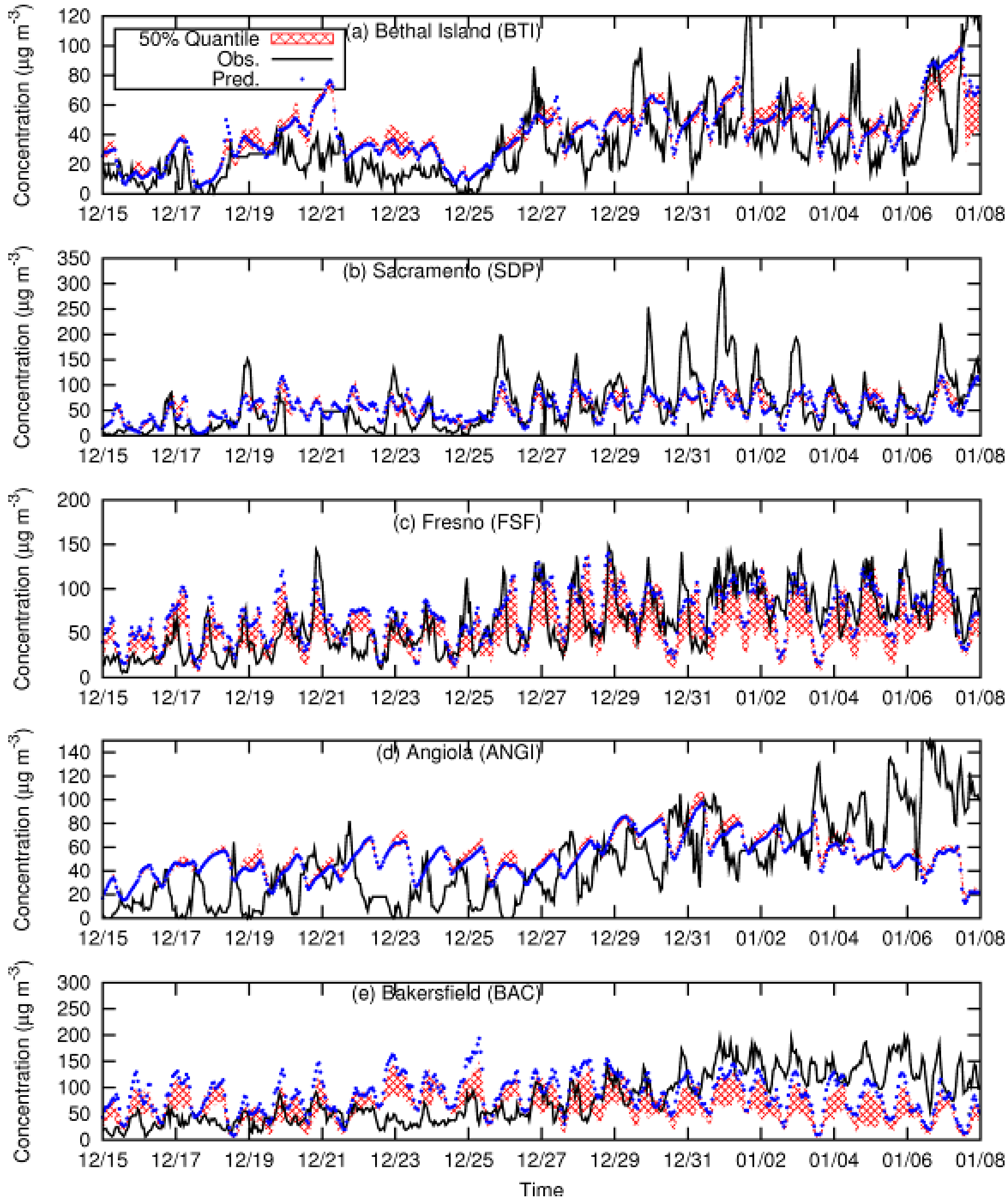
Blue Line – predictions

Red Shading – Mid 50% Quantile within 10km of monitor

Major trends are captured at most stations

Under-prediction of mass at Angiola and Bakersfield near the end of the episode

Source: Q. Ying, J. Lu, P. Allen, P. Livingstone, A. Kaduwela, and M. Kleeman "Modeling Air Quality During the California Regional PM10/PM2.5 Air Quality Study (CRPAQS) Using the UCD/CIT Source-Oriented Air Quality Model – Part I. Base Case Model Results.", Atmos. Env., 42, pg8954-8966, 2008.

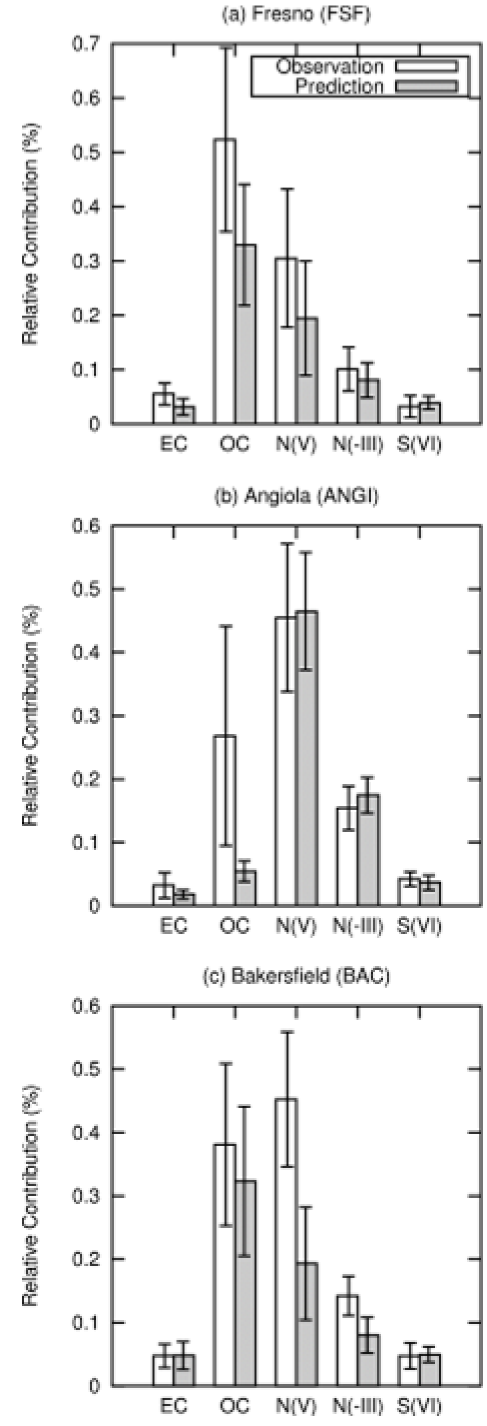


Relative Component Contributions to PM

Average and standard deviation of predictions and observations is based on 55 samples

Urban locations (Fresno and Bakersfield)
Predictions and observations match except for nitrate under-prediction at Bakersfield

Rural location (Angiola)
OC under-prediction. What primary sources are we missing? What SOA formation mechanisms are we missing?

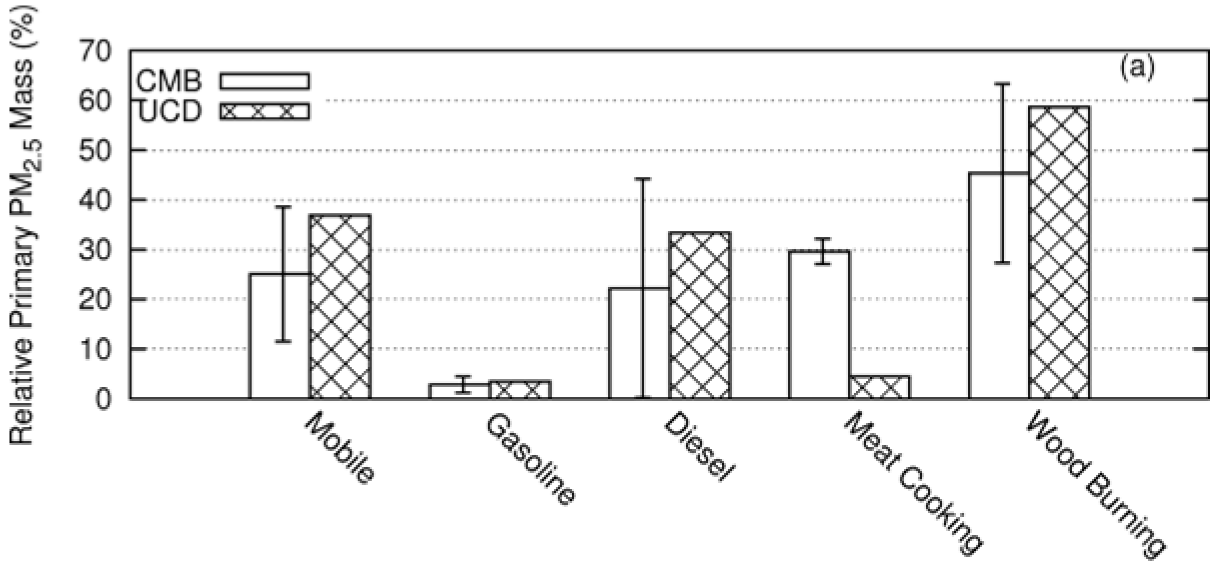


Source: Q. Ying, J. Lu, P. Allen, P. Livingstone, A. Kaduwela, and M. Kleeman "Modeling Air Quality During the California Regional PM10/PM2.5 Air Quality Study (CRPAQS) Using the UCD/CIT Source-Oriented Air Quality Model – Part I. Base Case Model Results.", Atmos. Env., 42, pg8954-8966, 2008.

Grid Model vs. CMB Source Apportionment

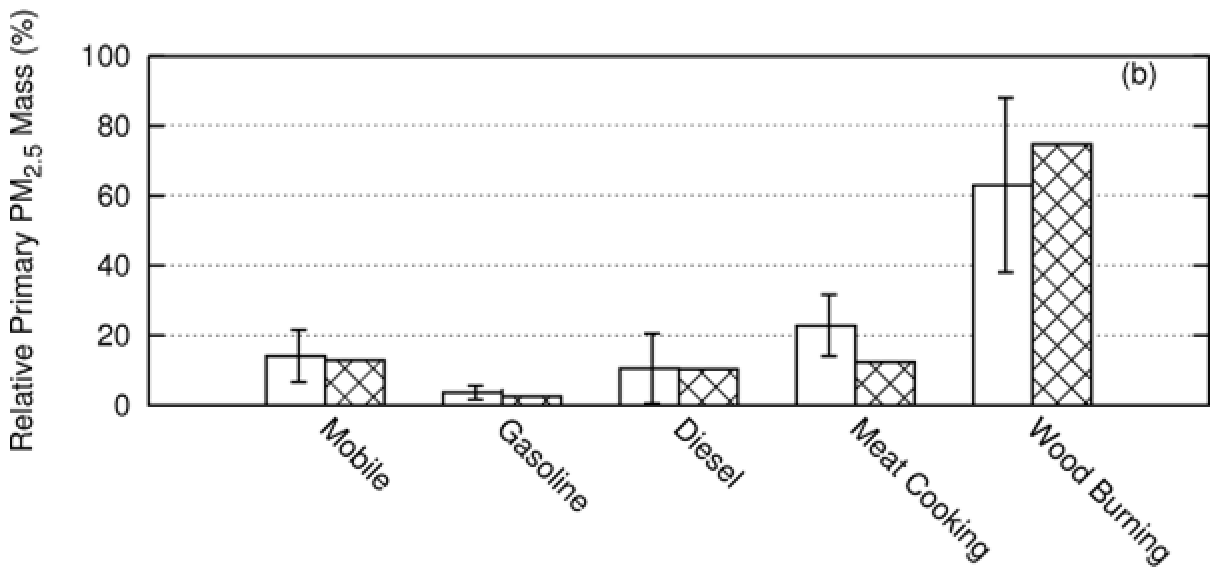
Angiola

**Dust sources removed from grid model



Fresno

**Dust sources removed from grid model

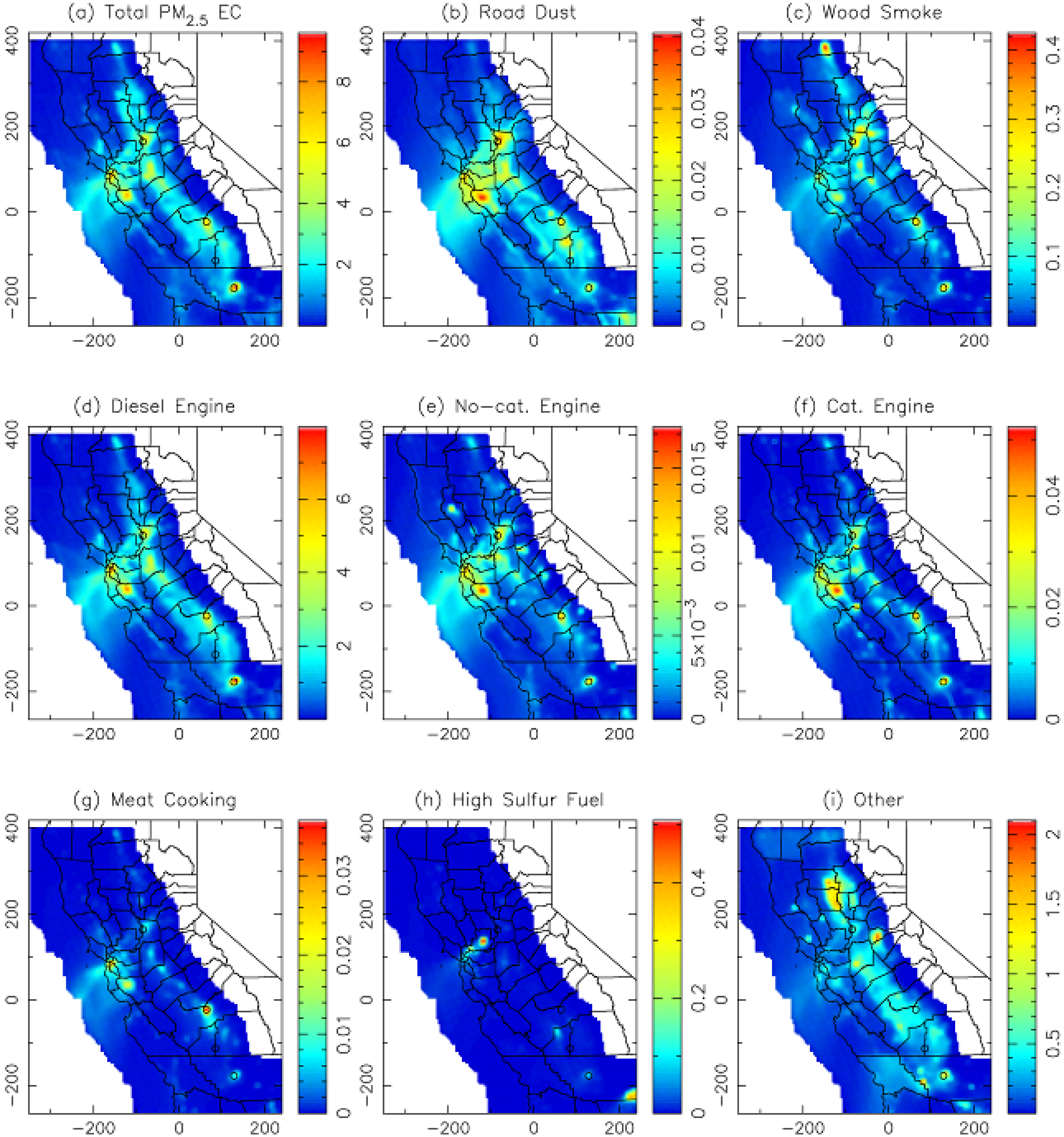


Source: Q. Ying, J. Lu, A. Kaduwela, and M. Kleeman "Modeling Air Quality During the California Regional PM10/PM2.5 Air Quality Study (CRPAQS) Using the UCD/CIT Source-Oriented Air Quality Model – Part II. Regional Source Apportionment of Primary Airborne Particulate Matter.", Atmos. Env 42, pp8967-8978, 2008.

Regional EC Source Contributions

Urban hotspots

Diesel dominates



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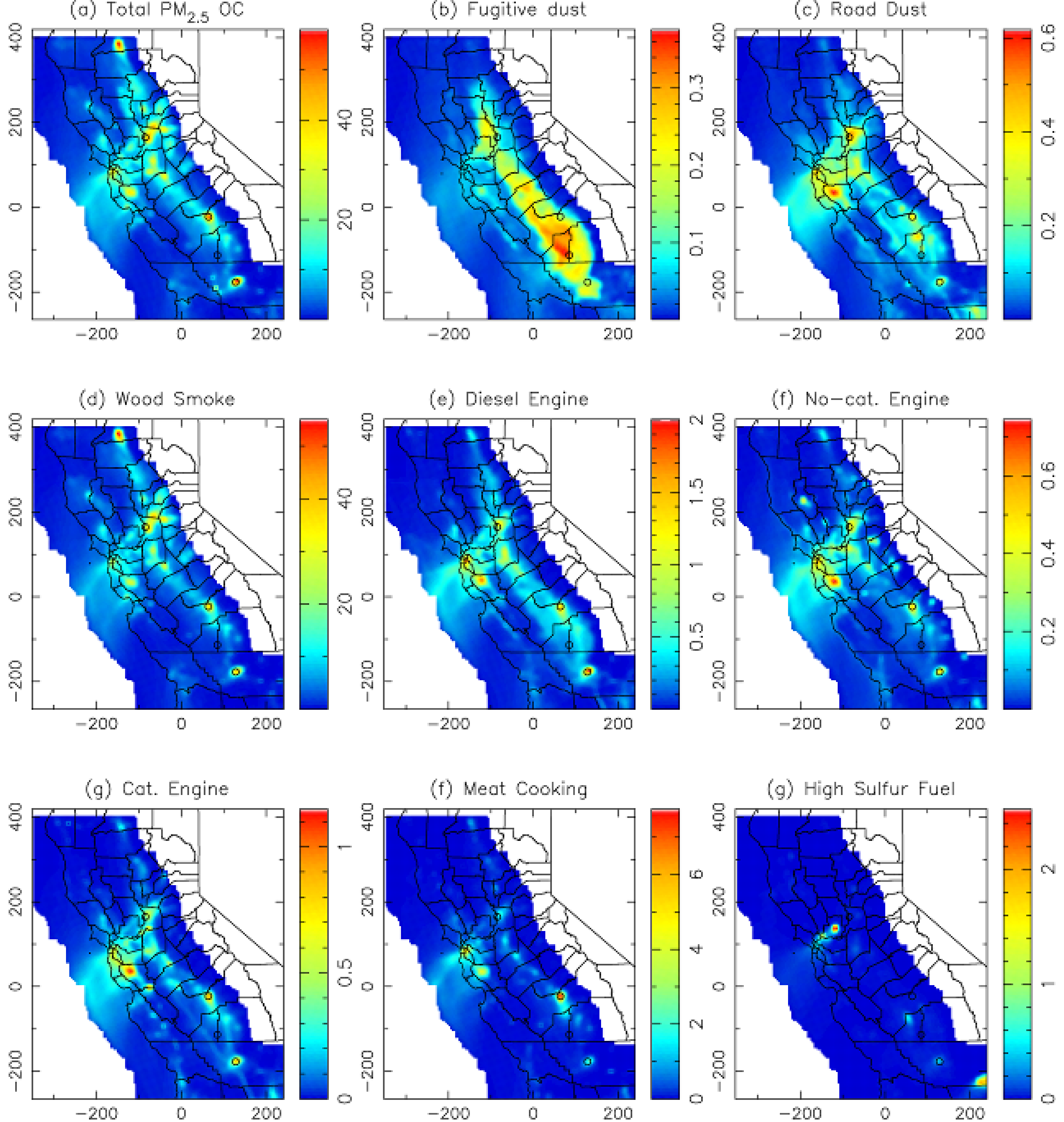
Regional OC Source Contributions

Urban hotspots

Wood smoke dominates



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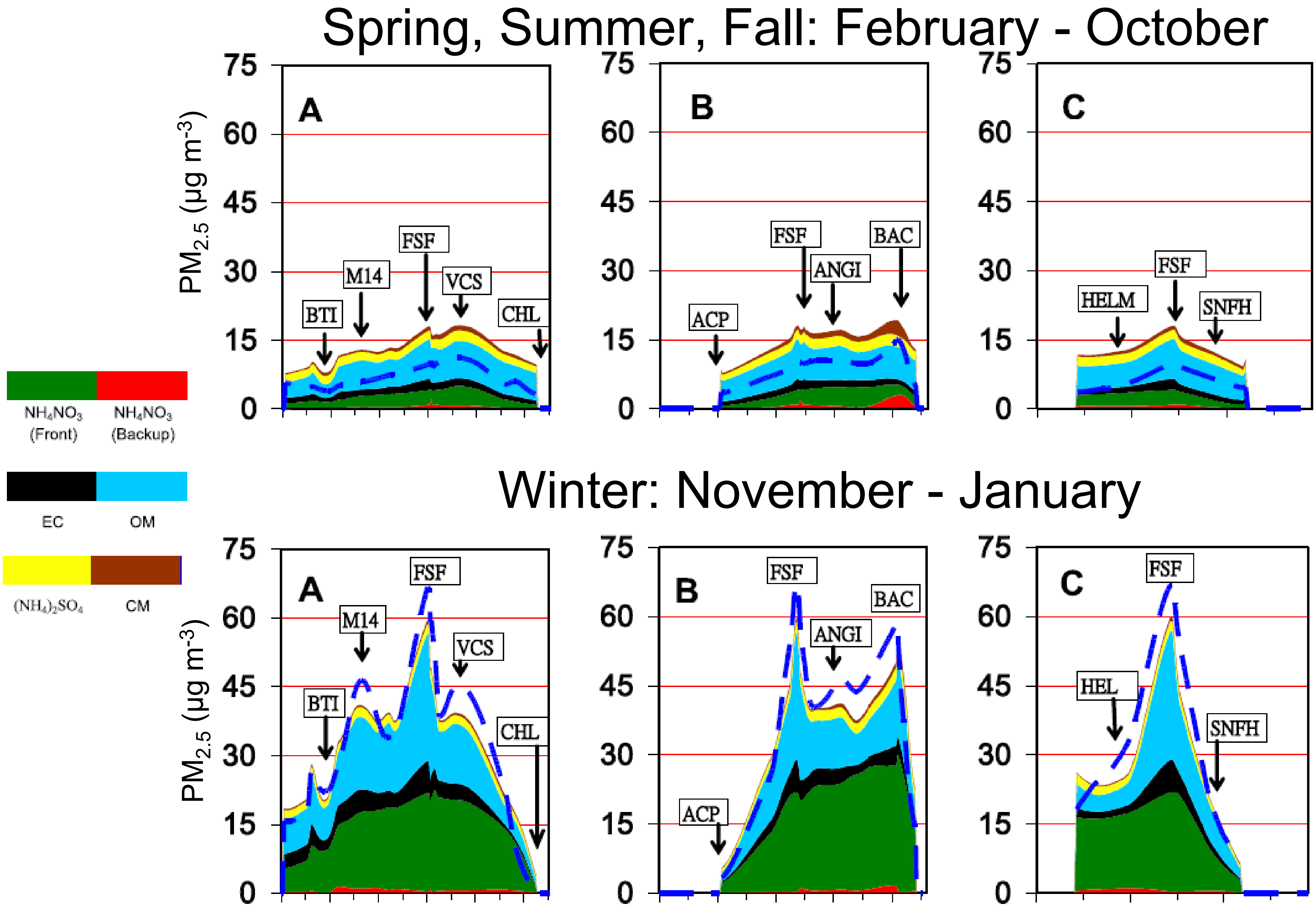

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Spectrum of Reactive Nitrogen Compounds

- NO, NO2, NO3, N2O5, HONO, PAN, HNO3

Direct Emissions

Reactive Intermediate Products

Stable End Product From Atmospheric Chemistry

- $HNO_3 + NH_3 \rightarrow NH_4NO_3$

Direct Emissions

Particle Phase Nitrate

Daytime/Summer Nitrate Formation

- $NO \xrightarrow{O_3} NO_2 \xrightarrow{OH} HNO_3$

- Main oxidant is OH – requires high sunlight, VOC rich environment

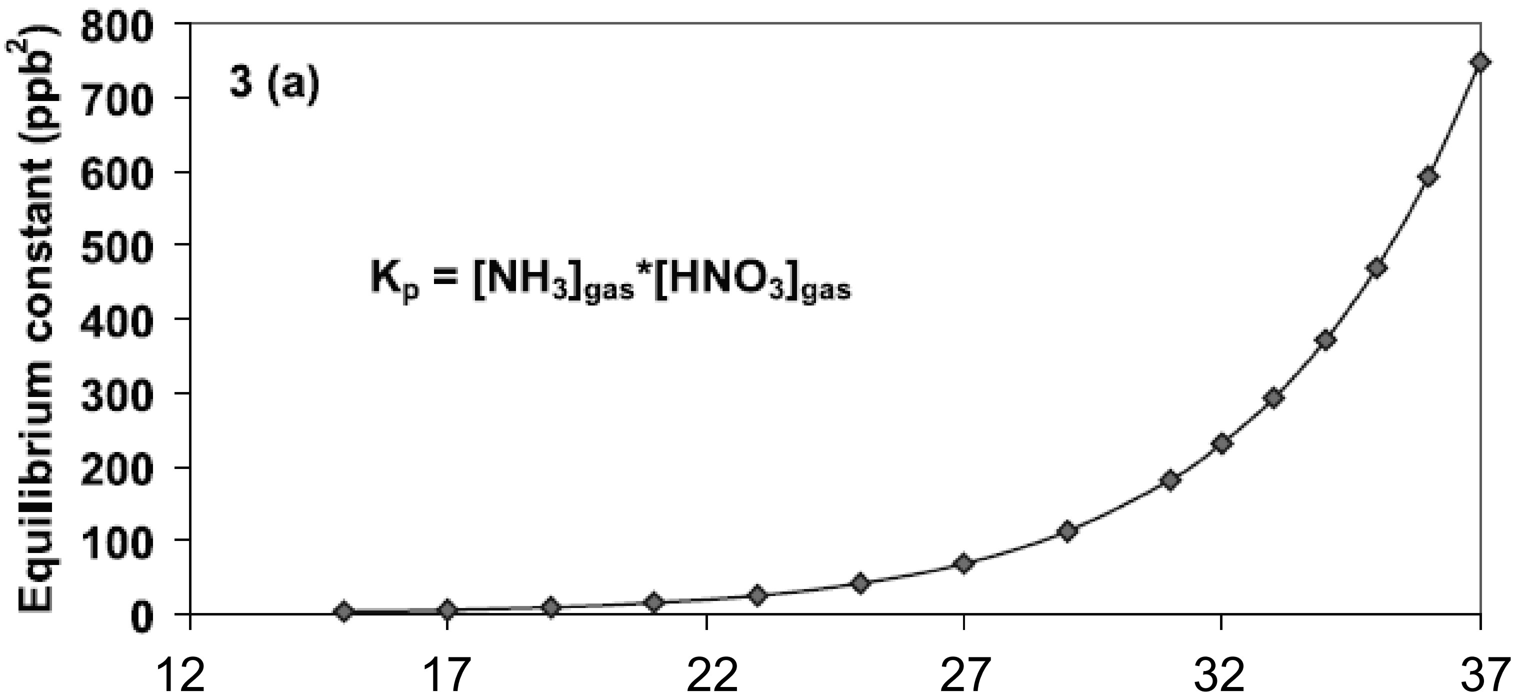
Nighttime/Winter Nitrate Formation

- $NO \xrightarrow{O_3} NO_2 \xrightarrow{O_3} NO_3 \longrightarrow N_2O_5 \xrightarrow{H_2O} 2HNO_3$

- Main oxidant is O_3 – favors low sunlight intensity, wet conditions

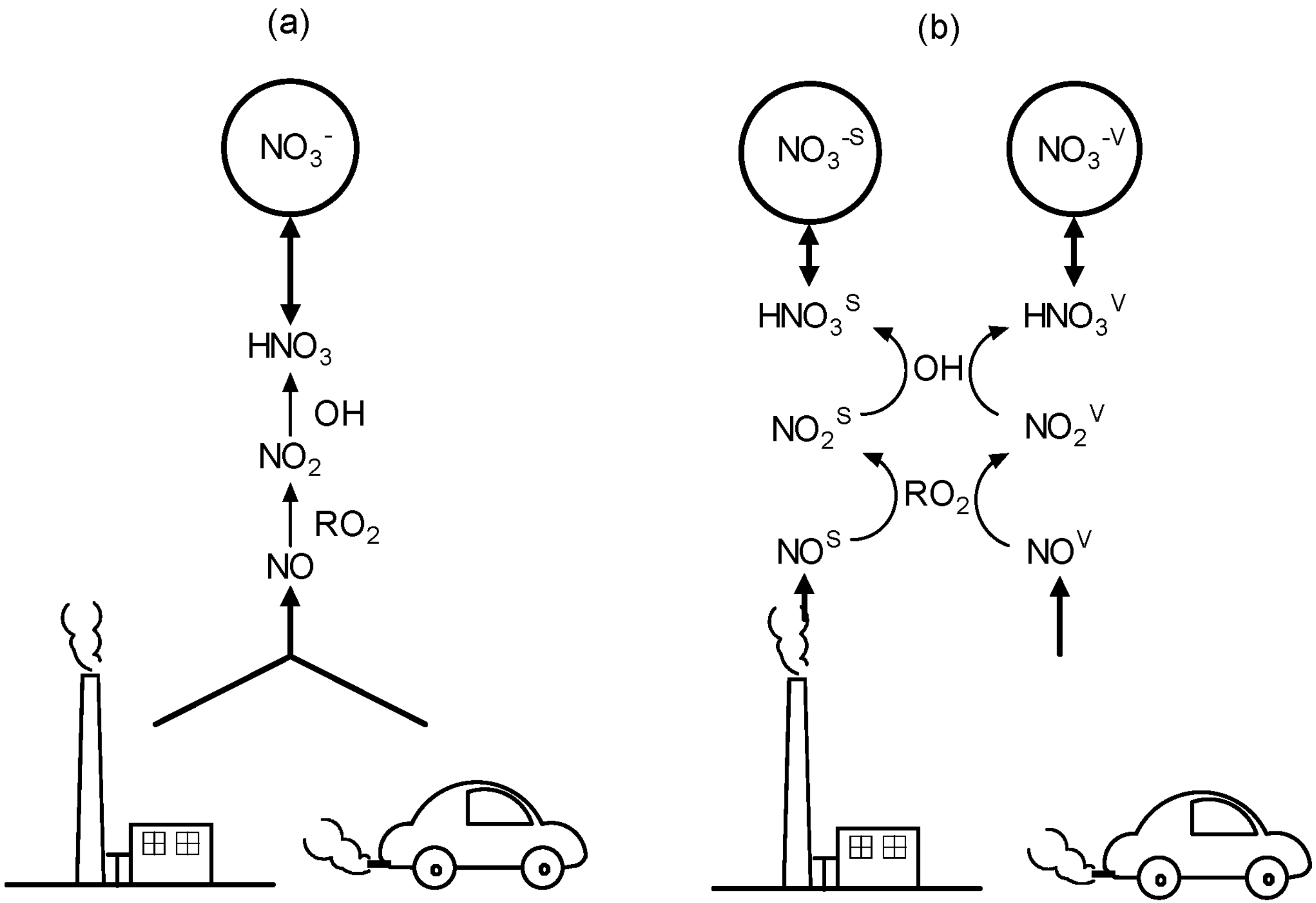
Equilibrium Dissociation Constant for Ammonium Nitrate

Ammonium nitrate will not form when $[NH_3]*HNO_3] < Kp$



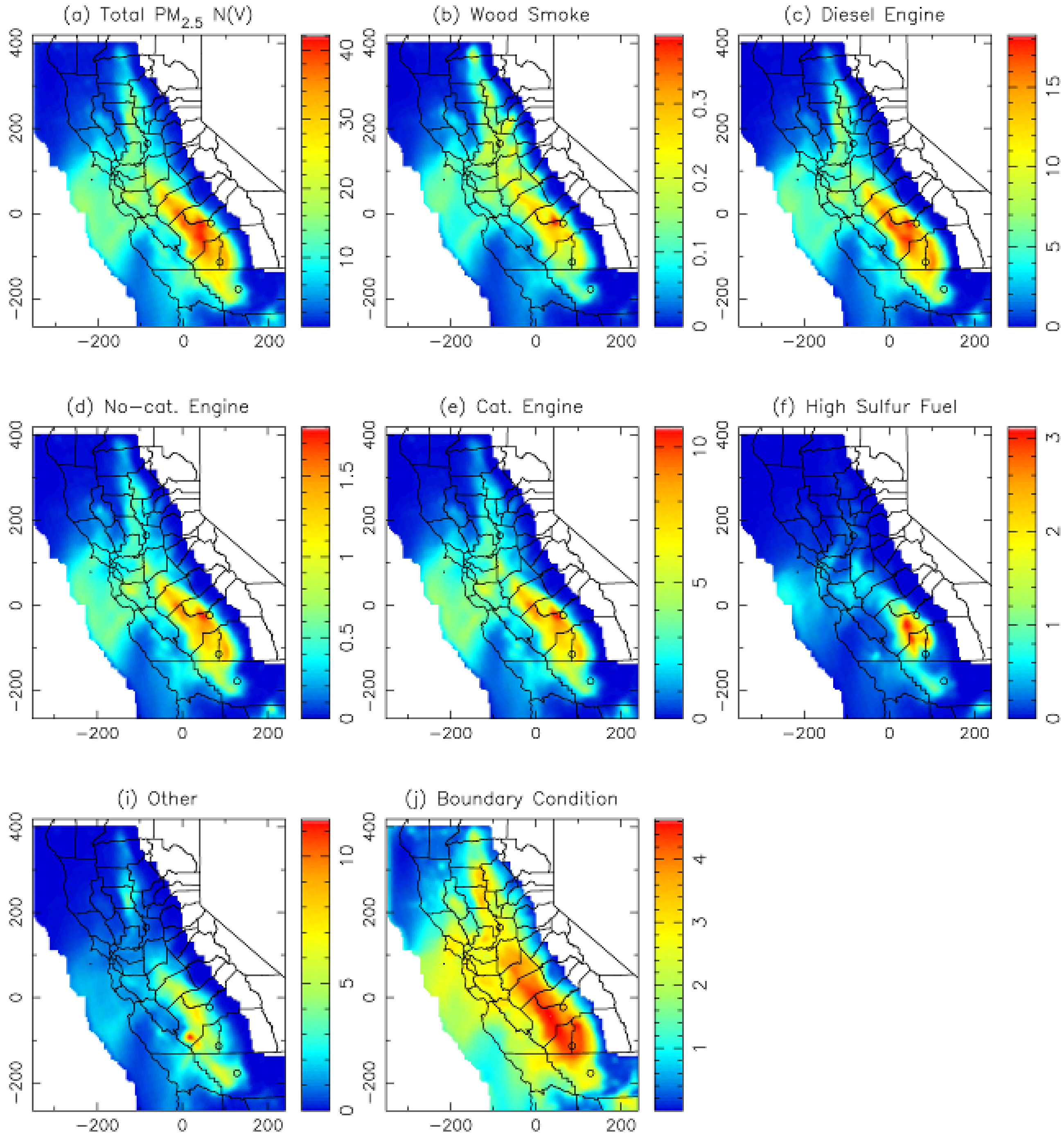
Temperature (°C)

Source Apportionment of Secondary PM

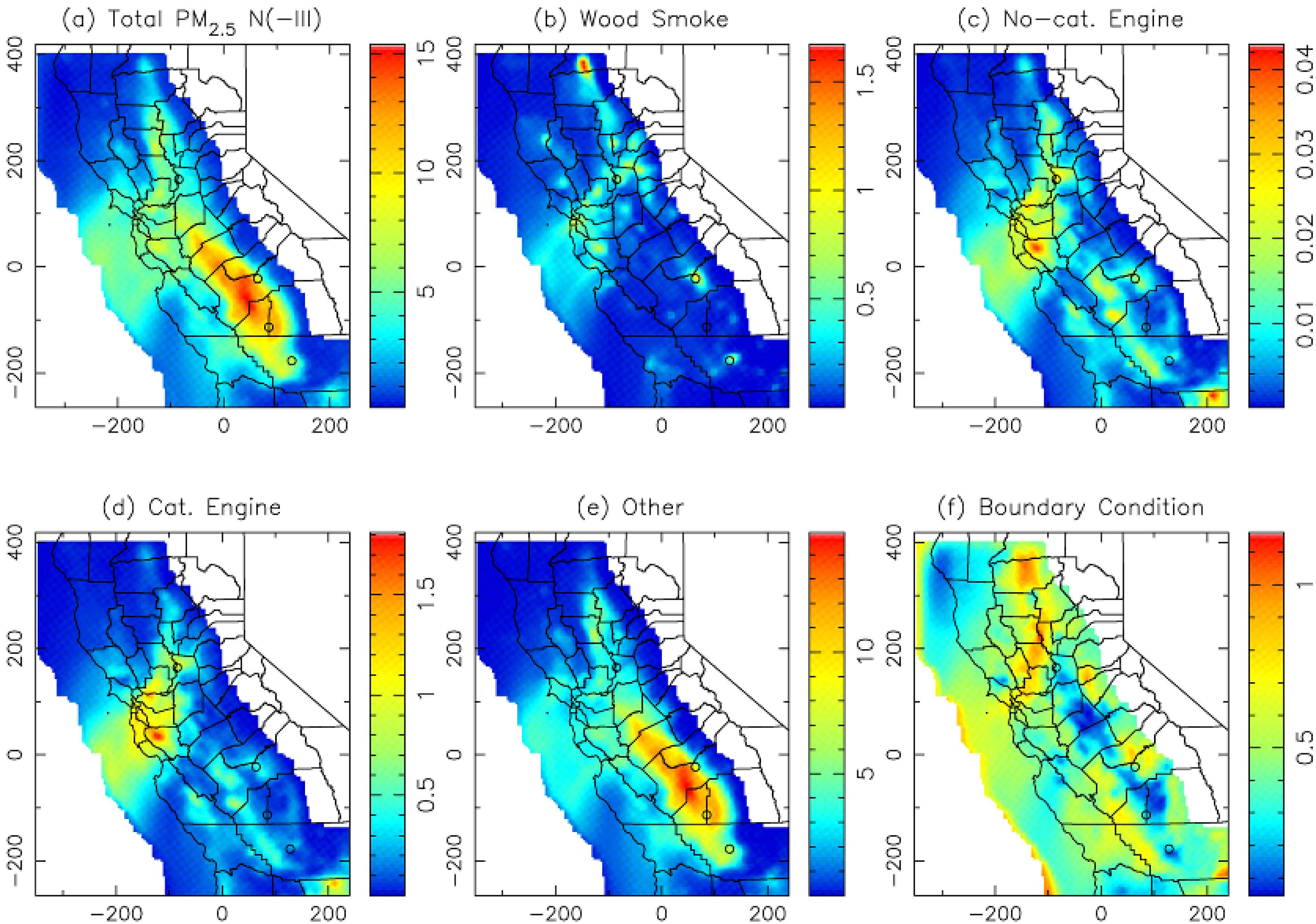


Source: Ying, Q. and M.J. Kleeman. "Source contributions to the regional distribution of secondary particulate matter in California." Atmospheric Environment, Vol 40, pp 736-752, 2006.

Regional Nitrate Source Contributions



Regional NH4+ Source Contributions



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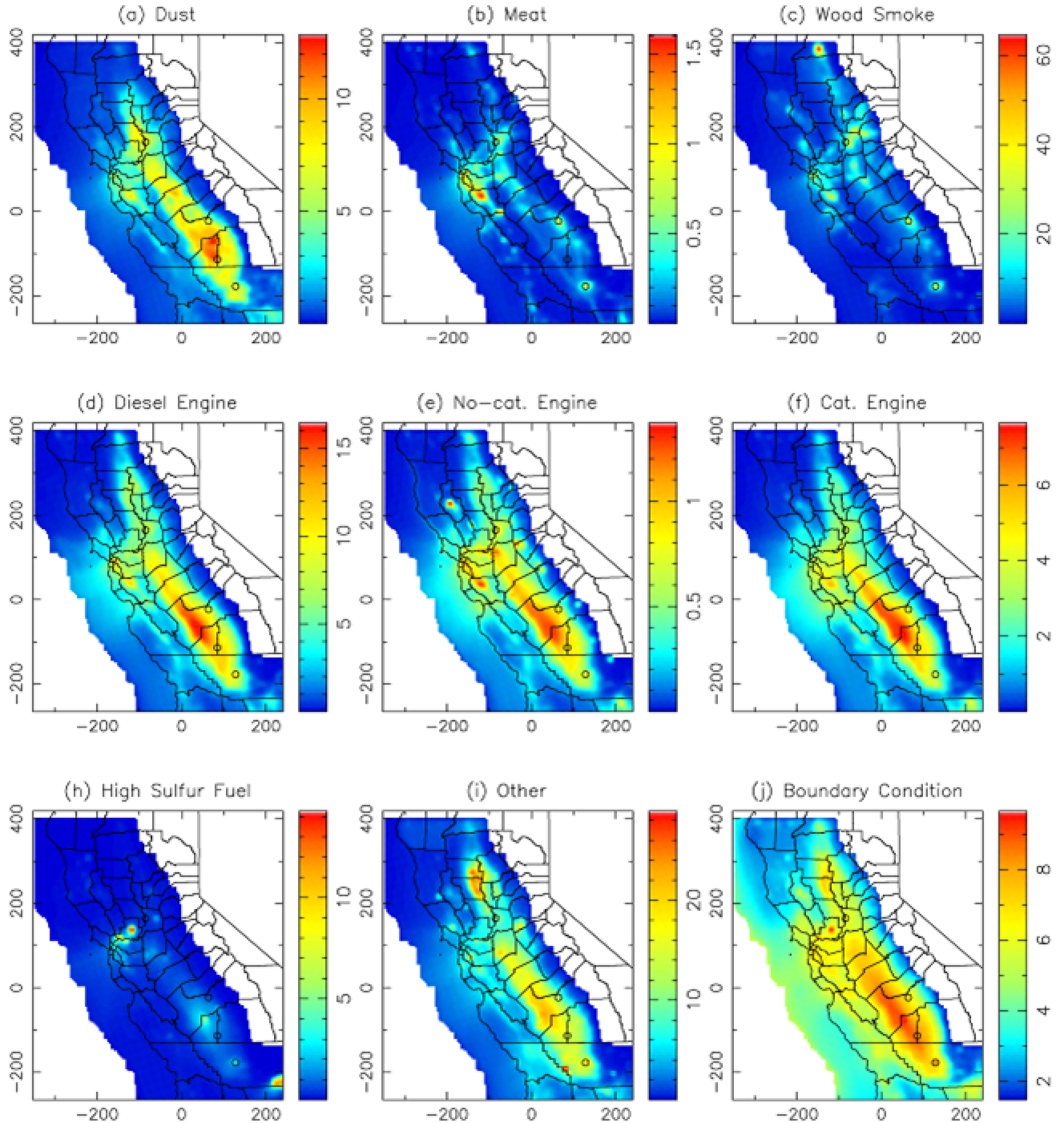
Regional PM2.5 (primary + secondary) Source Contributions



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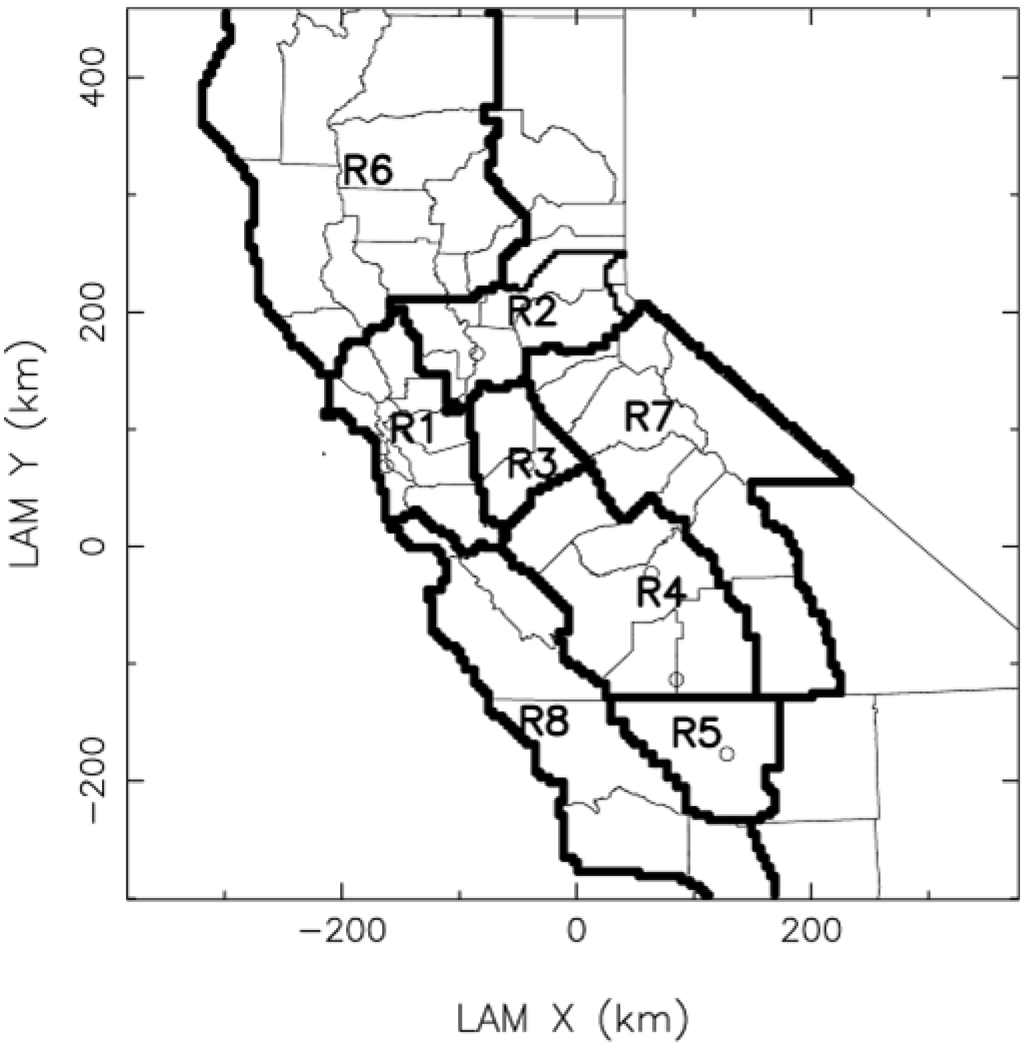
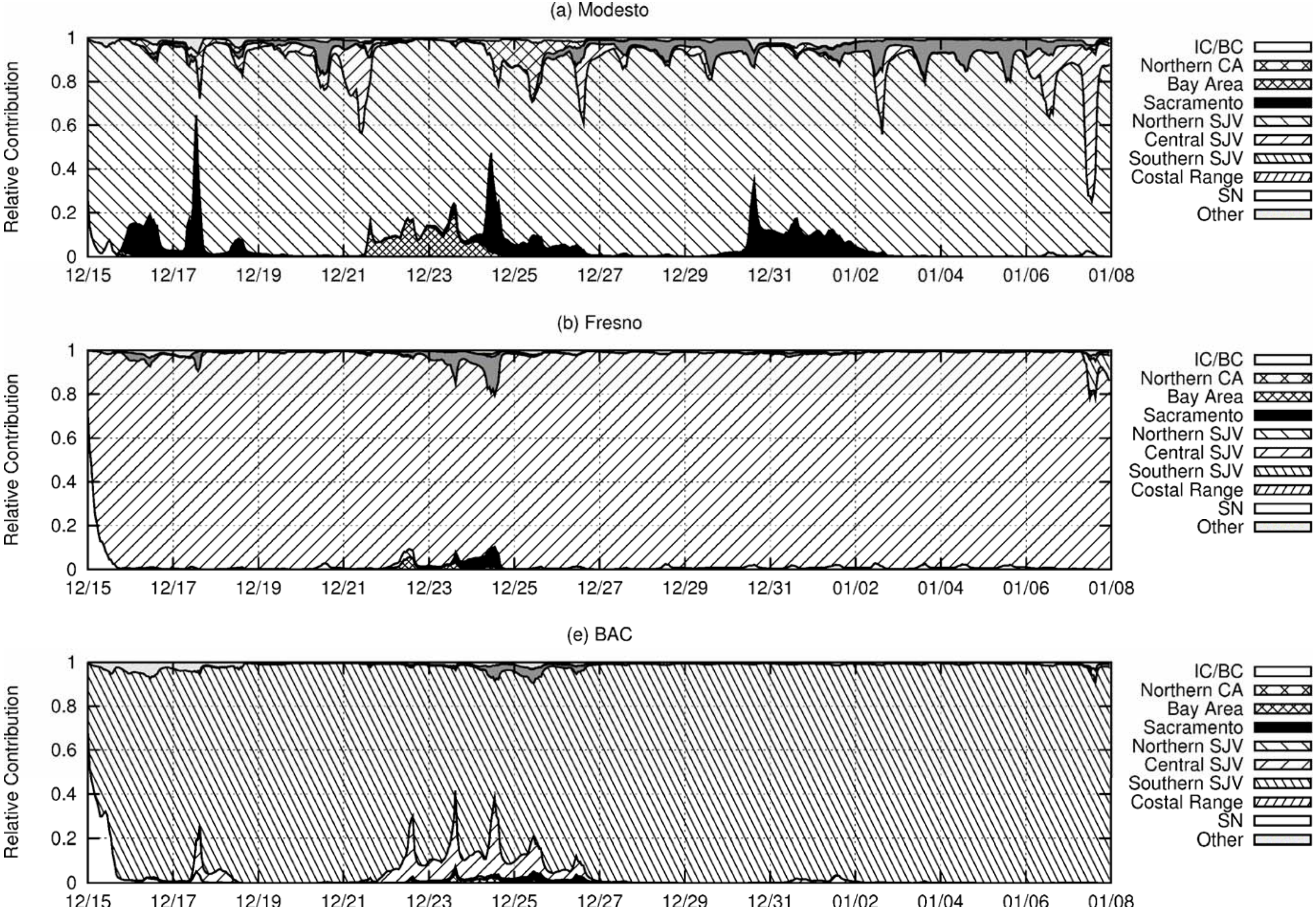
How Much PM Does Each Region Contribute to Other Regions?



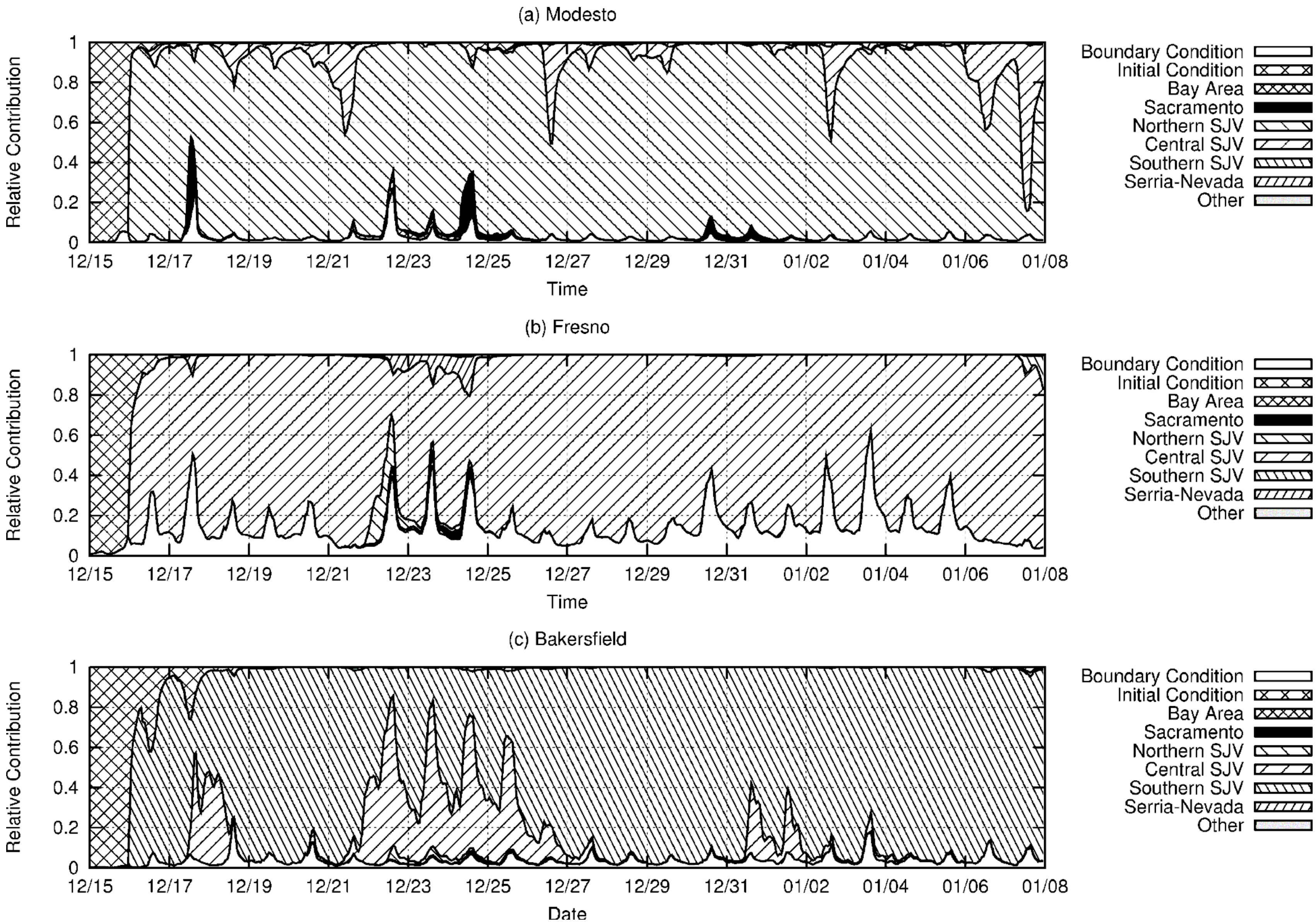
Source: Q. Ying, and M. Kleeman "Regional Contributions to Airborne Particulate Matter in Central California During a Severe Pollution Episode", Atmos. Env., 43, 1218-1228, 2009.

OC Region Contributions



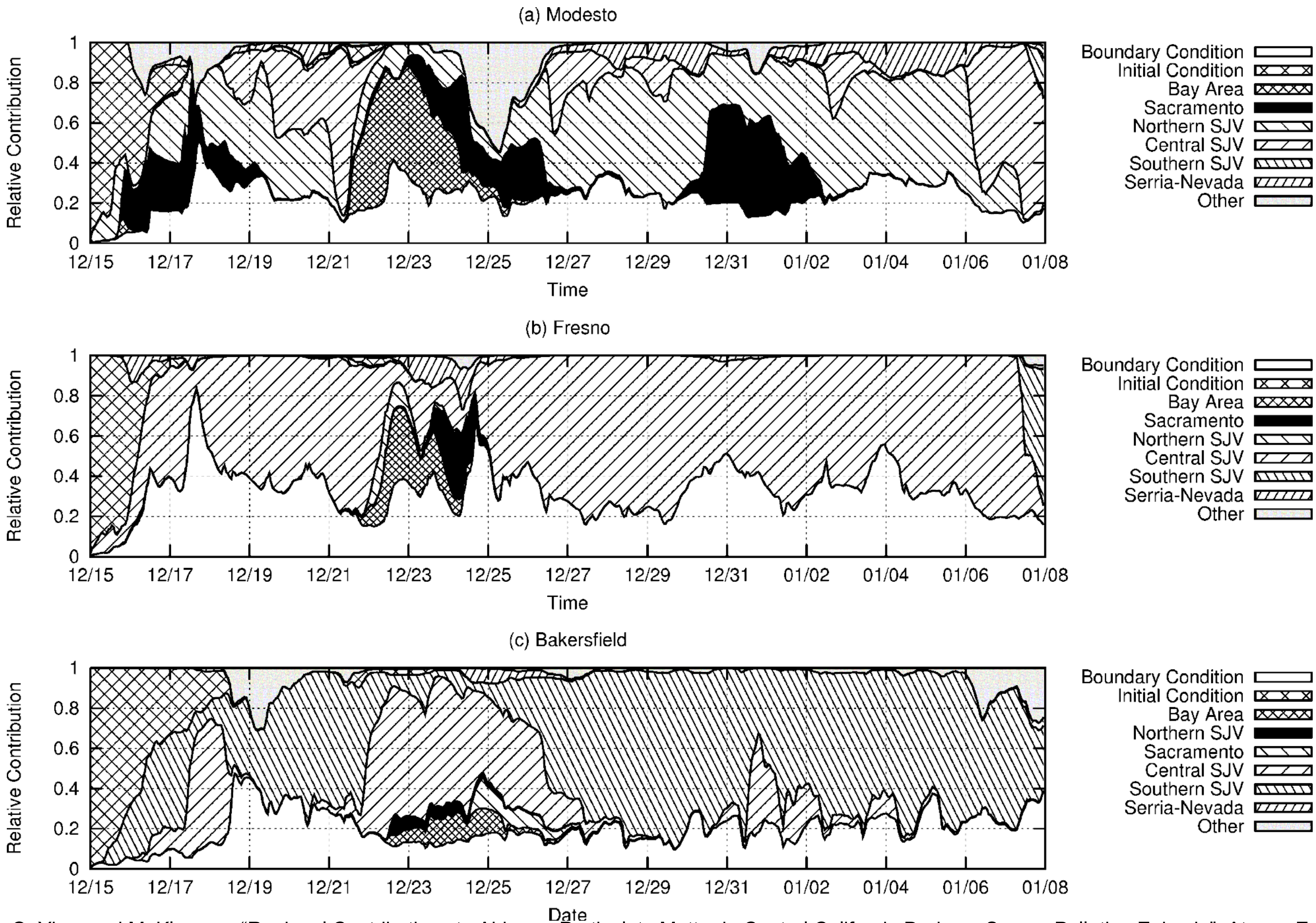
Source: Q. Ying, and M. Kleeman "Regional Contributions to Airborne Particulate Matter in Central California During a Severe Pollution Episode", Atmos. Env., 43, 1218-1228, 2009.

Ammonium Region Contributions



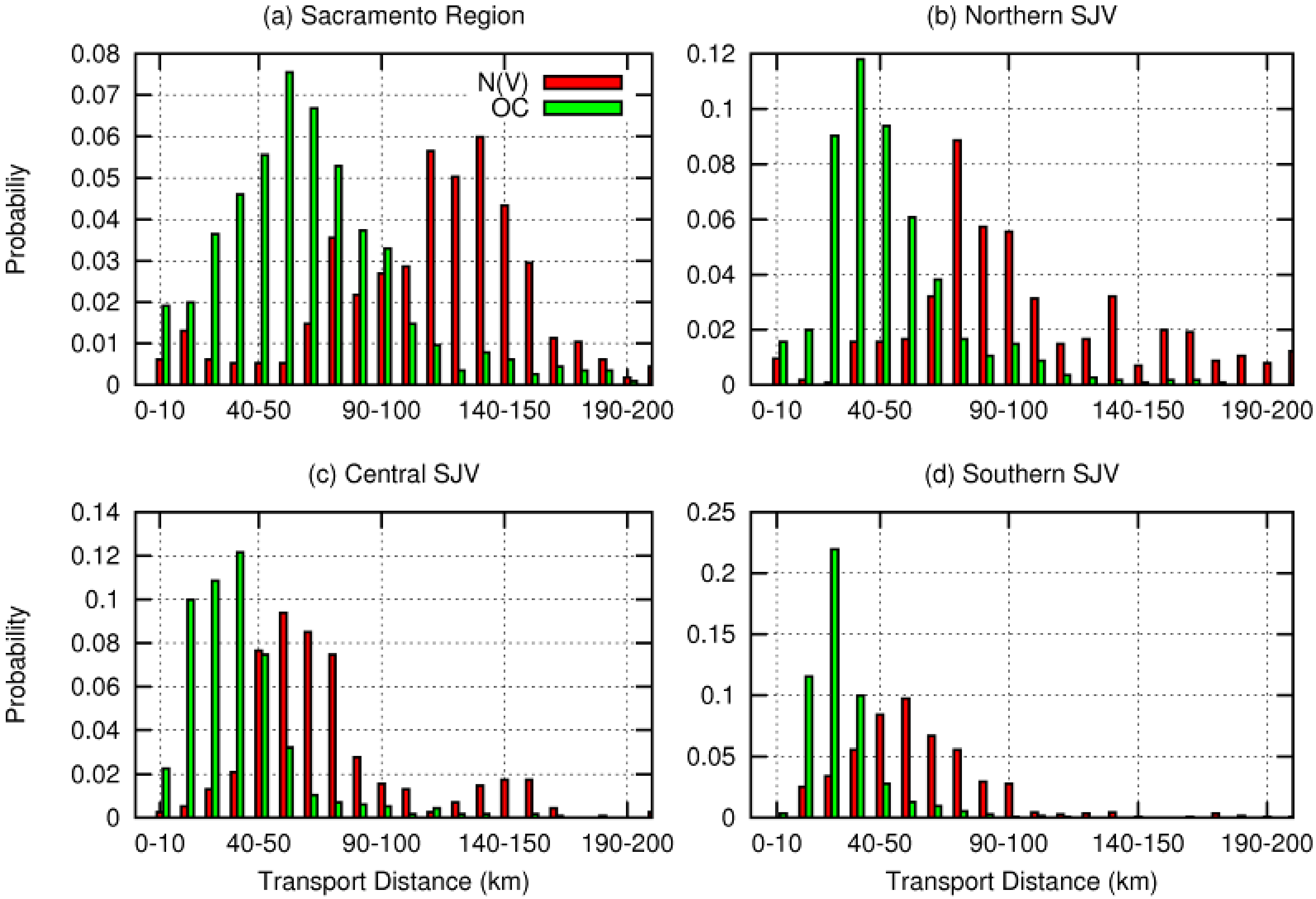
Source: Q. Ying, and M. Kleeman "Regional Contributions to Airborne Particulate Matter in Central California During a Severe Pollution Episode", Atmos. Env., 43, 1218-1228, 2009.

Nitrate Region Contributions



Source: Q. Ying, and M. Kleeman "Regional Contributions to Airborne Particulate Matter in Central California During a Severe Pollution Episode", Atmos. Env., 43, 1218-1228, 2009.

Distribution of Transport Distances



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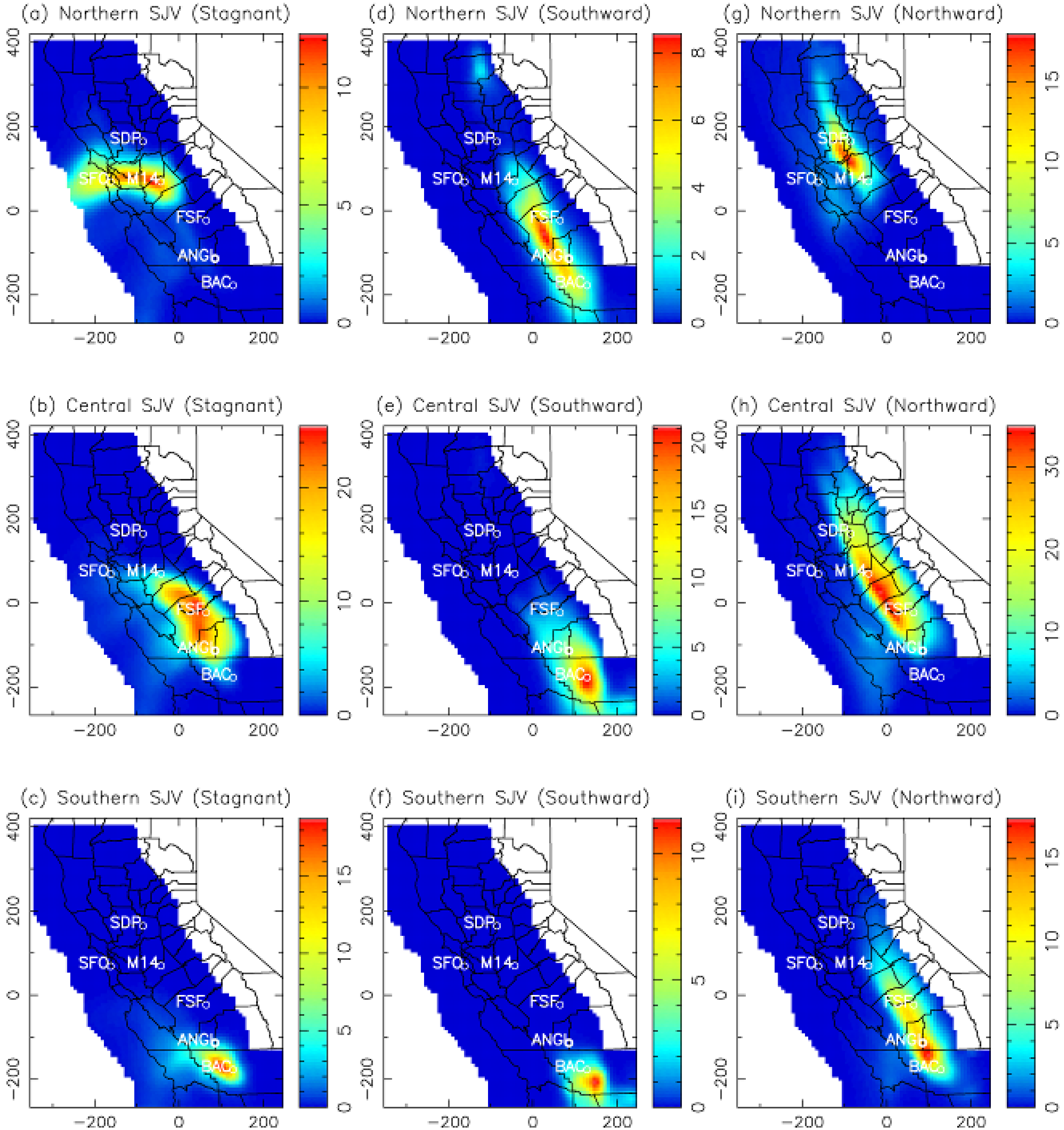
PM2.5 Nitrate



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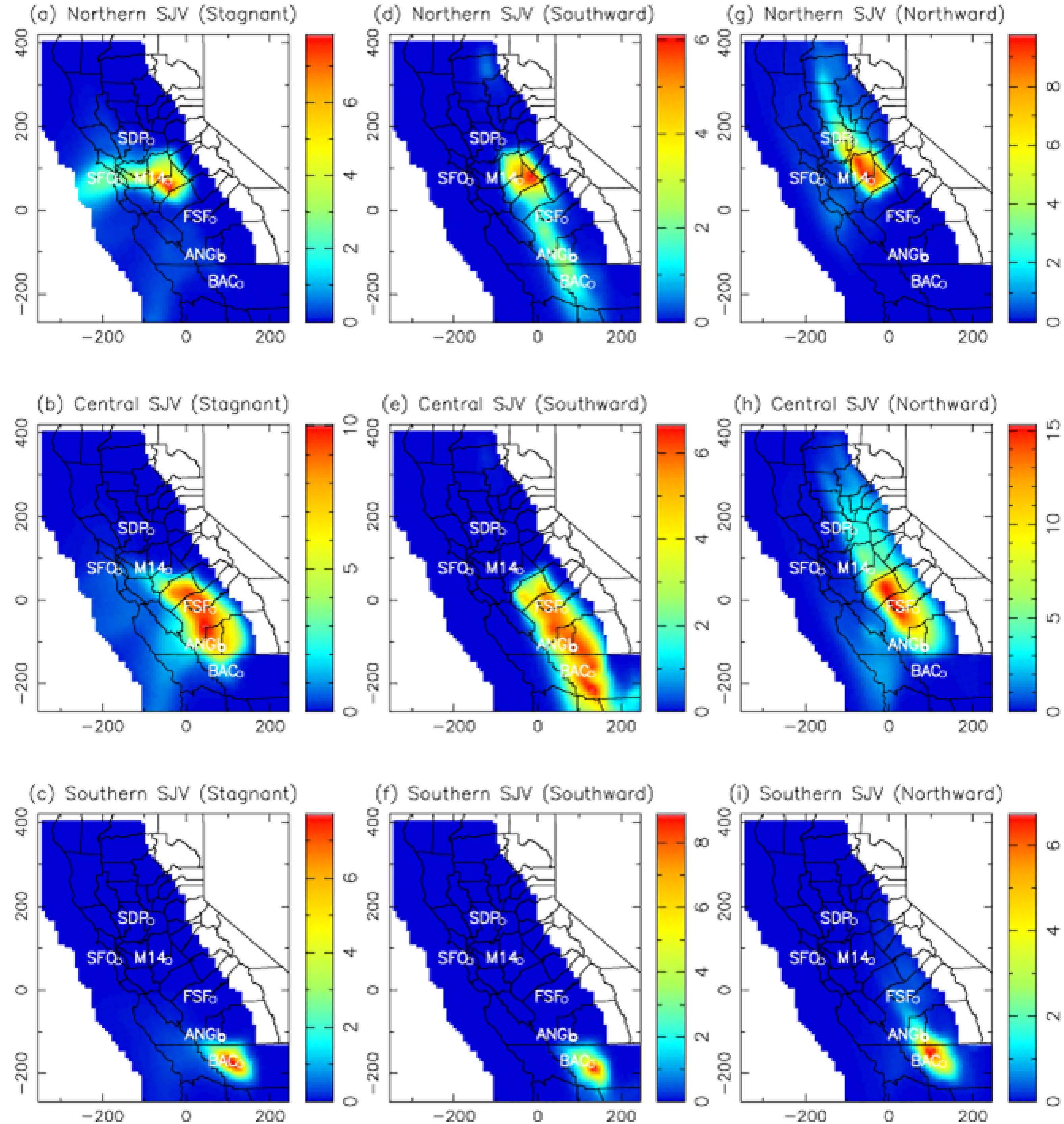
PM2.5 Ammonium



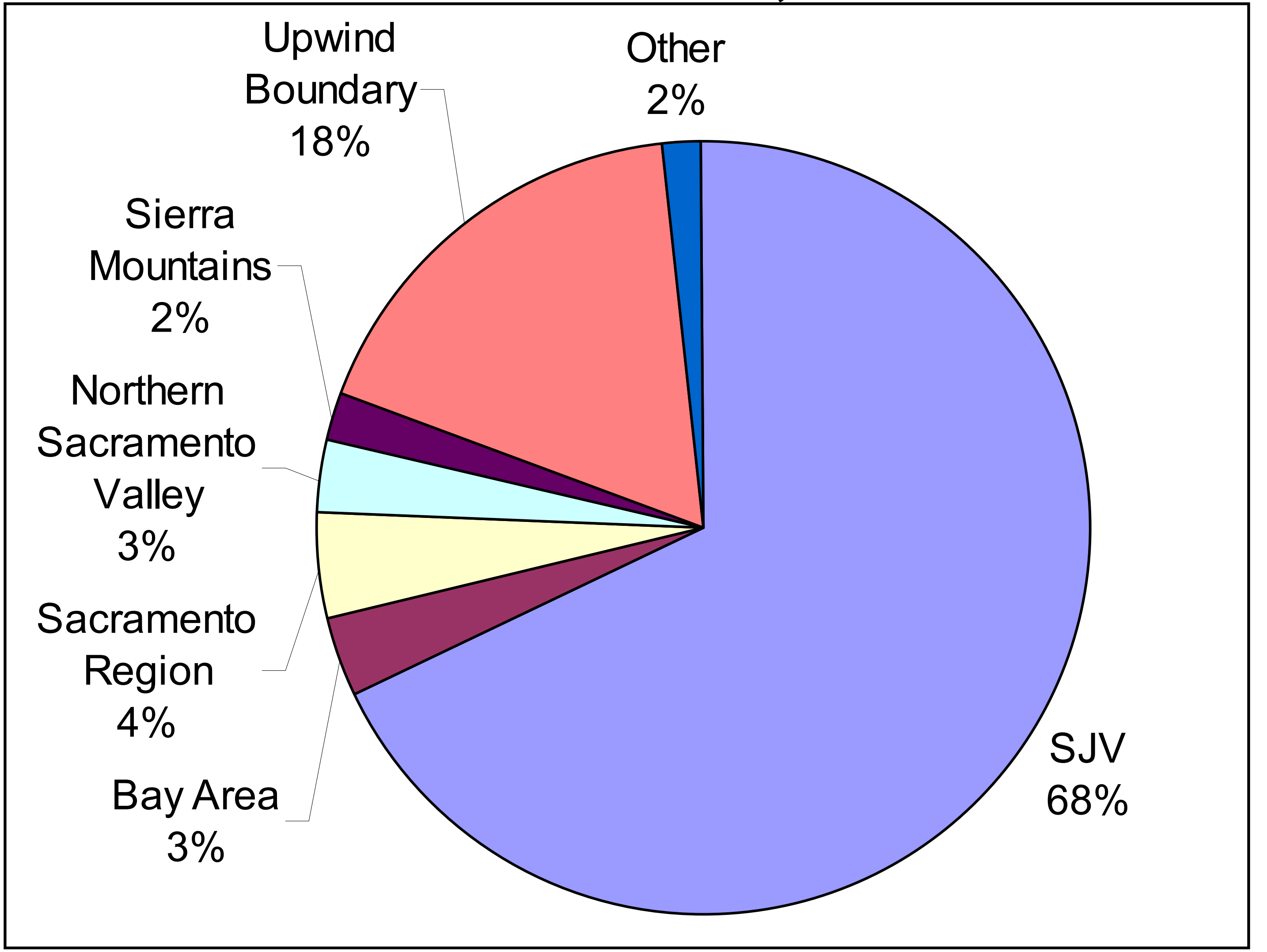
Source: Q. Ying, and M. Kleeman "Regional Contributions to Airborne Particulate Matter in Central California During a Severe Pollution Episode", Atmos. Env., 43, 1218-1228, 2009.

Nitrate Regional Contribution Summary

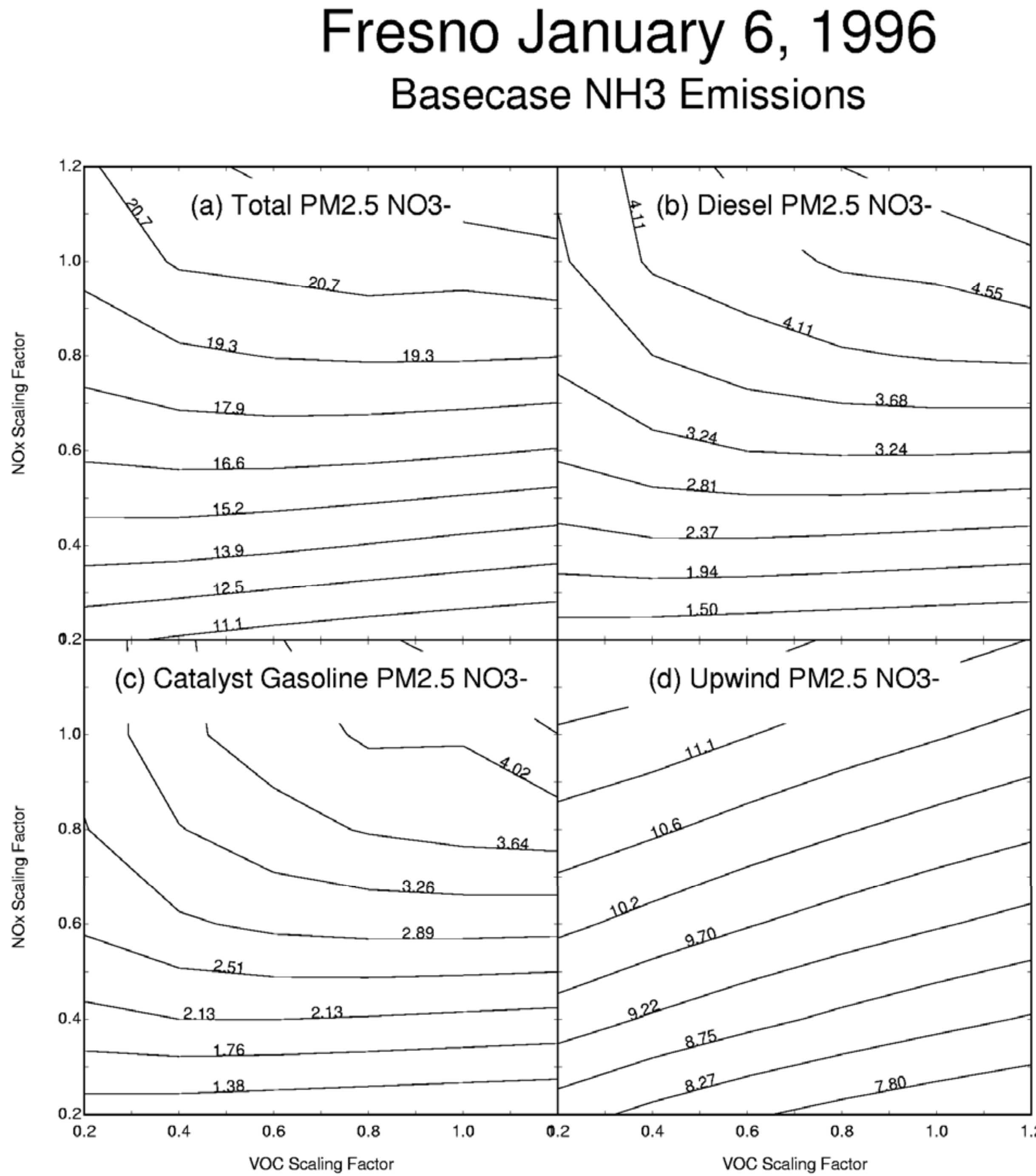
Receptor \ Source		BC S0	Bay Area S1	Sac S2	N SJV S3	C SJV S4	S SJV S5	N SacV S6	Sierra S7	Other S8	SUM
Bay Area	R1	2.1%	1.5%	1.8%	1.4%	0.4%	0.0%	0.2%	0.2%	0.7%	8.2%
Sac	R2	1.1%	0.2%	1.3%	0.3%	0.3%	0.0%	0.1%	0.1%	0.8%	4.3%
N SJV	R3	1.3%	0.3%	0.8%	1.7%	1.0%	0.0%	0.1%	0.4%	0.2%	5.9%
C SJV	R4	5.0%	0.8%	0.9%	1.7%	17.7%	0.7%	0.8%	0.4%	0.3%	28.3%
S SJV	R5	1.4%	0.3%	0.2%	0.2%	3.1%	3.1%	0.4%	0.0%	0.2%	9.0%
N SacV	R6	3.4%	1.1%	0.6%	1.1%	4.0%	1.4%	2.0%	0.1%	0.7%	14.5%
Sierra	R7	0.5%	0.1%	0.1%	0.1%	0.3%	0.0%	0.1%	0.2%	0.0%	1.5%
Other	R8	8.4%	3.9%	2.3%	1.7%	2.4%	0.6%	2.3%	0.2%	6.5%	28.4%
	SUM	23.2%	8.2%	8.1%	8.2%	29.3%	6.0%	6.0%	1.6%	9.4%	100.0%

Source: Q. Ying, and M. Kleeman "Regional Contributions to Airborne Particulate Matter in Central California During a Severe Pollution Episode", Atmos. Env., 43, 1218-1228, 2009.

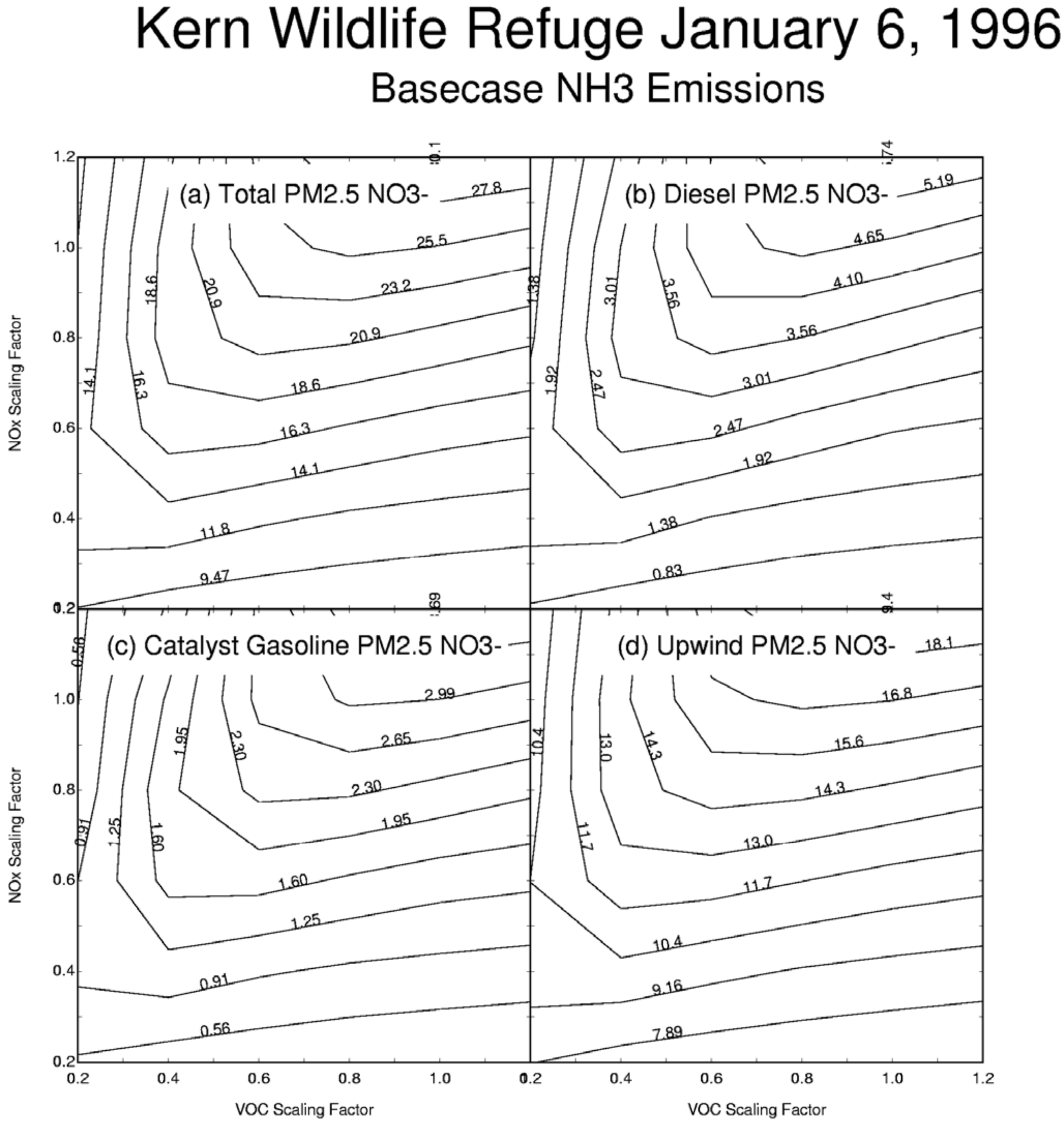
Regional Contributions to SJV PM2.5 Nitrate Between Dec 15, 2000 – Jan 7, 2001



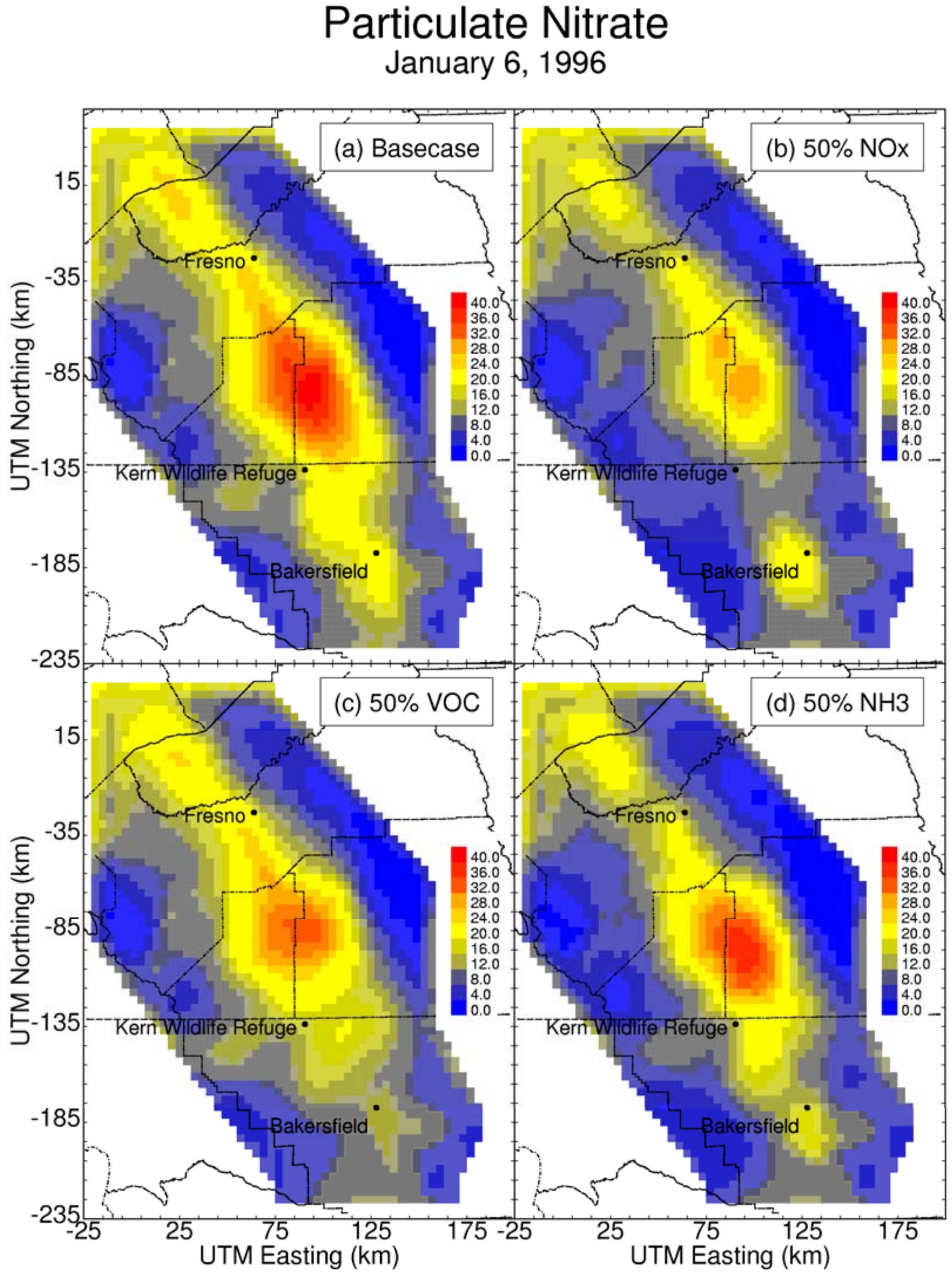
Nitrate Control Options



Nitrate Control Options



Control Strategy Effectiveness



Partial Answers

- *Primary vs. secondary PM 2.5 species*
  - *Elemental carbon (EC), organic carbon (OC), ammonium nitrate*
- *Sources of PM 2.5 in the region?*
  - *Wood smoke (OC) and diesel engines (EC) in urban areas*
  - *Diesel engines (nitrate) and gasoline engines (nitrate) contribute regionally*
  - *Agricultural activities (ammonium) contribute regionally*

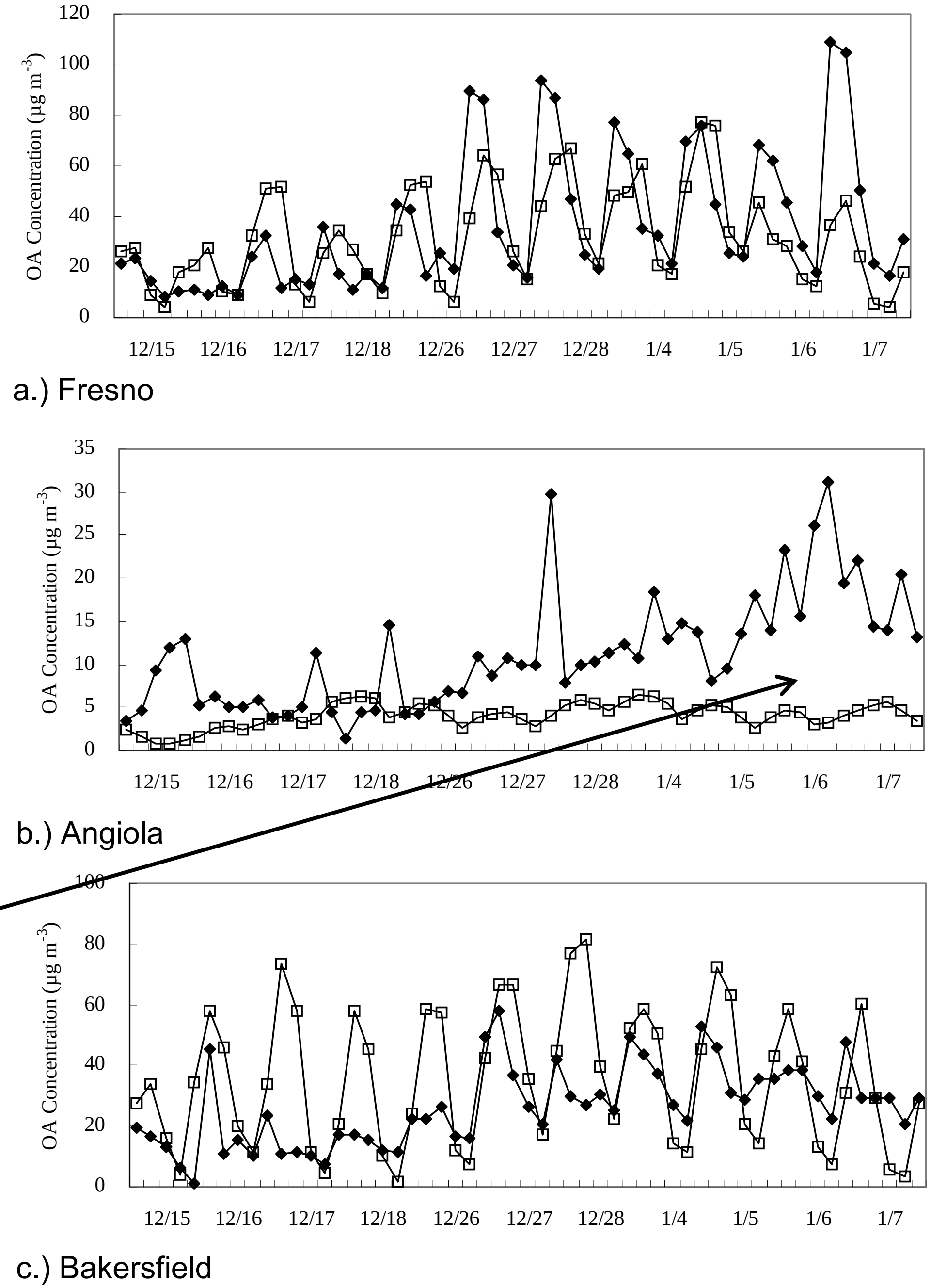
Partial Answers

- *Why do they concentrate in winter?*
  - *Lower mixing depths, colder temperature, home heating*
- *Where and when do PM 2.5 concentrations vary in the Valley?*
  - *Transport can be a factor, but mostly local emissions cause local air pollution*
- *What types of control measures have been most successful?*
  - *Restrictions on residential wood combustion*
  - *Restrictions on NO emissions*

Future Challenges:

Organic Particulate Matter

Predicted (open squares) and Observed OC (solid diamonds) using CACM



Large under-prediction at locations far away from urban sources

Acknowledgements

- Qi Ying, James Chen, Jianlin Hu, Jin Lu
- Karen Magliano, Ajith Kaduwela, Vernon Hughes
- Paul Allen, Paul Livingstone
- Everyone who made measurements during CRPAQS
- Zhan Zhao, Shuhua Chen

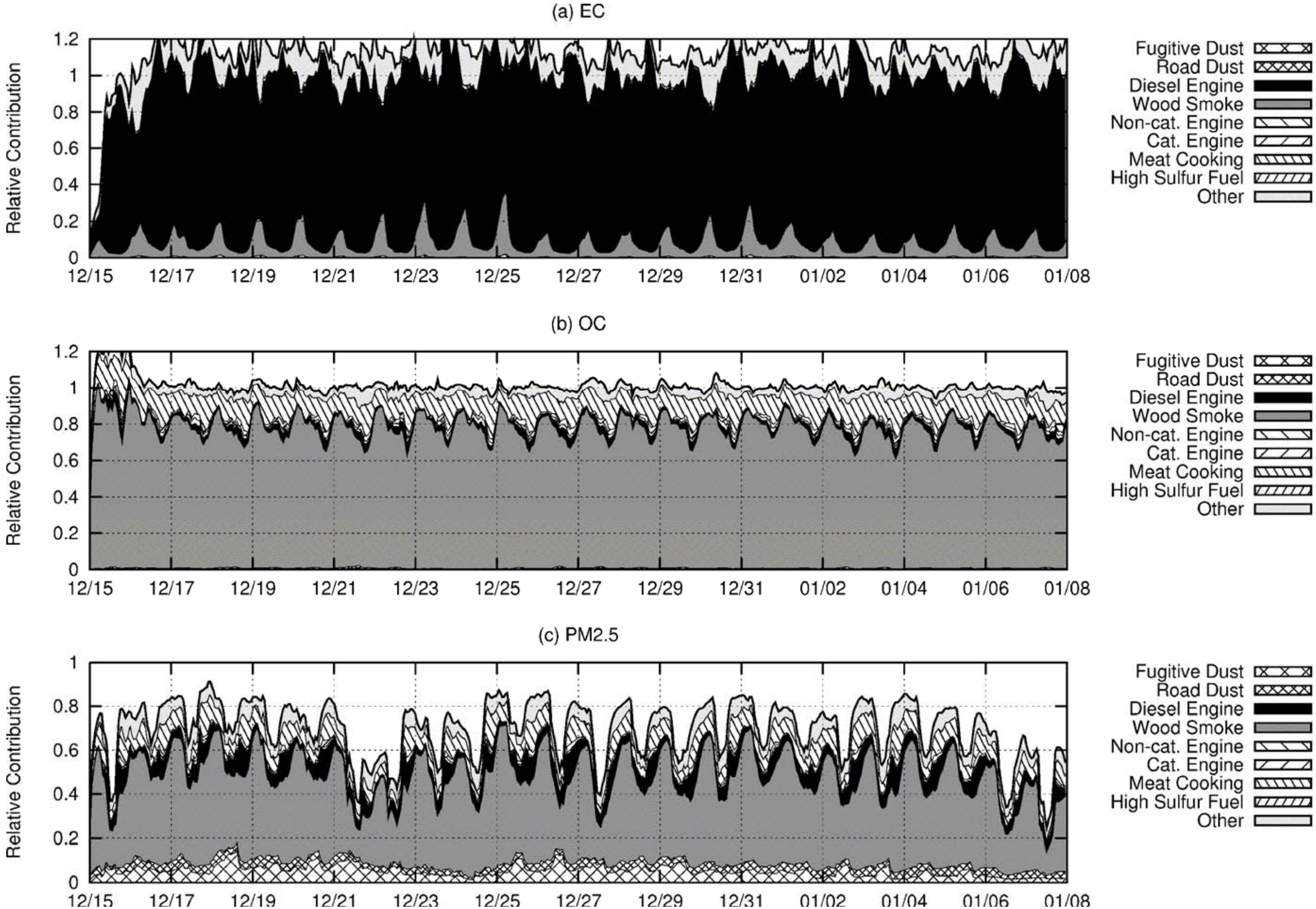
- San Joaquin Valleywide Air Pollution Study Agency
- United States Environmental Protection Agency

Supporting Slides

Atmospheric “Black Box” is Mostly Gone

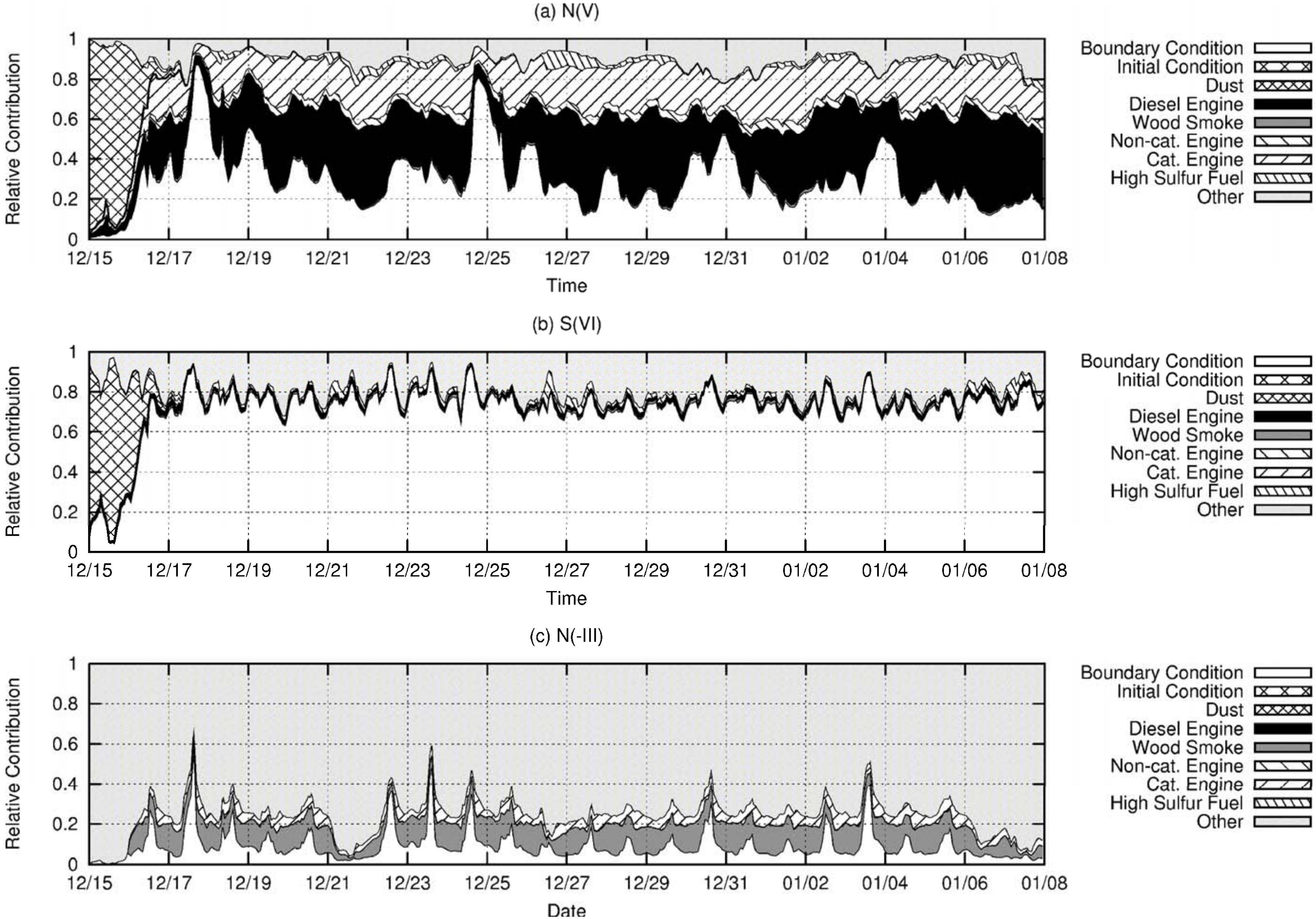
- Multiple techniques exist to identify source contributions to primary and secondary PM

Fresno PM2.5 Source Contributions



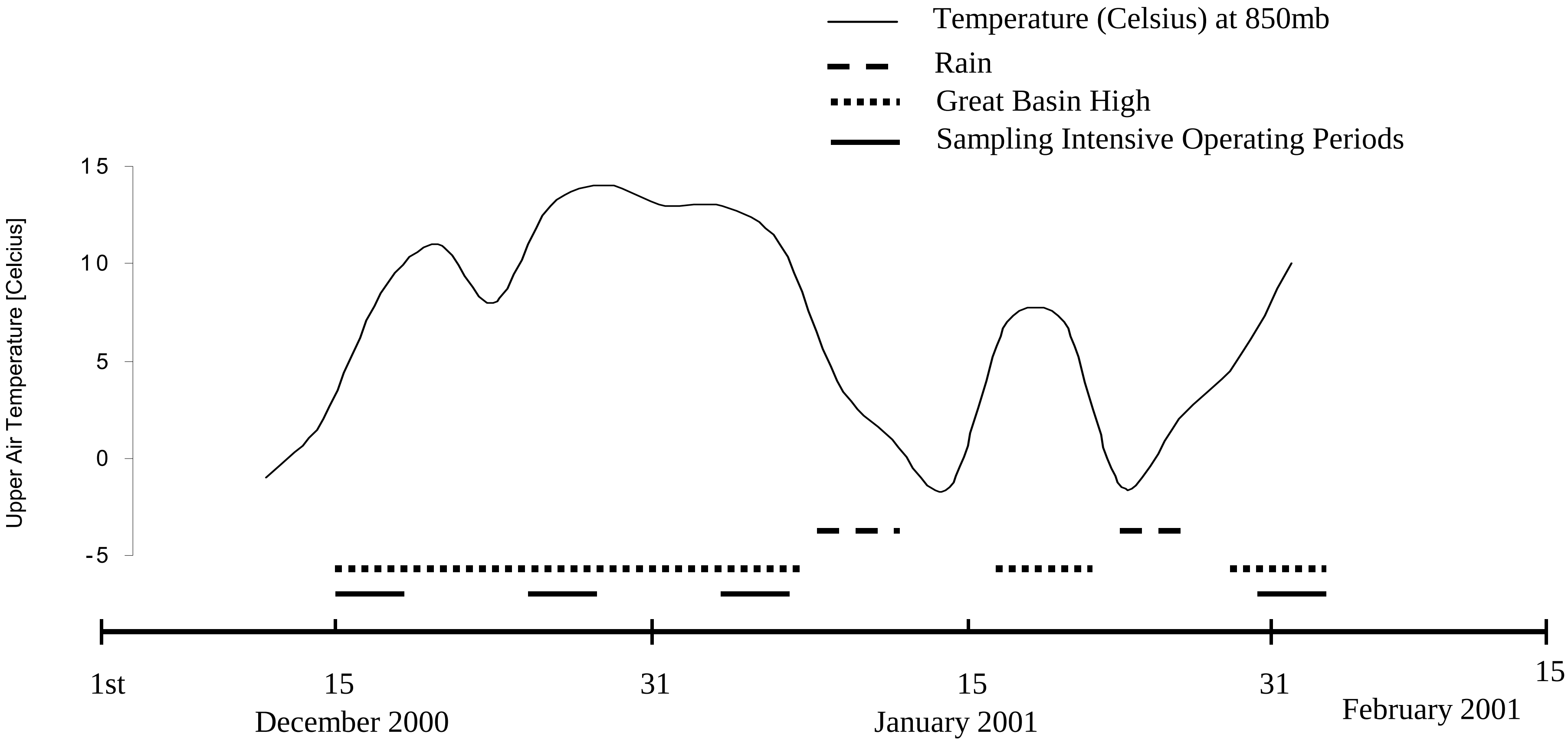
Source: Q. Ying, J. Lu, A. Kaduwela, and M. Kleeman "Modeling Air Quality During the California Regional PM10/PM2.5 Air Quality Study (CRPAQS) Using the UCD/CIT Source-Oriented Air Quality Model – Part II. Regional Source Apportionment of Primary Airborne Particulate Matter.", Atmos. Env., in press, 2008.

Fresno Source Contributions



Source: Q. Ying, J. Lu, A. Kaduwela, and M. Kleeman "Modeling Air Quality During the California Regional PM10/PM2.5 Air Quality Study (CRPAQS) Using the UCD/CIT Source-Oriented Air Quality Model – Part III. Regional Source Apportionment of Secondary and Total Airborne PM2.5 and PM0.1.", Atmos. Env., in press, 2008.

Meteorological Patterns During CRPAQS Winter Intensive



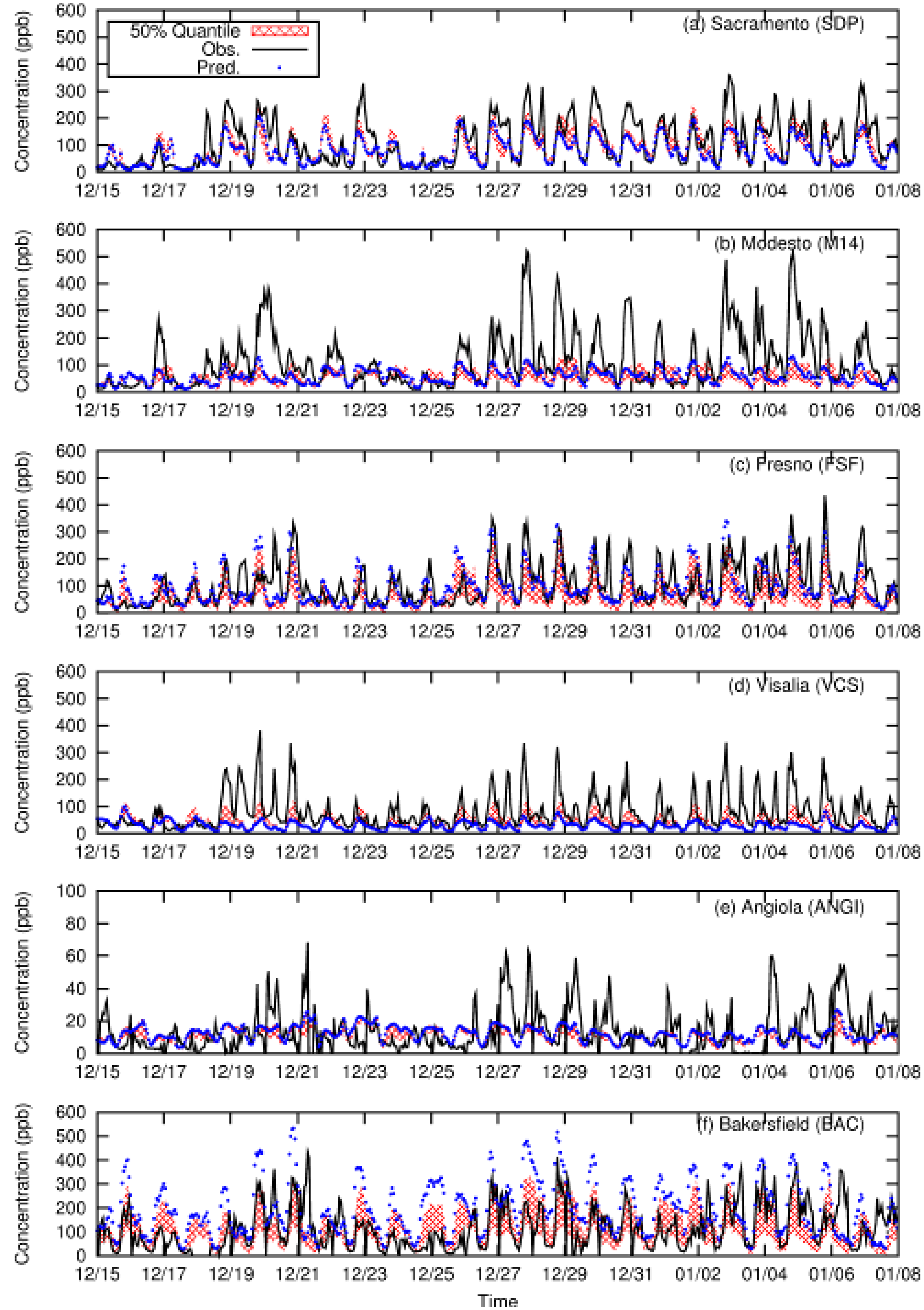
Source: J. Herner, J. Aw, O. Gao, D.P. Chang, and M.J. Kleeman, “Size and Composition Distribution of Airborne Particulate Matter in Northern California: 1 – Particulate Mass, Carbon, and Water-Soluble Ions”, J. Air. Waste Manag. Assoc., 55: 30-51, 2005.

NOx

Good agreement at Sacramento and Fresno

Slight over-prediction at Bakersfield, but spatial gradients are sharp

Miss the diurnal trend at Modesto, Visalia, and Angiola (what sources drive the observed trends?)



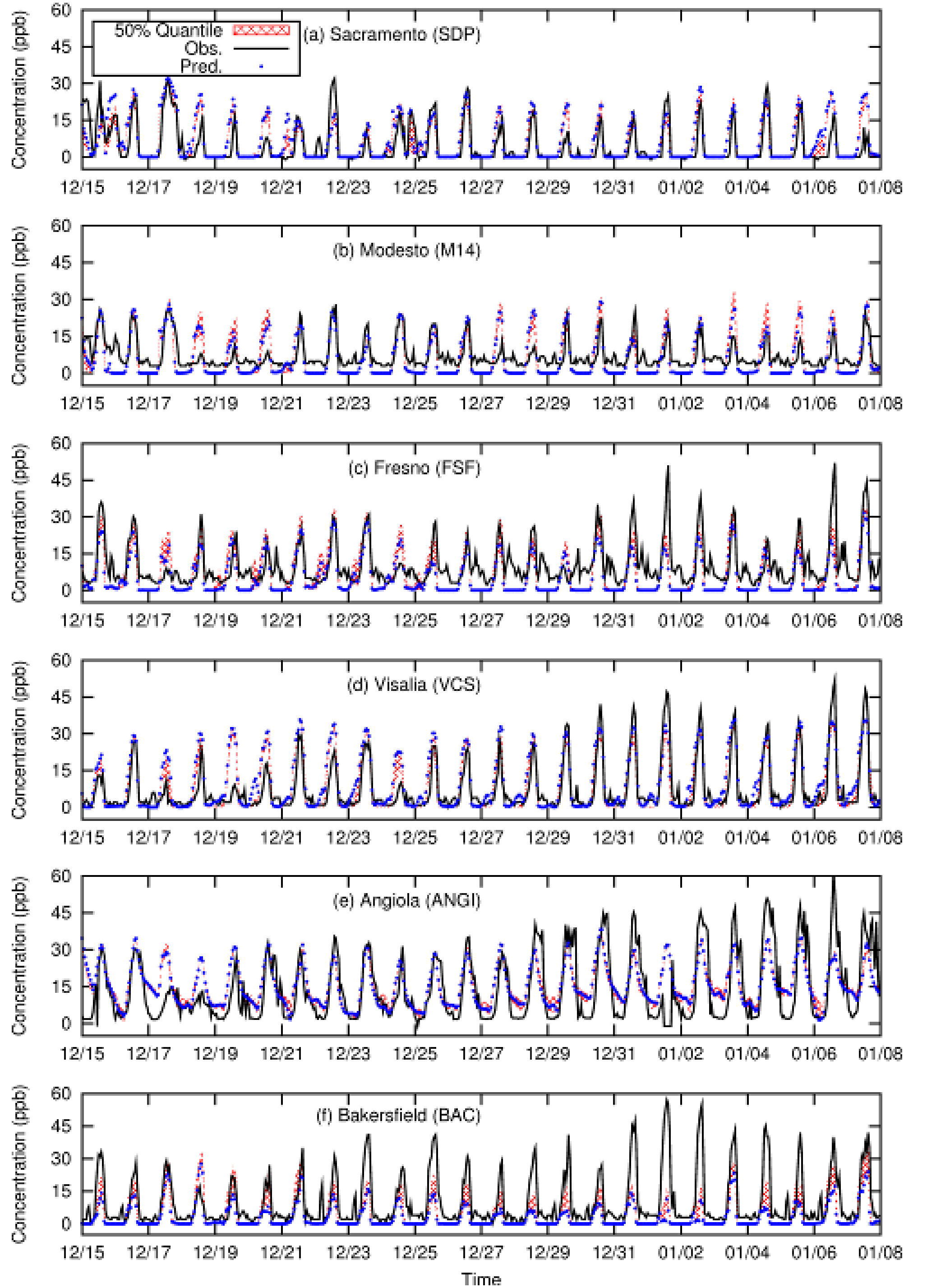
Source: Q. Ying, J. Lu, P. Allen, P. Livingstone, A. Kaduwela, and M. Kleeman “Modeling Air Quality During the California Regional PM10/PM2.5 Air Quality Study (CRPAQS) Using the UCD/CIT Source-Oriented Air Quality Model – Part I. Base Case Model Results.”, Atmos. Env., in press, 2008.

O3

Good agreement at most stations

Majority of the ozone is background that mixes down to the surface during the middle of the day

Background O3 is actually the dominant oxidant in the atmosphere



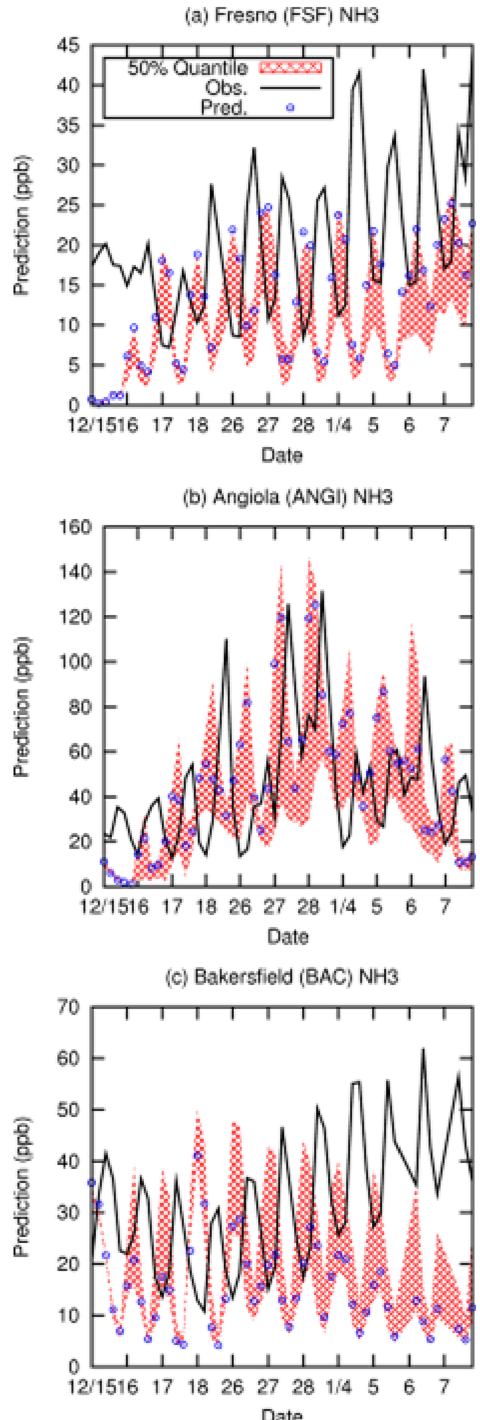
Source: Q. Ying, J. Lu, P. Allen, P. Livingstone, A. Kaduwela, and M. Kleeman "Modeling Air Quality During the California Regional PM10/PM2.5 Air Quality Study (CRPAQS) Using the UCD/CIT Source-Oriented Air Quality Model – Part I. Base Case Model Results.", Atmos. Env., in press, 2008.

NH3

Overall concentrations are order-of-magnitude correct

Diurnal cycle is exactly opposite measured values

Nitrate production is limited by production of nitric acid, so the details are not critical



Source: Q. Ying, J. Lu, P. Allen, P. Livingstone, A. Kaduwela, and M. Kleeman "Modeling Air Quality During the California Regional PM10/PM2.5 Air Quality Study (CRPAQS) Using the UCD/CIT Source-Oriented Air Quality Model – Part I. Base Case Model Results.", Atmos. Env., in press, 2008.

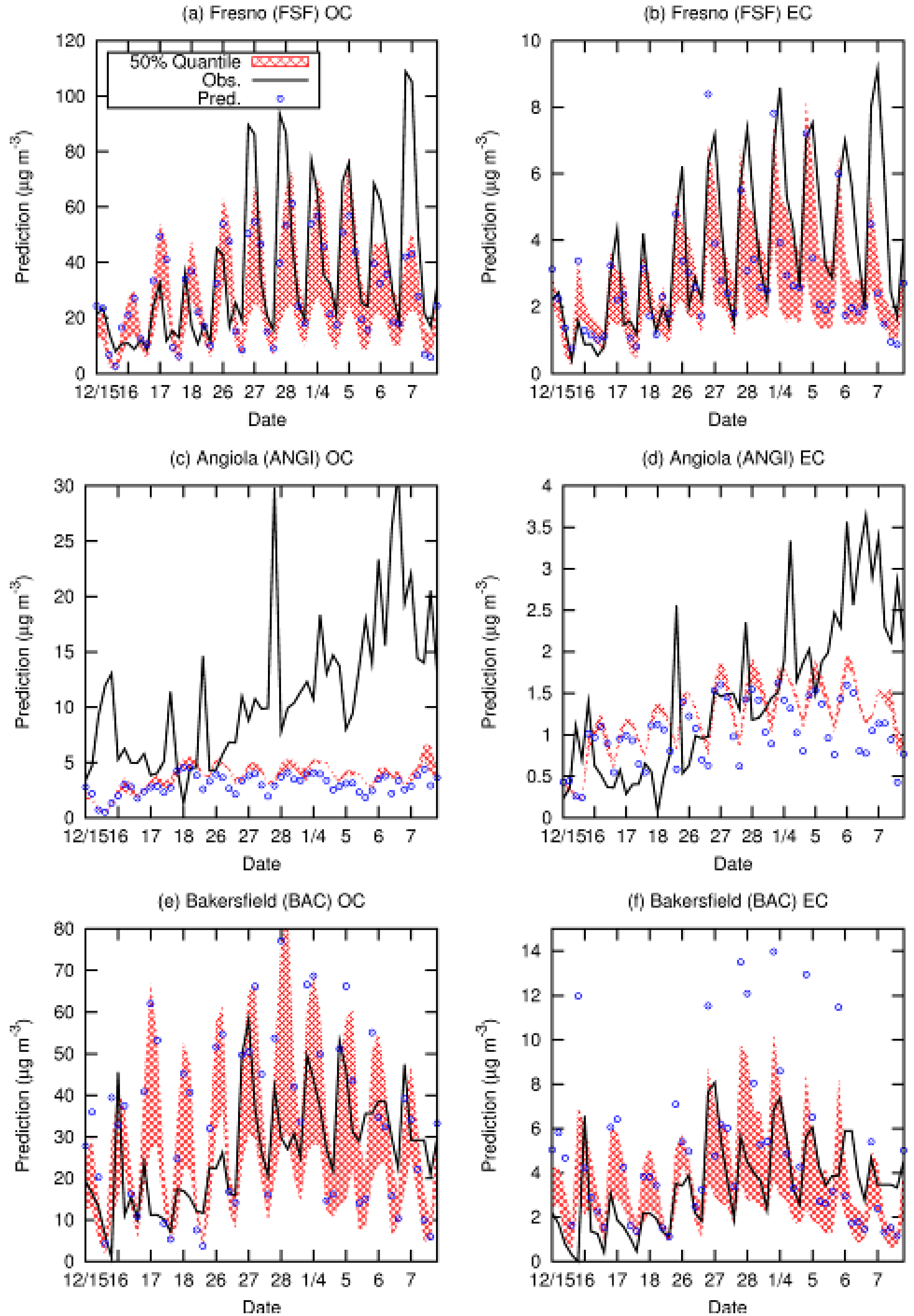
PM2.5 OC + EC

Black lines = measurements
Blue circles = predictions
Red Shading – Mid 50% Quantile within 10km of monitor

Diurnal pattern predicted correctly at urban sites

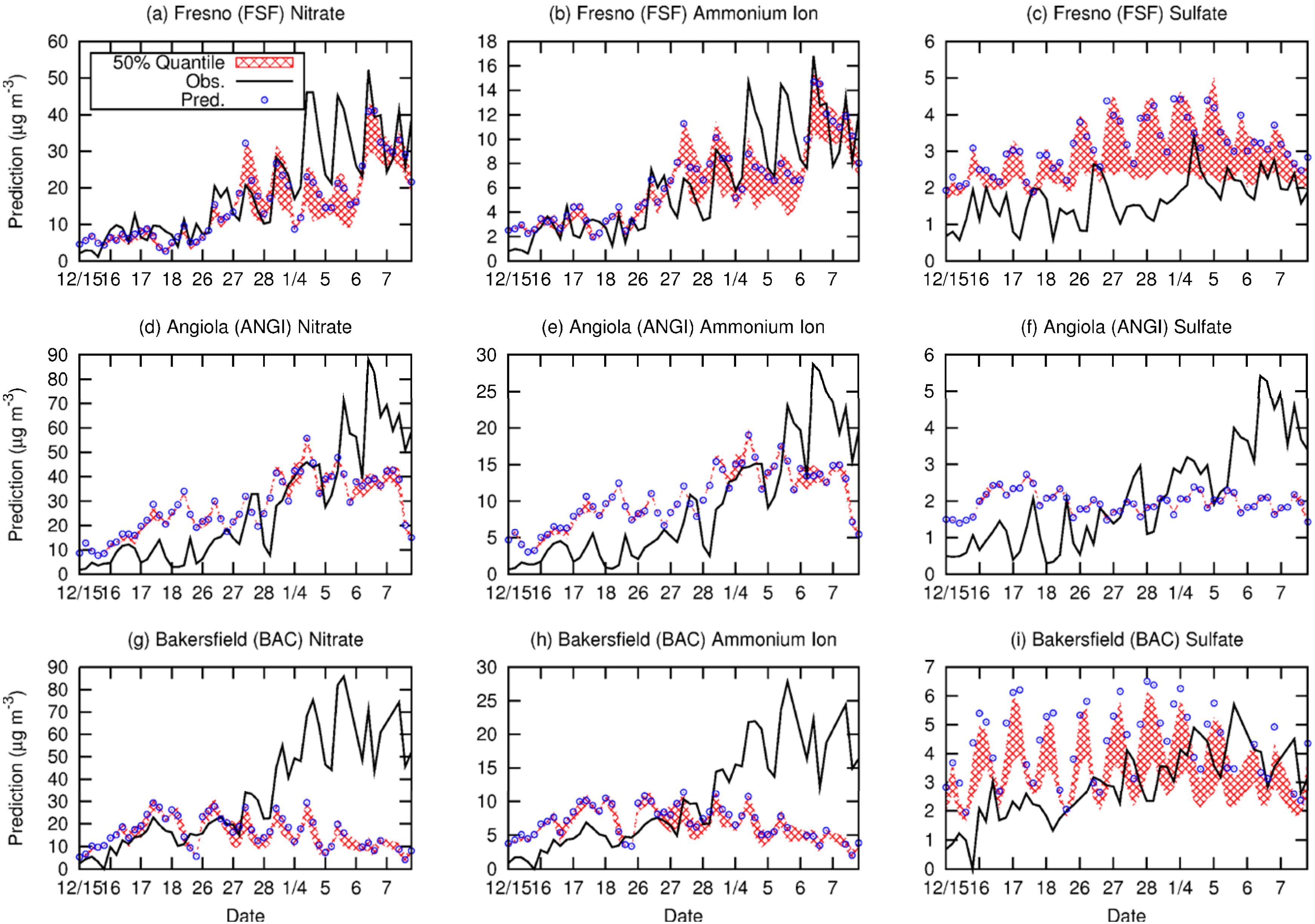
Peak values show reasonable agreement, especially considering the sharp gradients

Rural Angiola predictions are low. Where is the EC+OC coming from?



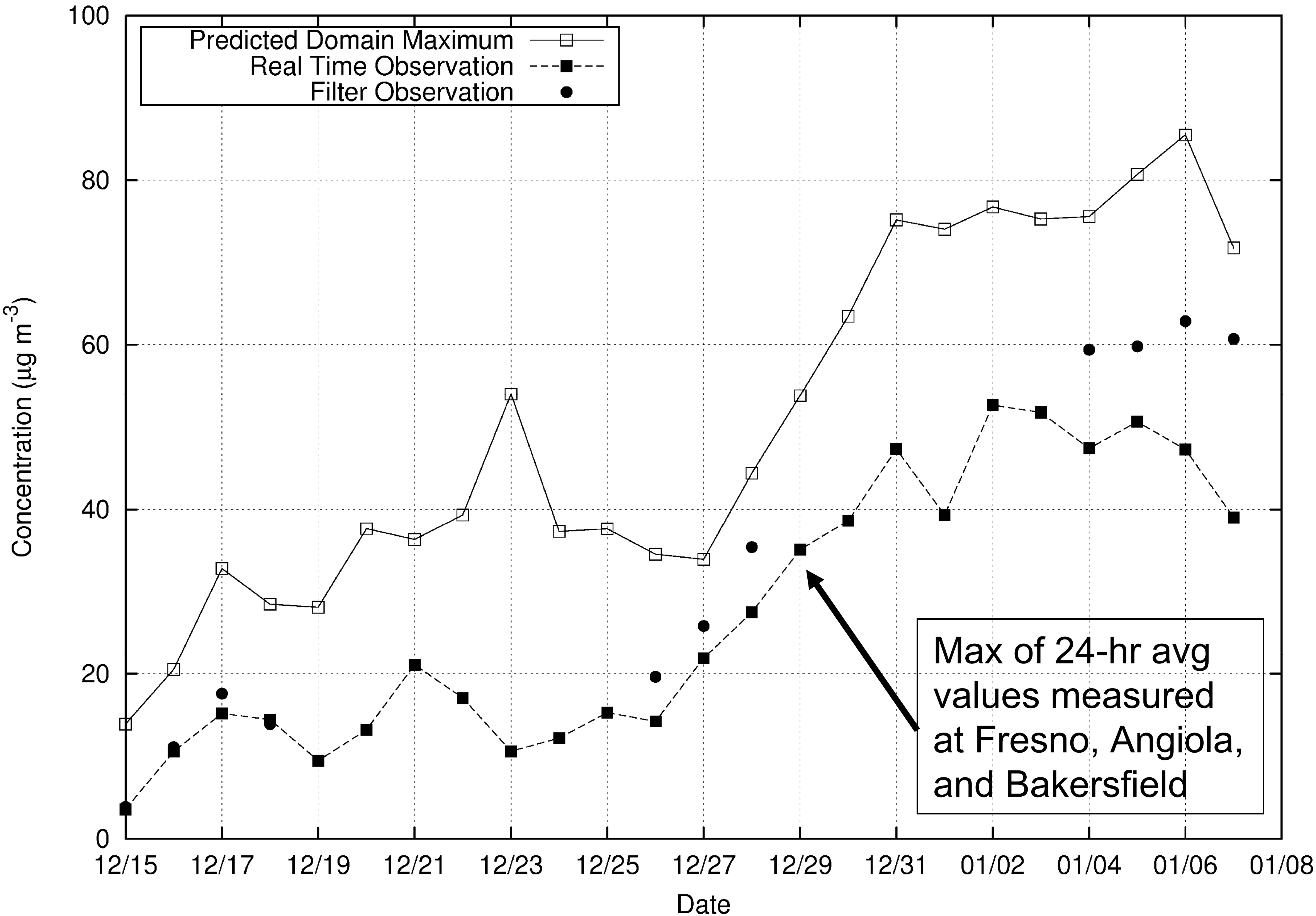
Source: Q. Ying, J. Lu, P. Allen, P. Livingstone, A. Kaduwela, and M. Kleeman "Modeling Air Quality During the California Regional PM10/PM2.5 Air Quality Study (CRPAQS) Using the UCD/CIT Source-Oriented Air Quality Model – Part I. Base Case Model Results.", Atmos. Env., in press, 2008.

PM2.5 Nitrate, Ammonium, Sulfate



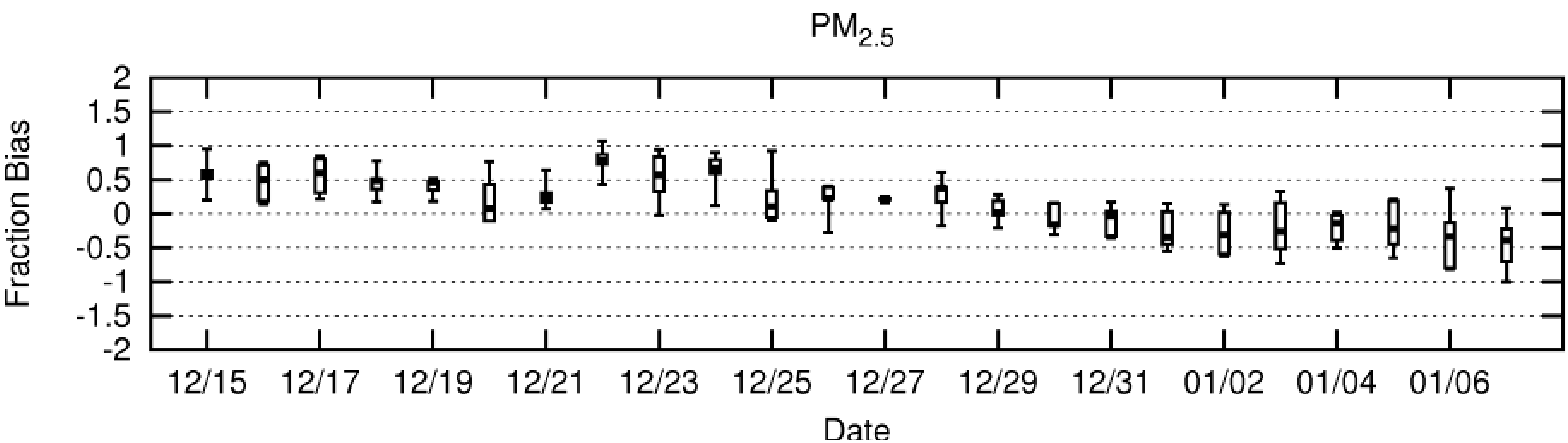
Source: Q. Ying, J. Lu, P. Allen, P. Livingstone, A. Kaduwela, and M. Kleeman “Modeling Air Quality During the California Regional PM10/PM2.5 Air Quality Study (CRPAQS) Using the UCD/CIT Source-Oriented Air Quality Model – Part I. Base Case Model Results.”, Atmos. Env., in press, 2008.

Predicted vs. Observed Nitrate Trends



Source: Q. Ying, J. Lu, P. Allen, P. Livingstone, A. Kaduwela, and M. Kleeman "Modeling Air Quality During the California Regional PM10/PM2.5 Air Quality Study (CRPAQS) Using the UCD/CIT Source-Oriented Air Quality Model – Part I. Base Case Model Results.", Atmos. Env., in press, 2008.

PM2.5 Fractional Bias



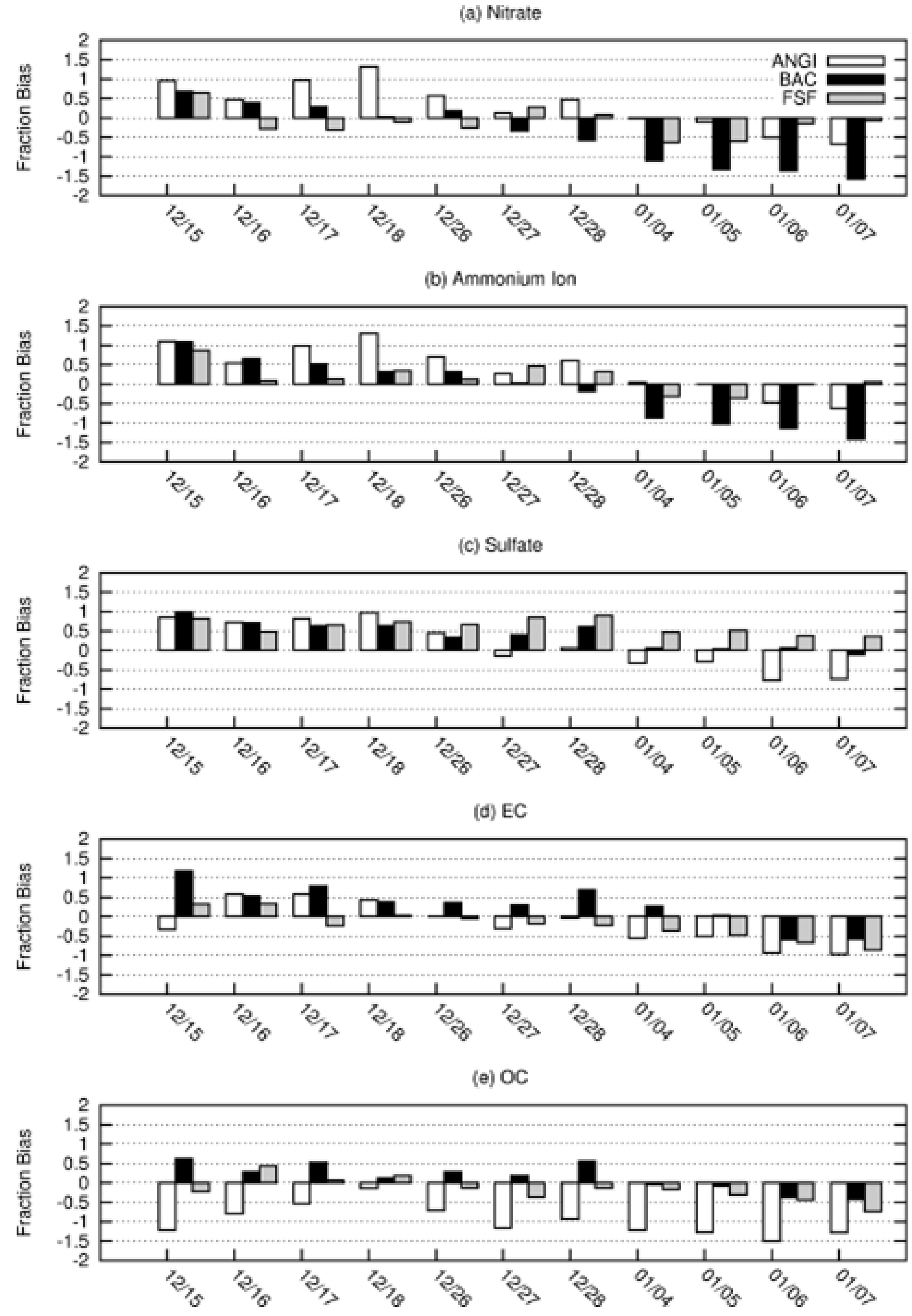
$$FB = \frac{2}{N} \times \sum \frac{C_{p,i} - C_{o,i}}{C_{p,i} + C_{o,i}}$$

Source: Q. Ying, J. Lu, P. Allen, P. Livingstone, A. Kaduwela, and M. Kleeman "Modeling Air Quality During the California Regional PM10/PM2.5 Air Quality Study (CRPAQS) Using the UCD/CIT Source-Oriented Air Quality Model – Part I. Base Case Model Results.", Atmos. Env., in press, 2008.

Fractional Bias of Individual PM2.5 Components

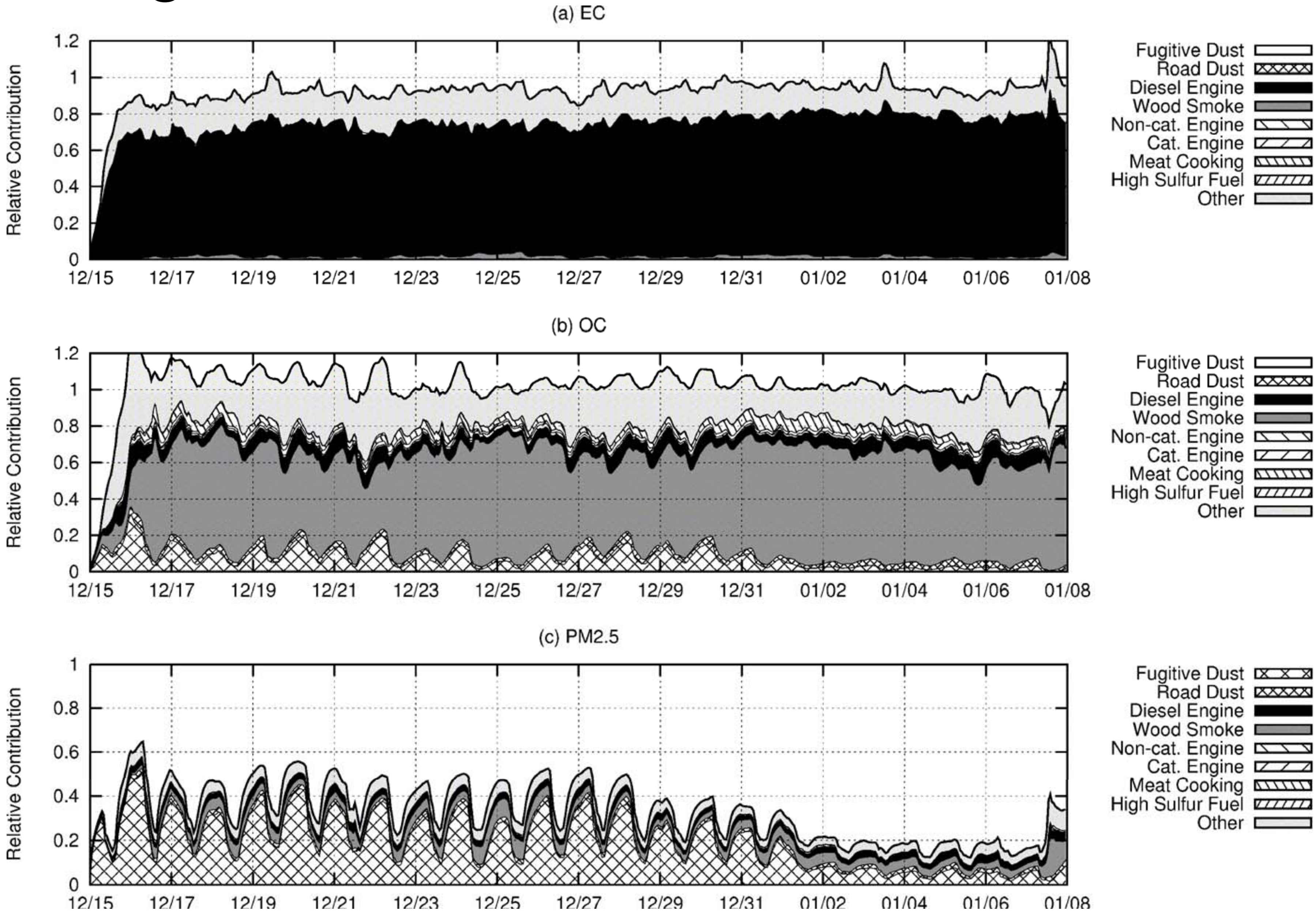
Most components – slight over-prediction during early portion of episode evolving to slight under-prediction later in episode

OC – always under-predicted at Angiola

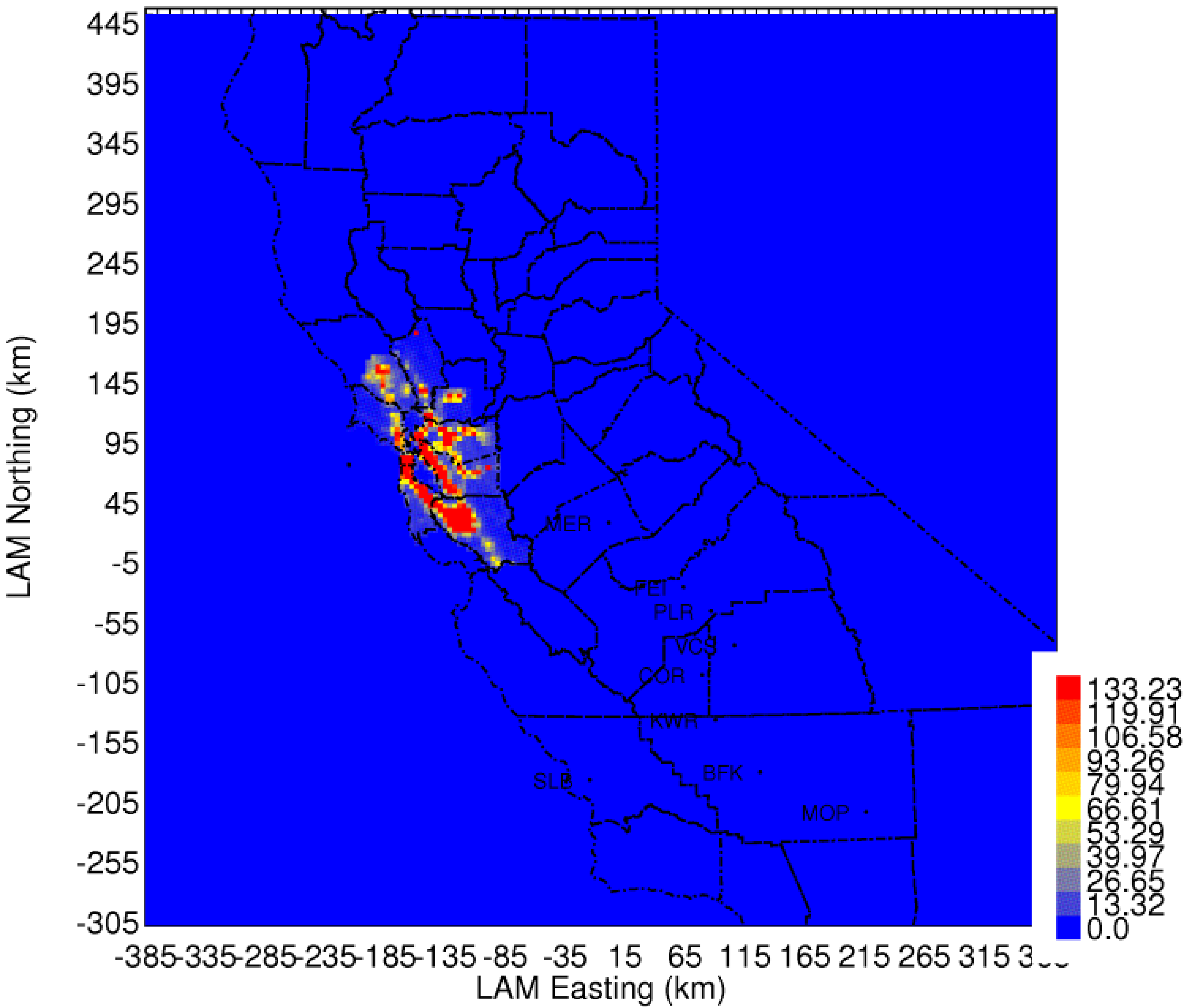


Source: Q. Ying, J. Lu, P. Allen, P. Livingstone, A. Kaduwela, and M. Kleeman "Modeling Air Quality During the California Regional PM10/PM2.5 Air Quality Study (CRPAQS) Using the UCD/CIT Source-Oriented Air Quality Model – Part I. Base Case Model Results.", Atmos. Env., in press, 2008.

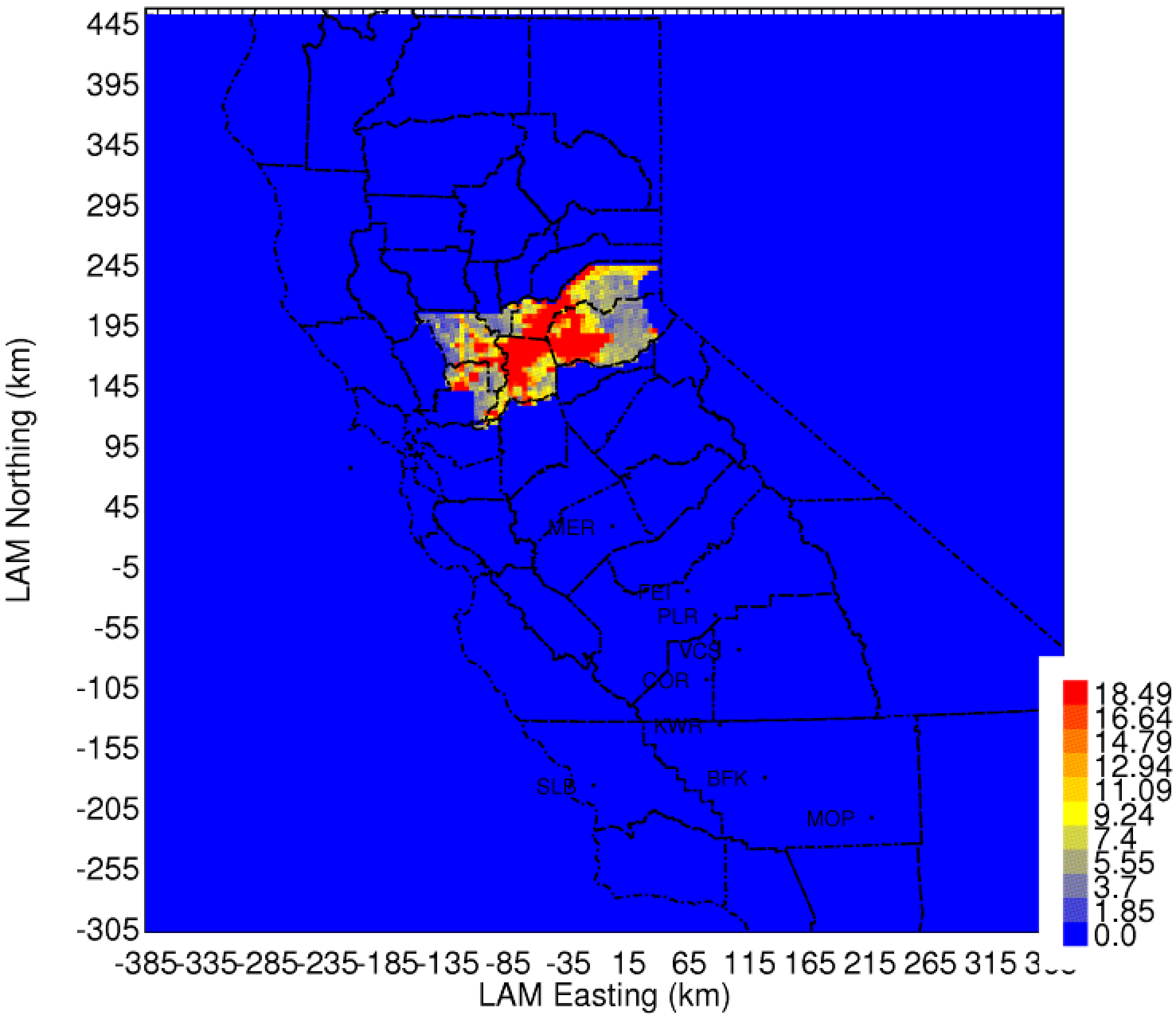
Angiola PM2.5 Source Contributions



Source: Q. Ying, J. Lu, A. Kaduwela, and M. Kleeman "Modeling Air Quality During the California Regional PM10/PM2.5 Air Quality Study (CRPAQS) Using the UCD/CIT Source-Oriented Air Quality Model – Part II. Regional Source Apportionment of Primary Airborne Particulate Matter.", Atmos. Env., in press, 2008.



LAM Northing (km)
445
395
345
295
245
195
145
95
45
-5
-55
-105
-155
-205
-255
-305
-385
-335
-285
-235
-185
-135
-85
-35
15
65
115
165
215
265
315
LAM Easting (km)
MER
FEI
PLR
VCS
COR
KWR
SLB
BFK
MOP
133.23
119.91
106.58
93.26
79.94
66.61
53.29
39.97
26.65
13.32
0.0



LAM Northing (km)
LAM Easting (km)
445
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-285
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-185
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-35
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115
165
215
265
315
MER
FEI
PLR
VCS
COR
KWR
SLB
BFK
MOP
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16.64
14.79
12.94
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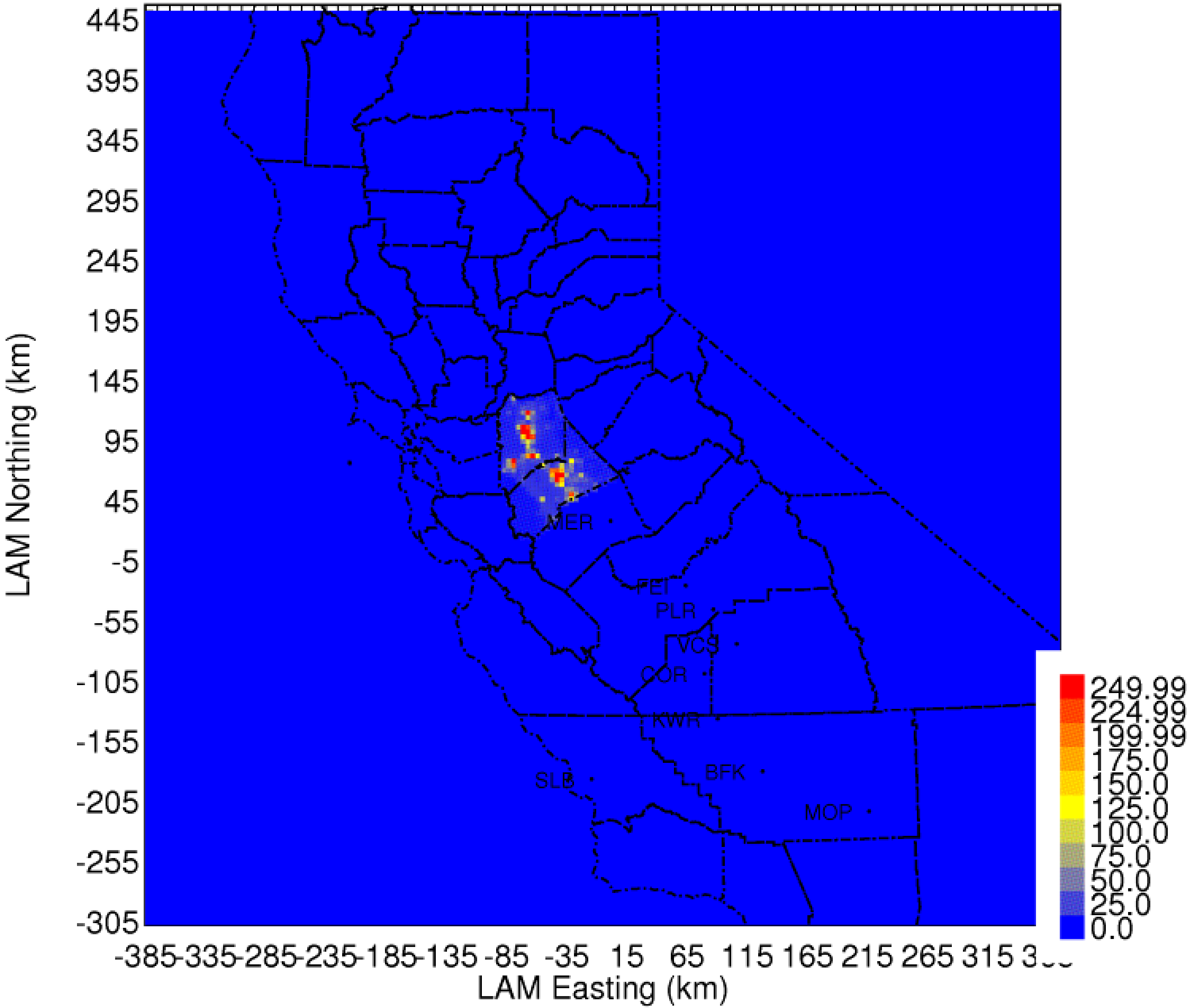
7.4
5.55
3.7
1.85
0.0


LAM Northing (km)
445
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-105
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-255
-305
-385-335-285-235-185-135 -85 -35 15 65 115 165 215 265 315
LAM Easting (km)
MER
FEI
PLR
VCS
COR
KWR
SLB
BFK
MOP
249.99
224.99
199.99
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125.0
100.0
75.0
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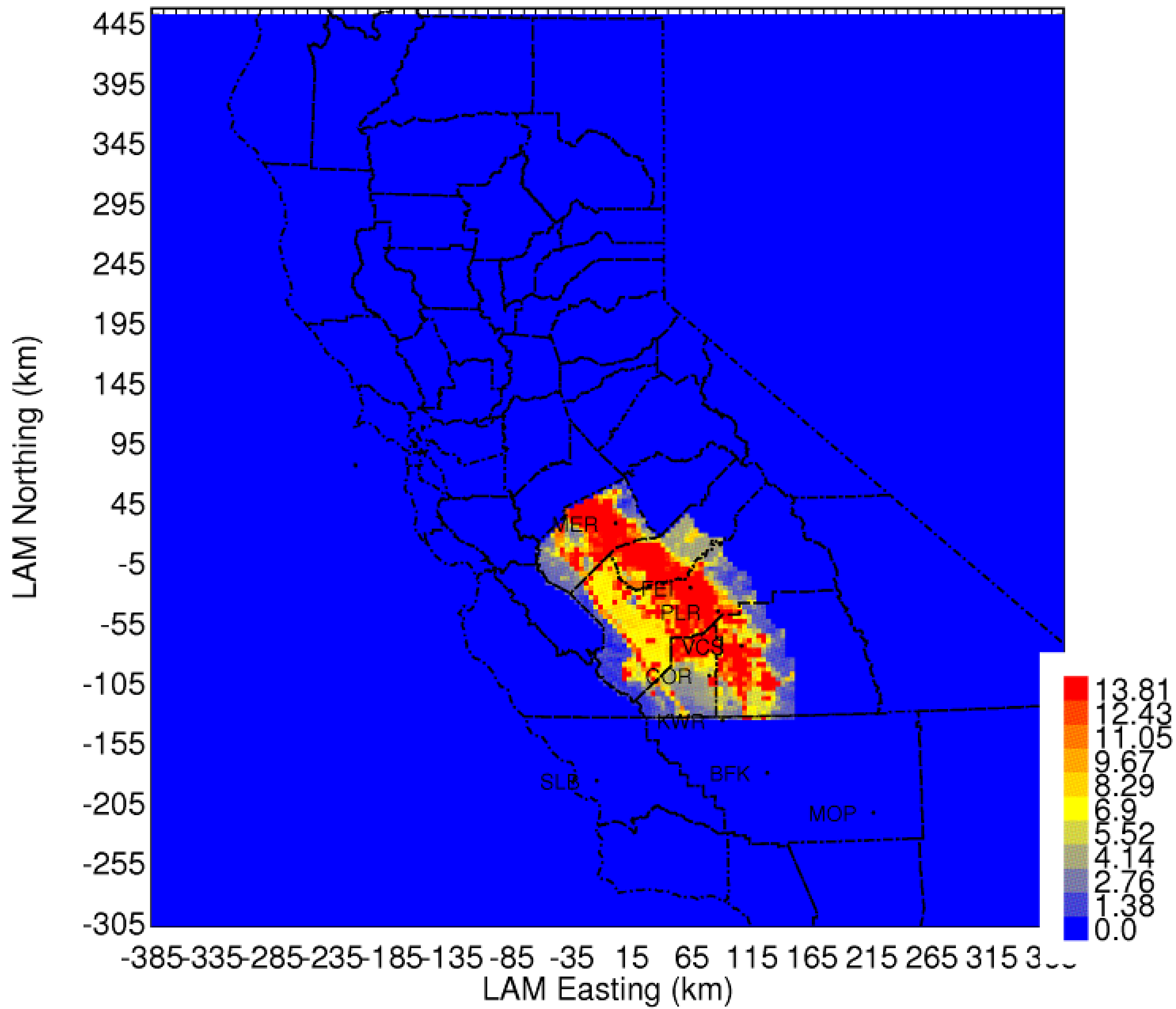
25.0
0.0



445
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195
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-5
-55
-105
-155
-205
-255
-305
LAM Northing (km)
-385 -335 -285 -235 -185 -135 -85 -35 15 65 115 165 215 265 315
LAM Easting (km)
MER
FEI
PLR
VCS
COR
KWR
SLB
BFK
MOP
13.81
12.43
11.05
9.67
8.29
6.9
5.52
4.14
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1.38
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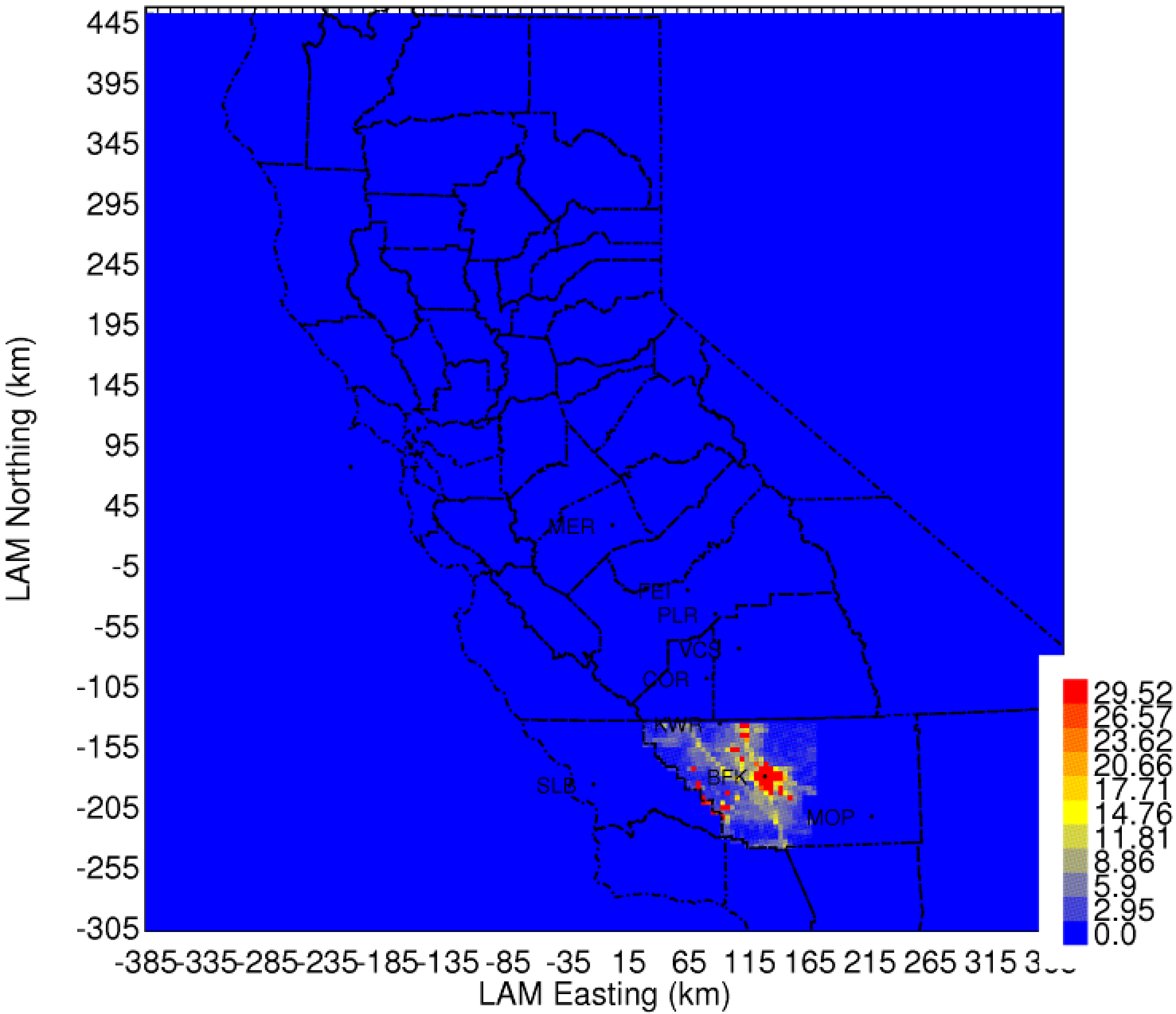

LAM Northing (km)
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-255
-305
-385-335-285-235-185-135 -85 -35 15 65 115 165 215 265 315
LAM Easting (km)
MER
FEI
PLR
VCS
COR
KWR
BFK
SLB
MOP
29.52
26.57
23.62
20.66
17.71
14.76
11.81
8.86
5.9
2.95
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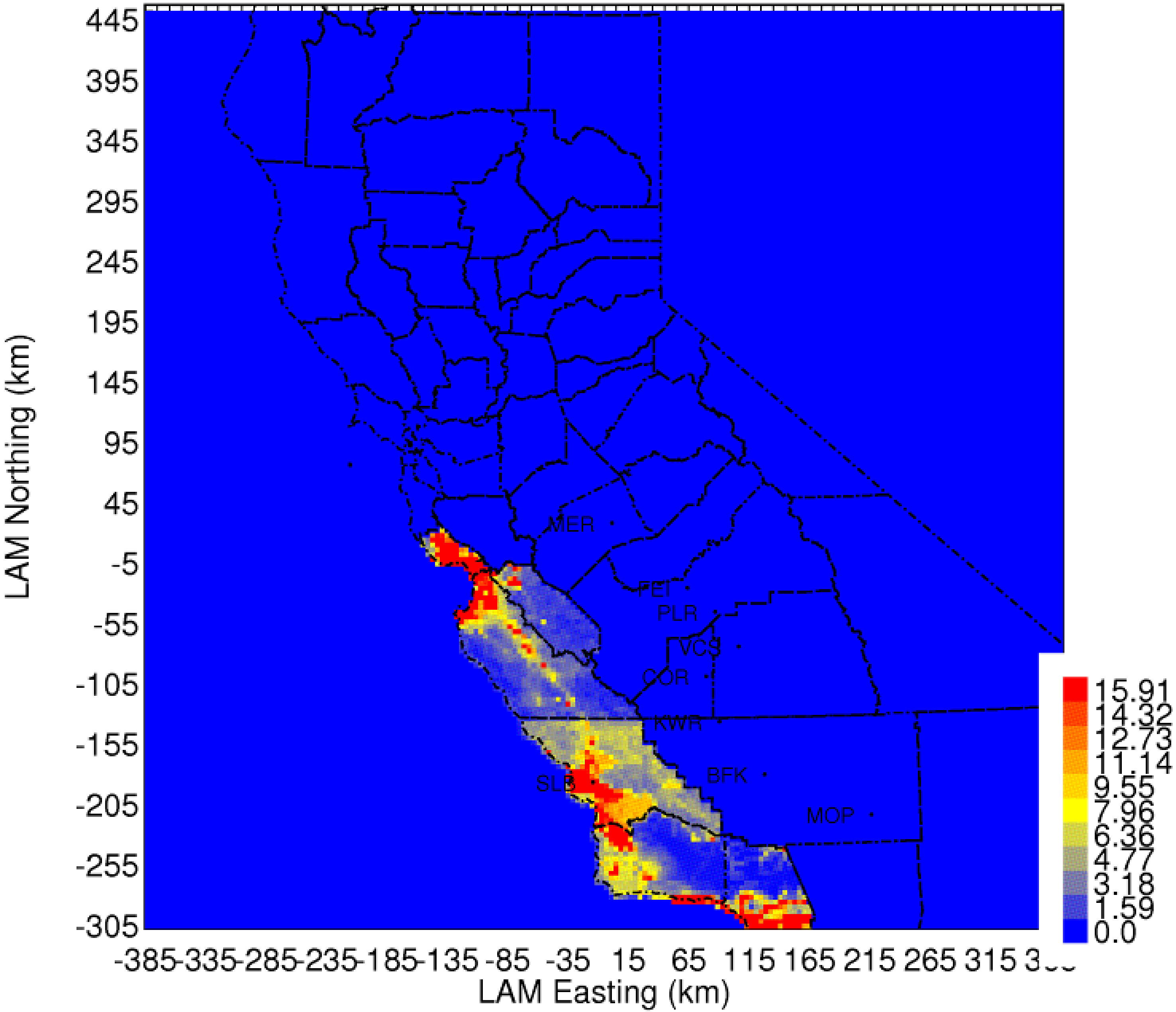
LAM Northing (km)
LAM Easting (km)
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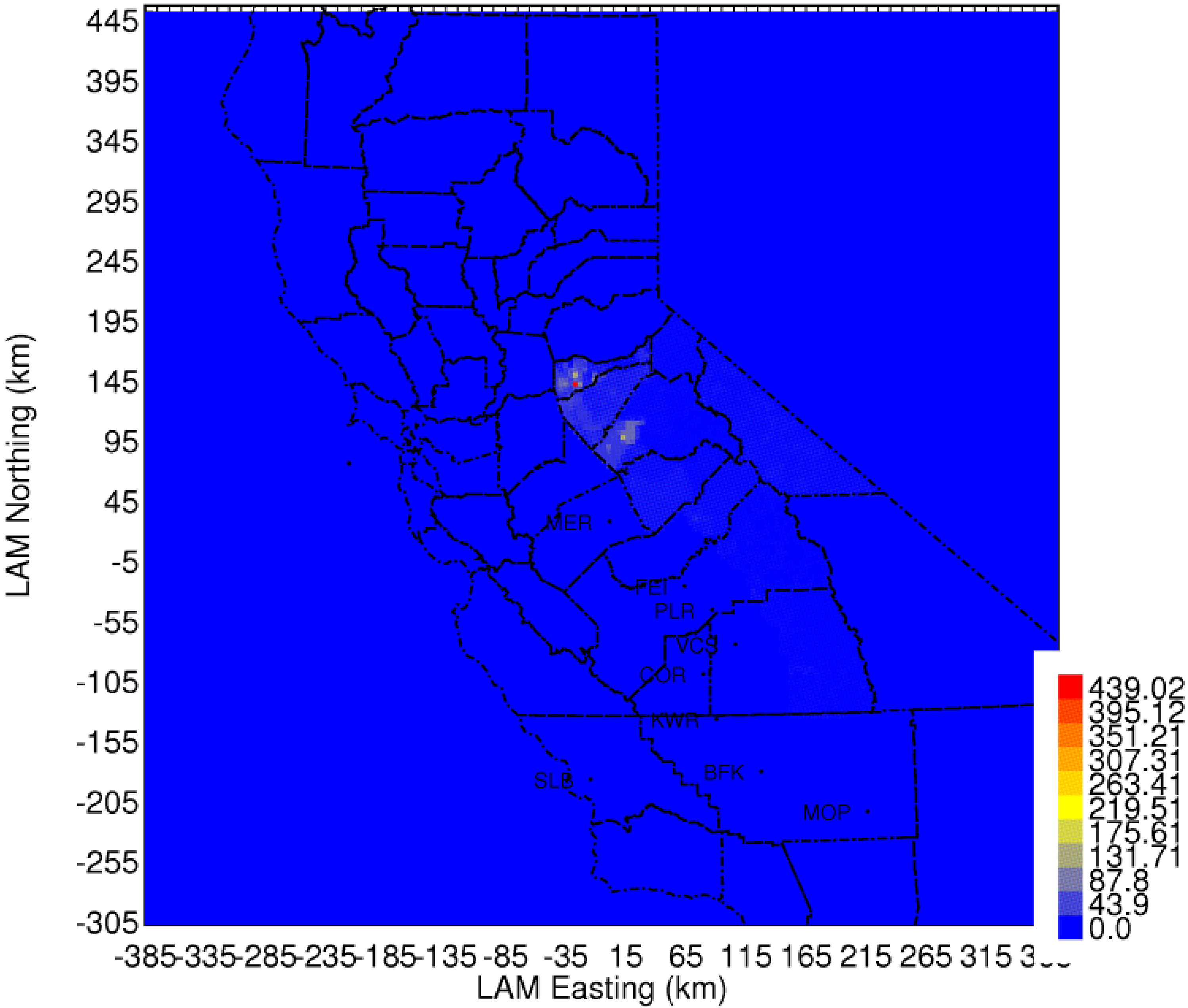
-285
-235
-185
-135
-85
-35
15
65
115
165
215
265
315
MER
FEI
PLR
VCS
COR
KWR
BFK
SLB
MOP
15.91
14.32
12.73
11.14
9.55
7.96
6.36
4.77
3.18
1.59
0.0


LAM Northing (km)
445
395
345
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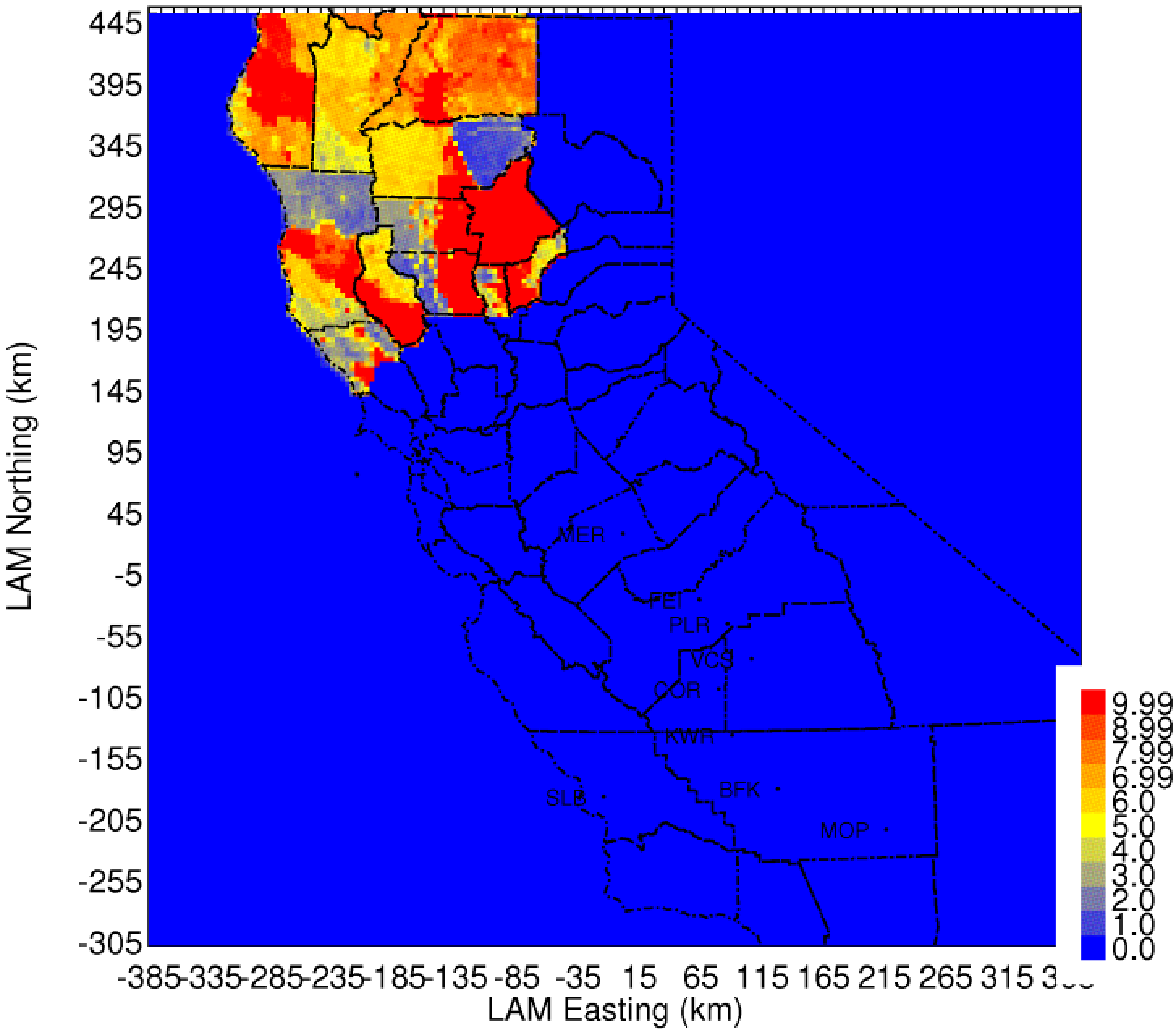
-205
-255
-305
-385
-335
-285
-235
-185
-135
-85
-35
15
65
115
165
215
265
315
LAM Easting (km)
MER
FEI
PLR
VCS
COR
KWR
SLB
BFK
MOP
439.02
395.12
351.21
307.31
263.41
219.51
175.61
131.71
87.8
43.9
0.0


LAM Northing (km)
445
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295
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-5
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-105
-155
-205
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-305
-385
-335
-285
-235
-185
-135
-85
-35
15
65
115
165
215
265
315
LAM Easting (km)
MER
FEI
PLR
VCS
COR
KWR
BFK
SLB
MOP
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8.99
7.99
6.99
6.0
5.0
4.0
3.0
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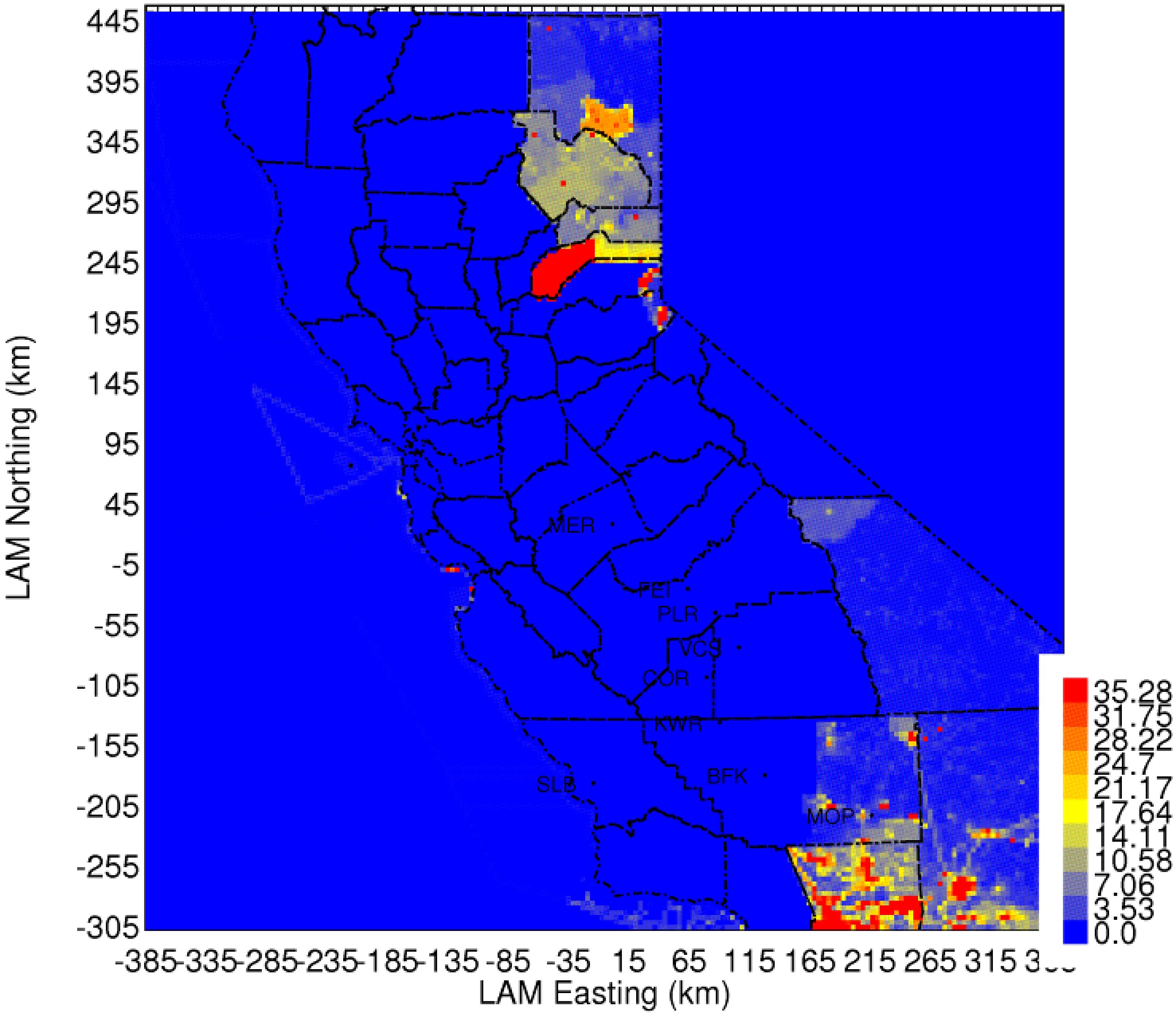
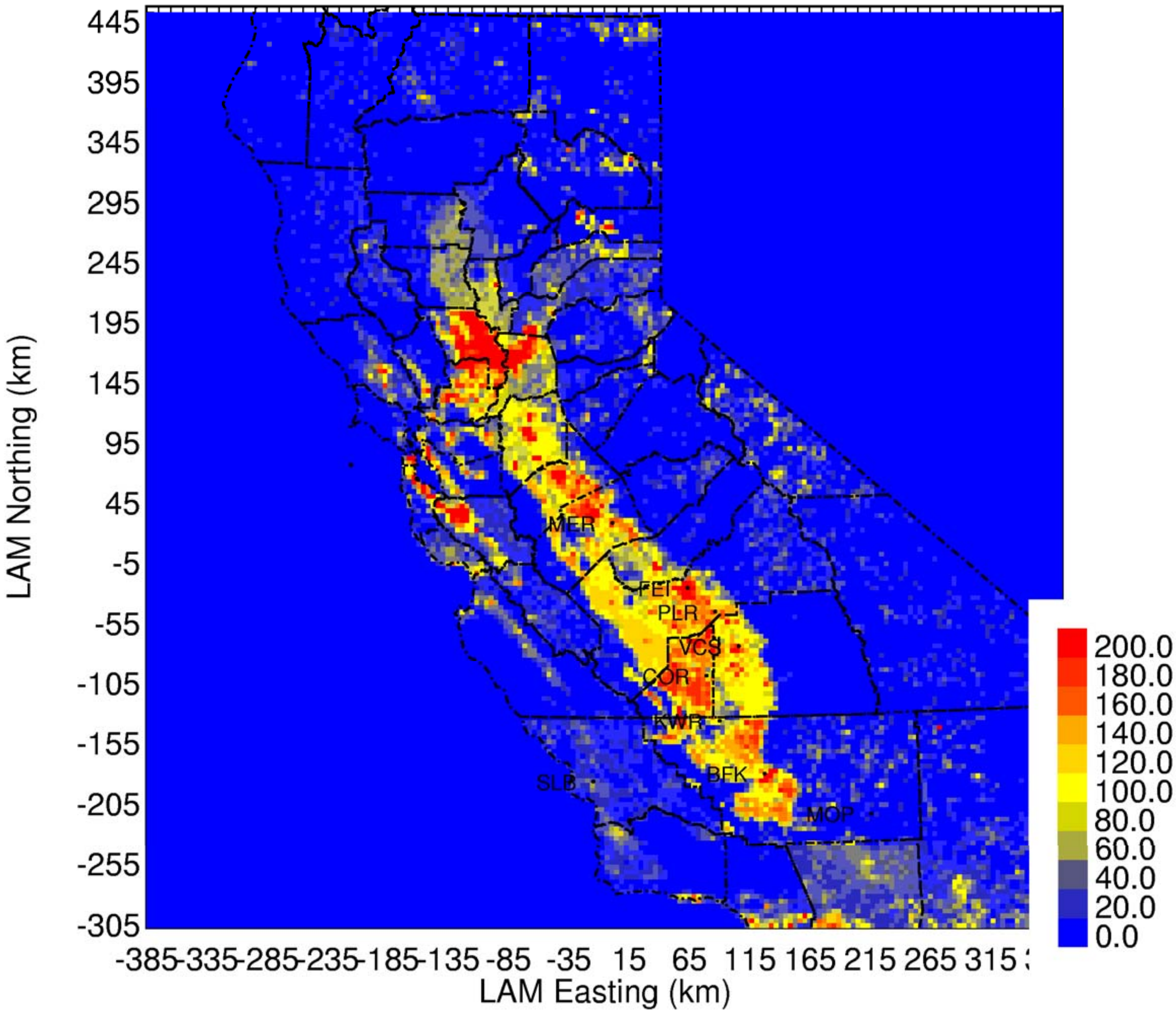
1.0
0.0

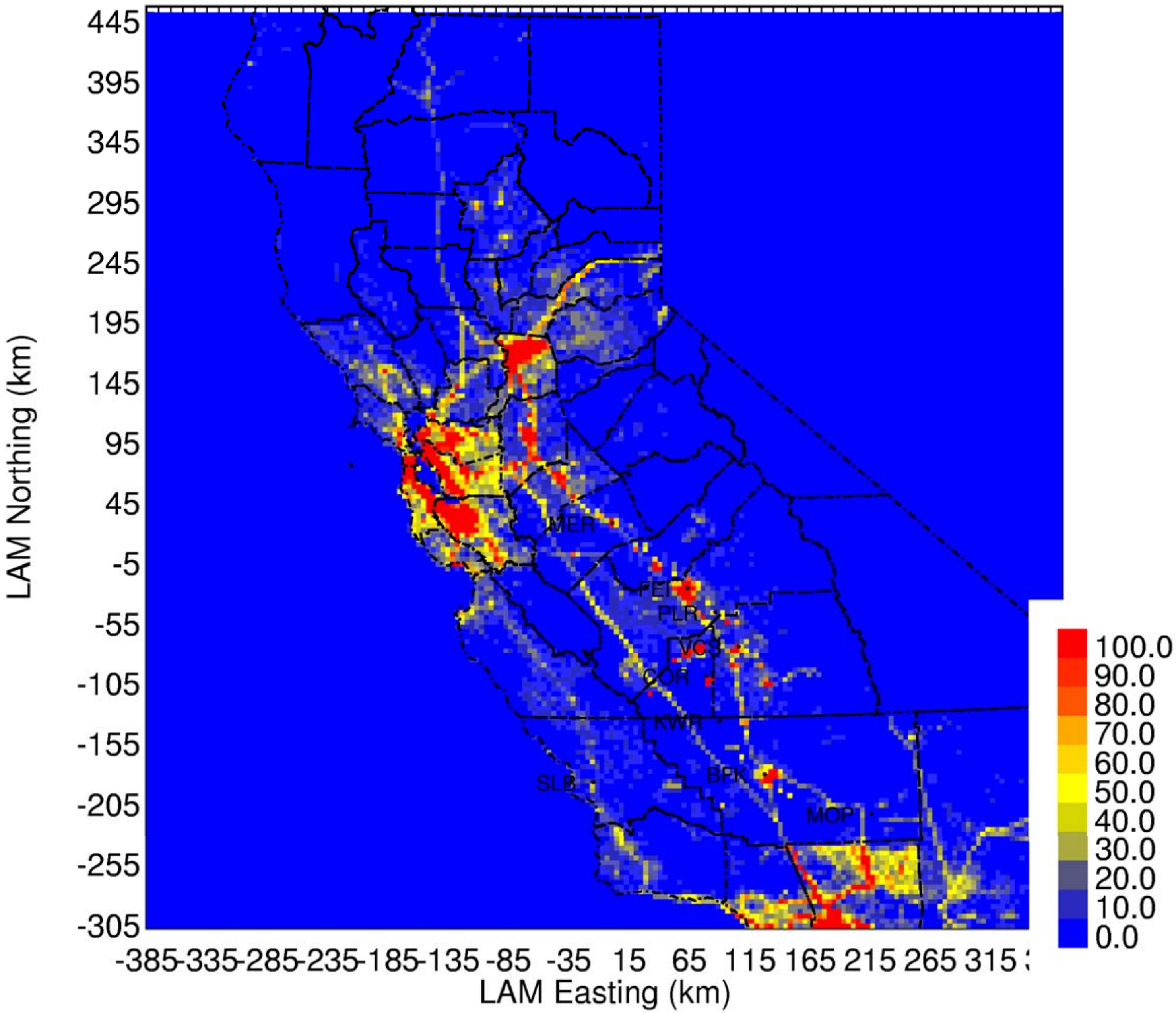


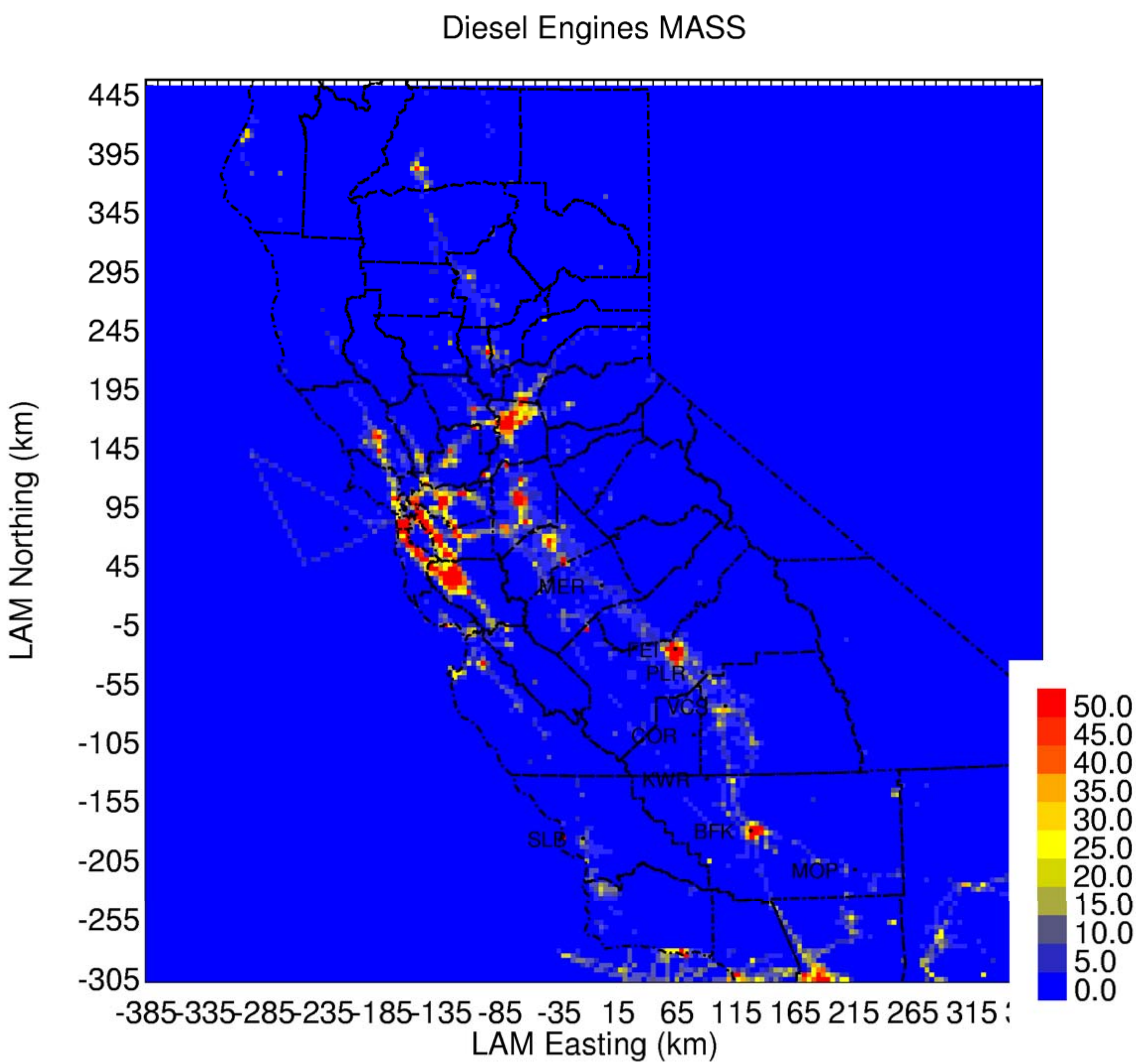
LAM Northing (km)
445
395
345
295
245
195
145
95
45
-5
-55
-105
-155
-205
-255
-305
MER
FEI
PLR
VCS
COR
KWR
BFK
SLB
MOP
35.28
31.75
28.22
24.7
21.17
17.64
14.11
10.58
7.06
3.53
0.0
-385
-335
-285
-235
-185
-135
-85
-35
15
65
115
165
215
265
315
LAM Easting (km)

Unpaved Road Dust MASS

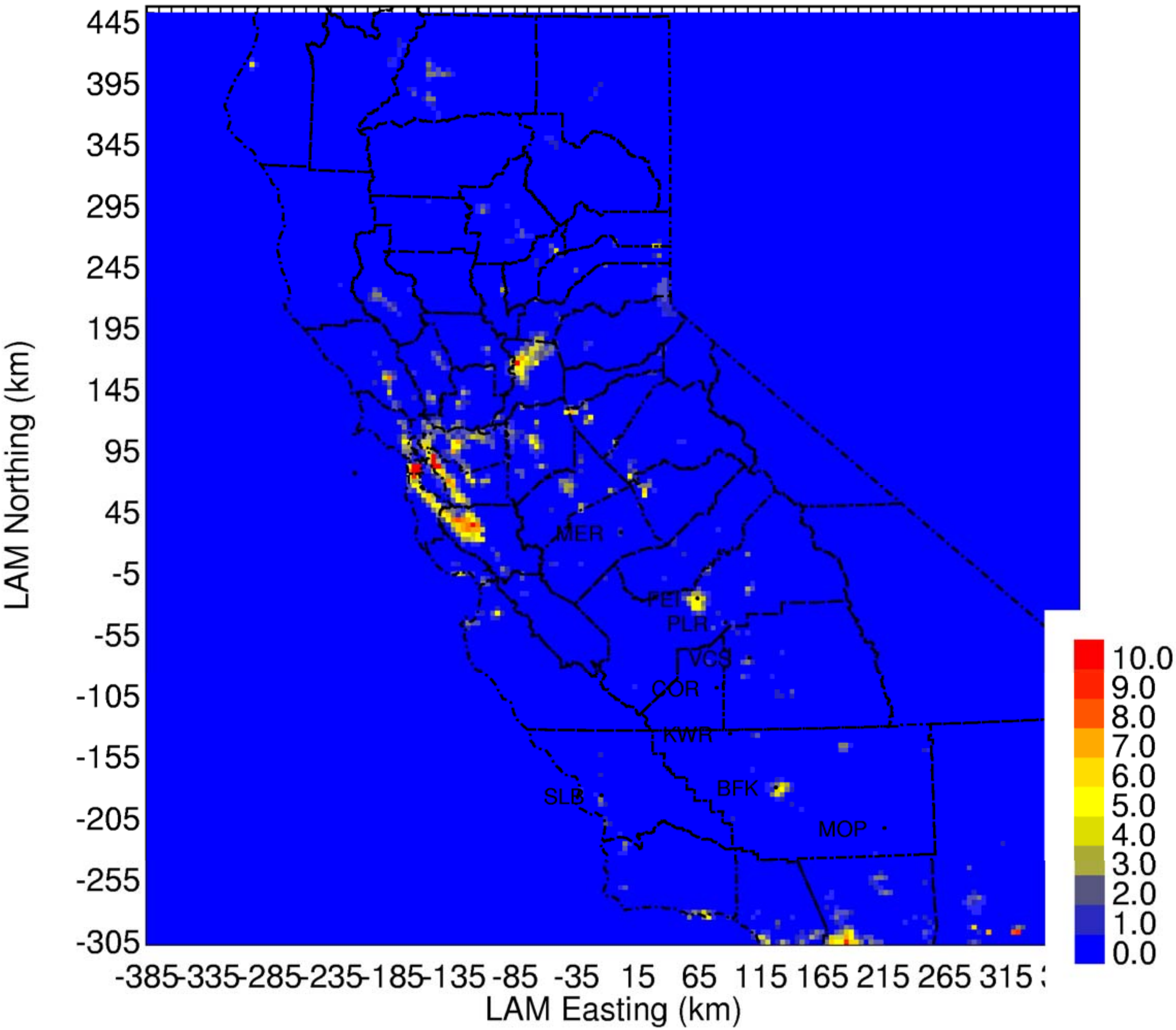


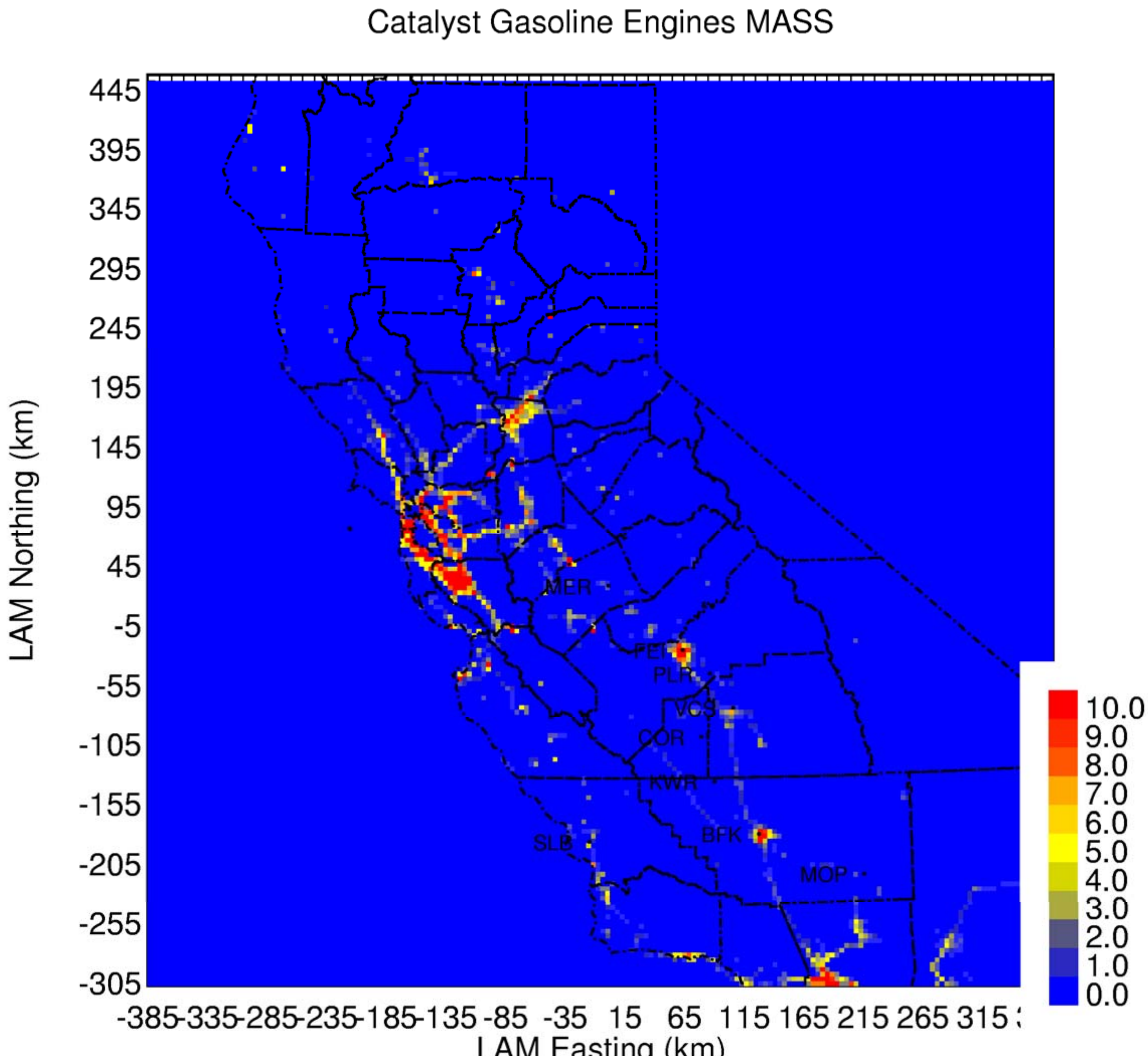
Paved Road Dust MASS

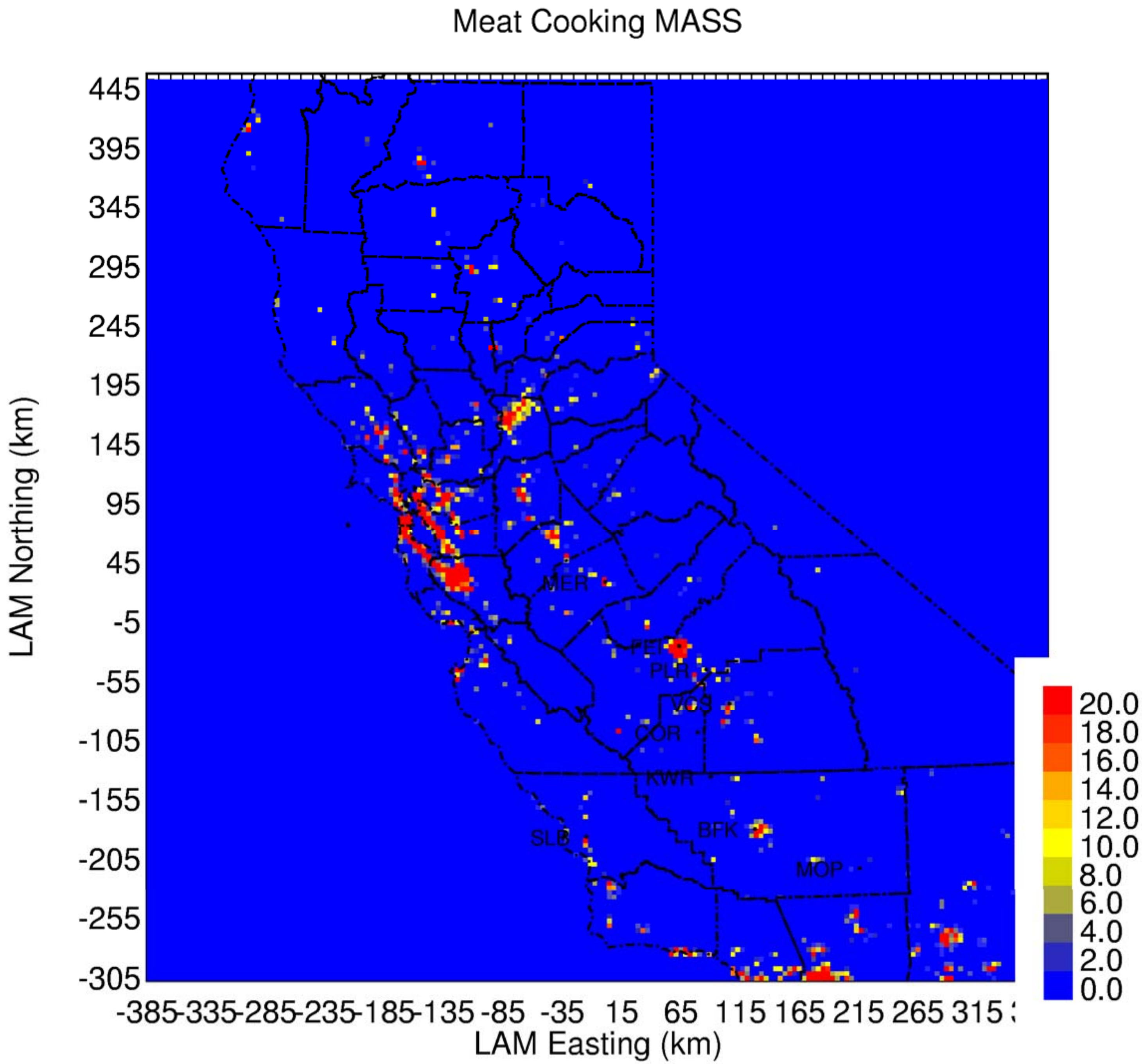



Diesel Engines MASS
LAM Northing (km)
LAM Easting (km)
445
395
345
295
245
195
145
95
45
-5
-55
-105
-155
-205
-255
-305
-385
-335
-285
-235
-185
-135
-85
-35
15
65
115
165
215
265
315
MER
FEI
PLR
VCS
COR
KWR
SLB
BFK
MOP
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0

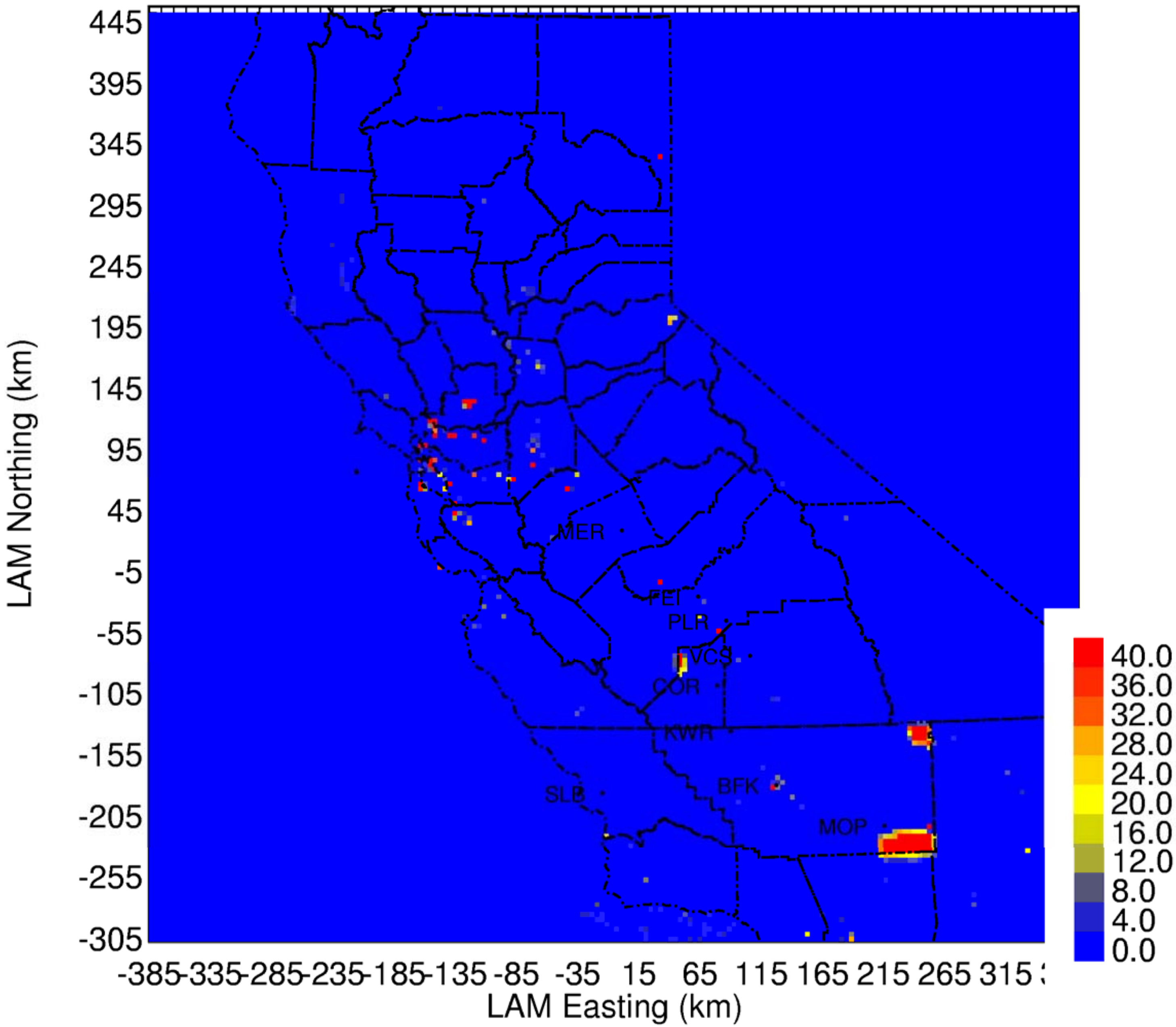
Non Catalyst Gasoline Engines MASS

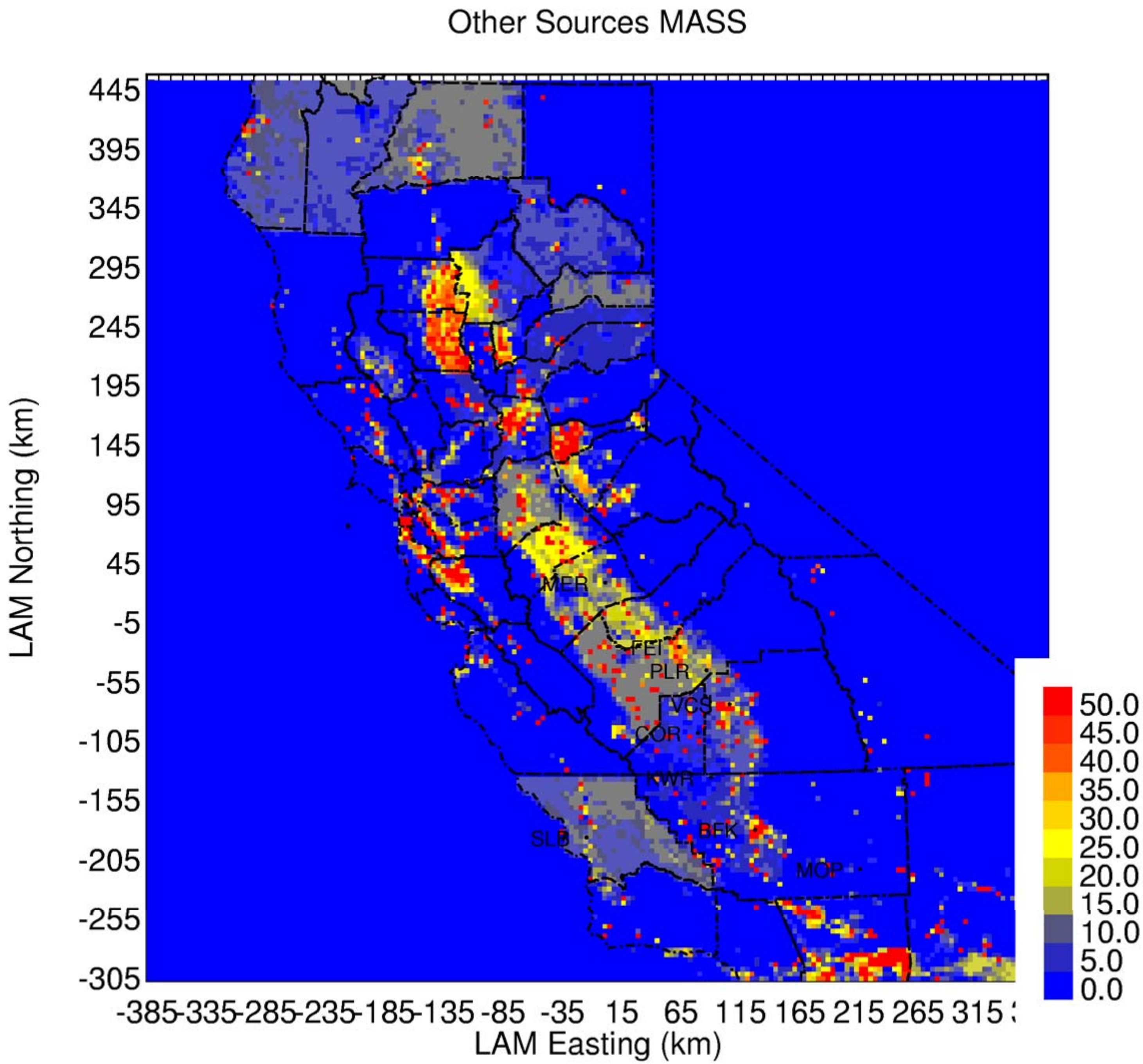



Catalyst Gasoline Engines MASS
LAM Northing (km)
445
395
345
295
245
195
145
95
45
-5
-55
-105
-155
-205
-255
-305
-385-335-285-235-185-135 -85 -35 15 65 115 165 215 265 315
LAM Easting (km)
MER
FET
PLR
VCS
COR
KWR
BFK
SLB
MOP
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0


Meat Cooking MASS
LAM Northing (km)
445
395
345
295
245
195
145
95
45
-5
-55
-105
-155
-205
-255
-305
-385-335-285-235-185-135 -85 -35 15 65 115 165 215 265 315
LAM Easting (km)
MER
FEI
PLR
VCS
COR
KWR
BFK
SLB
MOP
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0

High Sulfur Fuel Mass MASS





Other Sources MASS
LAM Northing (km)
LAM Easting (km)
445
395
345
295
245
195
145
95
45
-5
-55
-105
-155
-205
-255
-305
-385
-335
-285
-235
-185
-135
-85
-35
15
65
115
165
215
265
315
MER
FEI
PLR
VCS
COR
KWR
SLB
BFK
MOP
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0

Conclusions

- Source contributions to primary PM
  - Wood smoke at urban locations
- Source contributions to secondary nitrate
  - Diesel engines contribute most of the NOx
  - Gasoline engines also significant
  - Ammonium ion from agriculture dominates

Conclusions

- Primary and secondary PM concentrations are dominated by local sources
- Transport distance for Nitrate > Ammonium Ion > Organic Carbon
- Transport between regions seems relatively low during CRPAQS stagnant conditions
  - Material mixed to upper layers is quickly transported out of the domain.