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Atmospheric Chemistry and Physics Discussions

Supplement of

Spatial and temporal variability of sources of ambient fine particular matter ($PM_{2.5}$) in California

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Supplementary Information

Table S1. Select meteorological parameters at each sampling site during spring, summer, fall, and winter. Seasonal averages were calculated over 6 years (from 2002 to 2007).

Sampling Site	Season	Temperature (°C)	Relative Humidity (%)	Precipitation (cm)	Wind (vector-average)	
		Average ± Stdev	Average ± Stdev	Average of yearly total ± Stdev	Speed(mph) (% calm)	Prevailing direction
El Cajon	Spring	15.8 ± 2.8	73.3 ± 13.5	N/A[a]	2.1 (33.9)	SW
	Summer	21.6 ± 2.7	76.8 ± 9.8	N/A	2.4 (32.4)	SW
	Fall	18.1 ± 3.7	71.0 ± 16.1	N/A	1.4 (49.0)	SW
	Winter	12.1 ± 2.2	69.6 ± 17.3	N/A	0.7 (57.8)	SW
Rubidoux	Spring	17.1 ± 3.7	67.9 ± 17.5	5.0 ± 3.9	2.5 (20.0)	W
	Summer	24.7 ± 3.3	65.4 ± 12.4	0.1 ± 0.2	3.4 (16.1)	W
	Fall	19.7 ± 4.7	59.9 ± 21.0	2.4 ± 2.4	1.5 (24.1)	NW
	Winter	13.4 ± 3.1	57.5 ± 24.0	11.1 ± 10.8	1.3 (23.1)	N
Los Angeles	Spring	17.0 ± 3.1	59.2 ± 17.0	7.5 ± 6.6	2.4 (2.8)	SW
	Summer	22.3 ± 2.4	53.3 ± 25.0	0.0 ± 0.0	4.0 (2.1)	SW
	Fall	19.2 ± 3.7	50.8 ± 26.6	5.6 ± 3.3	0.6 (3.3)	W
	Winter	14.1 ± 2.7	54.1 ± 19.6	21.7 ± 17.1	1.2 (2.9)	NE
Simi Valley	Spring	14.8 ± 3.7	60.4 ± 18.6	5.5 ± 6.9	1.9 (18.1)	W
	Summer	20.5 ± 3.1	58.5 ± 14.9	0.0 ± 0.0	3.0 (17.6)	W
	Fall	18.0 ± 4.4	53.0 ± 22.6	2.3 ± 2.2	0.8 (25.3)	NW
	Winter	13.3 ± 3.8	50.3 ± 24.7	14.1 ± 13.0	1.7 (19.3)	NE
Bakersfield	Spring	18.2 ± 4.8	53.9 ± 13.4	3.8 ± 3.4	2.3 (1.8)	NW
	Summer	28.3 ± 3.2	39.5 ± 7.3	0.0 ± 0.0	2.8 (1.4)	NW
	Fall	18.7 ± 5.9	58.2 ± 15.3	2.0 ± 1.5	1.1 (3.6)	NW
	Winter	10.2 ± 3.1	73.4 ± 13.0	7.1 ± 3.6	0.4 (3.3)	NW
Fresno	Spring	17.3 ± 4.8	58.0 ± 13.0	9.1 ± 7.0	3.0 (1.4)	NW
	Summer	27.1 ± 3.3	42.1 ± 7.0	0.3 ± 0.5	4.4 (0.9)	NW
	Fall	18.3 ± 5.7	59.6 ± 14.8	2.7 ± 3.1	1.8 (3.6)	NW
	Winter	9.7 ± 2.9	77.9 ± 10.1	10.7 ± 3.8	0.2 (2.9)	E
San Jose	Spring	14.4 ± 2.9	66.3 ± 9.1	8.3 ± 5.3	N/A	N/A
	Summer	19.5 ± 2.5	65.7 ± 7.7	0.1 ± 0.2	N/A	N/A
	Fall	16.1 ± 3.5	63.9 ± 12.9	3.7 ± 1.7	N/A	N/A
	Winter	10.5 ± 2.4	75.2 ± 10.2	16.3 ± 3.9	N/A	N/A
Sacramento	Spring	15.4 ± 4	67.7 ± 12.7	11.7 ± 7.4	1.9 (9.2)	S
	Summer	23.4 ± 3.3	55.6 ± 10.2	0.5 ± 0.8	3.5 (5.3)	S
	Fall	16.3 ± 4.9	67.6 ± 15.7	5.9 ± 4.4	0.9 (22.7)	SW
	Winter	9.0 ± 2.7	78.6 ± 22.7	23.4 ± 7.1	0.6 (18.7)	S

[a] *N/A, data was not available.*

Table S2. Estimated OC artifact values (µg/m^3) from Thermal Optical Transmittance (TOT) NIOSH 5040 carbon method, at each sampling site. Errors correspond to one standard error.

Monitoring site	OC artifact value (µg/m^3)
El Cajon	1.84 ± 0.23
Rubidoux	3.33 ± 0.13
Los Angeles	3.61 ± 0.22
Simi Valley	2.30 ± 0.15
Bakersfield	3.24 ± 0.14
Fresno	2.02 ± 0.15
San Jose	1.09 ± 0.12
Sacramento	0.83 ± 0.13

Table S3 a-d. Seasonal average (± standard error) gravimetric $PM_{2.5}$ mass concentrations and estimated source contributions ($\mu g/m^3$), by site in a) spring, b) summer, c) fall, and d) winter. Seasonal averages were calculated over 6 years (from 2002 to 2007). ****uncertainty quantified by propagation of the uncertainties of the estimated source contributions and gravimetric $PM_{2.5}$ mass concentration.*

a) Spring

	Gravimetric PM2.5	Vehicular emissions	Secondary nitrate	Secondary sulfate	Fresh sea salt	Aged sea salt	Soil	Biomass burning	Copper smelters	Mixed industrial	Chlorine sources	Sulfate-bearing road dust	Ni-related industrial sources	Unapportioned mass*
El Cajon	12.0 ± 0.5	1.3 ± 0.1	3.0 ± 0.3	2.3 ± 0.2	0.7 ± 0.1	2.5 ± 0.1	1.0 ± 0.1	0.7 ± 0.1	0.4 ± 0.0	N/A	N/A	N/A	N/A	0.3 ± 0.7
Rubidoux	23.6 ± 1.3	3.2 ± 0.2	12.9 ± 1.0	3.1 ± 0.2	0.7 ± 0.1	1.7 ± 0.1	0.8 ± 0.1	0.4 ± 0.0	N/A	0.1 ± 0	N/A	N/A	N/A	0.6 ± 1.7
Los Angeles	18.1 ± 1.5	2.5 ± 0.2	5.2 ± 0.8	4.5 ± 0.5	0.3 ± 0.1	2.7 ± 0.2	1.0 ± 0.1	0.6 ± 0.1	N/A	N/A	N/A	N/A	N/A	1.3 ± 1.8
Simi Valley	12.8 ± 0.8	1.5 ± 0.1	3.1 ± 0.4	2.8 ± 0.3	0.4 ± 0.1	2.6 ± 0.2	1.2 ± 0.1	0.5 ± 0.1	N/A	N/A	N/A	N/A	N/A	0.6 ± 1.0
Bakersfield	11.8 ± 0.5	1.4 ± 0.1	4.0 ± 0.4	2.3 ± 0.1	1.6 ± 0.1	N/A	1.6 ± 0.1	0.9 ± 0.1	0.1 ± 0.0	N/A	0.1 ± 0.0	N/A	N/A	0.0 ± 0.7
Fresno	11.1 ± 0.5	1.4 ± 0.1	4.9 ± 0.4	N/A	N/A	N/A	N/A	2.4 ± 0.2	N/A	N/A	0.2 ± 0.0	2.0 ± 0.1	N/A	0.2 ± 0.7
San Jose	9.7 ± 0.4	0.9 ± 0.1	0.8 ± 0.1	1.1 ± 0.1	0.9 ± 0.1	2.3 ± 0.1	0.4 ± 0.0	2.6 ± 0.1	N/A	N/A	N/A	N/A	0.2 ± 0.0	0.5 ± 0.5
Sacramento	8.2 ± 0.3	2.5 ± 0.1	1.1 ± 0.1	1.4 ± 0.1	N/A	0.9 ± 0.1	0.5 ± 0.0	1.3 ± 0.1	N/A	N/A	0.2 ± 0.0	N/A	N/A	0.3 ± 0.4

b) Summer

	Gravimetric PM2.5	Vehicular emissions	Secondary nitrate	Secondary sulfate	Fresh sea salt	Aged sea salt	Soil	Biomass burning	Copper smelters	Mixed industrial	Chlorine sources	Sulfate-bearing road dust	Ni-related industrial sources	Unapportioned mass*
El Cajon	13.6 ± 0.3	1.6 ± 0.1	2.2 ± 0.2	4.6 ± 0.2	0.2 ± 0.0	3.1 ± 0.2	0.5 ± 0.0	1.1 ± 0.1	0.4 ± 0.0	N/A	N/A	N/A	N/A	0.0 ± 0.5
Rubidoux	25.6 ± 0.9	3.5 ± 0.2	12.5 ± 0.8	5.6 ± 0.2	0.3 ± 0.0	2.2 ± 0.1	0.7 ± 0.1	0.8 ± 0.1	N/A	0.1 ± 0.0	N/A	N/A	N/A	0.0 ± 1.2
Los Angeles	20.2 ± 0.7	2.2 ± 0.2	3.9 ± 0.4	7.8 ± 0.5	0.1 ± 0.0	4.1 ± 0.3	0.8 ± 0.1	0.9 ± 0.1	N/A	N/A	N/A	N/A	N/A	0.4 ± 1.0
Simi Valley	15.7 ± 0.5	1.9 ± 0.1	2.6 ± 0.3	5.3 ± 0.3	0.1 ± 0.0	3.5 ± 0.2	1.1 ± 0.1	1.2 ± 0.1	N/A	N/A	N/A	N/A	N/A	0.0 ± 0.7
Bakersfield	13.5 ± 0.4	1.7 ± 0.1	0.7 ± 0.1	3.8 ± 0.1	1.7 ± 0.1	N/A	2.6 ± 0.2	1.8 ± 0.1	0.4 ± 0.0	N/A	0.1 ± 0.0	N/A	N/A	0.8 ± 0.5
Fresno	10.5 ± 0.3	1.7 ± 0.1	2.2 ± 0.2	N/A	N/A	N/A	N/A	2.5 ± 0.2	N/A	N/A	0.3 ± 0.1	2.7 ± 0.1	N/A	1.1 ± 0.5
San Jose	9.6 ± 0.4	0.7 ± 0.1	1.0 ± 0.1	1.8 ± 0.1	0.6 ± 0.1	2.6 ± 0.2	0.3 ± 0.0	2.2 ± 0.1	N/A	N/A	N/A	N/A	0.3 ± 0.0	0.1 ± 0.5
Sacramento	9.2 ± 0.4	2.5 ± 0.1	0.2 ± 0.0	2.1 ± 0.1	N/A	1.4 ± 0.1	0.6 ± 0.0	1.3 ± 0.1	N/A	N/A	0.3 ± 0.1	N/A	N/A	0.8 ± 0.5

c) Fall

	Gravimetric PM2.5	Vehicular emissions	Secondary nitrate	Secondary sulfate	Fresh sea salt	Aged sea salt	Soil	Biomass burning	Copper smelters	Mixed industrial	Chlorine sources	Sulfate-bearing road dust	Ni-related industrial sources	Unapportioned mass*
El Cajon	14.8 ± 0.5	2.8 ± 0.2	3.8 ± 0.4	3.0 ± 0.2	0.2 ± 0.0	1.8 ± 0.1	1.0 ± 0.1	1.3 ± 0.1	0.5 ± 0.0	N/A	N/A	N/A	N/A	0.4 ± 0.8
Rubidoux	27.4 ± 1.5	5.4 ± 0.3	13.6 ± 1.2	3.4 ± 0.2	0.6 ± 0.1	1.1 ± 0.1	1.1 ± 0.1	0.7 ± 0.1	N/A	0.2 ± 0.0	N/A	N/A	N/A	1.2 ± 2.0
Los Angeles	20.8 ± 1.2	4.1 ± 0.3	7.3 ± 0.9	4.6 ± 0.5	0.1 ± 0.0	2.5 ± 0.2	1.0 ± 0.1	0.9 ± 0.1	N/A	N/A	N/A	N/A	N/A	0.3 ± 1.7
Simi Valley	14.2 ± 0.9	3.3 ± 0.2	3.3 ± 0.6	3.2 ± 0.3	0.1 ± 0.0	1.6 ± 0.1	1.2 ± 0.1	1.1 ± 0.1	N/A	N/A	N/A	N/A	N/A	0.5 ± 1.2
Bakersfield	24.6 ± 1.7	3.6 ± 0.2	10.8 ± 1.3	2.8 ± 0.2	1.3 ± 0.1	N/A	2.2 ± 0.2	3.0 ± 0.2	0.2 ± 0.0	N/A	0.4 ± 0.1	N/A	N/A	0.2 ± 2.2
Fresno	22.7 ± 1.2	2.7 ± 0.1	10.9 ± 0.9	N/A	N/A	N/A	N/A	6.1 ± 0.5	N/A	N/A	0.9 ± 0.1	2.7 ± 0.2	N/A	0.0 ± 1.6
San Jose	14.8 ± 0.8	1.8 ± 0.1	2.6 ± 0.3	1.4 ± 0.1	0.5 ± 0.1	1.9 ± 0.1	0.5 ± 0.1	5.4 ± 0.4	N/A	N/A	N/A	N/A	0.2 ± 0.0	0.5 ± 0.9
Sacramento	15.1 ± 0.9	4.5 ± 0.2	2.9 ± 0.4	1.5 ± 0.1	N/A	0.6 ± 0.1	0.9 ± 0.2	4.1 ± 0.4	N/A	N/A	0.2 ± 0.1	N/A	N/A	0.4 ± 1.1

d) Winter

	Gravimetric PM2.5	Vehicular emissions	Secondary nitrate	Secondary sulfate	Fresh sea salt	Aged sea salt	Soil	Biomass burning	Copper smelters	Mixed industrial	Chlorine sources	Sulfate-bearing road dust	Ni-related industrial sources	Unapportioned mass*
El Cajon	16.2 ± 0.7	4.1 ± 0.2	4.3 ± 0.4	0.8 ± 0.1	0.4 ± 0.1	0.9 ± 0.1	0.8 ± 0.1	3.5 ± 0.3	0.7 ± 0.1	N/A	N/A	N/A	N/A	0.8 ± 0.9
Rubidoux	20.0 ± 1.1	5.1 ± 0.3	8.9 ± 0.8	0.9 ± 0.1	0.7 ± 0.1	0.8 ± 0.1	0.7 ± 0.1	1.0 ± 0.1	N/A	0.3 ± 0.0	N/A	N/A	N/A	1.5 ± 1.4
Los Angeles	20.4 ± 1.6	5.8 ± 0.4	7.1 ± 1.1	1.5 ± 0.3	0.3 ± 0.1	1.2 ± 0.1	1.4 ± 0.2	1.7 ± 0.2	N/A	N/A	N/A	N/A	N/A	1.4 ± 2.0
Simi Valley	9.8 ± 0.8	2.9 ± 0.2	2.6 ± 0.4	1.1 ± 0.2	0.2 ± 0.1	1.0 ± 0.1	0.6 ± 0.1	1.2 ± 0.1	N/A	N/A	N/A	N/A	N/A	0.2 ± 0.9
Bakersfield	32.0 ± 1.8	3.0 ± 0.2	16.8 ± 1.3	2.3 ± 0.2	1.3 ± 0.1	N/A	0.6 ± 0.1	3.9 ± 0.3	0.3 ± 0.1	N/A	1.0 ± 0.2	N/A	N/A	2.7 ± 2.2
Fresno	34.4 ± 1.7	2.5 ± 0.1	15.8 ± 1	N/A	N/A	N/A	N/A	10.4 ± 0.6	N/A	N/A	2.5 ± 0.3	0.5 ± 0.0	N/A	2.8 ± 2.1
San Jose	18.6 ± 1.2	2.4 ± 0.2	3.8 ± 0.4	0.9 ± 0.1	0.5 ± 0.1	1.1 ± 0.1	0.3 ± 0.0	8.0 ± 0.6	N/A	N/A	N/A	N/A	0.1 ± 0.0	1.5 ± 1.4
Sacramento	23.5 ± 1.2	4.5 ± 0.3	8.0 ± 0.6	0.7 ± 0.1	N/A	0.4 ± 0.0	0.2 ± 0.0	7.4 ± 0.5	N/A	N/A	0.2 ± 0.0	N/A	N/A	2.1 ± 1.4

[a] *N/A, the source was not identified at the site.*

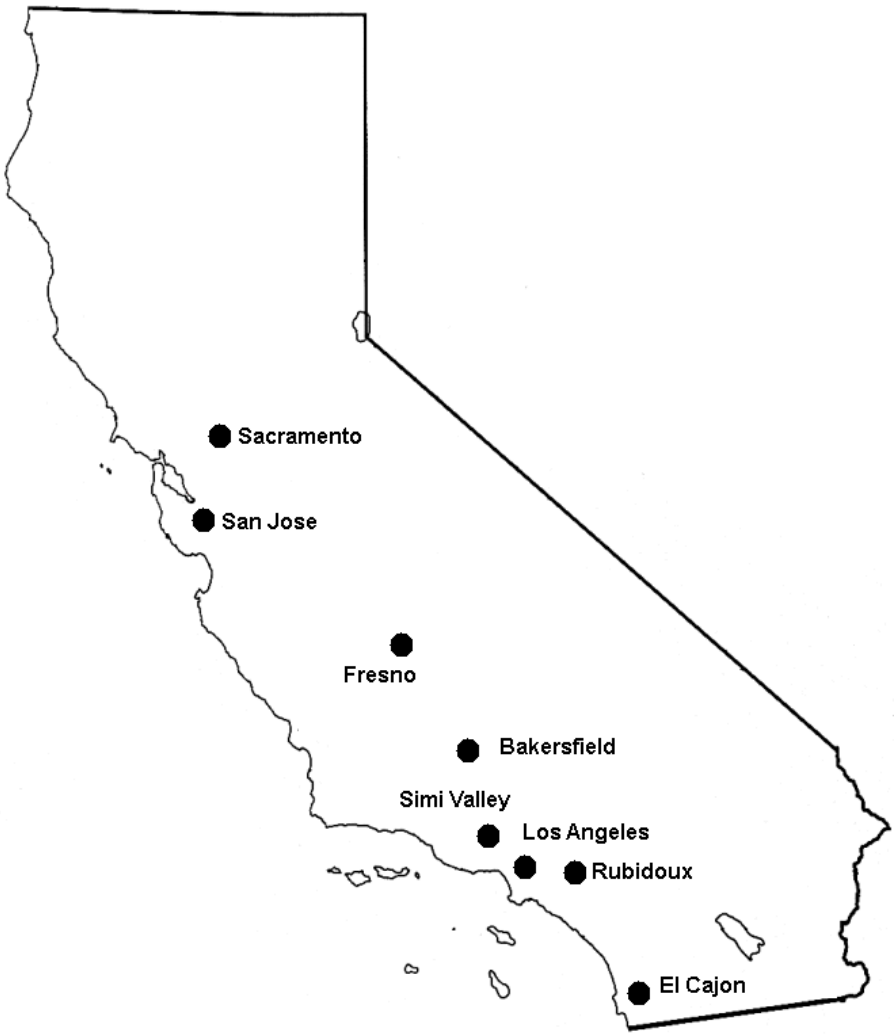
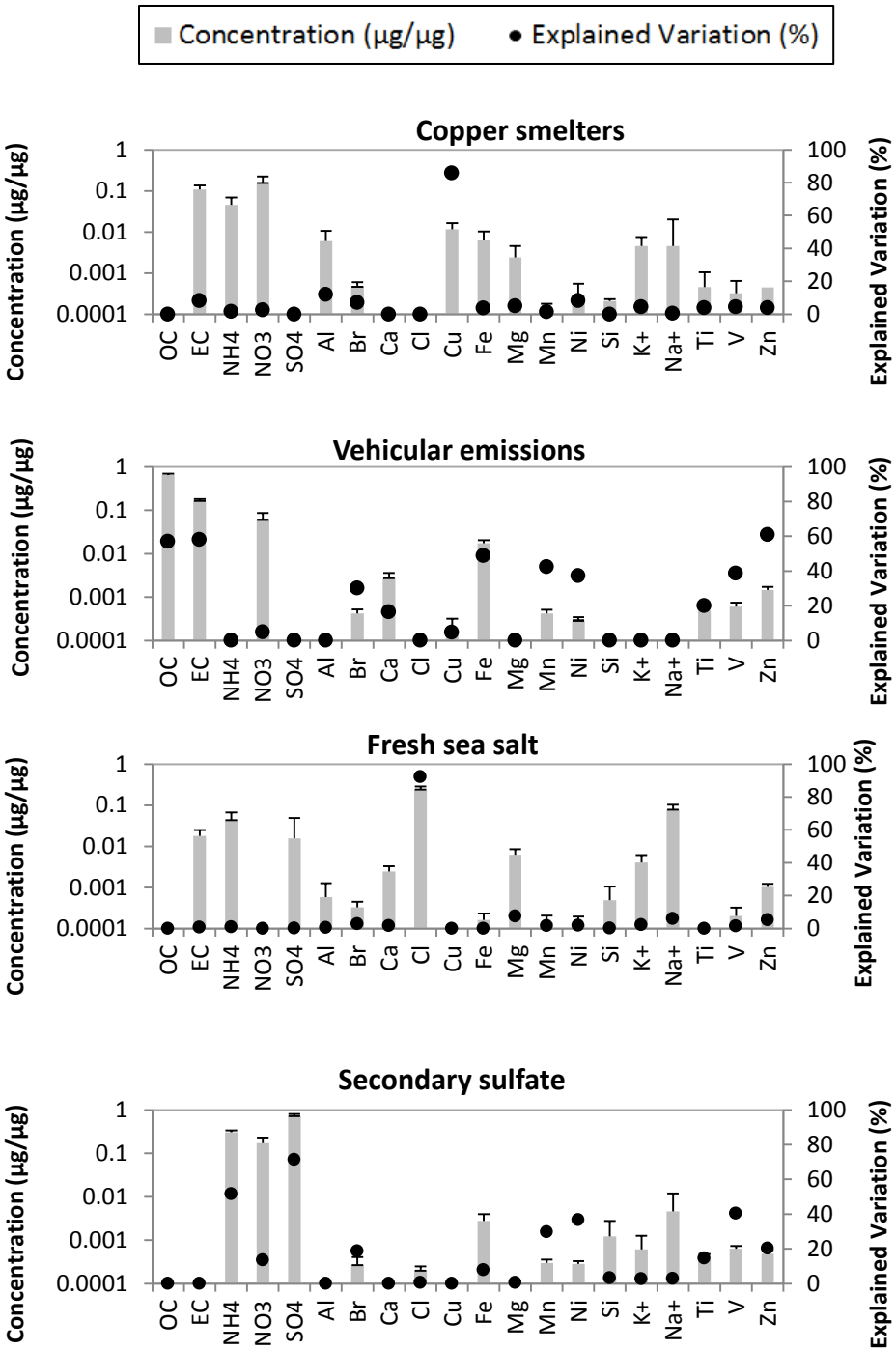
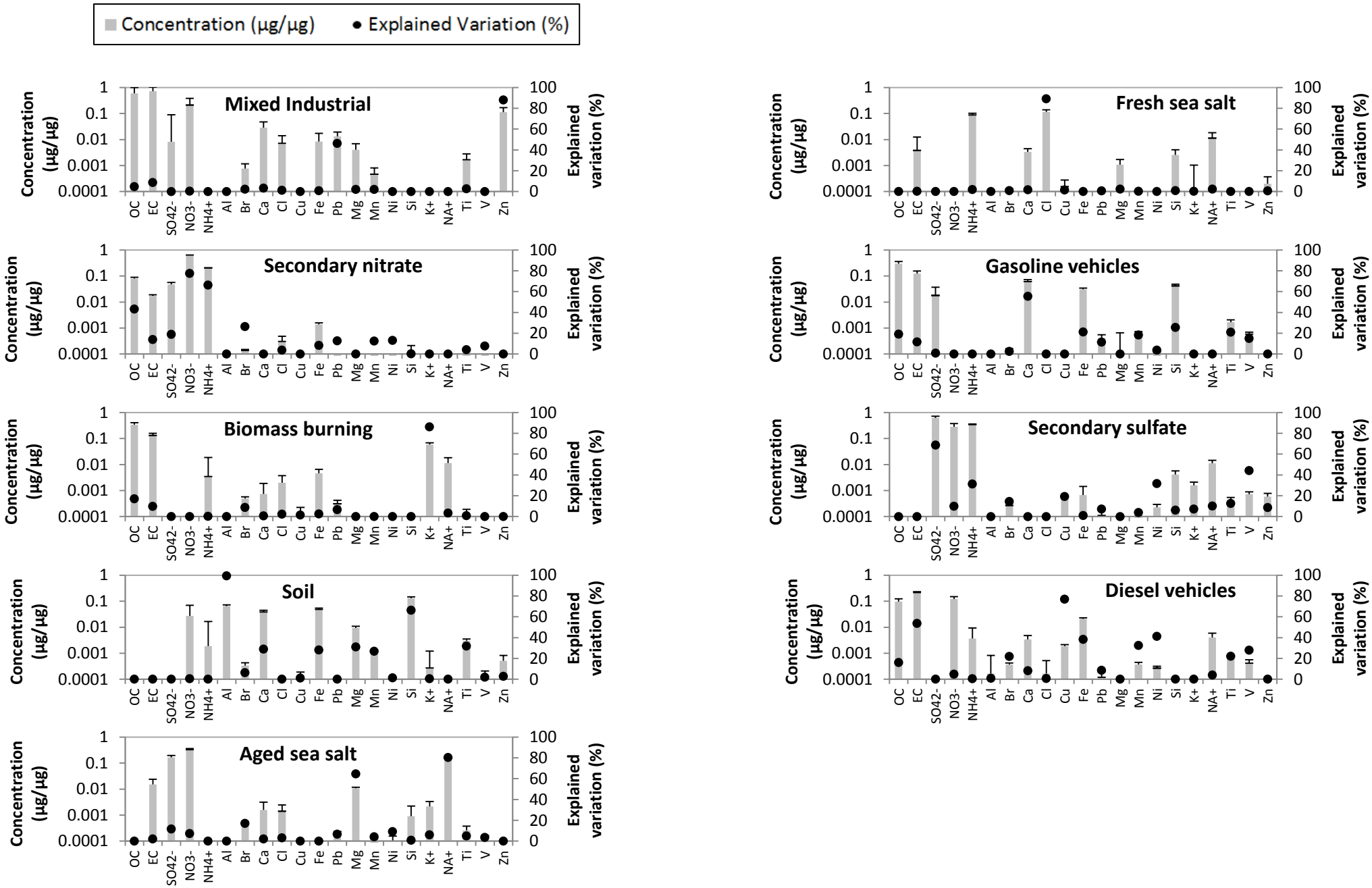
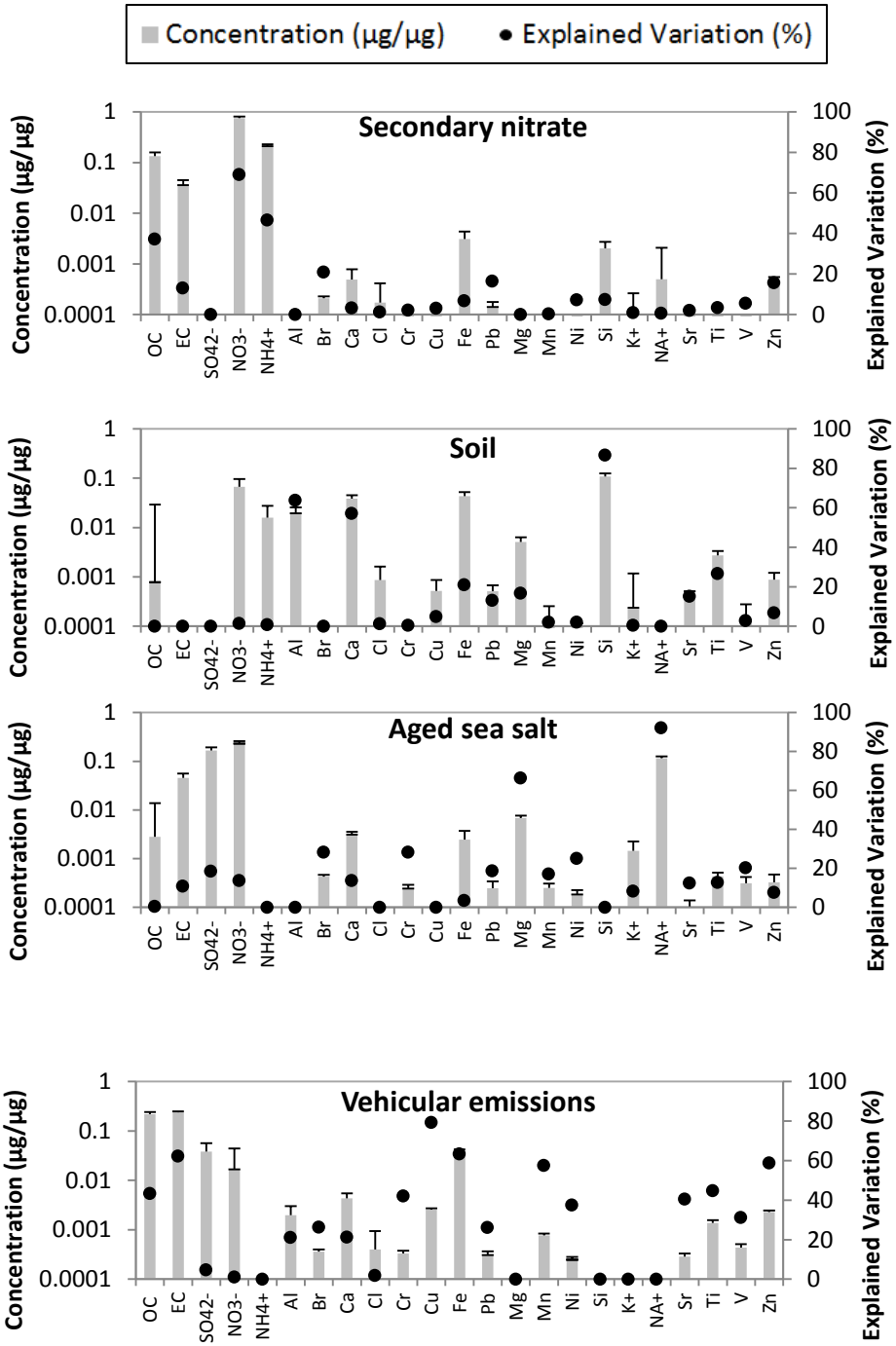


Figure S1. Location of the sampling sites.

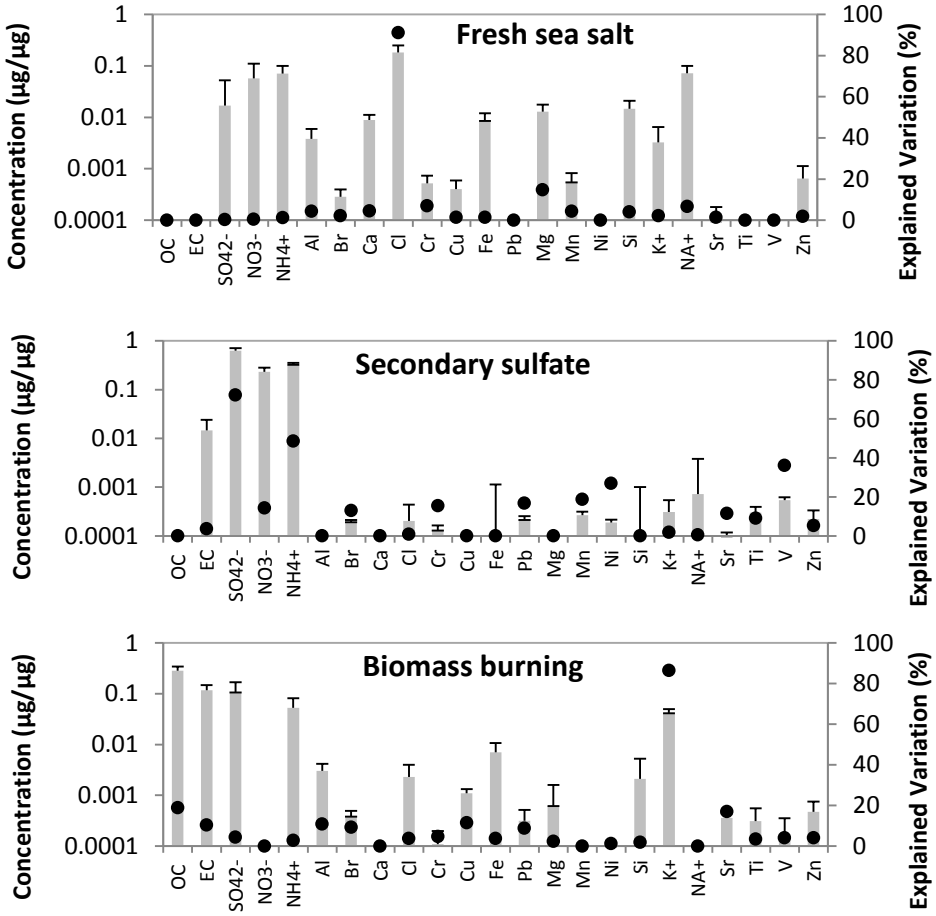

Concentration (µg/µg)
Explained Variation (%)
a) El Cajon
Copper smelters
Vehicular emissions
Fresh sea salt
Secondary sulfate
Aged sea salt
Secondary nitrate
Soil
Biomass burning
Concentration (µg/µg)
Explained Variation (%)
1
0.1
0.01
0.001
0.0001
100
80
60
40
20
0
OC EC NH4 NO3 SO4 Al Br Ca Cl Cu Fe Mg Mn Ni Si K+ Na+ Ti V Zn

b) Rubidoux

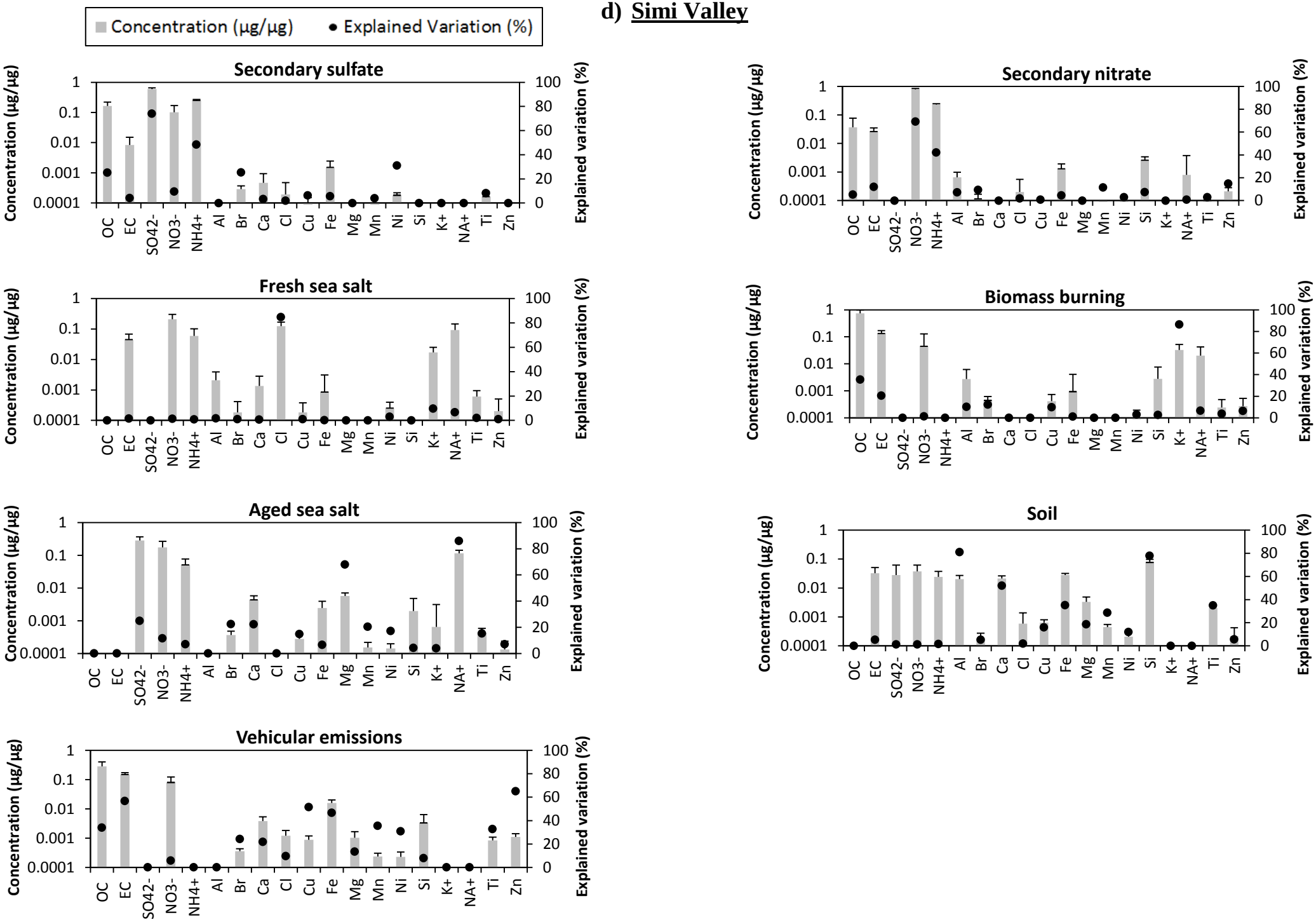

Concentration (µg/µg)
Explained Variation (%)
Mixed Industrial
Secondary nitrate
Biomass burning
Soil
Aged sea salt
Fresh sea salt
Gasoline vehicles
Secondary sulfate
Diesel vehicles
Concentration (µg/µg)
Explained variation (%)
1
0.1
0.01
0.001
0.0001
100
80
60
40
20
0
OC EC SO42- NO3- NH4+ Al Br Ca Cl Cu Fe Pb Mg Mn Ni Si K+ NA+ Ti V Zn



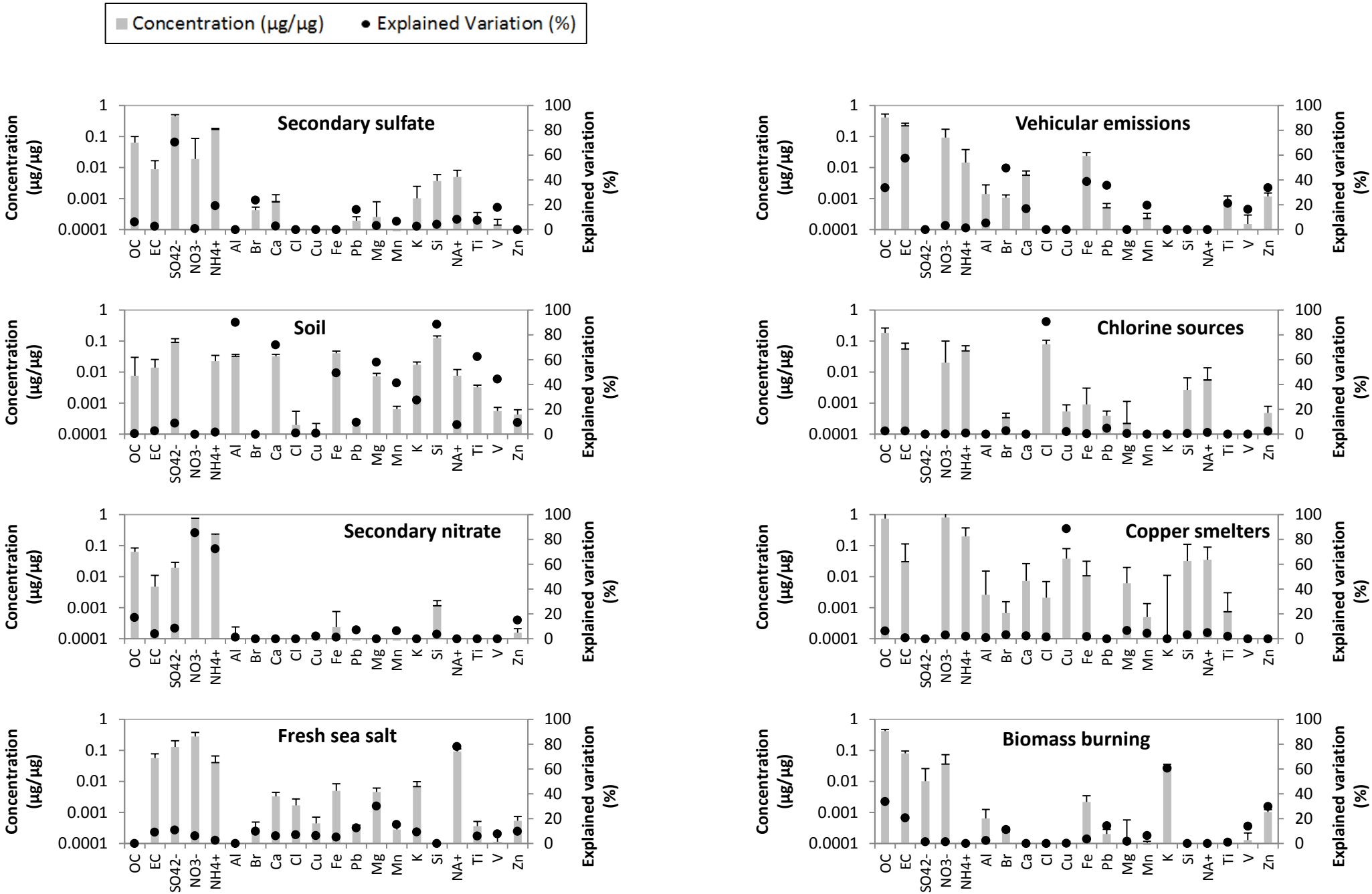
c) Los Angeles



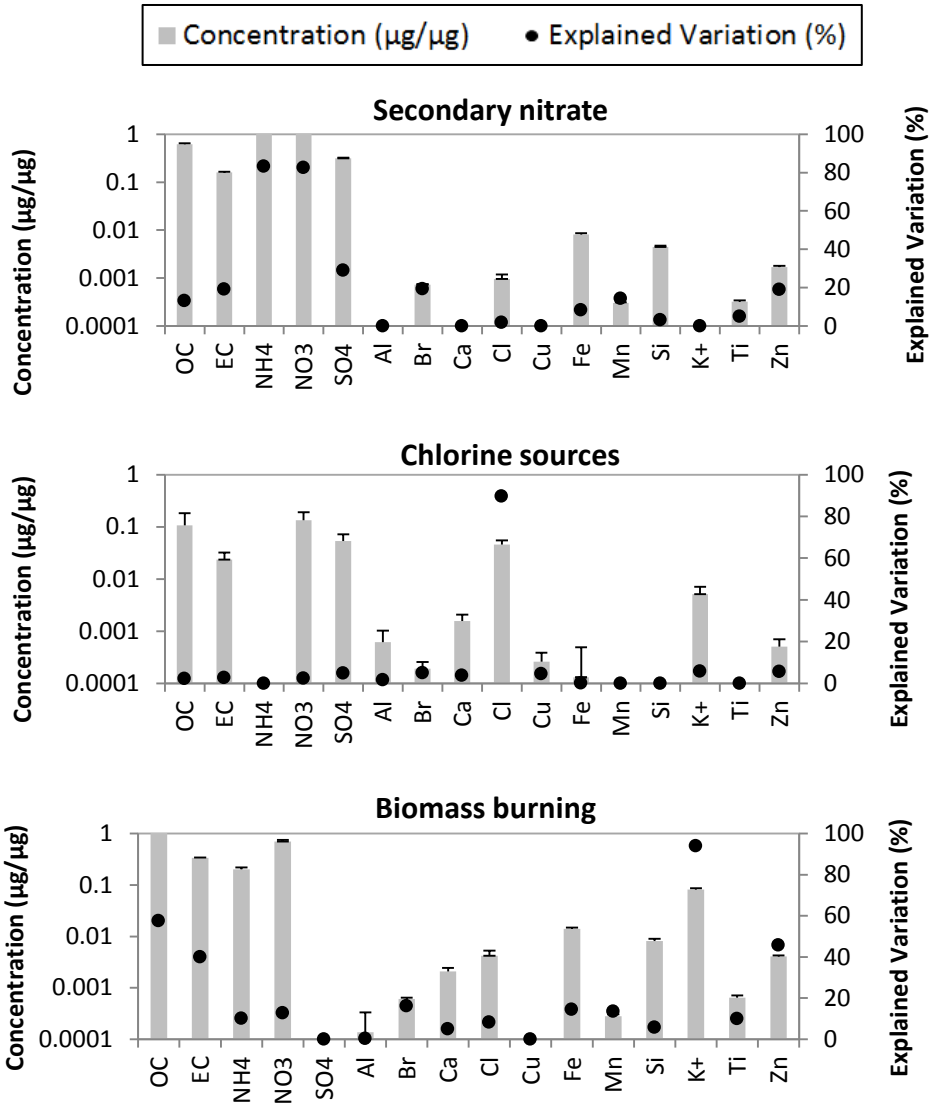
d) Simi Valley

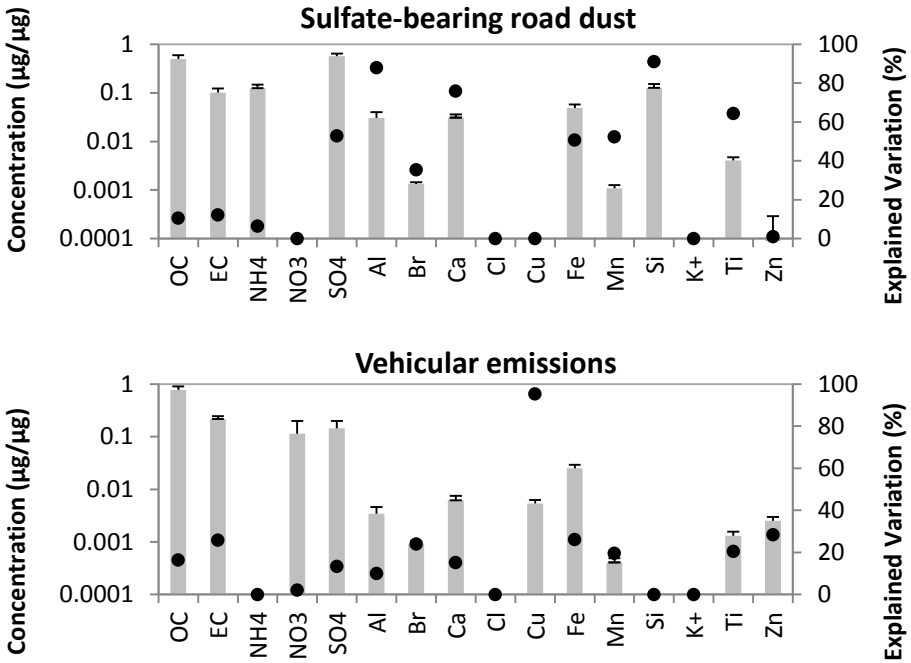


e) Bakersfield

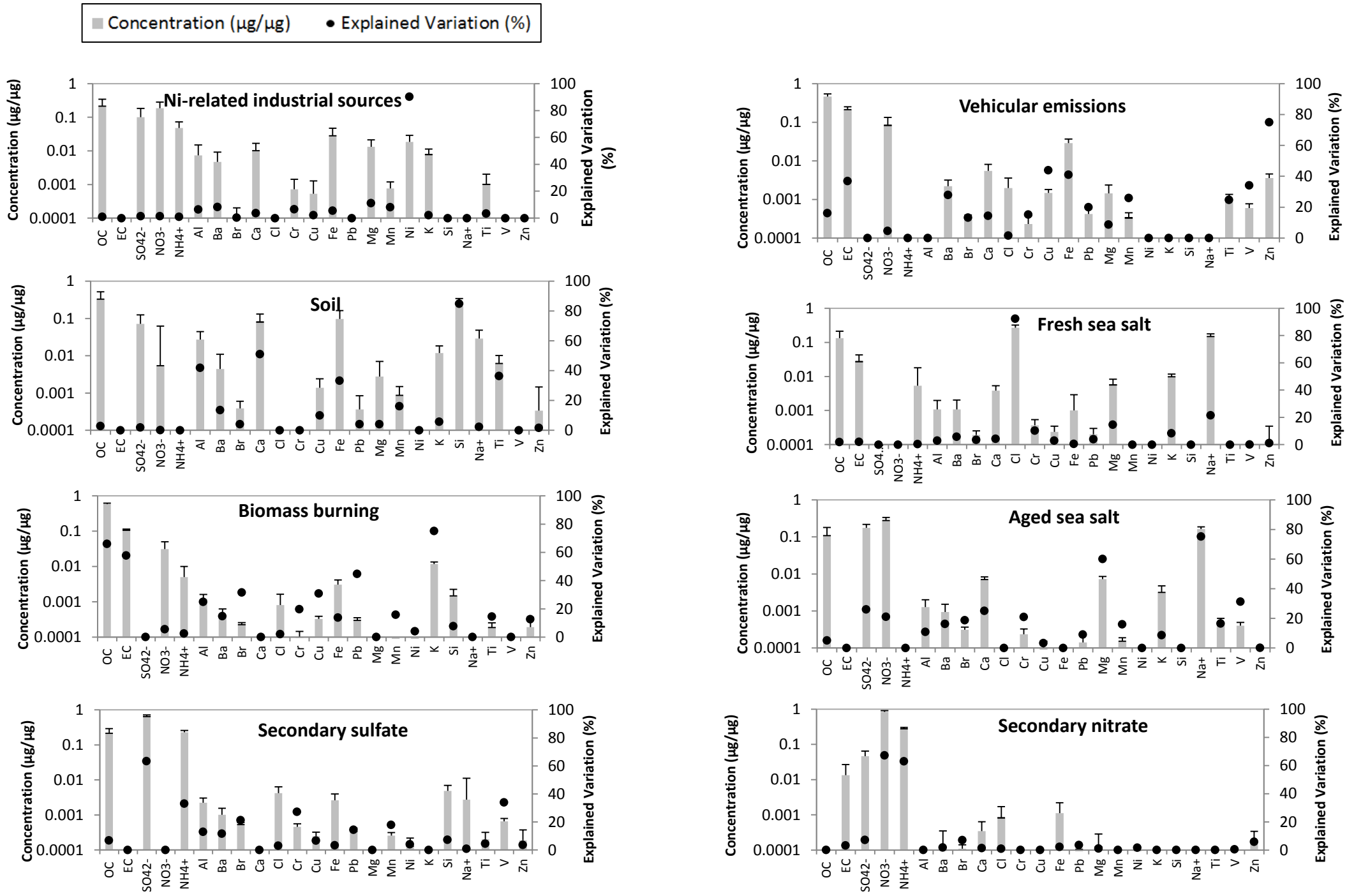


f) Fresno


Concentration (µg/µg)
Explained Variation (%)
Secondary nitrate
Chlorine sources
Biomass burning
Concentration (µg/µg)
Explained Variation (%)
1
0.1
0.01
0.001
0.0001
100
80
60
40
20
0
OC
EC
NH4
NO3
SO4
Al
Br
Ca
Cl
Cu
Fe
Mn
Si
K+
Ti
Zn


Sulfate-bearing road dust
Vehicular emissions
Concentration (µg/µg)
Explained Variation (%)
1
0.1
0.01
0.001
0.0001
100
80
60
40
20
0
OC
EC
NH4
NO3
SO4
Al
Br
Ca
Cl
Cu
Fe
Mn
Si
K+
Ti
Zn

g) San Jose


Concentration (µg/µg)
Explained Variation (%)
Ni-related industrial sources
Vehicular emissions
Soil
Fresh sea salt
Biomass burning
Aged sea salt
Secondary sulfate
Secondary nitrate
OC EC SO42- NO3- NH4+ Al Ba Br Ca Cl Cr Cu Fe Pb Mg Mn Ni K Si Na+ Ti V Zn

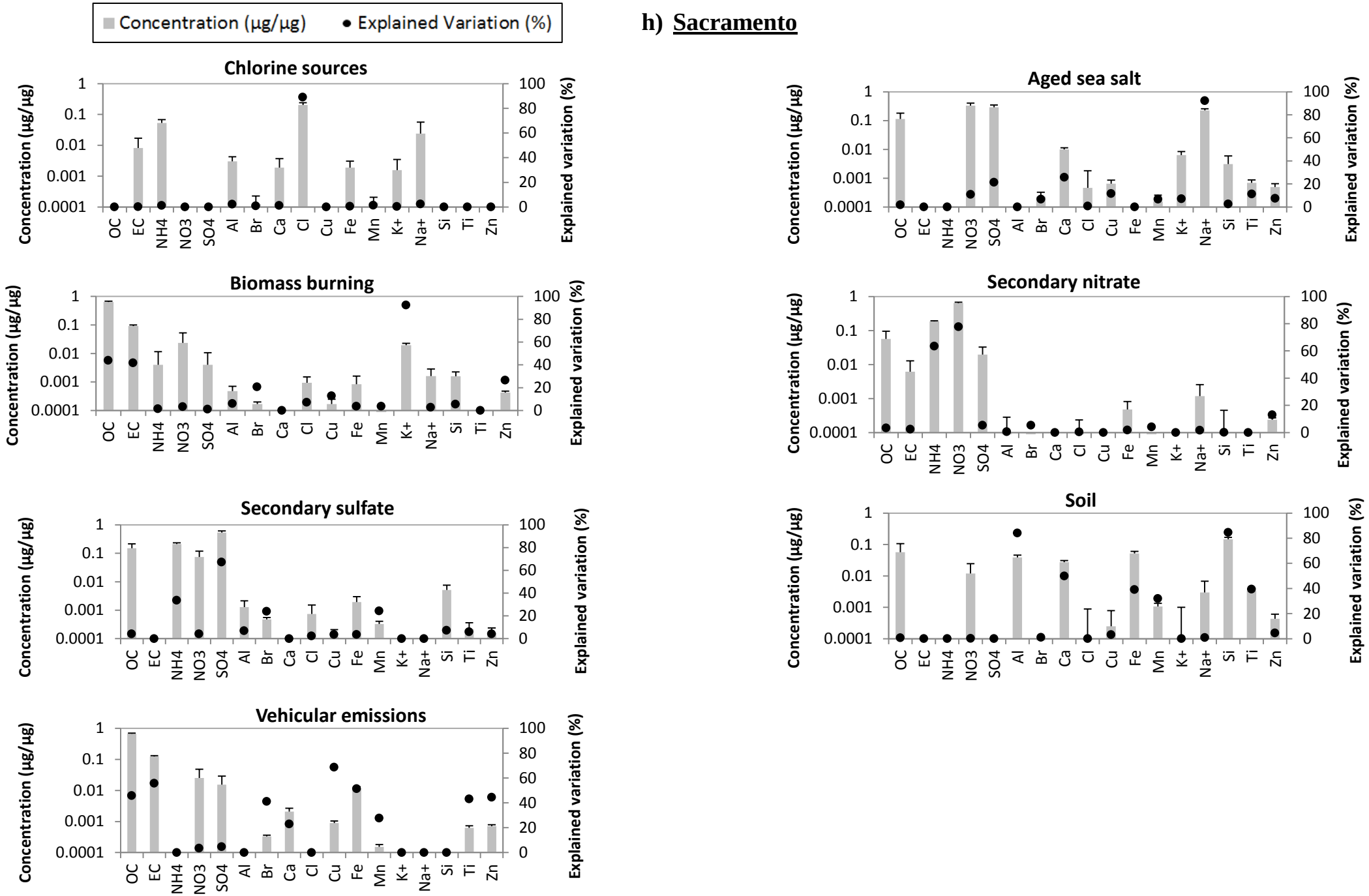


Figure S2 a-h. $PM_{2.5}$ source profiles and explained variation (EV) of each species in a) El Cajon, b) Rubidoux, c) Los Angeles, d) Simi Valley, e) Bakersfield, f) Fresno, g) San Jose, and f) Sacramento. Error bars correspond to one standard deviation obtained from bootstrap analysis.

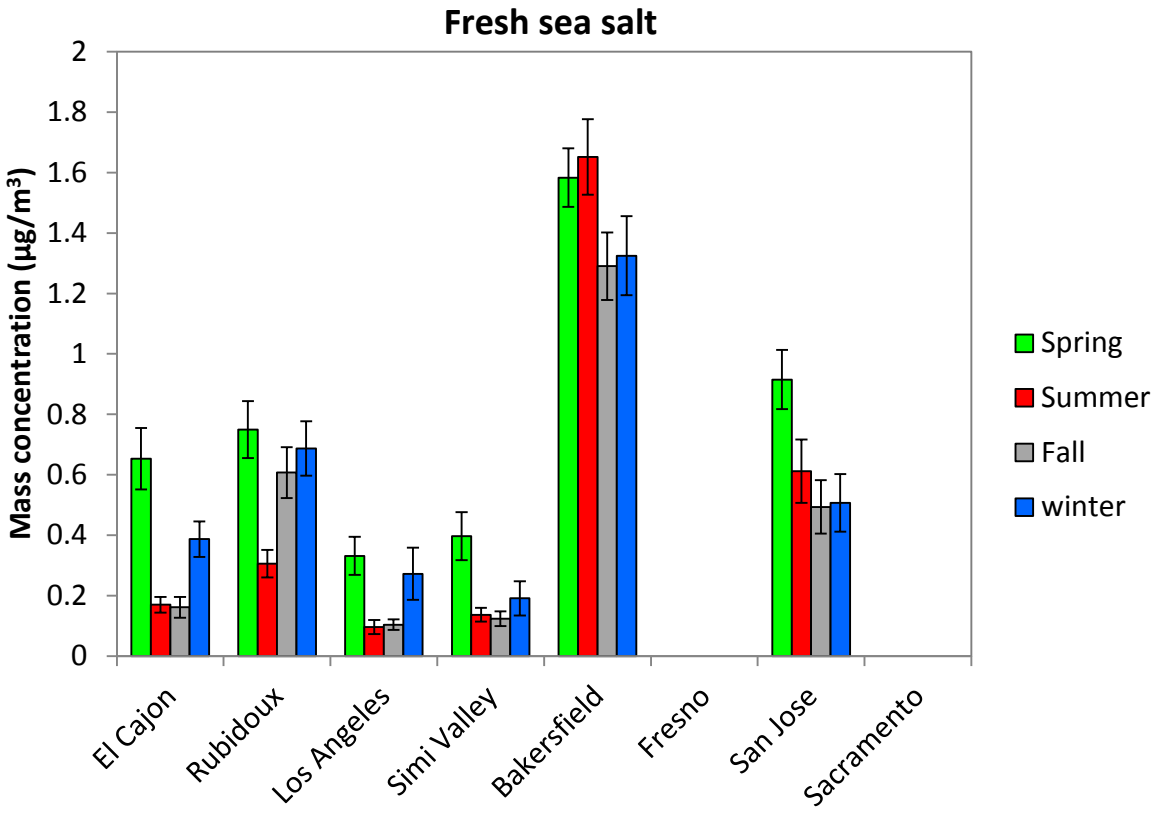


Figure S3. Seasonal average source contribution (µg/m^3) of fresh sea salt to ambient $PM_{2.5}$, by site. Error bars correspond to one standard error.

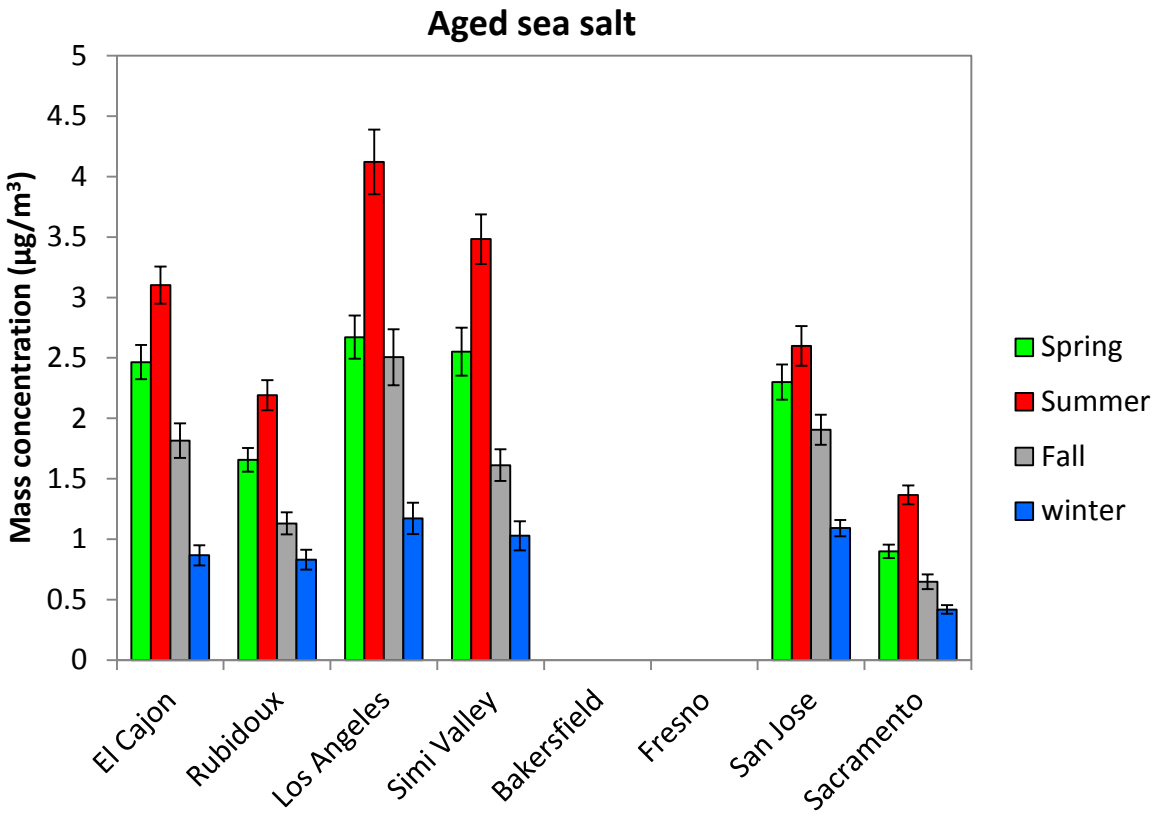


Figure S4. Seasonal average source contribution (µg/m^3) of aged sea salt to ambient $PM_{2.5}$, by site. Error bars correspond to one standard error.