Physical and Chemical Characteristics of Ultrafine PM;

Summary of 5 years Research by the Southern California Particle Center and Supersite

Constantinos Sioutas, Sc.D.
USC School of Engineering
Civil and Environmental Engineering
Southern California Particle Center and Supersite

Chairman's Air Pollution Seminar Series
California Air Resources Board
Sacramento, June 6, 2006

Acknowledgements

USC

Philip Fine, Michael Geller, Leonidas Ntziachristos, Satya Sardar, Katharine Moore, Subhasis Biswas, Harish Phuleria, Ning Zhi, Andrea Polidori, Manisha Singh

University of Wisconsin-Madison

Jamie Schauer, Rebecca Sheesley

UCLA

Yifang Zhu, Margaret Krudysz, William Hinds, Paul Mayo, Arantzazu Eiguren, Andre Nel, Arthur Cho, John Froines

Sponsors:

- **California Air Resources Board, South Coast AQMD**
- **Southern California Particle Center and Supersite funded by US EPA STAR Program**

Background and Introduction:

• Increasing epidemiological and toxicological evidence links cardio-respiratory health effects and exposures to ultrafine particles (Peters et al., 1997; Li et al., 2002 and 2003; Xia et al., 2004)

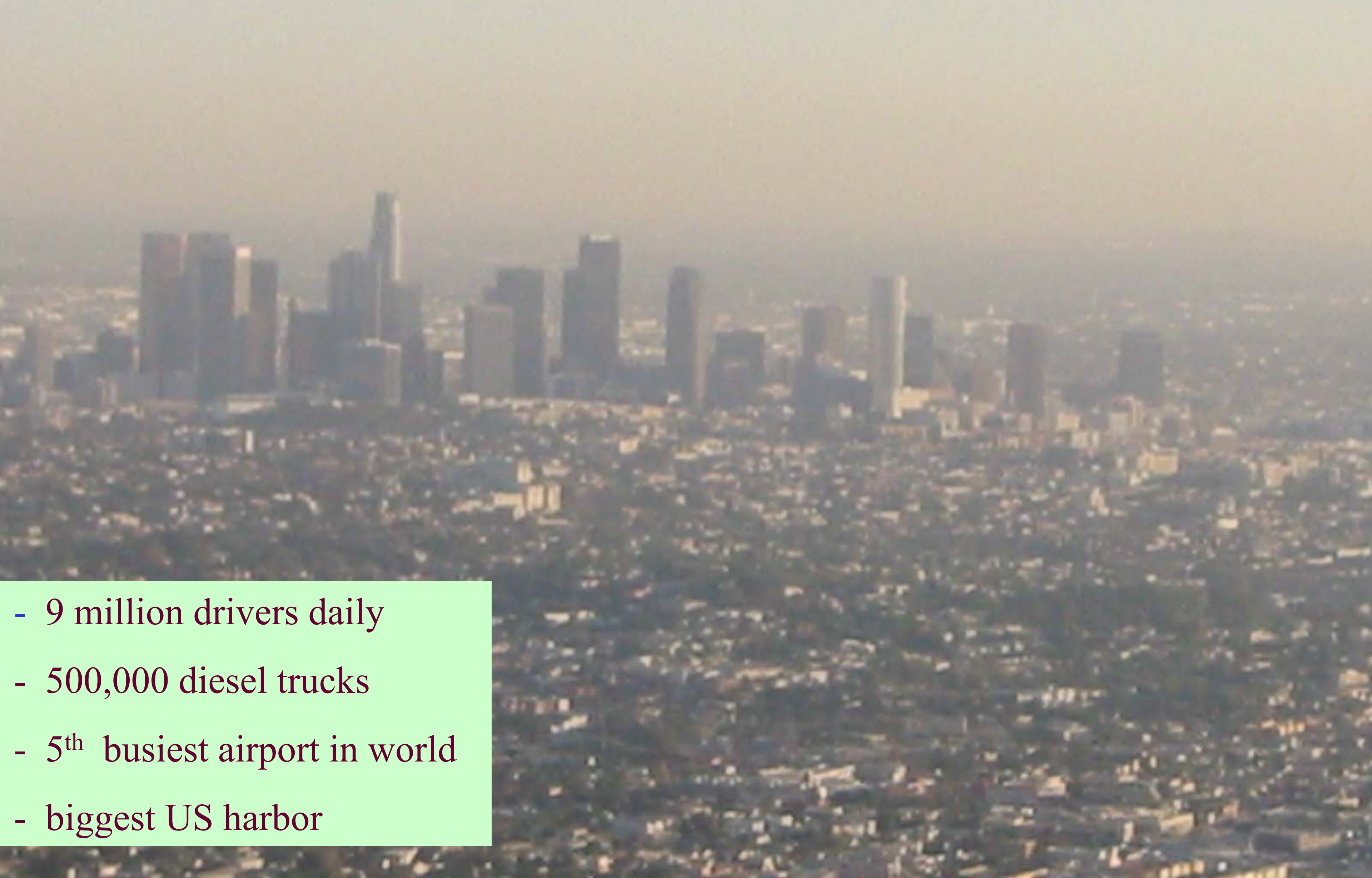
• PM from Mobile Sources ; major thrust area of the Southern California Particle Center and Supersite (SCPCS).

• Emphasis on : particle emission levels, particle transport and transformation away from the source --- busy roads and freeways, penetration to indoor environments, ultimately health effects

• Over 100 refereed journal publications in 5 years on ultrafine PM sources, formation mechanisms, physical and chemical properties and toxicity

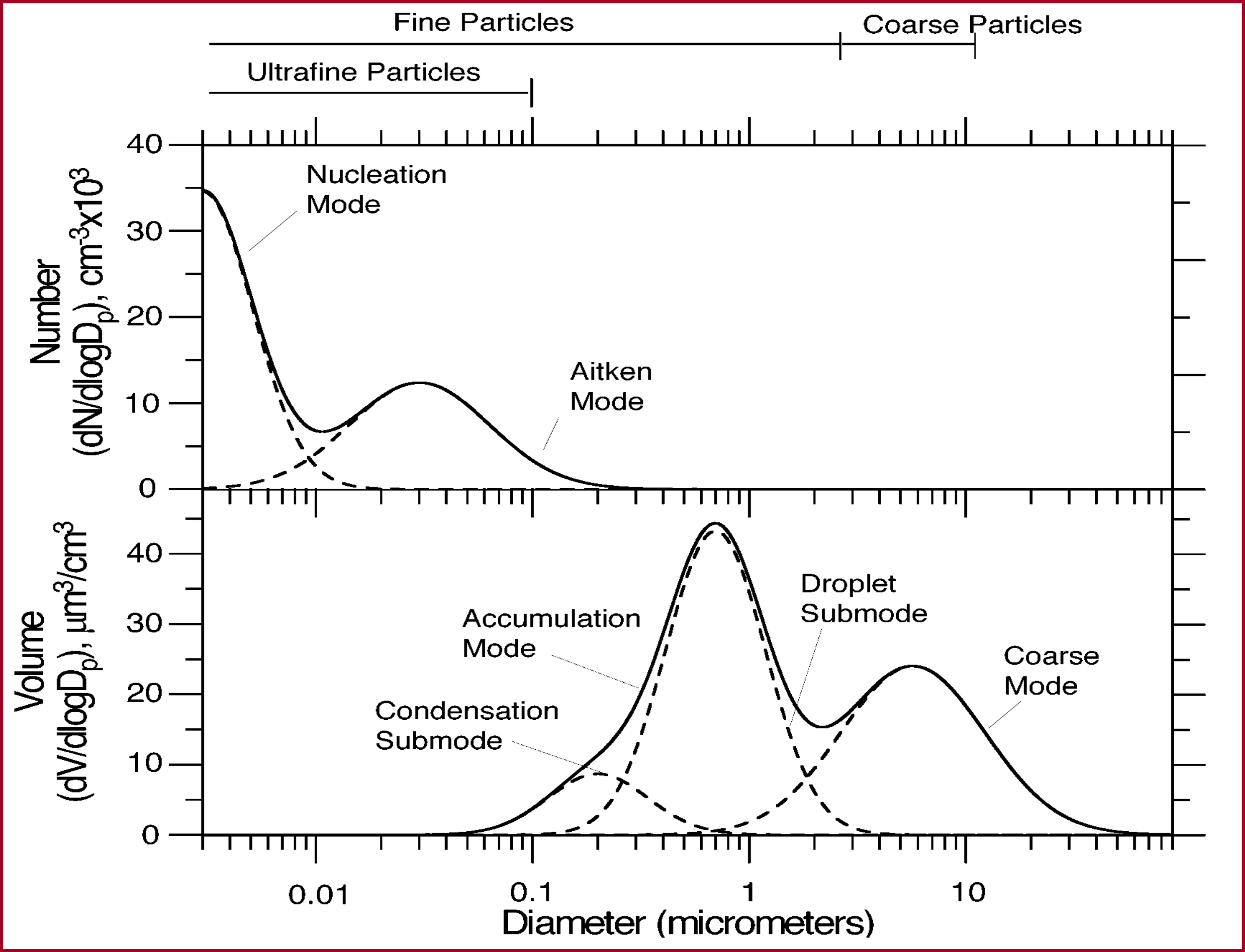
• This presentation summarizes research findings on physical and chemical characteristics of ultrafine PM generated by our SCPCS.

Overview of our Work
Air Pollution, Particulate Matter and Health Effects

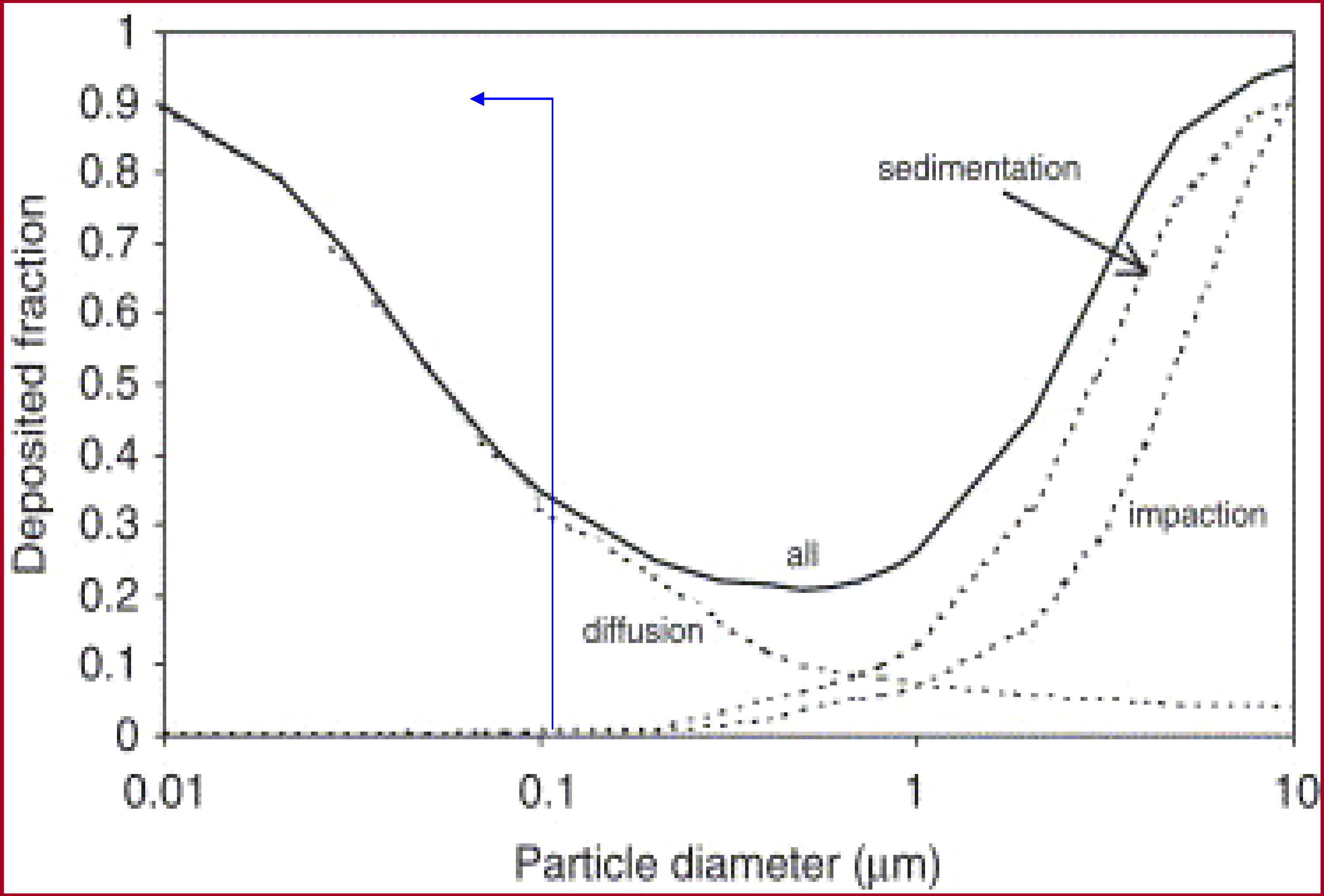


- 9 million drivers daily
- 500,000 diesel trucks
- 5th busiest airport in world
- biggest US harbor

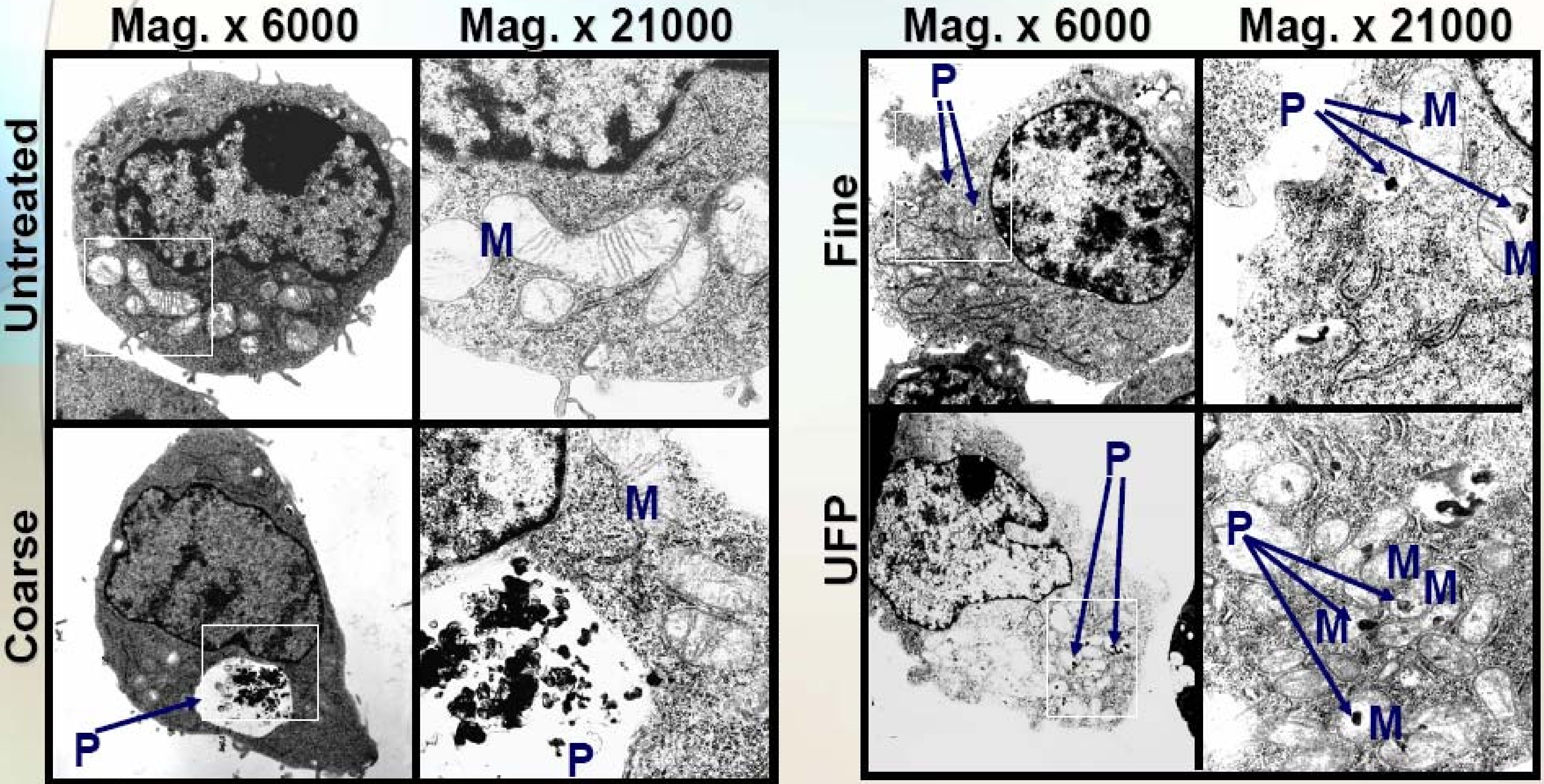
Why Are We Interested in Atmospheric Ultrafine PM



Ultrafine particle have a much higher deposition fraction in the lower lung than accumulation mode PM.



Mitochondria: An Important Subcellular Target of PM and a Source of ROS Generation

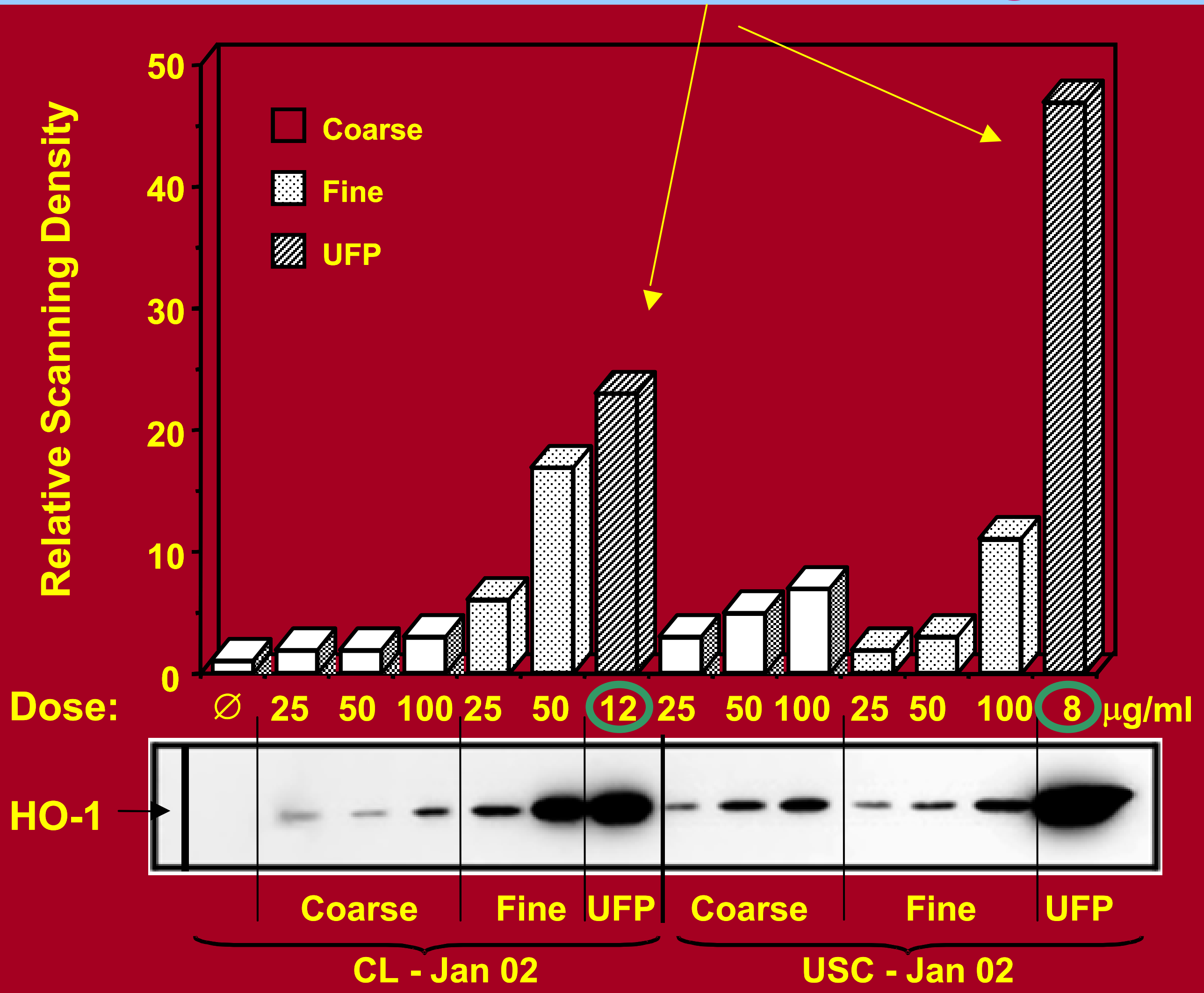


Mitochondria are redox active organelles

RAW 264.7

Source: Li, et al, 2003

Ultrafine Particles induce much higher oxidative stress on a per PM mass basis than other PM size ranges



SCPCS Studies of Ultrafine PM:

- Roadway Tunnels
- Freeway Environments
- Ambient Data in Source and Receptor Sites of the Los Angeles Basin
- Indoor locations with special emphasis on residences in close proximity to freeways

- **Location:** Caldecott tunnel in between Orinda and Berkeley, CA.
- The tunnel has two bores—one restricted to gasoline vehicles (LDV) and one 3.8% heavy-duty diesel vehicles (HDV).
- Emissions were apportioned to either HDV or LDV sources and emission factors calculated.

Bore 2 (12-18 h)	**Axle Class**			
Date	**3 + axles**	**2-axle-6 tire**	**2-axle-4 tire**	**% HD Diesel**
23-Aug	1	29	4041	0.38
24-Aug	3	38	4113	0.54
25-Aug	0	20	3982	0.25
26-Aug	0	28	4028	0.34
Bore 1 (12-18 h)	**Axle Class**			
Date	**3 + axles**	**2-axle-6 tire**	**2-axle-4 tire**	**% HD Diesel**
30-Aug	49	102	3013	3.2
31-Aug	76	109	2482	4.9
1st-sept	65	88	2951	3.5
2-Sep	66	66	2741	3.4

TABLE 6. Light-Duty Vehicle and Heavy-Duty Diesel Emission Factors (mg kg^{-1}) of Fuel Burned (average ± standard deviation)[a]

	coarse (2.5–10 μm)	accumulation (0.18–2.5 μm)	ultrafine (<0.18 μm)
Light-Duty			
mass	7.7 ± 1.6	40 ± 8	27.1 ± 3.2
OC	2.4 ± 0.9	7.4 ± 2.3	b
EC	1.0 ± 0.6	2.6 ± 1.2	26.8 ± 3.1
nitrate	0.6 ± 0.3	0.42 ± 0.2	1.2 ± 0.9
sulfate	0.8 ± 0.4	1.1 ± 0.9	2.7 ± 1.8
Mg	0.4 ± 0.2	0 ± 0	0 ± 0
Al	0.2 ± 0.4	0 ± 0	0.1 ± 0.1
Si	1.6 ± 1.3	0.1 ± 0.1	0.3 ± 0.1
Ca	0.8 ± 0.3	0.4 ± 0.2	0.3 ± 0.0
Fe	10.4 ± 3.1	3.7 ± 0.9	1.23 ± 0.50
Ti	0.3 ± 0.2	0.2 ± 0.1	0.1 ± 0.0
Ba	1.2 ± 0.9	0.3 ± 0.2	0 ± 0
Heavy-Duty			
mass	75 ± 15	304 ± 62	711 ± 65
OC	12.3 ± 2.6	10.0 ± 5.6	b
EC	66 ± 17	306 ± 44	403 ± 32
nitrate	0.4 ± 0.0	4.5 ± 1.0	1.8 ± 0.9
sulfate	1.9 ± 0.5	10.7 ± 0.4	37 ± 9
Mg	−8.2 ± 6.3	0.0 ± 0.0	0.0 ± 0.0
Al	−12.2 ± 1.9	0.0 ± 0.0	0.6 ± 0.2
Si	−51 ± 44	0.6 ± 0.1	0.6 ± 0.3
Ca	−30 ± 9	0.3 ± 0.1	0.2 ± 0.1
Fe	−154 ± 58	4.3 ± 2.0	2.8 ± 0.9
Ti	−3.3 ± 1.7	1.3 ± 0.2	0.8 ± 0.1
Ba	−15.2 ± 3.5	0.9 ± 0.1	0.0 ± 0.0

[a] Negative values reflect the higher tunnel entrance levels relative to exit levels. [b] Not presented due to a substantial organic adsorption artifact.

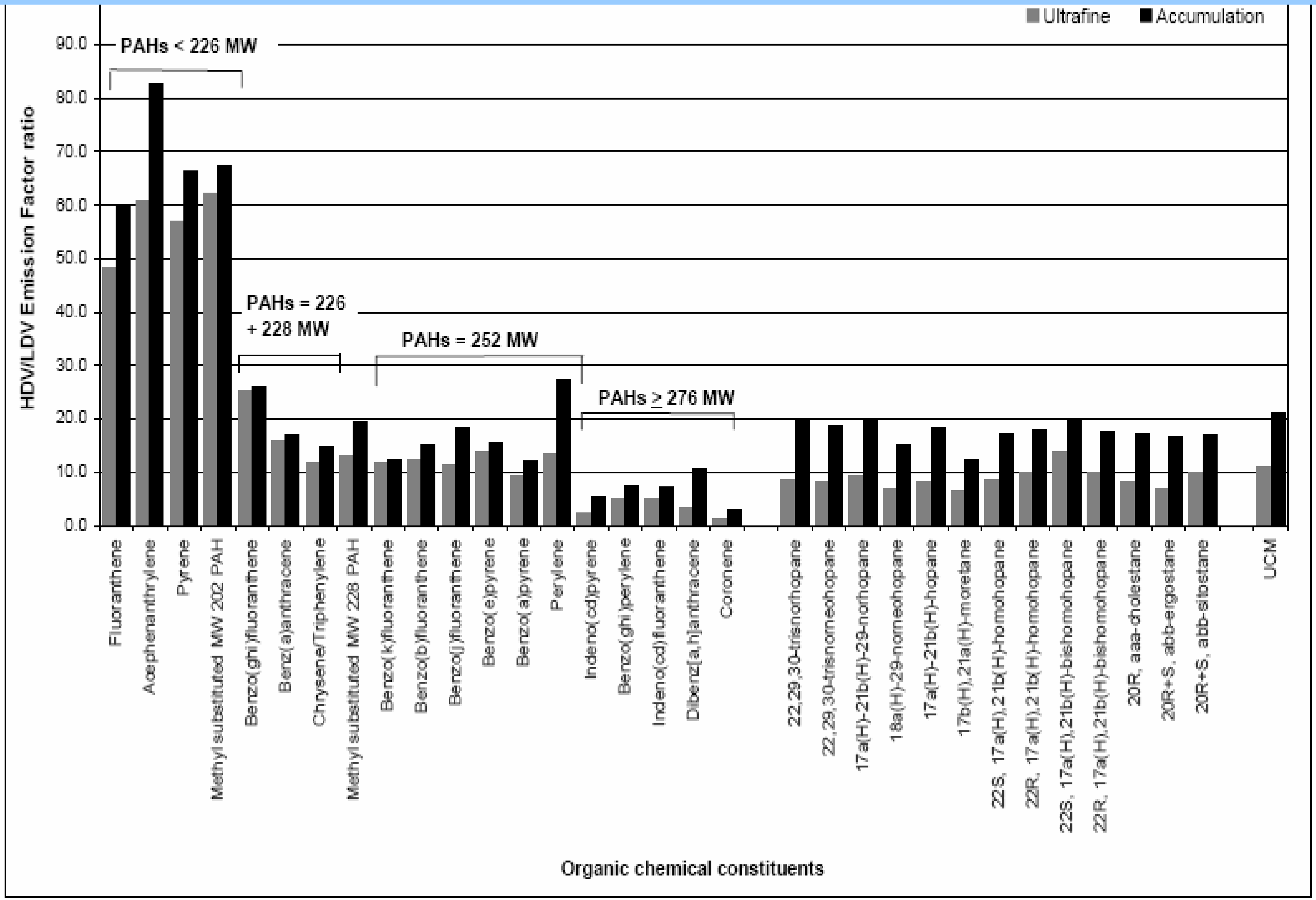
LDV and HDV Emission factors from the Caldecott Tunnel study

(Geller et al, ES&T, 2005)

HDV emissions are 10-30 fold higher for:

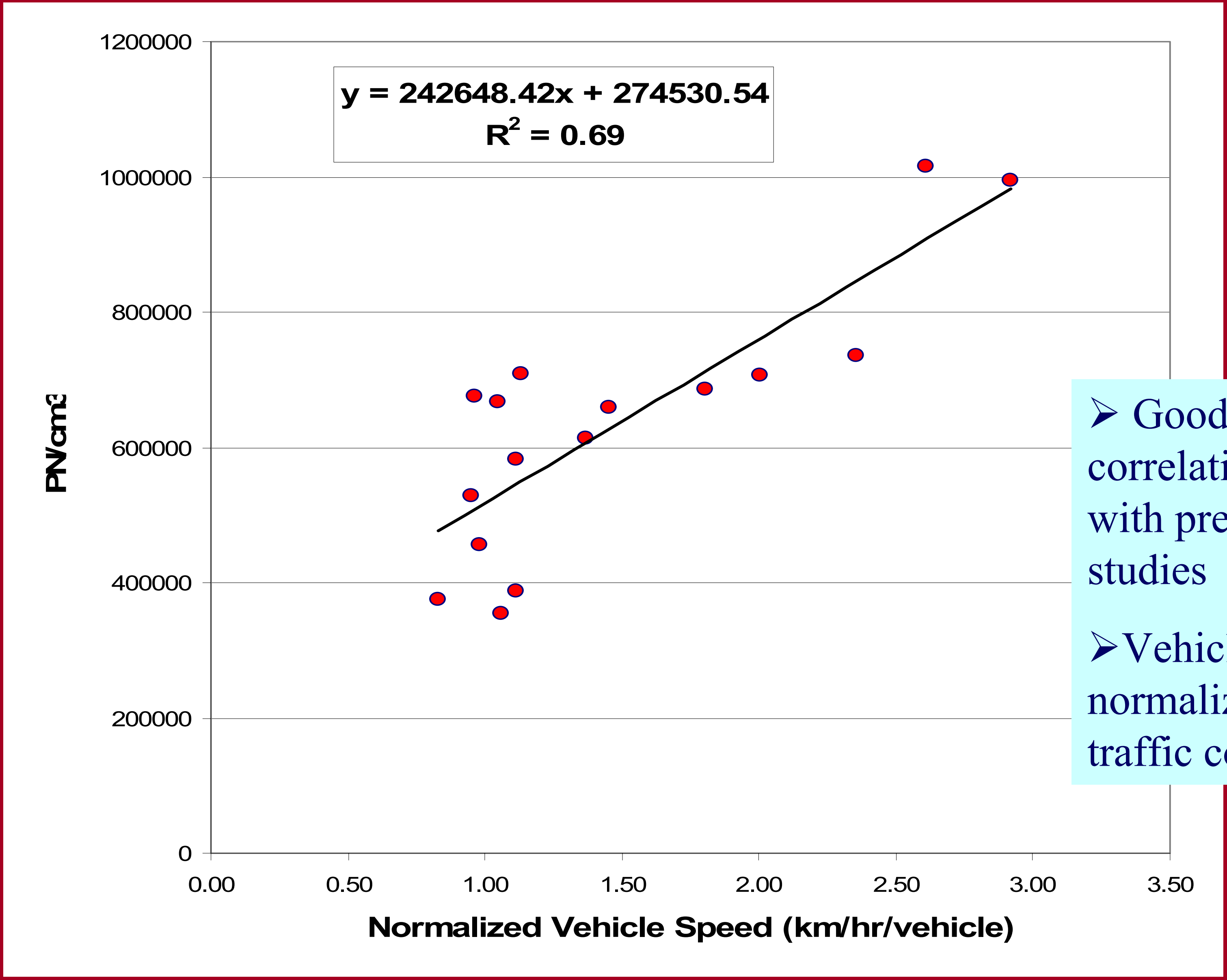
- **Mass**
- **EC**
- **Sulfate**

PAH, Hopane and Steranes Emission factors for HDV and LDV; (Phuleria et al, ES&T, 2006, in press)



Note: EF ratio for PAHs < 226 may be overestimated due to positive adsorption artifact in ultrafine size modes.

Effect of Vehicle Speed



$R^2 = 0.69$

- Good correlation, agrees with previous studies
- Vehicle speed normalized to traffic counts

Size-Segregated PN Emission Factors

Light-Duty Vehicles

Day	10-18 nm	18-32 nm	32-56 nm	56-100 nm	100-180 nm	>180 nm	Total
1	1.25E+15	6.50E+14	2.44E+14	1.30E+14	5.61E+13	5.94E+12	2.34E+15
2	1.91E+15	1.11E+15	3.72E+14	1.56E+14	6.69E+13	8.02E+12	3.63E+15
3	2.54E+14	2.13E+14	6.56E+13	3.44E+13	1.53E+13	2.16E+12	5.84E+14
4	8.32E+14	1.45E+15	6.25E+14	3.09E+14	1.30E+14	1.68E+13	3.36E+15
Grand Average	**1.06E+15**	**8.56E+14**	**3.27E+14**	**1.57E+14**	**6.72E+13**	**8.23E+12**	**2.48E+15**
Std dev	**6.99E+14**	**5.40E+14**	**2.35E+14**	**1.14E+14**	**4.76E+13**	**6.21E+12**	**1.38E+15**

Heavy-Duty Diesel Vehicles

Day	10-18 nm	18-32 nm	32-56 nm	56-100 nm	100-180 nm	>180 nm	Total
1	4.31E+15	1.61E+15	4.76E+14	3.25E+14	1.98E+14	9.30E+13	7.02E+15
2	4.85E+15	3.55E+15	1.43E+15	7.75E+14	4.16E+14	7.37E+13	1.11E+16
3	3.75E+15	1.11E+15	7.47E+14	4.72E+14	3.75E+14	5.97E+13	6.51E+15
Grand Average	**4.30E+15**	**2.09E+15**	**8.83E+14**	**5.24E+14**	**3.30E+14**	**7.55E+13**	**8.21E+15**
Std dev	**5.51E+14**	**1.29E+15**	**4.90E+14**	**2.29E+14**	**1.16E+14**	**1.67E+13**	**2.52E+15**

- HDVs emit more particles in every size range (factor of 3-10)
- Ratio of HDV-to-LDV emission factors increases with particle size range
- HDVs emit more fractal-like soot agglomerates

TABLE 7. Comparison of the Current Measured Concentrations of CO_2 and Emission Factors of $PM_{2.5}$ and PN to Measurements Made in Previous Studies at the Caldecott Tunnel

vehicle type	study	CO_2 (ppm)	$PM_{2.5}$ (g/kg)	particle number (particles/kg)
LDV	this work	384	0.07 ± 0.02	$(2.5 \pm 1.4) \times 10^{15}$
LDV	Kirchstetter et al. (*21*)	665	0.11 ± 0.01	$(4.6 \pm 0.7) \times 10^{14}$
LDV	Allen et al. (*20*)	738.5	0.07 ± 0.05[a]	*b*
HDV	this work	515	1.02 ± 0.04	$(8.2 \pm 2.5) \times 10^{15}$
HDV	Kirchstetter et al. (*21*)	373	2.5 ± 0.2	$(6.3 \pm 1.9) \times 10^{15}$
HDV	Allen et al. (*20*)	435.5	1.285 ± 0.2[a]	*b*

[a] Represents $PM_{1.9}$. [b] Not available.

- $PM_{2.5}$ emissions have declined by 37% (LDV) and 60% (HDV) since 1997
- PN emissions have increased
  - Factor of 5.4 for LDV
  - Factor of 1.3 for HDV

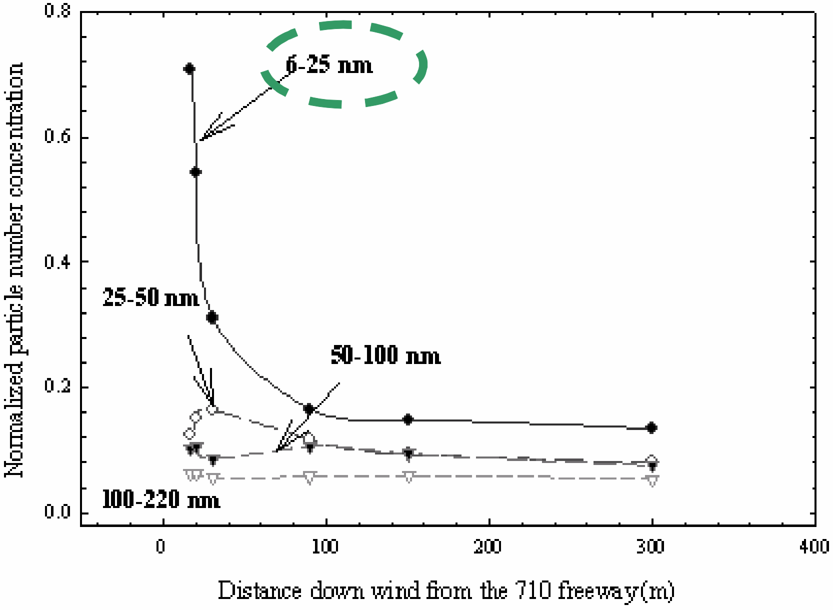
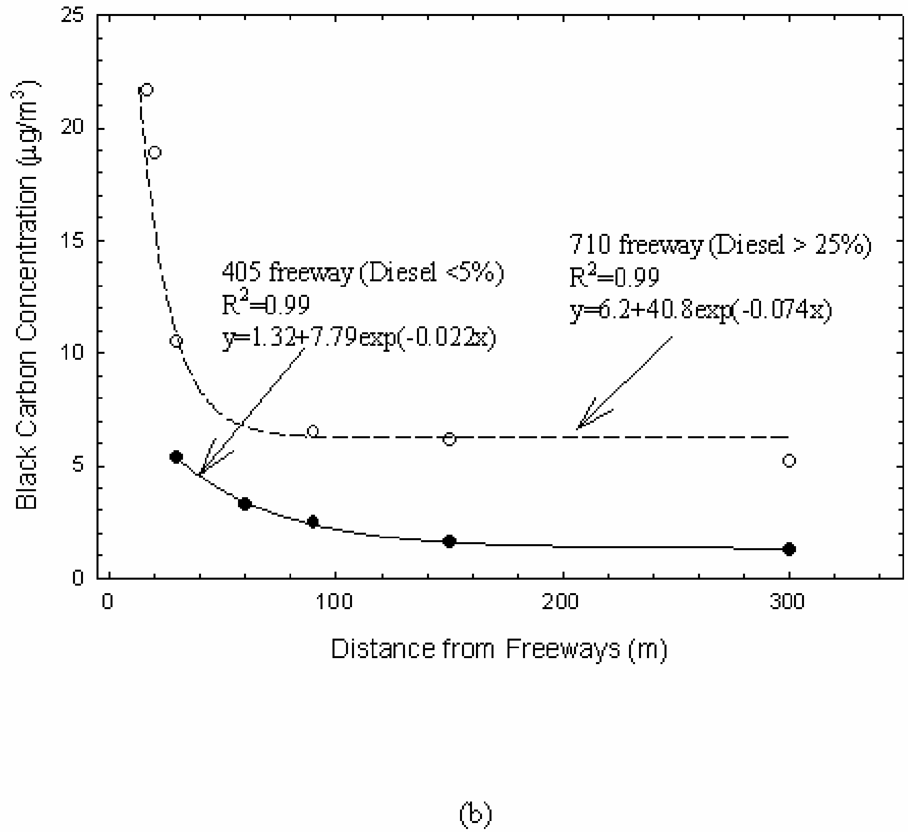


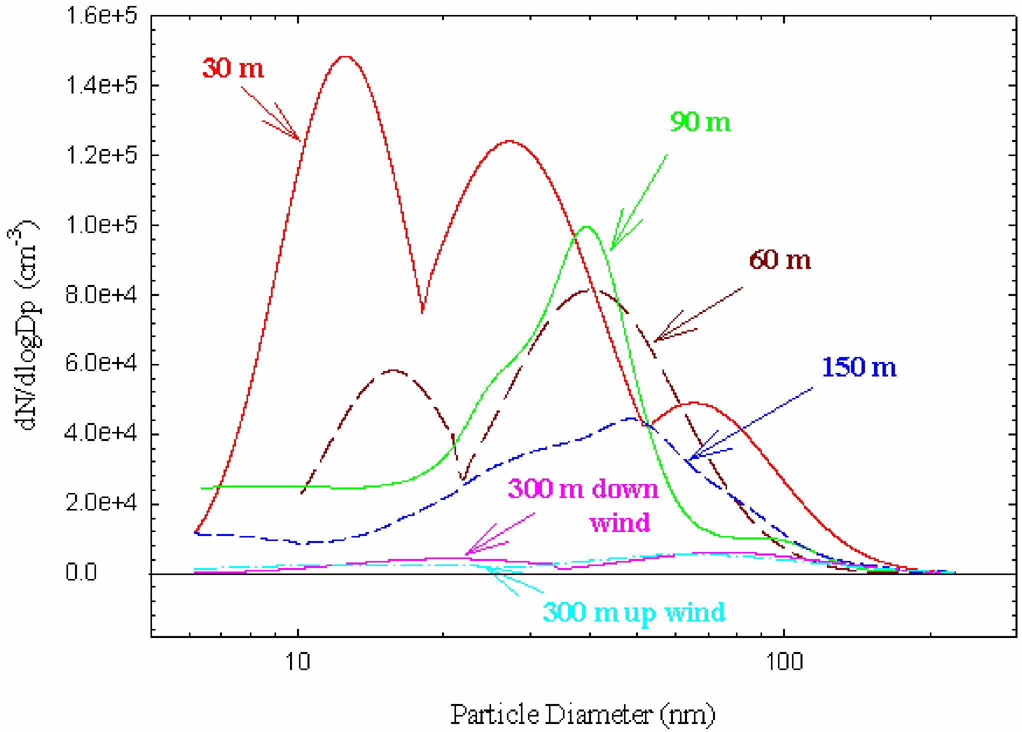
Figure 5. Normalized particle number concentration for different size ranges as a function of distance to the 710 freeway.

The decrease is more pronounced for the smallest particles

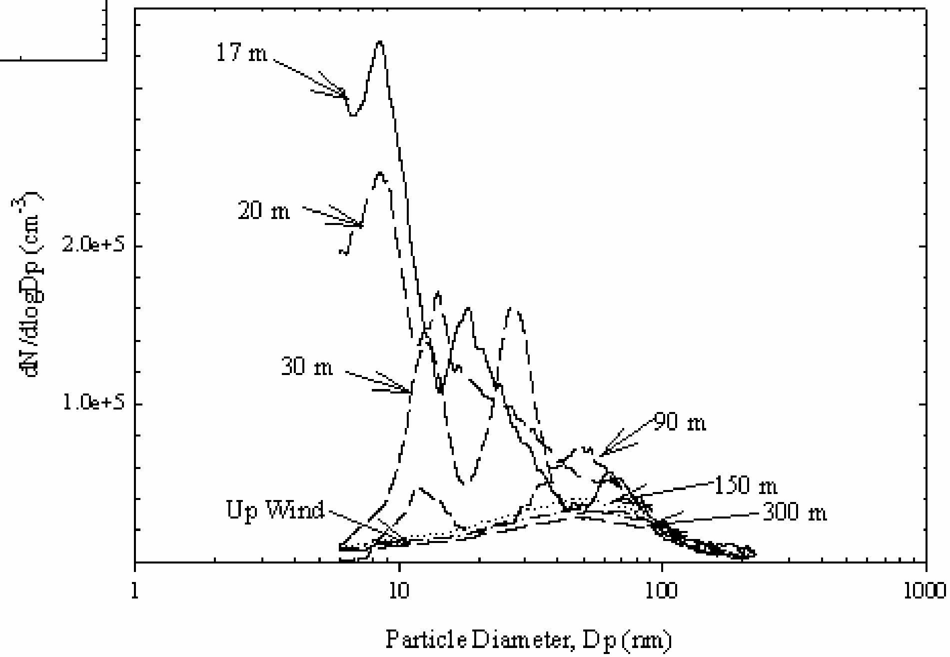
EC concentrations are much higher in the diesel traffic freeway



Significant changes occur in size distribution of PM with distance from roadway



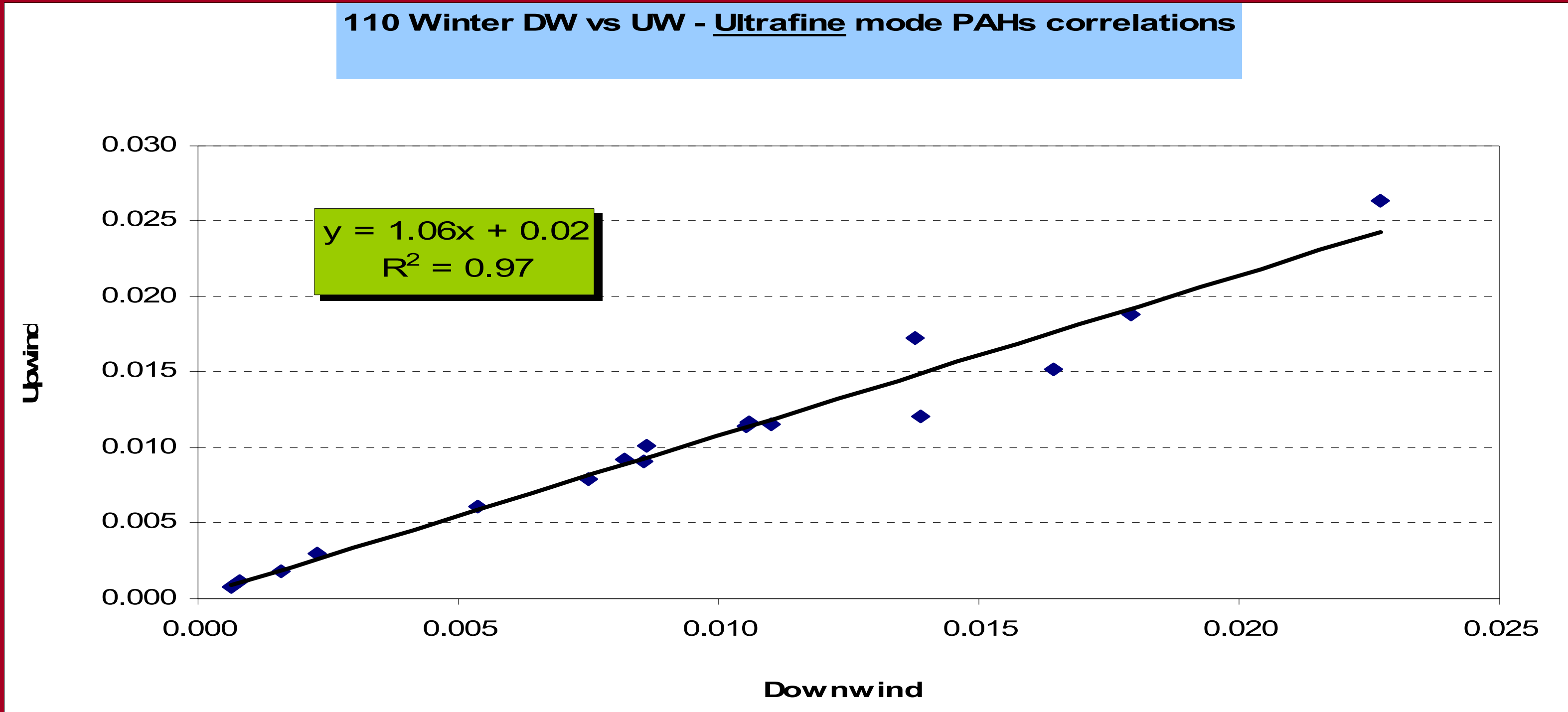
Generally, number concentration decreases and particle size increases with distance (Zhu et al., 2002b)

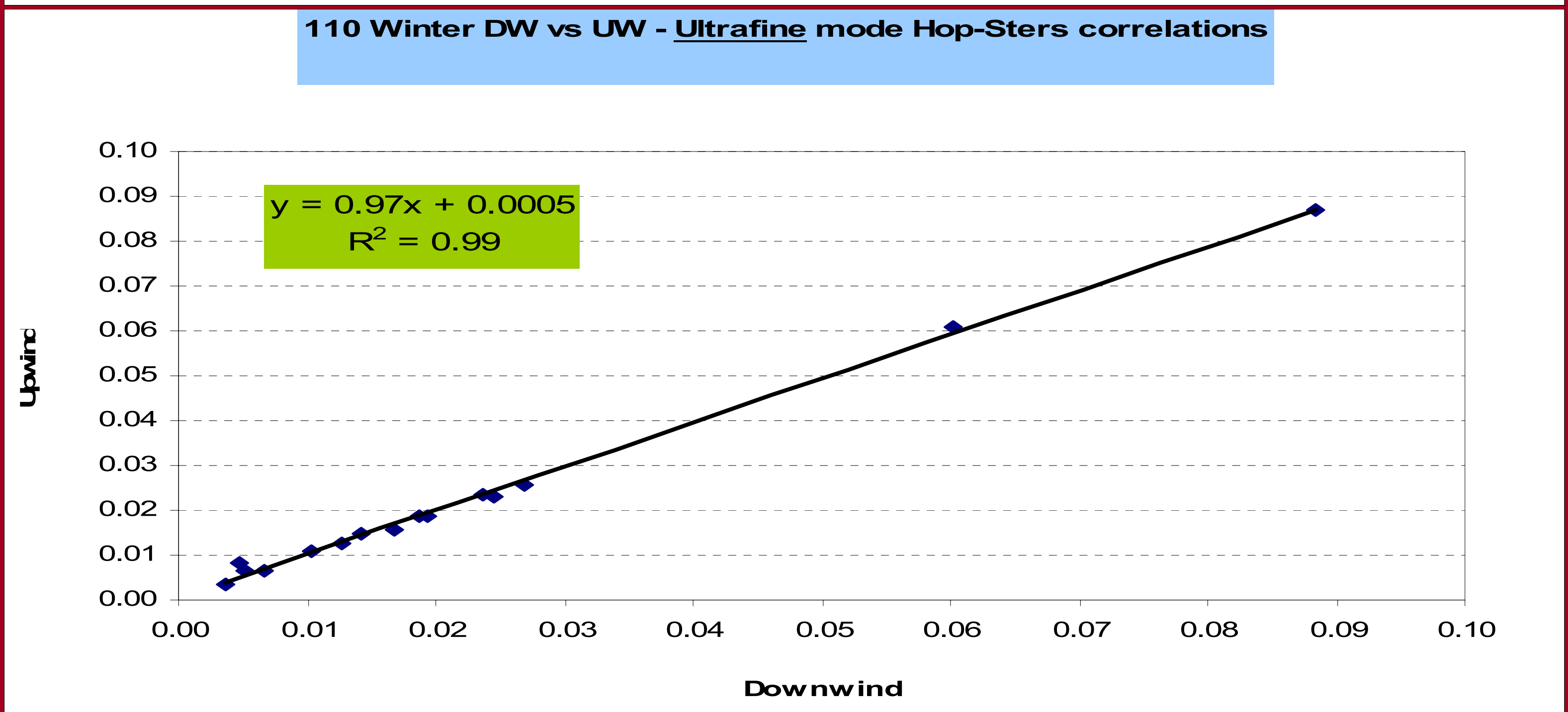


I-710 (mostly diesel)

Chemical Speciation of PM at the CA-110 LDV only Freeway

	Coarse A	Coarse B	Accumulation A	Accumulation B	Ultrafine A	Ultrafine B		Coarse A	Coarse B	Accumulation A	Accumulation B	Ultrafine A	Ultrafine B
Mass							**S**						
Mean	7.60	4.92	13.98	10.62	6.00	5.04	Mean	0.08	0.06	0.34	0.27	0.03	0.06
SD	0.66	0.58	11.13	5.48	1.54	1.17	SD	0.05	0.02	0.34	0.22	0.01	0.03
Nitrate							**Cl**						
Mean	0.67	0.49	2.38	2.49	2.82	3.01	Mean	0.10	0.11	0.02	0.01	0.00	0.01
SD	0.55	0.48	3.20	3.79	1.62	1.42	SD	0.07	0.09	0.03	0.01	0.00	0.01
Sulfate							**K**						
Mean	0.27	0.17	0.77	0.82	1.58	1.23	Mean	0.08	0.08	0.04	0.05	0.02	0.04
SD	0.20	0.10	0.71	0.90	0.79	0.36	SD	0.04	0.02	0.01	0.01	0.01	0.01
OC							**Ca**						
Mean	1.37	0.77	2.17	2.17	14.55	10.66	Mean	0.27	0.26	0.09	0.10	0.04	0.09
SD	0.67	0.46	0.93	1.02	5.76	7.41	SD	0.10	0.04	0.03	0.04	0.02	0.04
EC							**Ti**						
Mean	0.21	0.05	0.14	0.12	1.90	1.50	Mean	0.03	0.03	0.02	0.02	0.01	0.01
SD	0.21	0.04	0.07	0.03	1.30	1.04	SD	0.01	0.01	0.01	0.01	0.00	0.01
Na							**Fe**						
Mean	0.08	0.26	0.06	0.06	0.01	0.03	Mean	0.66	0.56	0.34	0.30	0.09	0.16
SD	0.06	0.25	0.06	0.03	0.01	0.03	SD	0.16	0.17	0.10	0.15	0.05	0.08
Mg							**Cu**						
Mean	0.02	0.01	0.00	0.04	0.02	0.00	Mean	0.03	0.02	0.02	0.02	0.01	0.01
SD	0.02	0.00	0.00	0.01	0.00	0.00	SD	0.01	0.01	0.01	0.01	0.00	0.00
Al							**Zn**						
Mean	0.15	0.15	0.04	0.06	0.39	0.47	Mean	0.01	0.01	0.02	0.02	0.00	0.01
SD	0.08	0.02	0.01	0.02	0.61	0.40	SD	0.01	0.00	0.01	0.01	0.00	0.00
Si							**Ba**						
Mean	0.56	0.54	0.17	0.21	0.11	0.20	Mean	0.04	0.03	0.03	0.02	0.00	0.01
SD	0.22	0.13	0.06	0.08	0.06	0.08	SD	0.01	0.01	0.01	0.01	0.00	0.01

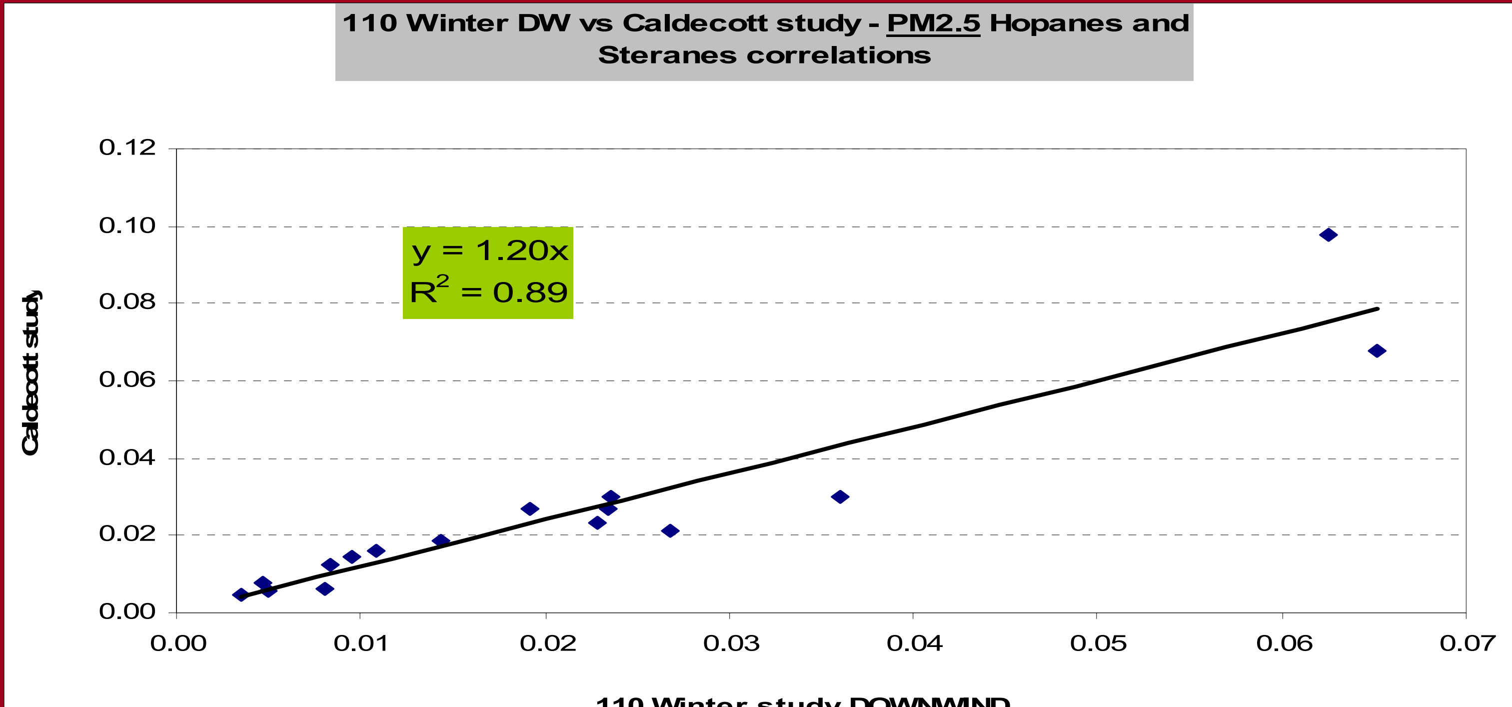


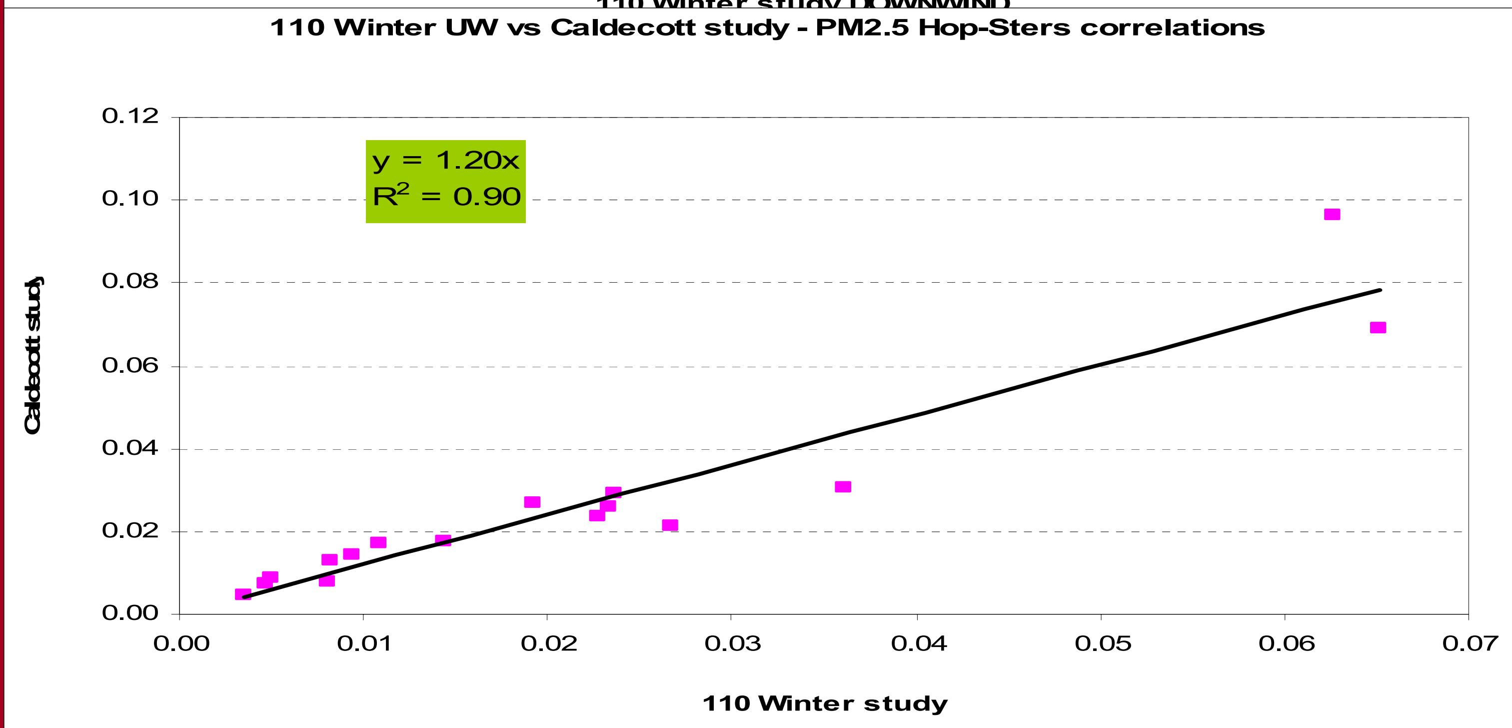


Similar PAH, hopanes and steranes levels upwind and downwind of the CA-110 freeway

DW; downwind

UW; upwind



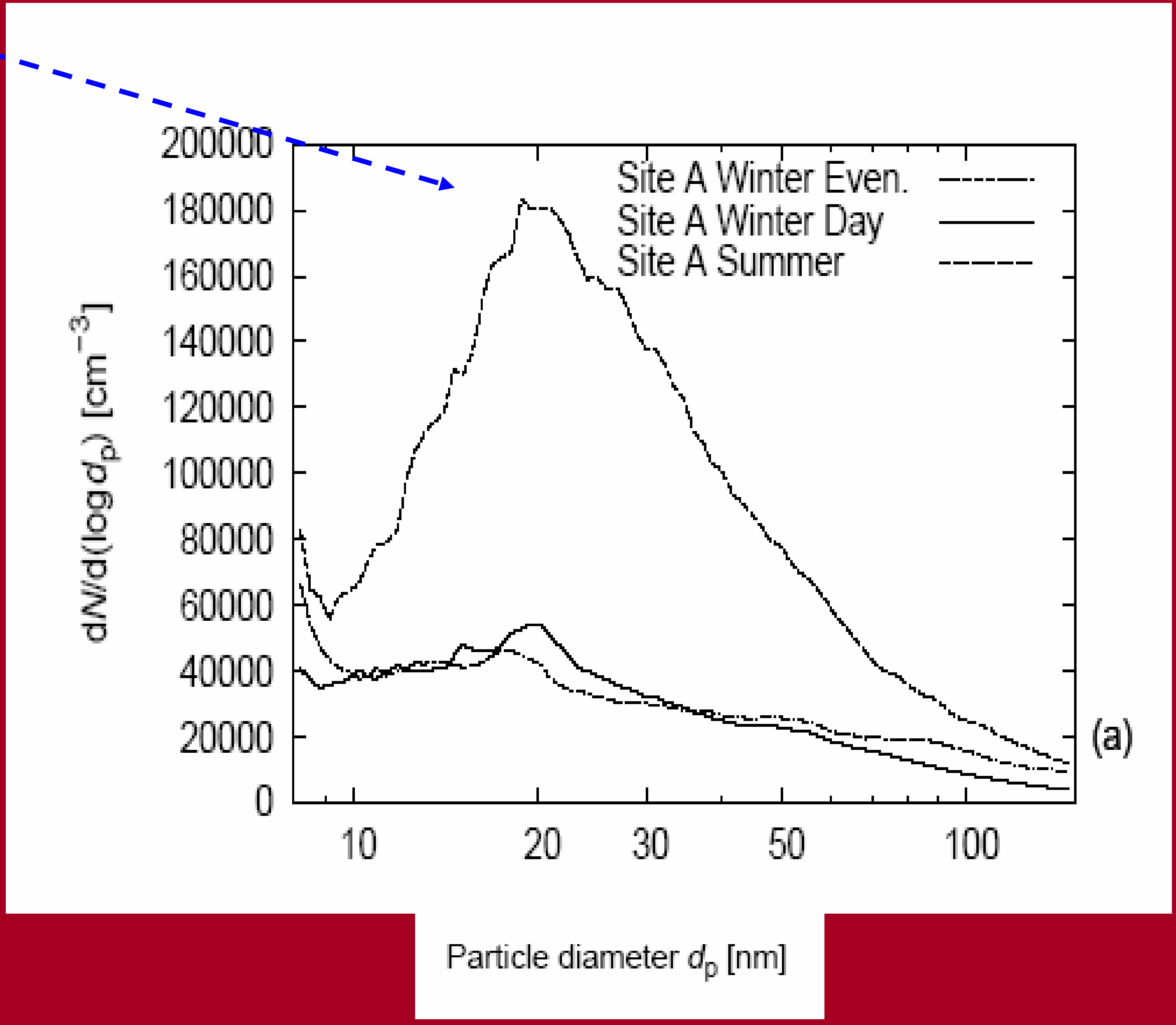


Similar Normalized Hopane and Steranes levels

upwind and downwind

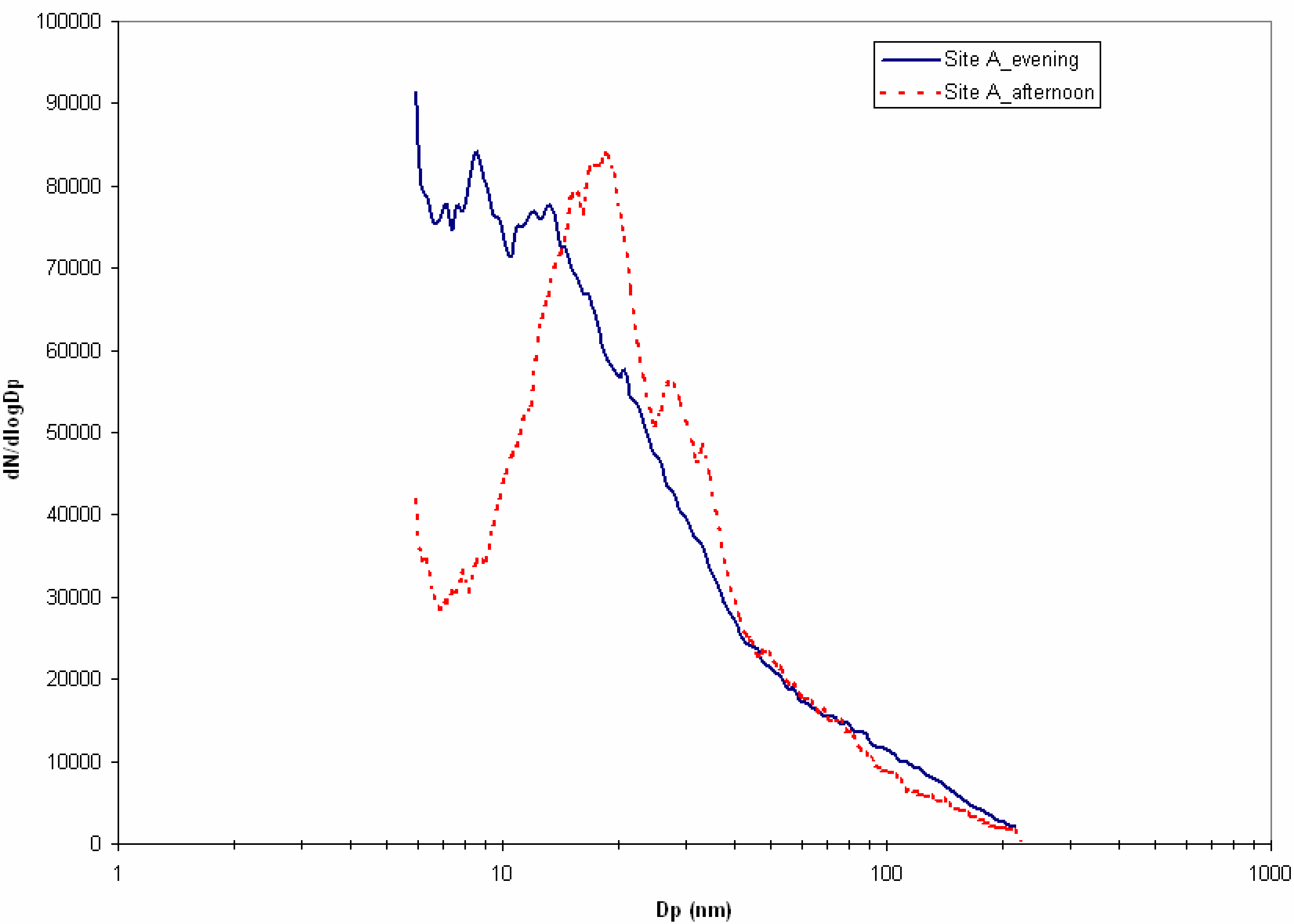
of the CA-110 freeway to those of the LDV Caldecott Bore

Major differences in PN between day vs. evening in winter suggest condensation or semi-volatile species as a major aerosol formation mechanism



Kuhn et al., 2005, Atmos. Environ.

Data on the I-710 freeway



The Issue of PM Volatility and Why it is Important

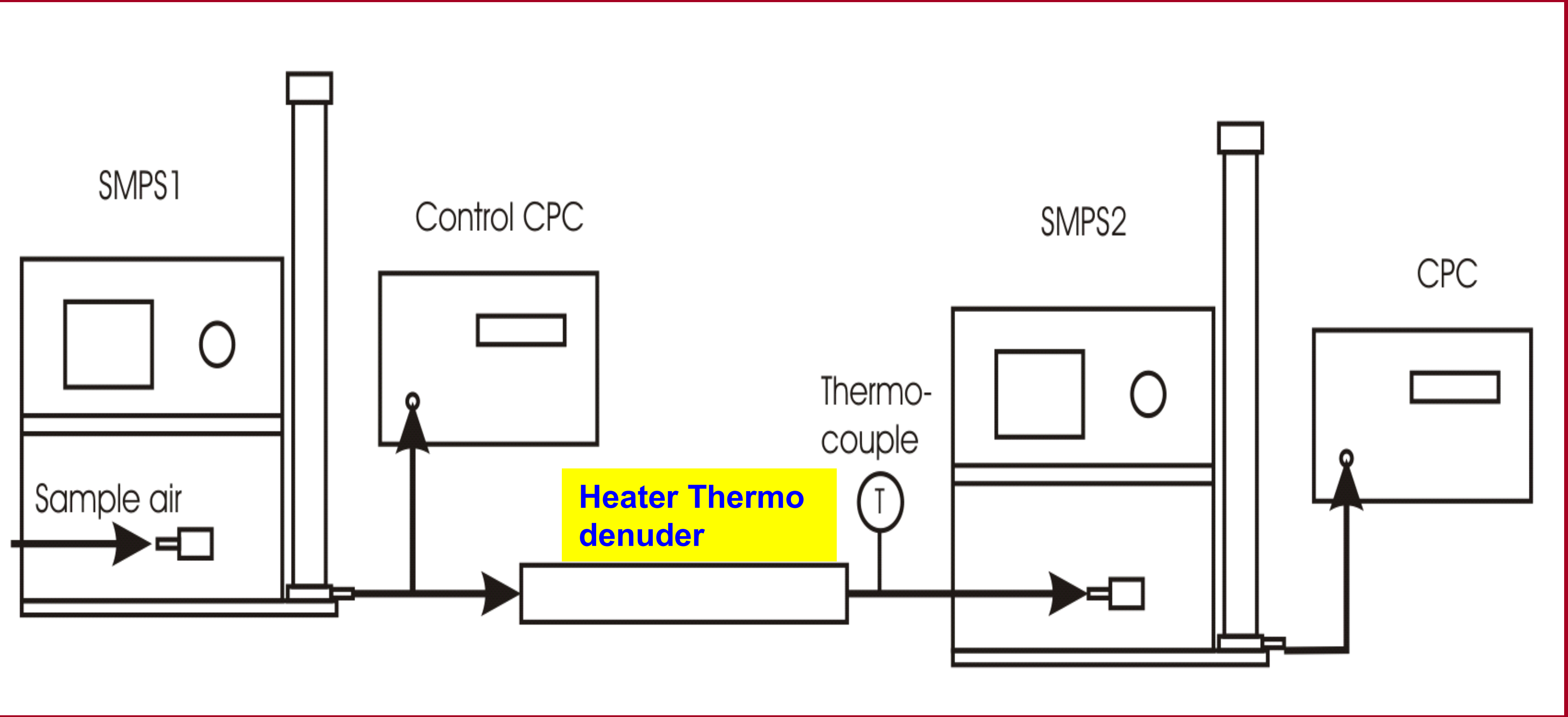
- **Exposure and health Implications**

- Exposure and dose of semi-volatile species may differ according to whether they are in the gas or particle phases.

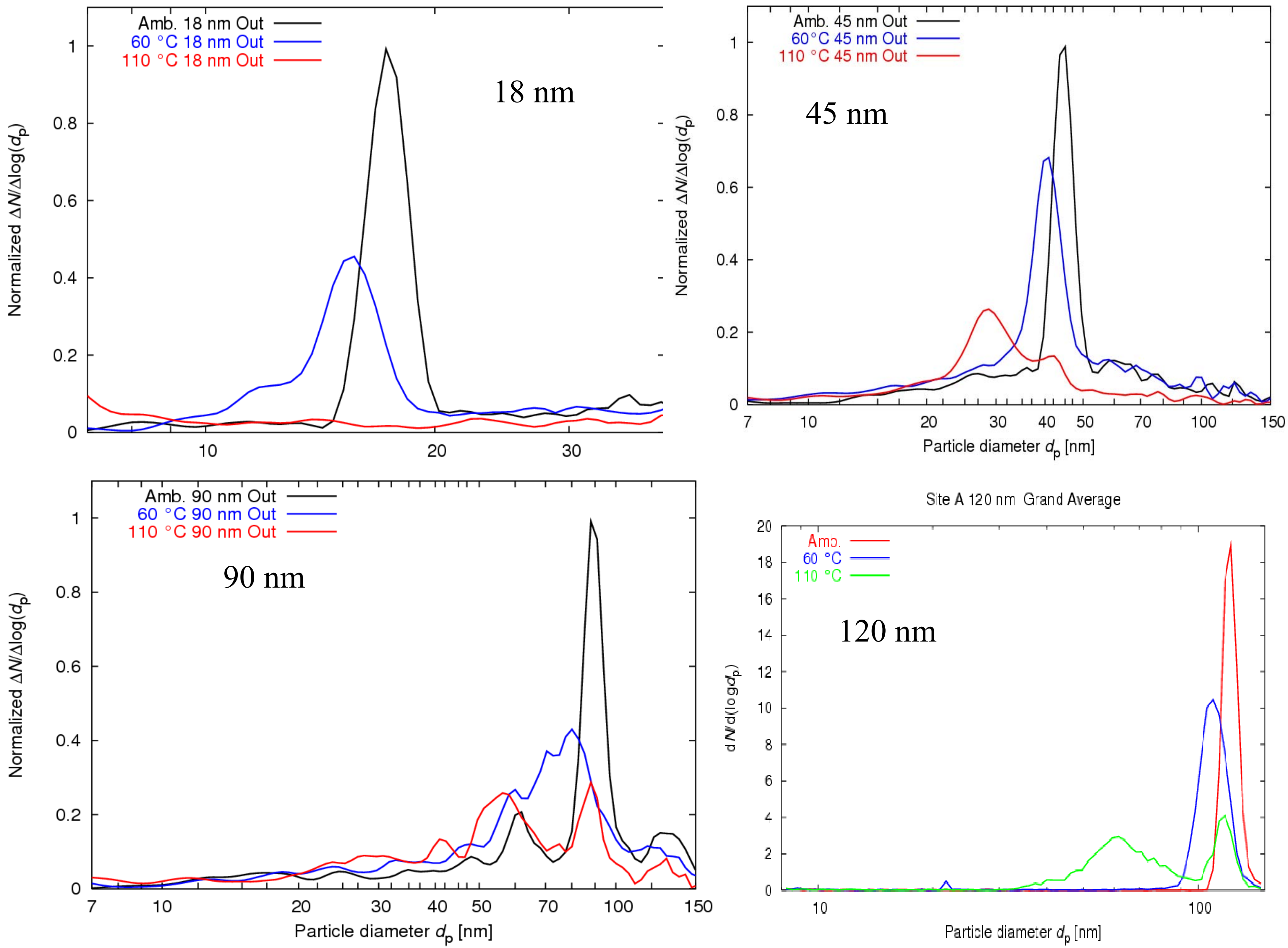
- The semi-volatile component of these particles may likely be present in its gaseous phase or associated with smaller sizes in indoor environments

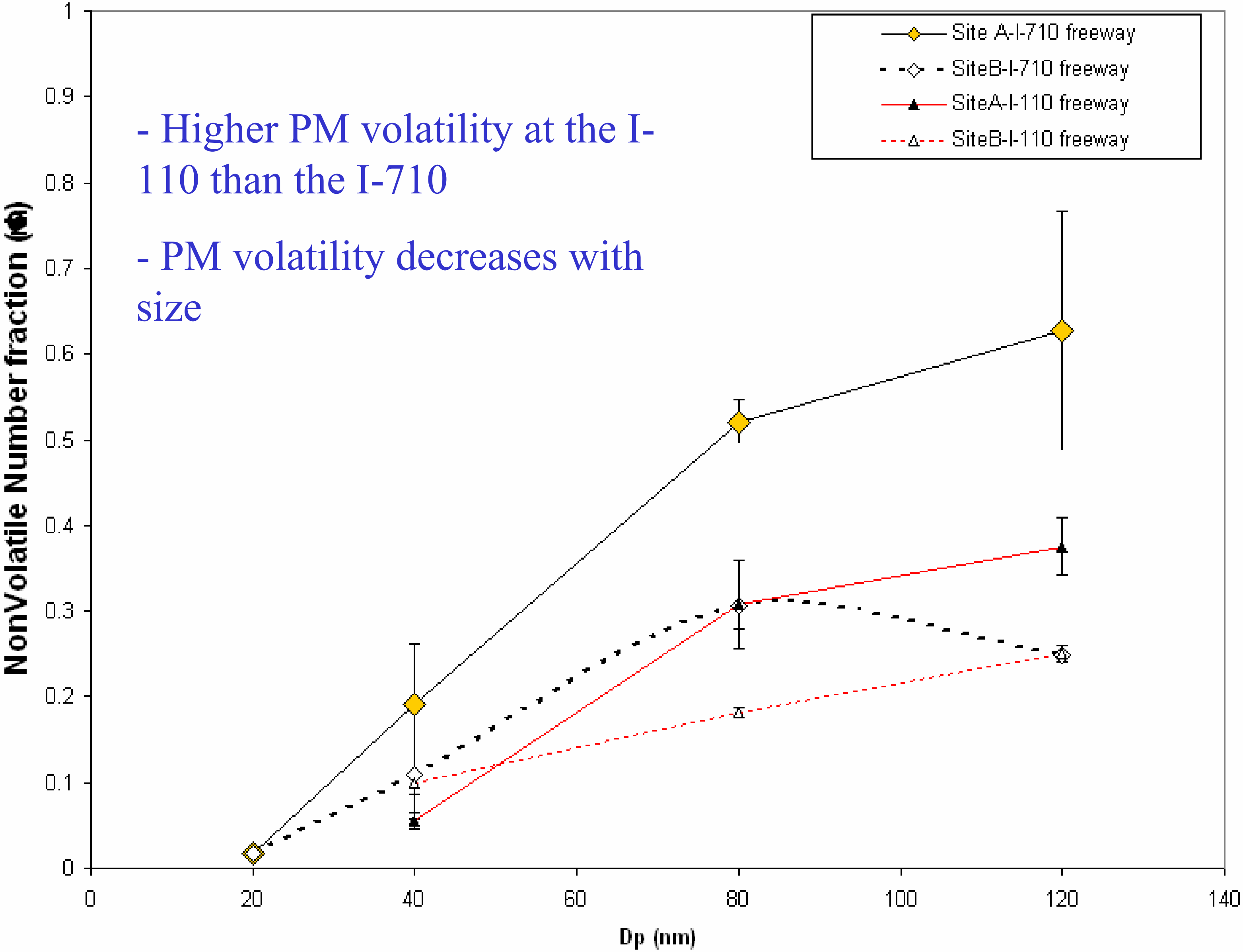
- Finally, given that the majority of people's exposure during commute will be dominated to these particles, it would be useful to know whether the non-volatile or semi-volatile material is more toxic.

Set-up: Tandem DMA
(Kuhn et al., J. Aerosol Science, 2004)

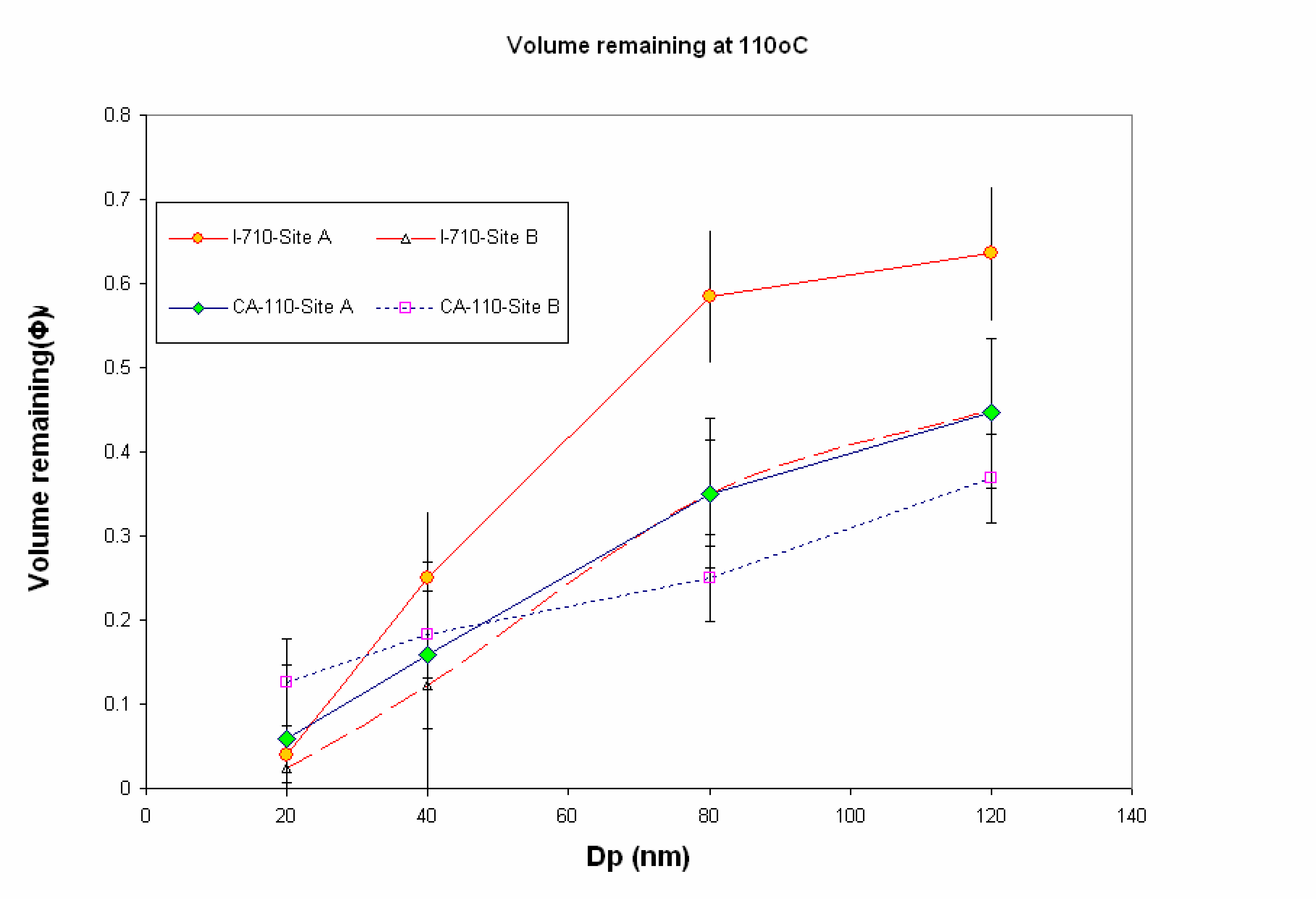


- Outdoor or Indoor aerosols in the I-405
- Outdoor only in the I-110 (gasoline freeway)


Amb. 18 nm Out
60 °C 18 nm Out
110 °C 18 nm Out
18 nm
Normalized ΔN/Δlog(dp)
0
0.2
0.4
0.6
0.8
1
10
20
30
Amb. 45 nm Out
60 °C 45 nm Out
110 °C 45 nm Out
45 nm
Normalized ΔN/Δlog(dp)
7
10
20
30
40
50
70
100
150
Particle diameter dp [nm]
Amb. 90 nm Out
60 °C 90 nm Out
110 °C 90 nm Out
90 nm
Normalized ΔN/Δlog(dp)
Particle diameter dp [nm]
Site A 120 nm Grand Average
Amb.
60 °C
110 °C
120 nm
dN/d(log dp)
0
2
4
6
8
10
12
14
16
18
20
Particle diameter dp [nm]

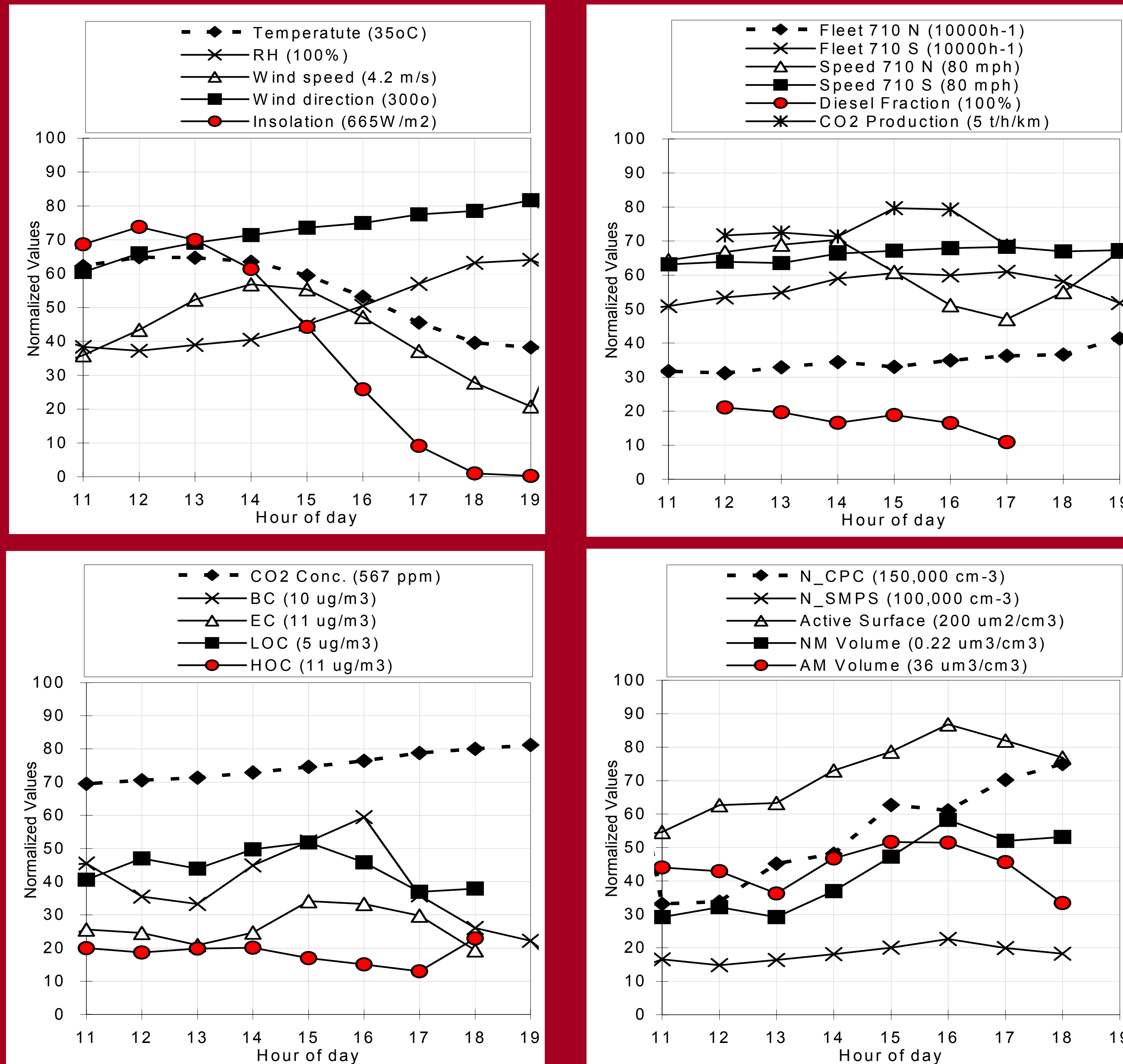


- Higher PM volatility at the I-110 than the I-710
- PM volatility decreases with size
Site A-I-710 freeway
SiteB-I-710 freeway
SiteA-I-110 freeway
SiteB-I-110 freeway
NonVolatile Number fraction
Dp (nm)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
20
40
60
80
100
120
140

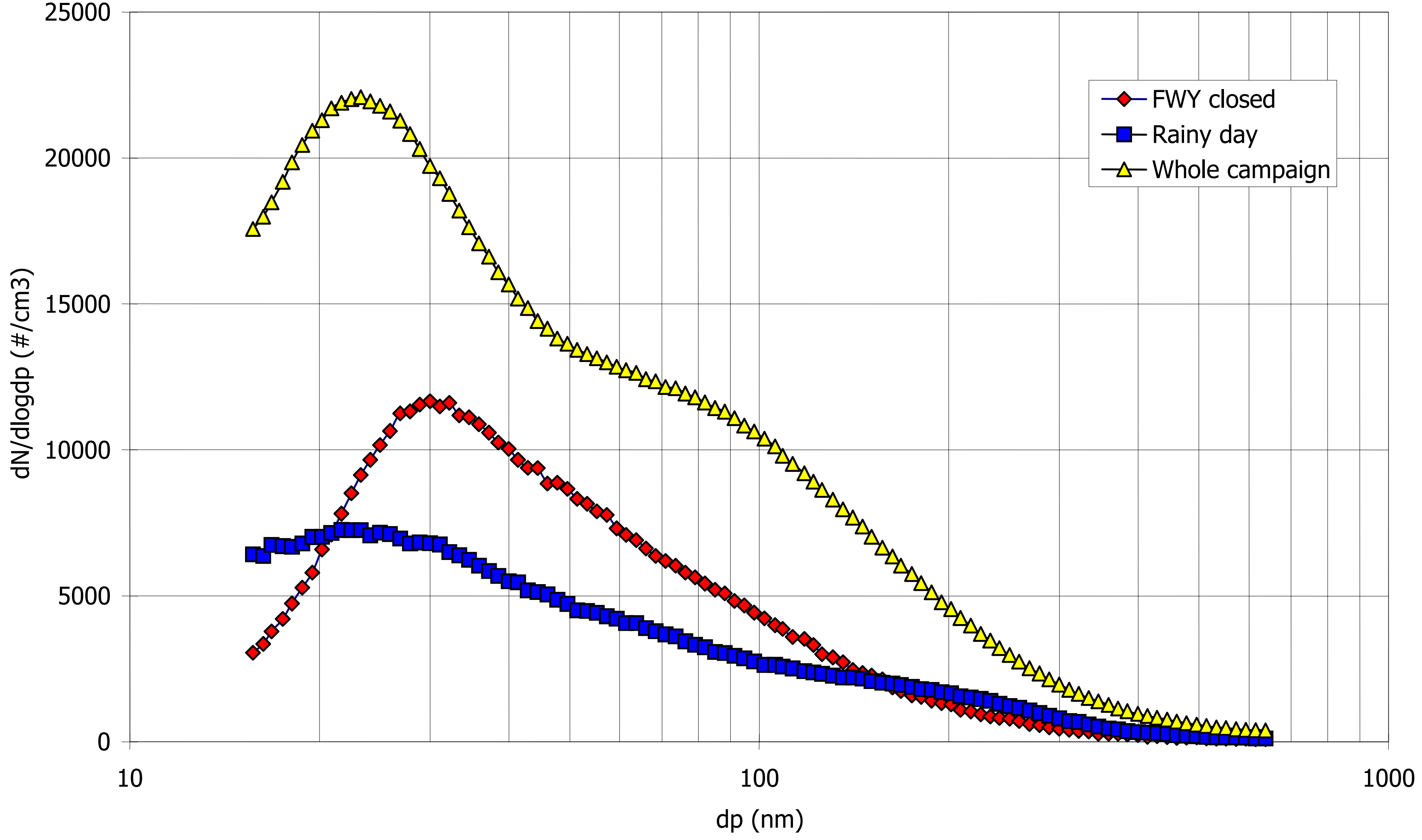


Volume remaining at 110oC
Volume remaining(Φ)
Dp (nm)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
140
I-710-Site A
I-710-Site B
CA-110-Site A
CA-110-Site B

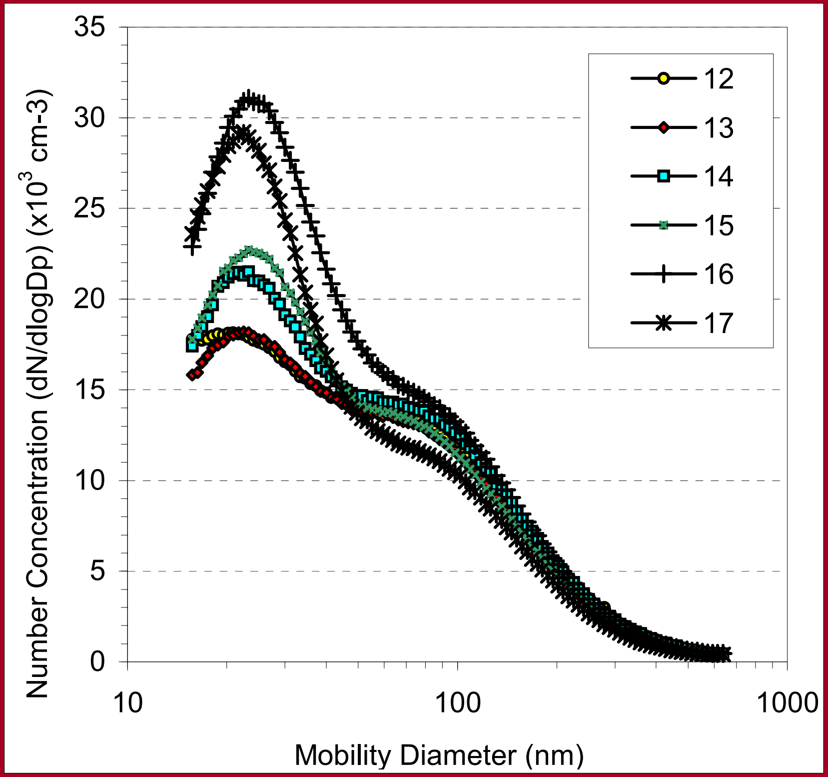
Diurnal Profiles At the I-710

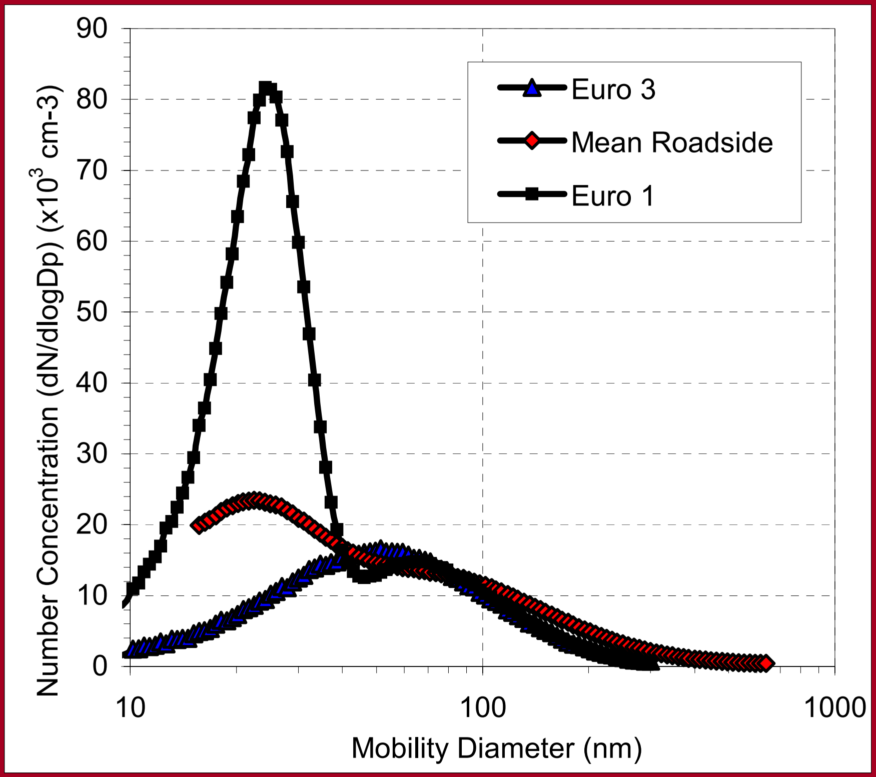


Events – Size Distributions



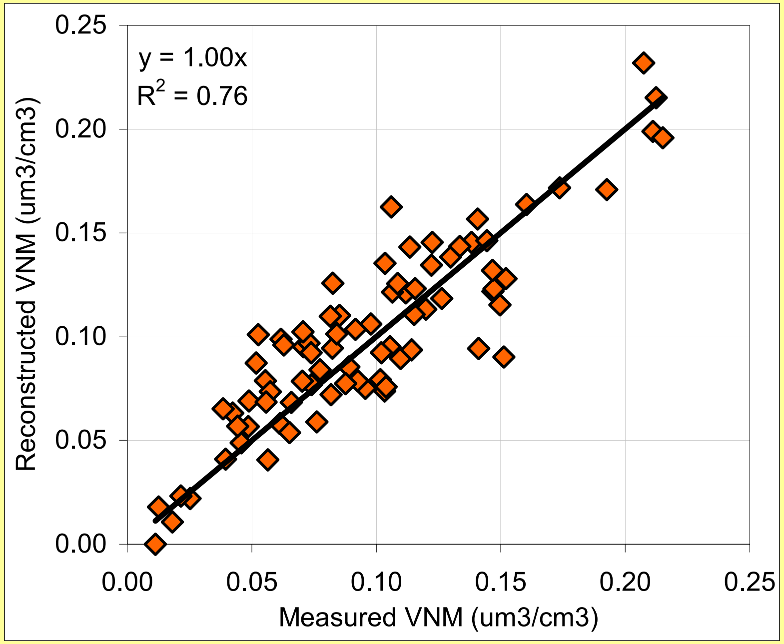
Size Distributions

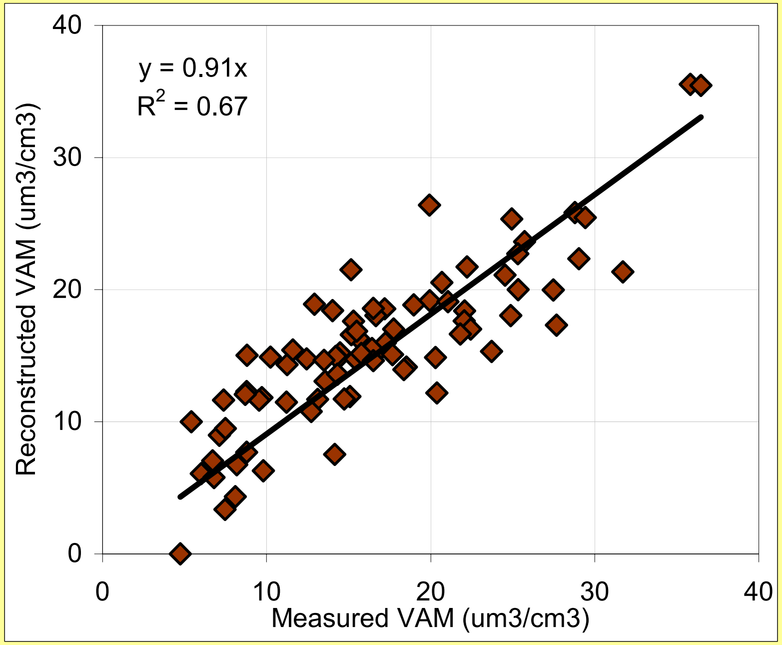




“Roadside” equivalent concentrations calculated assuming typical road engine operation conditions and CO2b=370ppm. DR=2200

Reconstructions





- **Nucleation Mode V Reconstruction**
  - CO_2: +0.51
  - Black Carbon: +0.33
  - Light OC: +0.22
  - Wind Speed: -0.18
- **Accumulation Mode V Reconstruction**
  - CO_2: +0.49
  - Black Carbon: +0.46
  - Heavy OC: +0.24
  - Solar Radiation: +0.35

DR Calculation: In Freeway, By Freeway, In tunnel

- 2006 Study - By freeway
  - CO_2: 100000[1]/(415-370)= 2200
- Westerdahl et al. (2005) - In freeway
  - CO_2: 100000[1] (ppm exh.)/ (850-370)= 210
  - NO: 200[1] (ppm exh.)/390 (ppb)= 500
  - CO: 700[1] (ppm exh.)/1.9 (ppm) = 350
- Geller et al. (2005) - In tunnel
  - CO_2: 122000[1] (ppm exh.) / (870-370)= 244
- Ratio of 2006 study and Westerdahl study
  - CO_2: 10
  - NO: 4
  - CO: 6
  - Take an average 7
- Ratio of 2006 study and Caldecott
  - CO_2: 9.3

(1) Mean exhaust concentration, corrected for HDV/LDV share

710 Comparison

Study	2006 Study		Westerdahl et al. 2005 (AE)		Geller et al. 2005 (ES&T)	
Location	I-710		I-710		Caldecott T. (B1)	
Period	Feb-Apr 2006		Feb-Apr 2003		Aug 2004	
Sampling Hours	12-16	17-19	-		12-18	
Distance from freeway (a)	20m		5 m		In tunnel (d)	
PCs (h^{-1})	8359	10250	7580(b)		4041	
LDT(h^{-1})	600	360	-		91	
HDTs (h^{-1})	1630	1225	1040(b)		64	
T	21.4	14.4	21		23.3	
RH	42	60	-		59	
Wind Speed (m/s)	2.16	1.21	2		-	
CPC	75000	98500	190000	42857	637500	86398
CO (ppm)	0.27	0.11	1.9	0.36	8.78	1.0
BC (μg/m^3)	4.6	2.8	12	5.1	27.5(c)	6.5
Dilution Ratio	1			1:7		1:9.3
CO_2 (ppm)	415	454	850	439	870	426

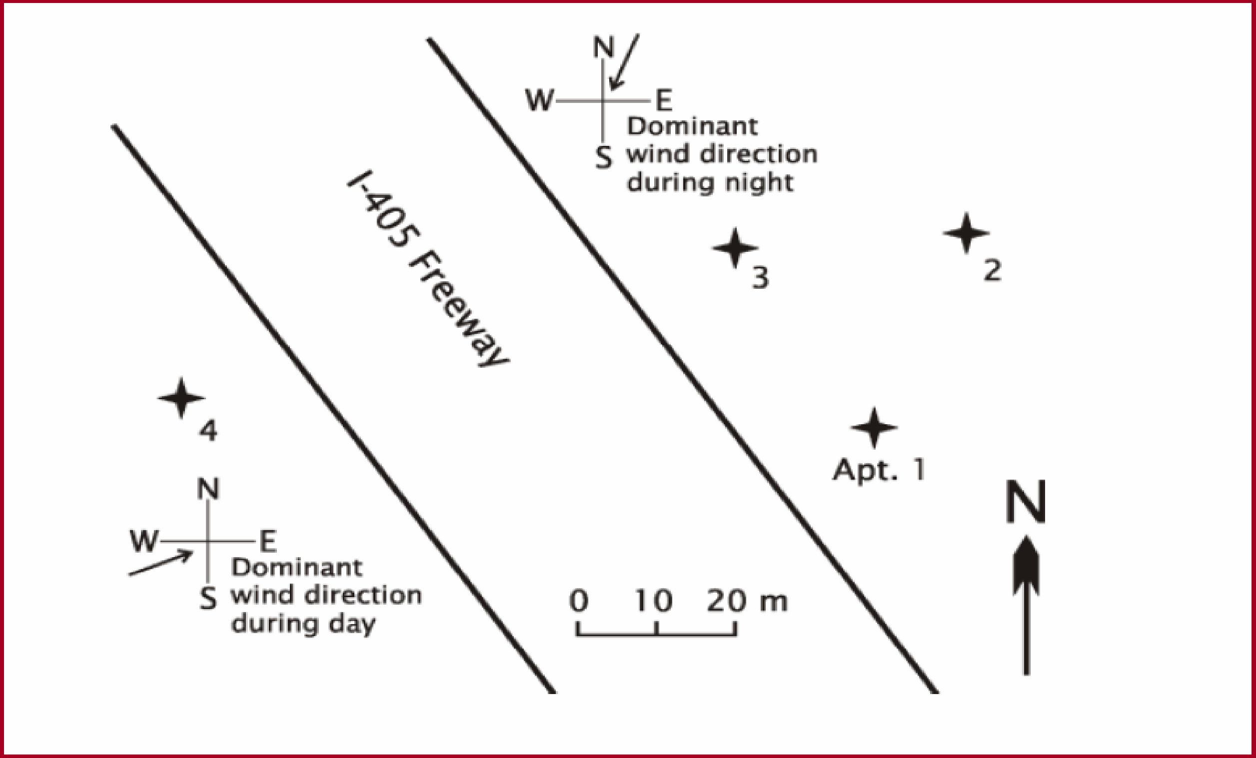
a Distances measured from median strip

b Daily averages from CalTrans

c Elemental carbon

d 4.2% uphill driving

What is the Impact of Mobile Sources In Indoor Environments?

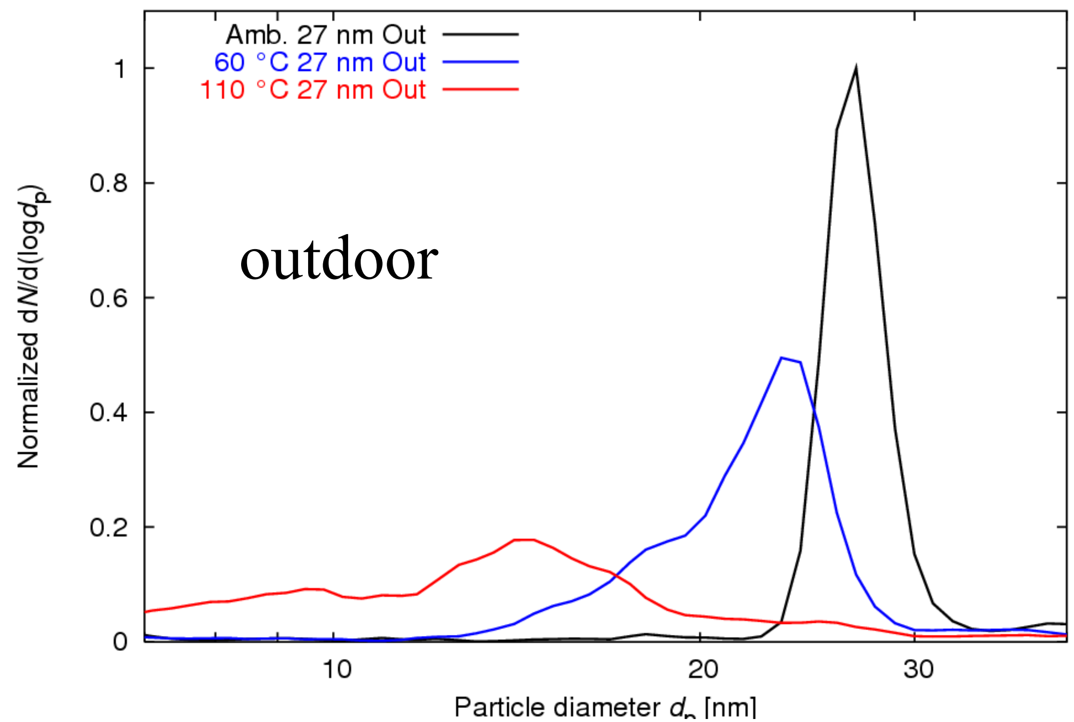


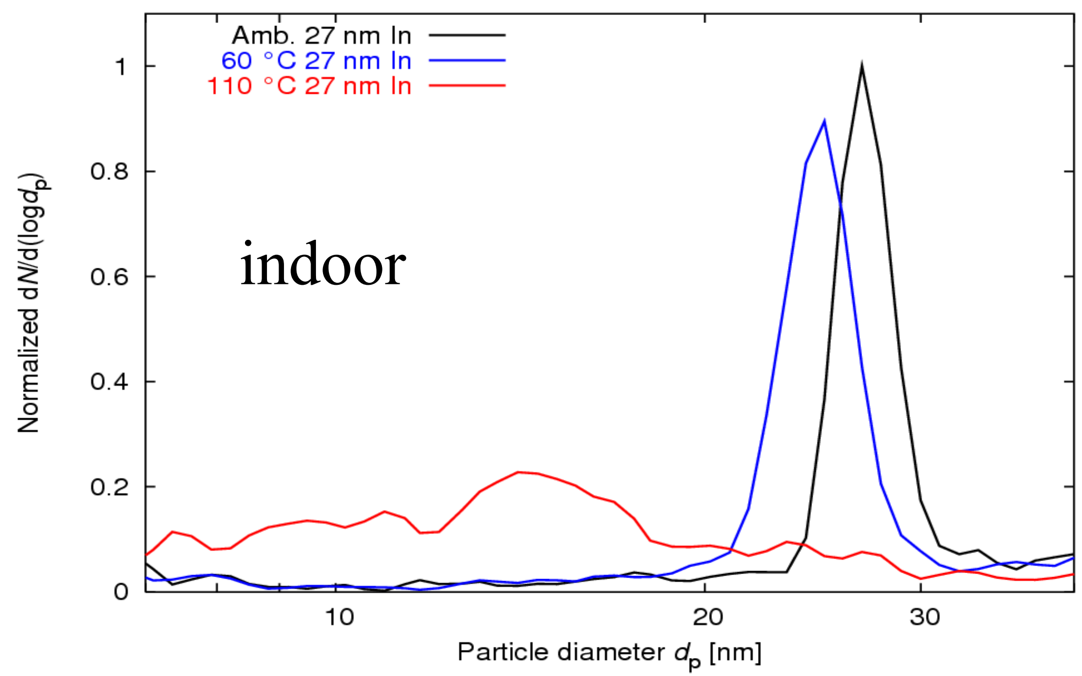
- 4 residences in proximity of I-405
- No indoor sources during tests
- 3 ventilation conditions tested

(Zhu et al., J Aerosol Science, 2004)

Indoor – Outdoor Comparisons

- It is evident that indoor particles of the same size are less volatile indoors
- This is because they may have already shrunk to that size from a larger outdoor particle





-Non volatile volume fraction of indoor PM consistently higher than outdoors.

- Volatility increases with decreasing particle size both indoors and outdoors

T. Kuhn et al. / Aerosol Science 36 (2005) 291–302

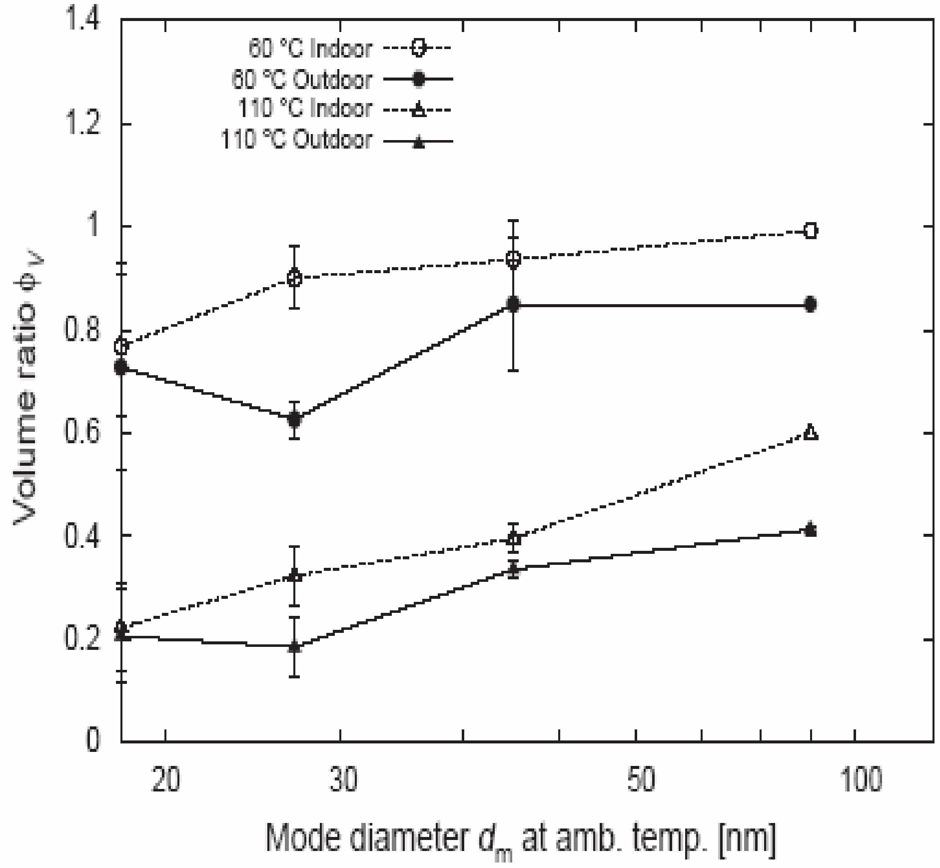
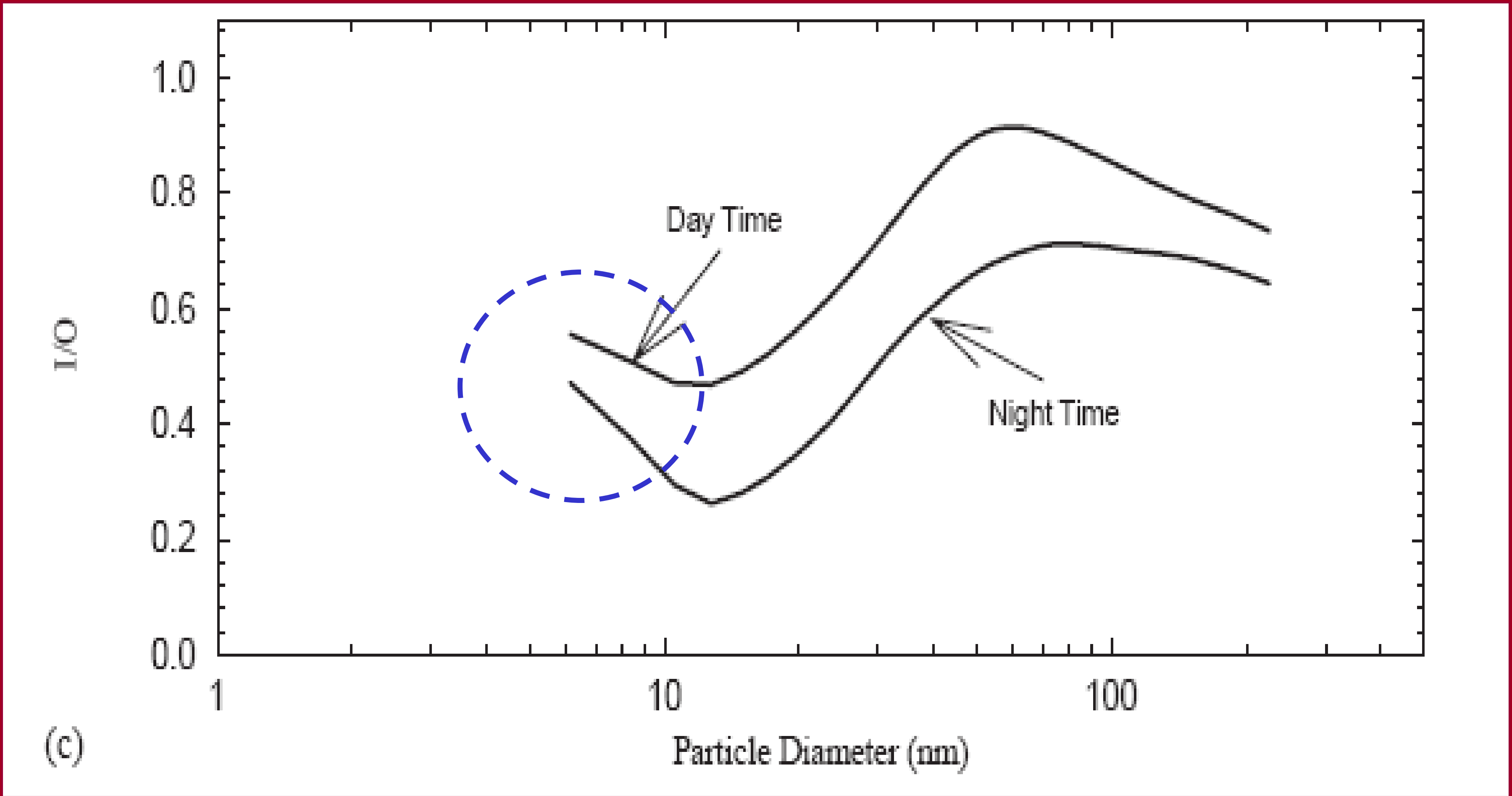


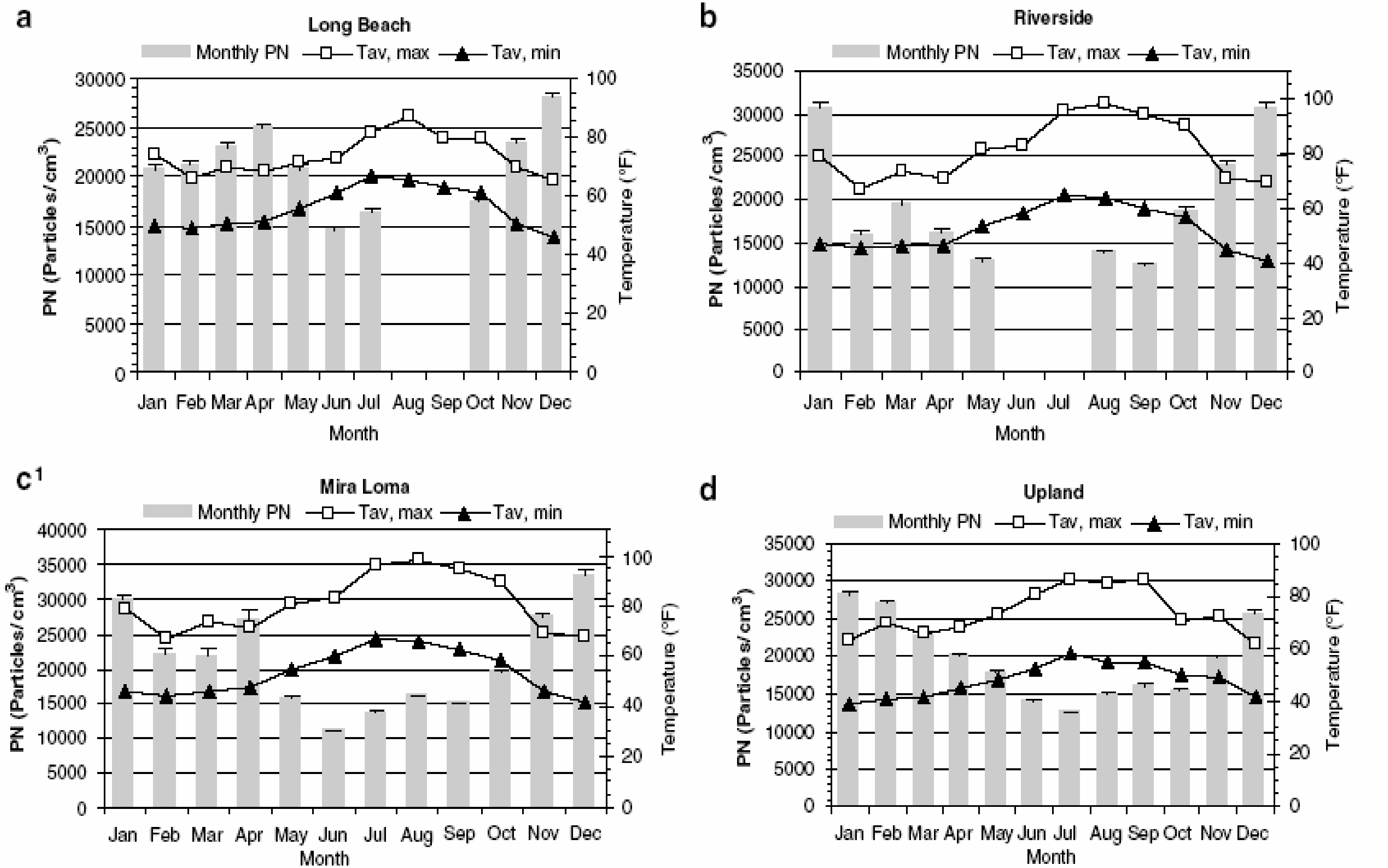
Fig. 6. Comparison of fractions ϕ_V for outdoor and indoor aerosols at Apt. 1.



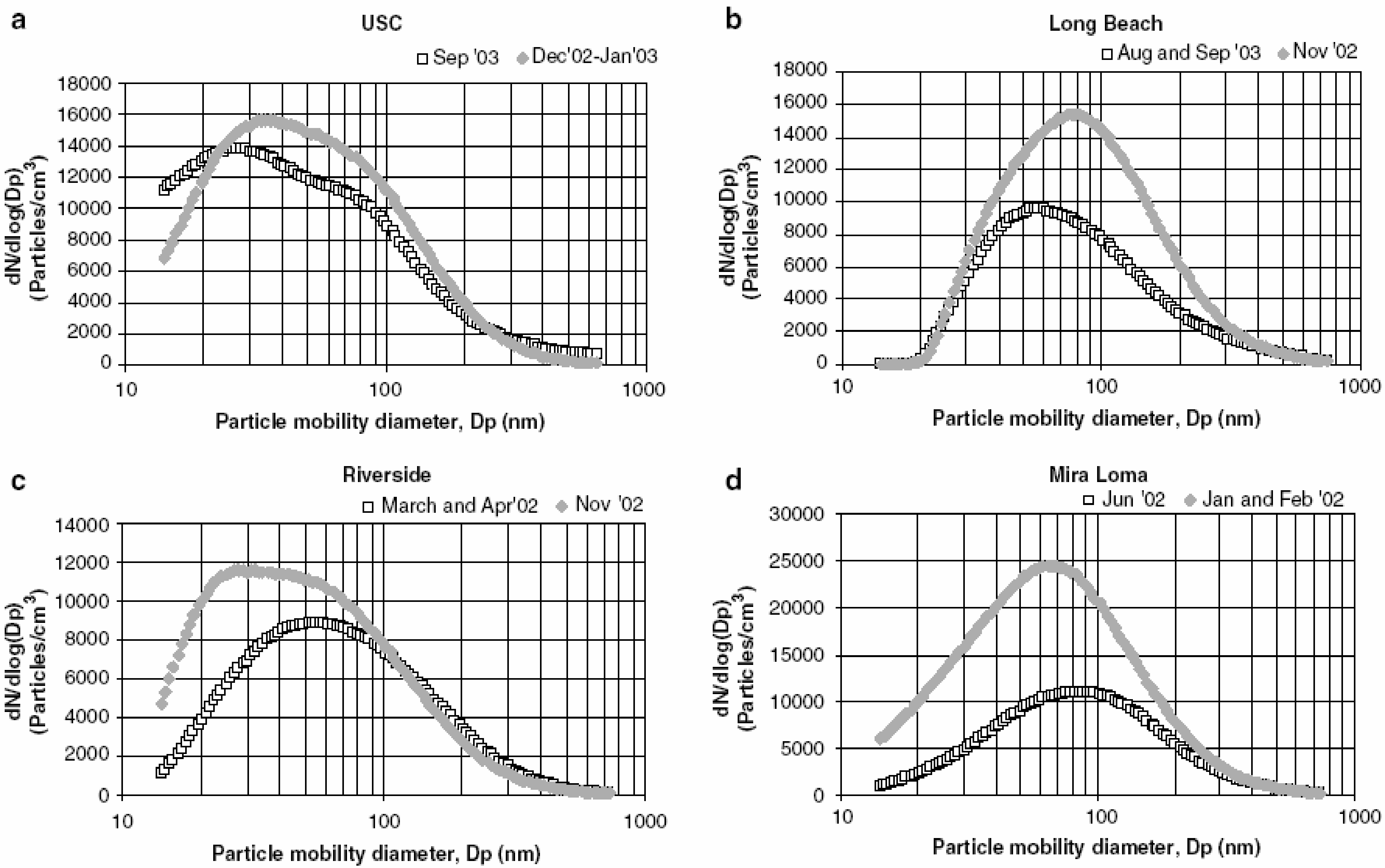
- For particles less than 20 nm, I/O ratios, penetration factors and deposition rates did not follow the trend of theoretical classic aerosol theory.

- Possible reason may be the unique, semi-volatile, nature of freeway ultrafine particles.

(Zhu et al., J Aerosol Science, 2004)



[1] The temperature data for Mira Loma was not available. The data plotted above was taken from the nearest available site Riverside firestation (around 10 kms east of Mira Loma)


a
USC
Sep '03
Dec'02-Jan'03
dN/dlog(Dp) (Particles/cm3)
Particle mobility diameter, Dp (nm)
b
Long Beach
Aug and Sep '03
Nov '02
dN/dlog(Dp) (Particles/cm3)
Particle mobility diameter, Dp (nm)
c
Riverside
March and Apr'02
Nov '02
dN/dlog(Dp) (Particles/cm3)
Particle mobility diameter, Dp (nm)
d
Mira Loma
Jun '02
Jan and Feb '02
dN/dlog(Dp) (Particles/cm3)
Particle mobility diameter, Dp (nm)

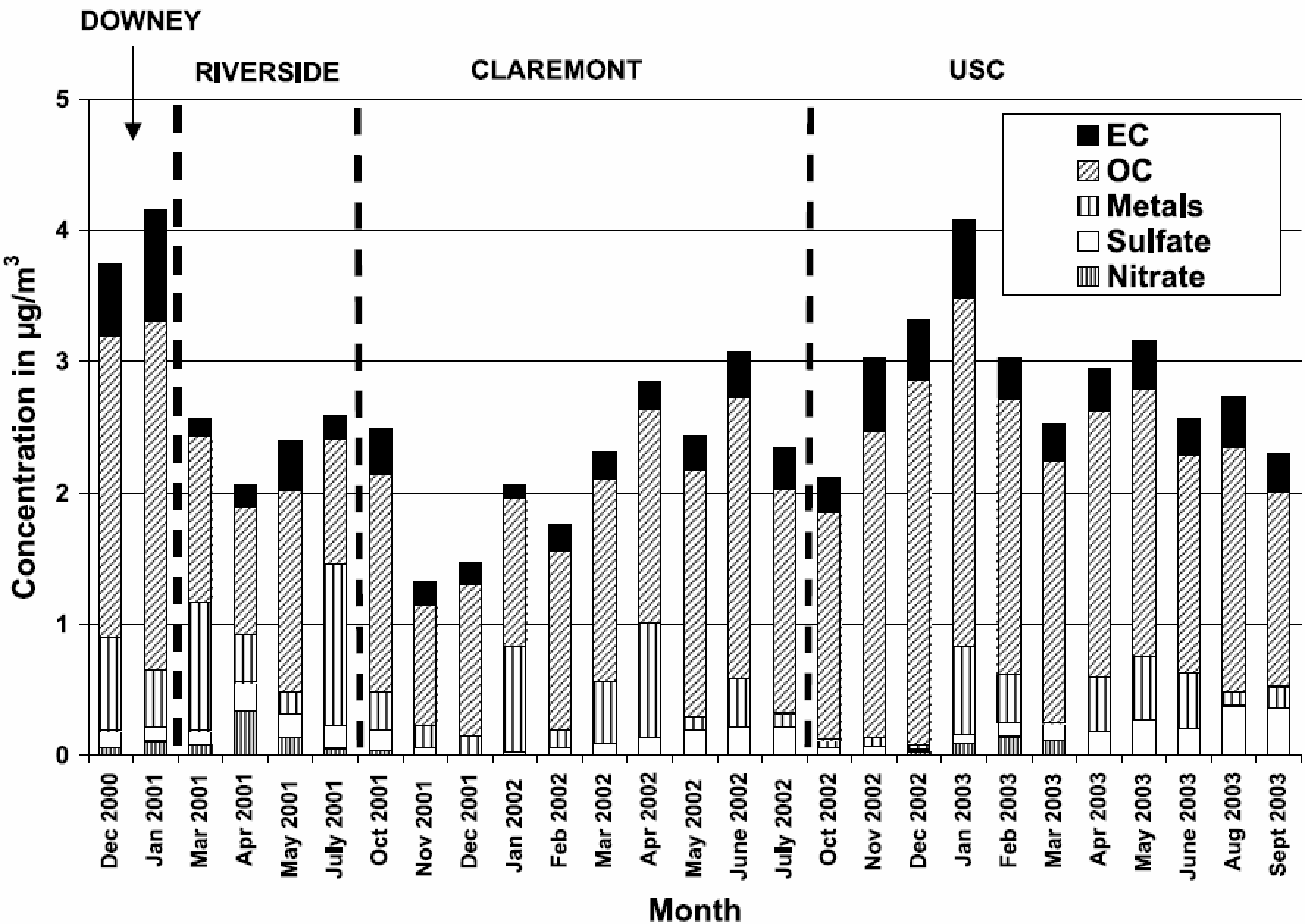


Figure 5. Monthly average PM chemical composition in the ultrafine mode.

Ultrafine Organics – Hi-Volume UF Sampler

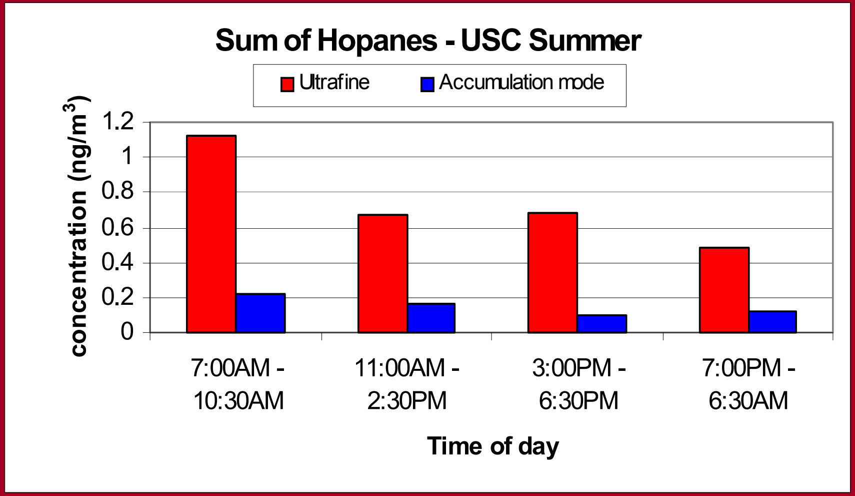
Impactor used to collect accumulation mode PM (>180 nm)

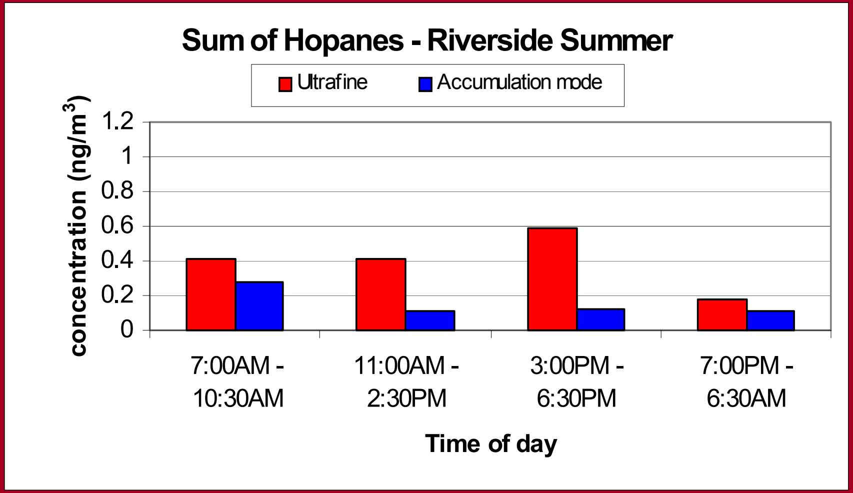
Hi-Volume Teflon-coated glass 8"x10" filter downstream for ultrafine collection

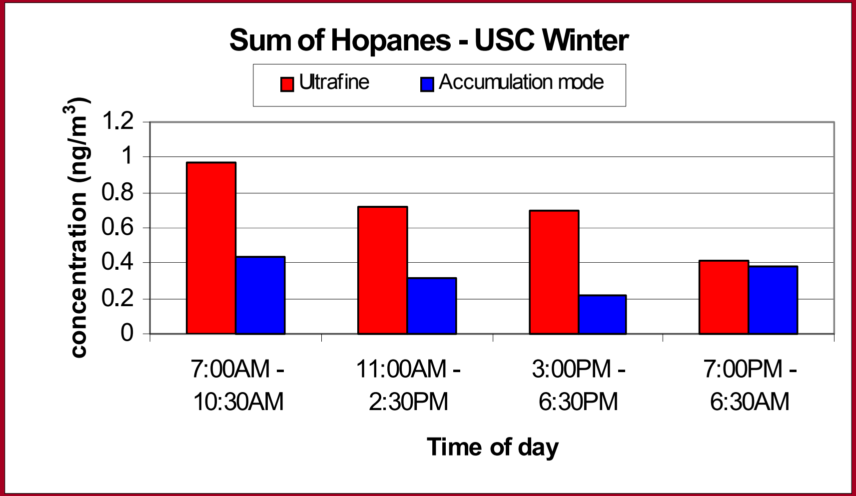
"High-Volume, Very Low Pressure Drop Impactor for Separation of Coarse-Fine-Ultrafine PM " Misra et al *Journal of Aerosol Science*, 33(5): 735-752, 2002

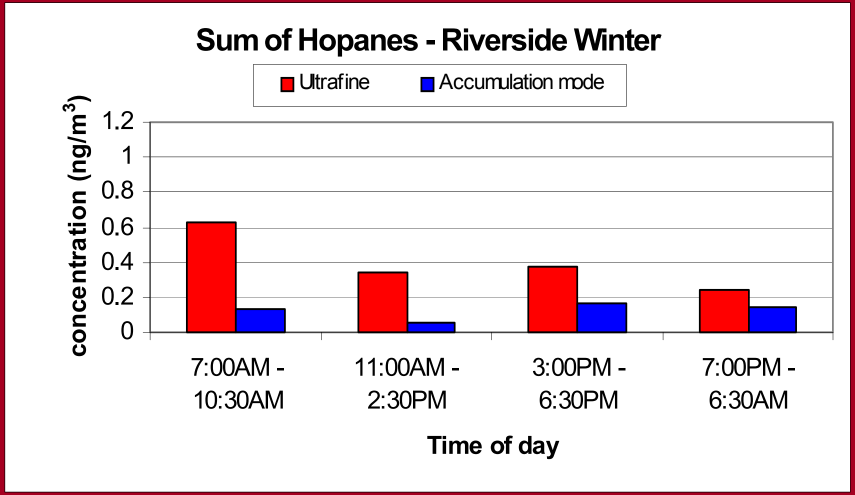
Ultrafine Organics – Vehicular Emissions

Sum of three predominant hopanes:
17a(H),21b(H)-hopane, 17a(H),21b(H)-29-norhopane, 22,29,30-trisnorneohopane





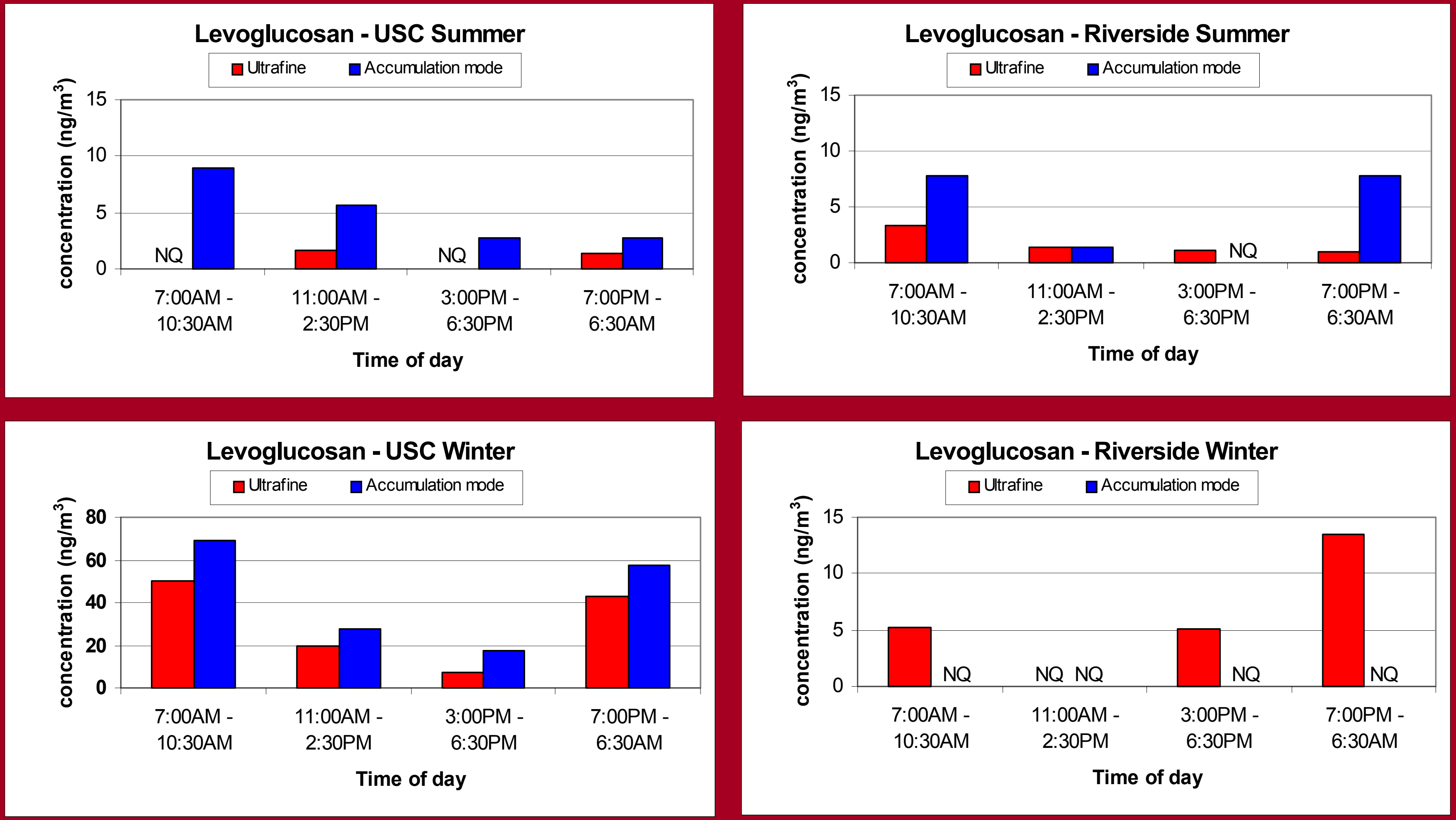




- **Higher at USC (downtown) than Riverside (inland)**
- **Enriched in ultrafine mode at both locations**

Ultrafine Organics – Wood Smoke

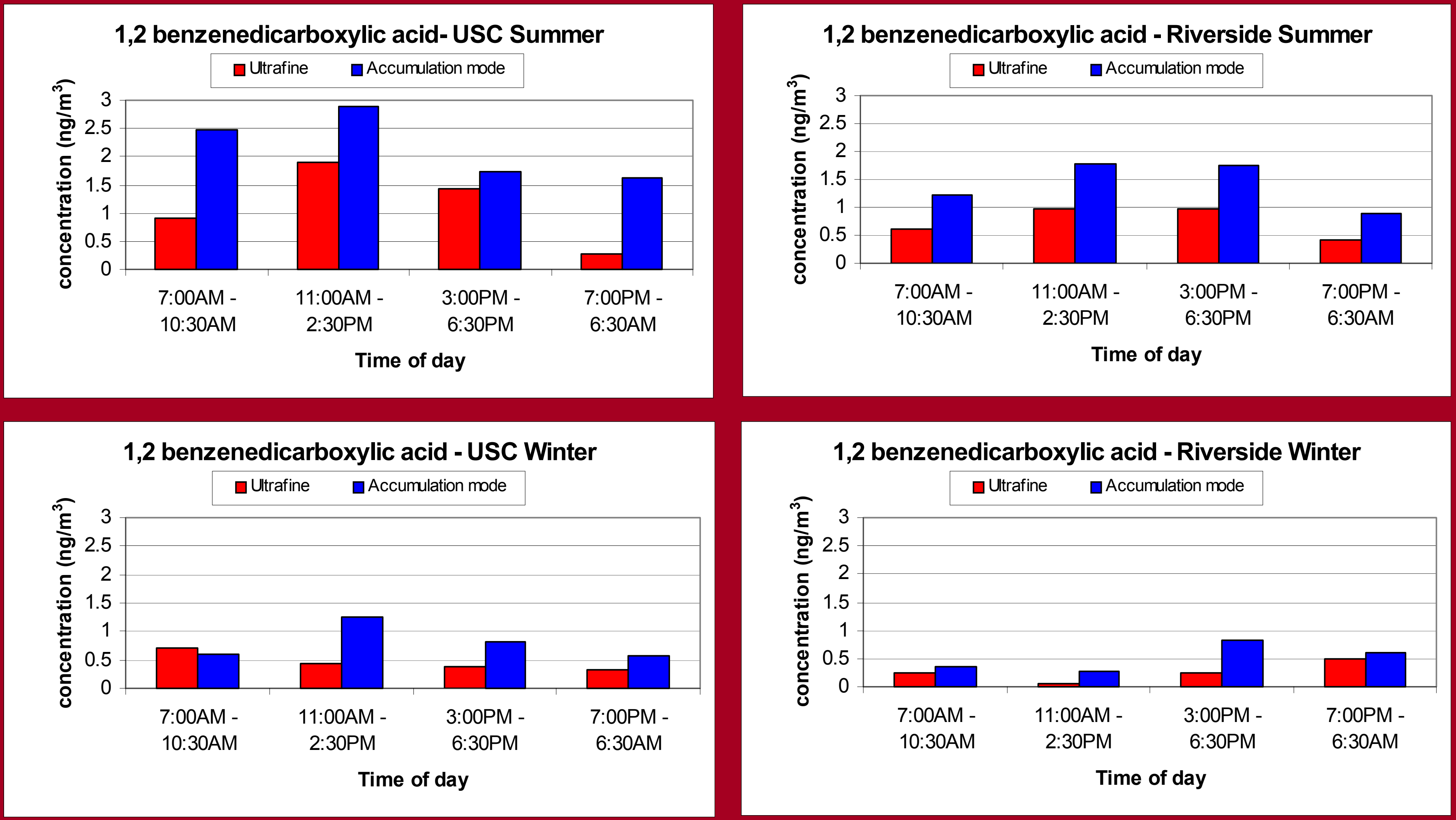
Levoglucosan used as tracer



- **Enriched in accumulation mode at both locations**
- **Higher in winter than summer (residential wood burning), extremely high at USC**

Ultrafine Organics – Secondary Organics

Several benzenepolycarboxylic acids quantified



- Higher in summer than winter (photochemistry), but surprisingly higher at USC than Riverside
- Higher in accumulation mode at both sites (condensation onto existing particles), but also in UF
- Peaks midday at USC but during evening at Riverside (advection across basin)

Table 1. Hourly Pearson Correlation Coefficient, r, of PN vs. Co-pollutant concentrations for the entire calendar year 2002, all sites

	Glendora	Long Beach	Mira Loma	Riverside	Upland
CO	0.13	0.46	0.47	0.52	0.66
NO	0.06	0.44	0.60	0.59	0.65
NO_2	0.21	0.50	0.24	0.32	0.17
PM_{10}	0.18	0.27	0.00	-0.16	0.14
O_3	0.30	-0.22	-0.34	-0.04	-0.26

Table 2. 24-hr Average Pearson Correlation Coefficient, r, of PN vs. Co-pollutant concentrations for the entire calendar year 2002, all sites

	Glendora	Long Beach	Mira Loma	Riverside	Upland
CO	0.00	0.50	0.44	0.39	0.63
NO	0.30	0.48	0.34	0.32	0.66
NO_2	0.07	0.68	0.11	0.23	0.08
PM_{10}	-0.18	0.10	-0.17	-0.32	-0.19
O_3	-0.31	-0.63	-0.33	-0.26	-0.54

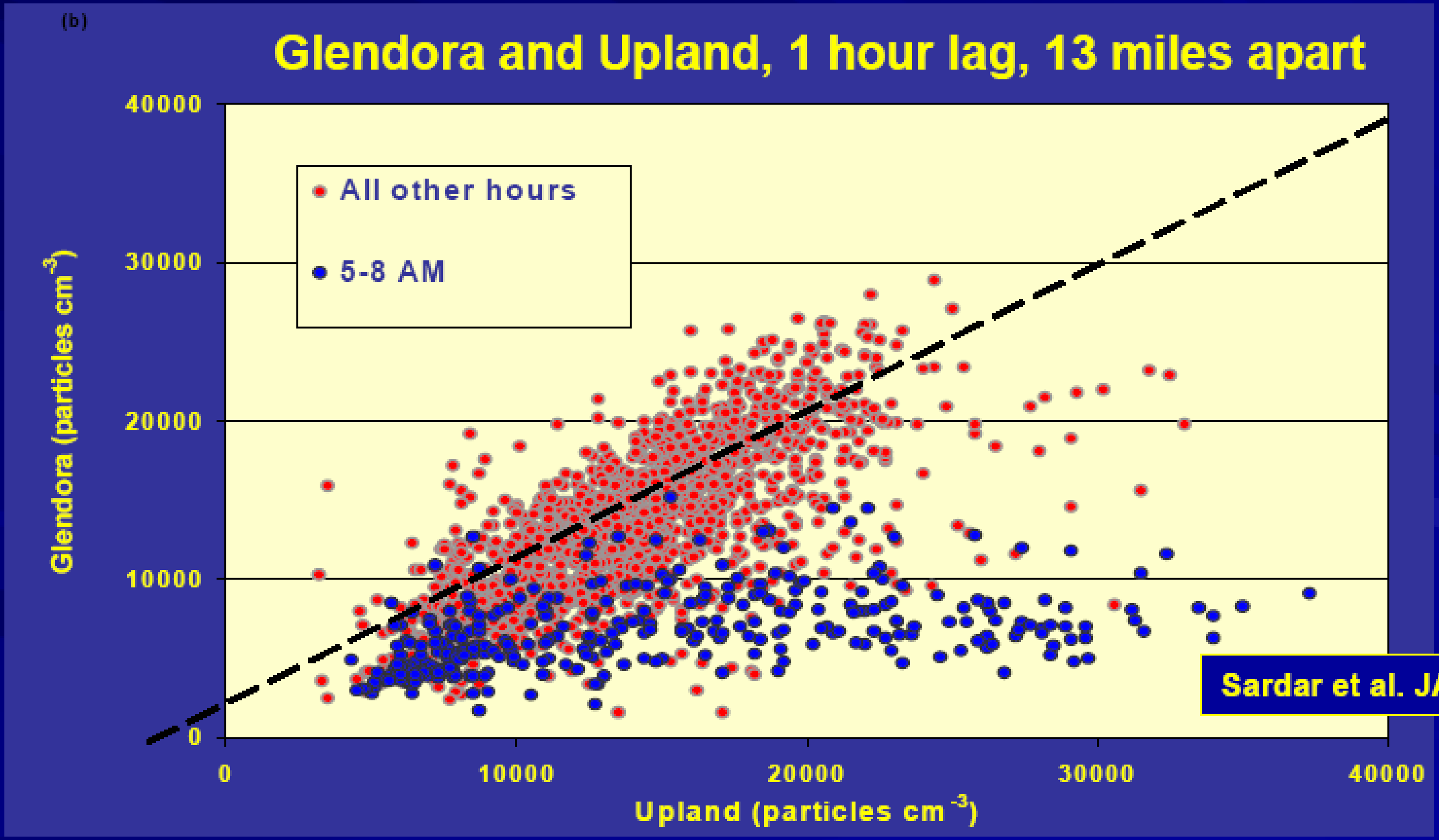
- **Generally low to moderate correlations between PN and gaseous co pollutants as well as PM10**

- **Hourly associations > 24 hr associations**

- ***(Sardar et al, JAWMA, 2004)***

UFP Are Spatially Inhomogeneous

- More challenging than more spatially homogeneous pollutants such as ozone and $PM_{2.5}$
  - Local sources (traffic) can dominate Ultrafine Number concentrations at any given location



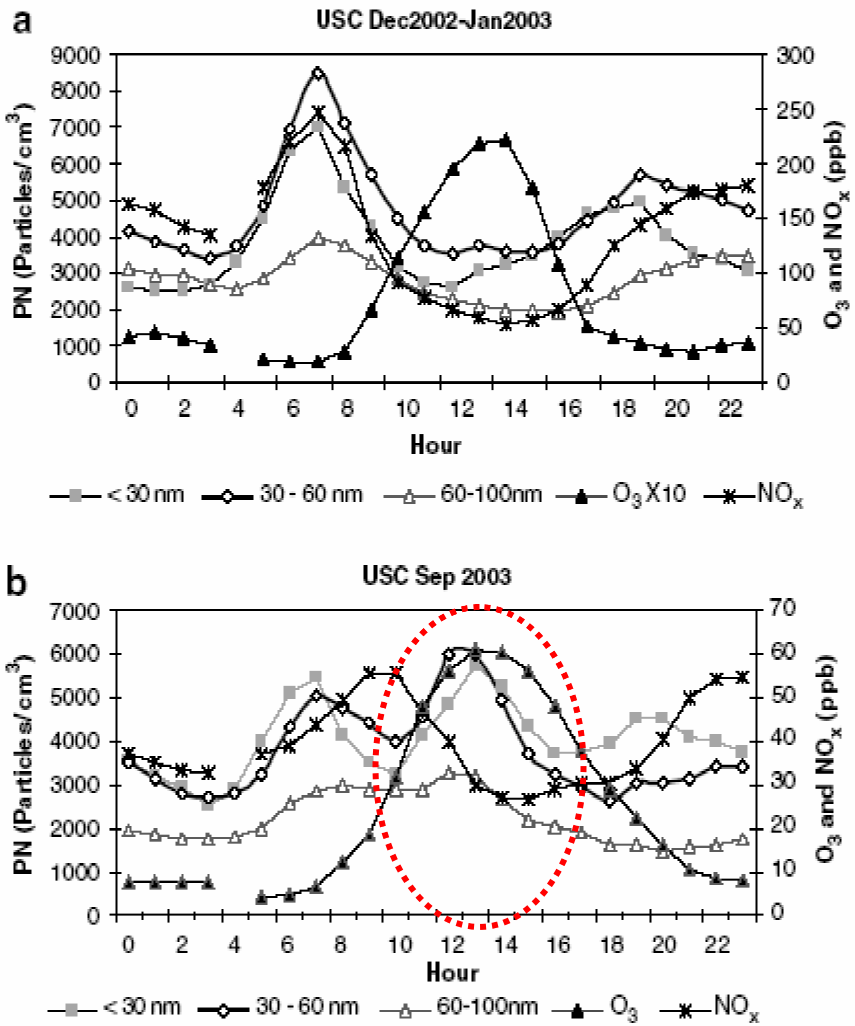


Figure 4. Diurnal trends of size-segregated particle number, O_3 and NO_x at USC during (a) Dec 2002–Jan 2003 and (b) Sep 2003.

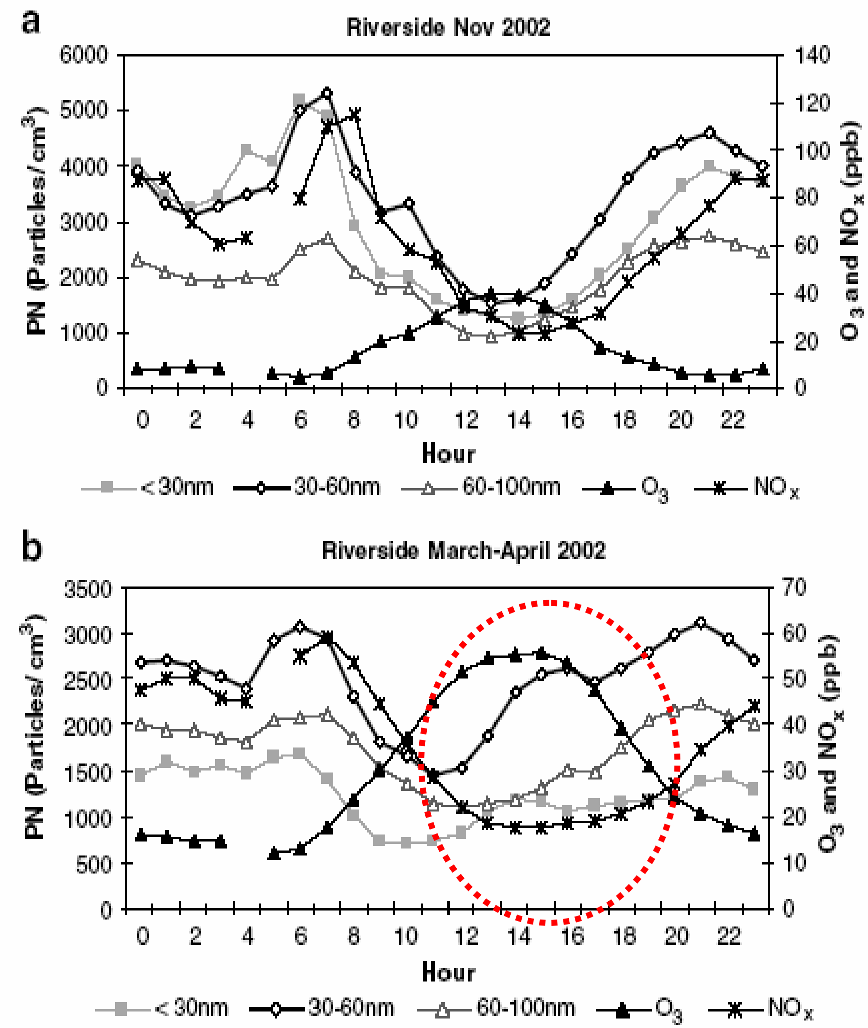


Figure 6. Diurnal trends of size-segregated particle number, O_3 and NO_x at Riverside during (a) Nov 2002 and (b) Mar–Apr 2002.

Photochemical Secondary Formation of Ultrafine PM in LA

Sardar et al., ES&T, 2005

TABLE 4. Size Fractionated PN vs Gas Pollutants — Pearson Correlation Coefficients (*r*) at Source and Receptor Sites

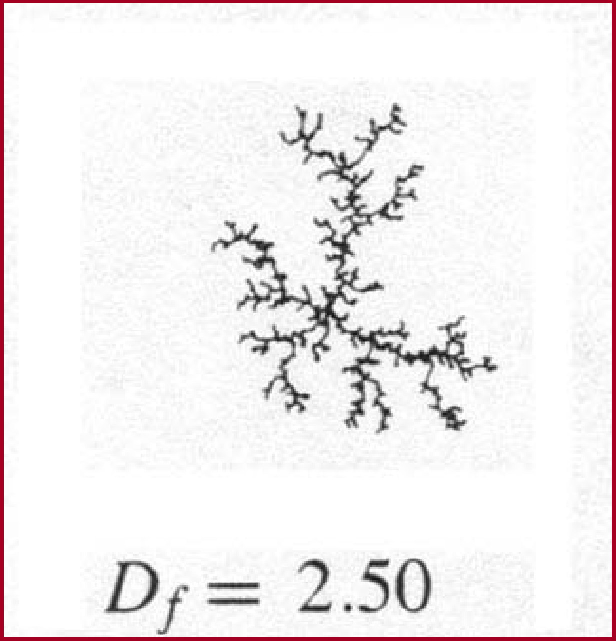
size range (nm)	CO	NO_x	O3
Fall Long Beach			
0—32	−0.26	−0.03	0.26
32—56	0.20	0.31	−0.15
56—100	0.49	0.52	−0.38
100—180	0.66	0.66	−0.50
180—320	0.68	0.70	−0.47
320—1000	0.48	0.56	−0.30
Winter USC			
0—32	0.09	0.23	−0.03
32—56	0.38	0.54	−0.10
56—100	0.65	0.78	−0.13
100—180	0.65	0.75	−0.05
180—320	0.64	0.62	−0.06
320—1000	0.53	0.45	0.01
Summer USC			
0—32	0.25	0.28	0.62
32—56	0.16	0.16	0.68
56—100	0.19	0.21	0.59
100—180	0.35	0.41	0.44
180—320	0.26	0.31	0.39
320—1000	0.29	0.36	0.21
Winter Long Beach			
0—32	0.48	0.66	−0.45
32—56	0.67	0.84	−0.50
56—100	0.78	0.80	−0.51
100—180	0.75	0.60	−0.37
180—320	0.69	0.46	−0.18
320—1000	0.59	0.32	−0.04
Summer Long Beach			
0—32	0.25	0.28	0.64
32—56	0.22	0.24	0.69
56—100	0.33	0.40	0.54
100—180	0.46	0.63	0.40
180—320	0.47	0.63	0.25
320—1000	0.32	0.61	0.14

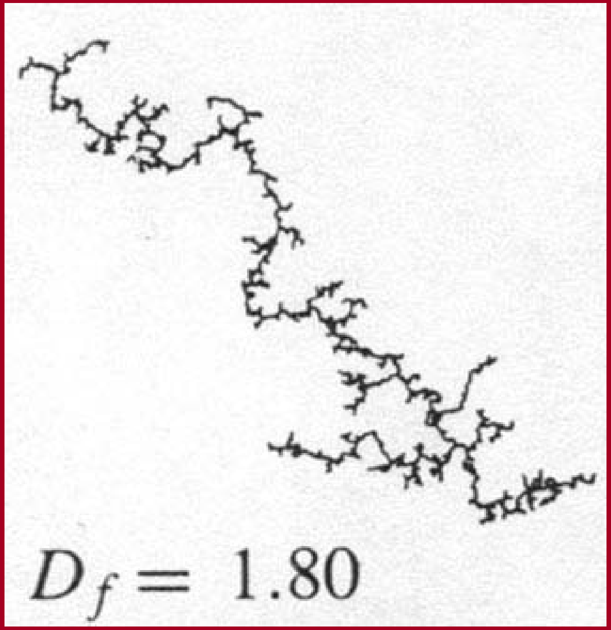
Sardar et al., ES&T, 2005

-high correlation between ultrafine PM and tracers of traffic (CO, NOx) in winter

- high correlation between ultrafine PM and O_3 in summer

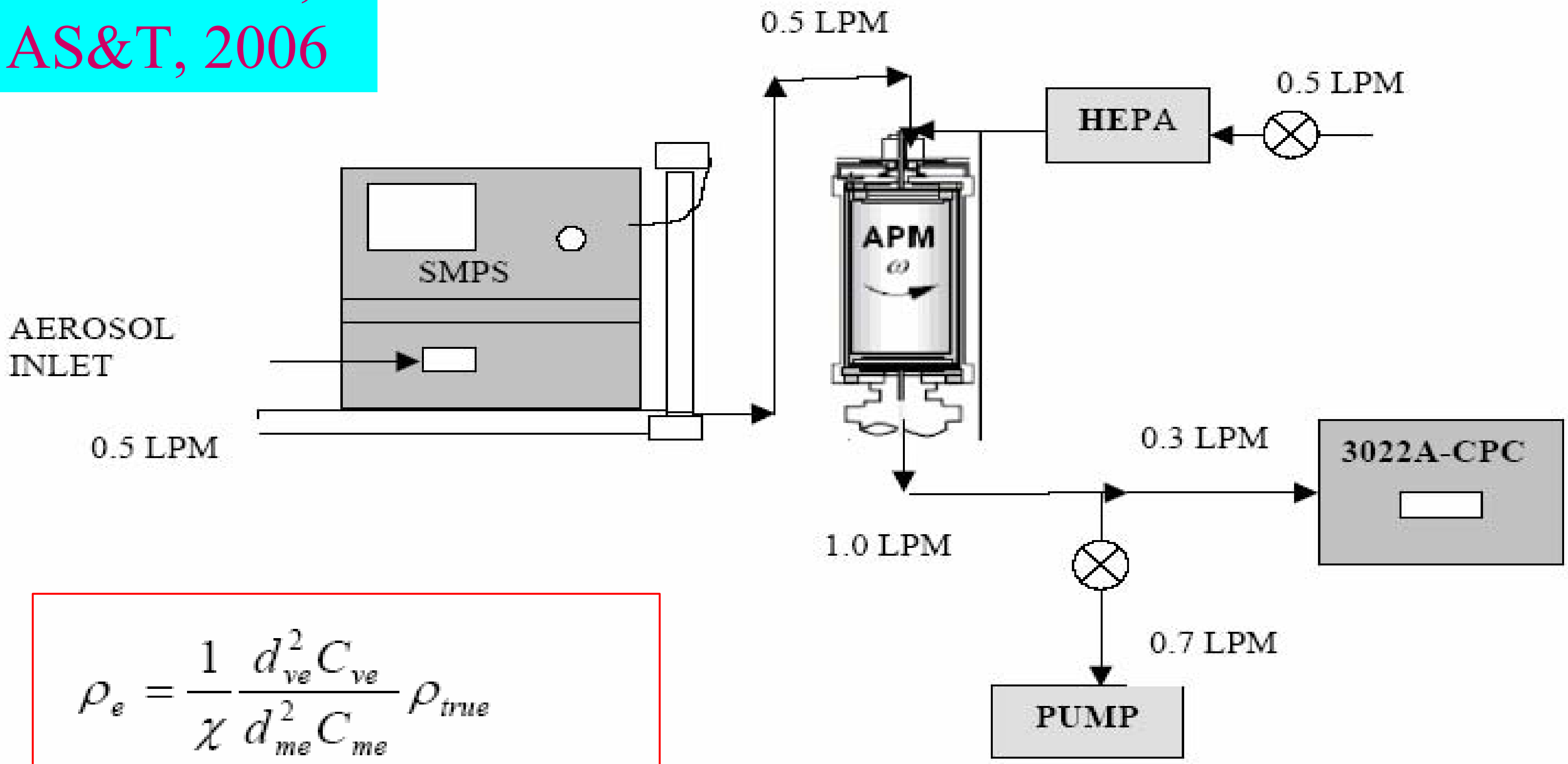
Effective Particle Density





Fractal-like combustion particles have a high surface area, hence electrical mobility, but a low density

Geller et al., AS&T, 2006



$$\rho_e = \frac{1}{\chi} \frac{d_{ve}^2 C_{ve}}{d_{me}^2 C_{me}} \rho_{true}$$

FIGURE 1. Schematic diagram of DMA-APM set-up

where ρ_e is the effective density, X is dynamic shape factor, d_{ve} is the volume equivalent diameter, d_{me} is the mobility equivalent diameter, C is the Cunningham correction factor, and ρ_{true} is the bulk density of the material (McMurry et al., 2002).

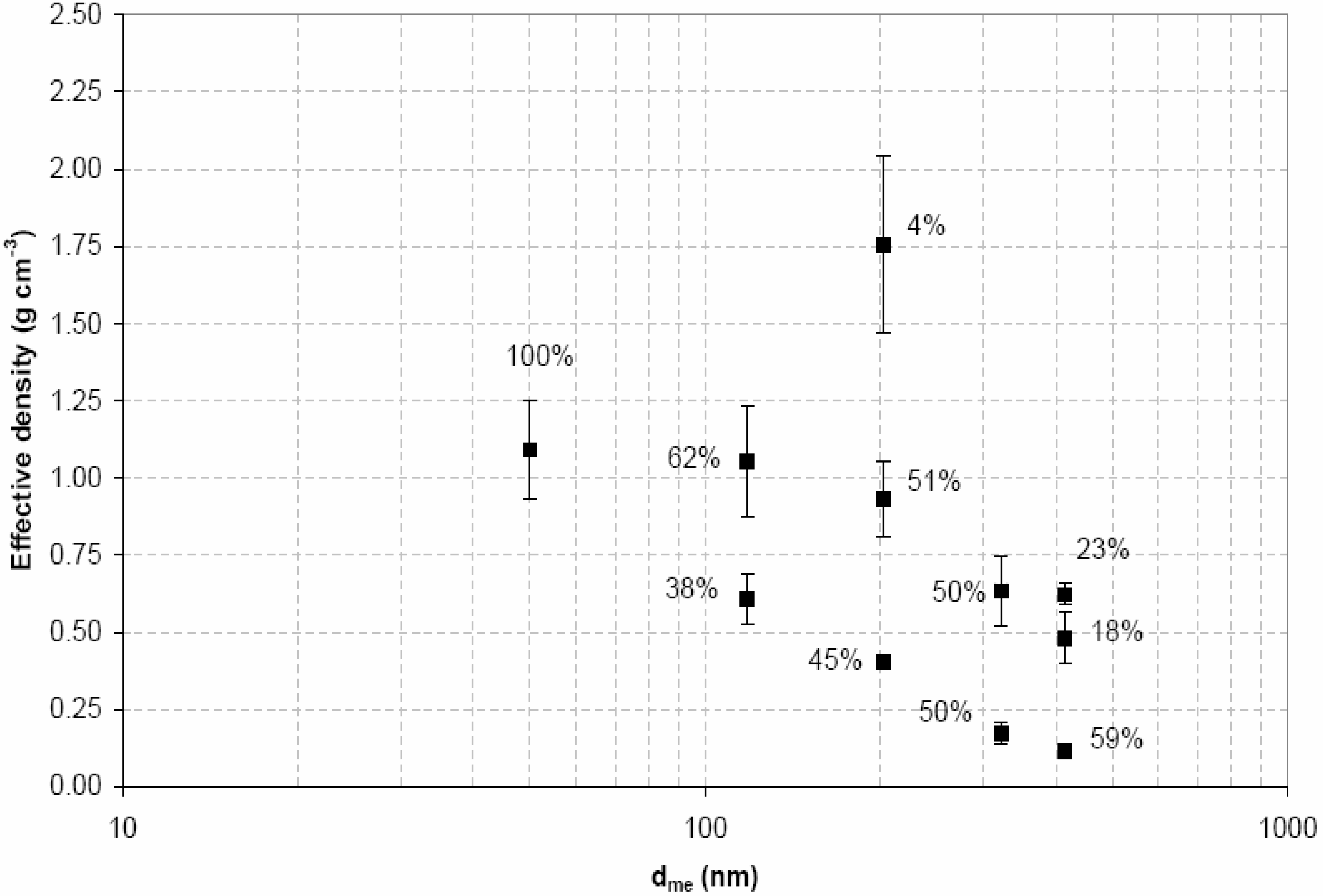


Figure 7. Effective density variation with respect to particle mobility diameter at I-710. Data labels indicate percentage of number concentration measured for each particle size with respective effective density.

Geller et al., AS&T, in press, 2006

Table 4. Summary of average effective densities of different field locations and their fractal dimensions

	Average Effective density (ρ_e), g cm^{-3}				
Mobility diameter (d_m, nm)	USC	710-freeway	110-freeway	Riverside	Coast
50	1.14 ± 0.1	1.13 ± 0.10	1.45 ± 0.12	1.40 ± 0.10	1.19 ± 0.10
118	1.12 ± 0.14	1.00 ± 0.12	1.17 ± 0.02	1.40 ± 0.06	1.14 ± 0.23
146	1.21 ± 0.08	0.94 ± 0.16	NA	1.29 ± 0.06	0.99 ± 0.10
202	1.14 ± 0.24	0.78 ± 0.26	0.99 ± 0.09	1.06 ± 0.09	1.06 ± 0.20
322	0.86 ± 0.11	0.49 ± 0.07	0.59 ± 0.27	NA	NA
414	0.73 ± 0.10	0.31 ± 0.02	0.58 ± 0.06	NA	NA
Fractal Dimension	2.79 ± 0.15	2.41 ± 0.22	2.54 ± 0.28	2.83 ± 0.06	2.92 ± 0.15

Geller et al., AS&T, in press, 2006

Future Research in Southern California

Renewed Southern California Particle Center, funded by US EPA:

- Determine the physical and chemical properties of ultrafine PM from real-world sources, including secondary formation, to evaluate how exposure to UFP vary with respect to:
  - location, season, and particle size,
  - assess their relative toxicity.

- Assess the contributions of these outdoor sources to indoor exposure and toxicity.

- Determine the physical, chemical and toxicological characteristics of the volatile and non-volatile UFP components that originate from mobile sources.

Physicochemical and toxicological assessment of the semi-volatile and non-volatile fractions of PM from heavy duty vehicles operating with and without emissions control technologies

Sponsors;

California Air Resources Board

South Coast Air Quality Management District

PI; C. Sioutas (USC), JR Froines (UCLA)

OBJECTIVE:

The objective of this 4-year project is to determine the physicochemical and toxicological properties of the semi-volatile and non-volatile fractions of PM from heavy and light duty vehicles operating with and without emissions control technologies.

Cardiovascular Health and Air Pollution Study (CHAPS)

Sponsors :NIEHS, CARB

PI; R. Delfino (UCI),

Co-PI: C. Sioutas (USC)

Study Overview:

- A repeated measures panel study to evaluate acute cardio respiratory health effects of exposure to ultrafine PM (UFP)
- All subjects have coronary heart disease (CHD)
- Subjects include 72 nonsmokers age 65 and older living in retirement homes in areas of the Los Angeles Air Basin
- We will investigate relationships of levels of circulating biomarkers of inflammation and thrombosis to PM exposures occurring over five days prior to each of the 12 biomarker measurements
- Indoor, Outdoor and Personal UFP concentrations will be determined by personal cascade impactors developed by USC.

What We Will Not do (but is greatly needed):

- UF particle volatility and its toxicological potential is a major issue
- Our EPA Center studies and CARB emissions study will address the relative toxicity of volatile vs non volatile particles in vitro
- These studies will focus on bulk chemical PM properties but will not address the issue of particle size
- This can only be addressed by conducting in vivo inhalation studies
- Expose human or animal (or both) to the volatile vs non volatile UF CAP fractions using the already existing VACES and Thermo denuder technologies
- Major Outcome of Such Studies: is it the size of the volatile particles or its chemical composition (or both) that determine the health outcomes