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Particle Concentration and Characteristics Near a Major Freeway with Heavy-Duty Diesel Traffic

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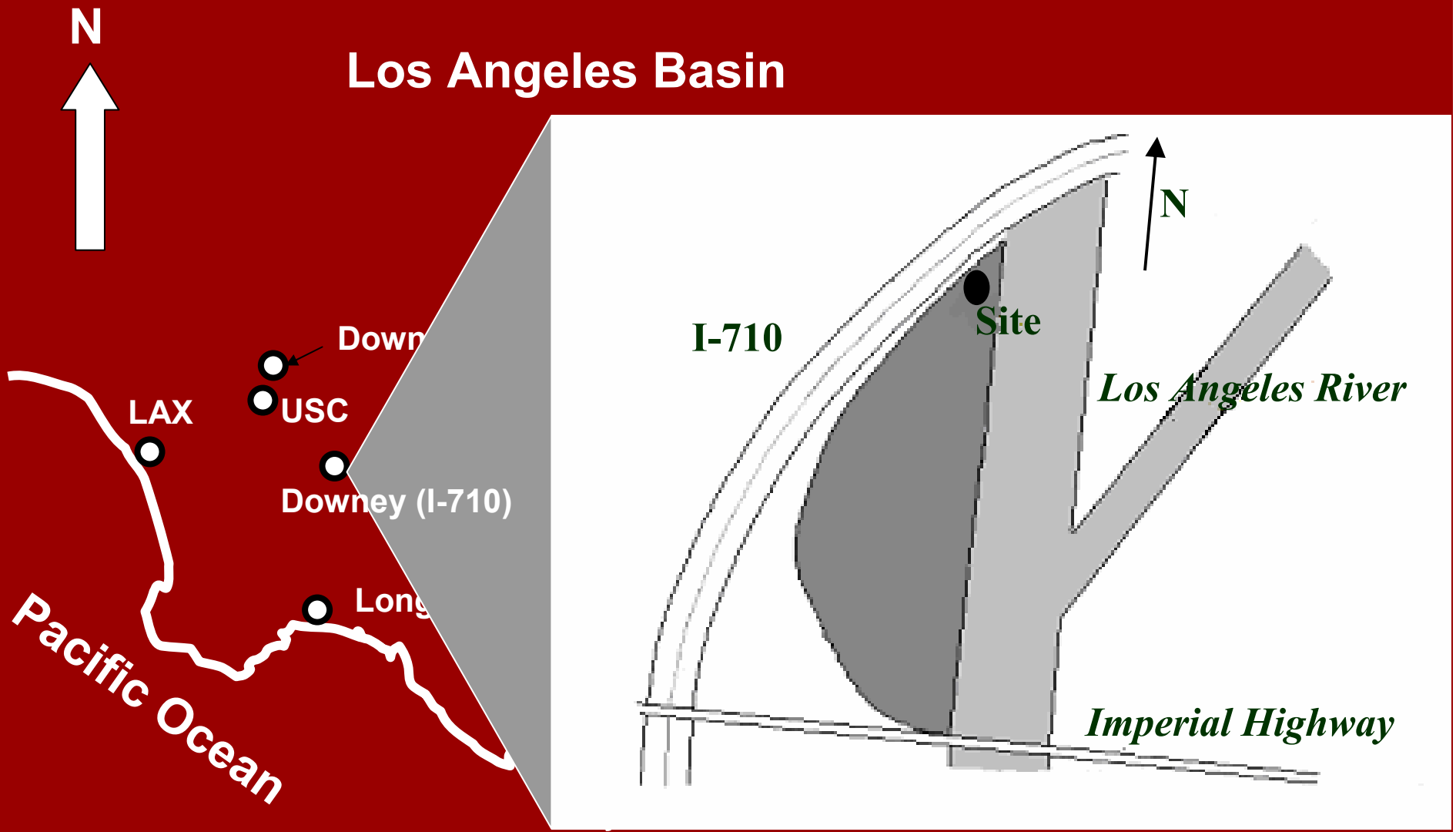
Background

- Dynamometer testing has shown that individual vehicles emit large particle number concentrations
- Measurements near freeways have found high particle number concentrations that decay to background levels at ~150m away from the road
- Concentrations on freeways have been reported as high as 10^6 particles/cm^3

Motivation

- Exposure to motor vehicle exhaust during commute may constitute a large fraction of daily PM dose, especially ultrafine PM
- Current environmental monitoring practice relies on central stations to measure PM and gaseous pollutants
- A shift to a particle number standard will require new methods for measurement of ambient concentrations and determination of human exposure

Map of Sampling Location



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Methods-Instrumentation

Instrument	Model/Manufacturer	Species Sampled
Q-Trak Plus	8554, TSI Inc.	CO, CO_2, Temperature, Relative Humidity
SMPS	3936L, consisting of DMA 3081L and CPC 3022A, TSI Inc.	Particle number/size distribution (16-638 nm mobility)
CPC	3022A, TSI Inc.	Number concentration (>6 nm mobility)
APS	3020A, TSI Inc.	Particle number/size distribution (0.7-2.5 µm aerodynamic)
NSAM	3550, TSI Inc.	Particle active surface concentration (< ~1 µm aerodynamic)
OC/EC	3F/Sunset Labs Inc.	Organic and elemental carbon
Aethalometer	AE-20/Anderson Instruments Inc.	Black carbon

Averages: Meteorology & Traffic

- Wind direction = 215° ± 39°
- Wind speed = 1.83 ± 0.85 m/s (~4mph)
- Temperature = 19.6 ± 5.0 °C
- Relative Humidity = 46.2 ± 16.3%

- Hourly vehicular traffic = 5180 ± 640 (northbound) & 5640 ± 800 (southbound)
- Traffic speed = 77.6 ± 27.7 km/h (northbound) & 84.5 ± 12.1 km/h (southbound)

Summary of Particle and Copollutant Levels

	Campaign Average			Rainy day			FWY Closed		
	Average	Range	SD[(a)]	Average	Range	SD[(a)]	Average	Range	SD[(a)]
N_{CPC} (cm^{-3})	8.6E4	1.1E4-3.2E5	5.4E4	3.4E4	1.3E4-8.3E4	2.2E4	3.1E4	2.5E4-3.8E4	6.8E3
N_{SMPS} (cm^{-3})	1.9E4	3.7E3-5.4E4	9.4E3	5.5E3	2.3E3-1.0E4	3.0E3	6.5E3	5.1E3-8.0E3	1.4E3
$PM_{0.7\text{-}2.5}$ (µg/m³)	6.4	1.7 - 30	3.6	8.2	6.7 - 8.8	0.85	2.1	1.7 - 2.3	0.27
Surface (µm²/cm³)	153	36 - 303	55	41	20 - 64	19	57	45 - 71	12
V_{NM} ($\mu m^3/cm^3$)	0.094	0.011-0.22	0.047	0.031	0.011 - 0.061	0.02	0.049	0.035 - 0.058	0.13
V_{AM} ($\mu m^3/cm^3$)	16.3	3.66 - 36.5	6.96	7.1	4.73 - 9.79	1.86	4.3	3.7 - 5.6	1.1
Geomean d_p (nm)	50	28 - 96	11	53	40 - 60	7	46	42 - 52	4
EC (µg/m³)	3.2	0.3-11.2	2.2	0.7	0.3-1.15	0.3	0.40	0.3-0.5	0.2
BC (µg/m³)	4.4	0.5-10.1	2.1	2.6	0.8-9.8	2.8	0.8	0.8	<0.1
LOC (µg/m³)	2.4	0.9-5.3	0.8	1.3	1.1-1.7	0.2	3.0	2.8-3.2	0.3
HOC (µg/m³)	2.0	0.1-11.2	1.4	1.2	0.9-1.8	0.3	1.6	1.5-1.8	0.2
CO (ppmv)	0.23	0.10-3.6	0.35	0.01	<0.09	0.02	0.29	<1.2	0.53
CO_2 (ppmv)	426	359-567	30	402	384-430	14	405	401-410	3.6

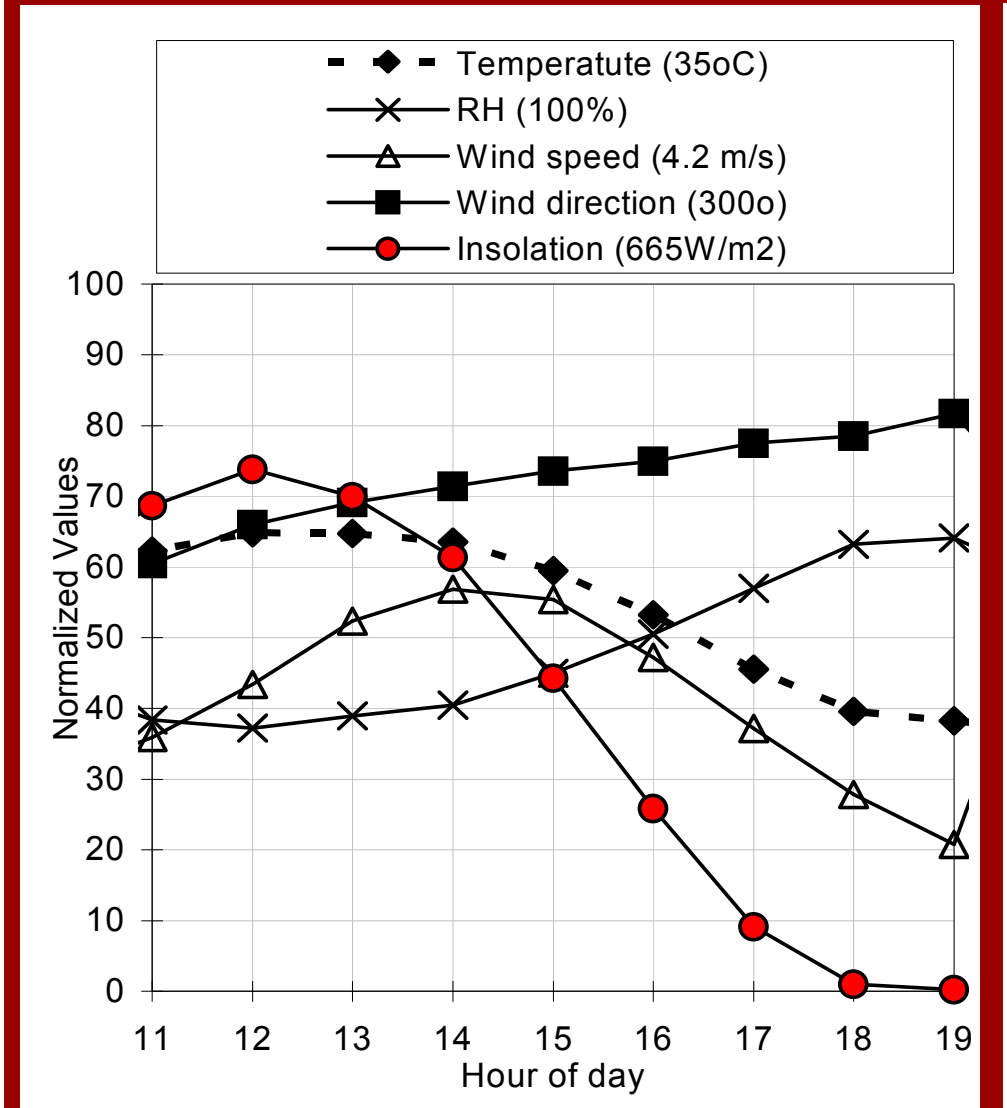
Summary of Particle and Copollutant Levels

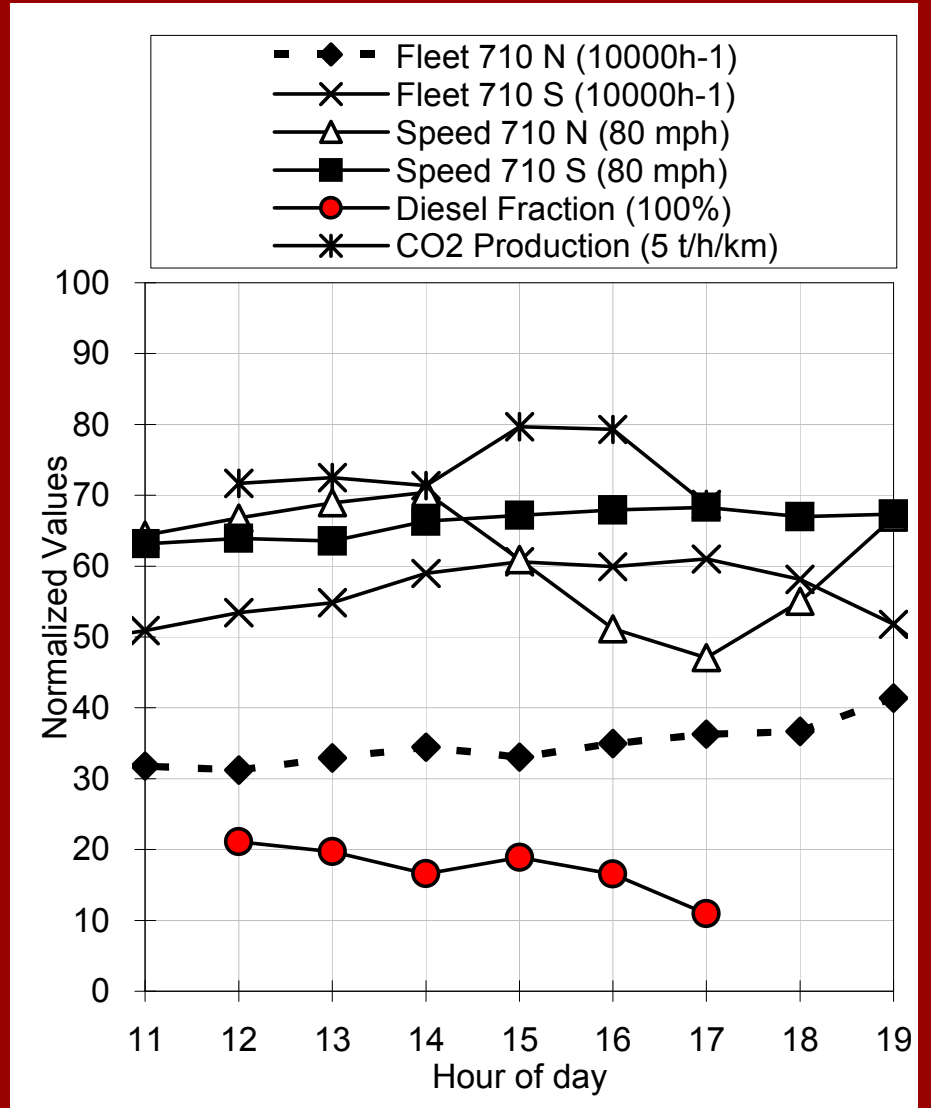
- Average CPC conc.= 86,000 #/cm^3
- Average SMPS conc.= 19,000 #/cm^3
  -- Large number of particles <16 nm
- Black carbon = 4.4 $\pm$ 2.1 μg/m^3
- Elemental carbon = 3.2 $\pm$ 2.2 μg/m^3
- Total OC = 4.4 $\pm$ 1.6 μg/m^3

Special Events

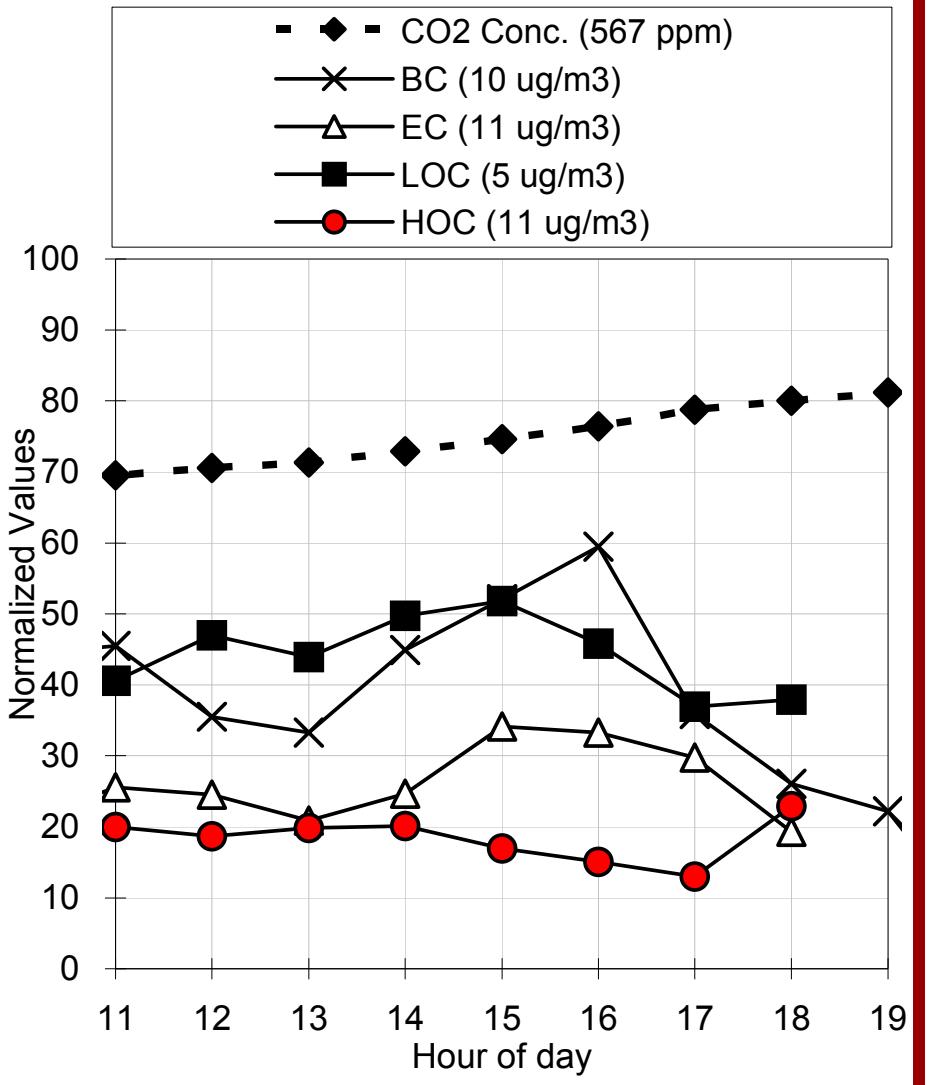
- Freeway closure on one of the sampling days resulted in much lower concentrations of all species
  - Exception: *OC experienced less of a decline*, likely due to sources of OC other than the freeway
- Rain event lowered number and surface area concentrations, likely because of particle scavenging

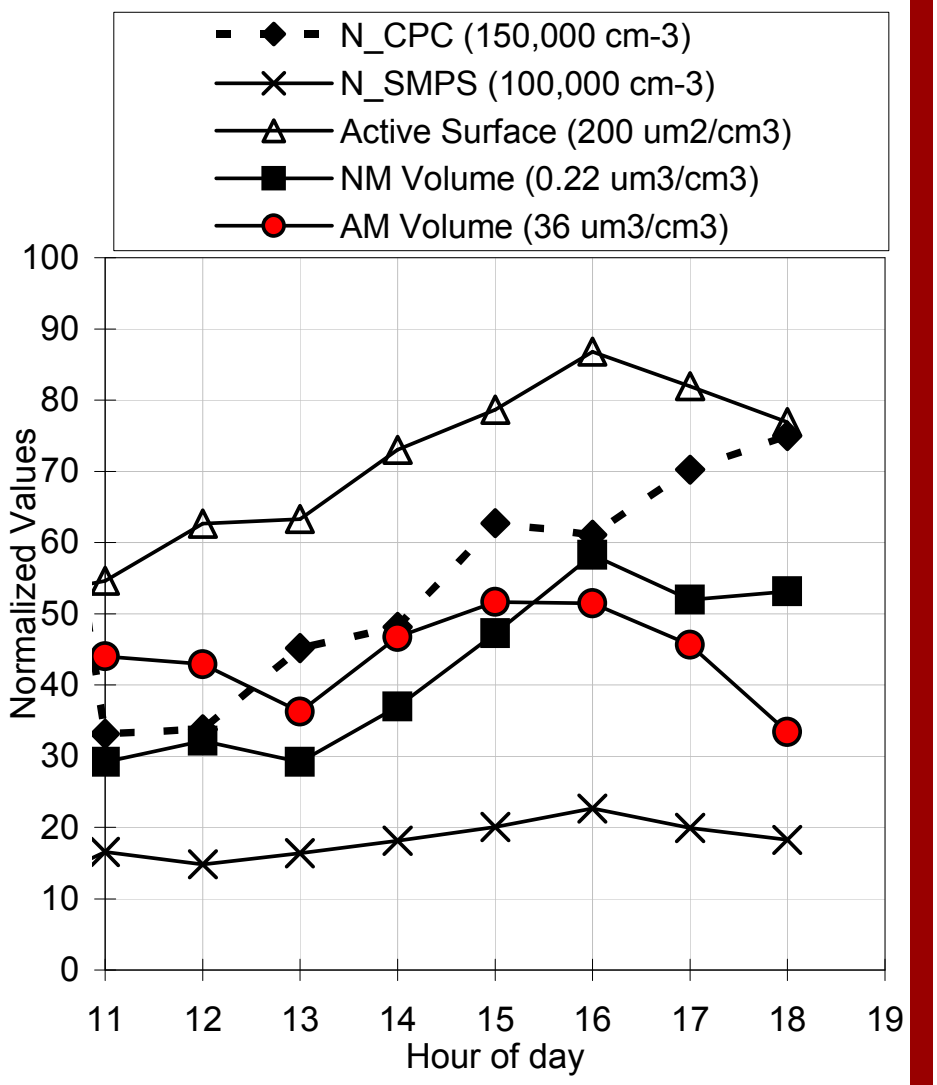
Diurnal Profile I





Diurnal Profile II





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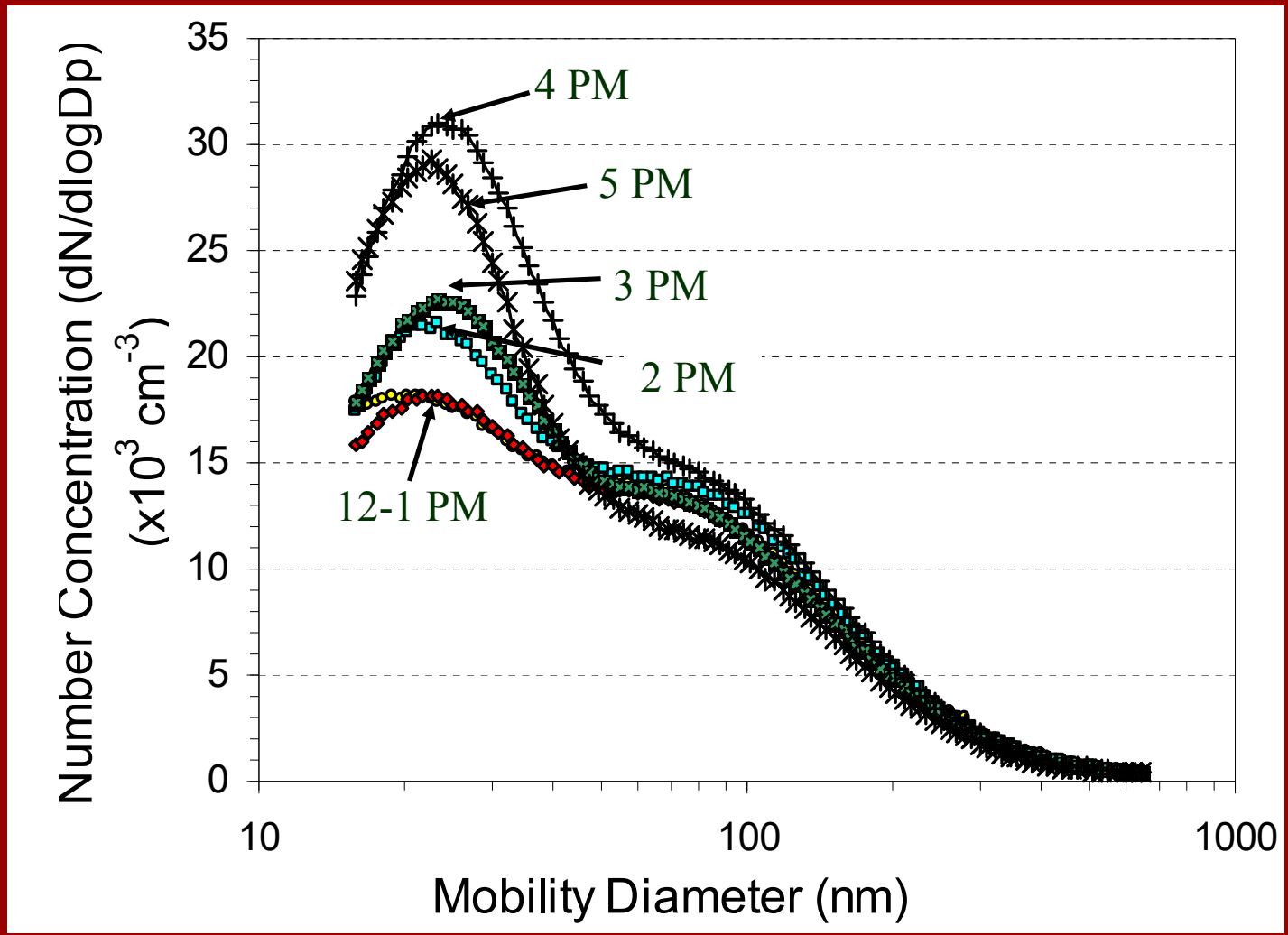
Mean Hourly Size Distributions



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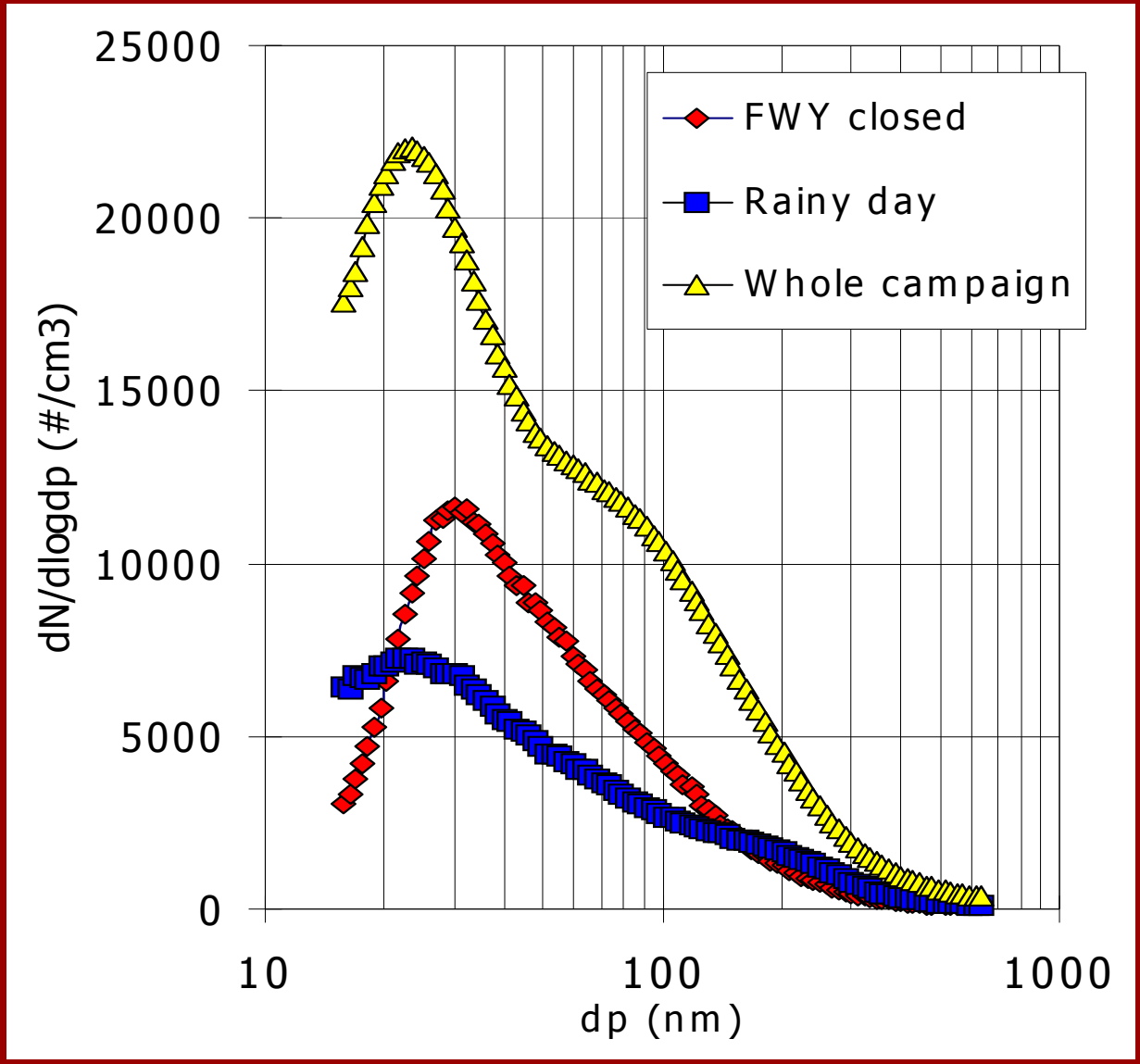
Particle Size Distributions



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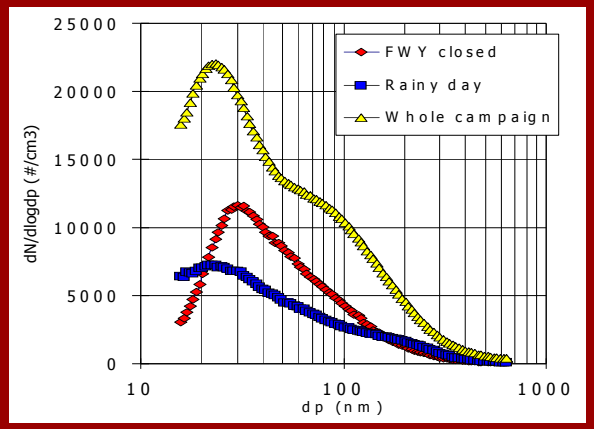
Particle Size Distributions



- Bimodal distribution is typical near freeways with diesel traffic and not seen near gasoline freeways

- Freeway closure resulted in significant concentration drop and monomodal distribution
- Rainy day concentration dropped by 70%

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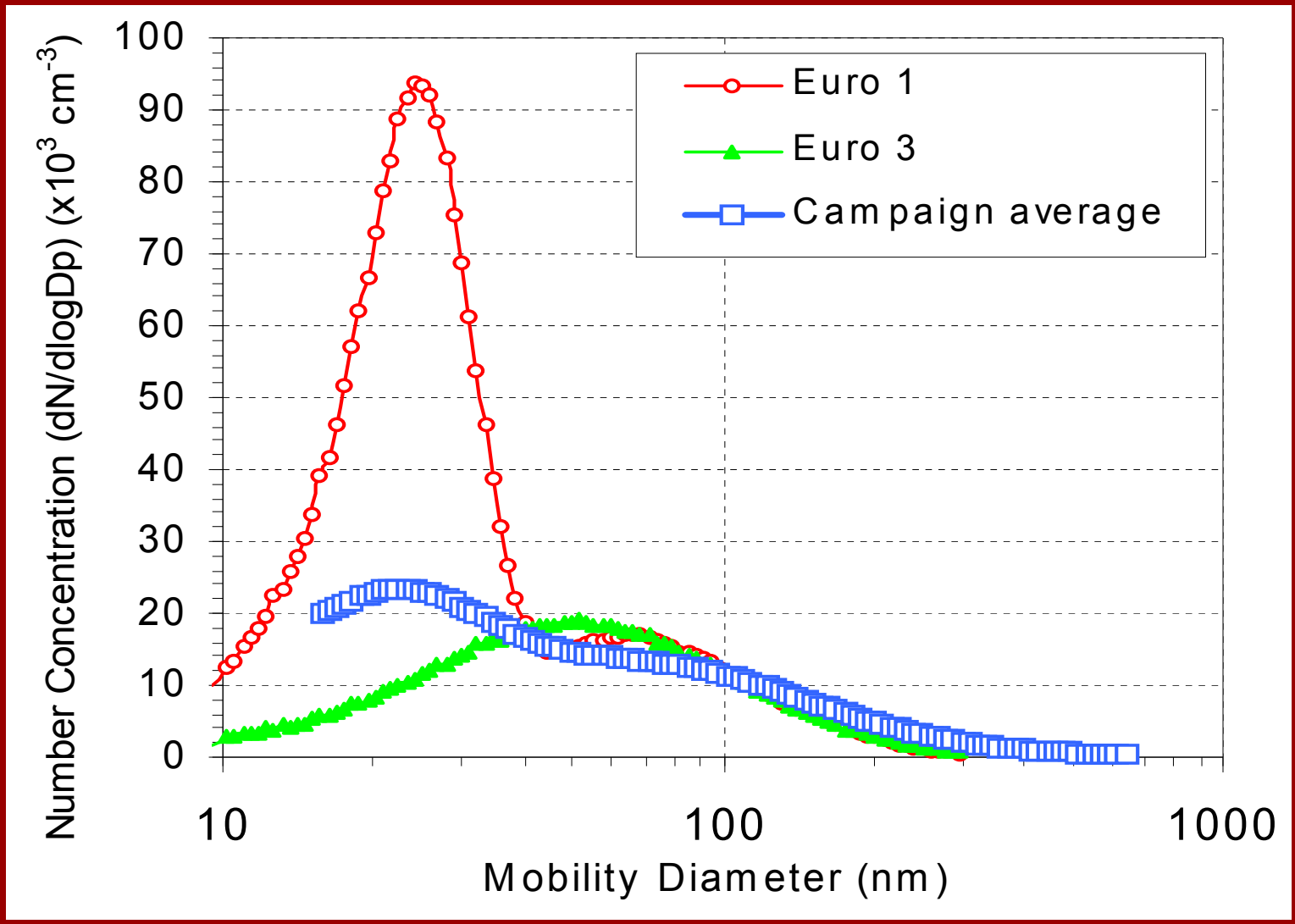
Freeway Vs. HDV



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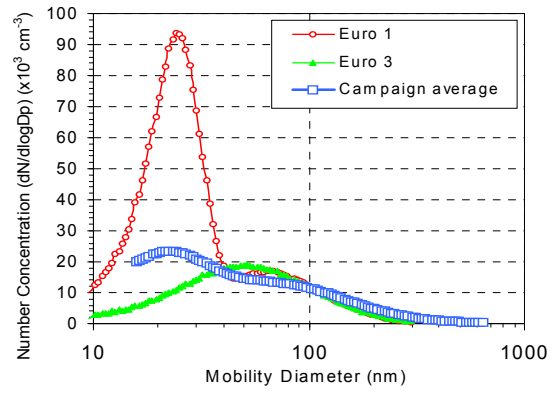

- Euro I (older technology) and Euro III (more recent) vehicles driven under typical freeway cycles (~60% of max speed and 50% load)
- Exhaust conc. corrected for dilution ratio at sampling location and %HDV exhaust flow
- Excellent agreement between shapes of distributions
- Actual number of nucleation mode particles depends on vehicle technology, sampling conditions, and gasoline-emitted species

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Comparison of Concentrations in Different Studies I

	2006 Study		Westerdahl et al. (*13*)	Geller et al. (*27*)
Location	I-710		I-710	Caldecott Tunnel (Bore 1)
Sampling site	20m from freeway median strip		Mobile lab following traffic	Tunnel exit
Period	Feb-Apr 2006		Feb-Apr 2003	Aug 2004
Sampling hours	12pm-4pm	5pm-7pm	-	12pm-6pm
Passenger cars (h^{-1})	8359	10250	7580[(a)]	4041
Light-duty trucks (h^{-1})	600	360	-	91
Heavy-duty trucks (h^{-1})	1630	1225	1040[(a)]	64
Temperature (°C)	21.4	14.4	21	23.3
RH (%)	42	60	-	59

Dilution Ratio (DR)

- Enables decoupling of the effects of fleet operation and ambient conditions from influence of sampling location
- Based on ratio of fleet-average exhaust CO_2 conc. over the incremental ambient CO_2 increase
- Calculations show DR next to freeway is 10.2 and 7.3 times higher than in-freeway and in-tunnel, respectively
- Consistent with Zhang et al. (2004), who estimated road-to-ambient dilution factor of ~10

Comparison of Concentrations in Different Studies II

- May be attributed to different mixing of exhaust when sampling in freeway as opposed to next to freeway
- Probability of following car higher than truck
  - -- CO/BC ratio higher for gasoline vehicles
  - -- On-road particle number emission factors lower for gasoline vehicles

CPC (cm^{-3})	75000	98500	190000	36638 (5404)	637500	92616 (10058)
CO (ppm)	0.27	0.11	1.9	0.28 (0.05)	8.78	2.18 (0.21)
BC ($\mu g/m^3$)	4.6	2.8	12	3.43 (0.61)	27.5[c]	6.8 (1.4)
Relative dilution ratio	1:1			1:10.2 (1.22)		1:7.3 (0.82)

Comparison of Concentrations in Different Studies III

- Uphill driving in tunnel significantly affects engine load
  -- Results in increased particle number (from gasoline vehicles) and black carbon concentrations (from diesel vehicles)

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Conclusions I

- Results agree with prior studies near freeways showing high particle number concentrations and dominance by carbon species
- Sampling differences between instruments may produce significant variance in results (SMPS vs. CPC)
- Shape of particle size distribution near freeway similar to that of selected heavy-duty diesel vehicles

Calculation of *dilution ratio* based upon CO_2 increase in ambient sampling can be used to *improve the link* between laboratory-measured exhaust emissions and roadside evolution of exhaust aerosol

Acknowledgements

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Thank You


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