Traffic Related Nanoparticles: Results of an On-Road Exposure study.

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Summary
In urban areas the biggest and most widespread source of nanoparticles is motor vehicles, particularly on limited access, multi-lane highways (freeways). Typical daily commuters on these highways get the majority of their exposure to nanoparticles during their highway travel. Solid nanoparticles deposit in the alveolar region of the lungs and may translocate to the bloodstream and other organs including the cardiovascular system. They can penetrate cell membranes as intact particles and damage cell organelles. Concentrated ambient ultrafine particles (diameter <100 nm) are associated with pulmonary and cardiovascular effects. A recent study found that the relative risk of myocardial infarction (MI) was increased two to threefold by time spent in traffic one or two hours prior to the MI onset compared with control periods (Peters, 2004).

These considerations led us to undertake a human subject study of short-term cardiovascular response to 2-hour exposures to freeway air on a diesel vehicle dominated (I-710) and a gasoline vehicle dominated (I-405) interstate highways in the Los Angeles area. A nine-passenger van was modified with a high-efficiency (HEPA) filtration system that delivered filtered or unfiltered air to a two-person exposure chamber inside the van. Nineteen volunteer subjects (average age 71 years) rode for two hours exposed at different times to filtered and unfiltered air on each freeway. Double-blind cardiovascular health assessments included 24-hour ambulatory ECG for the assessment of heart rate variability and heart rhythm; blood pressure, lung function, and blood biochemistry to assess systemic inflammatory markers (fibrinogen, IL-6, CRP, MPO, MCP-1); vascular response or injury (sE-selectin, VEGF, sVCAM, sICAM, MMP9, MPO, t-PAI-1), and myocardial response to hemodynamic changes (NT-proBNP).

The van was equipped with on-board instruments included those for measuring in near real-time particle size distributions (8-290 nm), number concentration, $PM_{2.5}$ and PM_{10} mass concentrations, elemental carbon, particle PAHs, NOx, CO, and CO_2. Van speed and position was recorded by a GPS and type and frequency of nearby vehicles by a wide-angle camcorder. Instruments were powered by 230 kg (500 lb) of deep-cycle, gel-type marine batteries and a pure sine wave inverter.

Ultrafine particle concentrations were significantly higher on the diesel dominated freeway than the gasoline dominated freeway (Zhu et al, 2008). Mean unfiltered particle number concentration was 107,500 and 77,800 particles/cm^3 and mean $PM_{2.5}$ mass concentration was 51.4 and 44.5 $\mu g/m^3$ for I-710 and I-405 freeways respectively. Ultrafine particle concentrations increased with the number of nearby heavy duty diesel trucks, Figure 1. The ratio of ultrafine particles to total particles was higher on the diesel dominated freeway than the gasoline dominated highway. Traffic moving at 64-80 km/hr (40-50 mph) gave the highest ultrafine particle concentrations. As shown in Figure 2, the particle size distribution on the diesel dominated highway showed a pronounced peak at 20 nm and a submerged peak at 70 nm; on I-405 both peaks are submerged in a broad distribution from 10 to 200 nm.

Atrial arrhythmias during and up to 20 hours after exposures increased by 20% for exposure to unfiltered air relative to that for filtered air. This effect was associated most strongly with increased particle count (p=0.01). Blood concentrations of VEGF, an indicator of vascular stress, and NT proBNP, an indicator of intra-cardiac pressure, increased by 30% with exposure to unfiltered air compared to filtered air (p<0.05).

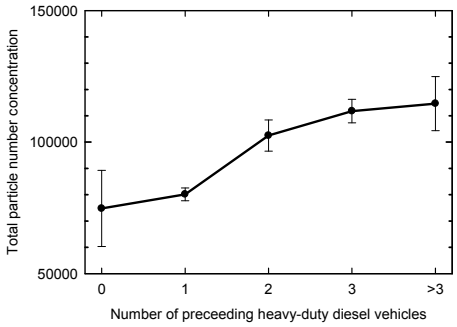

Figure 1. Effect of preceding diesel trucks

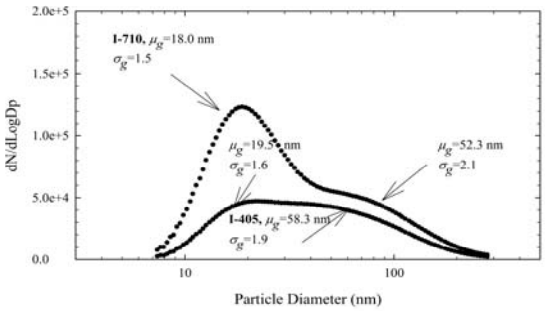

Figure 2. In-vehicle particle size distributions.

This study documents (1) a cardiac and vascular response associated with freeway travel and (2) high exposure to ultrafine particles on freeways especially when traveling near heavy duty diesel trucks. Rigorous double-blind conditions and filtered-air controls in this study rule out other traffic-related stresses or pollutant gases as causes of the observed cardiovascular effects. Because sustained arrhythmias (e.g. atrial fibrillation, AV nodal reentrant tachycardia) can be triggered by premature atrial beats, traffic exposure may play a role in their occurrence - a risk that could be mitigated by filtering particulate matter from the vehicle passenger cabins.

References

Peters, A.; von Klot, S.; Heier, M.; Trentinaglia, I.; Hormann, A.; Wichmann, H. E.; Lowel, H. Exposure to Traffic and the Onset of Myocardial Infarction; New Engl. J. Med. 351, 1721 (2004).

Zhu, Y., Fung, D.C., Kennedy, N., Hinds, W.C., and Eiguren-Fernandez, A. Measurements of Ultrafine Particles and Other Vehicular Pollutants inside a Mobile Exposure System on Los Angeles Freeways. J. Air & Waste Mgmt. Assoc. 58: 424-434 (2008).

Acknowledgement

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Traffic Related Nanoparticles: Results of an On-Road Exposure Study

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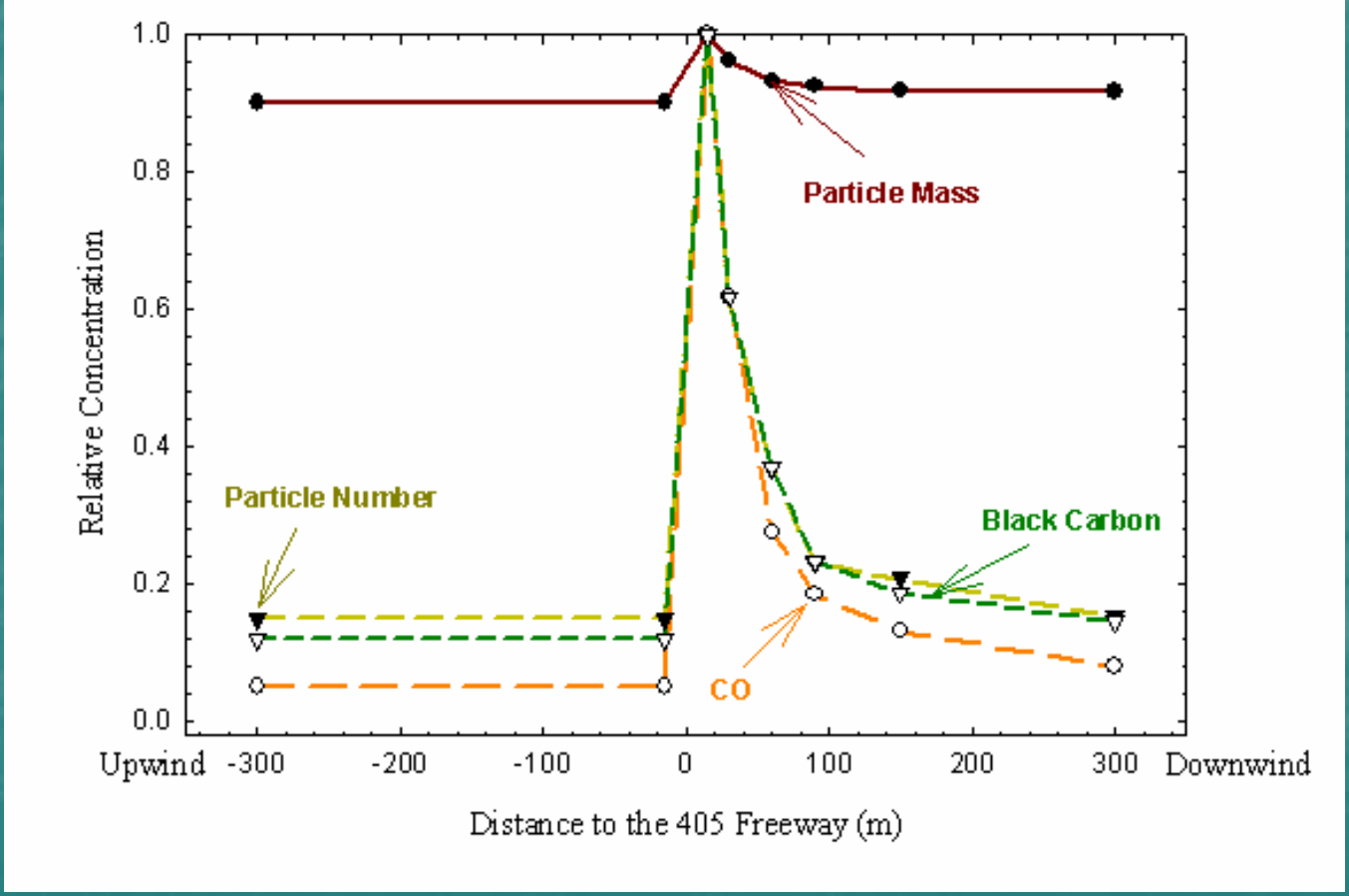
Impetus for Study

PREVIOUS STUDY: Relative Particle Number, Mass, Black Carbon, CO Concentration, vs. Downwind Distance from Freeway 405 during daytime.



Yifang Zhu, William C. Hinds, Seongheon Kim and Constantinos Sioutas "Concentration and size distribution of ultrafine particles near a major highway", 2002, *J. of Air and Waste Management Association*, 52:1032-1042.

Impetus for Study

- High concentration of ultrafine particles on or near freeways (Zhu et al, 2002)
  - For typical LA commuter bulk of daily exposure occurs on freeway
- Change in HRV associated with PM-2.5 for NC highway patrol (Riediker et al, 2004)
- Risk of MI increases with time spent in traffic preceding 2 hours (Peters et al, 2004)

Objectives

- Expose subjects to filtered and unfiltered in-vehicle freeway air
  - Gasoline dominated freeway (I-405)
  - Diesel dominated freeway (I-710)
  - Rigorous double blinding
- Determine if exposure to LA freeway air changes heart rhythm, HRV, or blood biomarkers
- Provide data for estimating in-vehicle exposure to ultrafine particles on freeways

Experimental Design

Subjects (60 or older) were exposed, 1 or 2 at a time, for 2-h periods (~10:00-12:00), at 1 week intervals, random order/double-blind, to:

- **I-710 freeway (mostly diesel trucks) unfiltered and filtered**
- **I-405/105 freeway (mostly gasoline cars) unfiltered and filtered**

Environmental measurements in near real time during exposure:

- **PM-10, PM-2.5, UFP, size dist.**
- **BC, P-PAH**
- **CO, CO_2, NOx**

Responses were measured in terms of:

- **24-h Holter ECG (heart rate variability, arrhythmia incidence)**
- **24-h ambulatory blood pressure record**
- **Spirometry & vital signs (pre-, 0, 2, 22 h post-exposure)**
- **Blood biomarkers (pre, 2, 22 h)**
- **Symptom and time-activity diary recording**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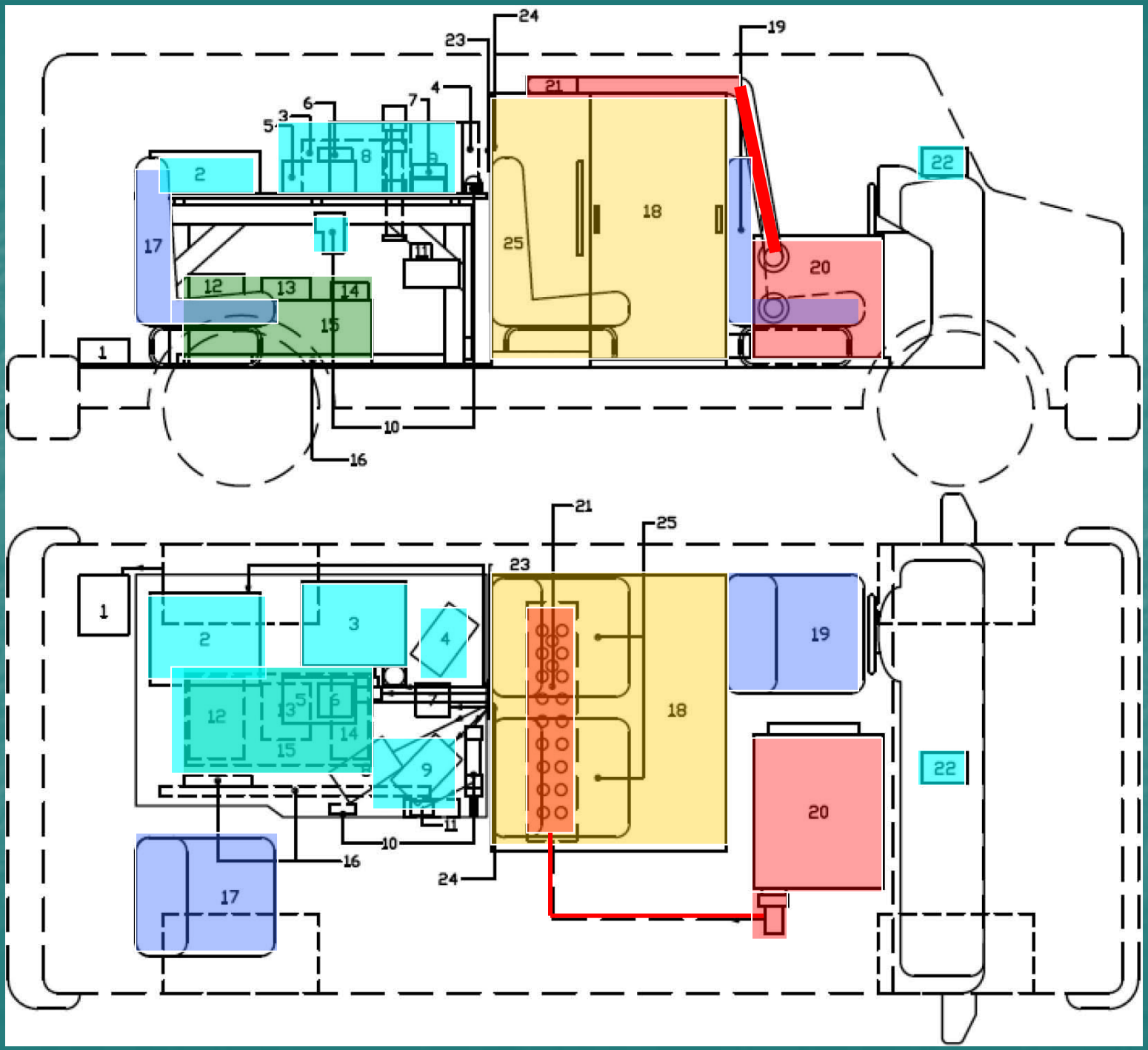
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Instruments

SMPS: Particle Size Distribution

Water CPC: Total Particle Number Concentration

Dust Trak: Real time PM10, PM2.5

Q-Trak: CO, CO2, Temp, Rh

Portable Aethelometer: EC

PEM: PM2.5 Filter Samples

EcoChem PAS2000: Particle bound PAHs

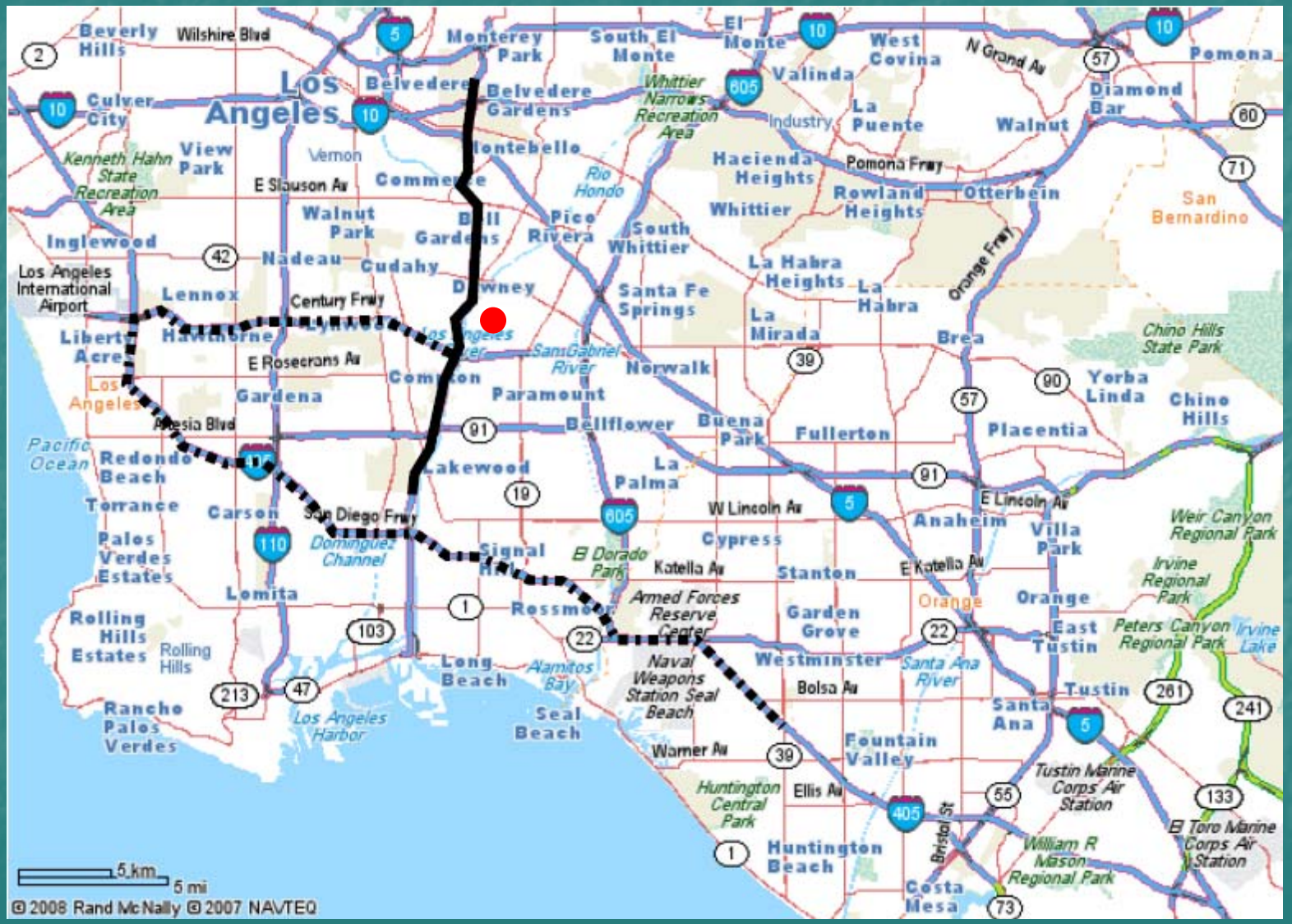
API 200AU:

NO, NO_2, NOx

GPS: position, speed


Magee Scientific
Aethalometer™
RUN PAUSE CHECK ERROR STOP
Condensation
Particle Counter
8.22e4 #/cm³
COMPAQ
GPS

Exposure Routes



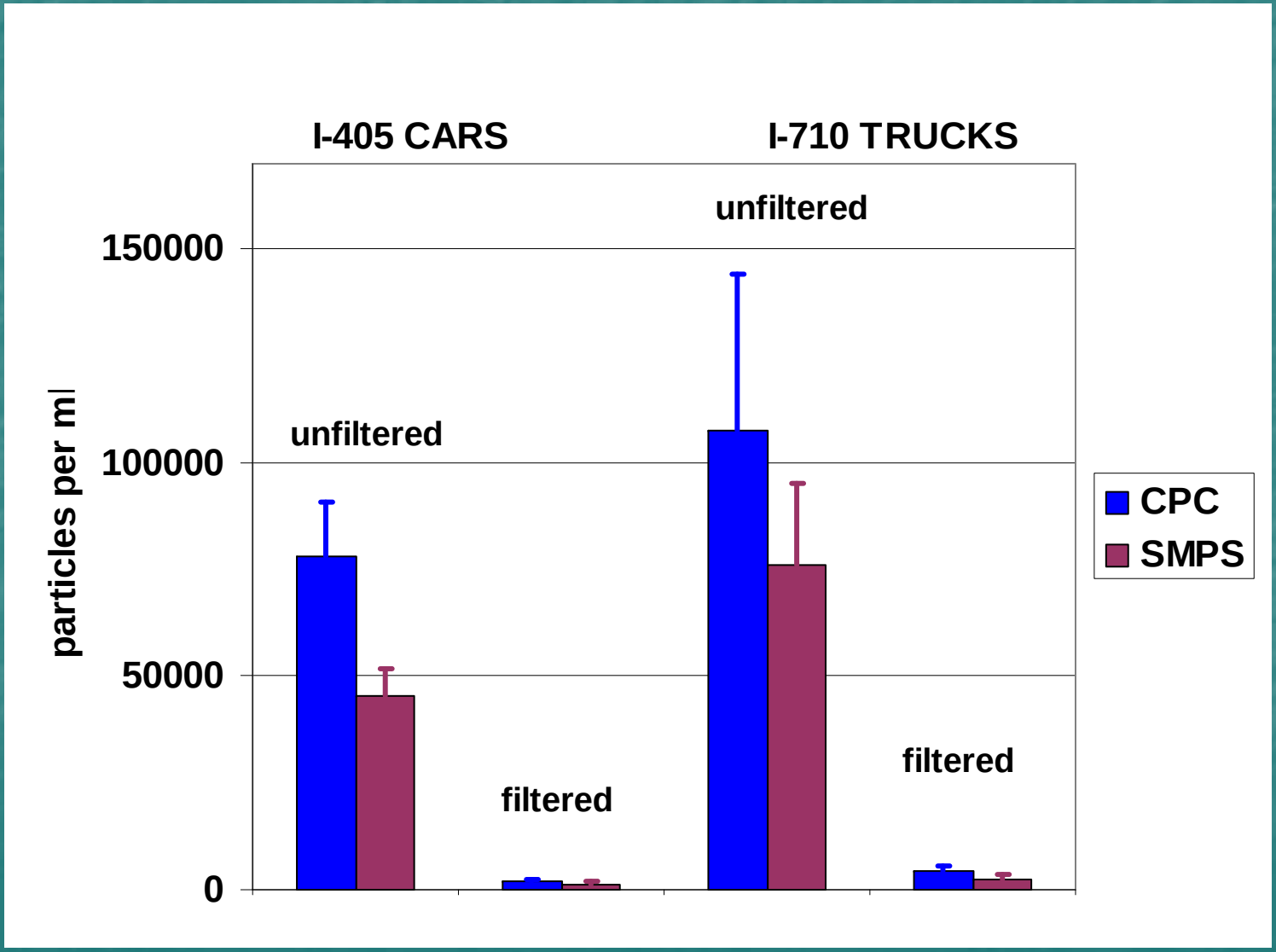
I-405 and I-710 Freeways

Zhu et al., 2002 "Concentration and size distribution of ultrafine particles near a major highway", *J. of Air and Waste Management Association*, 52:1032-1042.

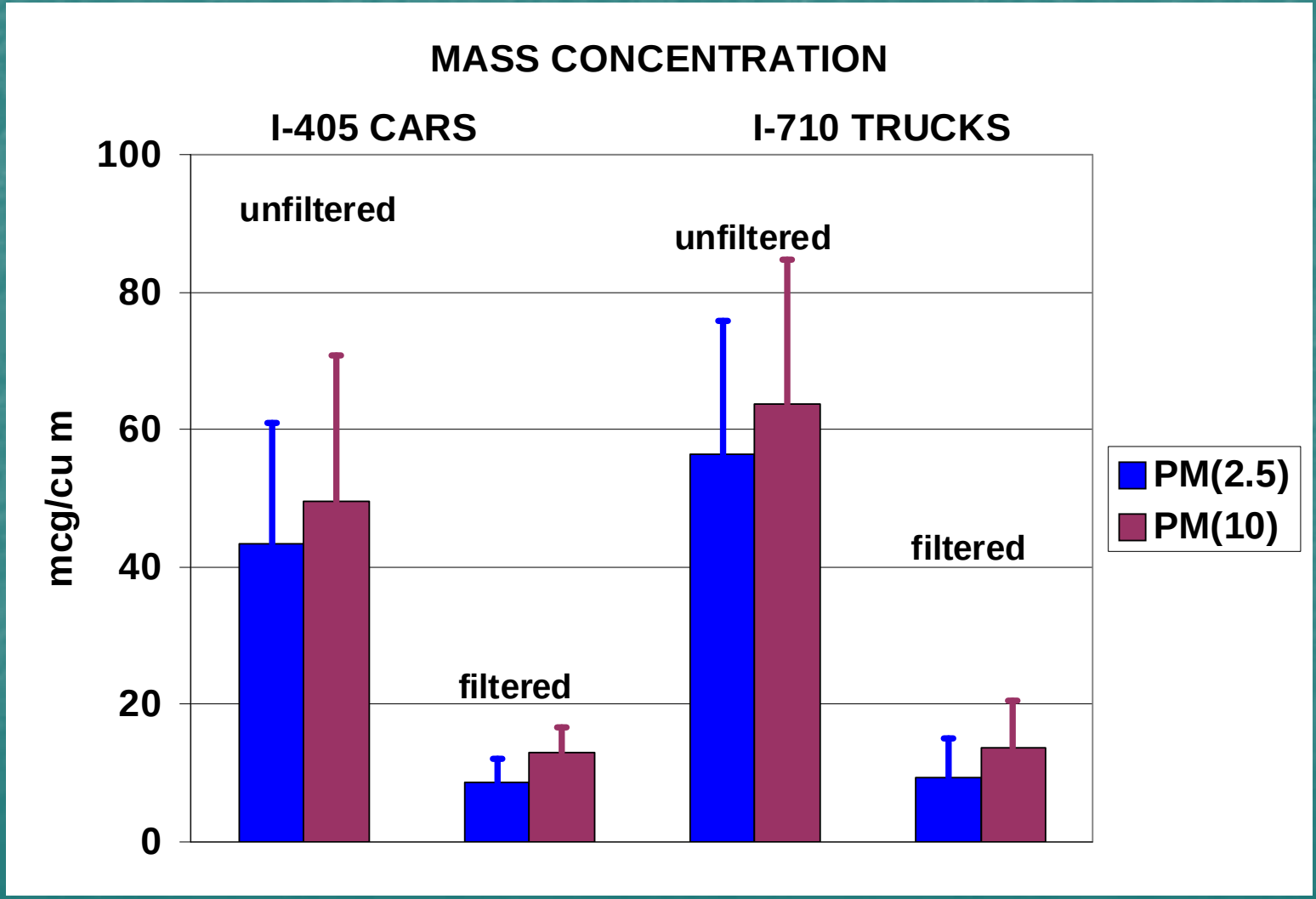
Zhu et al., 2002 "Study of Ultrafine Particles near a Major Highway with Heavy-duty Diesel Traffic", 2002, *Atmospheric Environment*, 36: 4323-4335.

Environmental Results

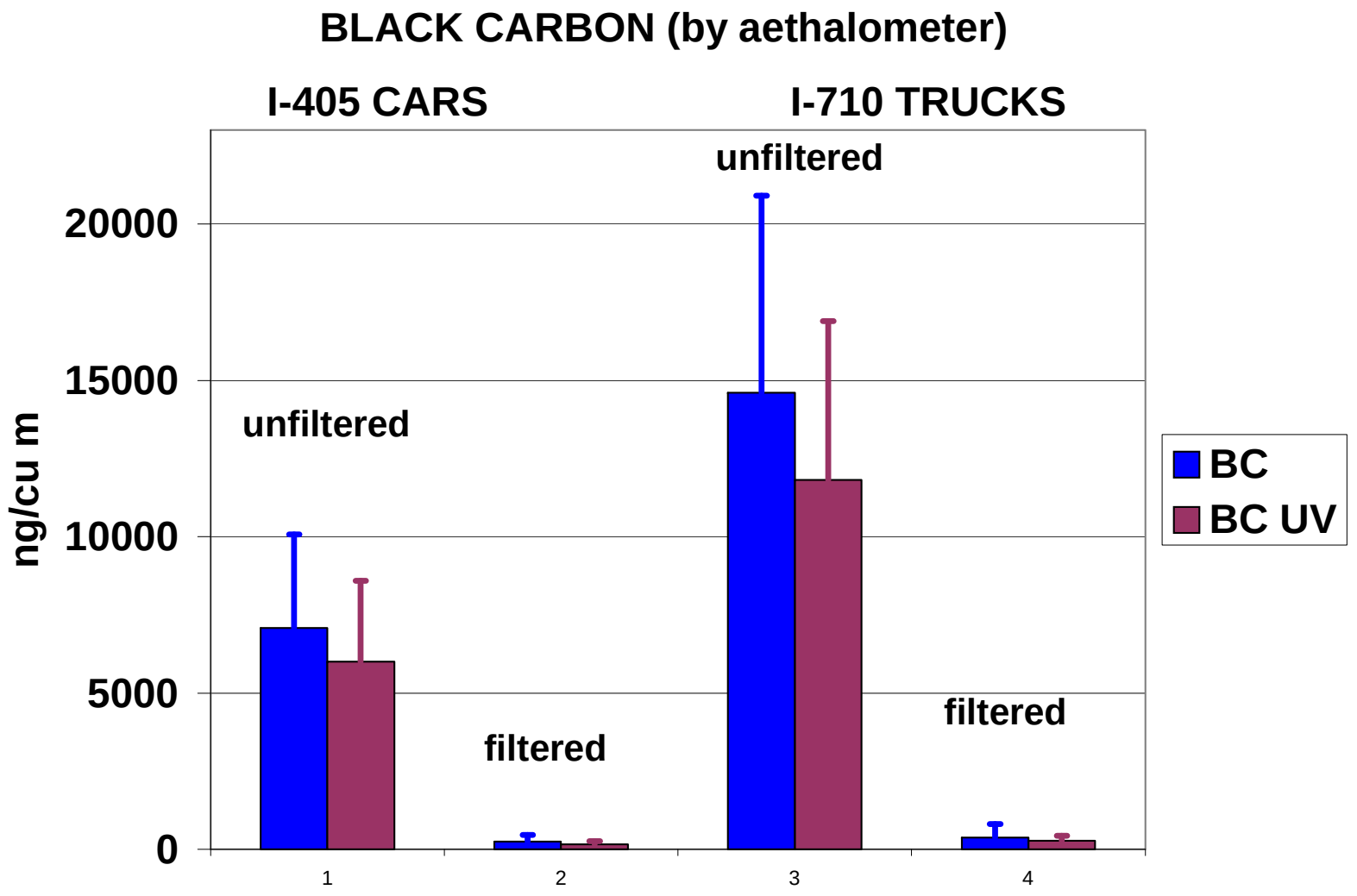
Particle Number Concentration



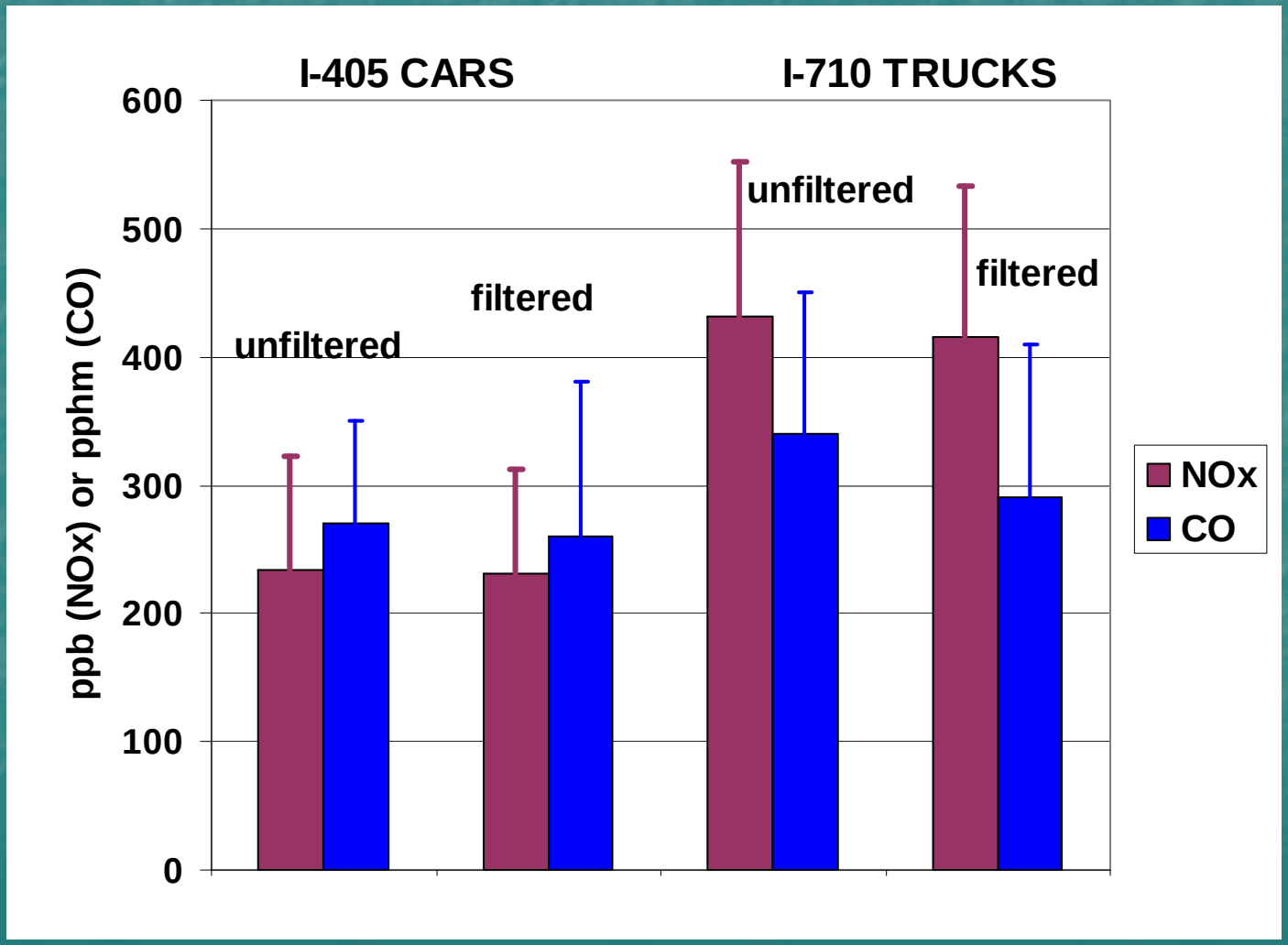
Particle Mass Concentration



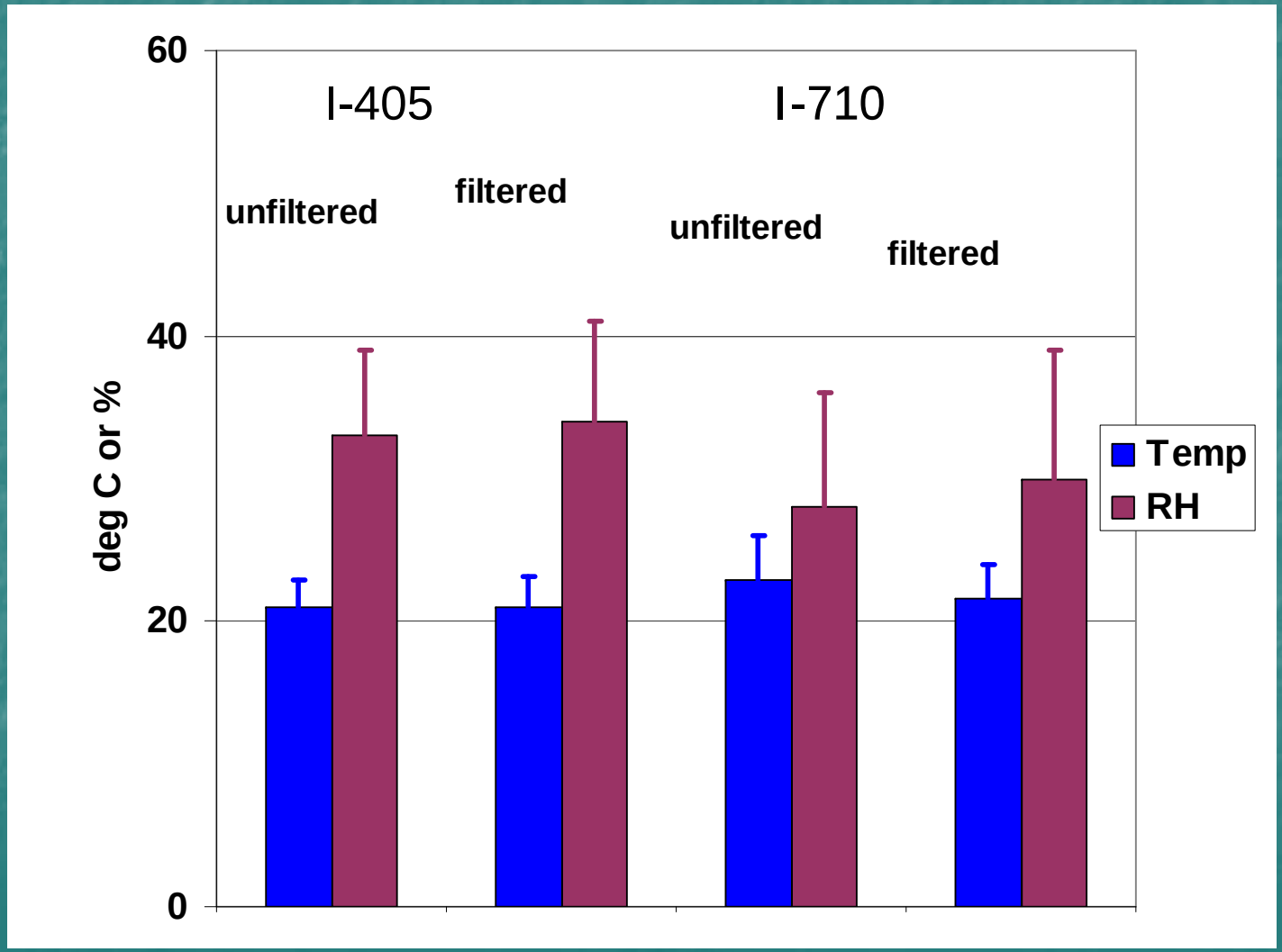
Black Carbon



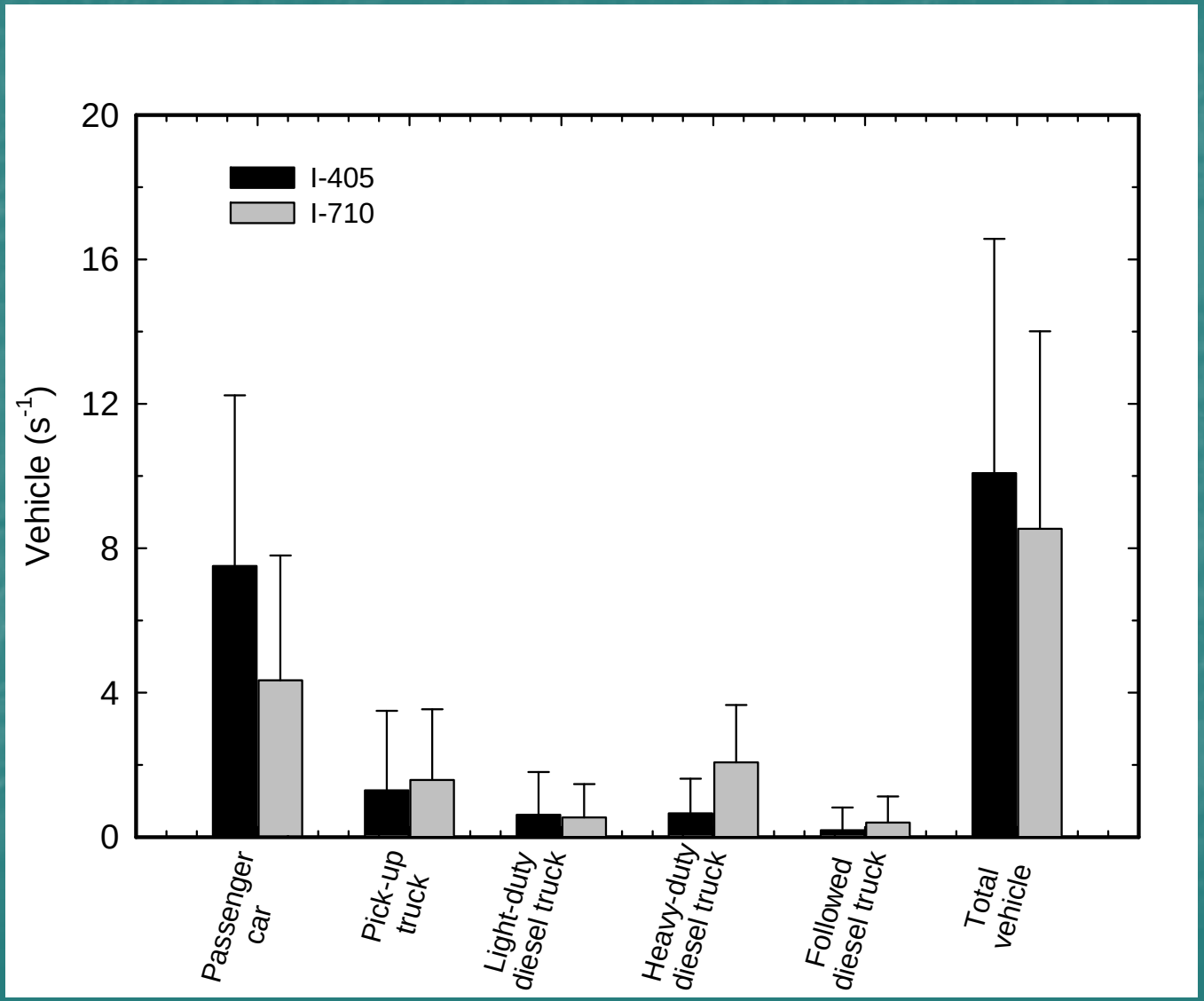
OXIDES OF NITROGEN
CARBON MONOXIDE



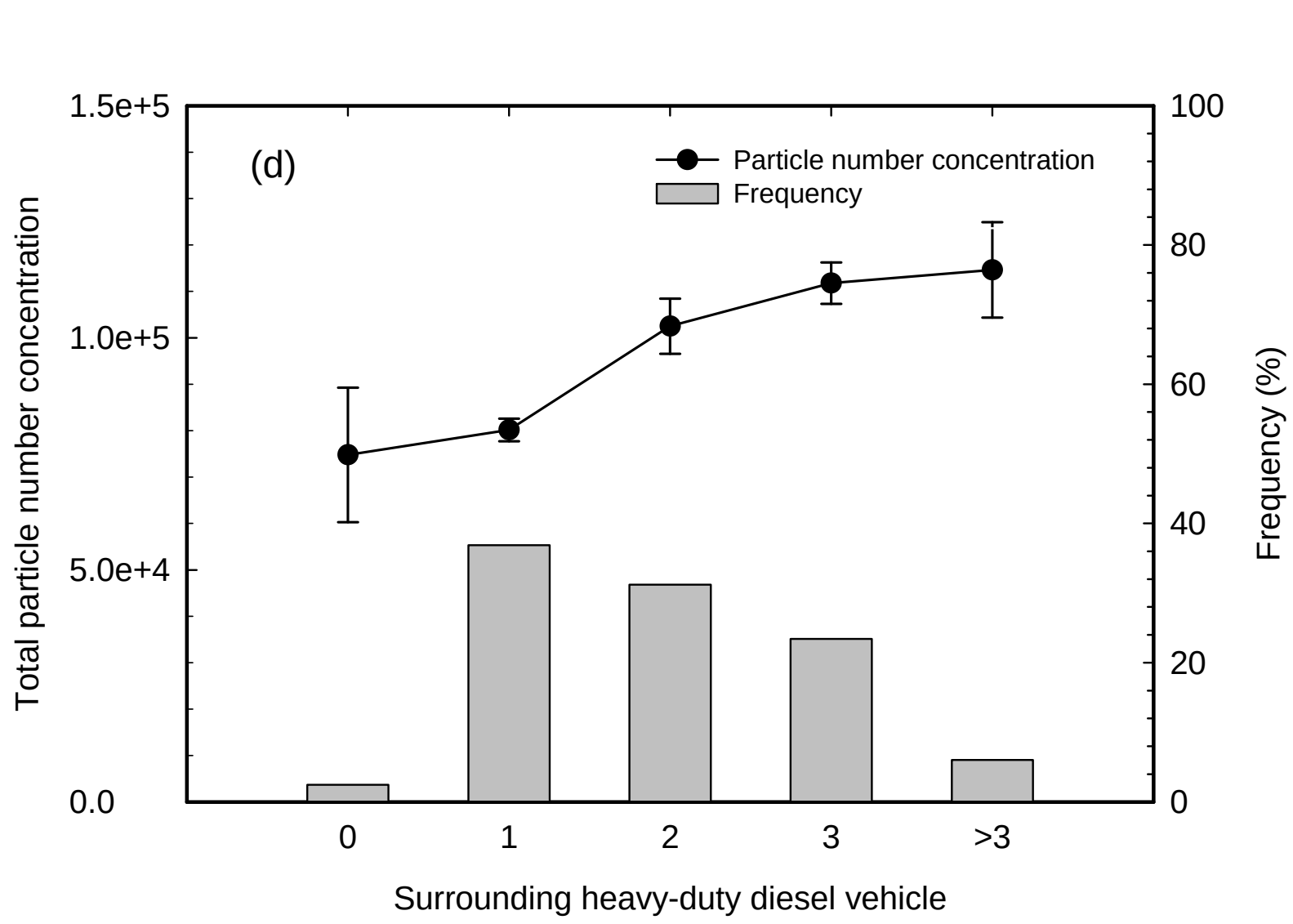
Temperature, Relative Humidity



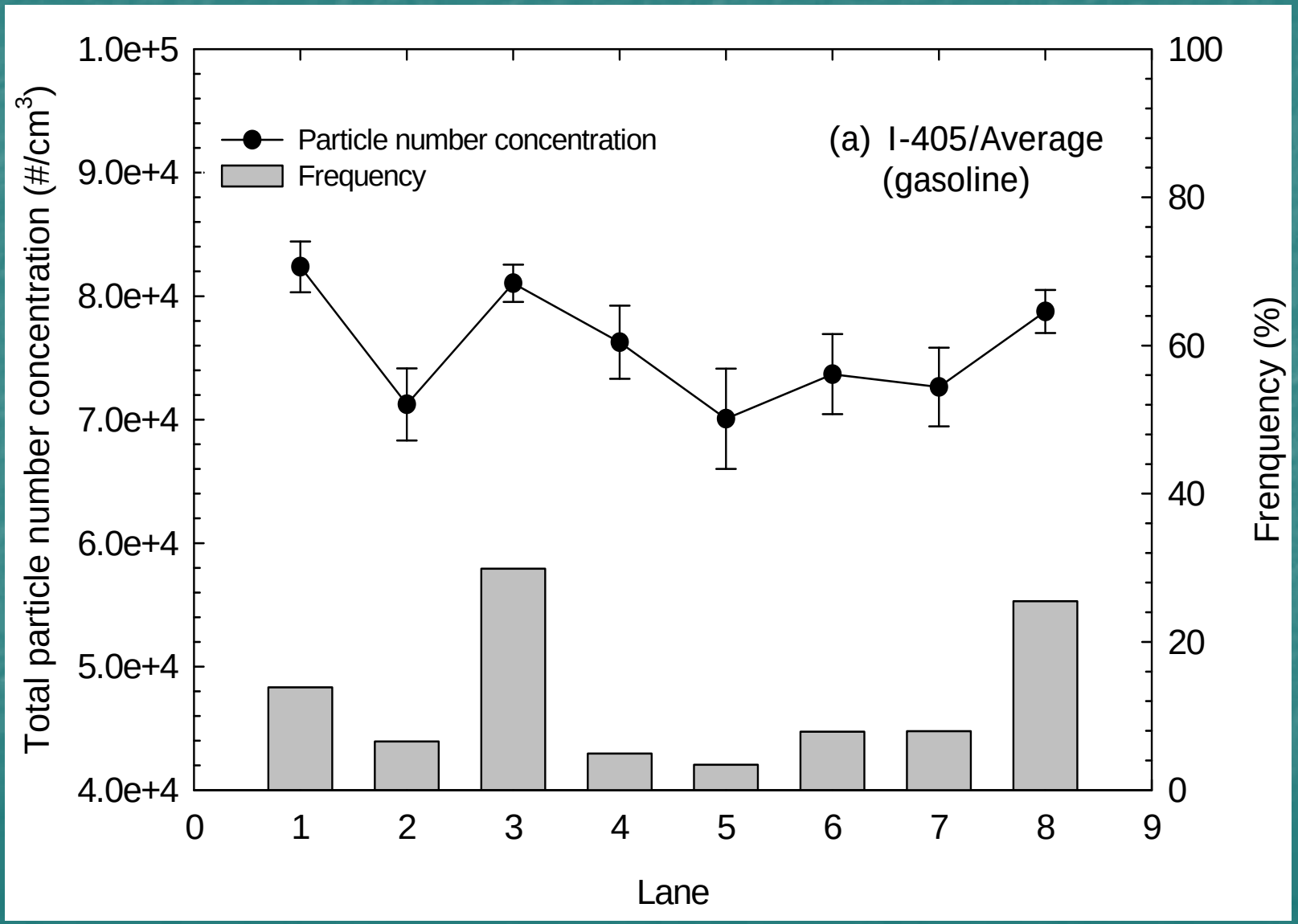
Vehicle Distribution



Effect of Nearby Vehicles



Effect of Driving Lane



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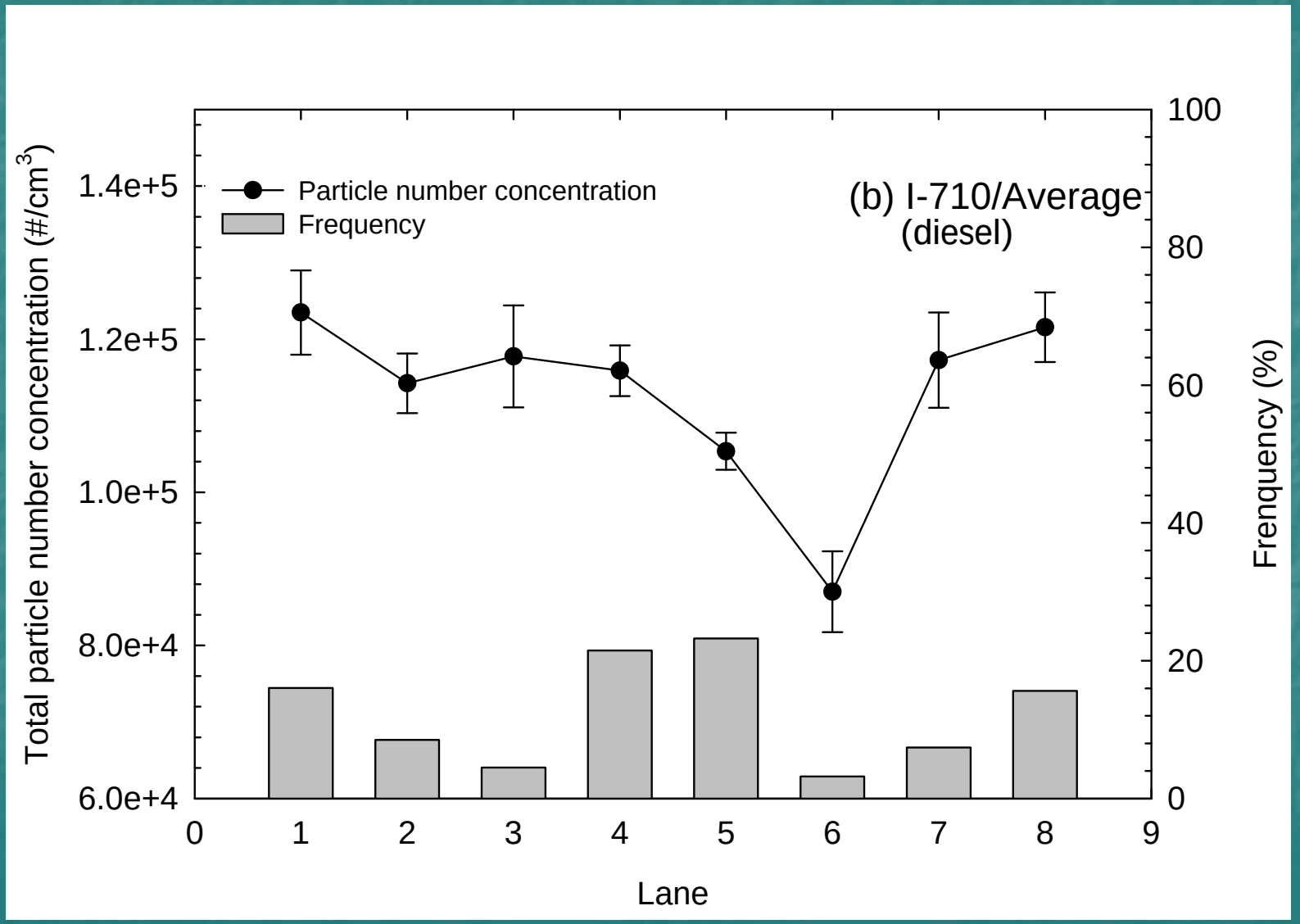
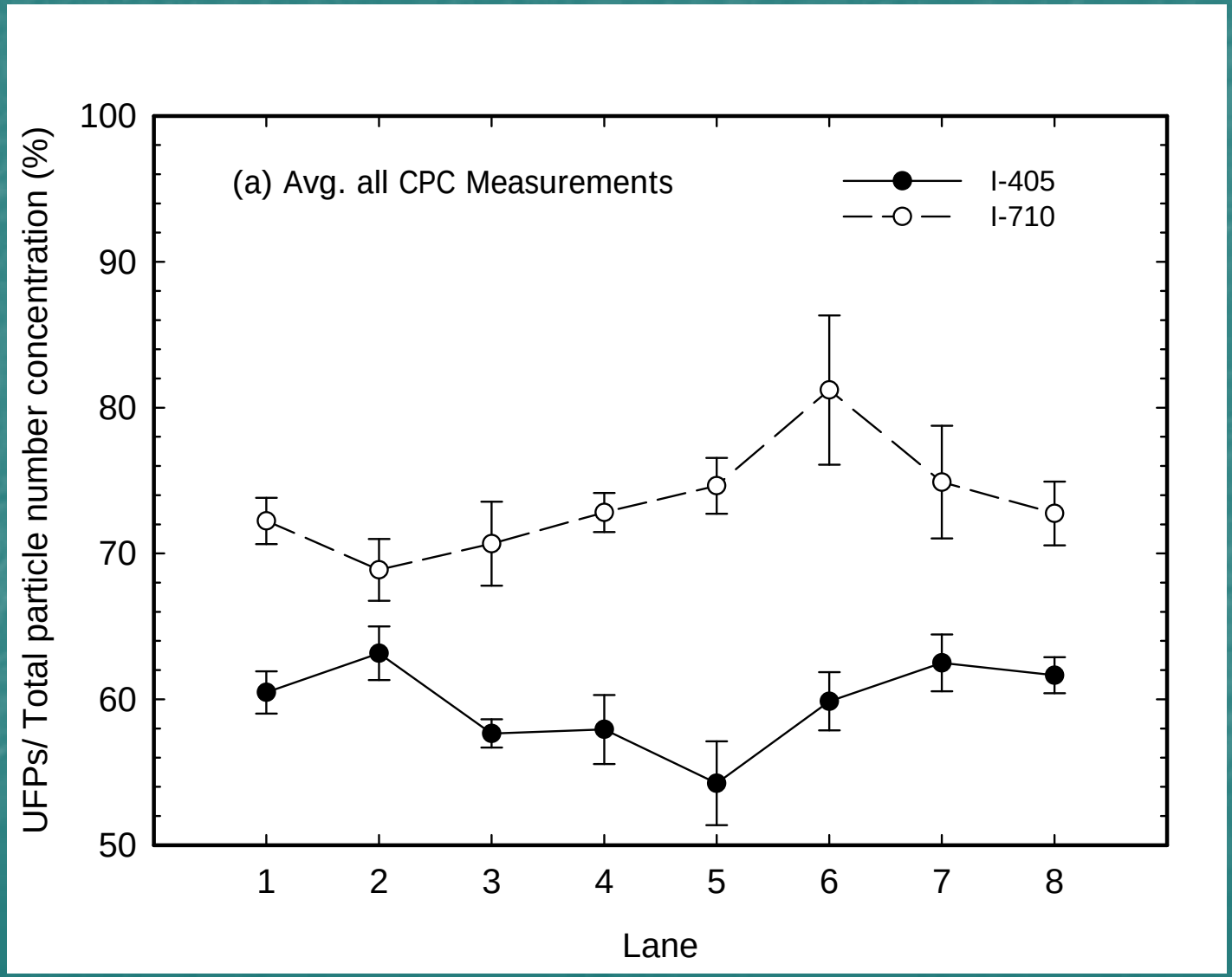
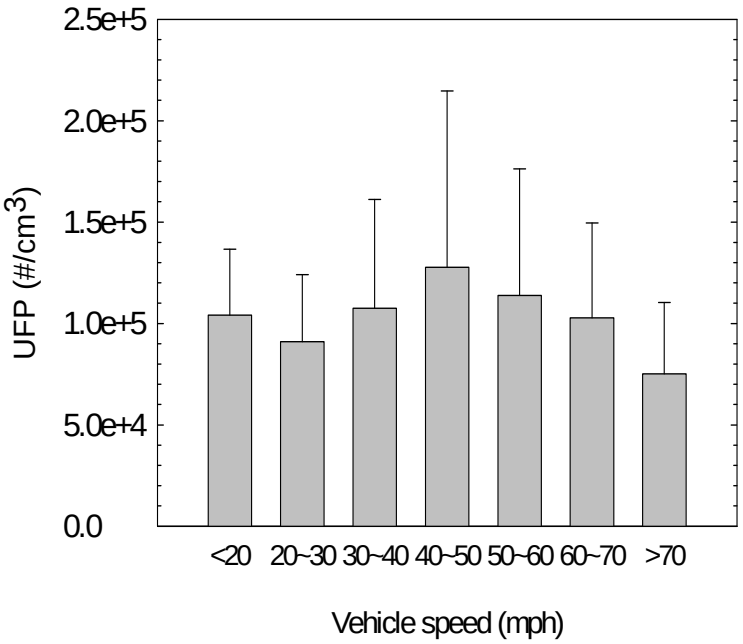
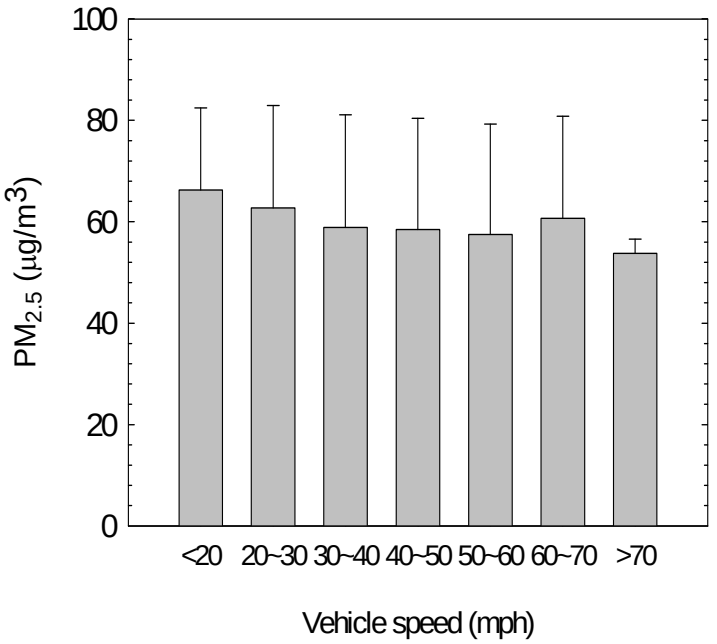


Effect of Driving Lane



Effect of Vehicle Speed





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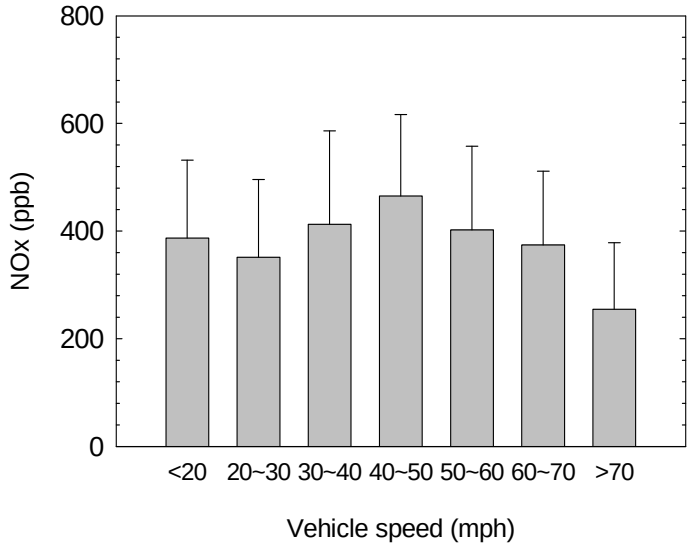

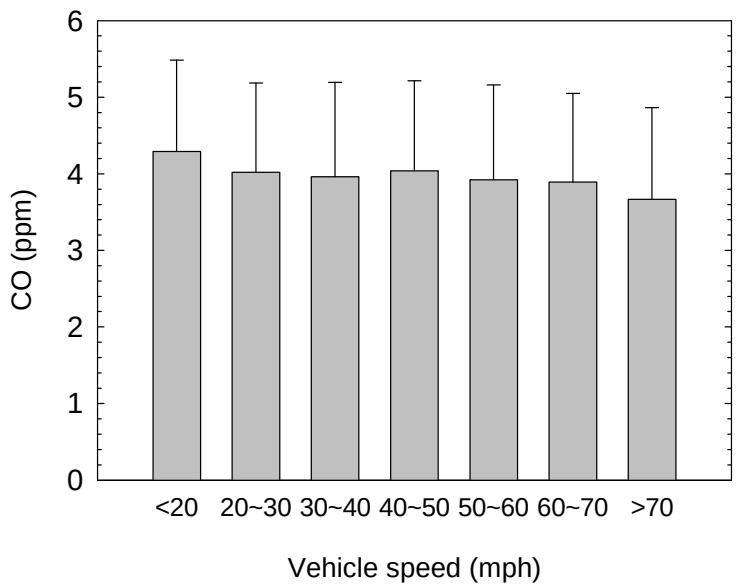

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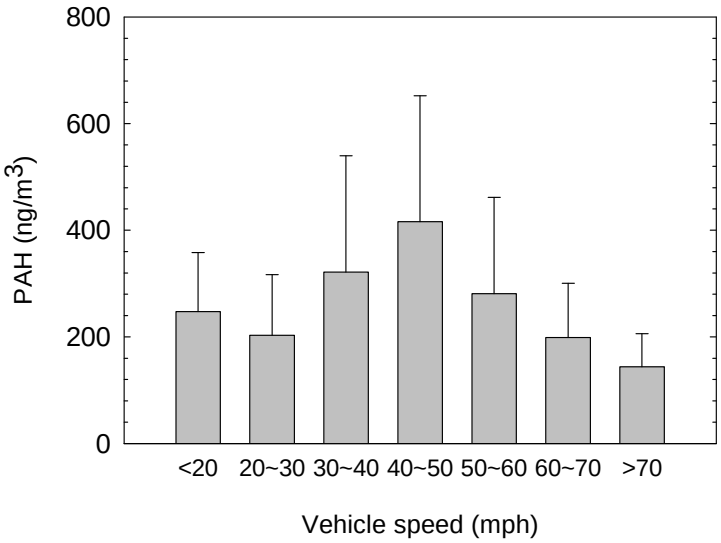
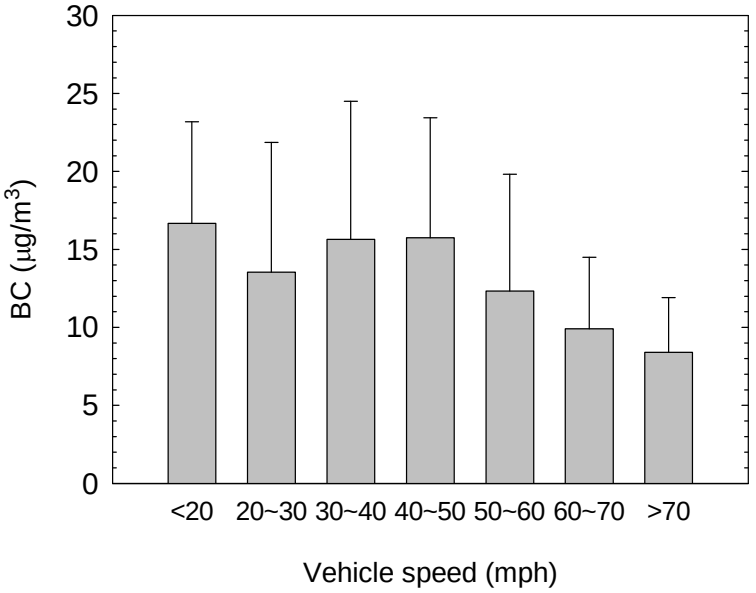
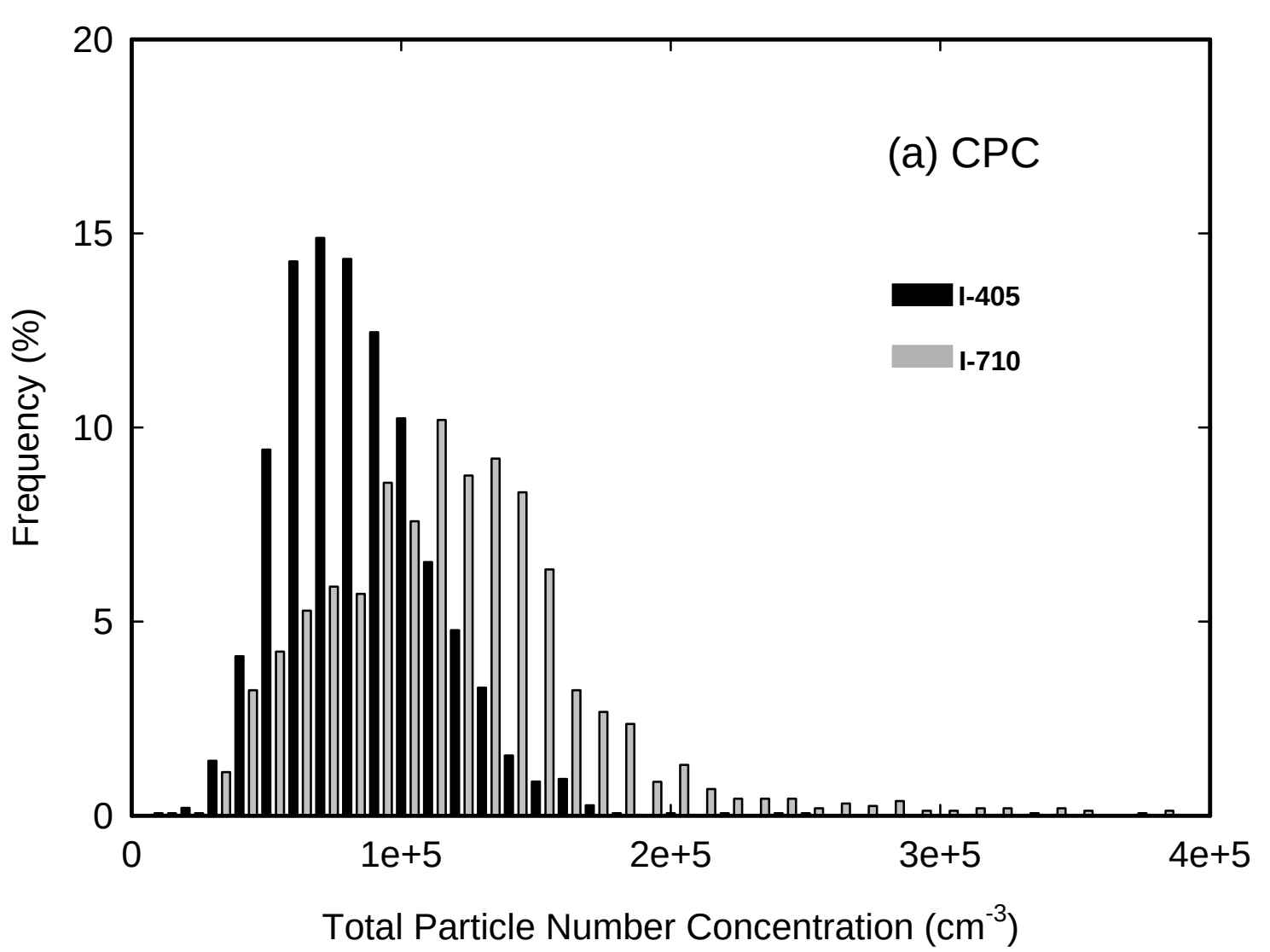




Distribution of Concentrations



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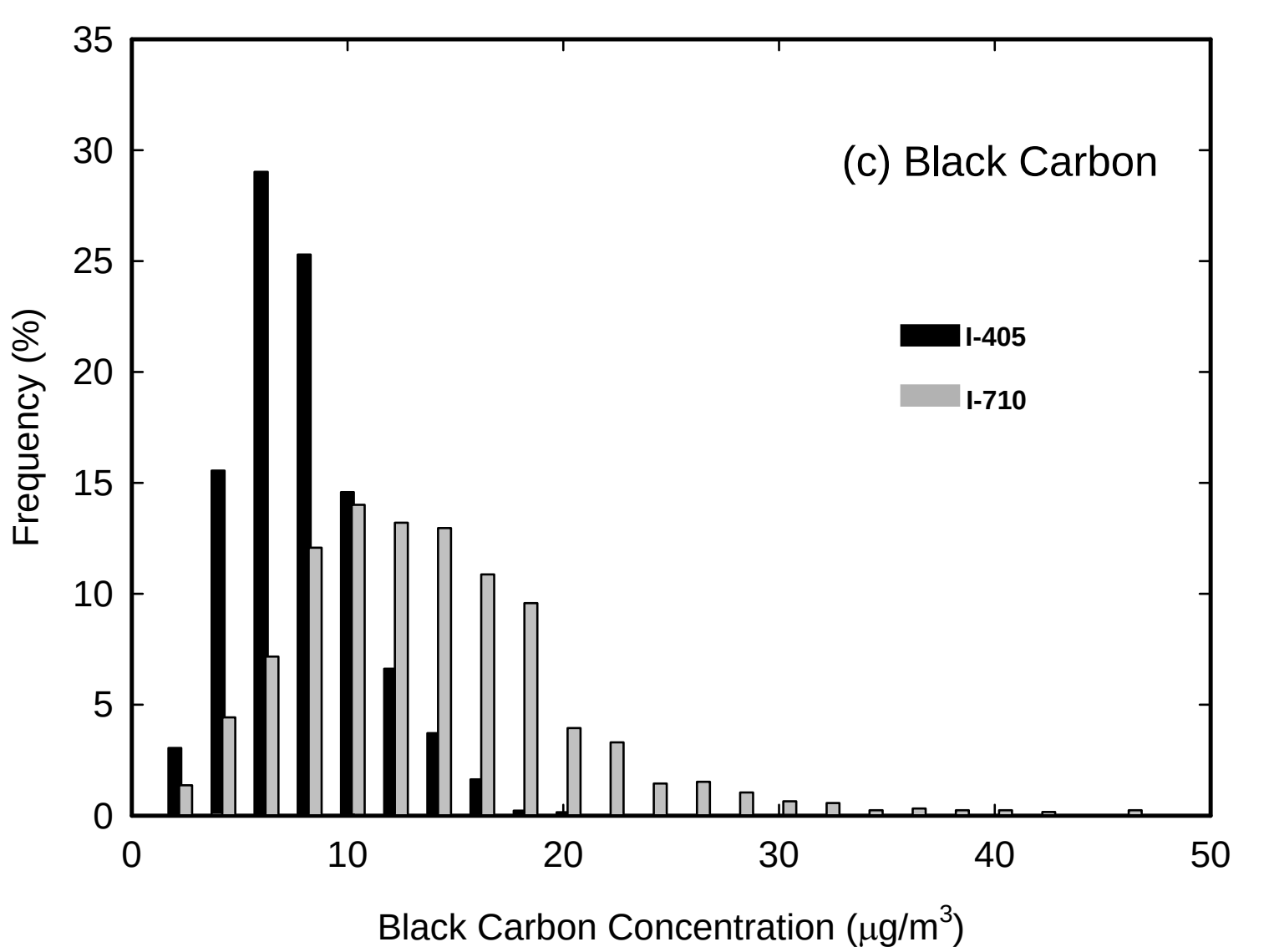

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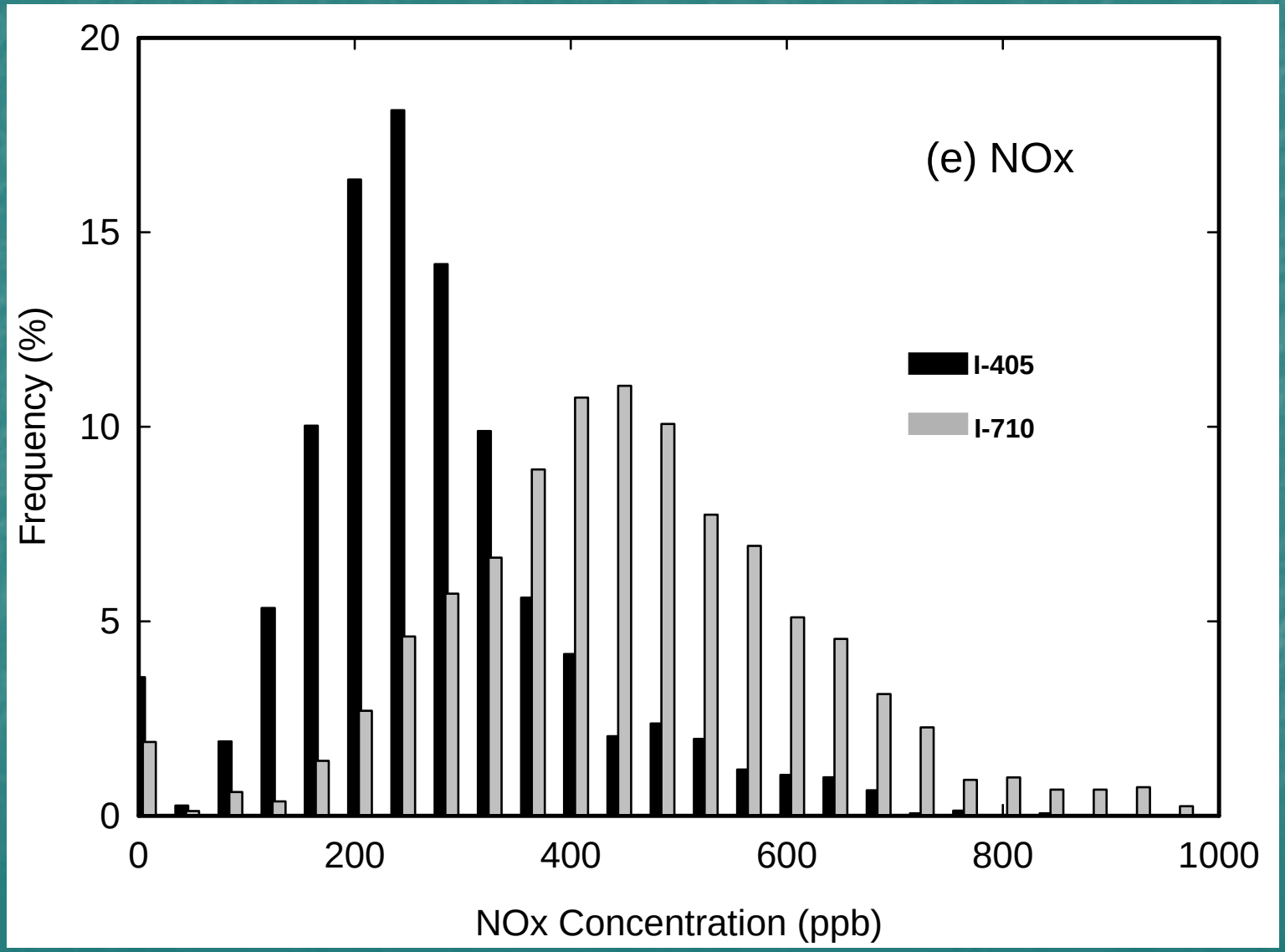

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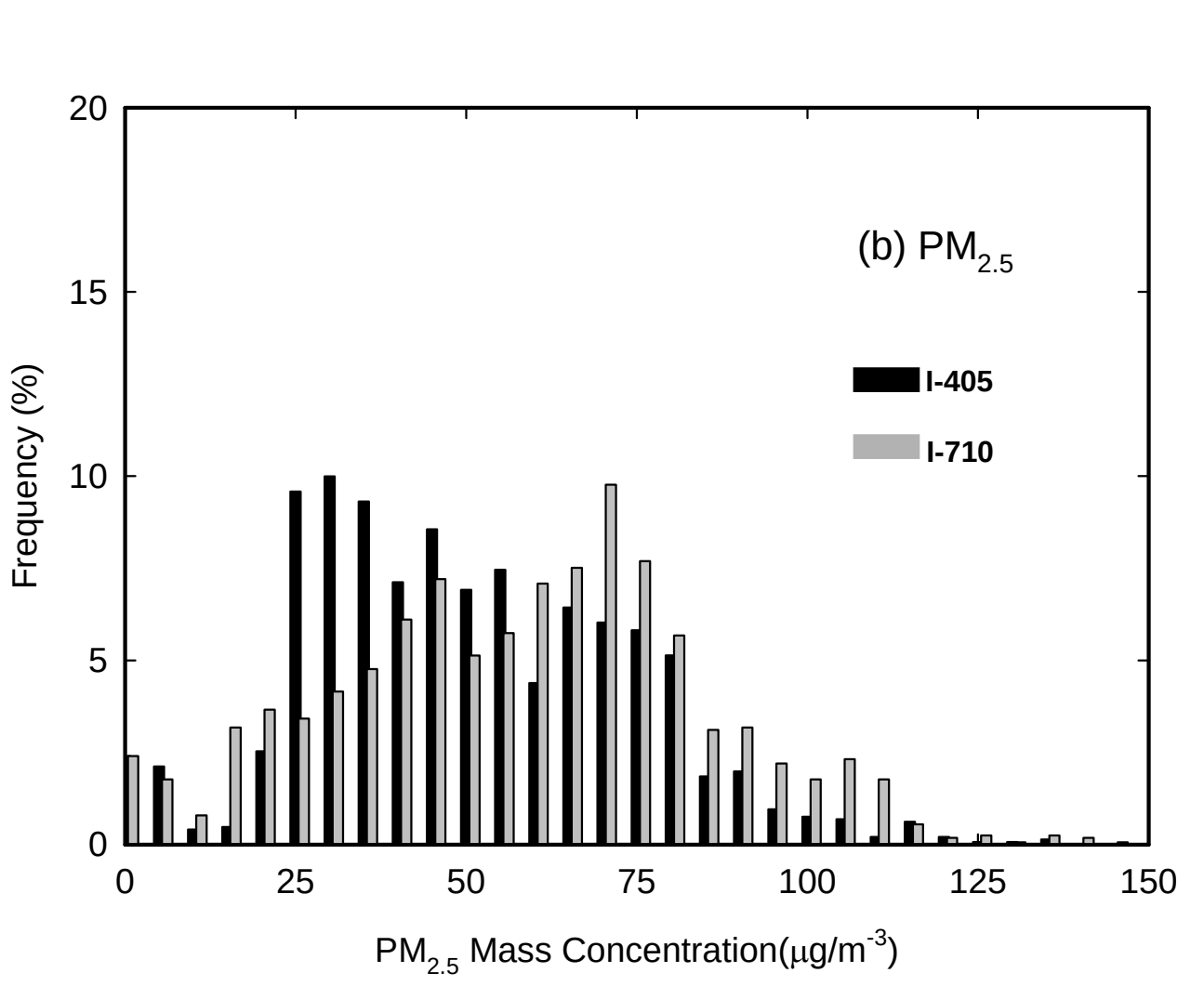
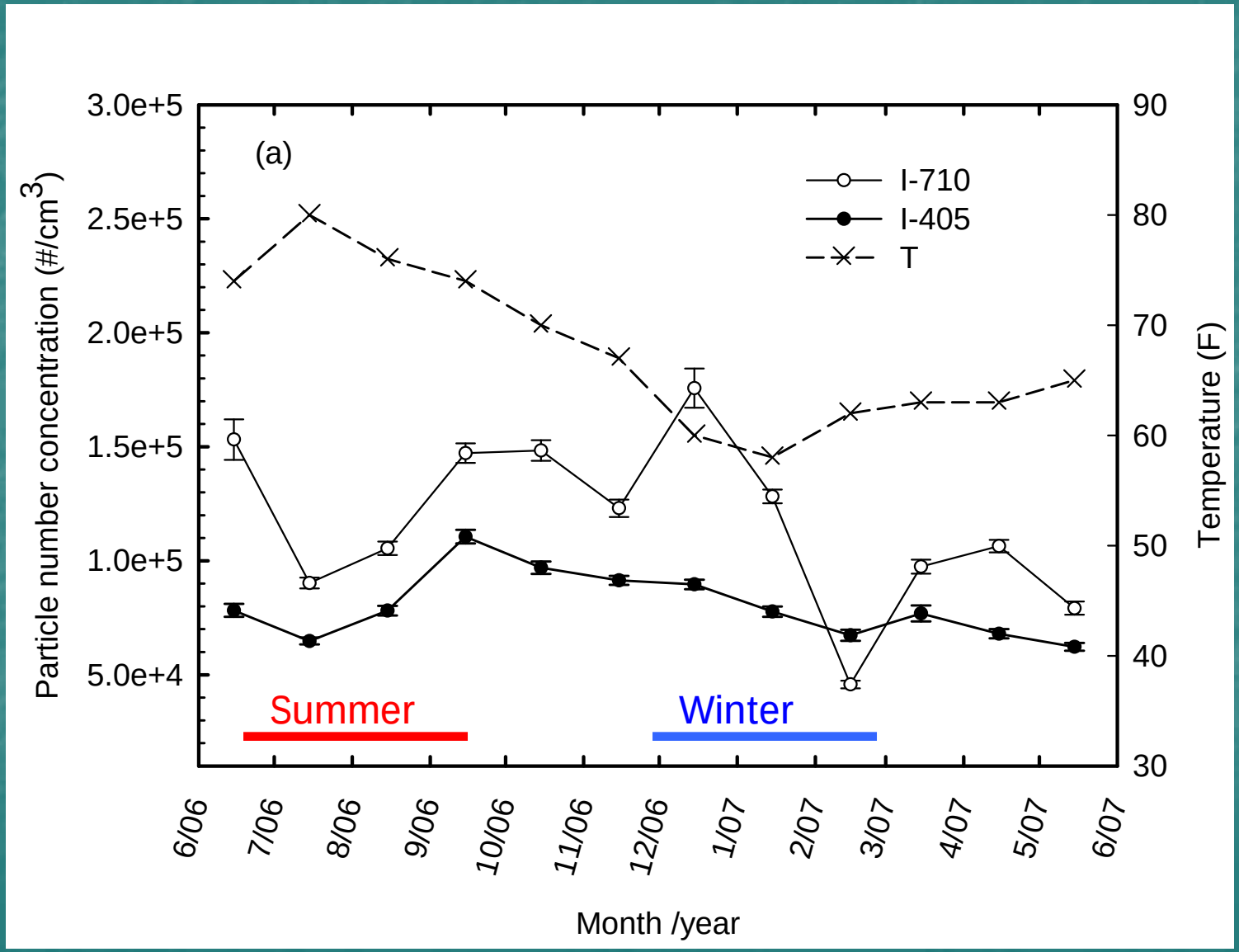
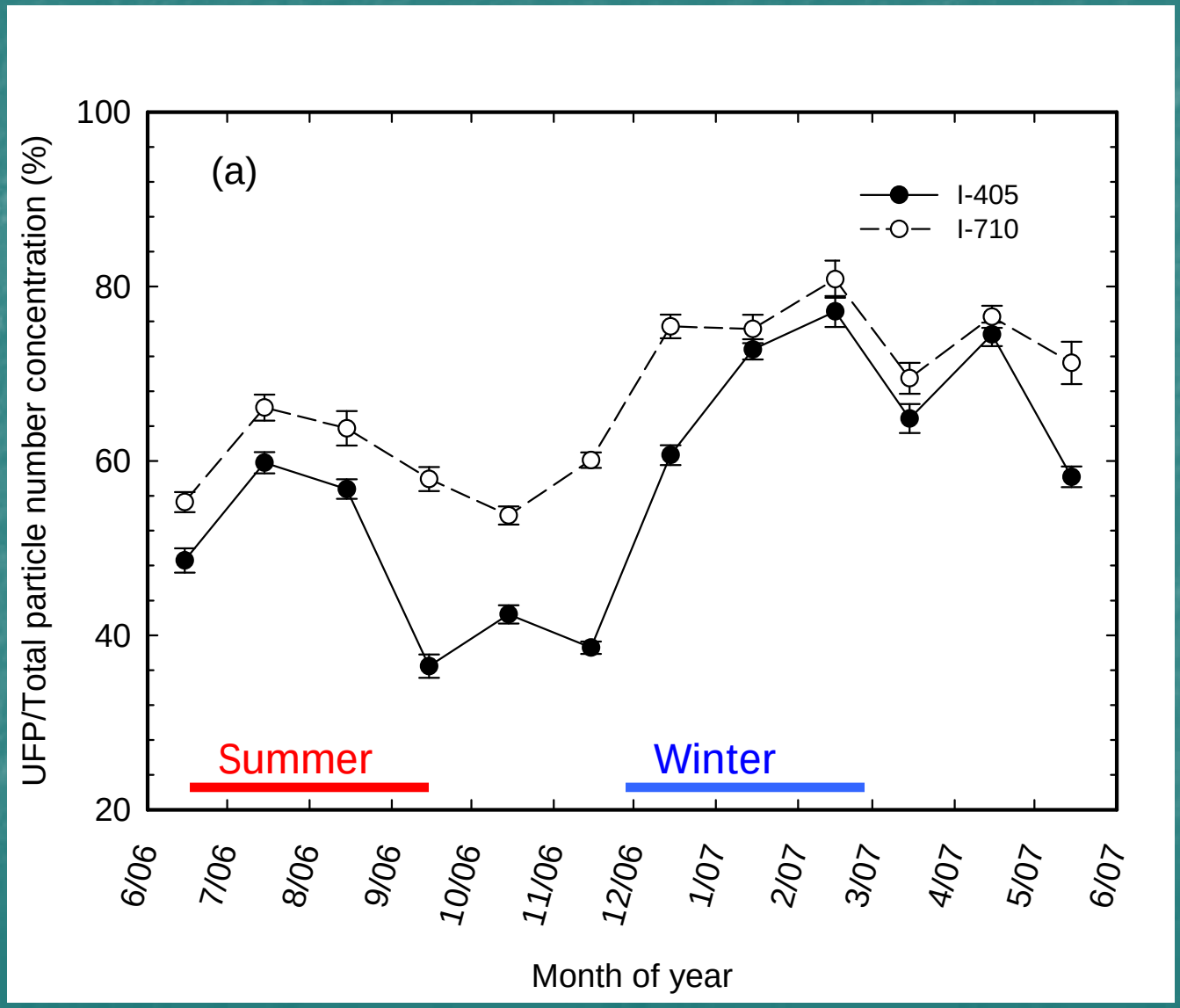


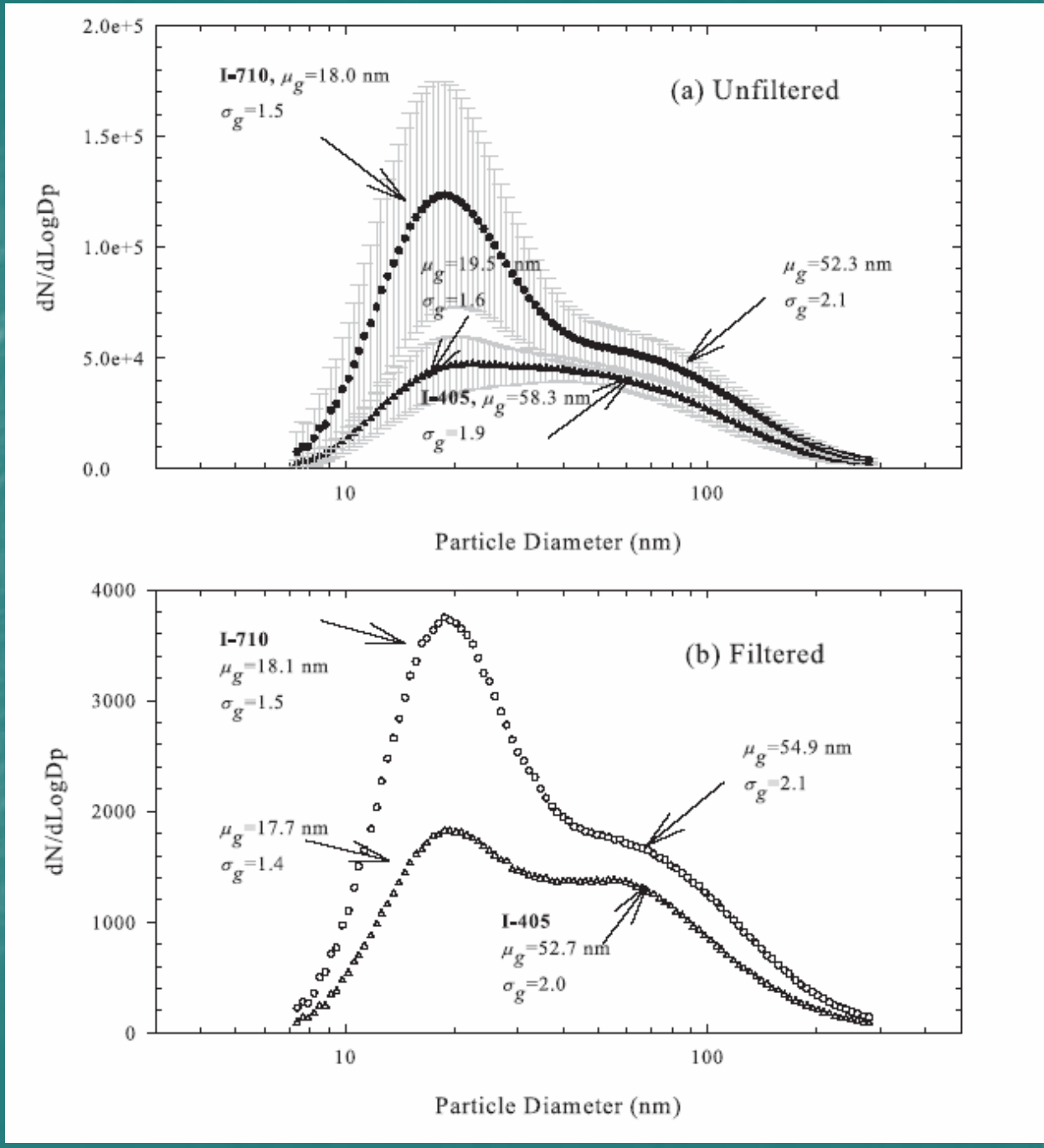
Seasonal Effects



Seasonal Effects

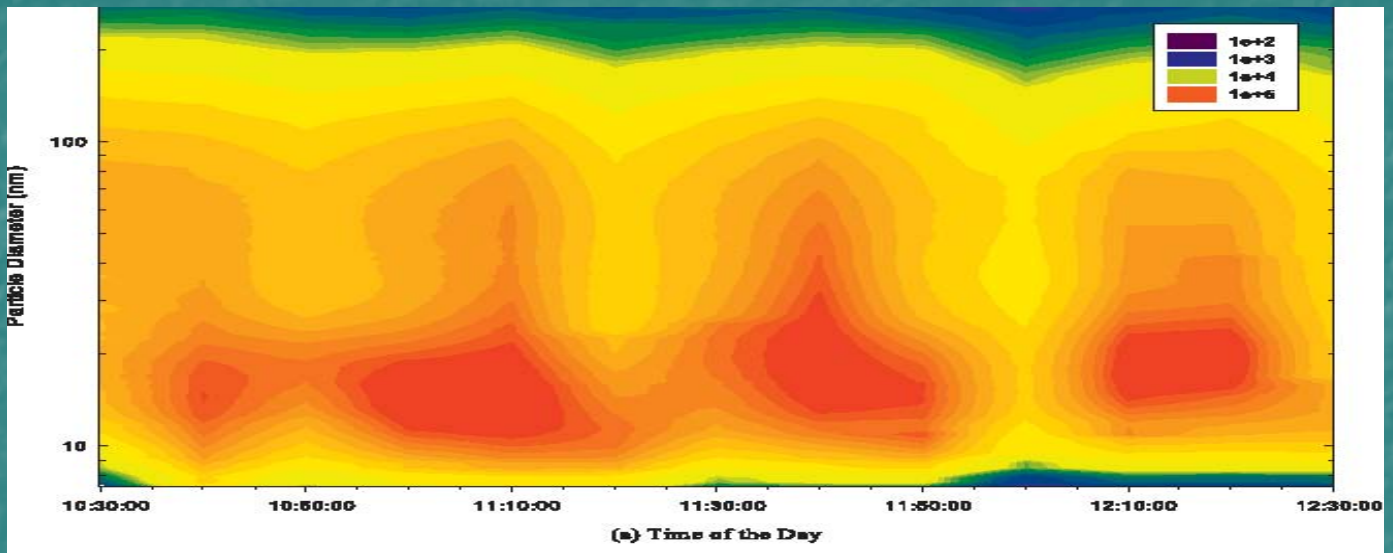


Particle Size Distributions In Exposure Chamber

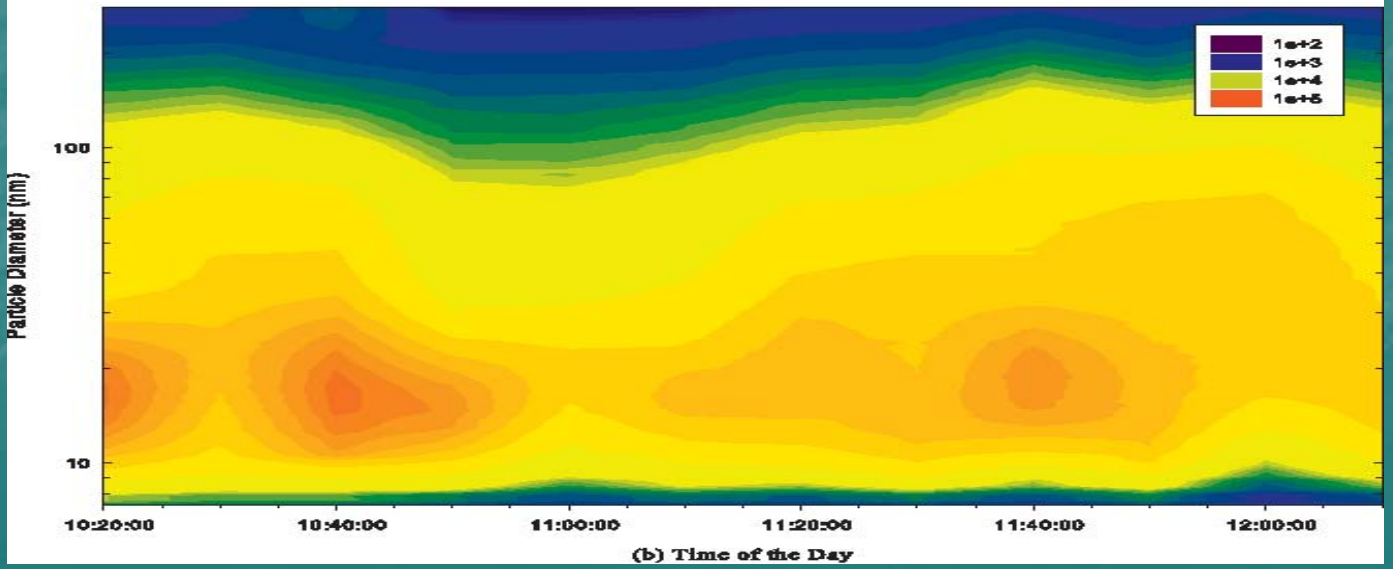


Contour Plots of UF Size Distributions v. time

I-710



I-405



Summary of Study Results

- For this study average concentrations greater on I-710 (diesel) than I-405 (gasoline)
  - Particle number +37%*
  - P-PAH +69%*
  - BC +89*
  - PM-2.5 +15%
  - NOx +84%*
  - CO +26%
  - * significant at p<=0.05

PHYSIOLOGIC RESULTS

Summary of Study Results

- Significant Results:
  - Unfiltered air compared to filtered air
    - Increased frequency atrial arrhythmias
      - +20% ectopic beats
      - Not significant for healthy individuals
      - Can trigger sustained arrhythmias in susceptible individuals
    - Increased concentration of NTproBNP
      - +38%
      - Marker for intra-atrial pressure
    - Increased concentration of VEGF
      - +30%
      - Marker for vascular response/injury

Summary of Study Results

- No significant differences in HRV
- No significant differences in respiratory response or blood pressure
- Suggests effect more strongly associated with ultrafine particles, P-PAH, and BC
  - p=0.01 for number concentration
  - p=0.02 for P-PAH
  - P=0.04 for BC
  - P=0.07 for mass concentration

Summary of Study Results

- In-vehicle concentration of UFP high on heavily used freeways
- UFP fraction of total particulate higher on 710 than 405
- UFP not correlated with other pollutants
- UFP, BC, and P-PAH exposure can be reduced by:
  - Avoiding heavy-duty diesel trucks on freeways
  - Use of in-vehicle filtration

Acknowledgements

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  - California Air Resources Board (Contract # 04-324),
  - additional support by Southern California Environmental Health Sciences Center (National Institutes of Health Grant # 5P30ES07048-12), and
  - USEPA Southern California Particle Center
- Contributions by faculty and staff at:
  - UCLA, LAREI, ECU, TA&M, USC

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- Questions ?