Source Contributions to Ambient Black Carbon in Colorado's Northern Front Range and California's South Coast Air Basin

Eric M. Fujita, Barbara Zielinska, William P. Arnott,
David E. Campbell, and Judith C. Chow

Division of Atmospheric Sciences
Desert Research Institute
University and Community College System of Nevada
Reno, Nevada

Black Carbon Emissions and Climate Change: A Technical Workshop
San Diego
October 13-15, 2004

Outline of Presentation

- DOE's Gasoline/Diesel PM Split Study
  - Source characterization of SI and CI vehicles.
  - Black carbon concentrations relative to PM in vehicle-dominated locations with varying CI and SI traffic.
  - Relative contribution of SI and CI to ambient elemental carbon by Chemical Mass Balance receptor modeling.
- Northern Front Range Air Quality Study (NFRAQS) - apportionment of elemental carbon.
- Diurnal and day-of-week variations in BC relative to major co-pollutants (NOx, CO and NMHC).

Gasoline/Diesel PM Split Study

Objective:

- To quantify the relative contribution of PM emissions from gasoline- and diesel-powered engines in the South Coast Air Basin
- Examine range of uncertainties that may be associated with sample collection, chemical analysis and source apportionment

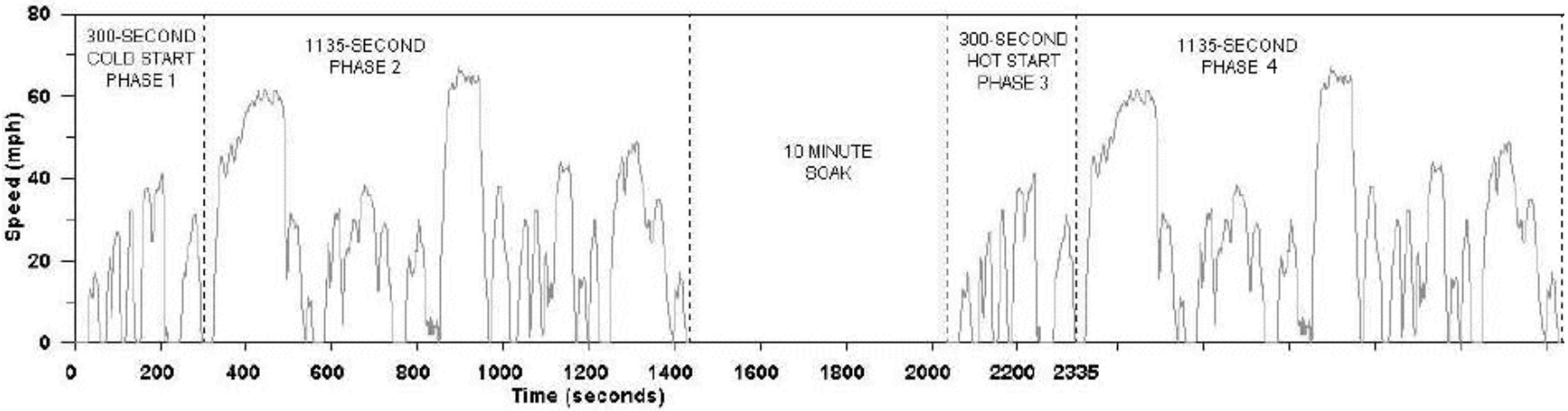
Participants:

- U.S. Environmental Protection Agency (EPA) and Clean Air Vehicle Technology Center (CAVTC)
  - LDGV and LDDV vehicle dynamometer measurements
- Bureau of Automotive Repair (BAR)
  - Light-duty vehicle recruitment and Smog check
- West Virginia University (WVU)
  - HDD truck dynamometer measurements
- Desert Research Institute (DRI) and University of Wisconsin Madison (UWM)
  - Source and ambient measurements and source apportionment

Gasoline/Diesel PM Split Study- Approach

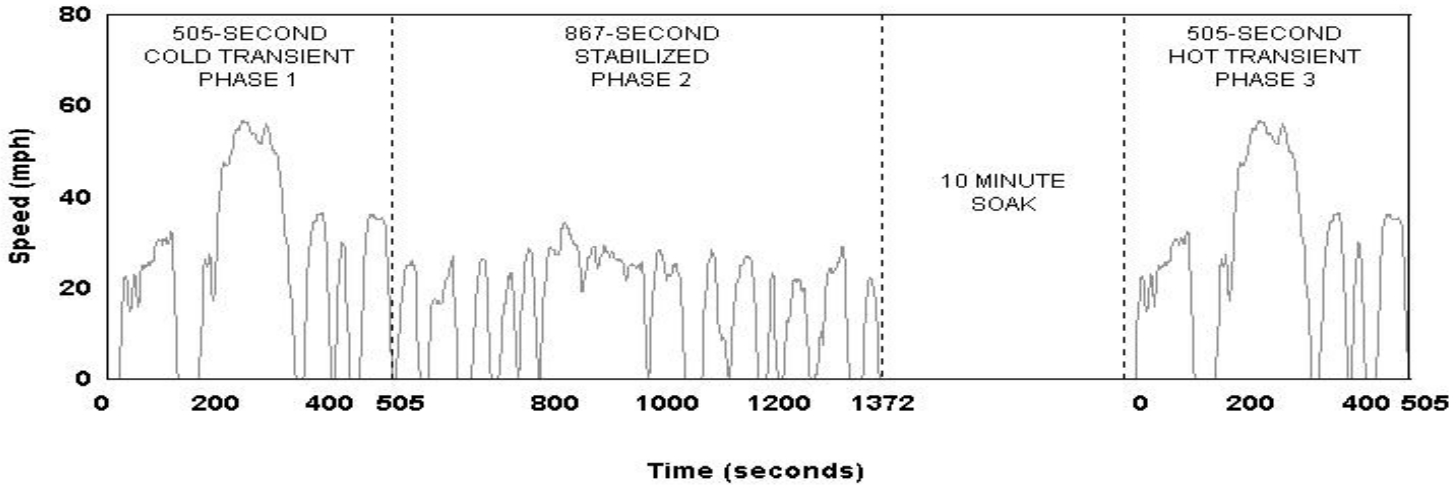
- Source testing of SI and CI vehicles using EPA/CAVTC's and WVU's transportable dynamometers (May-September 2001).
  - 51 LDGV (9 groups of model years and mileage), 6 LDGV smokers and 2 LDDV using modified Unified Driving Cycle.
  - 32 HDDV (3 weight class and 4 model-years groups) and 2 transit buses using City Suburban Route (CSR), Highway (HW), Idle and Manhattan.
- Ambient samples (June -July 2001)
  - Downtown Los Angeles and Azusa - daily 24 hour for four consecutive weeks, composite by day-of-week
  - Variety of locations with variable amount of gasoline and diesel traffic
- Chemically analyze source and ambient samples
  - Organic and elemental carbon, ions, elements, semi-volatile and particulate PAH, hopanes, steranes, polar organics and alkanes.
  - Continuous mass and black carbon.
- Construct source profiles
- Perform Chemical Mass Balance (CMB) receptor modeling
- Publish results in peer-reviewed literature

Light-Duty Vehicle Driving Cycle: Modified Unified Driving Cycle (LA92)

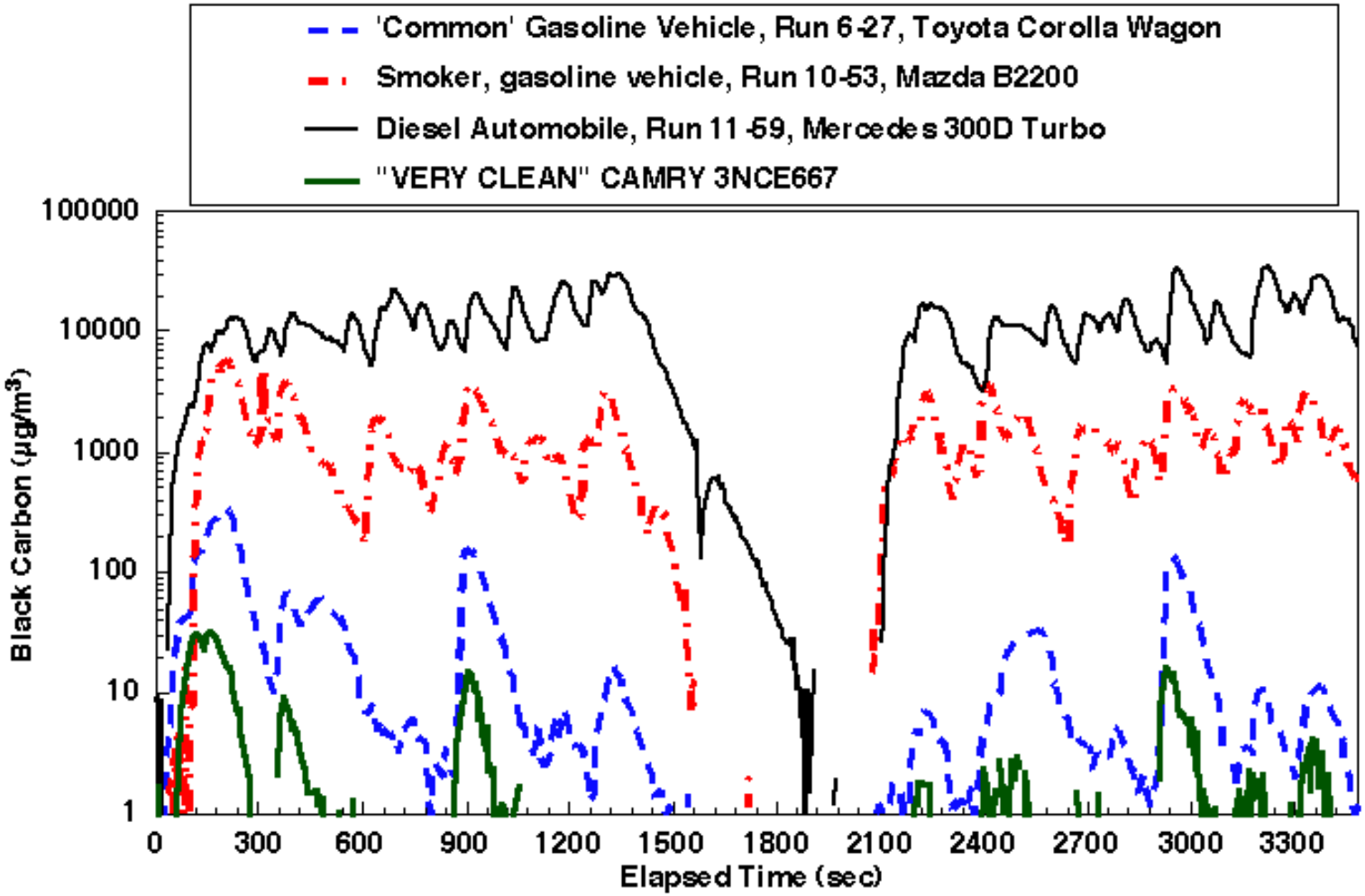


Cold UDC **Warm UDC**

Federal Test Procedure



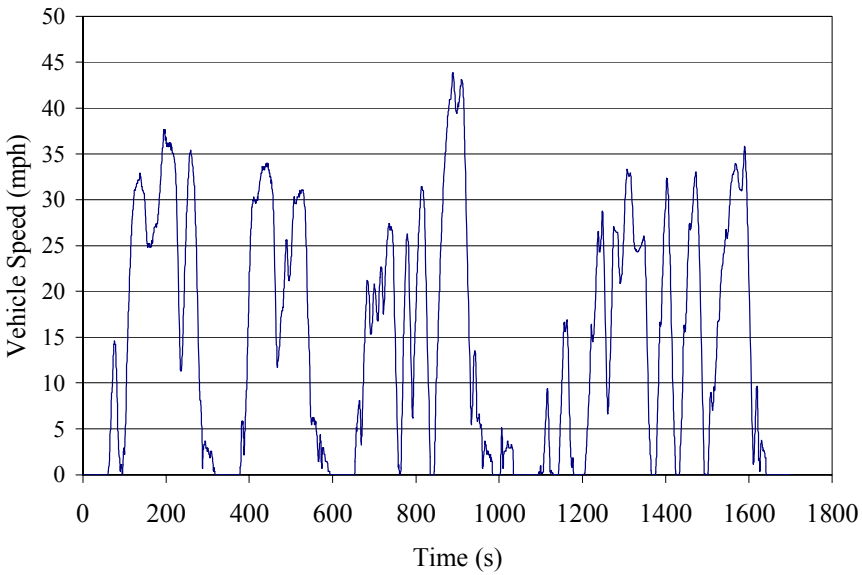
Black Carbon Emission Rates During UDC



Source: Pat Arnott (2005)
NREL Gas/Diesel Split Study

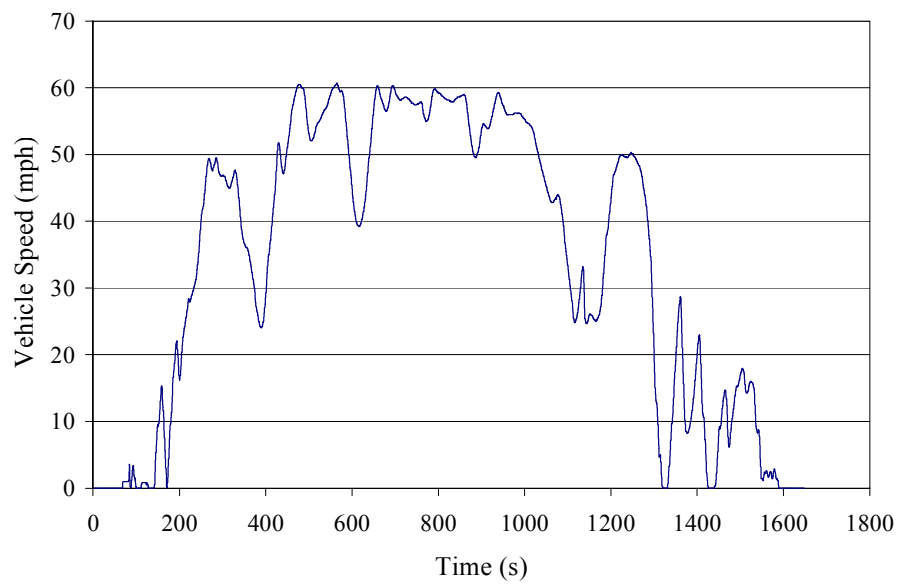
Most PM emissions during UDC from cold start and hard accels with higher fraction of black carbon.

Heavy-Duty Diesel Truck Test Cycles

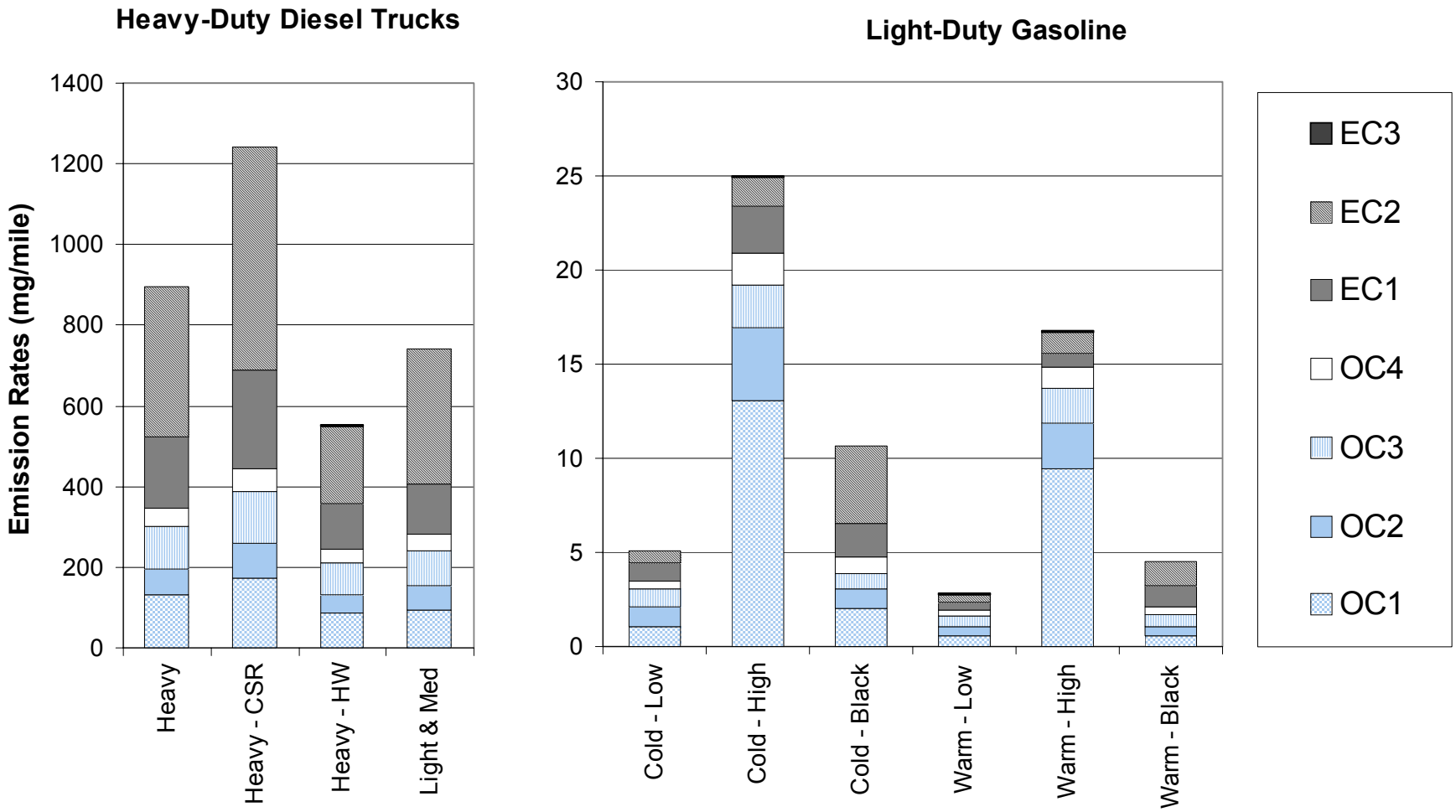


City-Suburban Route

Highway

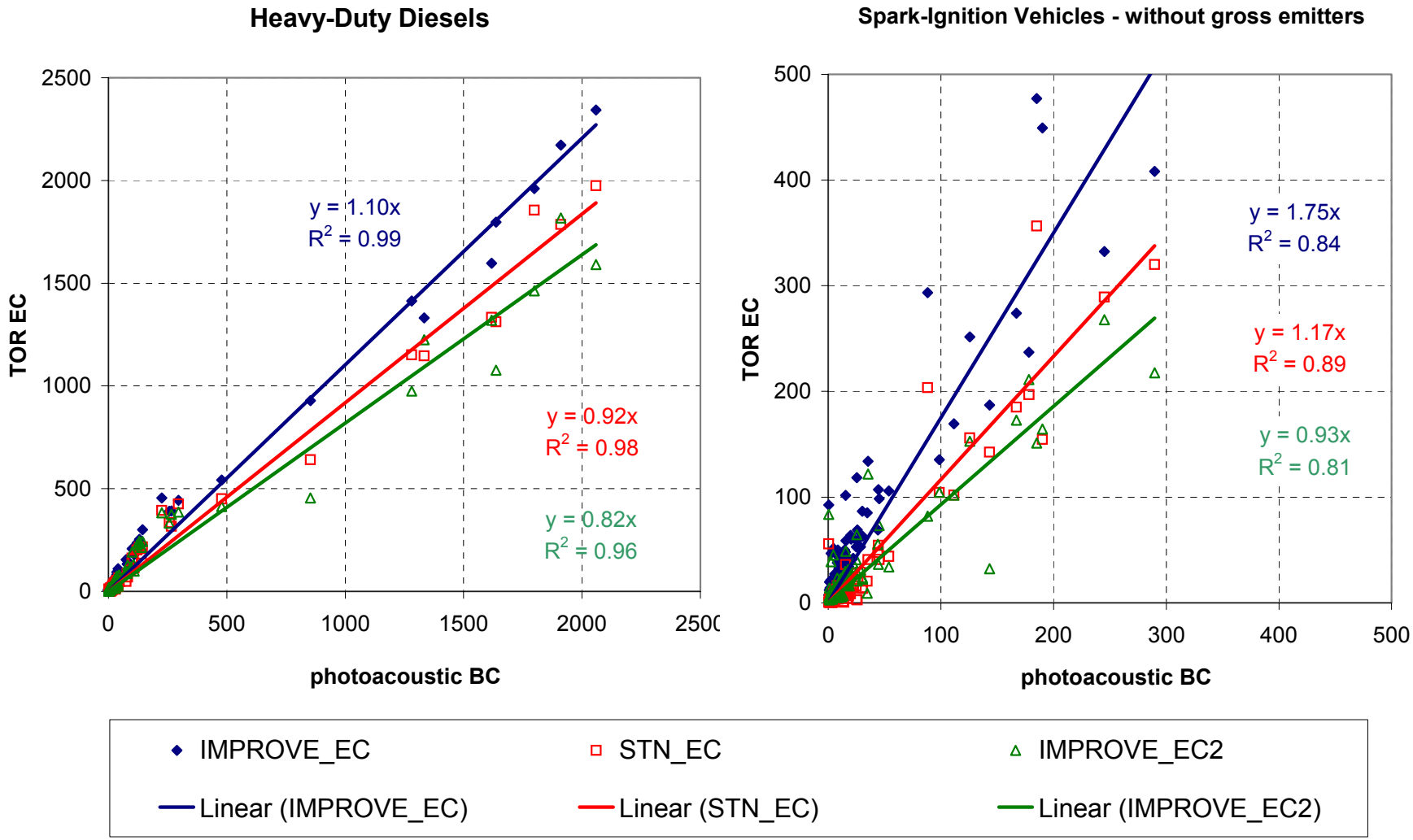


Vehicle Profiles – Carbon Fractions by TOR (IMPROVE)



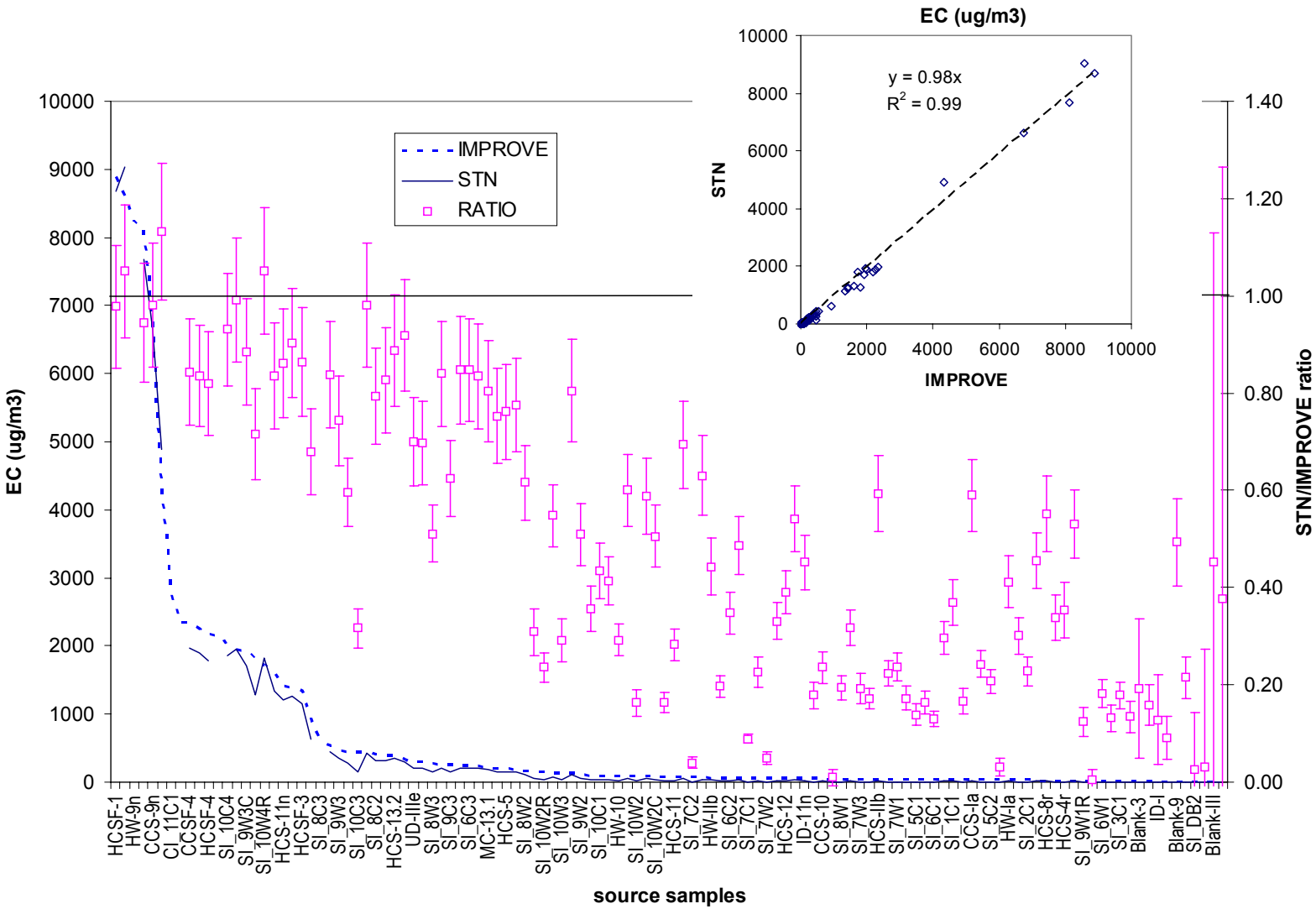
Gasoline/Diesel PM Split Study, Fujita et al., 2005

Photoacoustic Black Carbon Versus IMPROVE and STN Elemental Carbon



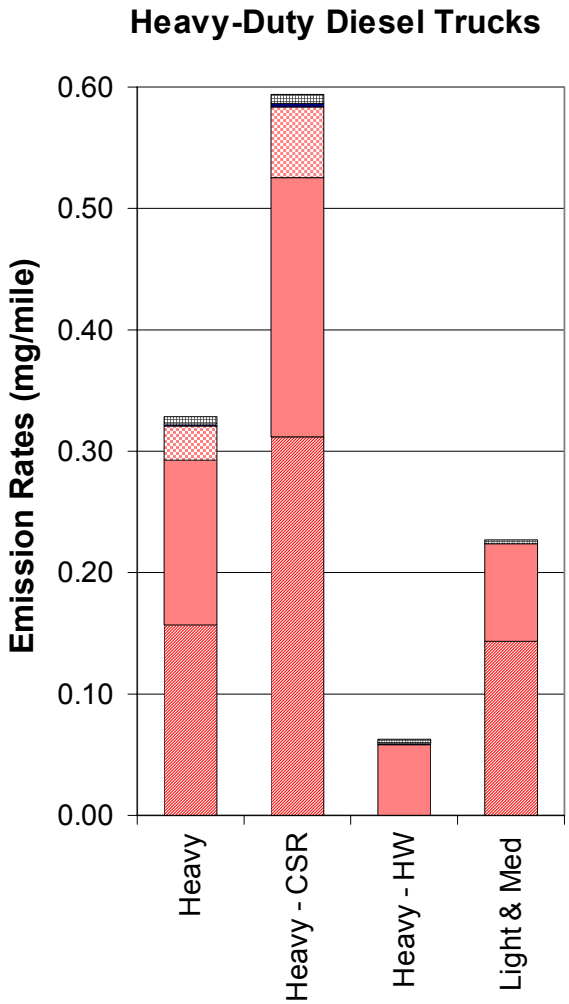
Gasoline/Diesel PM Split Study

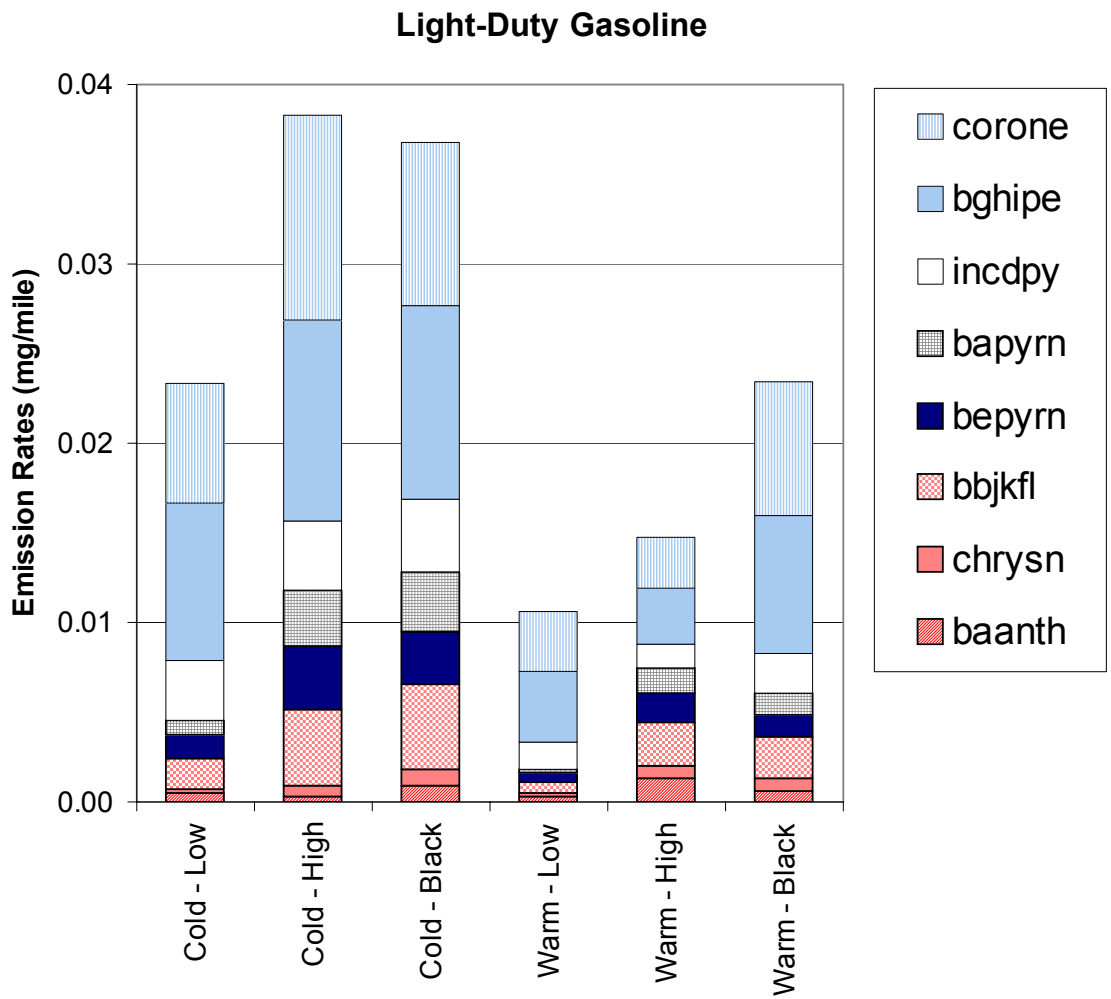
IMPROVE Versus STN Elemental Carbon for SI and CI Exhaust



Gasoline/Diesel PM Split Study

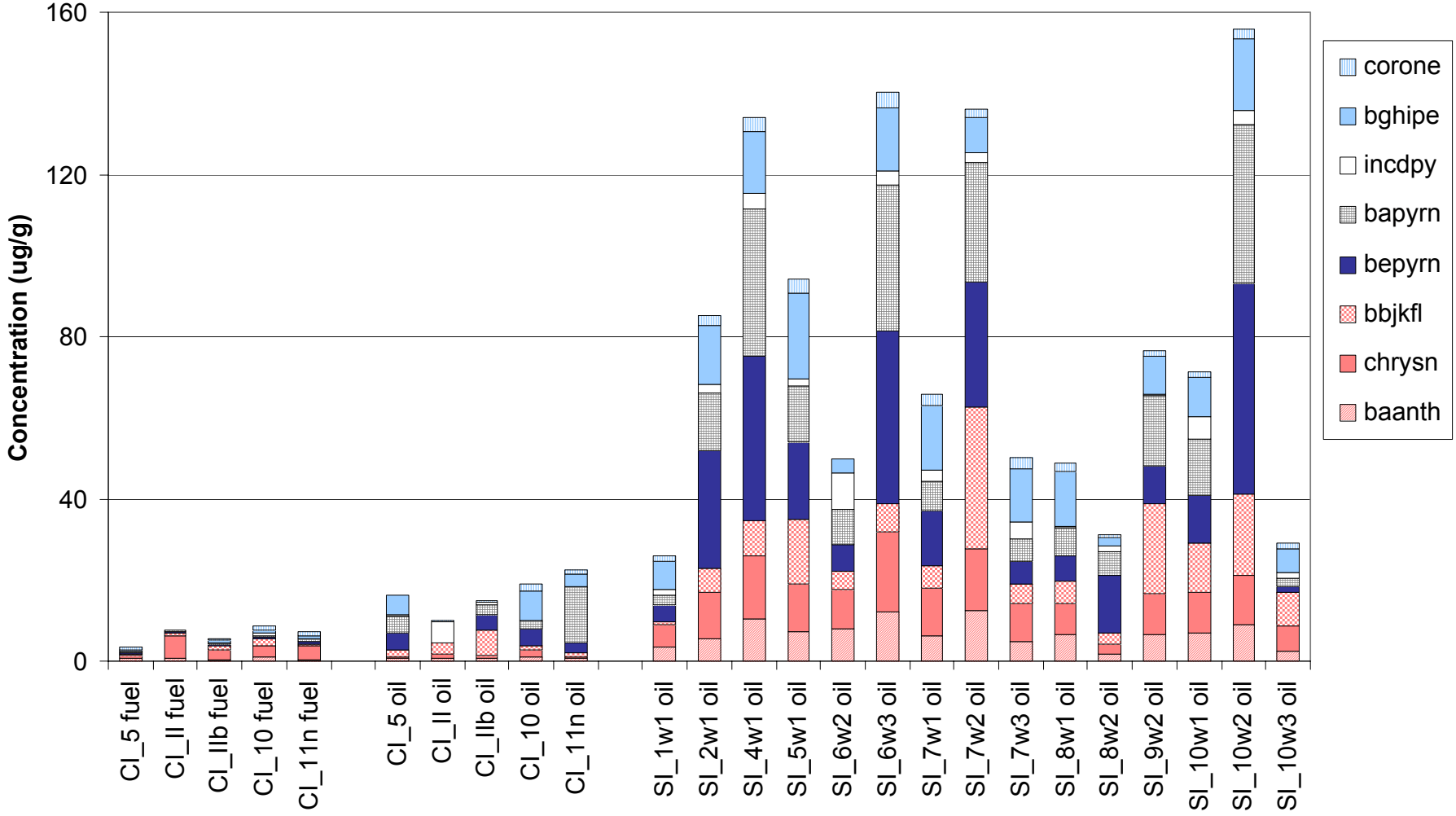
Emission Rates of Particulate PAH in SI Exhaust





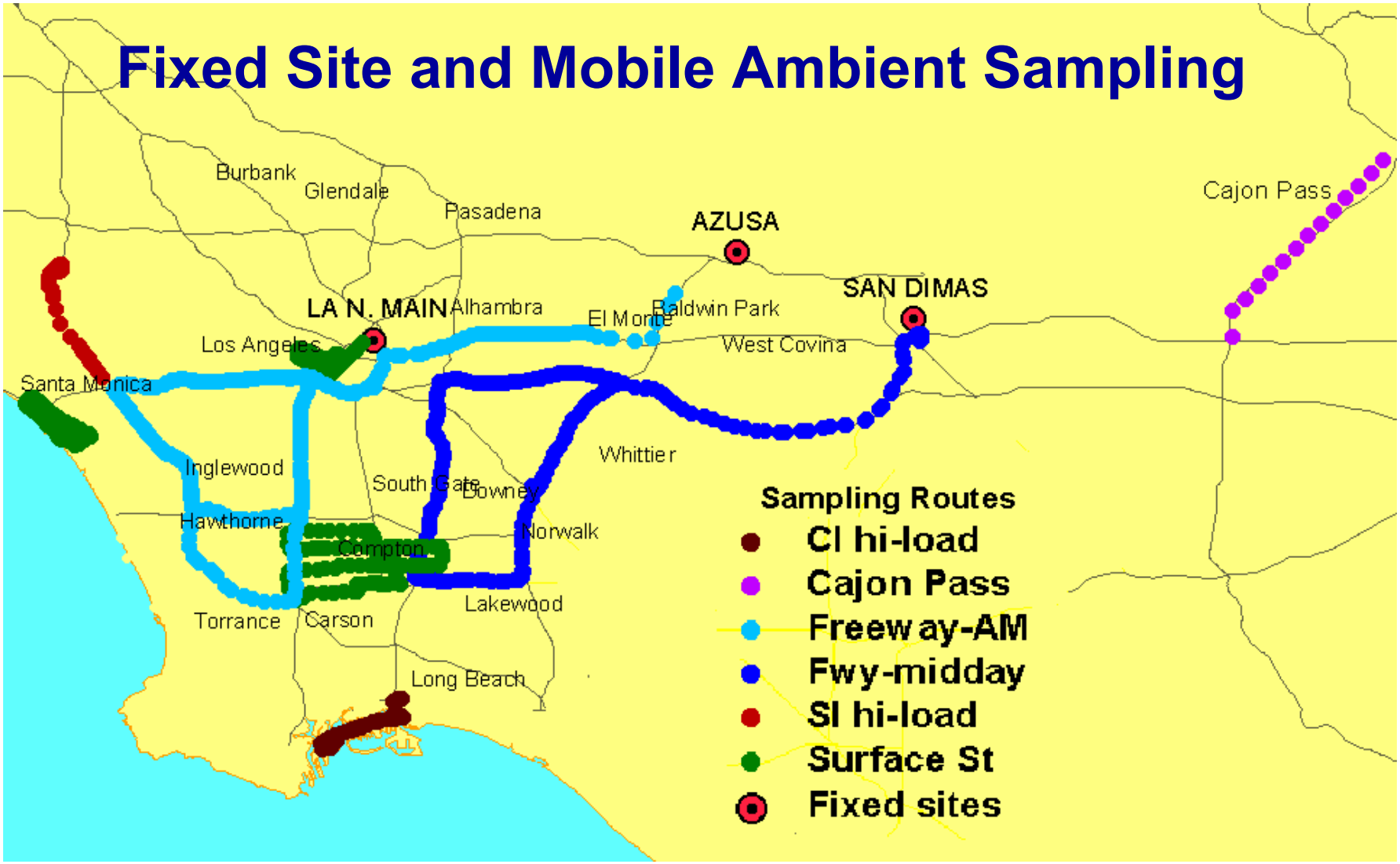
Gasoline/Diesel PM Split Study, Fujita et al., 2005

Concentrations of Particulate PAH in Lube Oil



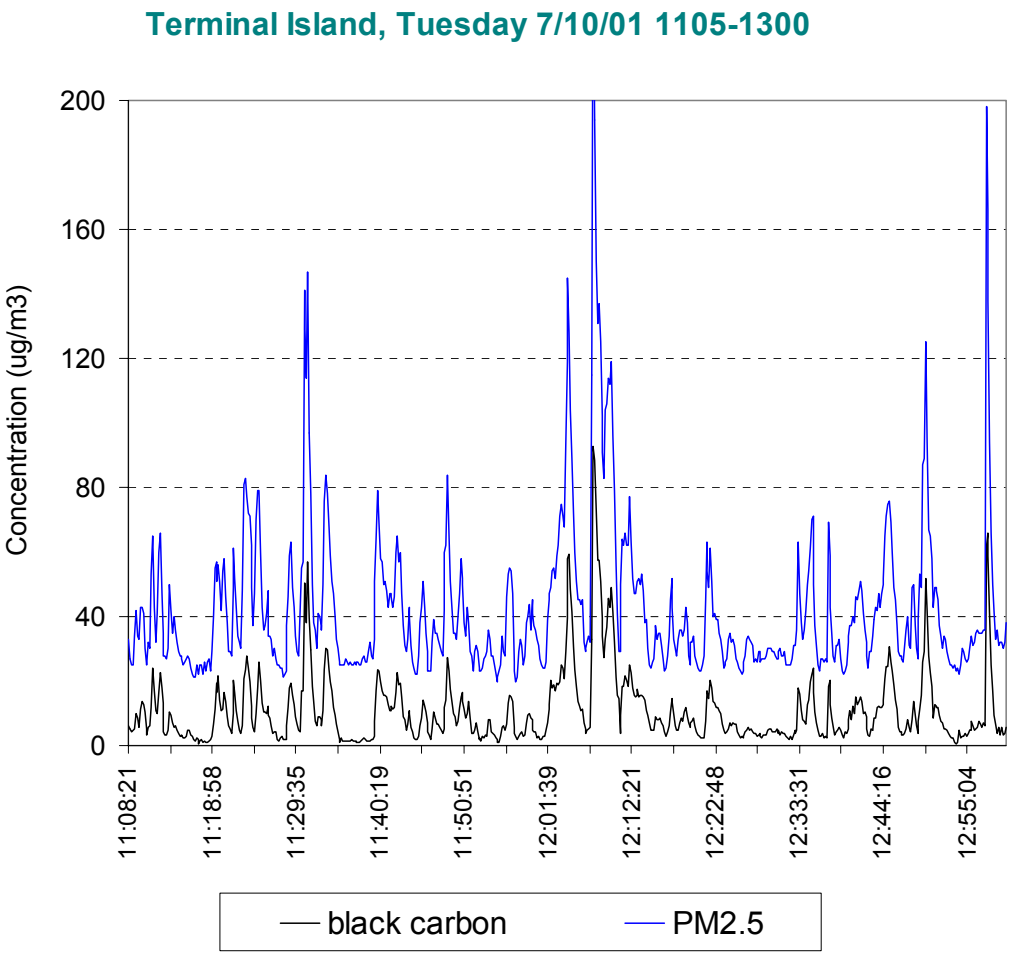
Gasoline/Diesel PM Split Study, Fujita et al., 2005

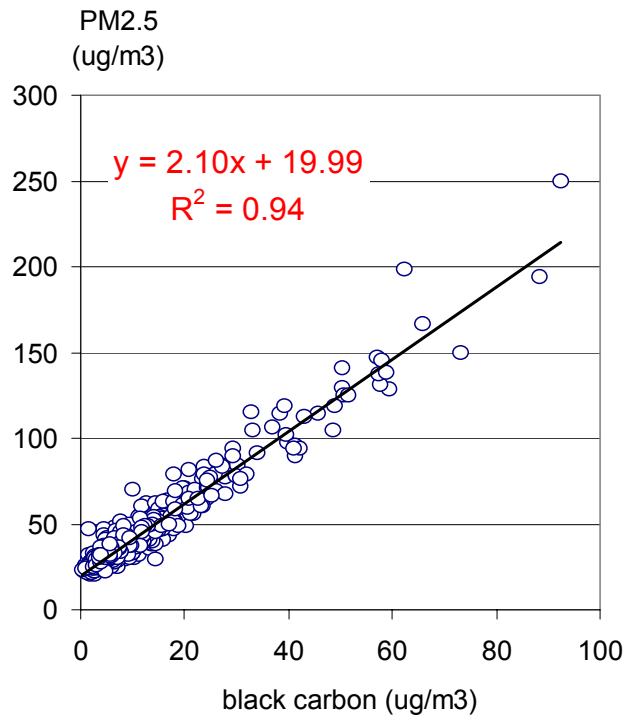
Fixed Site and Mobile Ambient Sampling



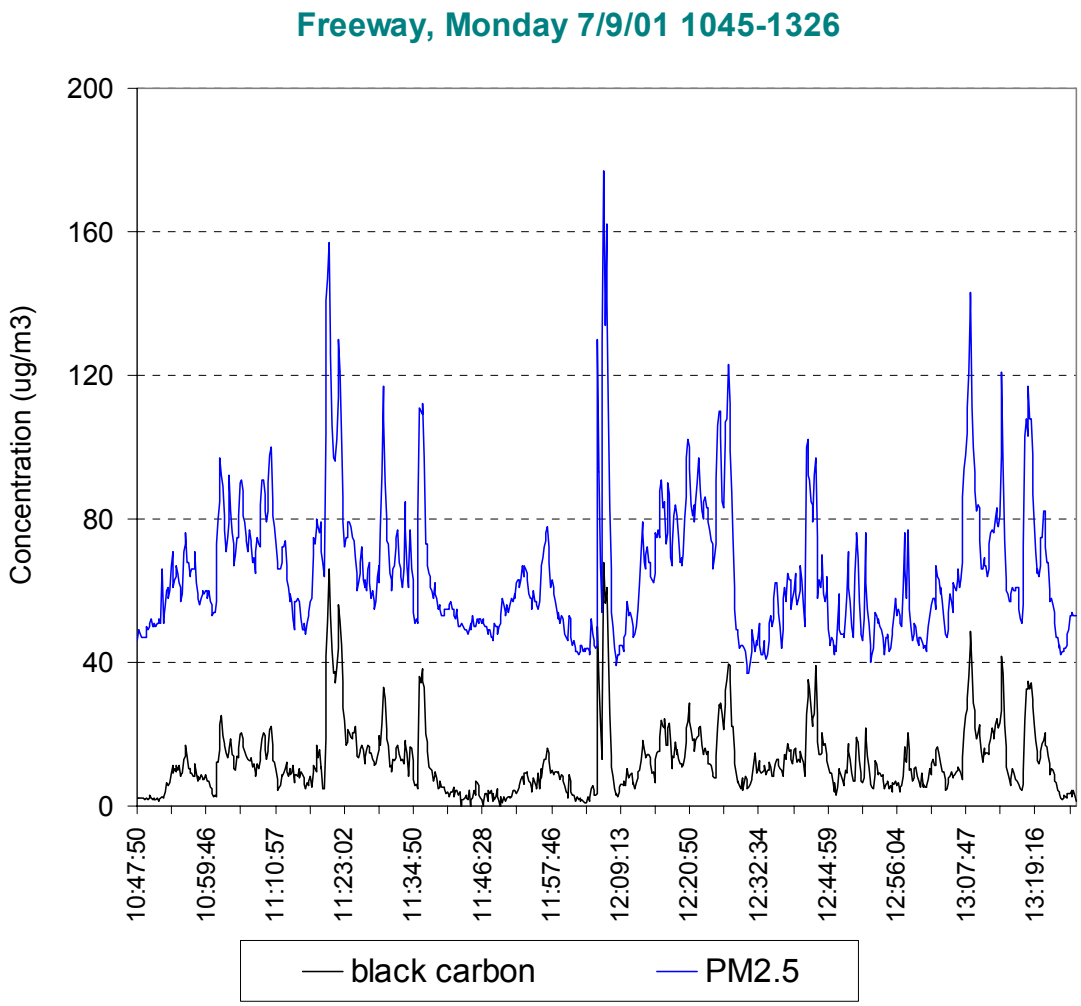
- Downtown Los Angeles and Azusa - daily 24 hour for four consecutive weeks, composite by day-of-week
- Variety of locations with variable amount of gasoline and diesel traffic

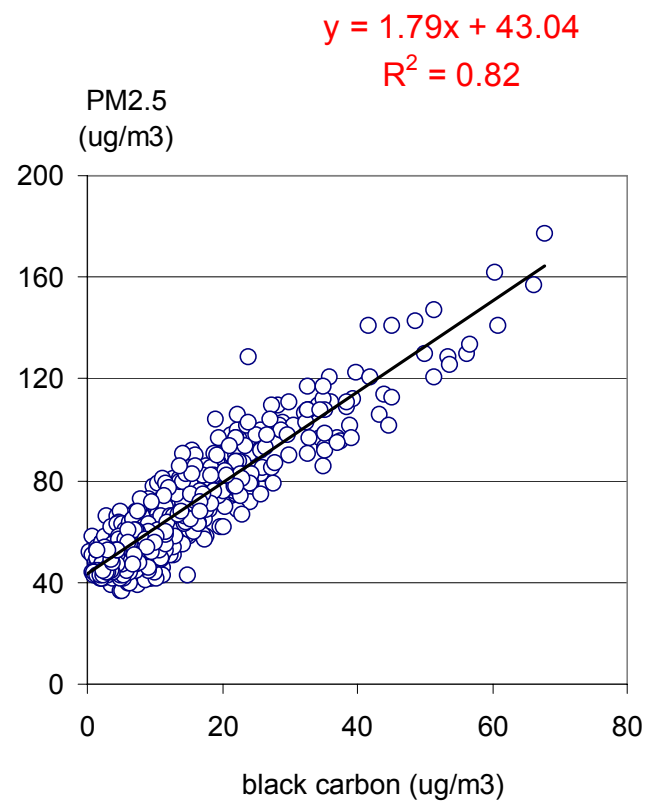
Mobile Sampling – Photoacoustic BC and DustTrak $PM_{2.5}$ Terminal Island – Port Area



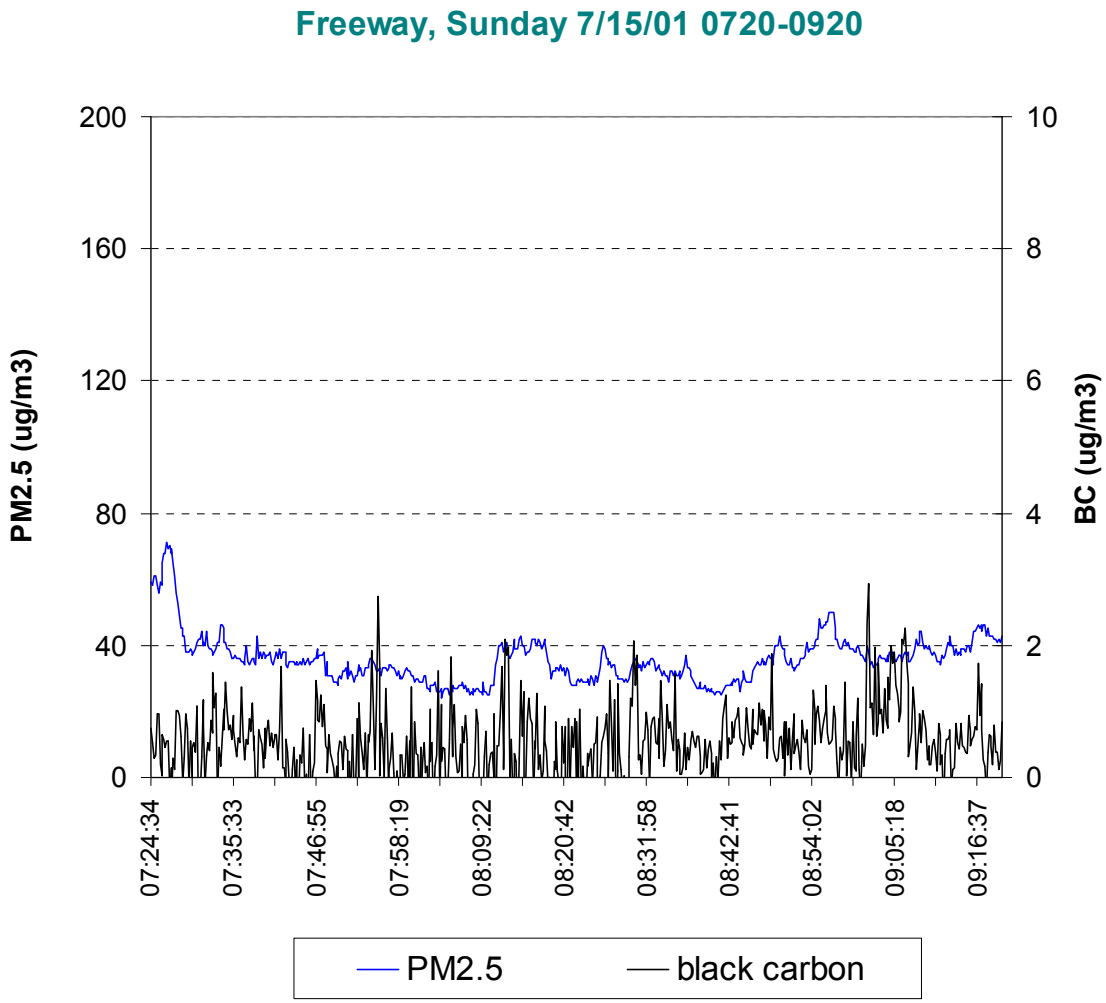


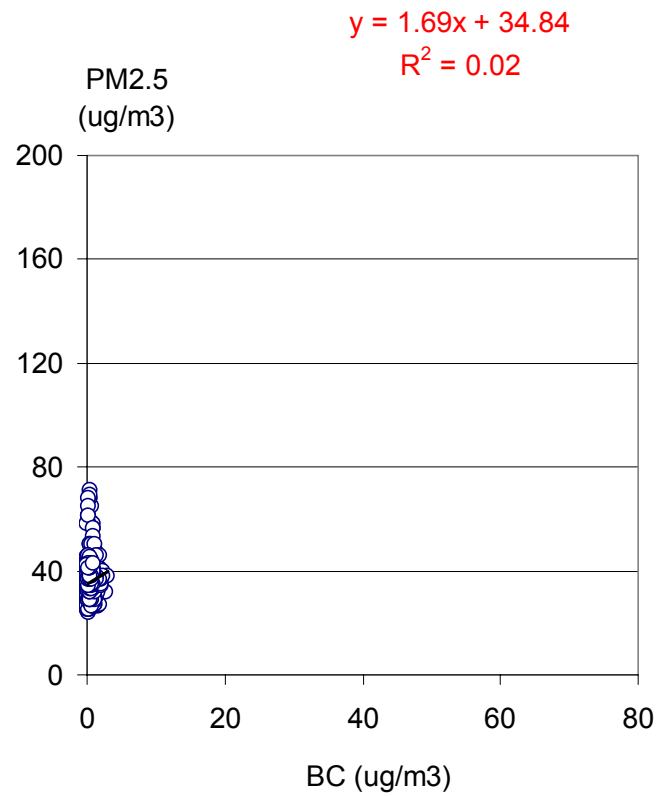
Mobile Sampling – Photoacoustic BC and DustTrak $PM_{2.5}$ Freeway Loop with High Proportion of Truck Traffic



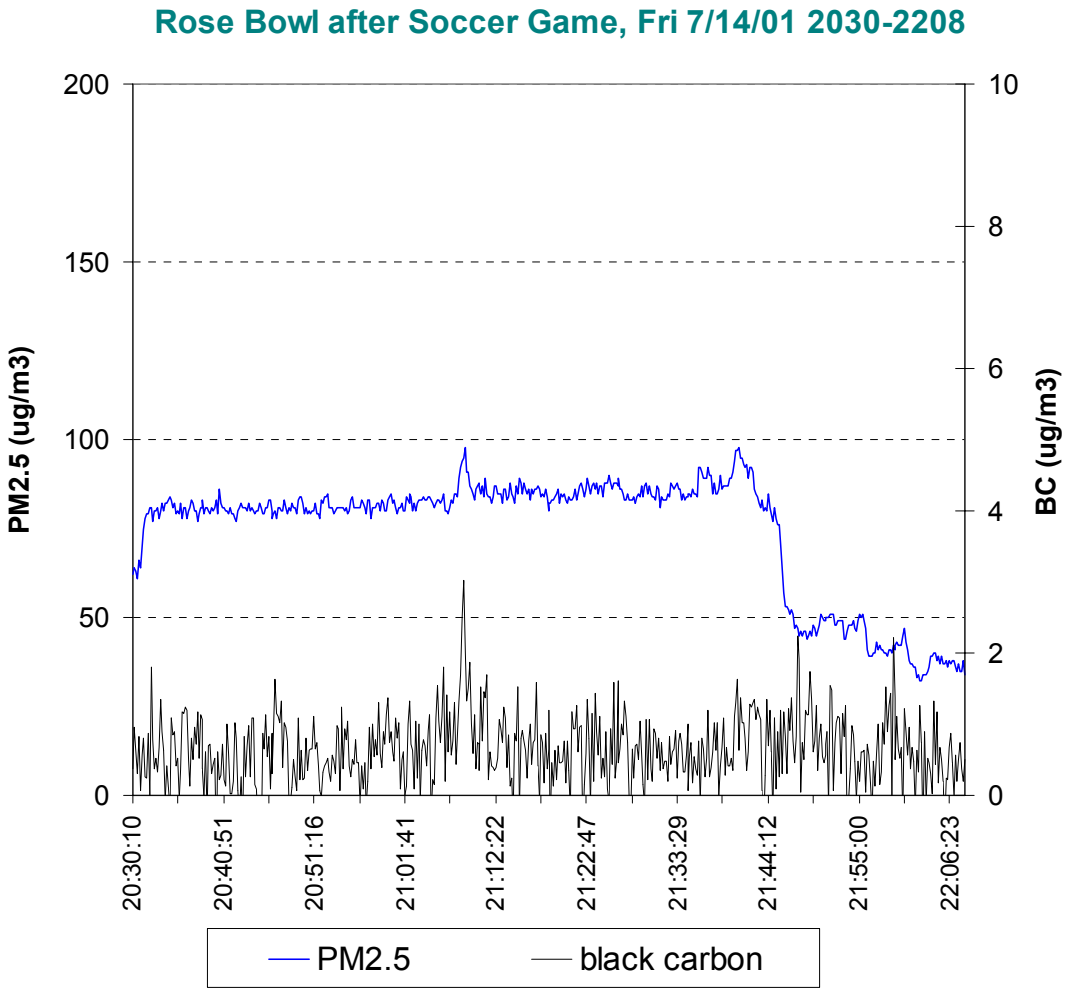


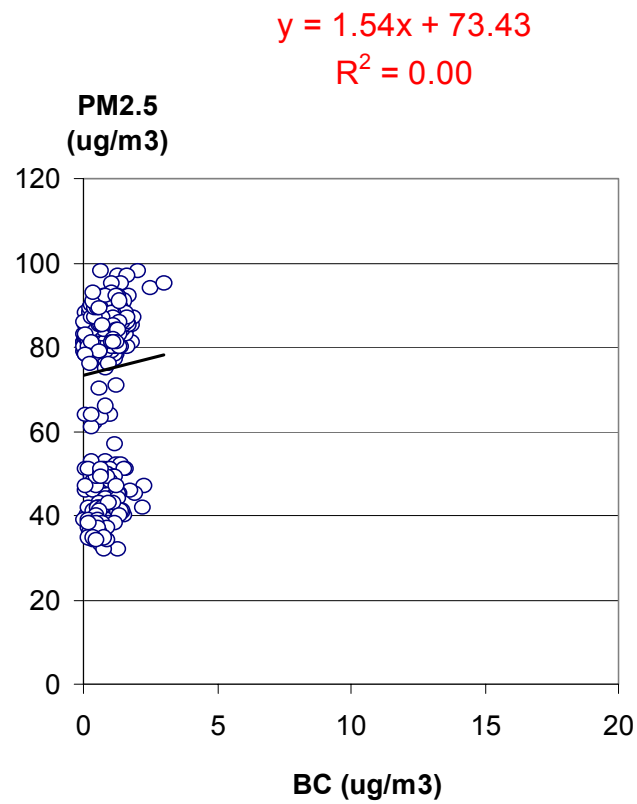
Mobile Sampling – Photoacoustic BC and DustTrak $PM_{2.5}$ Freeway Loop – Sunday Morning



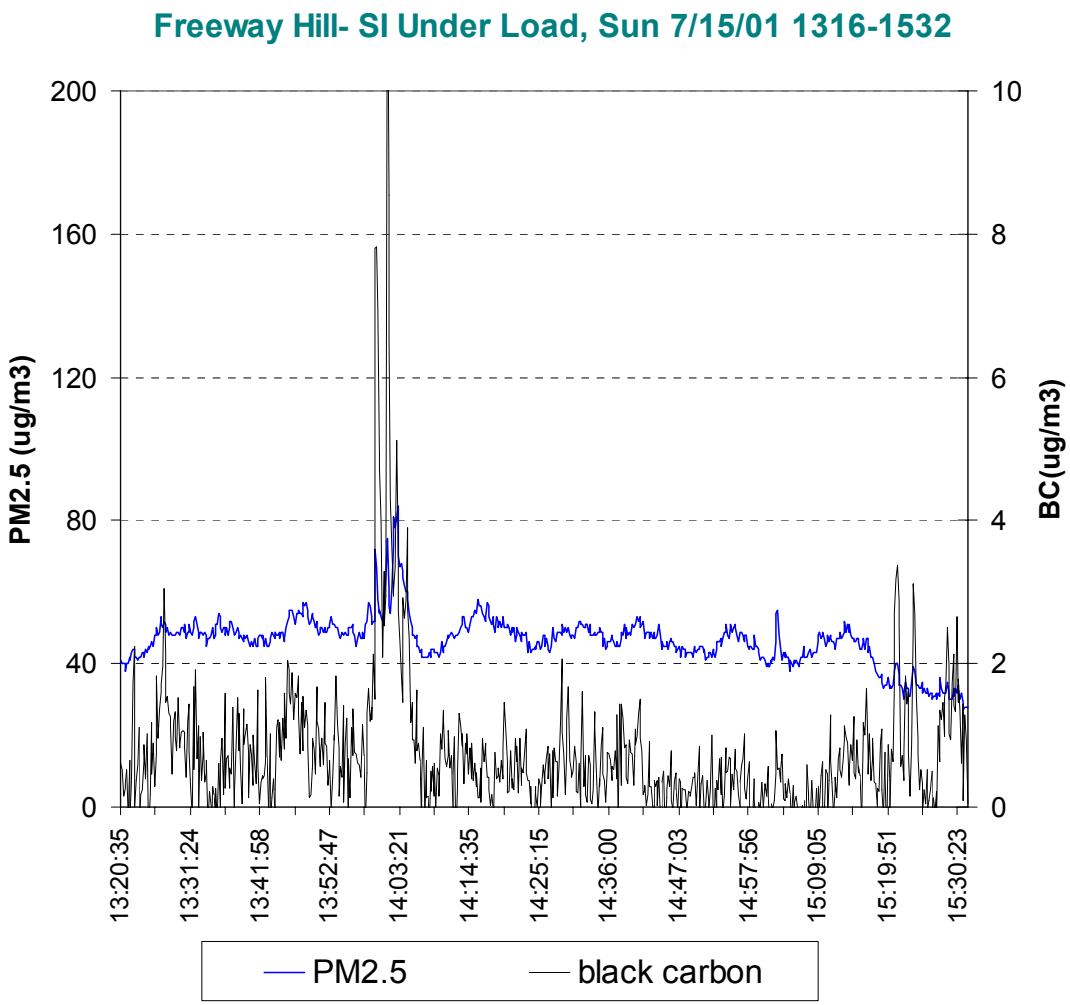


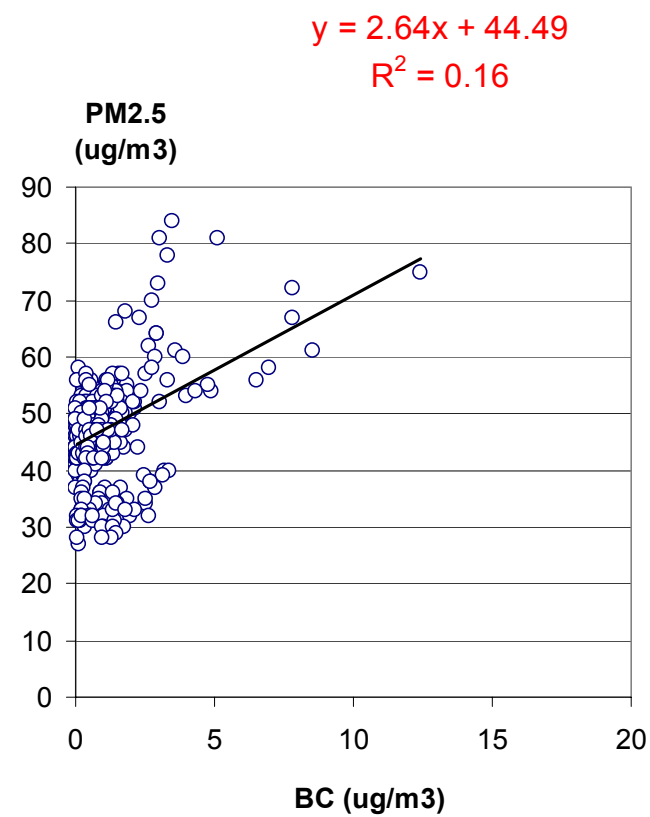
Mobile Sampling – Photoacoustic BC and DustTrak $PM_{2.5}$
Parking Lot After Sporting Event



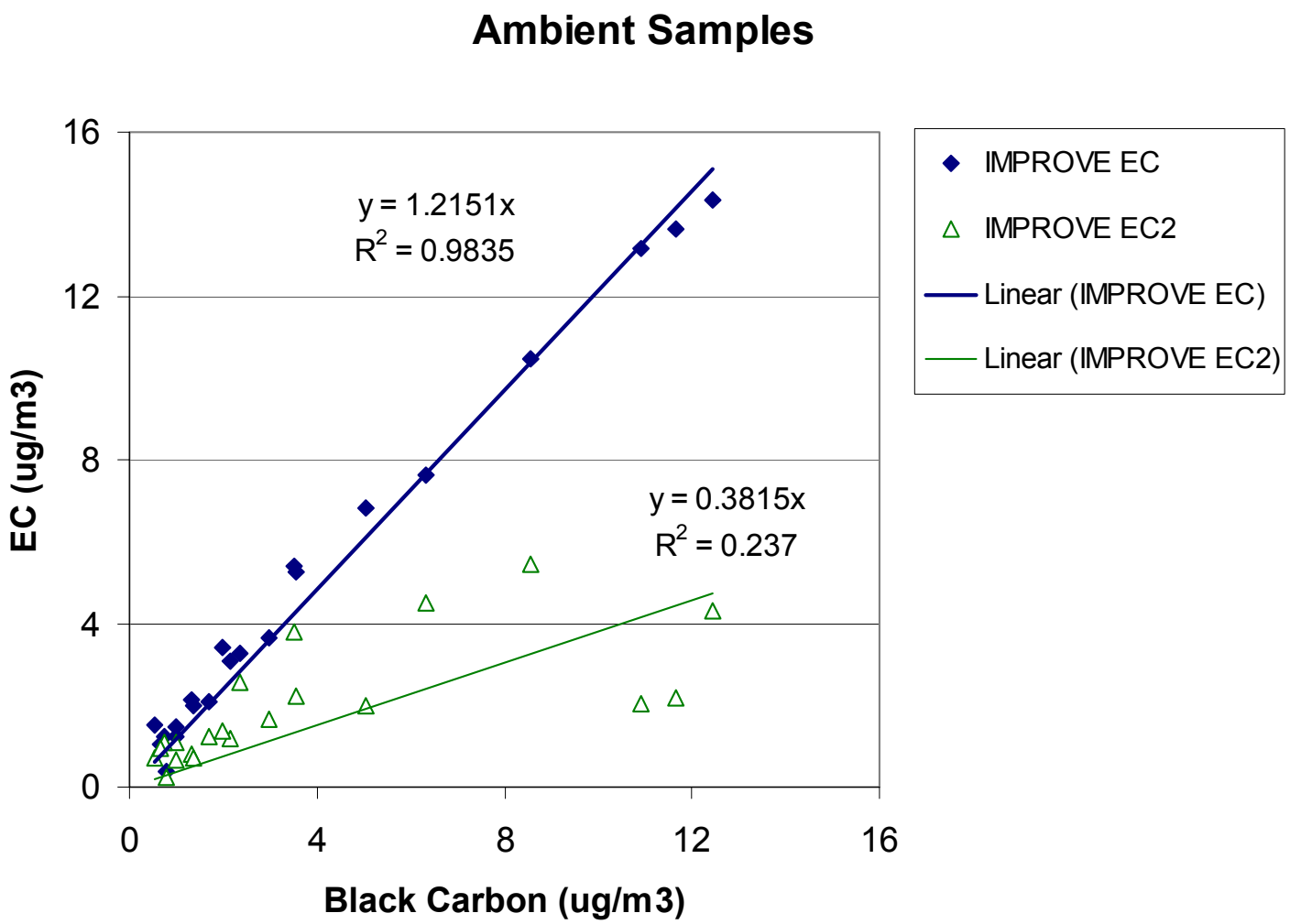


Mobile Sampling – Photoacoustic BC and DustTrak $PM_{2.5}$
I-405 with Hill on Weekend



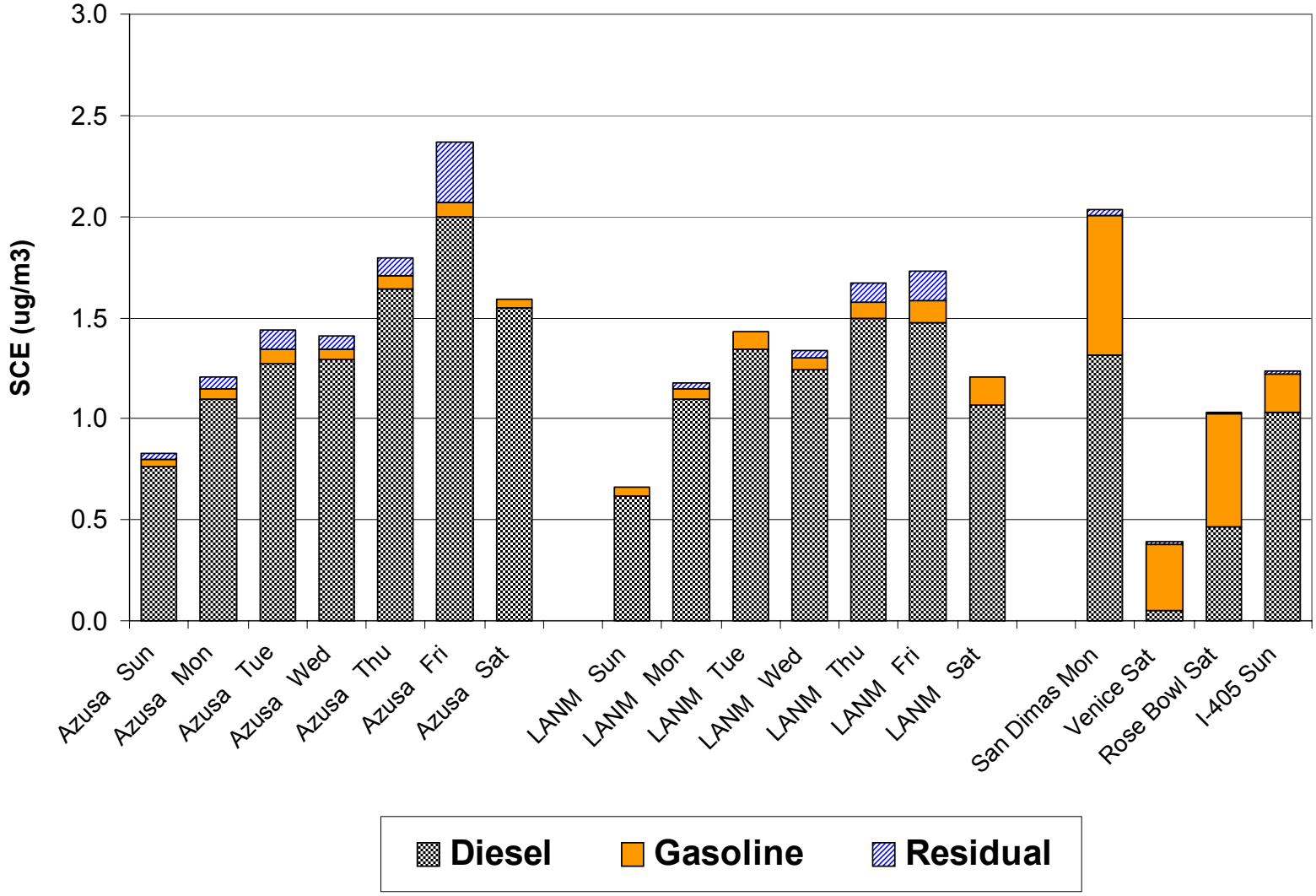


Photoacoustic Black Carbon Versus IMPROVE EC and EC2



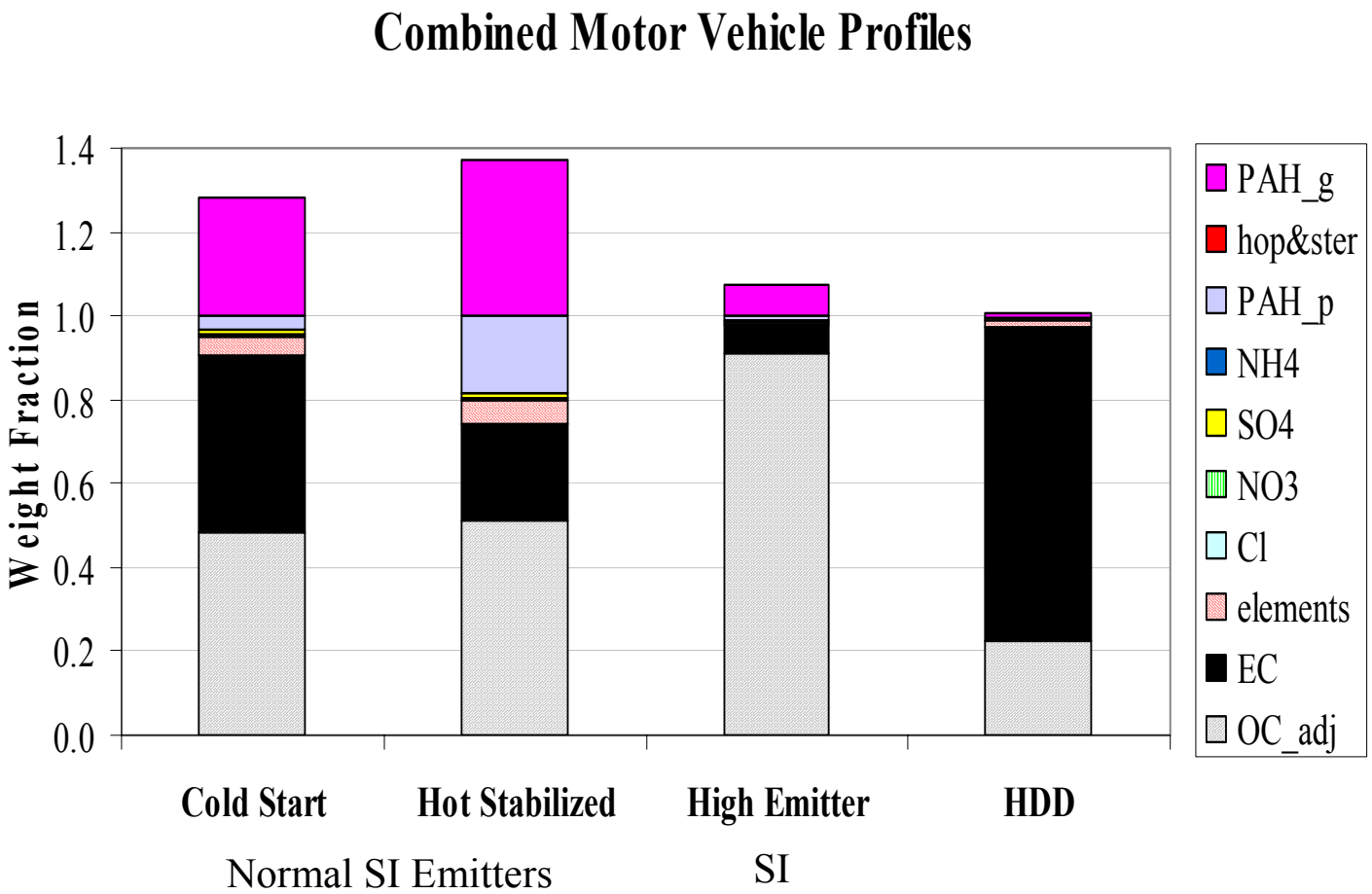
Gasoline/Diesel PM Split Study

Ambient Apportionment of Elemental Carbon



Gasoline/Diesel PM Split Study

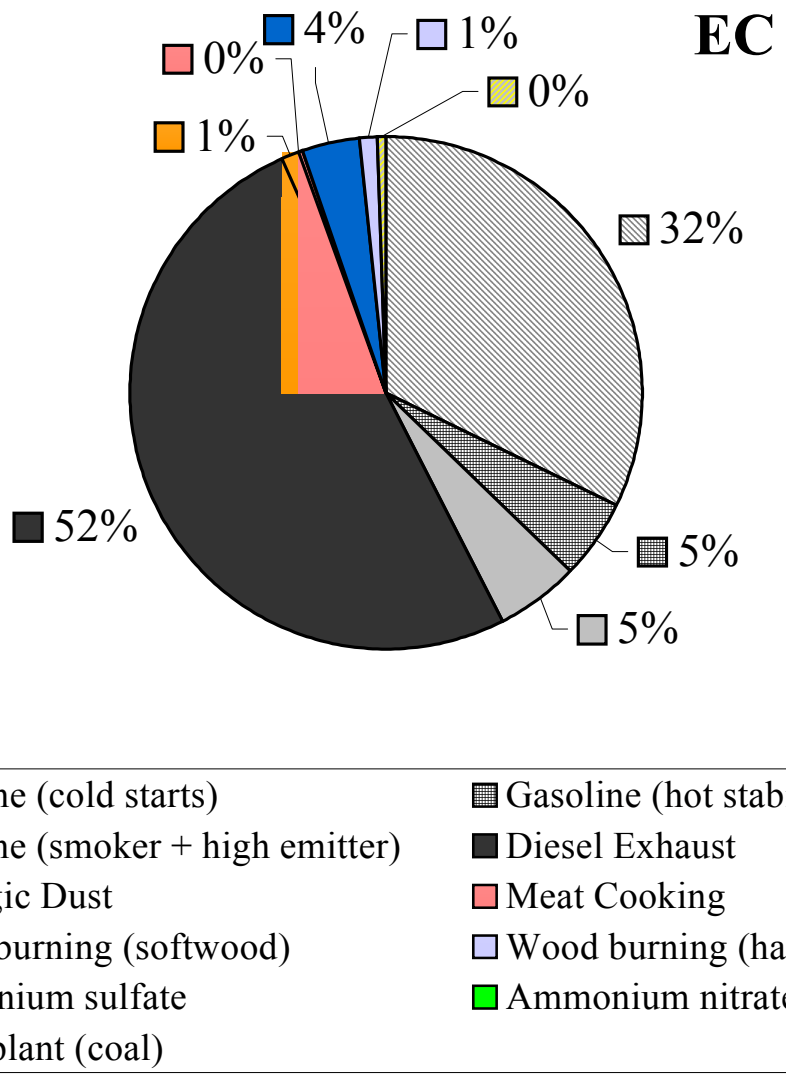
Northern Front Range Air Quality Study
Vehicle Composition Profiles for Winter Conditions in Denver Area*

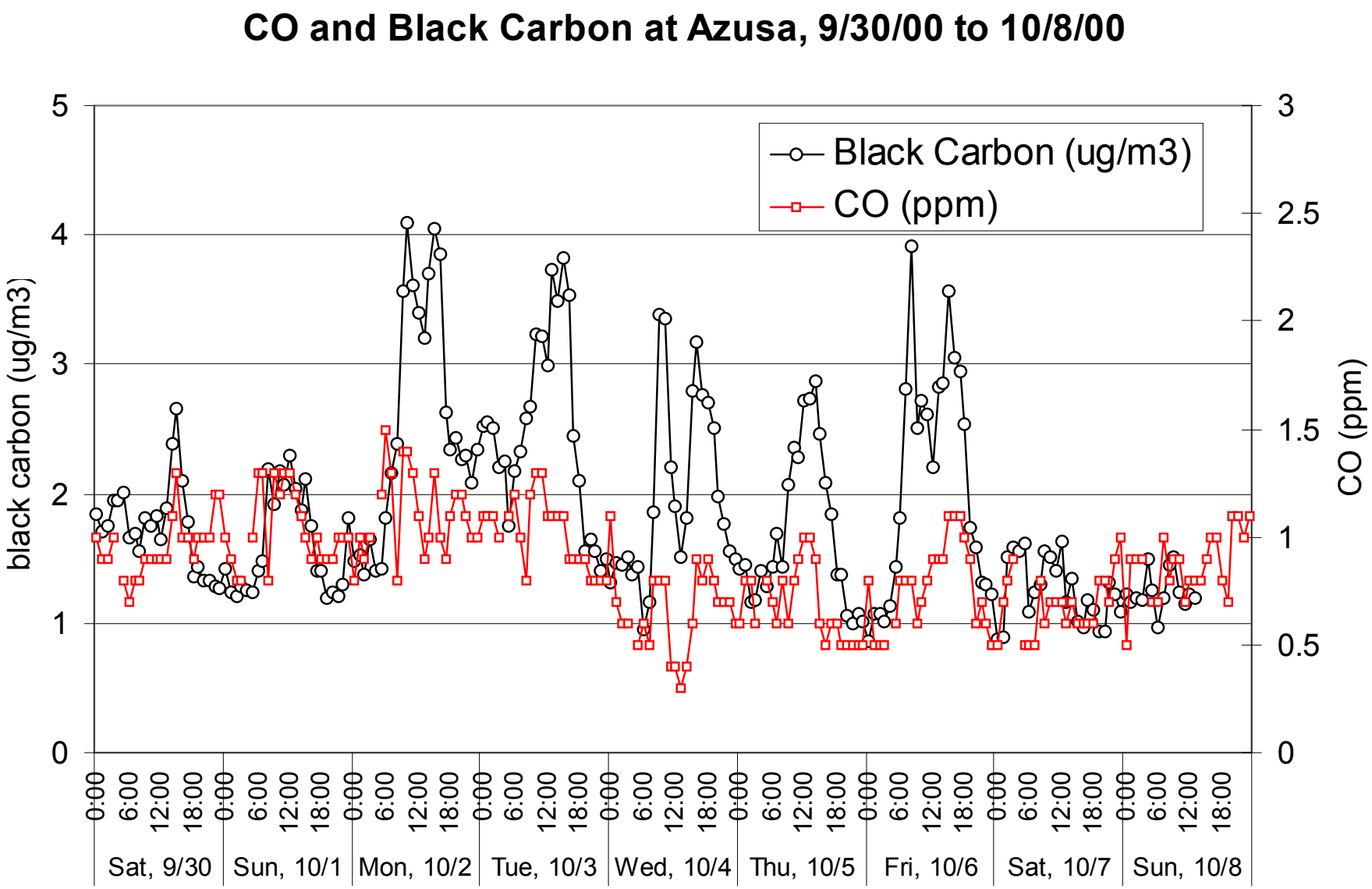


* Based on dynamometer test using the Federal Test Procedure (FTP) cycle. Carbon measurements by Thermal Optical Reflectance (TOR) Method using the IMPROVE protocol.

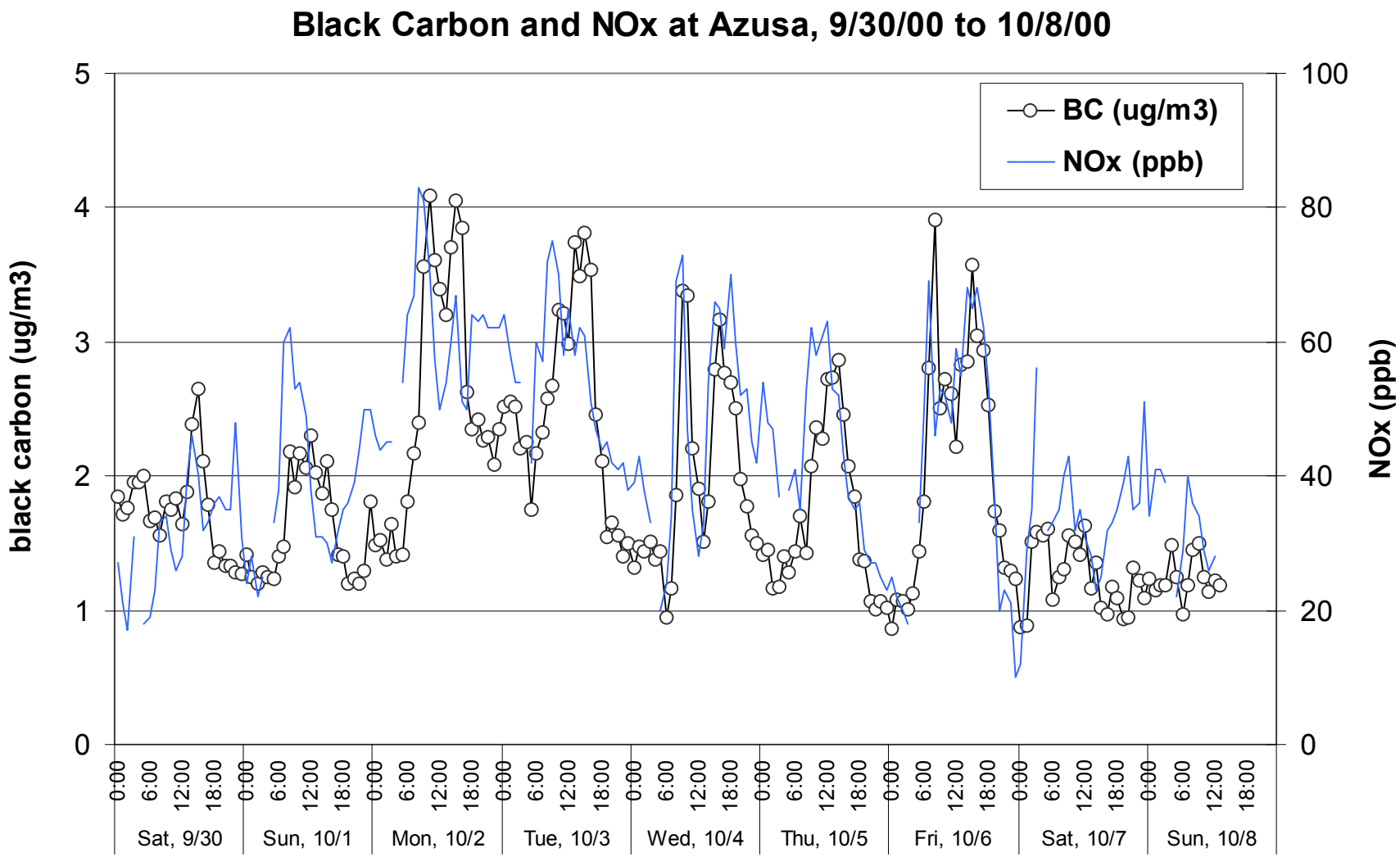
Source Contributions to $PM_{2.5}$, TC and EC

Welby - Winter 1996-97 NFRAQS

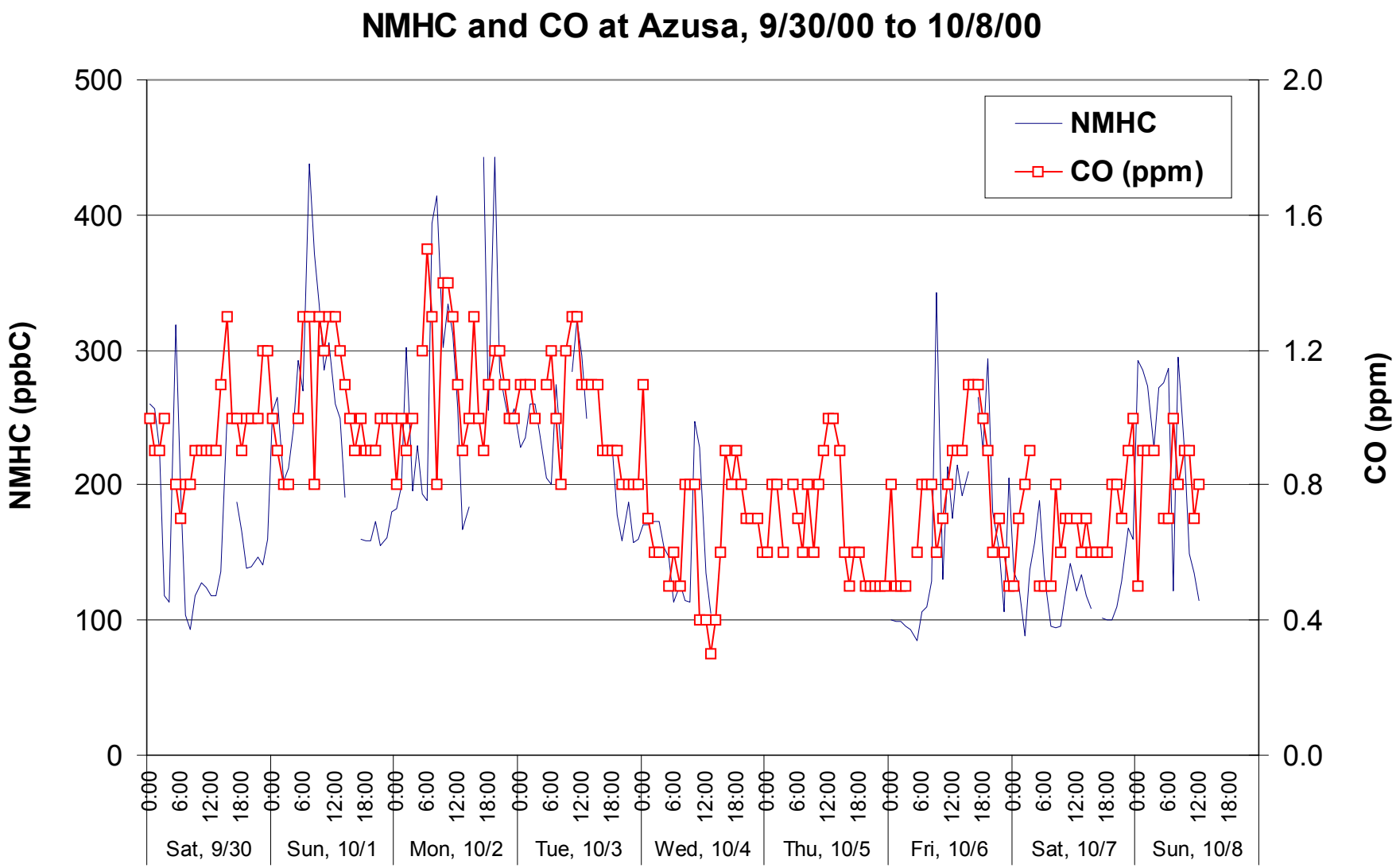




Weekend Ozone Study (Fujita et al., 2002)



Weekend Ozone Study (Fujita et al., 2002)



Weekend Ozone Study (Fujita et al., 2002)

Summary

- CI vehicles are the dominant source of EC at Azusa and LANM. However, apportionment of the contribution of SI and CI vehicles to particulate carbon is highly dependent on local source contributions.
- EC is not a unique tracer for diesel exhaust.
- For SI "normal" emitters, most PM emissions are from the cold start and high accels with higher fraction of BC. Composition profiles derived from UDC may not be representative of aggregate SI emissions in a major urban area like the South Coast Air Basin.
- SI exhaust contain several high-molecular weight PAHs that are not detected in most diesel exhaust samples. They are present in used lubrication oil in similar proportions but in concentrations that apparently increase with age of the oil.
- EC in diesel exhaust is mostly E2 in dynamometer samples. Ambient samples have greater fraction of E1 relative to E2 even in diesel-dominated locations. Implications for multivariate methods using carbon fractions?
- EC by thermal optical methods are in good agreement for IMPROVE and STN protocols for highly loaded samples. STN/IMPROVE substantially lower for cleaner source samples and ambient samples.
- Ambient measurements of BC along with NOx, CO and NMHC can be used to corroborate temporal variations in the emissions. Siting is a critical consideration.

Acknowledgments
Gasoline/Diesel PM Split Study

Sponsor

DOE's Office of FreedomCAR and Vehicle Technologies

Dr. James Eberhardt

Additional Support

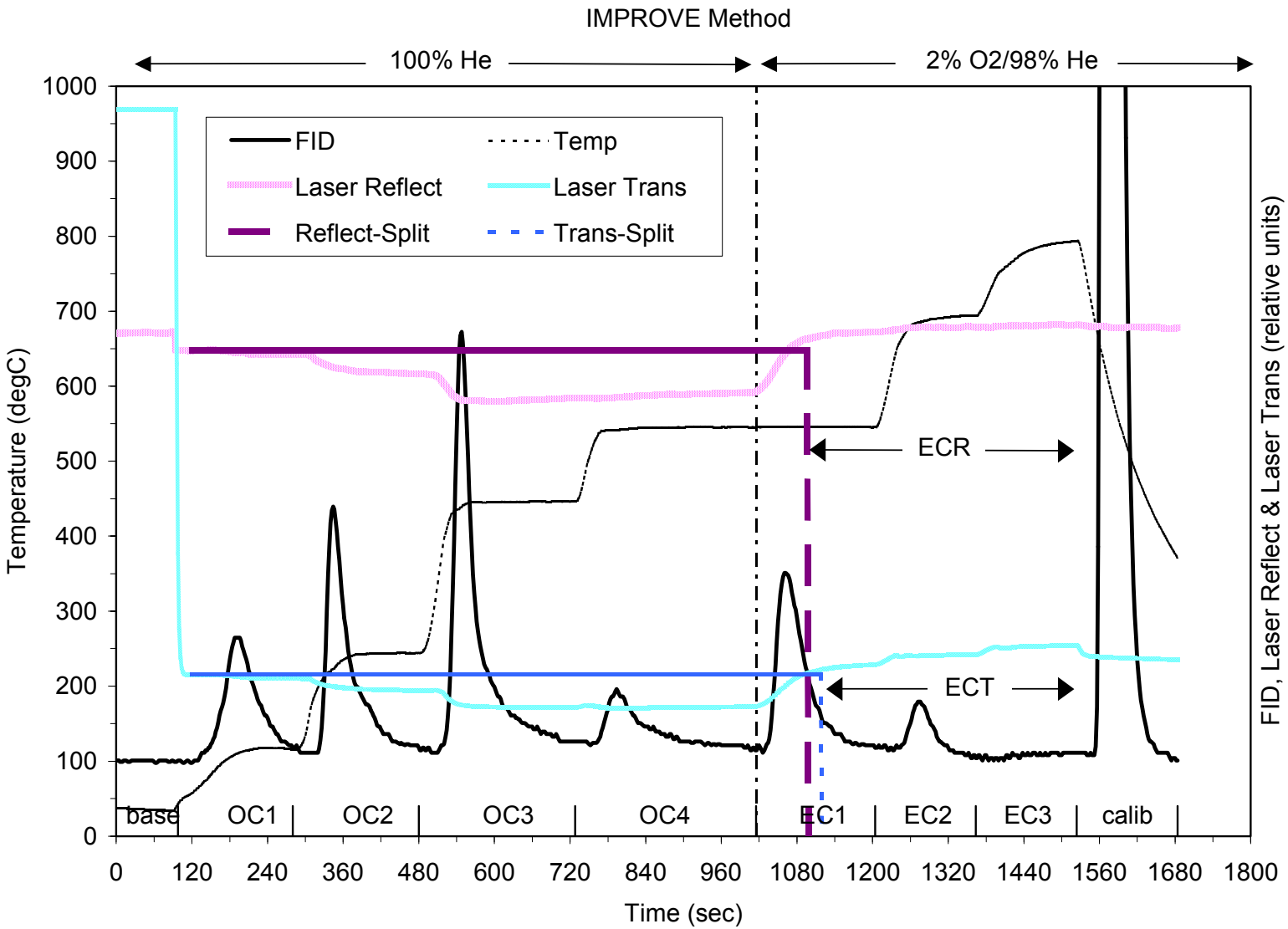
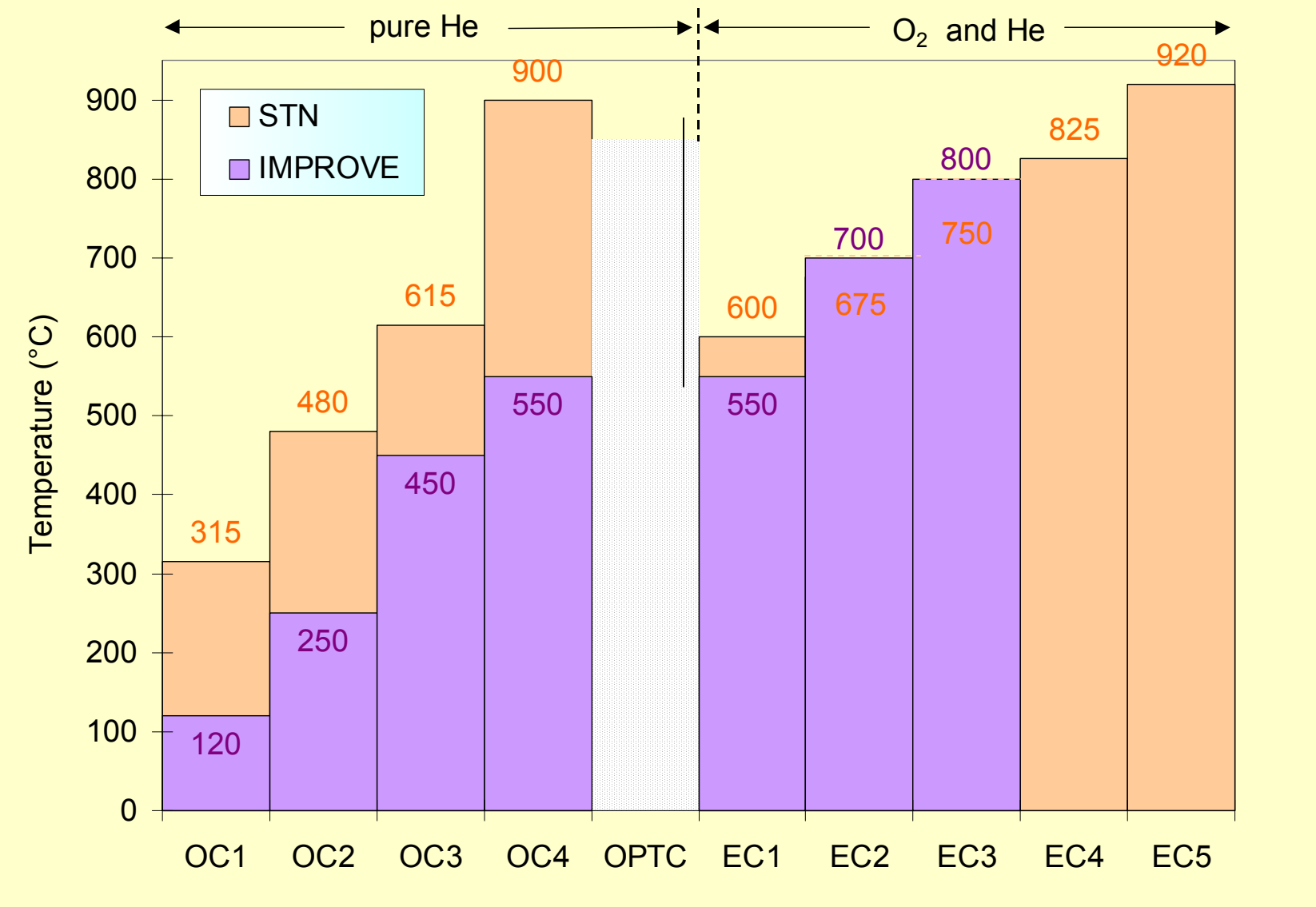
U.S. Environmental Protection Agency

California Bureau of Automotive Repair

South Coast Air Quality Management District

Ralph's Supermarket Distribution Center

Carbon Measurement by Thermal Evolution



Comparison of IMPROVE/STN Temperature Profiles