Gasoline Particulate Emission Rate Development for MOVES

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MOVES

Outline

- Kansas City Background
- General Results
- Modal Trends
- EC/OC
- Application for MOVES

Sponsors for Kansas City Data

- **U.S. EPA's Office of Transportation & Air Quality (OTAQ)**
- **U.S. EPA's Emission Inventory Improvement Program (EIIP)**
- **Coordinating Research Council – (CRC)**
- **Department of Energy – National Renewable Emission Laboratory (NREL)**
- **Department of Transportation**

Why Kansas City?

- No I/M or RFG
- Centrally located
- Large metropolitan area w/ summer & winter seasons (no extreme temperatures)
- Moderate driving and commuter patterns
- Previous work using Remote Sensing Device (RSD)
- Previous work conducted by DOT to develop a statistical representative “cohort”

Test Program Specifications

- **Regulated gases (THC, CO, NO_x, & CO_2) and $PM_{2.5}$ emission rates measured for 480 light-duty vehicles randomly recruited in the Kansas City metropolitan area**
- **The vehicles were conditioned & tested as received:**
  - ✓ Conditioning & testing done under prevailing ambient conditions
  - ✓ Conditioned on prescribed road route
  - ✓ Cold soaked overnight before test
  - ✓ Tested on dynamometer using Unified driving cycle (LA-92)
- **Approximately half of the vehicles tested in Round 1 (summer) and the other half in Round 2 (winter).**

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Two Rounds of Emission Testing

	Round 1	Round 2
Dates Conducted	July 14- Oct 1, 2004	Jan 12- Apr 8, 2005
Average Temperature, °F	77	45
Temperature Ranges, °F	59- 96	12 - 72
Average Humidity, grains/lb	69	23
Number of Vehicles Tested	247	233
Fuel	Summer Grade Fuels	Winter Grade Fuels

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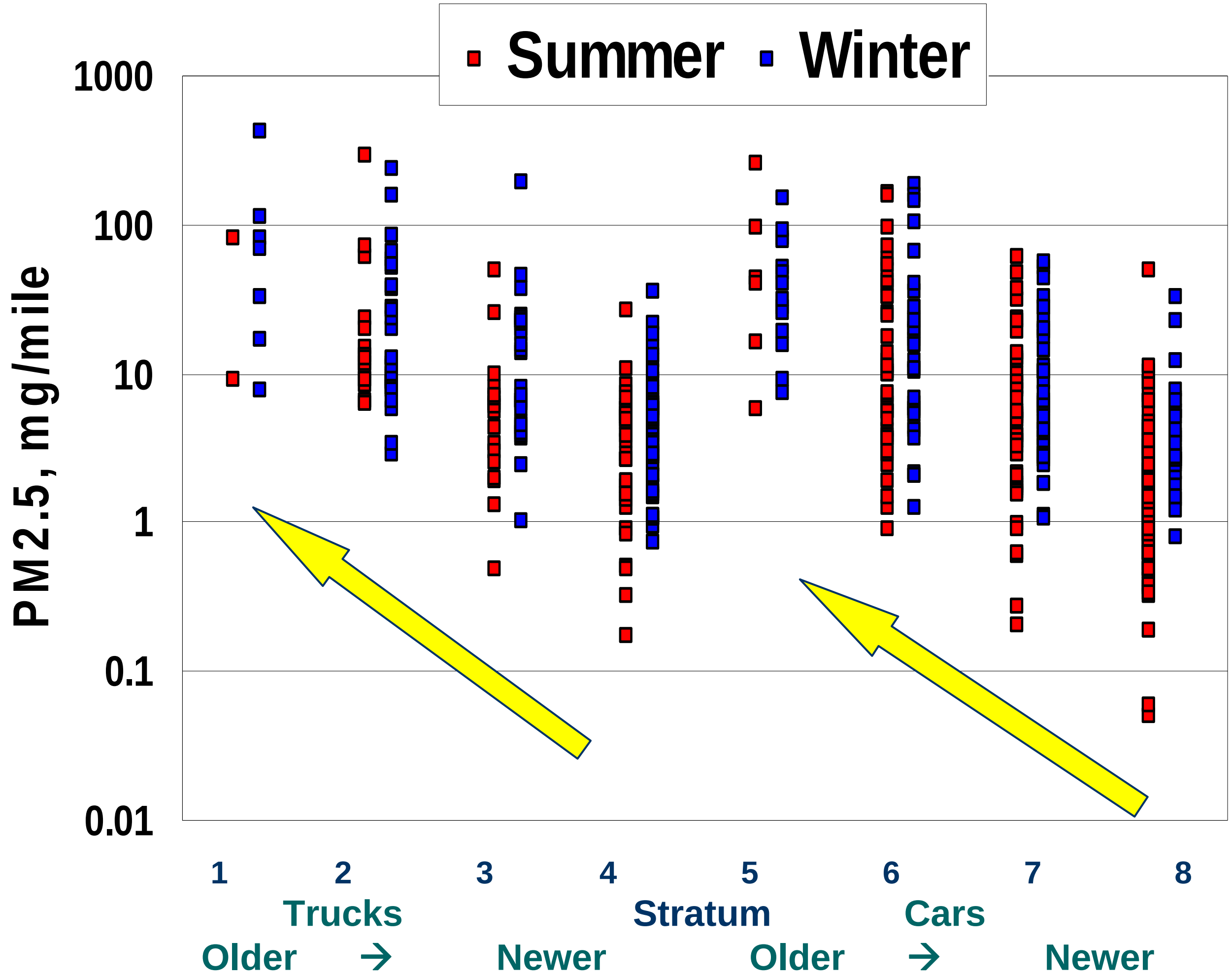
Stratified Random Sampling of Fleet

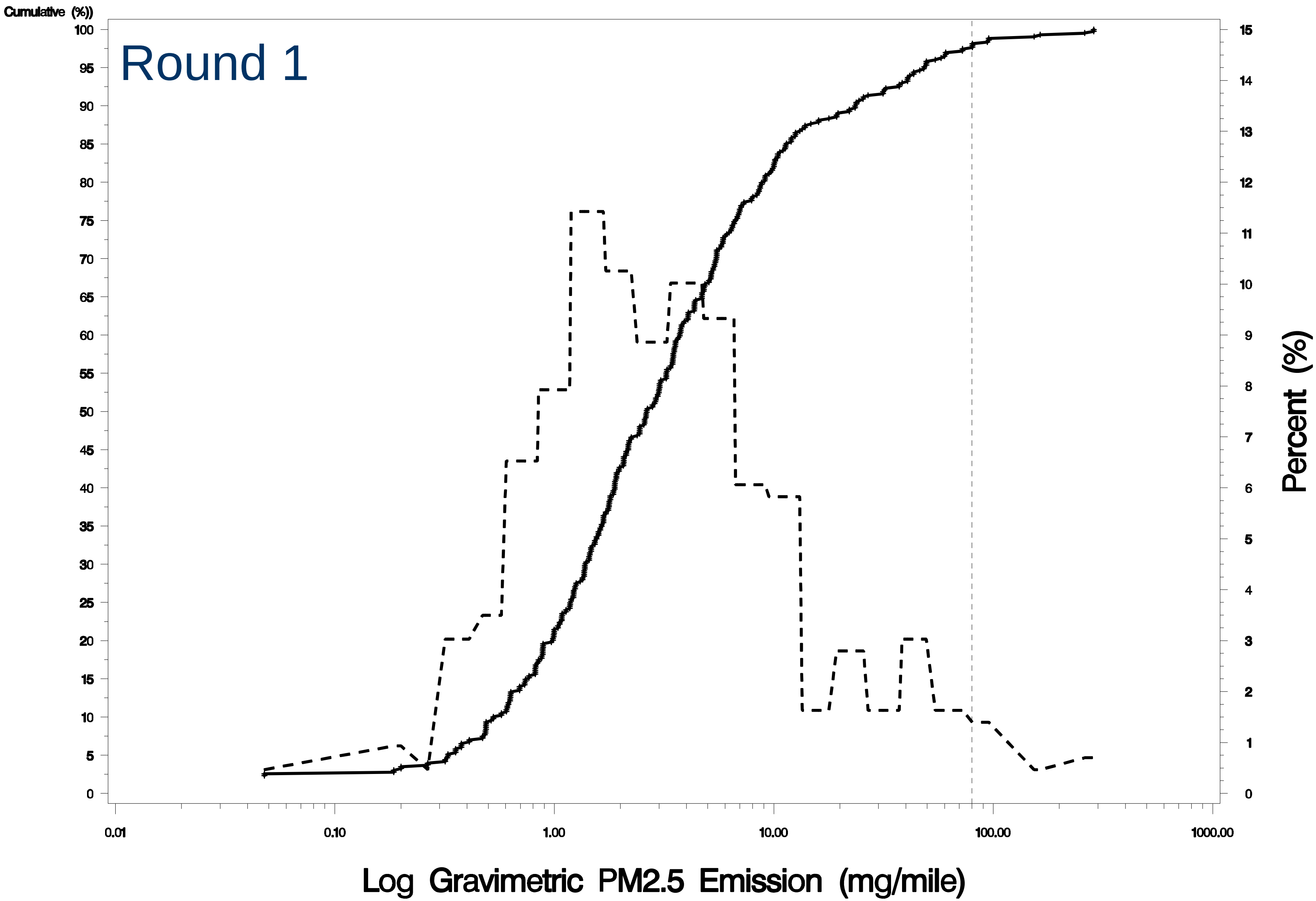
Stratum	Type	Model Yr	Number of Vehicles- Round 1	Number of Vehicles- Round 2
1	**Truck***	**1980 & Older**	**2**	**7**
2	**Truck***	**1981-1990**	**14**	**29**
3	**Truck***	**1991-1995**	**17**	**31**
4	**Truck***	**1996 & newer**	**34**	**51**
5	**Car**	**1980 & Older**	**6**	**14**
6	**Car**	**1981-1990**	**43**	**36**
7	**Car**	**1991-1995**	**41**	**37**
8	**Car**	**1996 and Newer**	**90**	**28**

*Note: Trucks included pick-ups, vans (mini & cargo), and SUVs

$PM_{2.5}$ Weighted Emission Rates



Cumulative Plot of Emission by Simulated Fleet Distribution (Log Scale)



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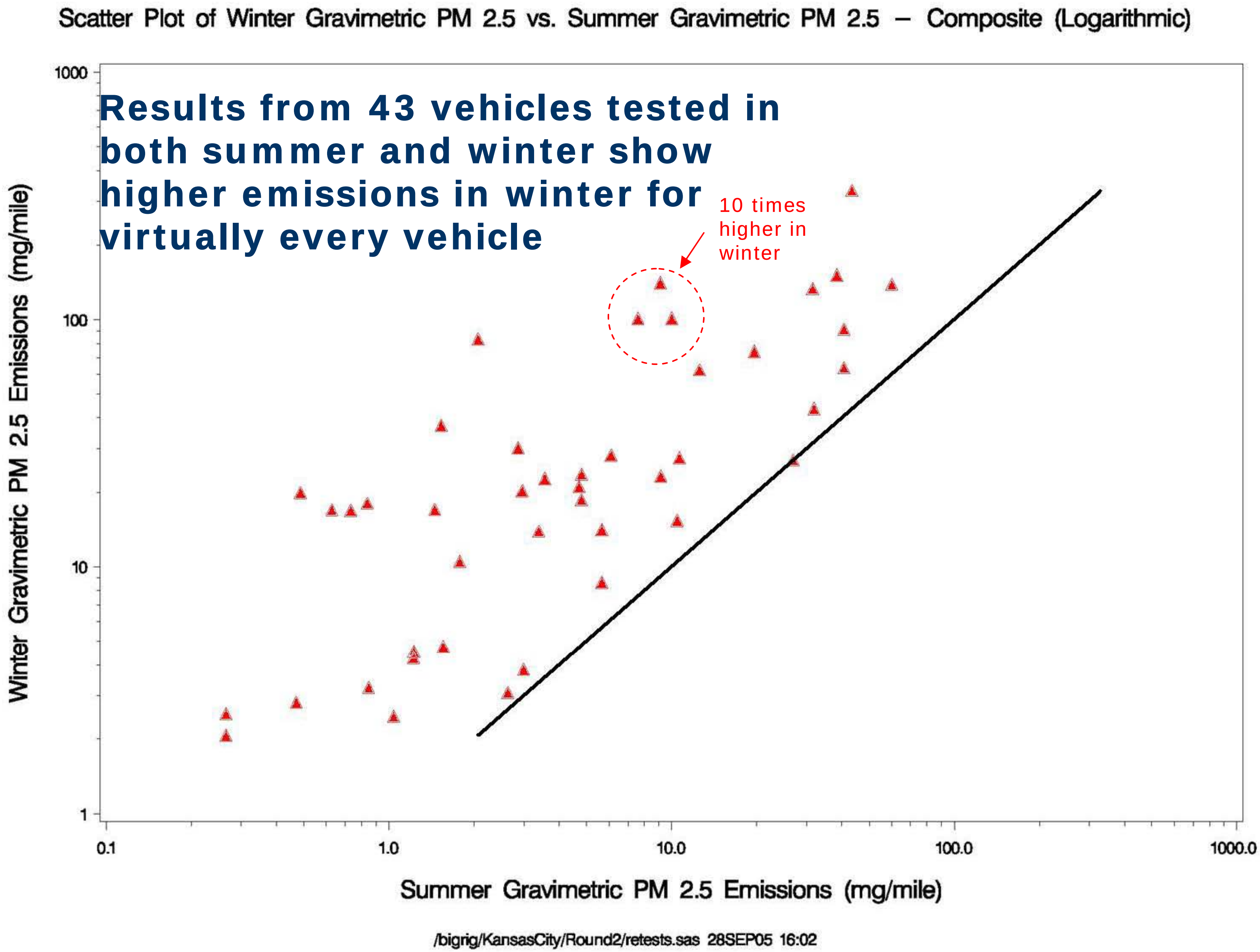
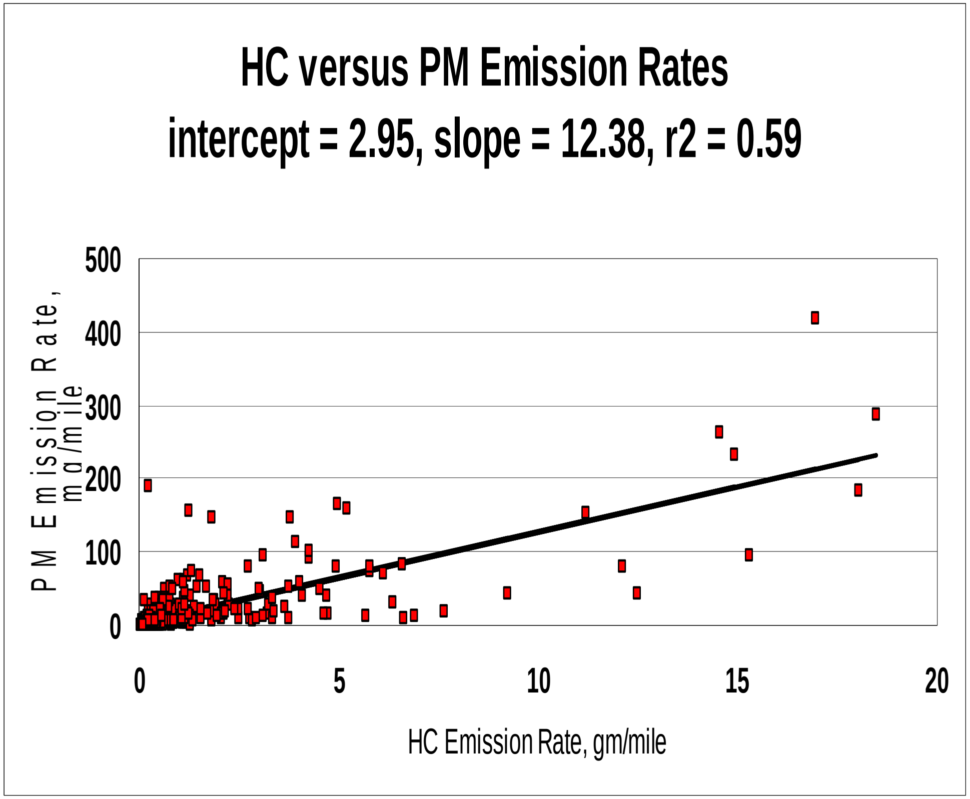
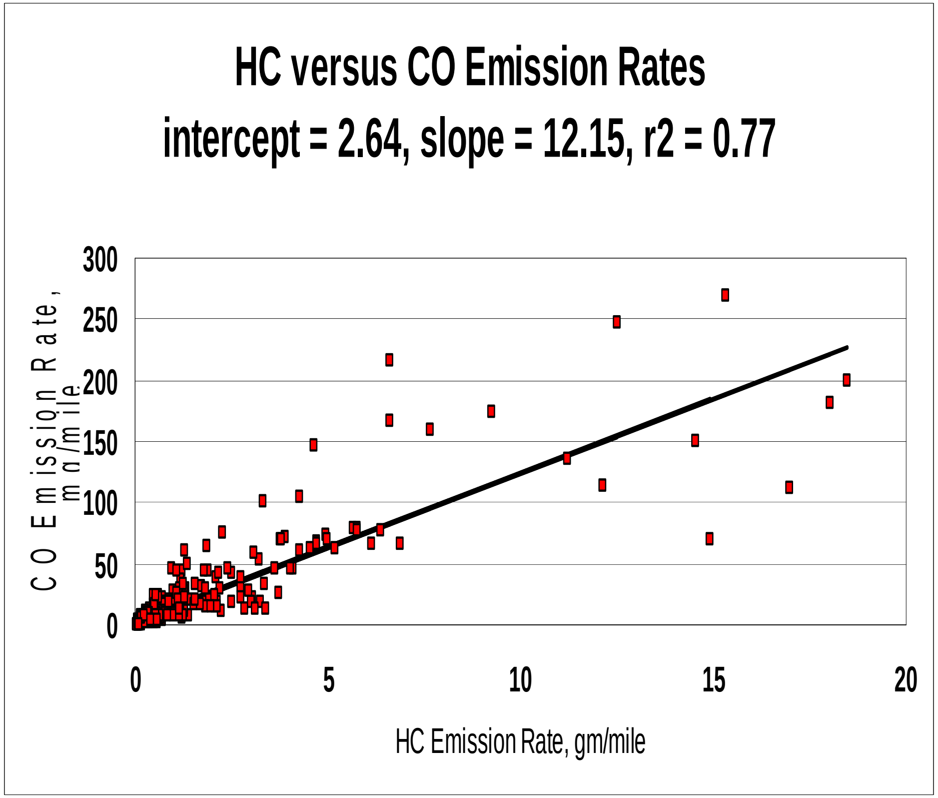

Scatter Plot of Winter Gravimetric PM 2.5 vs. Summer Gravimetric PM 2.5 – Composite (Logarithmic)
Results from 43 vehicles tested in both summer and winter show higher emissions in winter for virtually every vehicle
10 times higher in winter
Winter Gravimetric PM 2.5 Emissions (mg/mile)
1000
100
10
1
0.1
1.0
10.0
100.0
1000.0
Summer Gravimetric PM 2.5 Emissions (mg/mile)
/bigrig/KansasCity/Round2/retests.sas 28SEP05 16:02

Correlation of HC to PM & CO





What causes high gasoline PM?

- **Over-fueling**
  - Cold start
  - High load (WOT)
  - Sensor failures
  - Fuel system failures
- **Component wear**
  - Leaky injectors
  - Valve seal
  - Piston rings…
- **Fuel Properties**
  - T# performance
  - Aromatics
  - Sulfur
- **Lubricating Oil**
  - PCV: Positive Crankcase Ventilation
  - Direct Leak into cylinder
  - Oil Composition

Preliminary Findings

- Kansas City seems to be a representative sample
- Ambient temperature plays a major role in (cold start) PM formation
- Older vehicles have higher PM emissions
    - Is it technologies or deterioration?

Modal Gasoline Particulate Emission Trends

- **Background**
- **Goals**
- **Description of study**
- **Applying Model PM data to MOVES**
  - Modeling Methodology
  - Activity
  - PM Emission Rates by VSP
  - Results
- **Correlations**
- **EC/OC fraction**
- **Future analysis**

Background

- **Existing PM Measurement Methodology:**
  - Vehicle on dynamometer
  - Tailpipe emissions collected on Filter
  - **Limited:** Can't assign emissions to modes: starts, idle, speeds, accelerations etc.
- **Require Real-time PM data for MOVES**
  - Models average emissions from "typical" vehicles
  - Second by second data required

Kansas City Study Addressed these needs.

Kansas City Study

- **Gasoline Cars and Trucks**
  - Light Duty Vehicles (LDV)
  - Light Duty Trucks (LDT)

- **Measurement Instruments**
  - Particulate Matter
    - Aggregate: Gravimetric Filter, TOR (EC/OC)
    - Oscillating Crystal: Quartz Crystal Microbalance (QCM),
    - Optical: Photo-Acoustic (PA), DustTrak (DK), DataRam (DM)
  - Other
    - Hydrocarbons (HC), Carbon Monoxide (CO), Oxides of Nitrogen (NO_x), Carbon Dioxide (CO_2)

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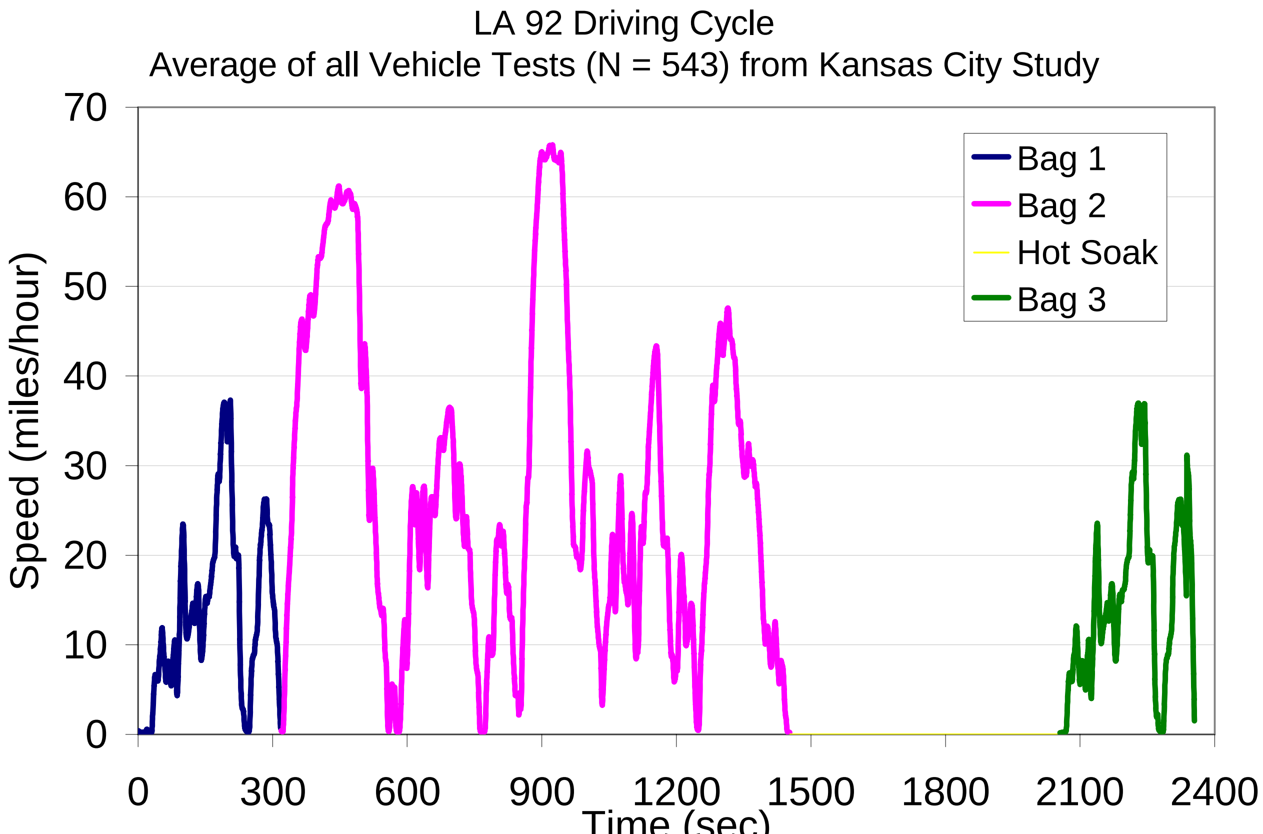
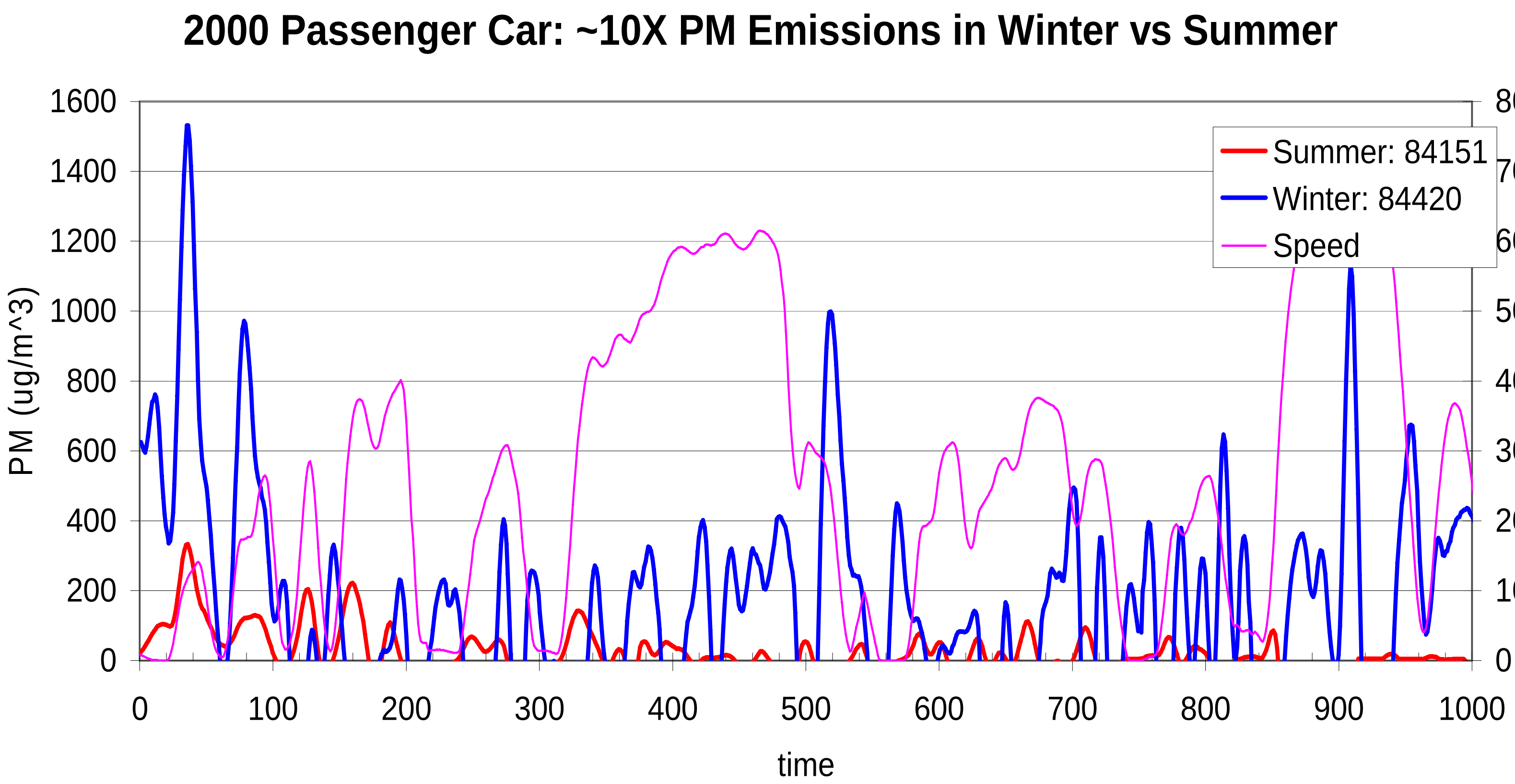
Kansas City Driving Cycle



Prepare Kansas City Modal PM Data for MOVES

- **Preparation Steps**
  - Interpolating to 1 Hz
  - Time Aligning to VSP
  - Normalization to Filter or TOR
  - Examine correlations to “fill holes”
  - Elemental Carbon / Organic Carbon ratios

QCM During Cold Start/Cold Running



Preparing PM Data for MOVES

- **Normalizing Modal Total PM to the Filter**
  - DustTrak, DataRAM, QCM

$$PM_{i,f,j} = PM_{i,0,j} \frac{Grav_j}{PM_{agg,j}}$$

Where:

- i is the second being normalized of Bag 2 of the LA92 driving cycle
- j represents the instrument, where j take on 3 different values of either QCM, DusTrak, or DataRam
- f is the final result for the modal PM value (grams)
- 0 is the initial value for the modal PM (grams)
- Agg is the integrated value for the PM instrument over Bag2, mg/mi
- Grav is the gravimetric filter value for Bag 2, mg/mi

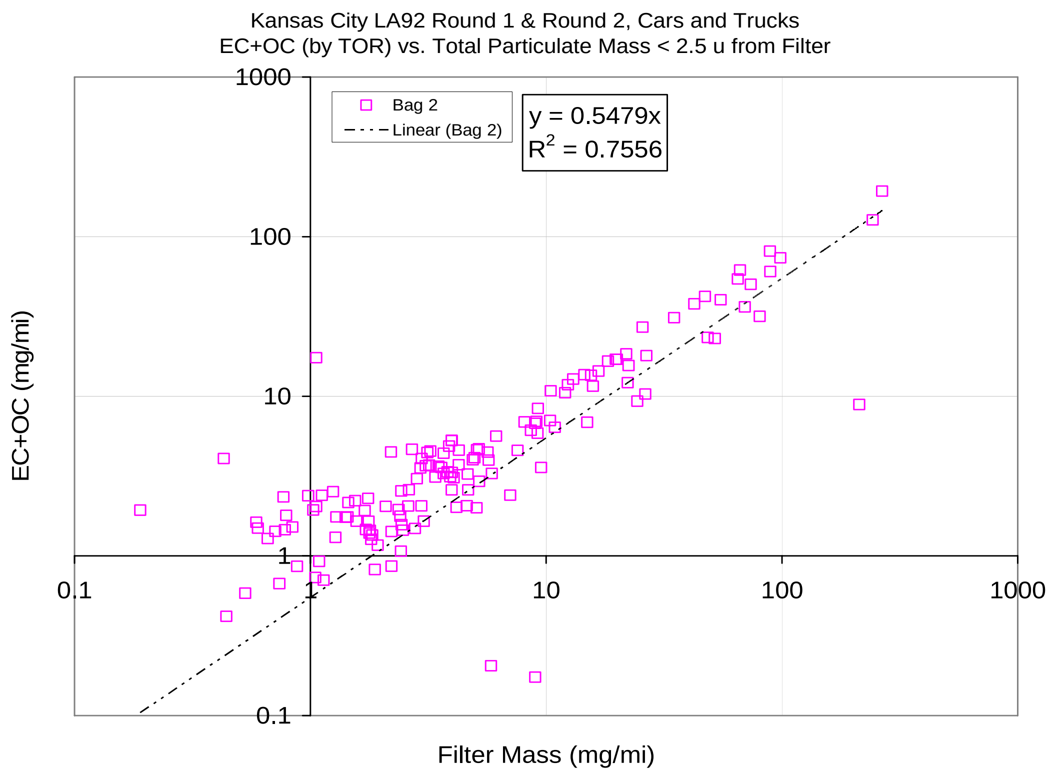
Preparing PM Data for MOVES

- **Normalizing Modal EC to the TOR-EC**
  - From N ~150 values of EC by TOR
    - **Average Bag 2:**
      - LDT
      - LDV
      - Round 1
      - Round 2

	Ratio of Averages
TOR-EC / Photoacoustic	1.65

Preparing PM Data for MOVES

- **Assumption about PM:** $TotalPM = EC + OC + Extras$



Preparing PM Data for MOVES - TOR

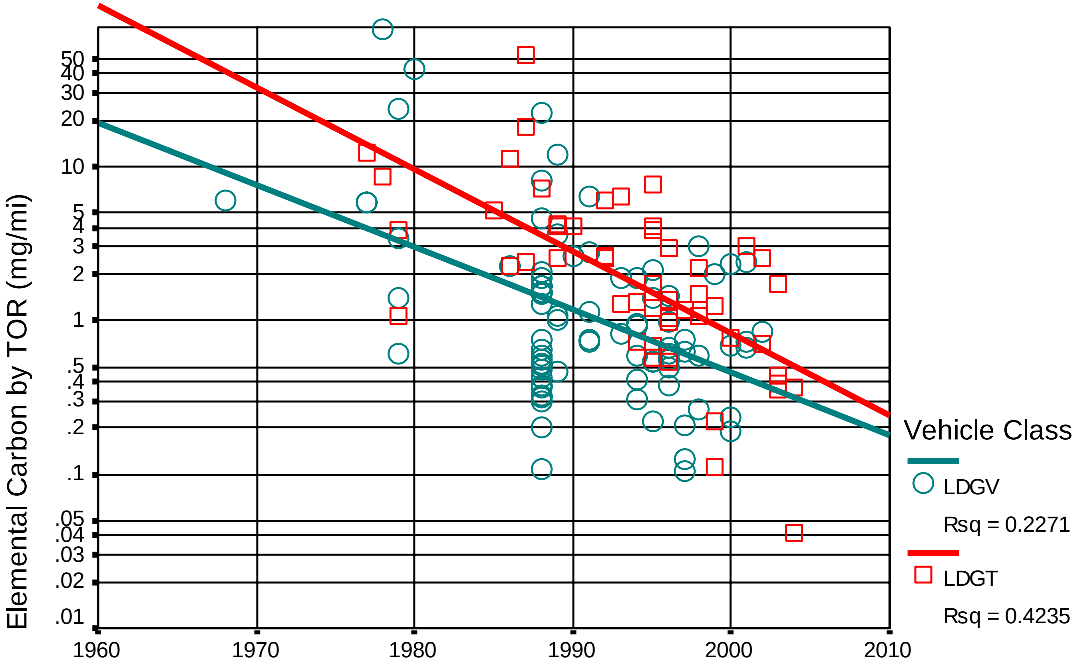
- 18% of Total PM from LDGV is "Extra"
- 45% of Total PM from LDGT is "Extra"

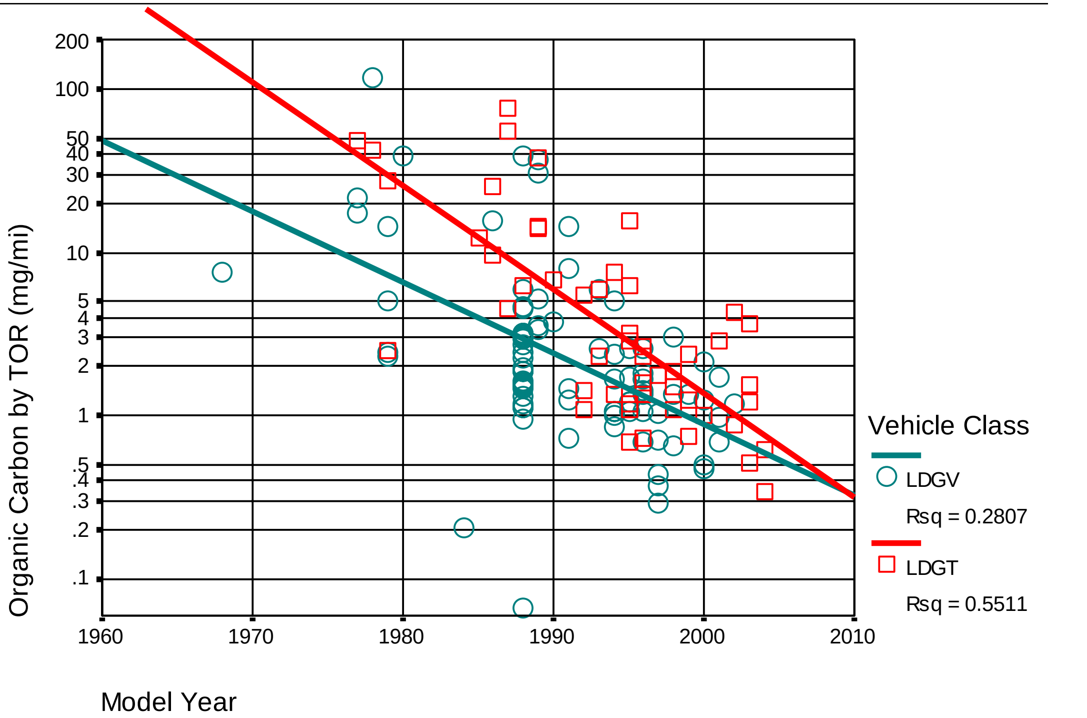
	LDGV Extras	LDGT Extras
$\frac{Ave(Grav) - [Ave(EC) + Ave(OC)]}{Ave(Grav)}$	0.18869553	0.45790762

EC & OC Fractions of Total PM from TOR (Bag 2)			
	LDGV & LDGT	LDGV	LDGT
OC (PM)	44%	52%	38%
EC (PM)	22%	30%	16%

Trends within Model Year

- Elemental and Organic Carbon show downward trends by Model Year



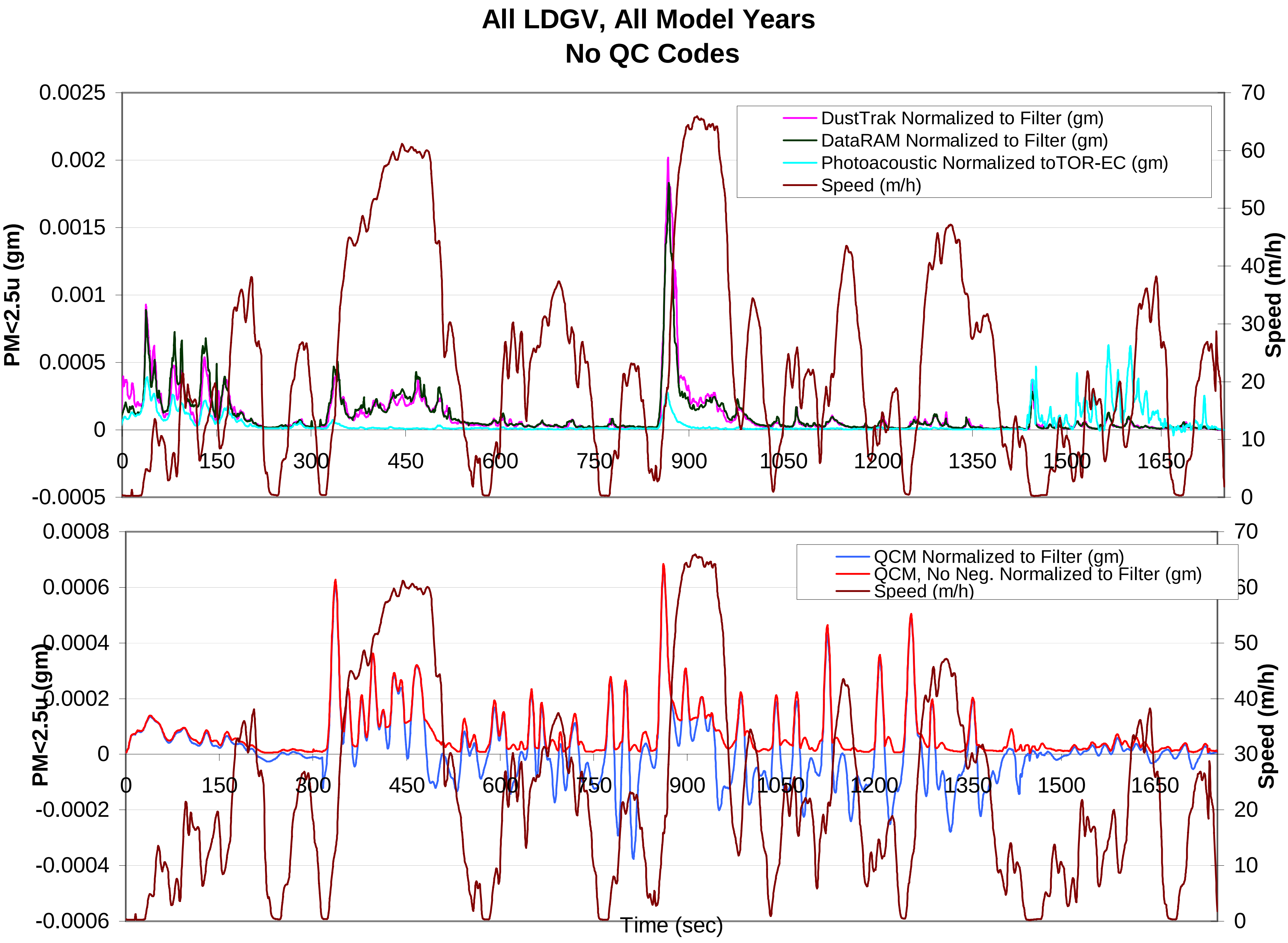


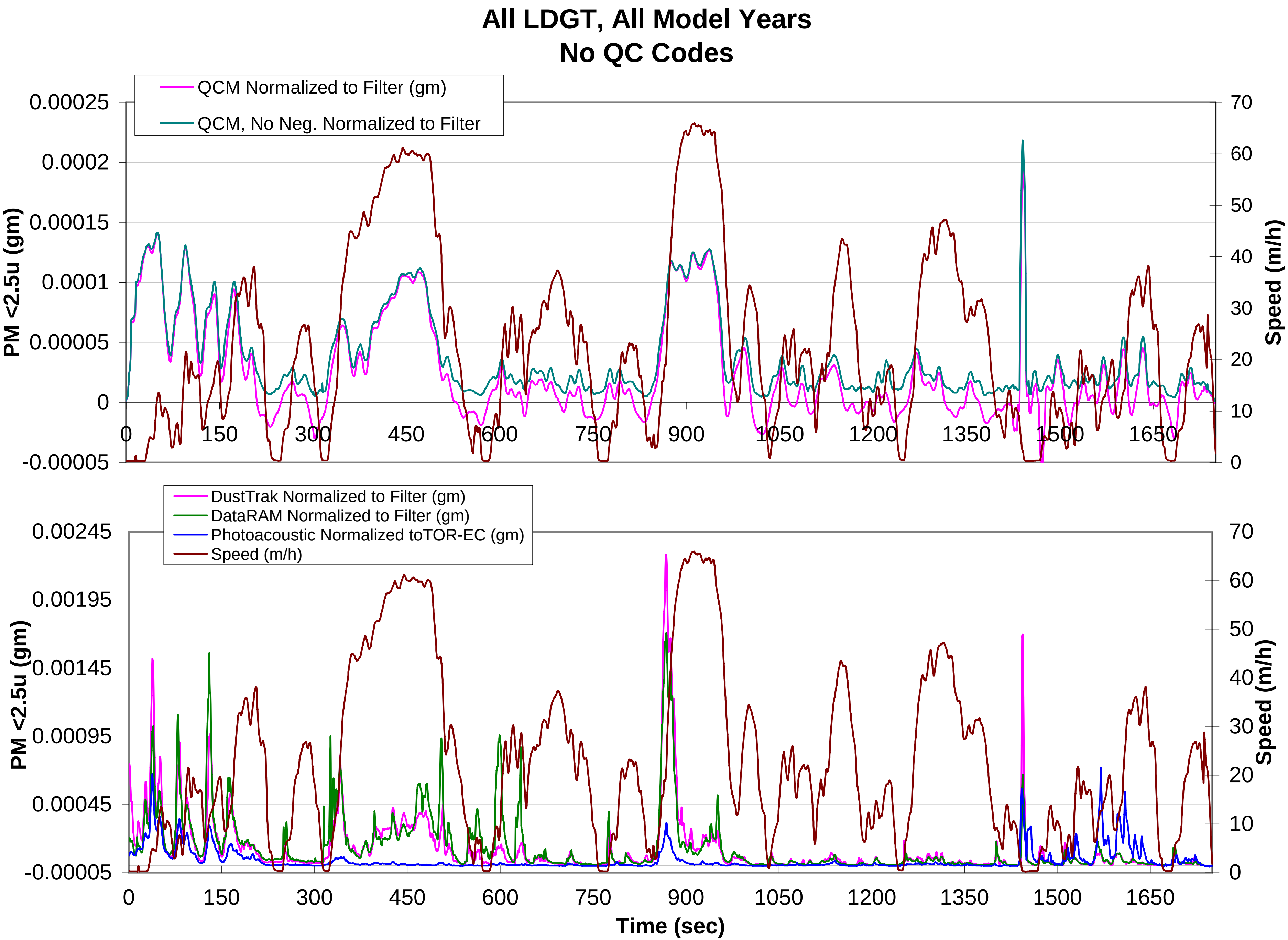
A Comparison of Real-time Instruments

- **QCM**
  - Strengths:
    - Correlates with filter well
    - Capture organics as well as inorganics
  - Weaknesses:
    - 10 sec average
    - Significant negative emission rates
- **Optical (Dustrak, Dataram)**
  - Strengths:
    - Sec-by-sec emissions that follow power events
  - Weaknesses:
    - Saturated on high emissions events

Composite Car

- For modeling, current goal is to apportion filter PM to modes of driving (NOT necessarily to accurately characterize second-by-second PM)
- Each corresponding second averaged to make a "composite car".
- This technique allows for second by second (& modal) trends to show up


All LDGV, All Model Years
No QC Codes
DustTrak Normalized to Filter (gm)
DataRAM Normalized to Filter (gm)
Photoacoustic Normalized toTOR-EC (gm)
Speed (m/h)
PM<2.5u (gm)
Speed (m/h)
0.0025
0.002
0.0015
0.001
0.0005
0
-0.0005
70
60
50
40
30
20
10
0
0
150
300
450
600
750
900
1050
1200
1350
1500
1650
QCM Normalized to Filter (gm)
QCM, No Neg. Normalized to Filter (gm)
Speed (m/h)
PM<2.5u (gm)
Speed (m/h)
0.0008
0.0006
0.0004
0.0002
0
-0.0002
-0.0004
-0.0006
Time (sec)



All LDGT, All Model Years
No QC Codes
QCM Normalized to Filter (gm)
QCM, No Neg. Normalized to Filter
PM <2.5u (gm)
Speed (m/h)
0.00025
0.0002
0.00015
0.0001
0.00005
0
-0.00005
70
60
50
40
30
20
10
0
DustTrak Normalized to Filter (gm)
DataRAM Normalized to Filter (gm)
Photoacoustic Normalized toTOR-EC (gm)
Speed (m/h)
0.00245
0.00195
0.00145
0.00095
0.00045
-0.00005
0
150
300
450
600
750
900
1050
1200
1350
1500
1650
Time (sec)

Conclusions for KC PM

- **Modal PM data has many limitations**
- **Preliminary trends shown**
- **Future considerations**
  - QCM
    - Apply to Bag1, Bag3
    - Quantify summer (base) to winter emission factors
    - Negative Emission Rates? - Compensate for Volatile loss
  - How to use optical measurements?
  - Apportion to other Pollutants: HC/CO/NO_x/CO_2?
  - Inspection and Maintenance
  - Hole filling

Acknowledgments

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