Particulate Matter Exhaust Emissions from Light-Duty Gasoline Vehicles in Kansas City

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Acknowledgments

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- Eastern Research Group (ERG)
  - Subcontractors: BKI, DRI, NuStats, Sensors, ESP

Study Sponsors

- U.S. EPA
- U.S. Department of Energy
  - via National Renewable Energy Laboratory
- Coordinating Research Council
- NACAA (Emission Inventory Improvement Program)
- U.S. Department of Transportation

Total cost: $4 million

What we are presenting today

- Overview of the study
- Preliminary findings on gasoline PM emissions with respect to:
  - Newer vs. older vehicles
  - Temperature effects
  - High emissions & "smokers"
  - PM:HC relationship

What requires more work

- Inventory assessment
  - requires accounting for future fleet emissions and regional variations
  - Kansas City data do not directly provide this
  - MOVES development will address this

What requires more work cont.

- Future fleet emissions
  - Effect of technology changes vs. aging
    - What will Tier 2 vehicles do as they age?
  - Effect of EPA control programs on future PM emissions
    - e.g. MSAT cold start HC standards, I/M, etc.
- Regional variations
  - Vehicle activity
    - e.g., starts per day, shorter soaks, aggressive driving
  - Fuels: sulfur, E10
  - Temperature
- Will consider other data in addressing these
  - We are considering further testing

Implications

- We are presenting PM data gathered:
  - At one point in time
  - Under ambient conditions in Kansas City
  - Over a single driving cycle
- These results should <u>not</u> be confused with inventory impacts either today or in the future
- We are undertaking the needed work as part of MOVES process

Putting KC Results in MOVES Framework

- MOVES is being developed to account for future fleet emissions and regional variations
- Significant work is also required to allow microscale (“hot spot”) PM modeling
  - Allows modeling of specific driving patterns
  - This requires analyzing second-by-second data
- Public release of draft MOVES (~Sept 2008)
- Final release of MOVES (~Sept 2009)

Outline

- Major Objectives
- Study Design
- Preliminary Results
  - Overall Trends
  - Temperature Effects
  - High Emissions & Smokers
  - PM:HC Relationship
  - Comparison to Past Programs
- Conclusions

Major Objectives

- Address the need for representative gasoline PM emission estimates from the current fleet
  - Recommended in NRC review (2000)
  - Improve basis for modeling PM
    - MOBILE6 derived from PART5, which is based on testing conducted in 1970's & 1980's
    - No effect of temperature, deterioration or speed
  - First random sample for gasoline PM
  - Quantify distribution of PM emissions in the fleet
  - Quantify effect of ambient temperature on PM emissions
  - Develop PM and Toxics speciation profiles

Major Objectives cont.

- Other Goals
  - Evaluate alternative PM measurement techniques
    - E.g. Collect real-time gas PM data on the fleet
  - Evaluate performance of PEMS
  - Real world data on emissions, activity & fuel economy
  - Collect emissions and fuel economy data from hybrids

Study Design

- Study conducted in Kansas City 2004-05
- 496 gasoline light-duty cars and trucks tested
  - Model Years 1968-2005
- Summer and winter testing
  - Vehicles tested at ambient temperature
  - About ½ of the vehicles tested each season
  - 43 vehicles tested in <u>both</u> winter and summer

Sampling Plan

- Representative sampling a critical objective
- Used stratified random sample methodology
  - Strata defined by car/truck, model year group
  - Samples sized to estimate fleet mean to within ± 20% (95% confidence)
  - Non-respondents re-recruited (Phase 1 only)
- Representativeness of sample fleet generally supported
  - Socio demographics
  - Fleet composition
  - But difficult to recruit targeted number of older vehicles

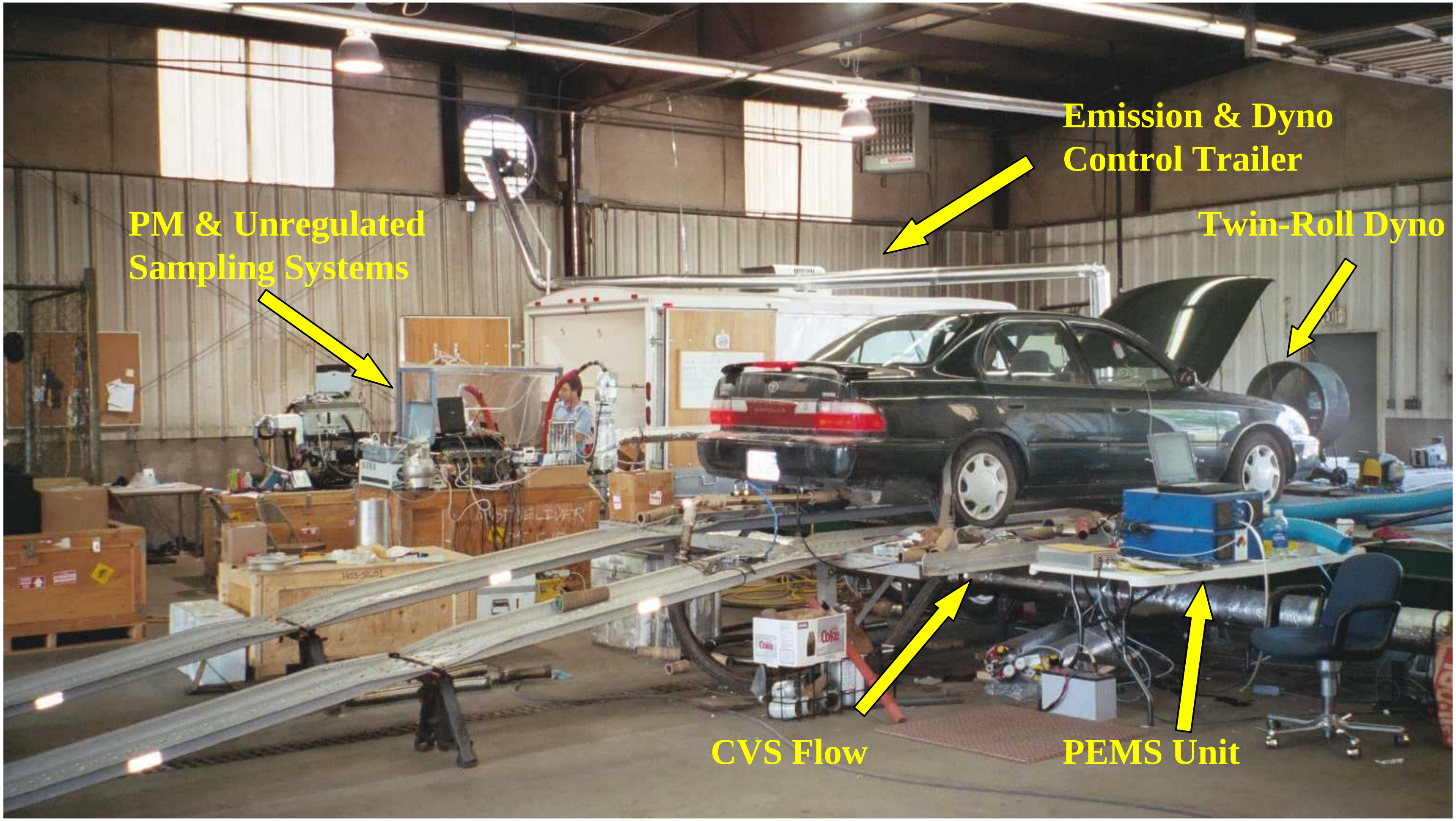
Vehicle Sample by Strata

Strata	Class	MYR	Actual	Goal
1	Truck	Pre 81	11	30
2	Truck	1981-1990	50	50
3	Truck	1991-1995	49	50
4	Truck	1996+	89	75
5	Car	Pre 81	20	30
6	Car	1981-1990	85	100
7	Car	1991-1995	76	65
8	Car	1996+	116	80
		Total	496	480

Testing Protocol

- Vehicles tested on dynamometer over LA92 cycle
  - Three bags (cold start, transient, hot running)
  - More aggressive than light-duty FTP
- Bag and sec-by-sec data for HC, CO, NOx, PM, CO_2
- Toxic emissions measured on 50 vehicles
- Fuel and oil samples taken on most vehicles
- Identification of visible smoke at idle on 406 vehicles
- Portable Emission Measurement System (PEMS)
  - Included on each vehicle on dynamometer
  - 50 vehicles did additional “drive-away” testing (1 day)

KC Test Facility - Instrumentation

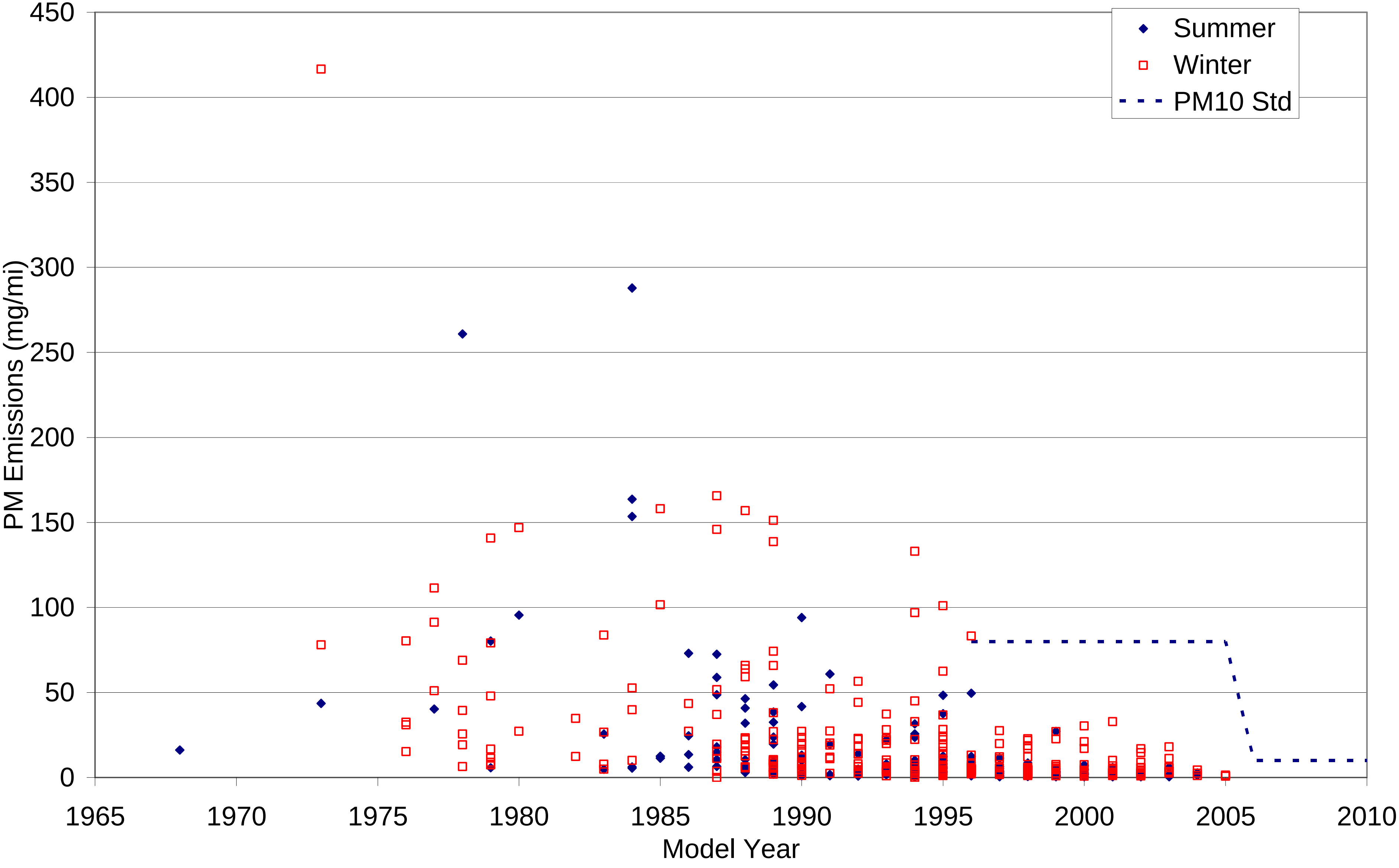


Vehicles driven on LA92 drive cycle under ambient temperatures

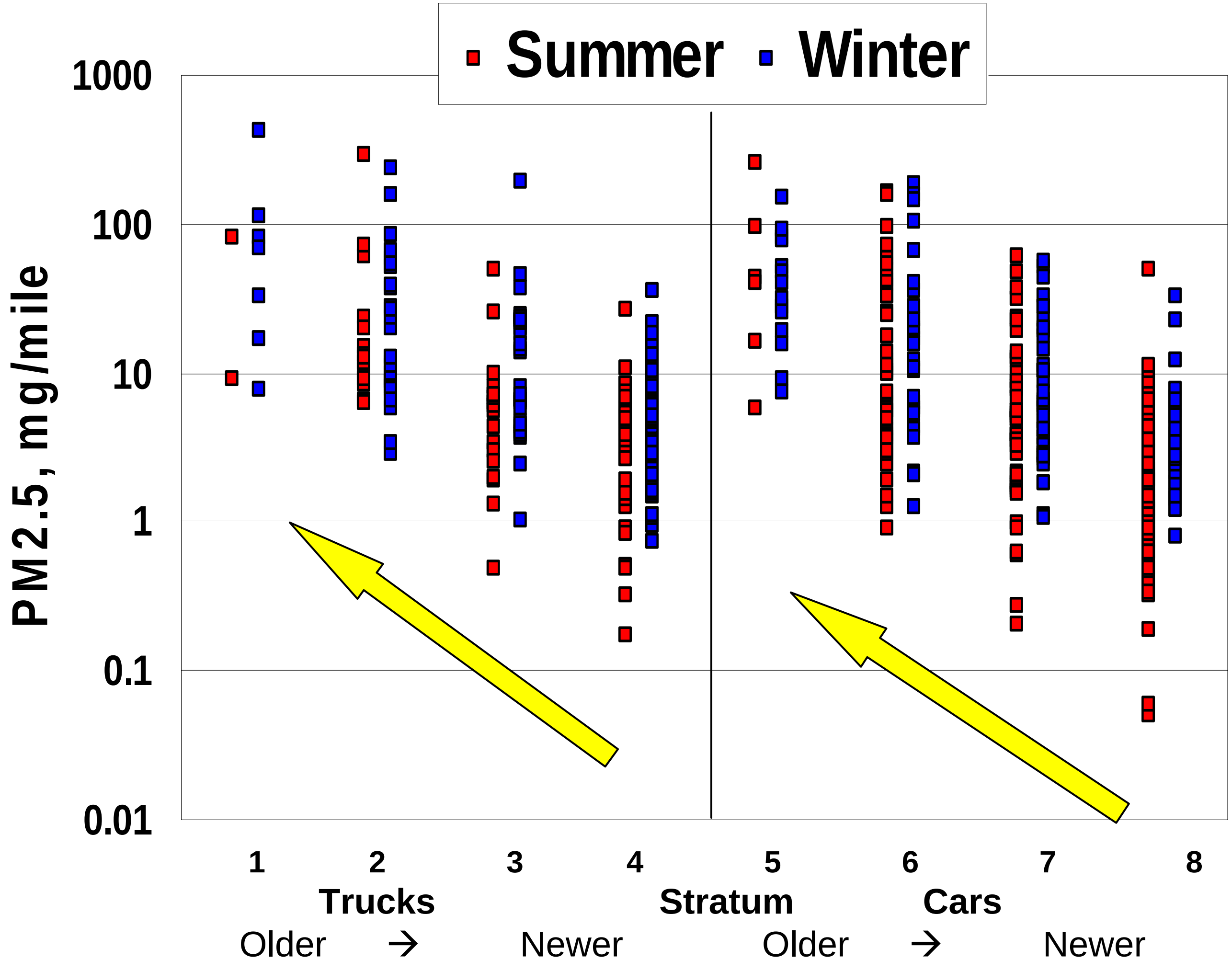
Preliminary Results

- Kansas City study suggests that PM emissions are:
  - Higher in winter than summer
  - Higher from older vehicles than newer vehicles
  - Higher from trucks than cars (smaller effect)
  - Small number of vehicle produce higher proportion of emissions, but many were not identified as "smokers"

LA92 Results by Vehicle



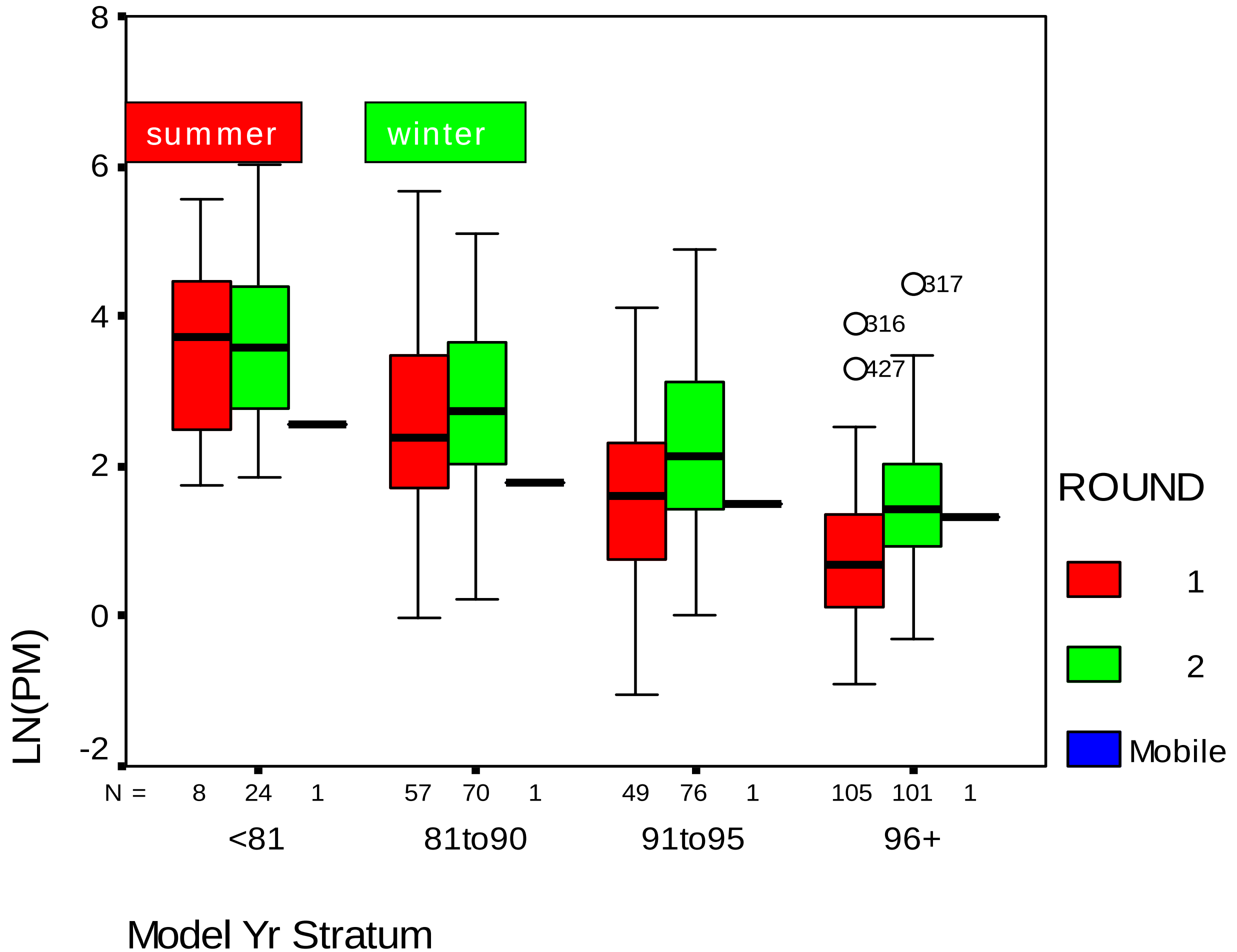
LA92 Results by Strata & Season



Emissions are higher in the winter
Emissions are higher for older vehicles

LA92 Results by Model Year & Season

- Box plot shows range of data points (log scale)
- Older vehicles higher than MOBILE6, newer vehicles lower
- Uncertain how much of trend is technology or deterioration

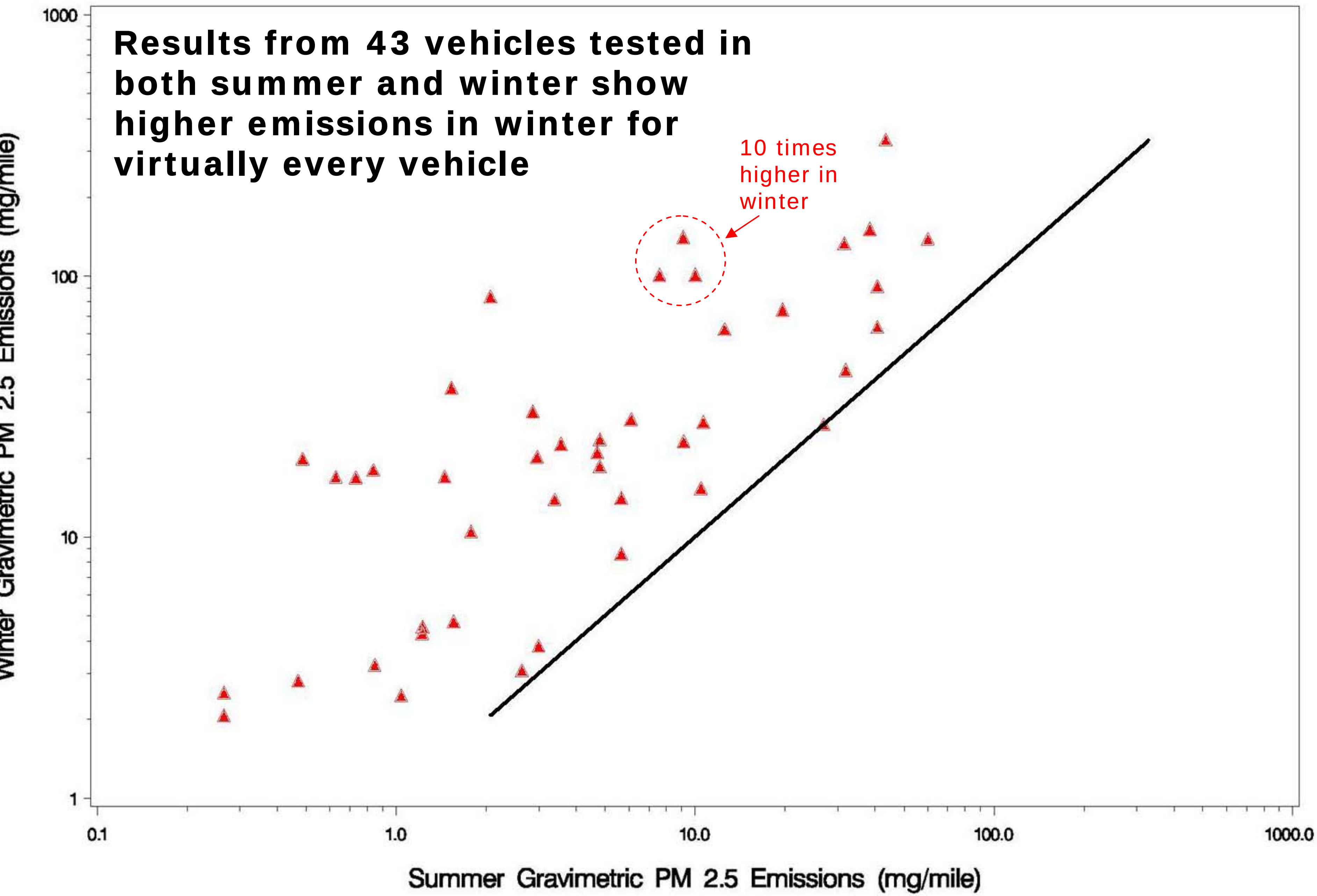


Black line: median; boxes: 25th & 75th %-ile; whiskers: range; + outliers

Assessment of Temperature Effects

- Vehicle tested at ambient temperatures
- Winter Temperatures:
  - avg ~ 45ºF, min ~ 20ºF
- Summer Temperatures:
  - avg ~76ºF, max ~100ºF
- 43 vehicles (of ~480) repeat tested summer and winter
- Correlation vehicle tested 24 times over a range of temperatures

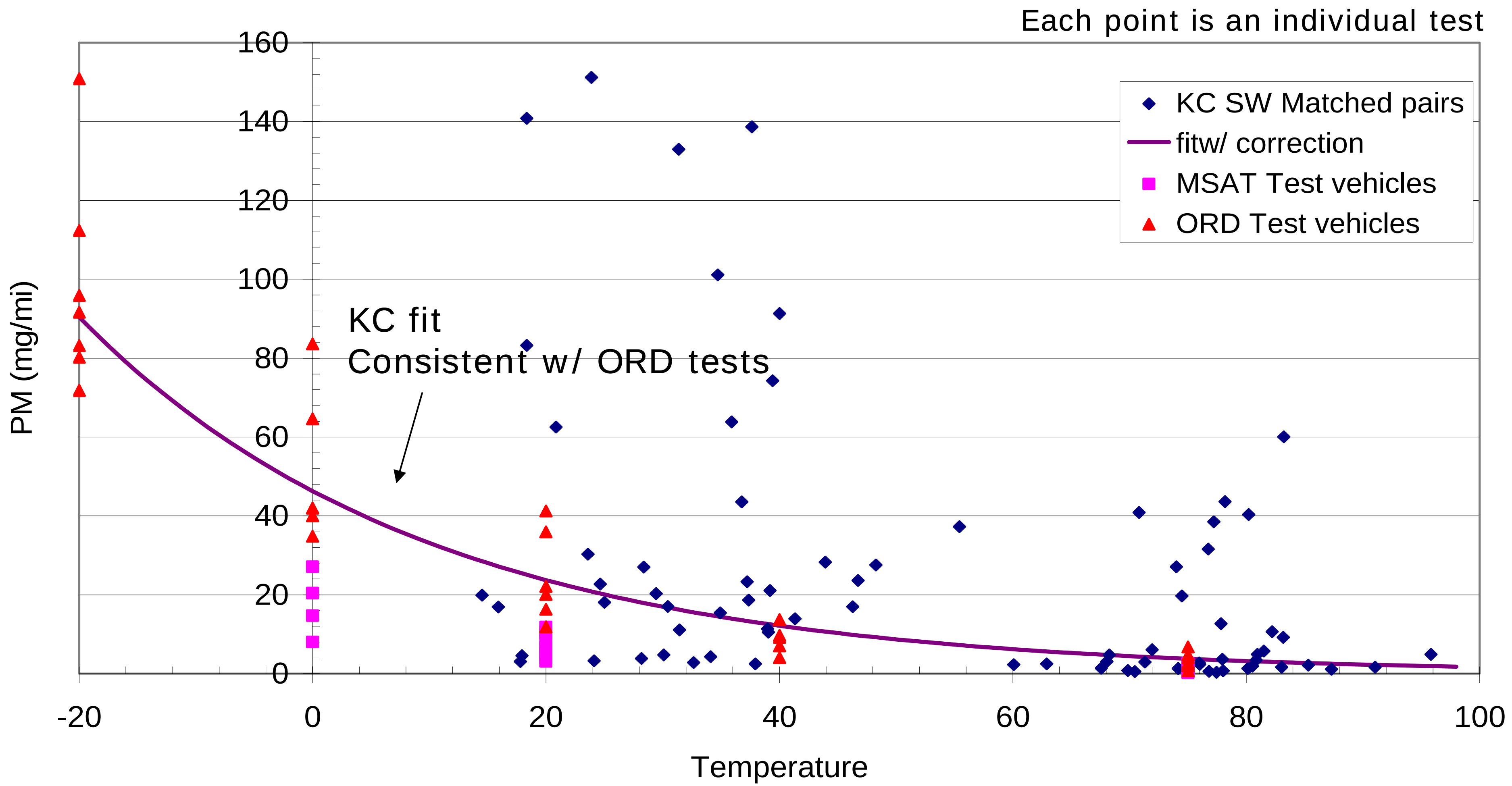
Scatter Plot of Winter Gravimetric PM 2.5 vs. Summer Gravimetric PM 2.5 – Composite (Logarithmic)



Recent Studies of PM Temperature Effect

- EPA/ORD: 8 1987-2001 MY vehicles
  - Tested over temperatures from -20ºF to 75ºF
  - PM emissions doubles every 18ºF drop
- EPA/OTAQ: 4 Tier 2 vehicles (in support of MSAT cold VOC std)
  - Tested over temperatures from 0ºF to 75ºF
  - PM emissions doubles every 19ºF drop

Comparison of Temperature Effects to Recent Studies

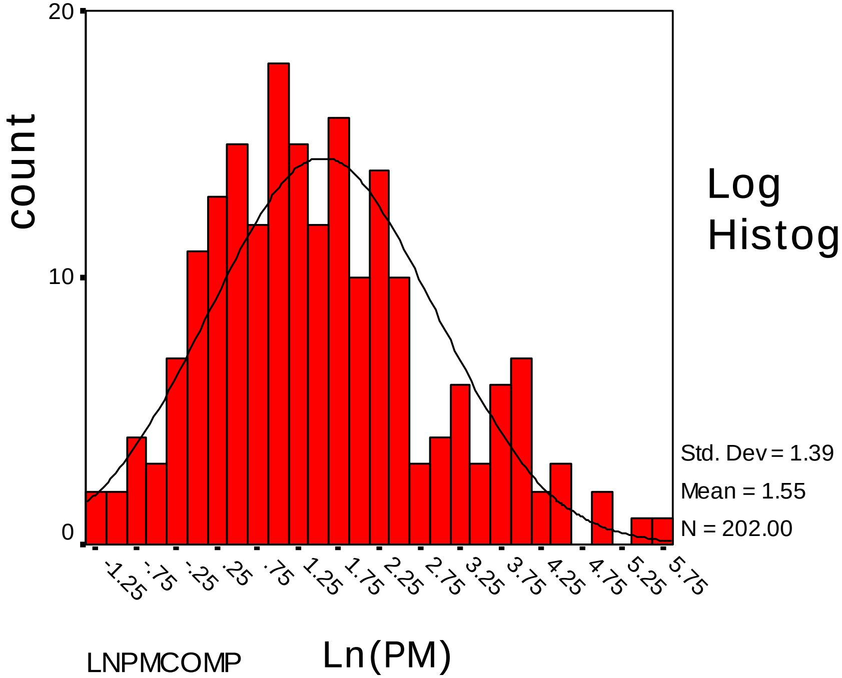


Kansas city PM emissions doubles with every 20^{o}F drop
- This is fairly consistent with other studies

High Emissions & Smokers

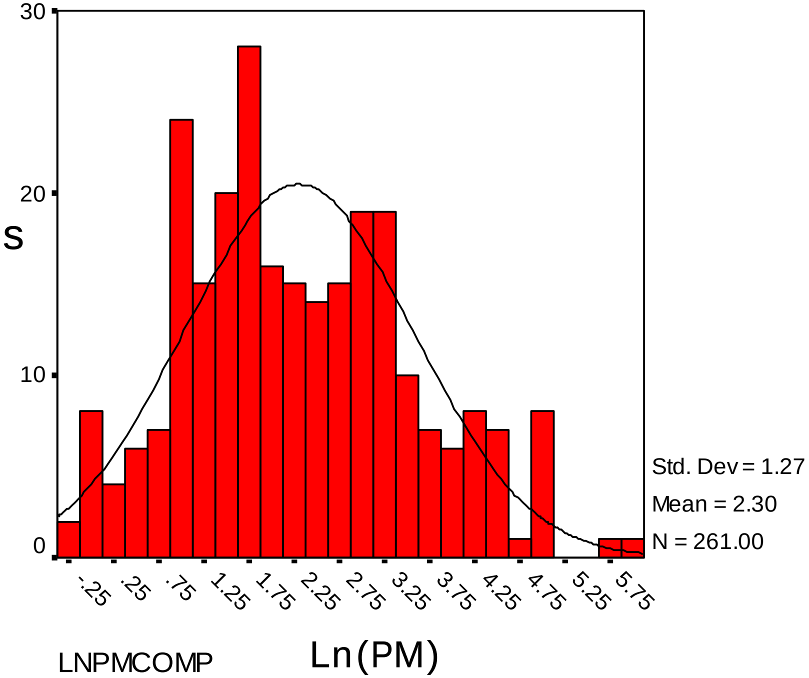
- No good definition of a PM “high emitter”
  - Standard is too high to use as a definition
  - 2 or 3 sigma from mean is not descriptive is mean is low – also emissions not normally distributed
  - Vehicles may have higher emissions at times and lower emissions at other times
  - “Smoker” is a subjective definition

High Emissions Analysis



summer

Log Histograms



winter

- Emissions distribution skewness of sampled fleet confirms presence of high emitting vehicles
- 50% of emissions coming from 13% of vehicles

Smokers

- Of 496 vehicles, 406 were checked for smoke **at idle**
- Not all of the highest emitting vehicles were identified as smokers
  - In summer, of vehicles (14) emitting over 50 mg/mi
    - Only 1 MY 96+, others were older
    - Only 2 had barely visible smoke
  - Significantly Smoking vehicles only seen in winter:
    - 11% of winter vehicles significantly smoking
    - Only 1 MY 96+, others older
- Conclusion: “smokers” are not always the highest emitting vehicles, and vice versa

What causes high gasoline PM?

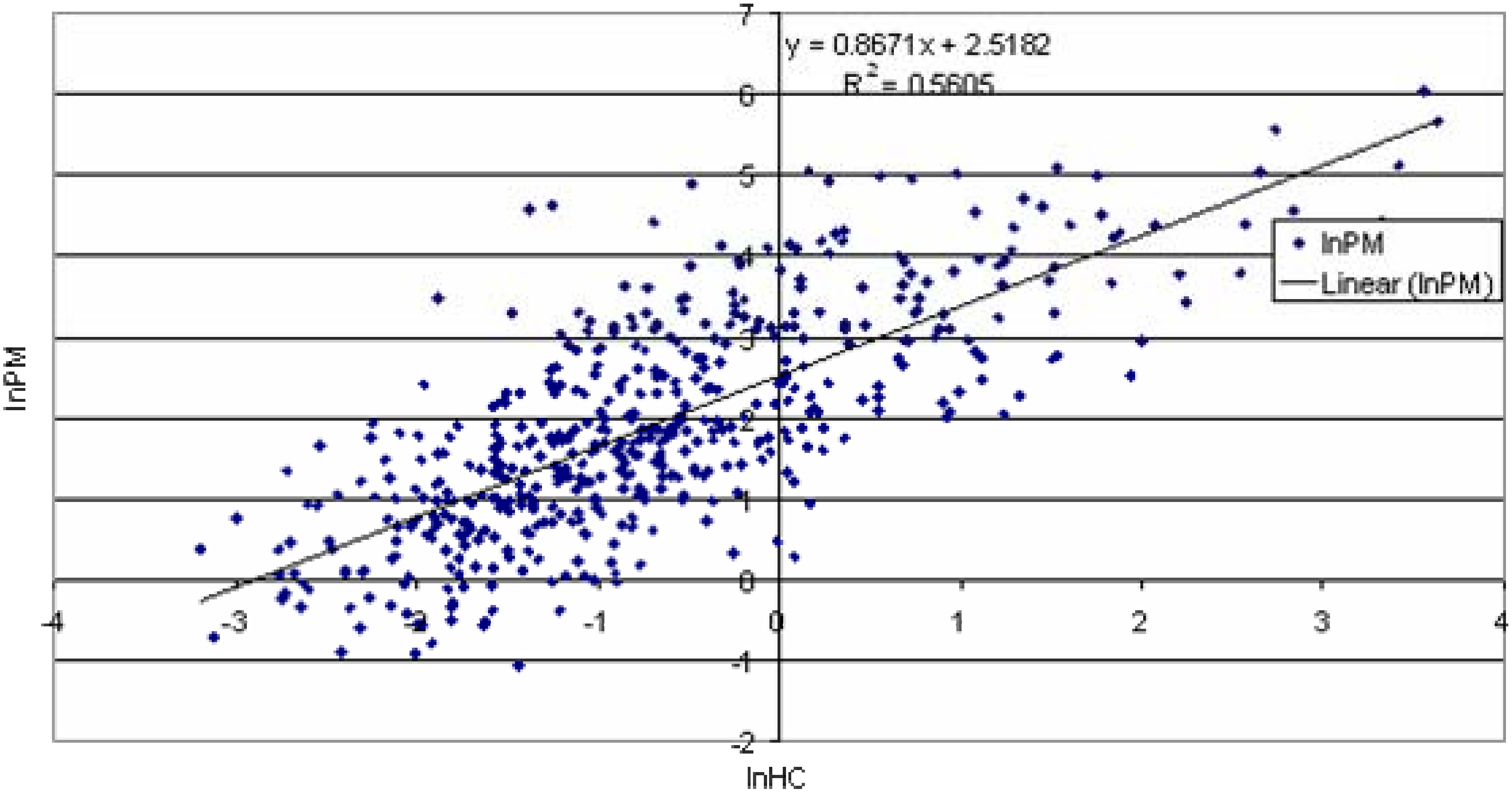
- Over-fueling
  - Cold start
  - High load (WOT)
  - Sensor failures
  - Fuel system failures
- Component wear
  - Leaky injectors
  - Valve seal
  - Piston rings…
- Fuel Properties
  - T# performance
  - Aromatics
  - Sulfur
- Lubricating Oil
  - PCV: Positive Crankcase Ventilation
  - Direct Leak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

Further work required to determine prevalence of these

PM versus HC

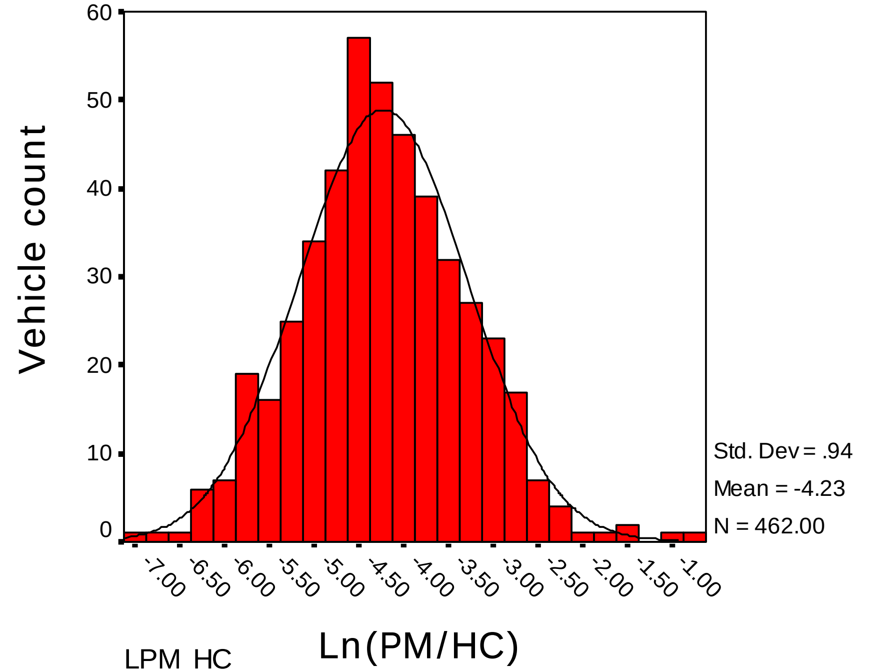
- The relationship between PM and HC is important to understand
- To the extent PM tracks HC it can give clues to:
  - PM emissions outside of the test protocol, such as shorter soak periods or more aggressive driving
  - Potential for PM reduction from HC control strategies

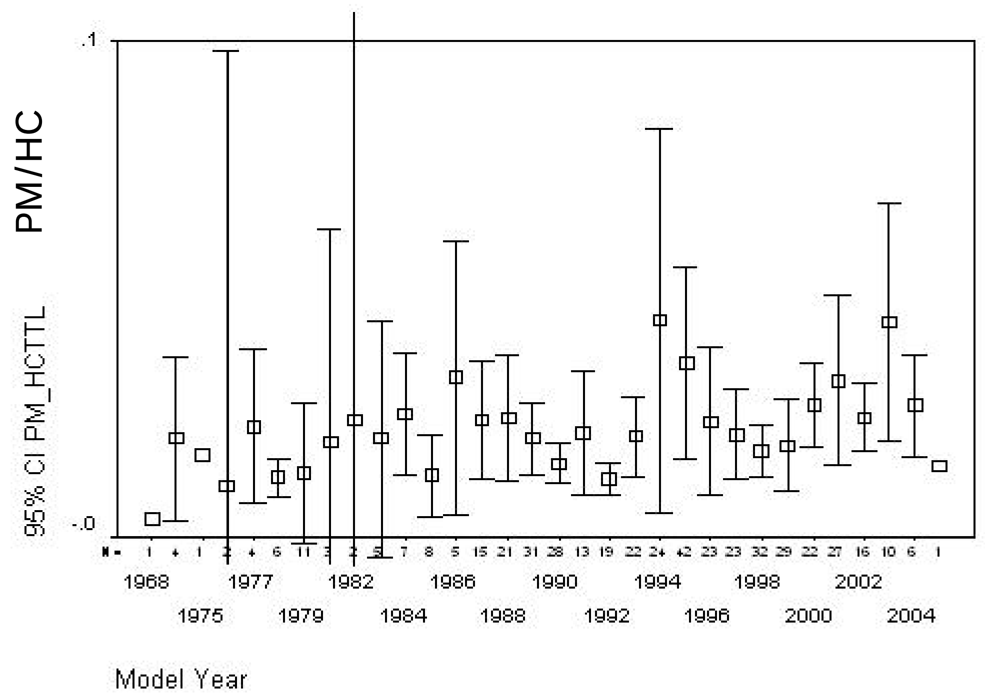
Trends in PM:HC



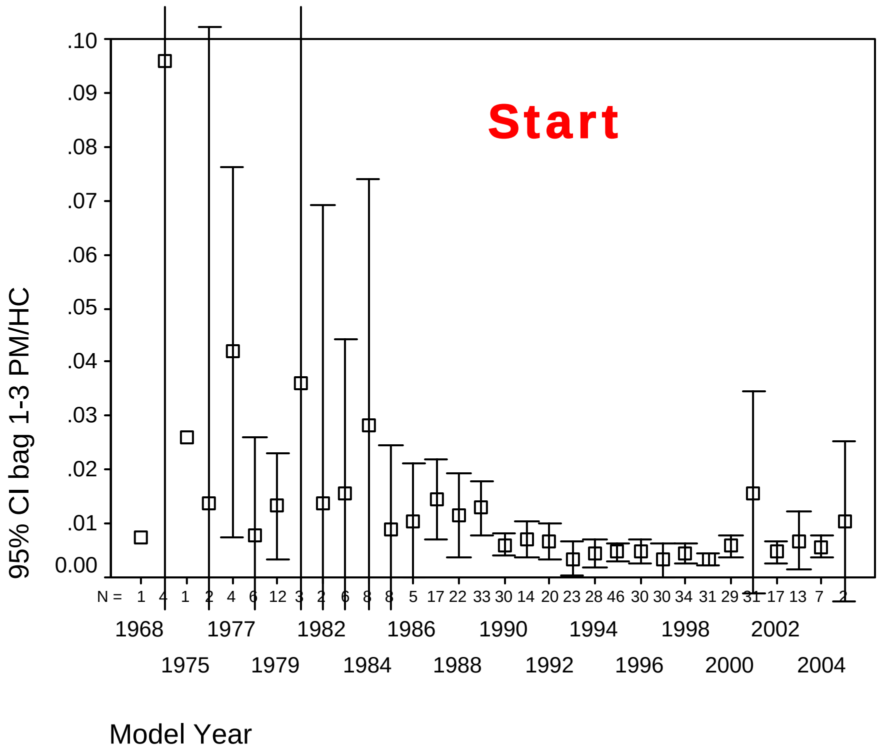
PM:HC Ratio

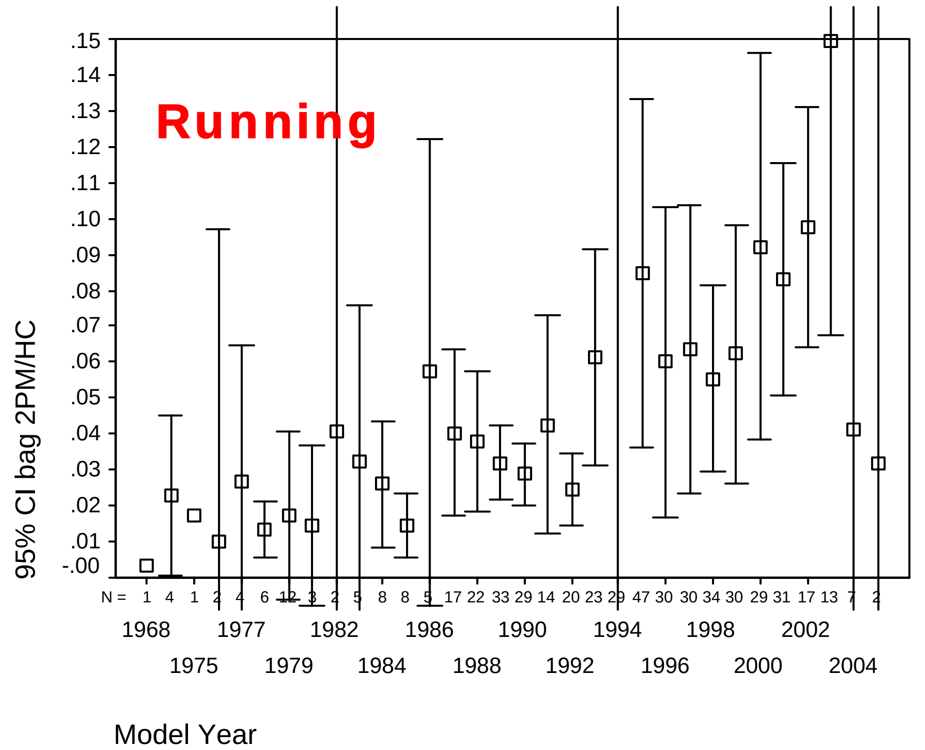
- Avg PM:HC ratio = 0.023 +/-0.003
- Independent of Model Year
- Consistent with ratio of 0.022 used in MSAT to estimate PM benefit from cold HC standard
- There are limitations to this comparison, however…





PM:HC for Starts vs Running





- Ratio for Starts decreases with model year
- Ratio for Running increases with model year
  (though there may also be age effects)
- This shows limitations of the PM:HC correlation

PM:HC Trends – Possible Explanations

- Starts:
  - Transition from carbureted to FI gave higher fuel and ignition quality, thus reducing PM faster than HC.
  - Engines running richer in the past, thus producing more soot
- Running:
  - HC is controlled, but PM is approaching practical limit (oil consumption?)

Comparison to Past Studies

Program differences significant

	CRC E24-1	CRC E24-2	CRC E24-3	Gasoline-Diesel Split	Kansas City
Region	Northern Front Range, CO	SCAQMD	San Antonio, TX	LA/SCAQMD	Kansas City
Recruitment	Local Merchant lots, newspaper, etc.	Registration + phone	SwRI employee vehicles + local school	BAR via smog check + local advertising	Random digit dialing + registration database
Test Year	1996-1997	1996-1997	1996-1997	2001	2004-2005
Drive Schedule	FTP	FTP	FTP	LA92	LA92
Temperatures	23-67F in winter	Lab	Lab	64-99F	20-100F
PM size	PM10	PM10	PM10, PM2.5	PM2.5	PM2.5
Fuel	Local	Local	Local	Local	Local
Fleet Certificatio	National	CA	National	CA	National

Difficult to compare programs

Comparison to Other Studies

Model Yr Group	KC Summer 2004		KC Winter 2005		E24_1_Summer 1996		E24_1_Winter 1997		E24_2 1996 - 1997		E24_3 1996 - 1997		Gas-Diesel Split 2001	
	PM2.5	N	PM2.5	N	PM ttl	N	PM ttl	N	PM ttl	N	PM ttl	N	PM2.5	N
pre-1981	77.5 ± 64.4	7	75.8 ± 39.0	25	95.4 ± 34.7	25	78.3 ± 36.3	15	34.0 ± 12.2	14	148.5 ± 94.4	10	59.0 ± 54.4	6
81to90	29.6 ± 12.9	55	31.8 ± 9.8	67	46.0 ± 24.1	47	37.8 ± 11.4	33	28.1 ± 19.1	54	64.4 ± 29.3	25	34.2 ± 16.2	18
91to95	9.6 ± 3.6	48	18.4 ± 5.5	73	2.5 ± 0.7	17	30.4 ± 32.6	7	2.8 ± 1.2	50	5.8 ± 1.2	12	3.6 ± 1.6	26
1996+	3.4 ± 1.2	92	8.2 ± 2.2	97	4.5 ± 5.0	3	3.0	1	2.3 ± 2.2	11	6.4 ± 1.7	6	3.9 ± 3.7	3

- KC results in line with other studies
- Study differences important source of variability:
  - Ambient conditions
  - Recruitment
  - Test cycles & equipment
  - Fuels
  - Fleet, demographics & geography

Conclusions

- Kansas City is the most comprehensive program focused on light-duty gasoline PM ever run
- Preliminary analysis of study results indicates:
  - Emission trends by age and car/truck are as expected
  - Temperature effects are large
  - 50% of emissions coming from 13% of vehicles, but not all high emitters are smokers and vice versa
  - PM has a correlation with HC overall, but start and running PM:HC ratios show opposite trends by MY
  - KC results in line with previous studies, although study differences limit this comparison

Conclusions cont.

- Further analysis will be done in the development of MOVES (draft release ~ Sept. 2008)
- Substantially more work required to translate KC results into inventory which accounts for regional differences and future fleet emissions