Particulate Matter from Gasoline Light Duty Vehicles Based on Kansas City and Other Studies

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Introduction

- Why do we need to study PM from gasoline sources?
  - Questions about the dominance of gasoline vs diesel in inventory
  - Update outdated emissions models for regional State Implementation Plans and conformity analyses made timely by new PM NAAQS stds
  - Develop baseline PM inventories to apply fuel effects (eg. Ethanol).
- Kansas City Results
  - Study Design
  - Preliminary Results
  - KC PM rates are largely representative
  - High Emissions Analysis
  - How does temperature affect PM emissions?
  - How can we model deterioration in cars? (model year vs age: technology vs deterioration)
    - Two models introduced: additive and multiplicative
  - Preliminary inventory comparison for 2002
- What requires more work
  - Longitudinal study of vehicles to quantify deterioration

Background

- Does Gas or Diesel dominate the PM inventory?
  - Many past source apportionment studies have had conflicting results on whether diesel or gasoline PM dominate
  - Emission inventories generally indicate diesel dominates
  - This study only addresses the gasoline portion (and not the diesel, which also requires an update)

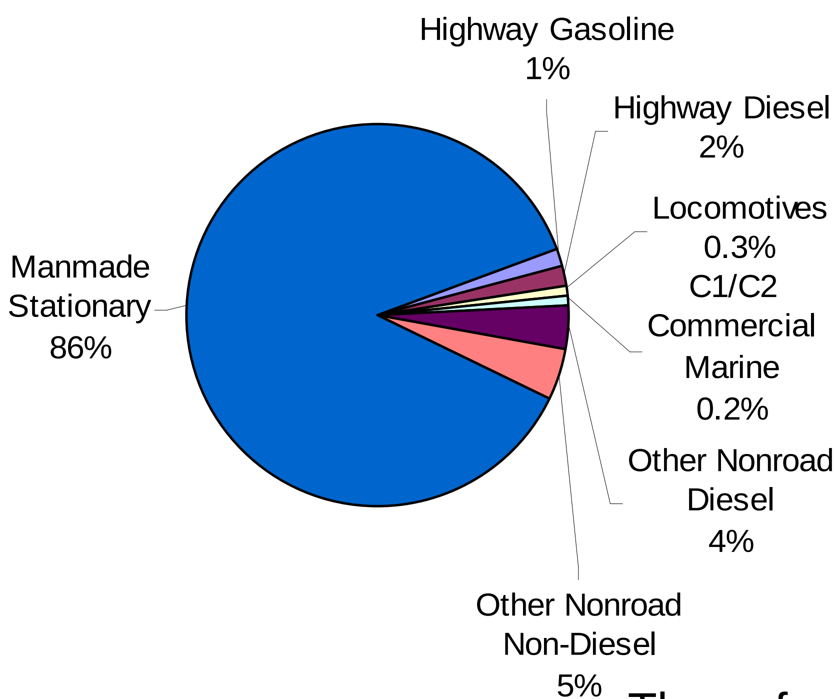
2009 National PM2.5 Breakdown

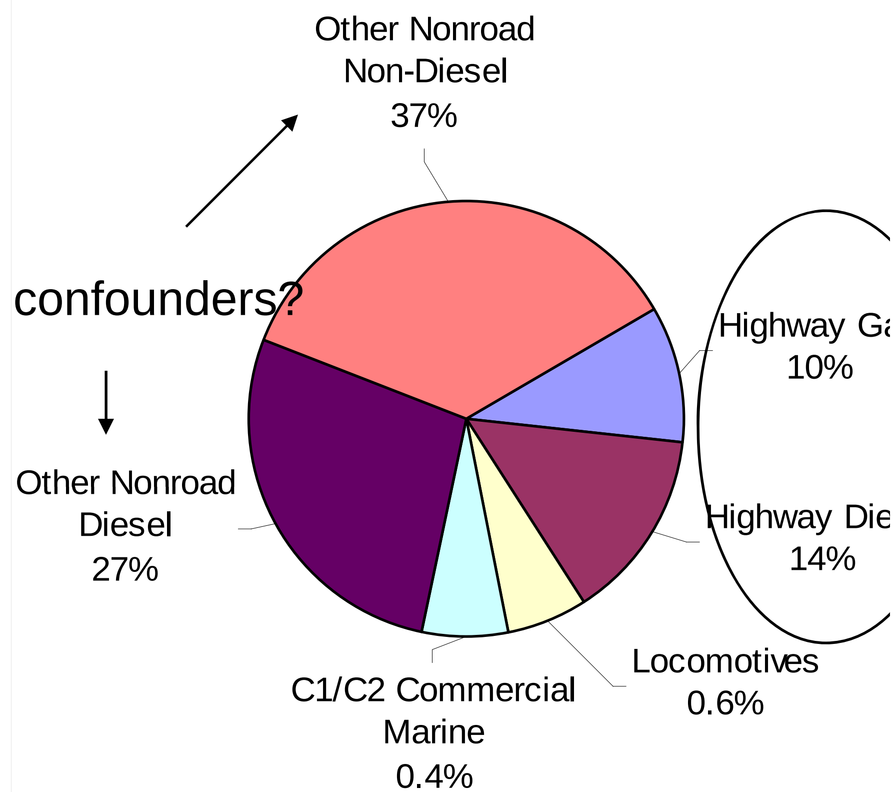
These are estimations based on MOBILE modeling (bottom up)

2009 Total PM25 (mobile+stationary)

onroad gas sources contribute ~1% of PM from all sources and ~10% of mobile sources

Mobile Source PM





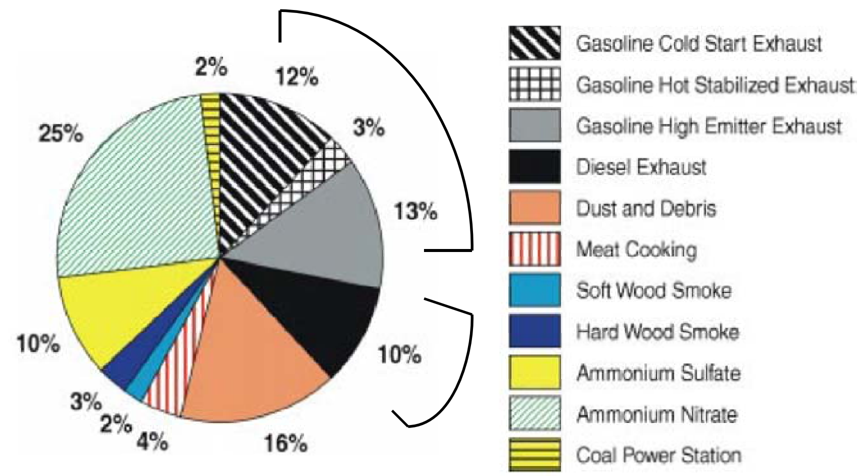
These fractions are being updated

NFRAQS DRI Study

- Study done in 1996-1997 in Denver
- Study focused on wintertime ambient and emission data
- Vehicle emission testing performed locally
- Extensive ambient PM sampling and speciation
- Study concludes that Gas PM dominates diesel PM 3:1

Welby Site (Denver)

Fine PM apportionment results



Can't compare pie to previous chart due to denominator discrepancy

Questions continue

- Source Apportionment Studies “Top-Down”
  - Gas >> Diesel
    - NFRAQS, LADCO (OC), SCAB Split (Schauer), PAQS (using Schauer diesel profile)
  - Gas ~= Diesel
    - SCAB Split (Fujita), Atlanta
  - Diesel >> Gas
    - SCAB (’82), SEARCH, PAQS (using NFRAQS diesel profile)
  - Major uncertainties of source apportionment studies
    - Secondary aerosol formation accounts for large portion of ambient PM
    - Dependent on uncertain (and scarce) profiles
      - Emissions profiles from small nonroad engines (including 2-stroke cycle engines) are unknown and potentially significant
    - Emissions profiles from other man-made sources are unknown
- EPA (OTAQ) will report on this issue soon
  - Using Kansas City + recent Diesel testing data using a “bottom-up” approach
  - KC also has new source profiles to add to the SA databases

KC PM Results Caveat

- We are presenting PM data gathered:
  - At set point in time
- These results should <u>not</u> be confused with inventory impacts in the future
- The definition of what exactly PM is and how measured PM relates to ambient PM is still being studied
  - sampling temp, dilution, location, measurement media
- Contract report and Results report are now on EPA/OTAQ website (emission factor research)

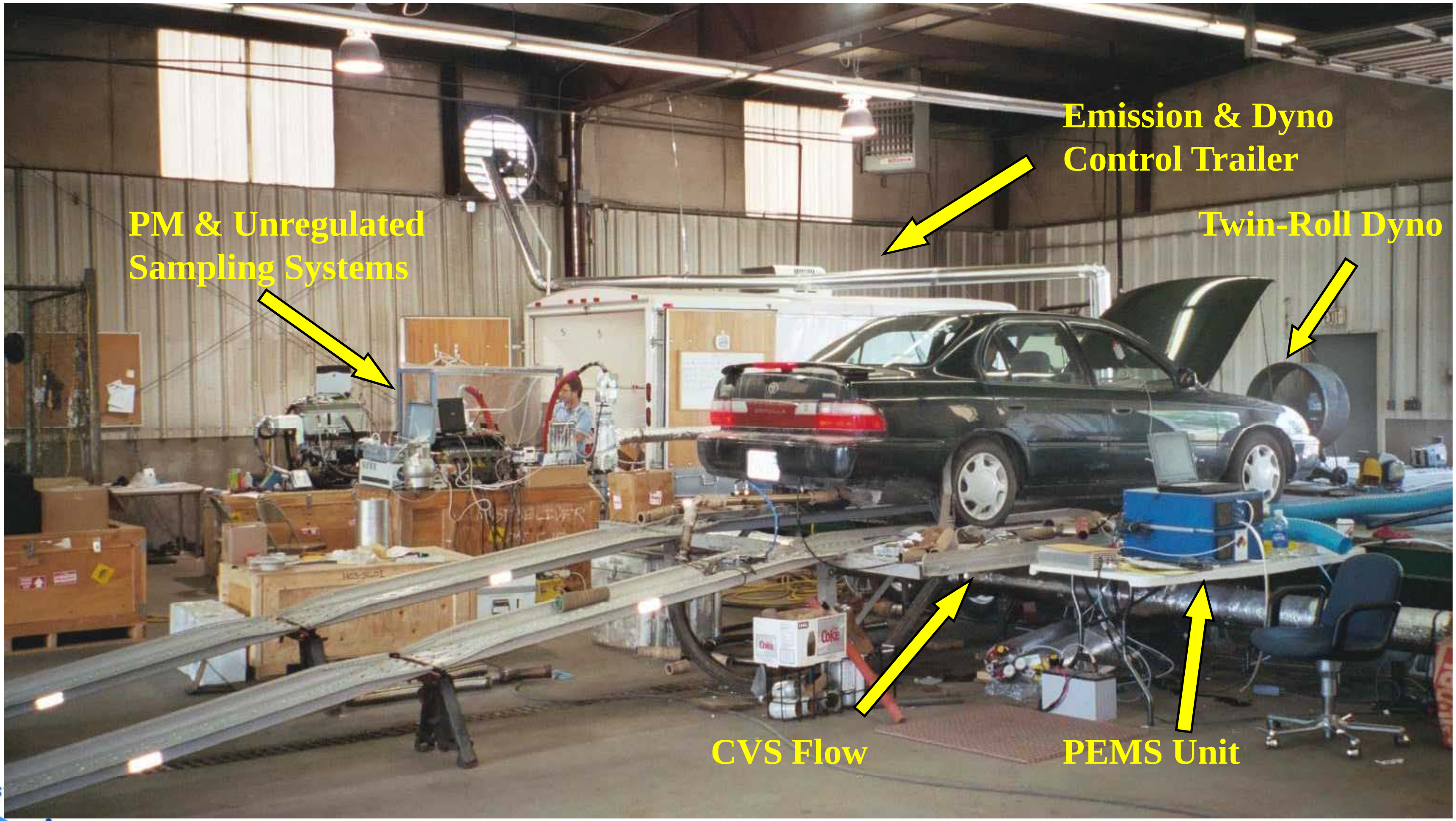
Major Objectives of KC Program

- Address the need for representative gasoline PM from the current fleet
  - 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 large random sample methodology used in recruiting gasoline LDVs/LDTs**
  - Quantify distribution of PM emissions in the fleet
  - Quantify effect of ambient temperature on PM emissions
  - Develop PM and Toxics speciation profiles
- Other Goals
  - Evaluate alternative PM measurement techniques
    - E.g. Collect the first real-time gas PM data on a fleet
  - Evaluate performance of PEMS
  - Real world data on emissions, activity & fuel economy

KC study background

- Address need for representative gasoline PM emission estimates from current fleet
- Evaluate alternative measurement techniques
- 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
- Representative sampling a critical objective
- We believe that the vehicles represent an accurate cross-section of KC demographics and that sufficient high-emitters were captured

KC Test Facility - Instrumentation

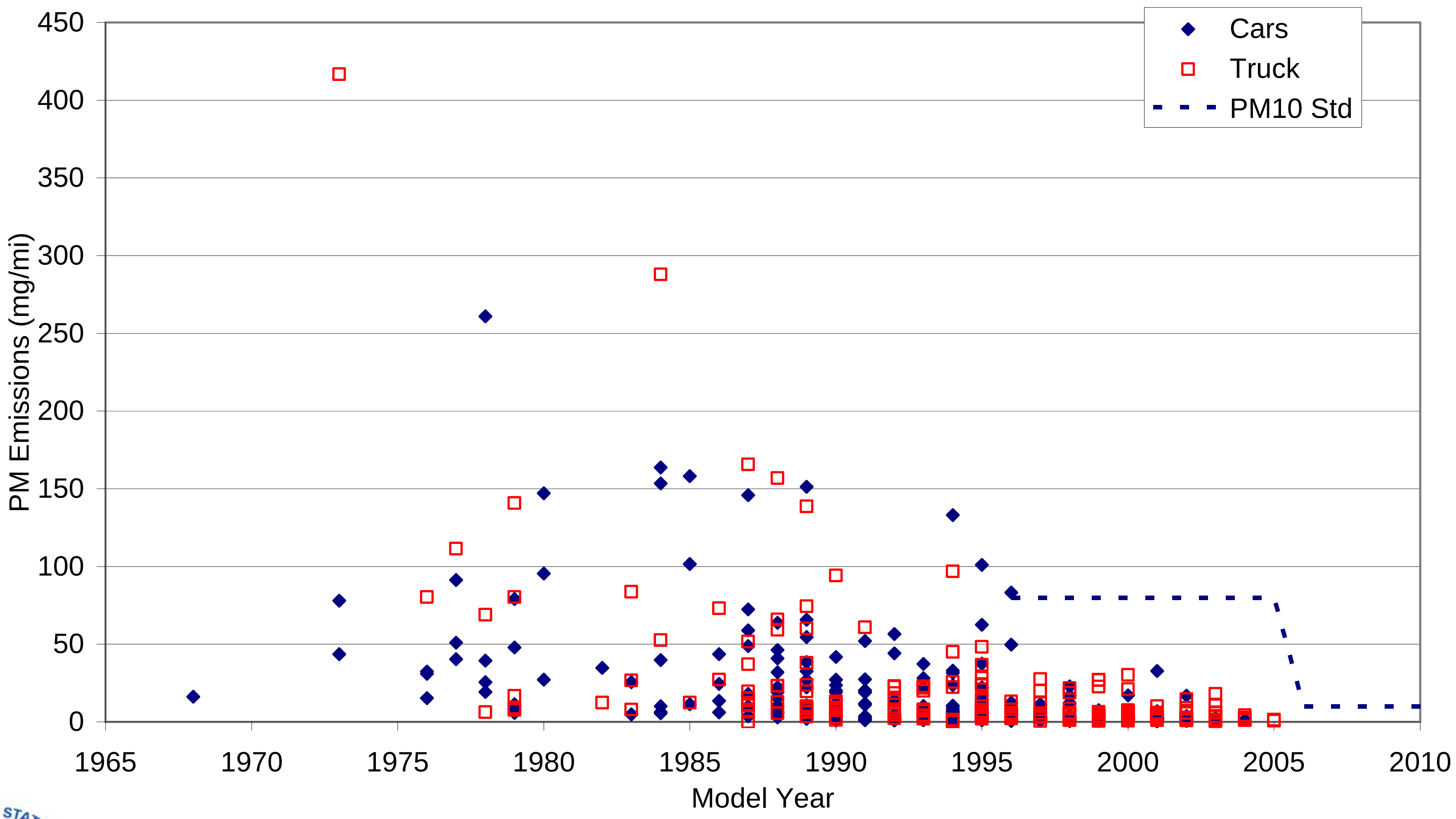


Vehicles driven on LA92 drive cycle under ambient temperatures

Preliminary Results

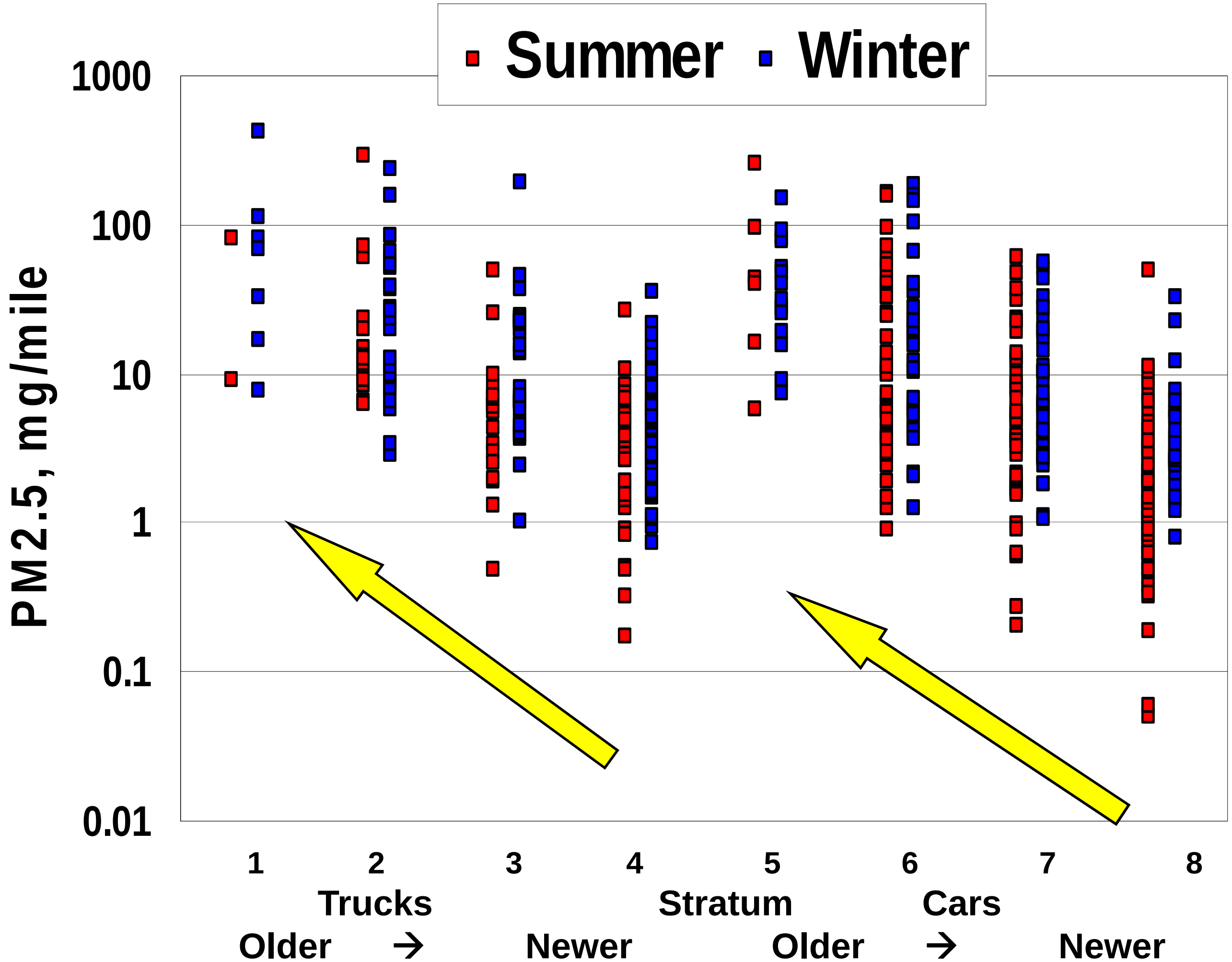
- Kansas City study suggests that PM emissions are:
  - largely consistent with past gas PM measurement programs
  - correlated with HC more than any other pollutant, but correlation is far from perfect
  - Higher from trucks than cars
  - Higher from older vehicles than newer vehicles
  - Coming from a small number of high emissions vehicles, but many were not identified as “smokers”
  - can be highly variable from test to test
  - Higher (exponentially) in winter than summer
  - **We have found strong evidence that some vehicles have high PM levels due to oil burning**

Results by Vehicle



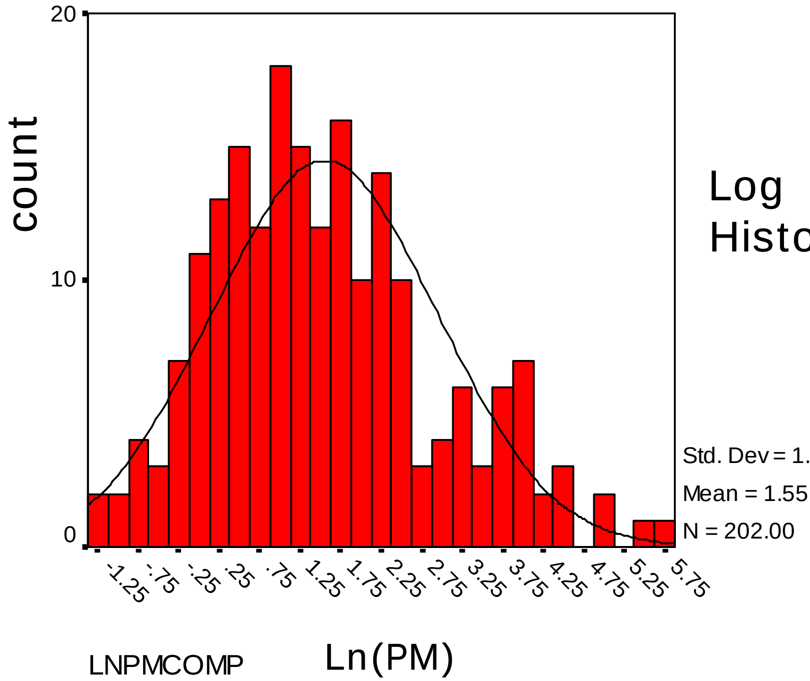
Each point is a vehicle result on an ambient LA92 test
So cannot compare directly to emissions standard

Results by Strata and Season



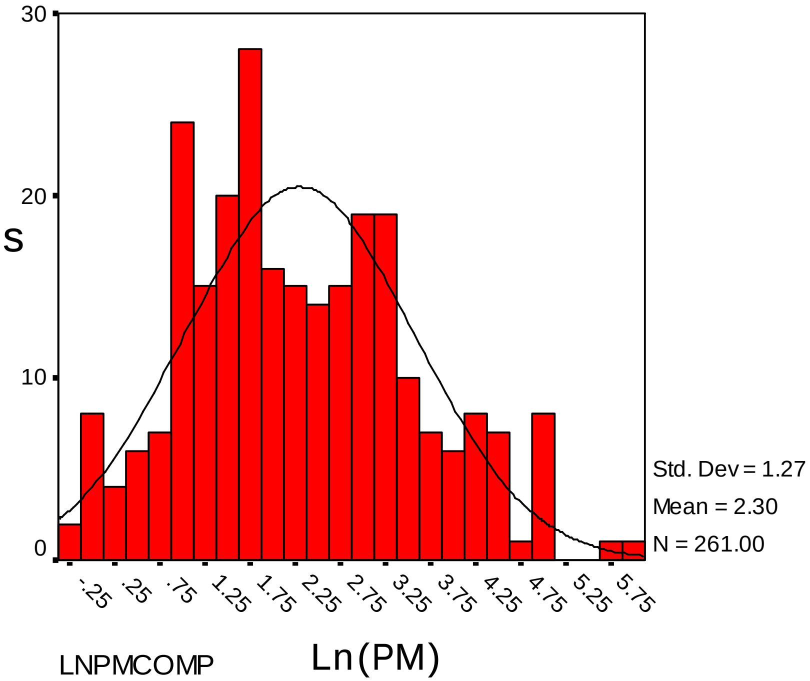
Emissions are higher in the winter
Emissions are higher for older vehicles

High Emissions Analysis



summer

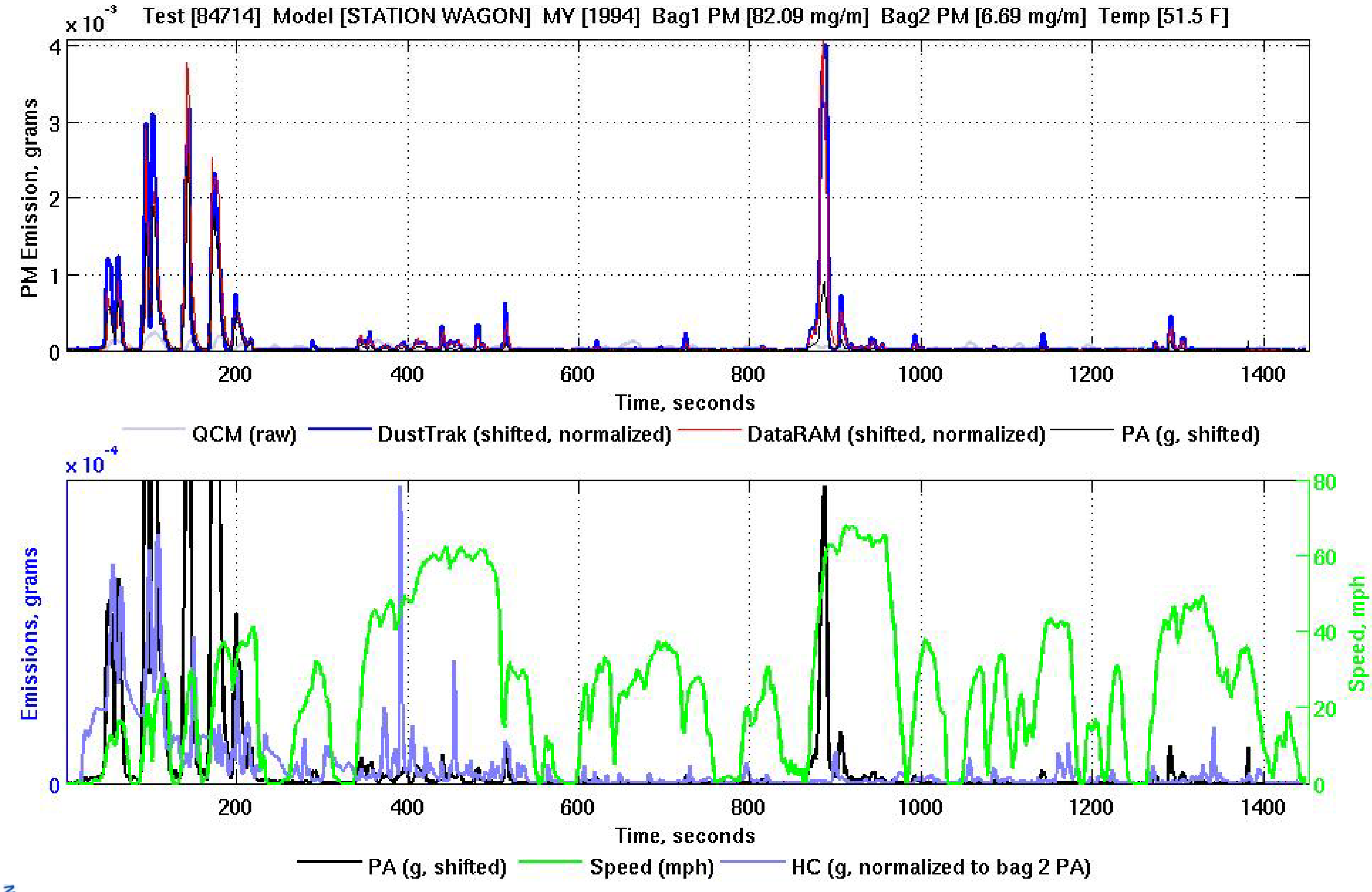
Log
Histograms



winter

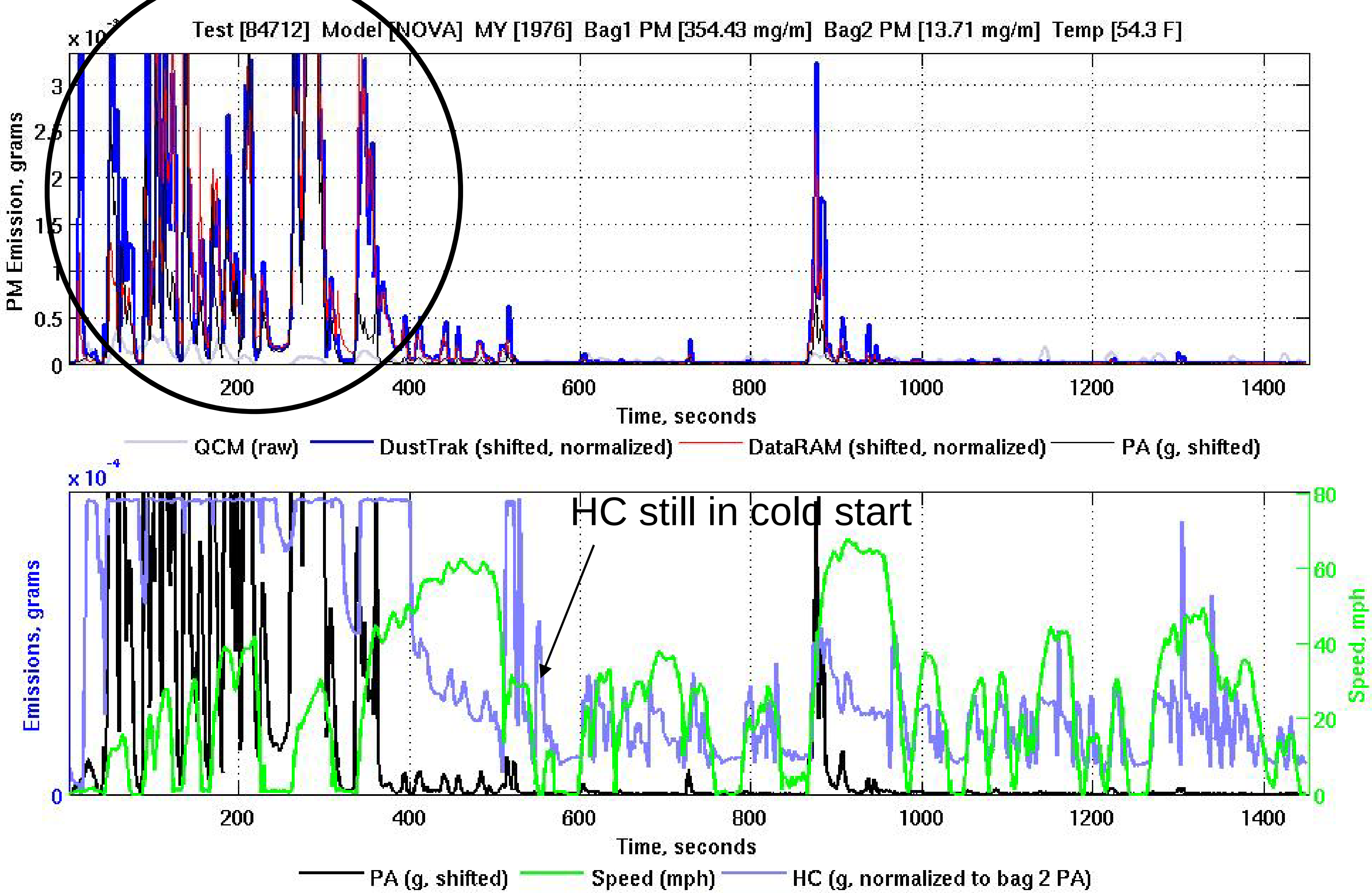
- Emissions distribution skewness of sampled fleet confirms presence of high emitting vehicles
- Emissions are roughly log-normally distributed
- 50% of emissions coming from 13% of vehicles
- Look at sec by sec data to get an idea of what is causing high emissions

Typical results: PM spike at ~840 sec



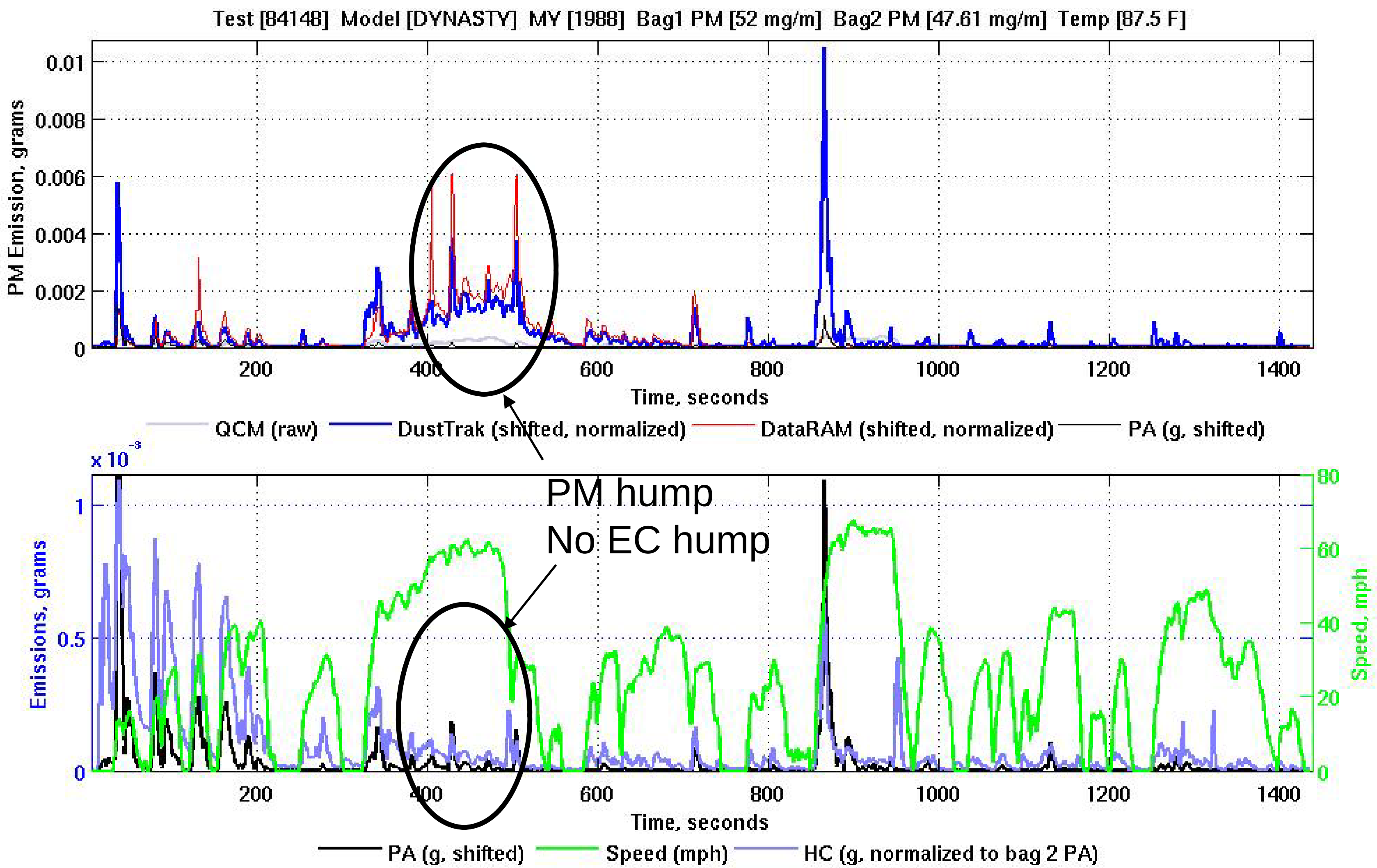
With a relatively prominent cold start

e.g. High Emitter due to hi cold start



Cold Start bleeding into bag 2
Not a very cold temperature test, Not common

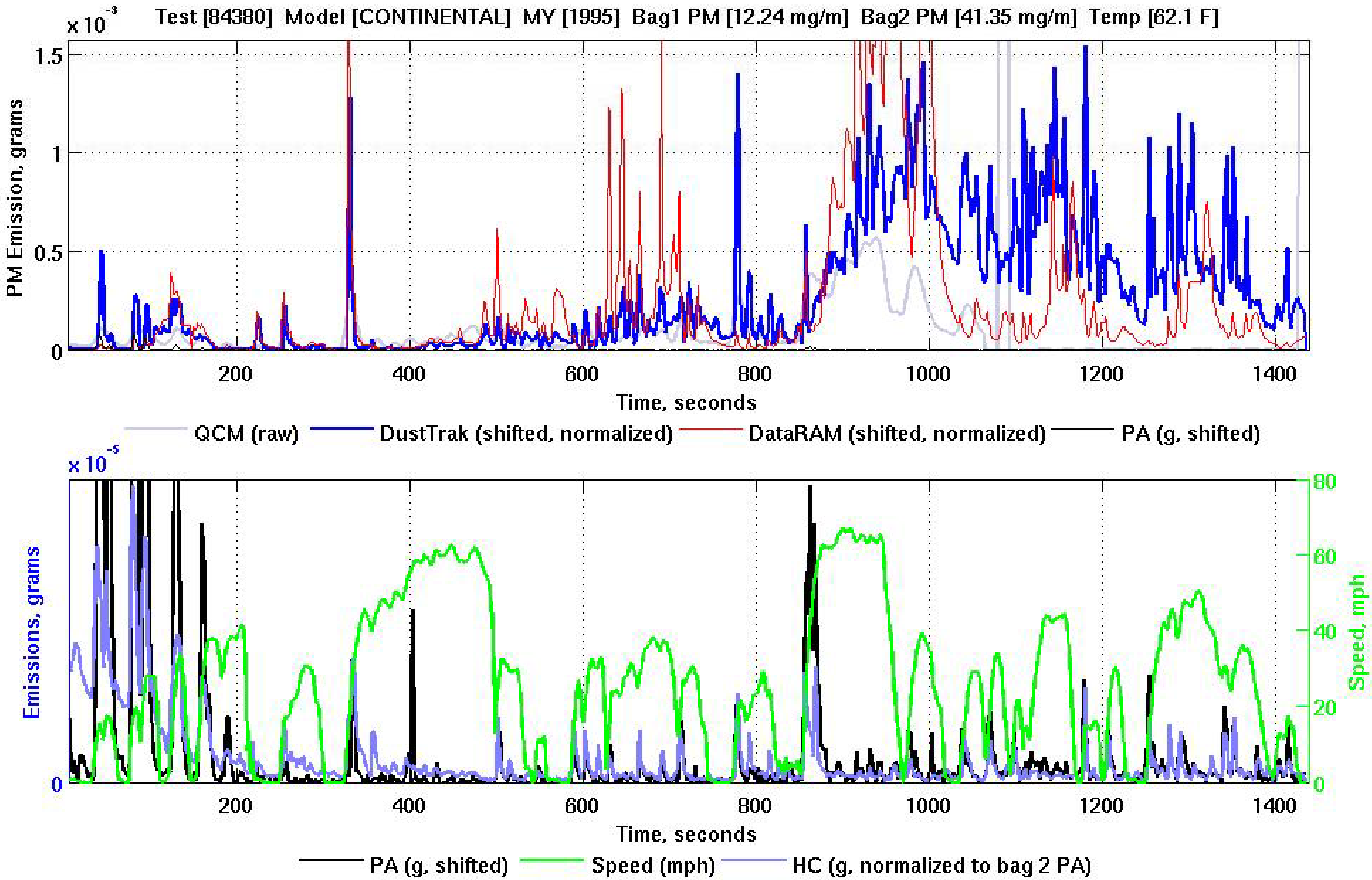
Broad PM humps (likely OC, or oil)



Not cold start – probably Organic PM from oil or stored in measurement system

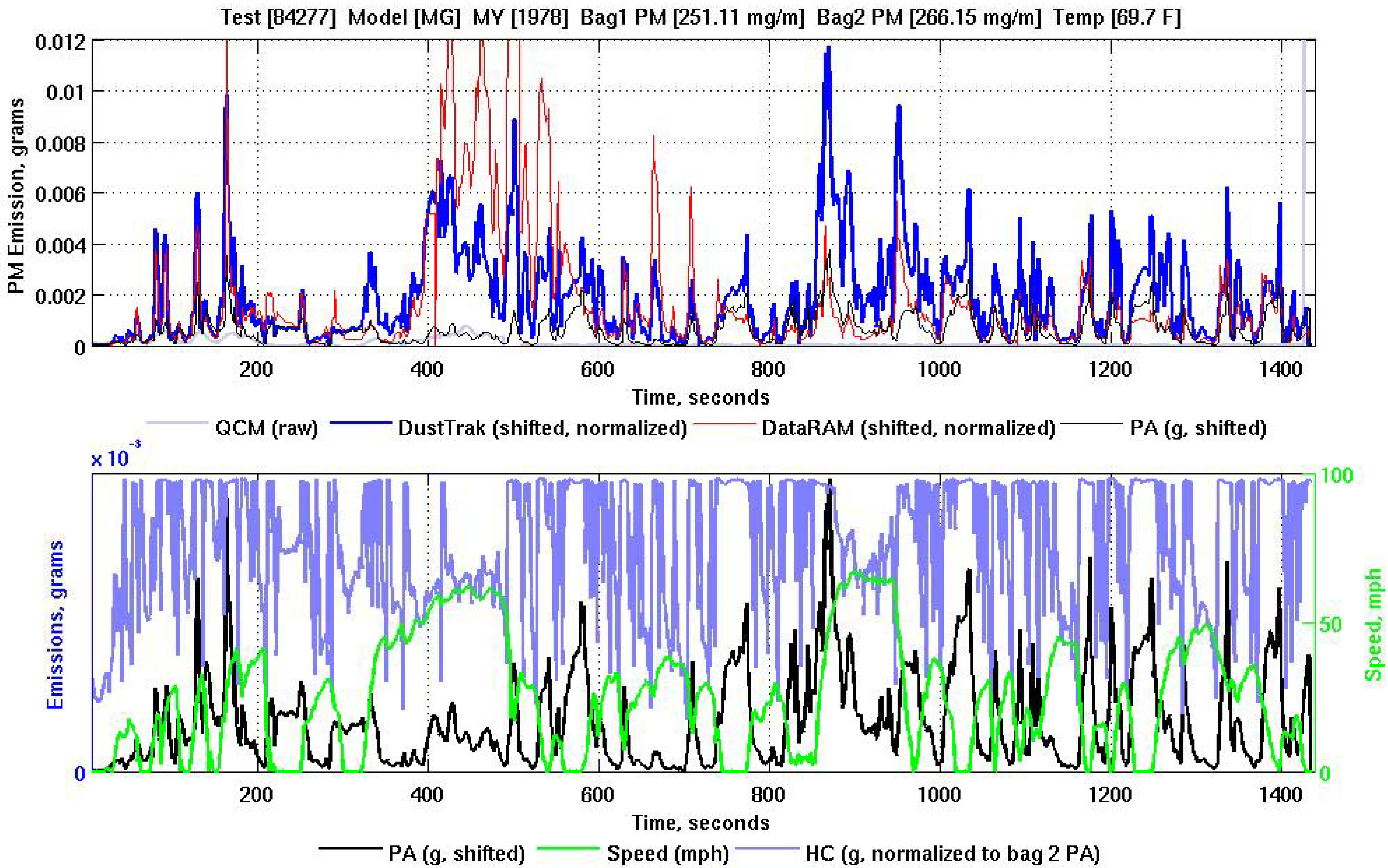
Occurs appx on 40 tests with avg PM ~ 50mg/mi (skewed)

Most likely an oil burner



Mostly OC, intermittent, not necessarily load dependent
not necessarily reflected in HC

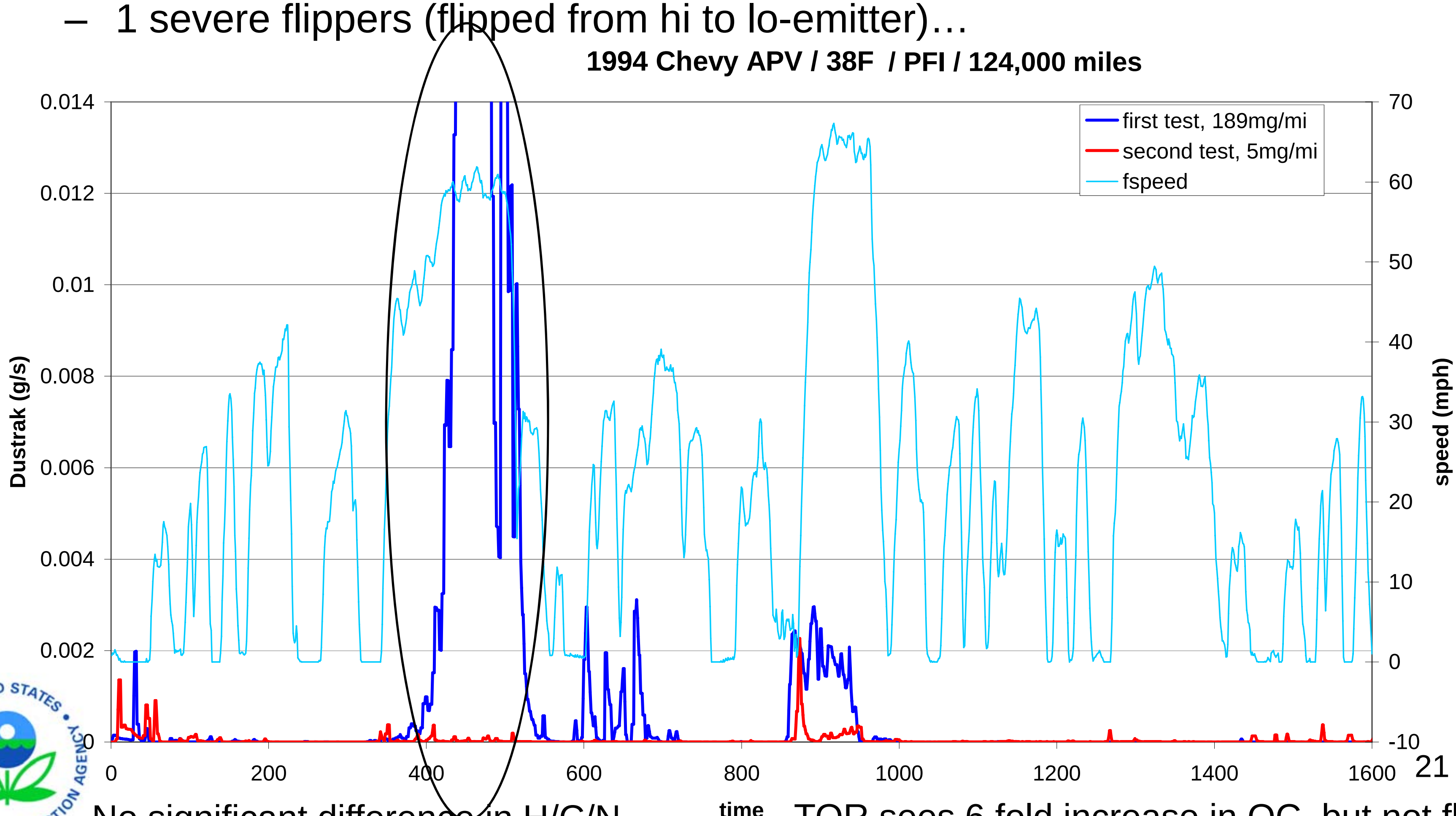
Old Hi Emitter (poor fuel control)



limited fuel control & may be burning oil

Test-to-test variability

- Out of 24 repeat test vehicles (consecutive days)
  - There was considerable variability
  - 1 moderate flipper (flipped from moderate to lo)
  - 1 severe flippers (flipped from hi to lo-emitter)…

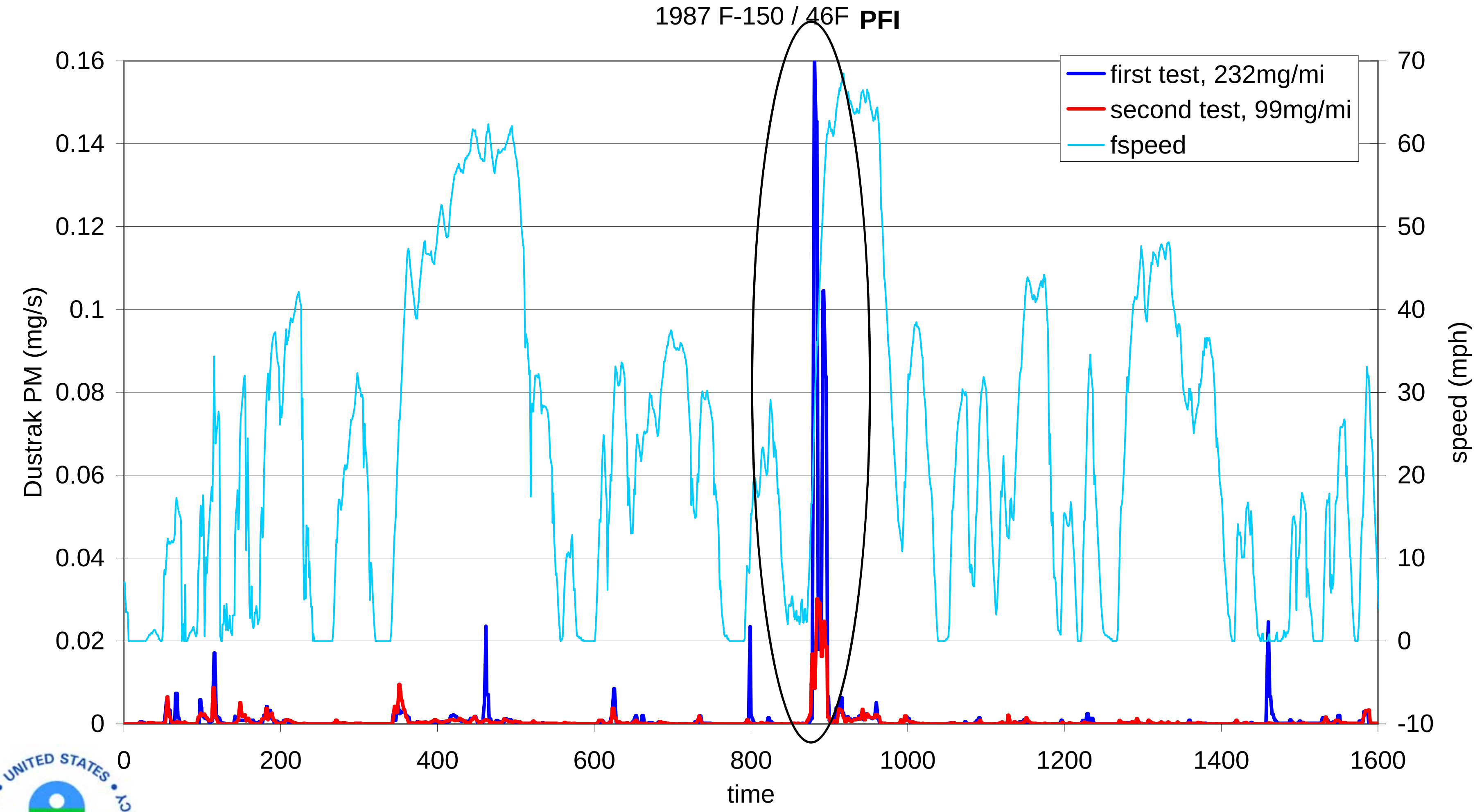


No significant difference in H/C/N

TOR sees 6 fold increase in OC, but not flipper

Hi-emitter variability

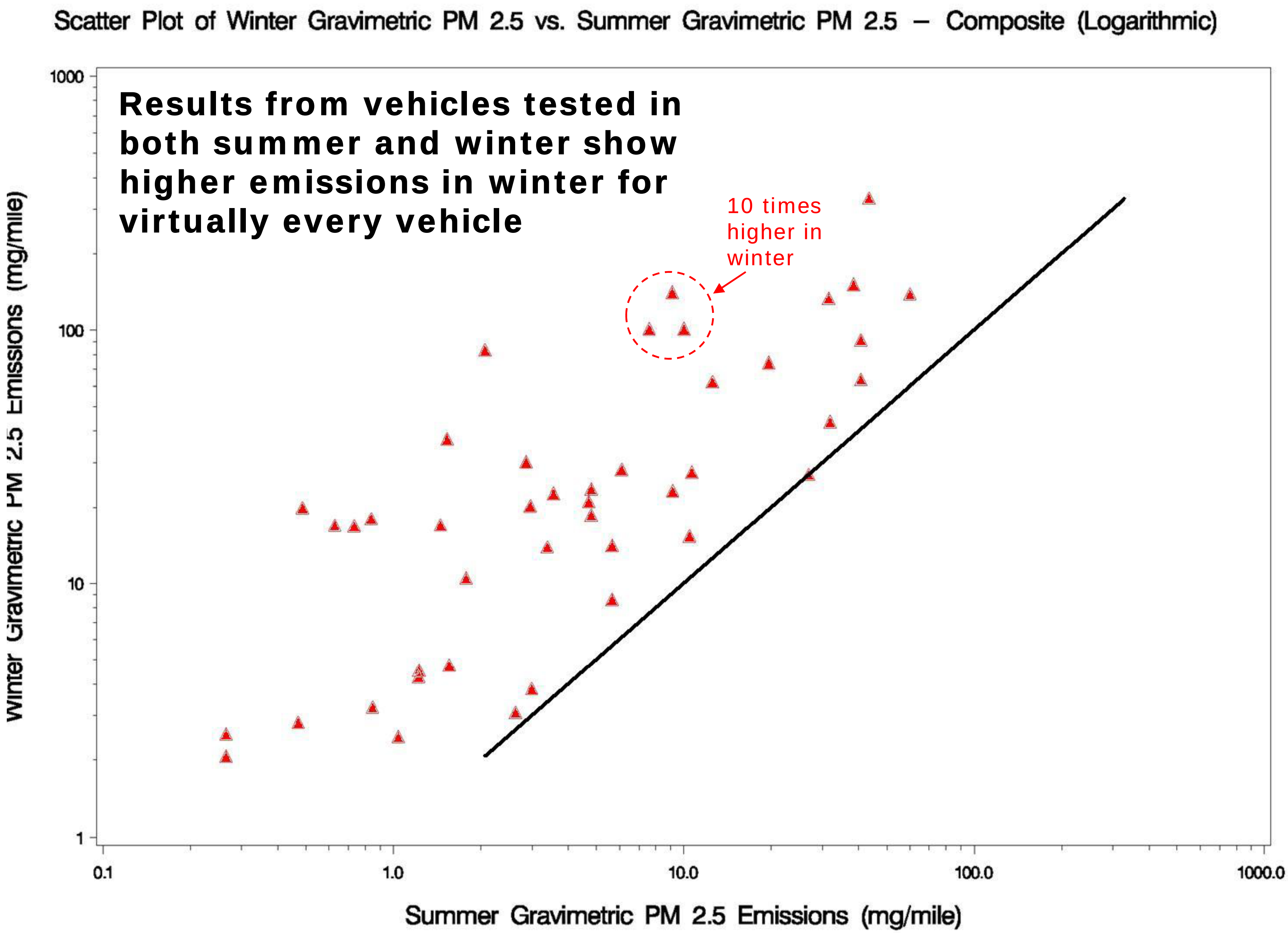
- Variability is more common for PM compared to H/C/N



QCM doesn't see it, but TOR does – even instruments are variable

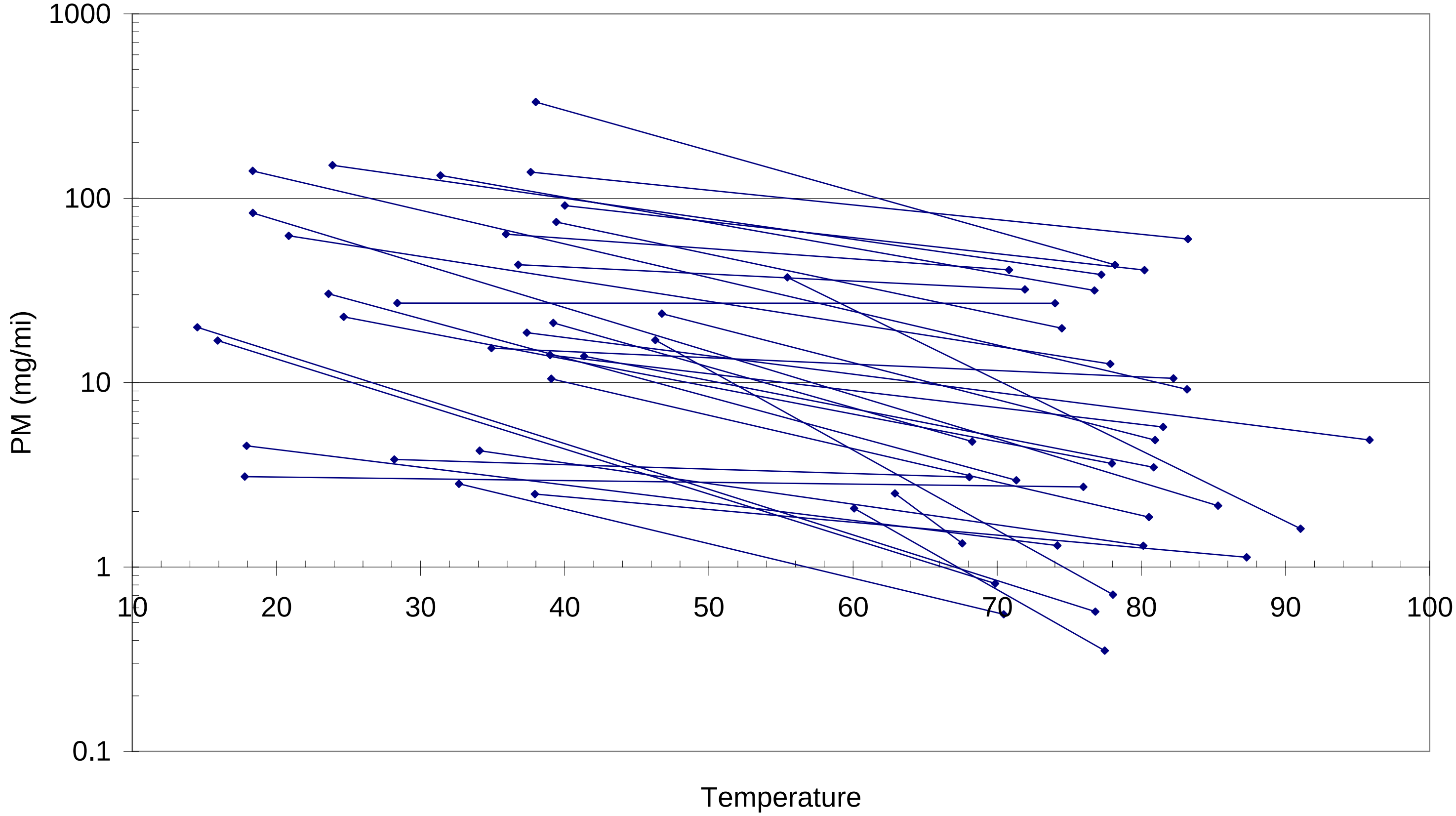
Assessment of Temperature Effects

- Vehicle tested at ambient temperatures
- Winter Temperatures:
  - avg ~ 45ºF, min ~ 20ºF
- Summer Temperatures:
  - avg ~76ºF, max ~100ºF
- 43 vehicles tested summer and winter (33 remain after QA)
- Correlation vehicle tested 24 times over a range of temperatures



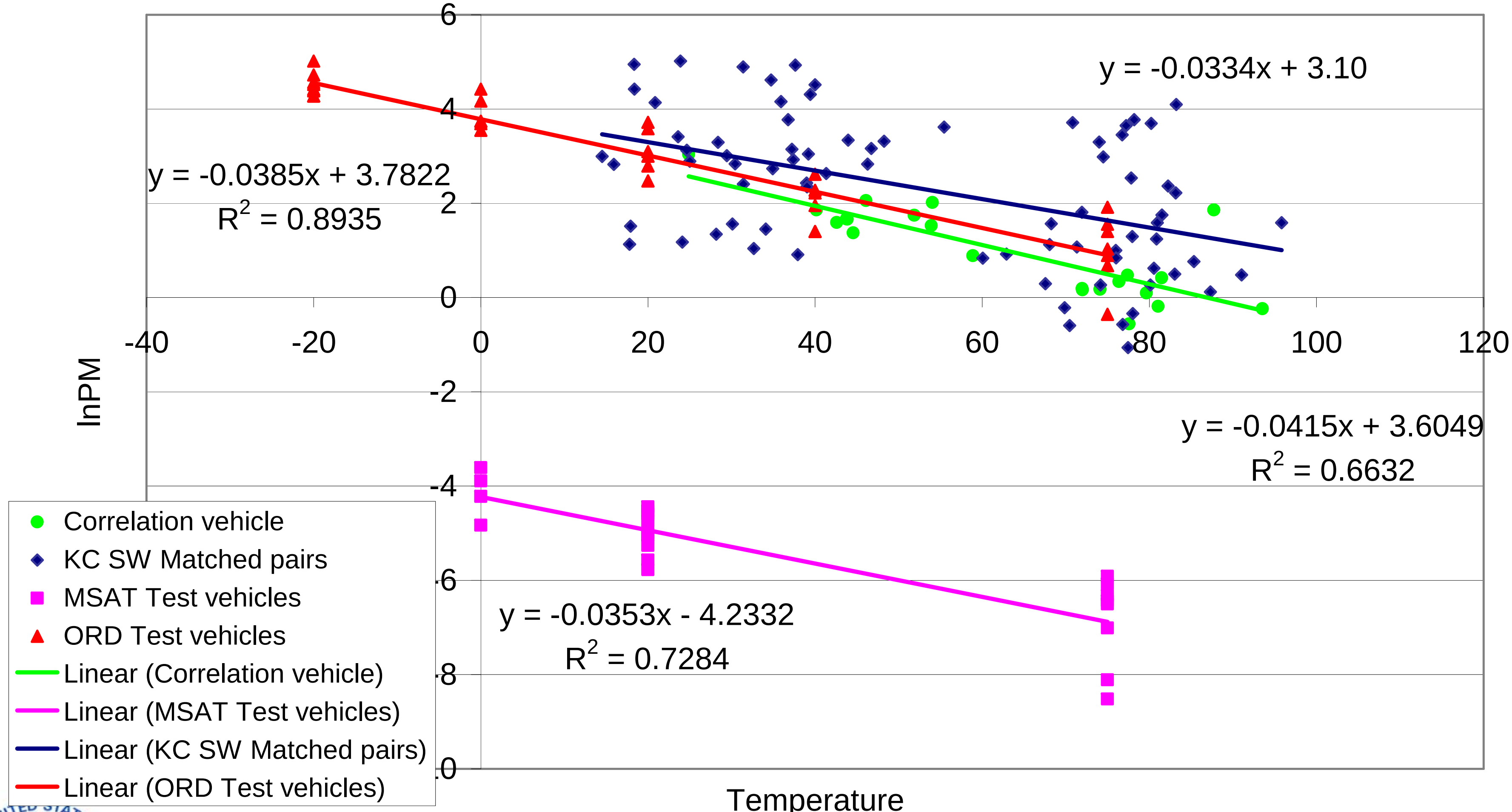
Scatter Plot of Winter Gravimetric PM 2.5 vs. Summer Gravimetric PM 2.5 – Composite (Logarithmic)
Results from vehicles tested in both summer and winter show higher emissions in winter for virtually every vehicle
10 times higher in winter
Winter Gravimetric PM 2.5 Emissions (mg/mile)
1000
100
10
1
0.1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

Variability & temperature effect from 33 matched pairs



- Test to test variability should average out with sufficient matched pair testing
- What remains is temperature effect

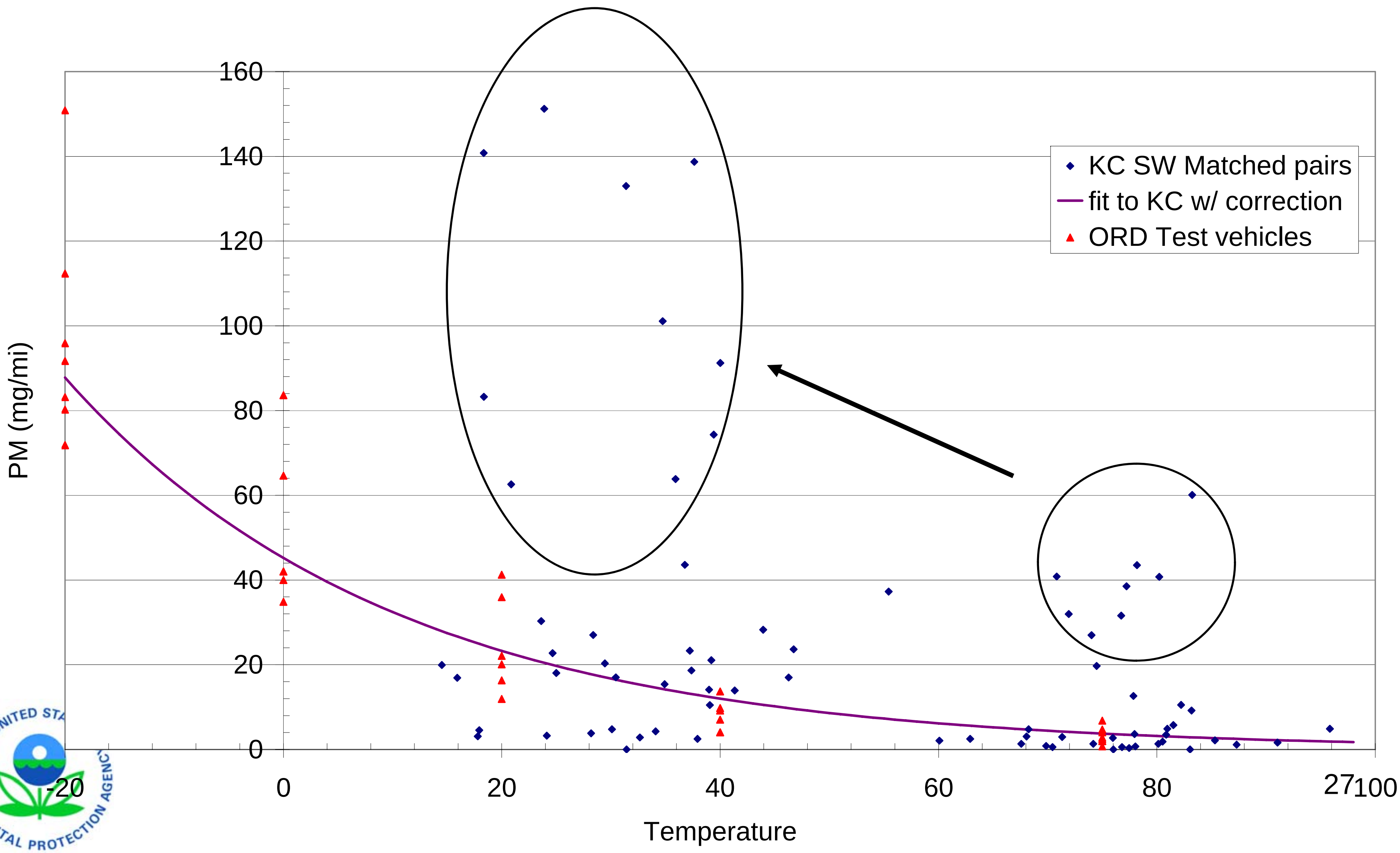
Comparison of Temperature Effects to Recent Studies



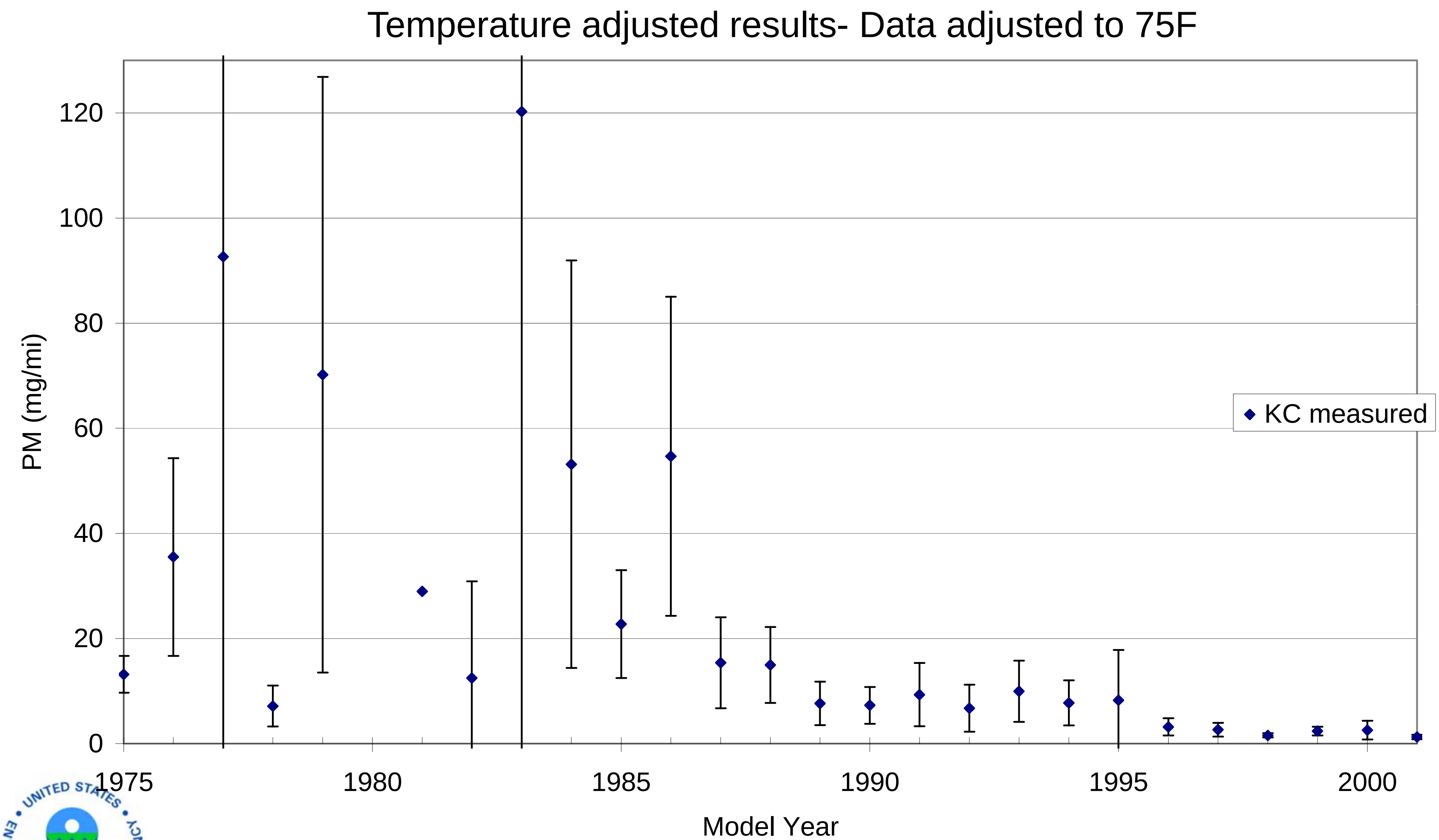
Kansas city PM emissions doubles per 20°F drop - This is fairly consistent with other studies

Temperature Effects

- PM increases exponentially as temperature decreases



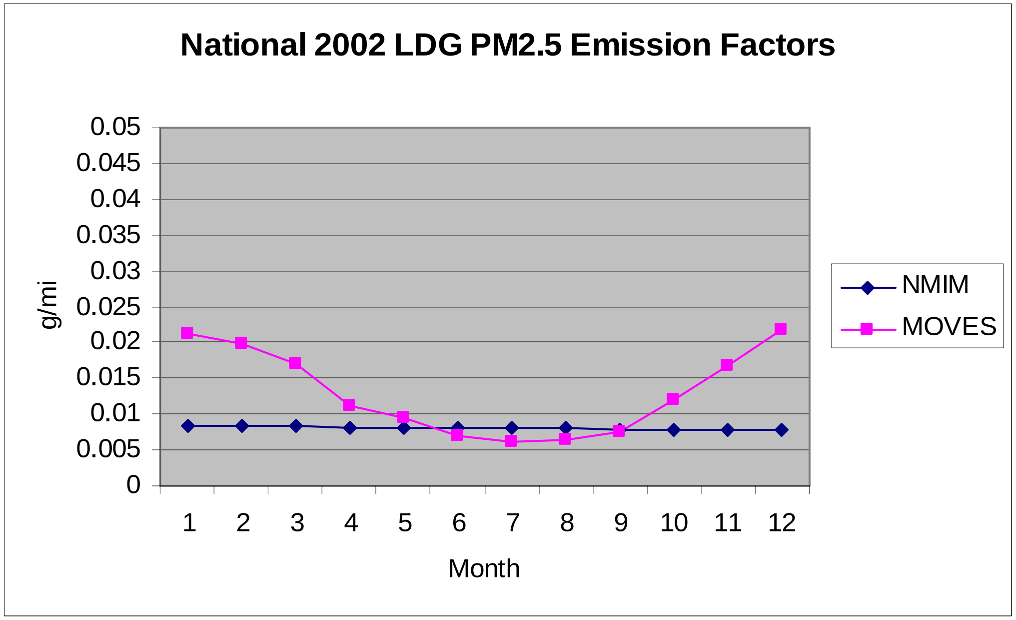
PM Rates at a Snapshot in Time



2002 KC Rates were put into MOVES & compared with MOBILE/NMIM

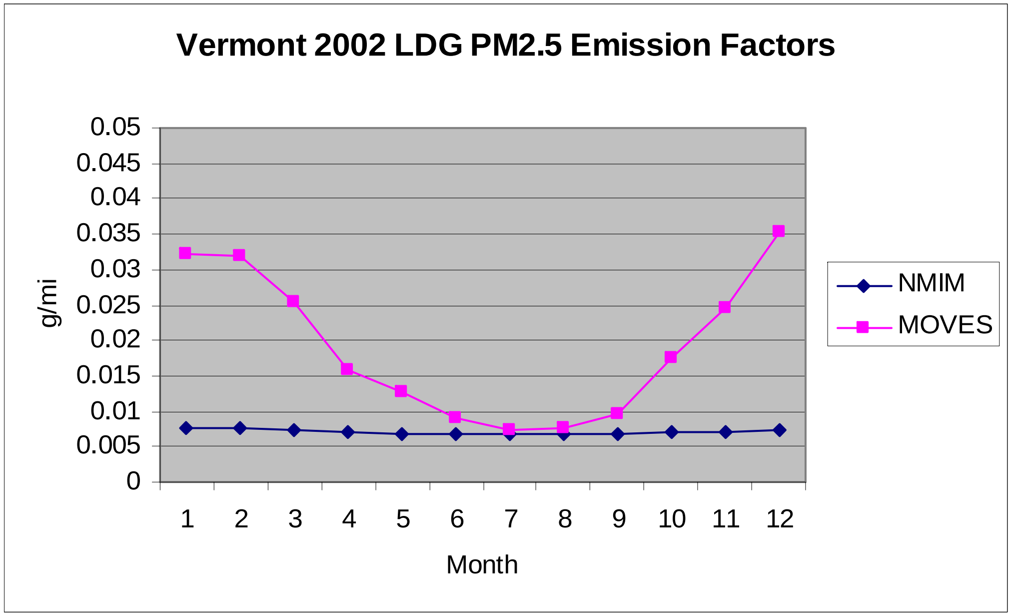
- This is a preliminary simple model (no modal rates, speed effects, deterioration rates, etc) and does not predict actual emission inventory effects
- Monthly runs for each state (aggregation level)
- Nationally, MOVES is about 1.6x higher than MOBILE/NMIM
  – But these will vary significantly by region

  * This is a preliminary comparison

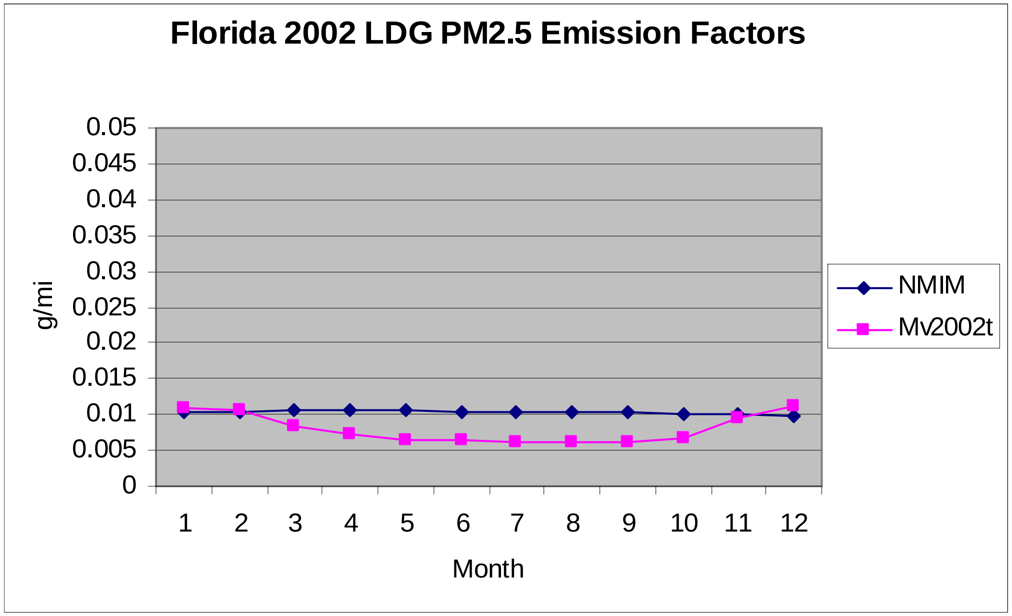


Regionally, there can be large differences especially in winter (examples)

- Vermont (2.61)



- Florida (0.76)



But what will these do in the future?

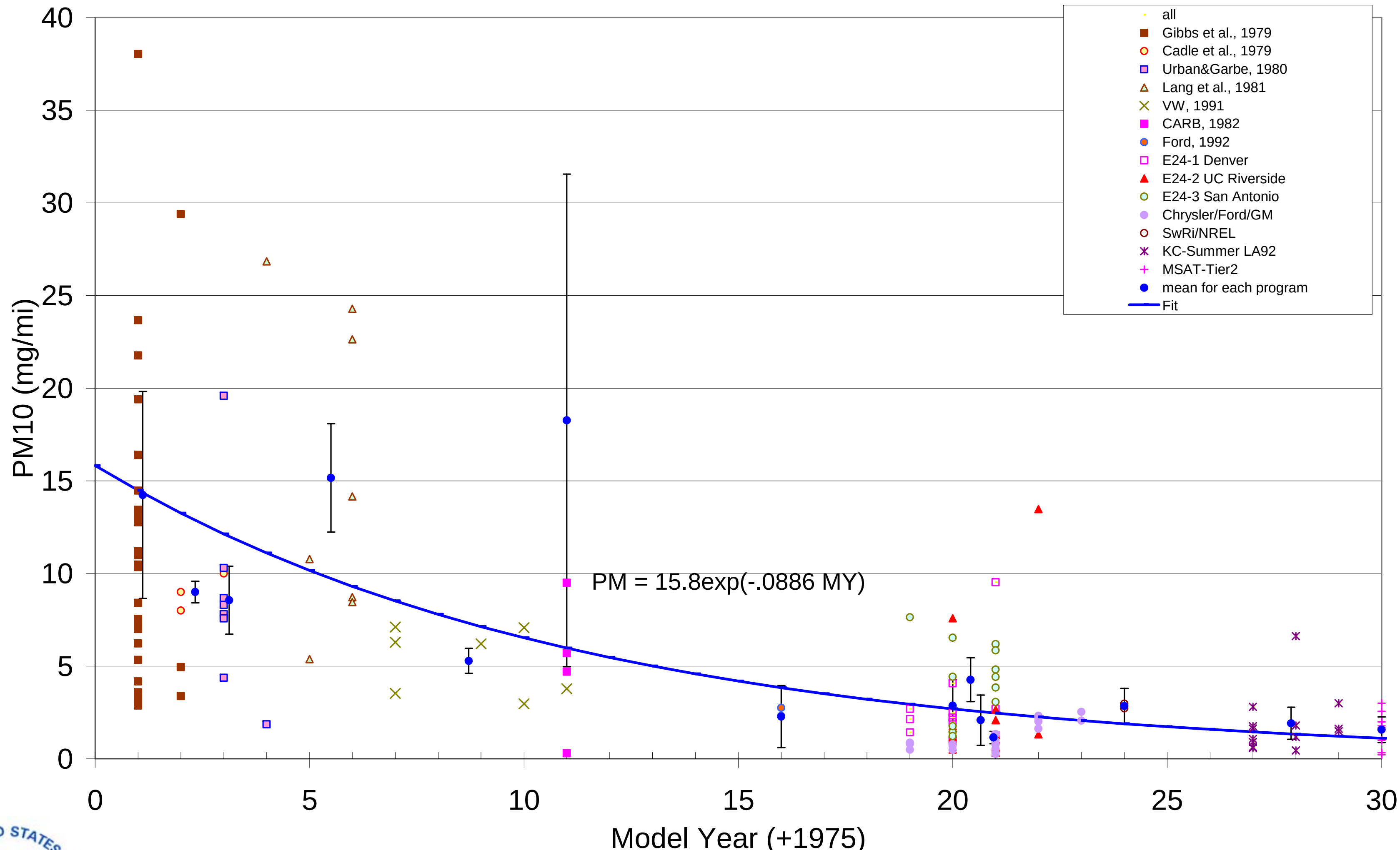
Deterioration Model

- Only way to definitely quantify deterioration is to conduct a large longitudinal study (none exist)
- Another option is to establish new car rates (ZML or Zero Mile Levels) based on past studies
- Then use KC as a guide for how PM may deteriorate to present levels
- Two potential models were explored
  - Additive
  - Multiplicative
  - Both are consistent with the data, but predict different inventories into the future

Deterioration Model

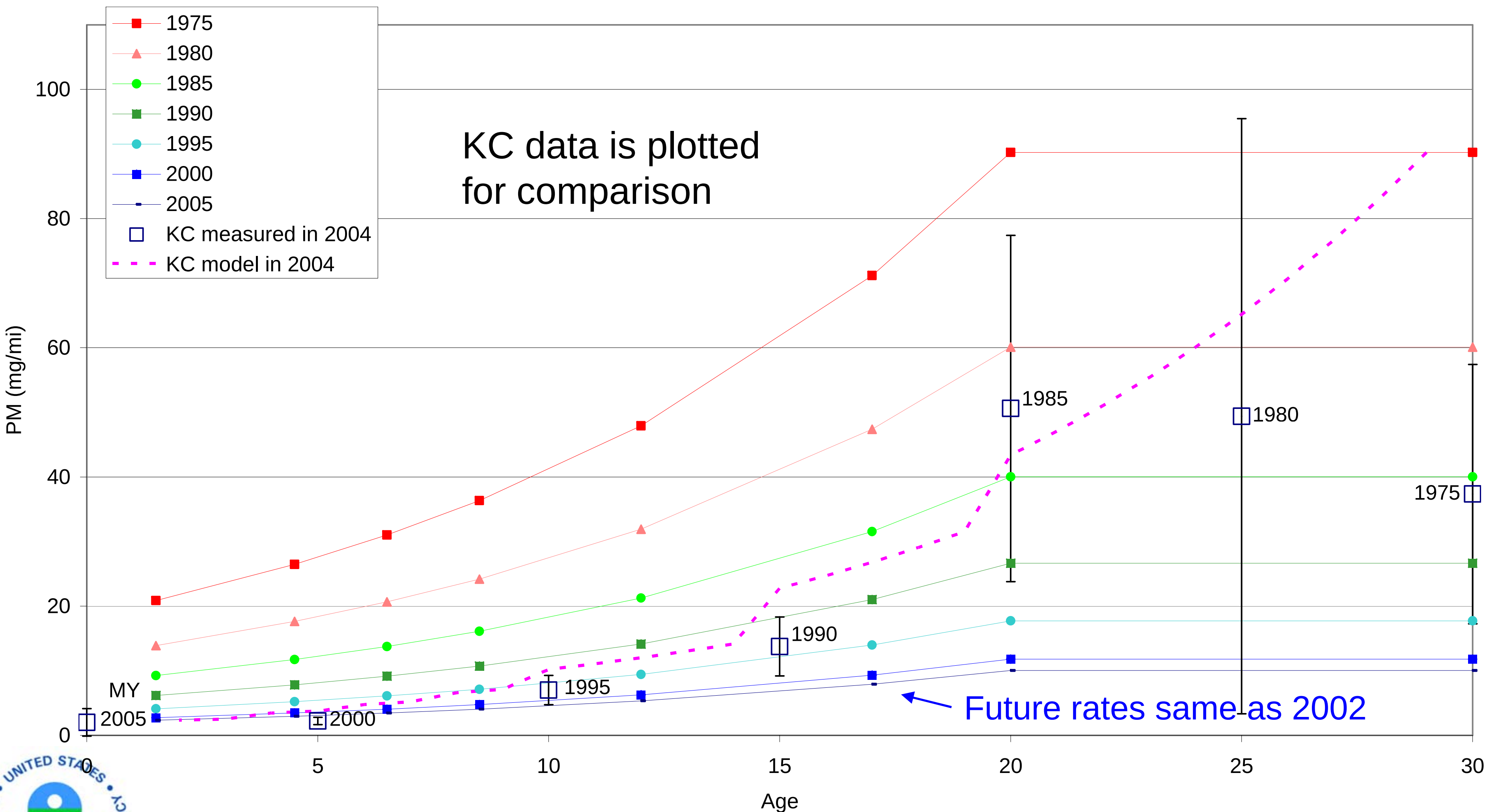
- We have chosen to use the multiplicative model for MOVES LD Gas PM for the following reasons:
  - It is more consistent with trends in HC
    - Fuel control deterioration
    - Aftertreatment deterioration
    - Longer useful life standards (120K vs 50K)
  - Oil consumption and burning may be less of a problem with newer technologies than older
- This implies that PM inventories from light duty gas are likely to decrease in the future compared to the new baseline

ZML: 15 Test Programs from 1979-2006 tested new vehicles



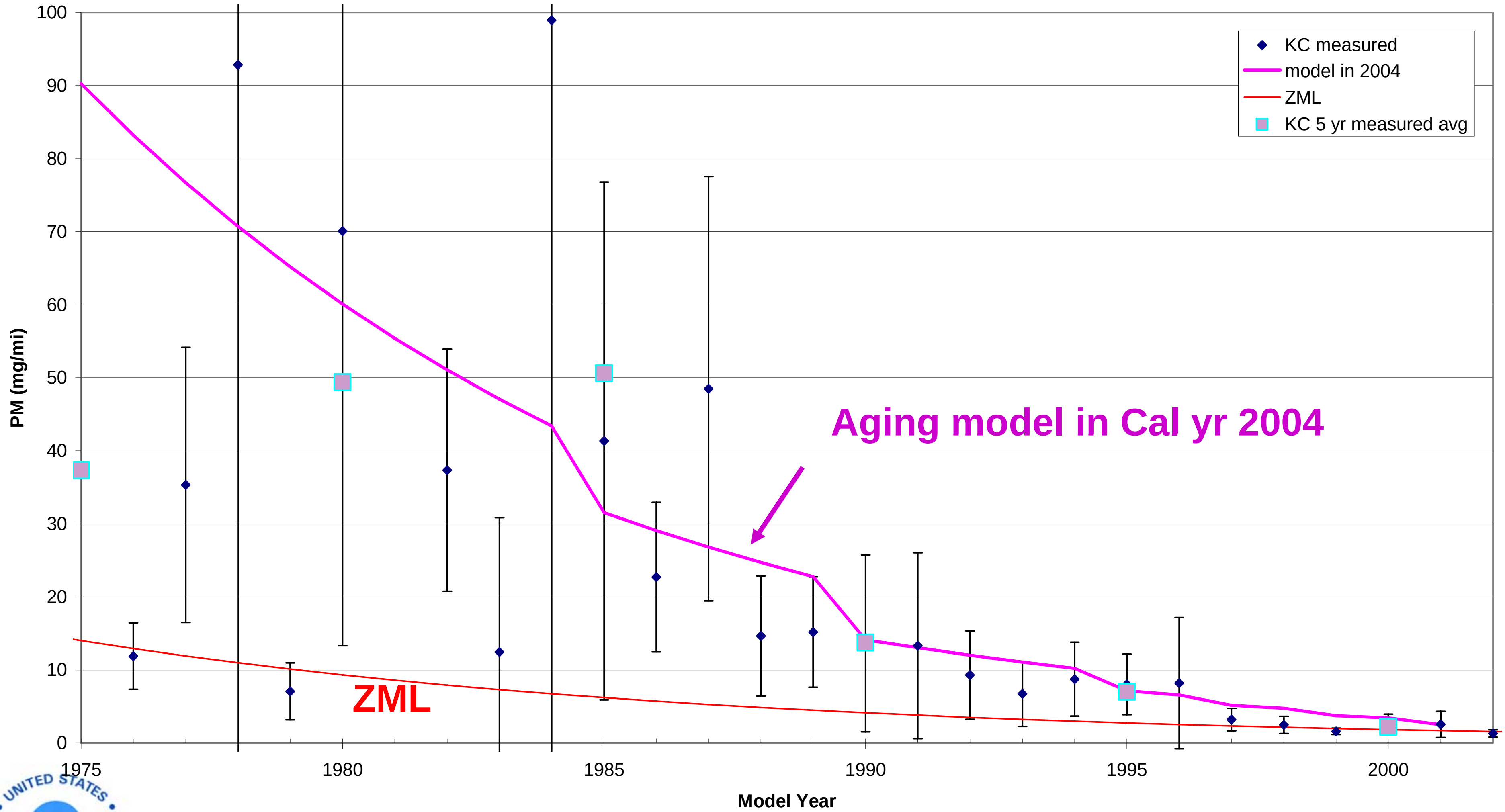
PM emissions from new cars have dropped by a factor of 10 in 30 years.
This is likely from: improved fuel control, & aftertreatment.

PM LDV ZML+ Deterioration



Future rates: there is no evidence in data that ZMLs continue to drop in Tier2+

Model compared to data in 2004



Conclusions

- Direct tailpipe PM emissions are are largely affected by:
  - ambient conditions (temperature)
  - vehicle type: model year/age of vehicle & car vs truck
- Modal analysis will help us understand PM formation, deterioration, and measurement
  - PM spikes in rich and cold start events
  - PM seems to increase exponentially with load
  - Organic PM humps emitted after storage, or possibly oil burning on some high emitters
  - Variability is a natural aspect of any PM testing program
- Comparing new vehicle rates with aged vehicle rates from KC, we present two deterioration models:
- Rates from KC data (without deterioration) were run with (a preliminary version of) MOVES and compared to MOBILE/NMIM. Direct tailpipe PM emissions in MOVES are about 1.6 times larger nationwide, but colder regions and climates have larger differences

Workgroup Comments

- Awaiting comments on 2nd PM presentation on deterioration and real-time PM
- First round of comments:
  - Most comments were detail oriented
  - There were two comments on the “conservative” assumptions made in the additive deterioration model.
    - Upon further analysis and research, the EPA is now seriously considering the multiplicative approach, which assumes lower deterioration rates for late model year vehicles than in the past.

Next steps & Issues for MSTRS

- Next Steps for MOVES
  - Determine modal rates
  - Finalize emission rates in MOVES for LD as well as heavy-duty
  - Compare the relative contribution of inventory from gas vs diesel (bottom up)
  - Quantify the fuel effects of ethanol on PM
  - PM Speciation
- Issues for MSTRS
  - Given time constraints of modeling needs
  - Issues related to deterioration model
  - Issues with any of the analysis approaches or measurements
  - Recommendations for further research? Partners?
    - High emitters, deterioration, measurement techniques, on-road emissions, oil burning, etc.

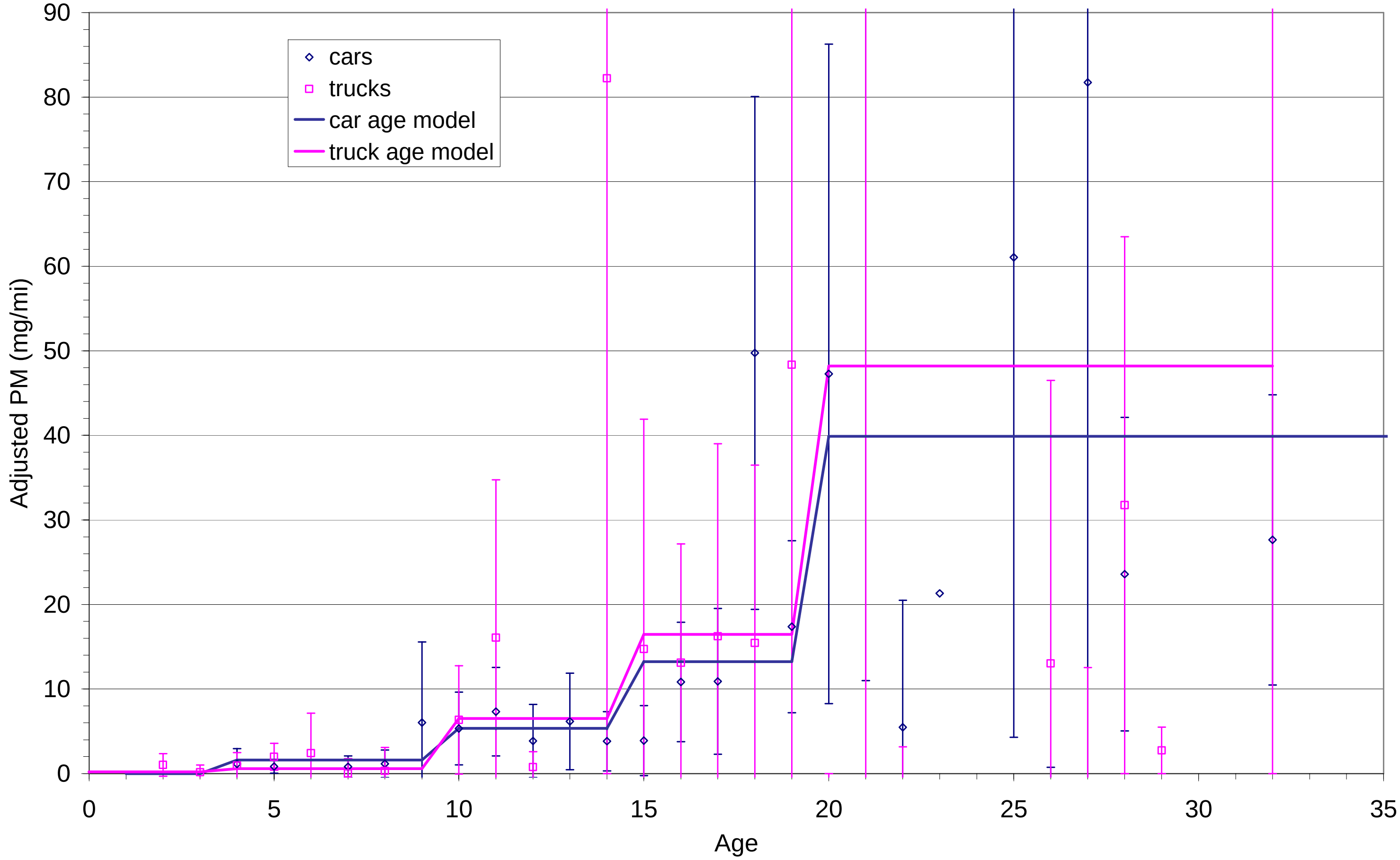
Appendix

What causes higher gasoline PM?

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

Option 1: Additive Deterioration model

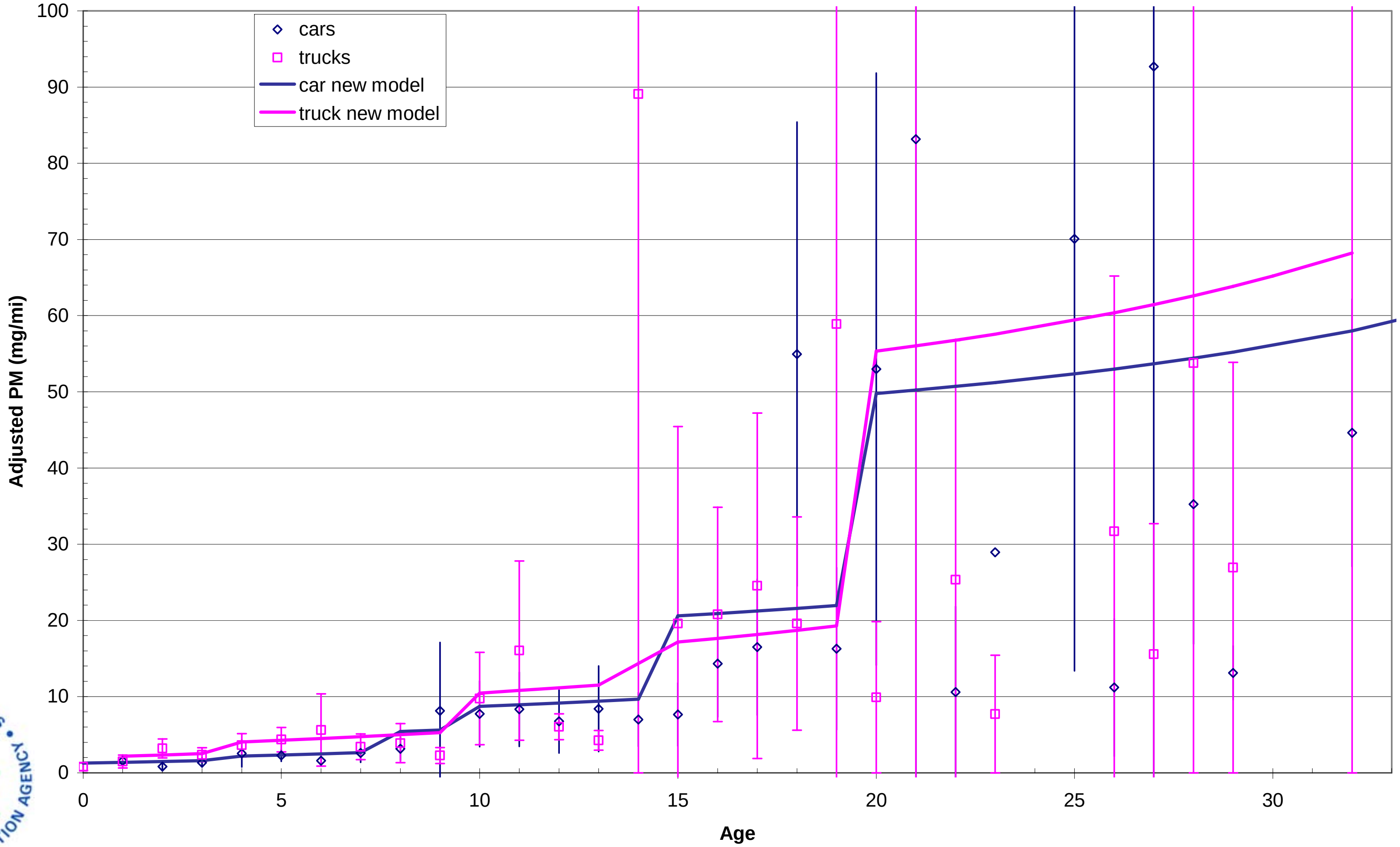
- The difference between the temperature adjusted Kansas City Results and the ZML (by age) is the remaining Age Effect in 2004



Steps originate from the MOVES binning structure

Additive model combined with ZML

- ZML trends account for ~20% of Emission Rate,
- Deterioration accounts for the rest



Additive Age Effect Comments

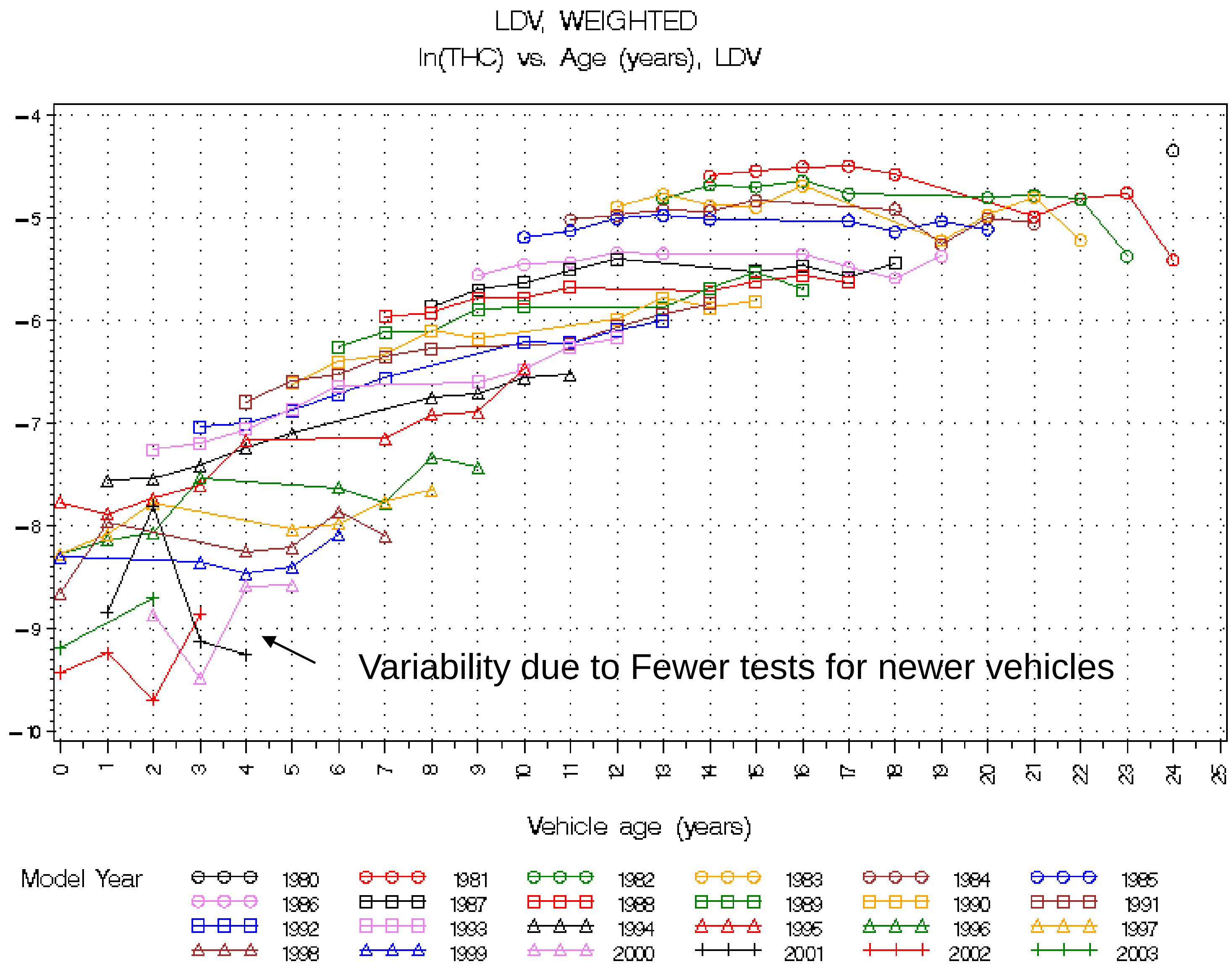
- Comparing ZML with Age:
  - There is very little deterioration for young vehicles (<9 yrs old)
- Additive model implies that 20 years from now today's vehicles will have their emissions increase from about 1.5 mg/mi to about 50 mg/mi
- Advantages:
  - More environmentally conservative estimate of future projections
  - Describes how PM from oil consumption deterioration may be the same now as it was in past (i.e. oil consumption for 10 yr old MY 2000 vehicle is same as 10 yr old MY 1980 vehicle)
  - Describes how tightly controlled newer vehicles have much more room for deterioration than older vehicles
  - Less sensitive to very low ZMLs
- Alternative model - multiplicative

Option 2: Multiplicative Deterioration Model

- A Multiplicative Deterioration model is easier analyzed in log-scale since the model is "additive in log-transformed space"
- We also rely on hydrocarbon trends to guide us (which seem largely multiplicative in deterioration)
- Multiplicative model assumes that newer technologies will last longer than the older ones

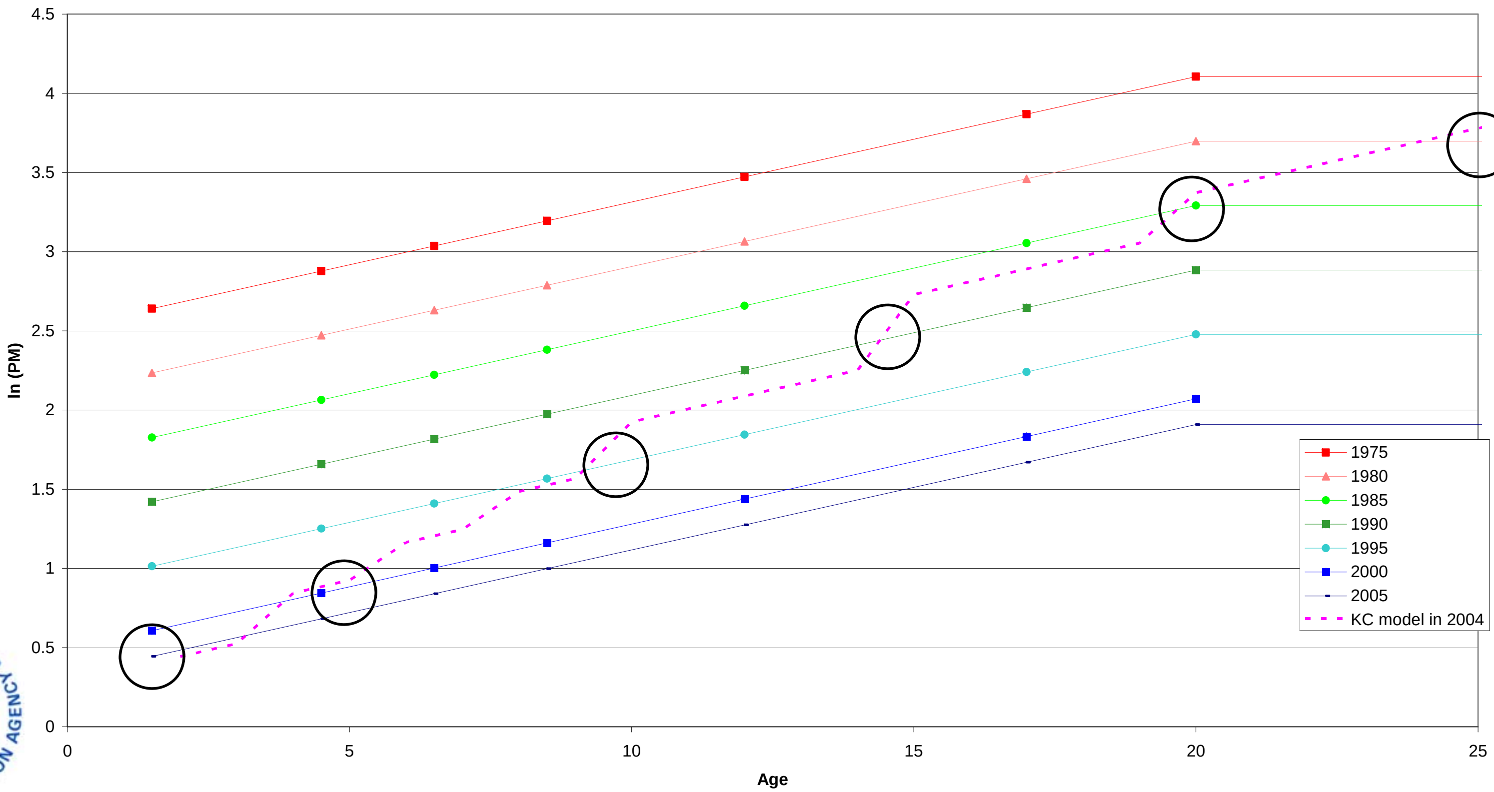
HC Deterioration from AZ, 2004

- Random tests (warmed up) at nominal temperatures
- Nearly 2000 LDGV tests
- Emissions average rates
- Parallel lines in log space
- ZMLs (Zero mile levels) offset from each other
- DFs level off in 10-14 age bin



PM log slopes from KC

- We expect log-transformed PM rates to follow similar "railroad tracks" (as HC)
- Level off at around 20 years (instead of 12)
- We assume future vehicles follow same trend



Model year groups

Multiplicative deterioration model comments

- Multiplicative model implies that 20 years from now today's vehicles will have their emissions increase from about 2 mg/mi to about 10 mg/mi
- Advantages:
  - Fuel control deterioration is likely a multiplicative Deterioration phenomenon
  - Statistically, H/C/N deterioration tends to be consistent with multiplicative approach
  - DFs should maintain HC/PM ratio over time (as observed in data)
- Disadvantage: Much more sensitive to low (and uncertain) ZMLs
- Multiplicative model tentatively planned for use in MOVES