Applying Real-World Heavy-Duty Emissions Data to Inform Inventory Development

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Background of EMFAC

- Vehicle Activity Updates
- Latest Emission Testing Data
- New Features
- New Forecasting Frameworks
- Latest Regulatory Measures

EMFAC

Mobile Source Strategy

Community Air Protection

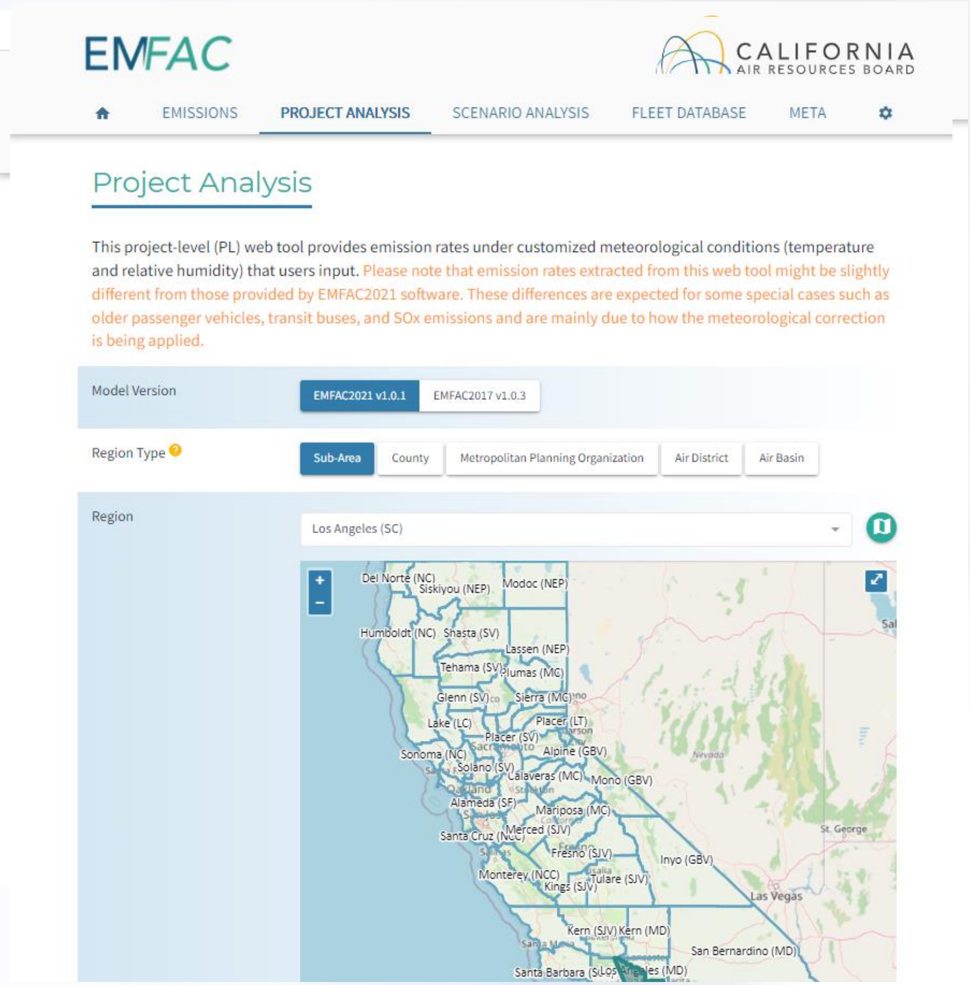
State Implementation Plans

Regulatory Development

Decades of EMFAC Evolvement

from humble beginnings…

https://arb.ca.gov/emfac/



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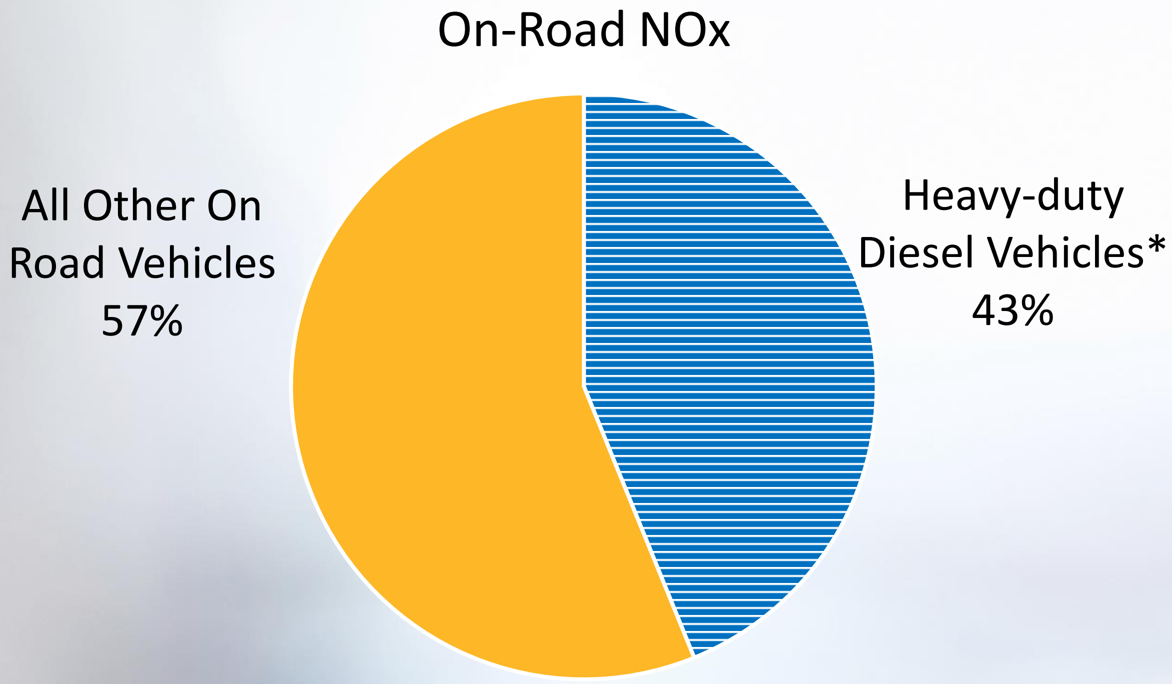
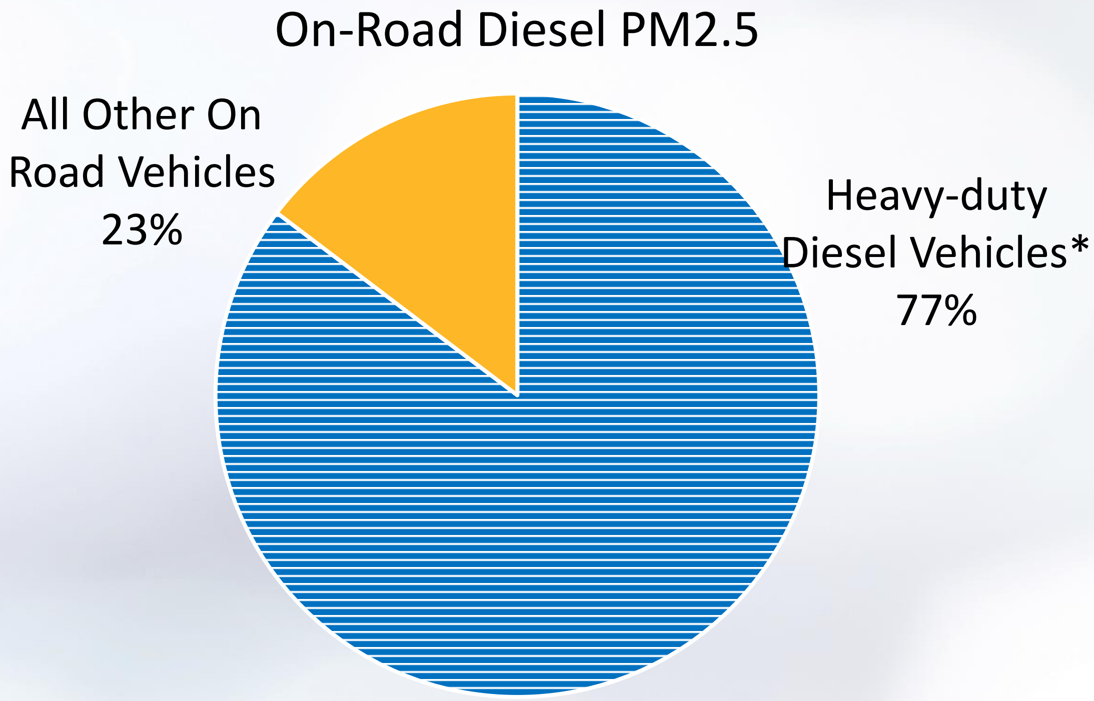
Heavy-Duty Diesel Vehicles Are a Major Contributor to Air Pollution in CA





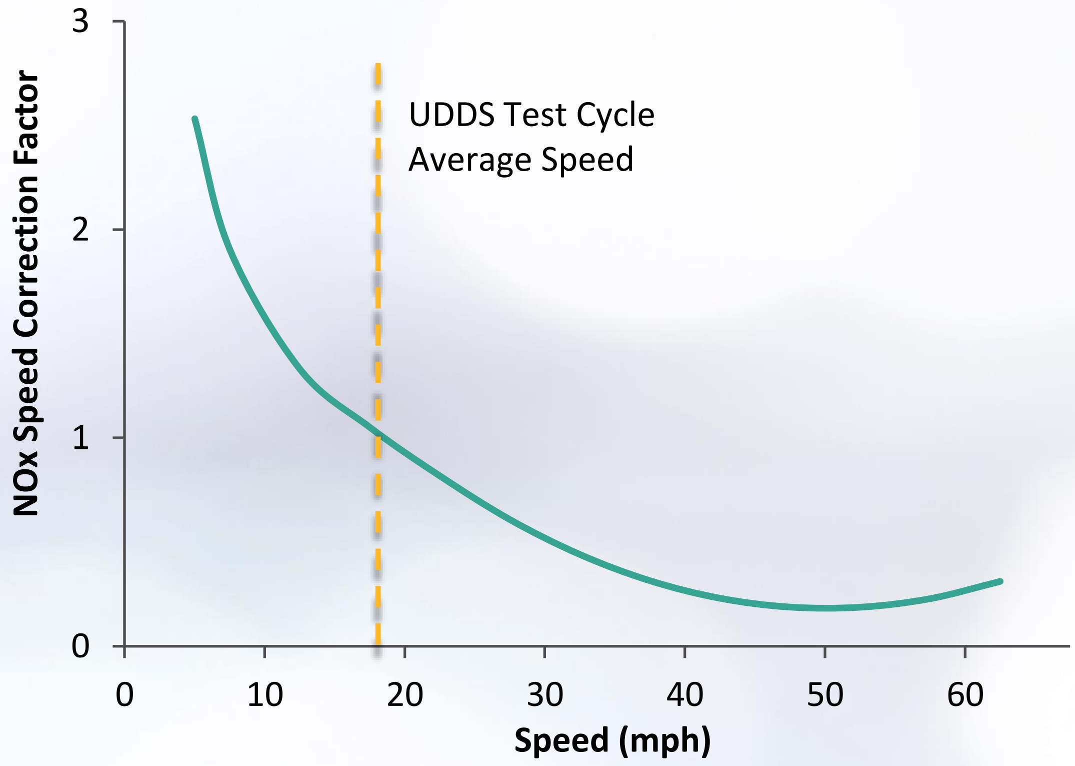
*Gross vehicle weight rating >14,000 lbs
Calendar Year 2023
(EMFAC2021)

Modeling Heavy-Duty (HD) Emission Rates in EMFAC

$$Emission\ Rate\ \left(\frac{g}{mile}\right) = BER \times SCF$$

- Base Emission Rates (BER) are developed for each Model Year group and weight class group (MHD/HHD).
- Speed correction factors (SCFs) account for variation of emissions under different vehicle speed.

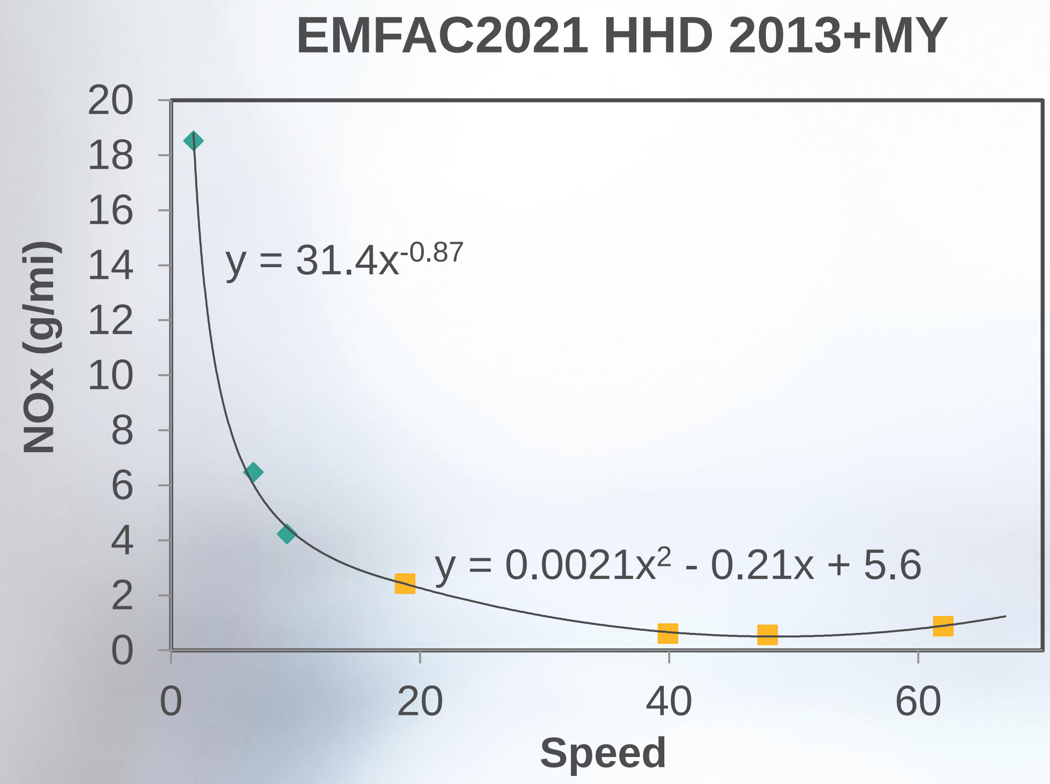
Typical SCFs of SCR*-equipped HD Vehicles



*SCR=Selective catalytic reduction

Heavy-duty Vehicle Speed Correction Factors (SCFs) Modeling in EMFAC

Current SCFs developed using Dyno data



- EMFAC2021
  - Used mostly lab dyno testing data for HD emission rates and SCFs
  - SCFs differentiated by weight class (MHD, HHD)
- Potential EMFAC202Y Improvements
  - More detailed SCFs by vocation and MY group
  - One step forward to transition emission data analysis from lab dyno testing toward PEMS based approaches

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Heavy-duty Portable Emissions Monitoring Systems (PEMS) Testing

New Riverside Lab

Heavy-duty Portable Emissions Monitoring Systems (PEMS) Testing

New Riverside Lab

Goal: to explore how PEMS can be used to better inform EMFAC HD emission rates

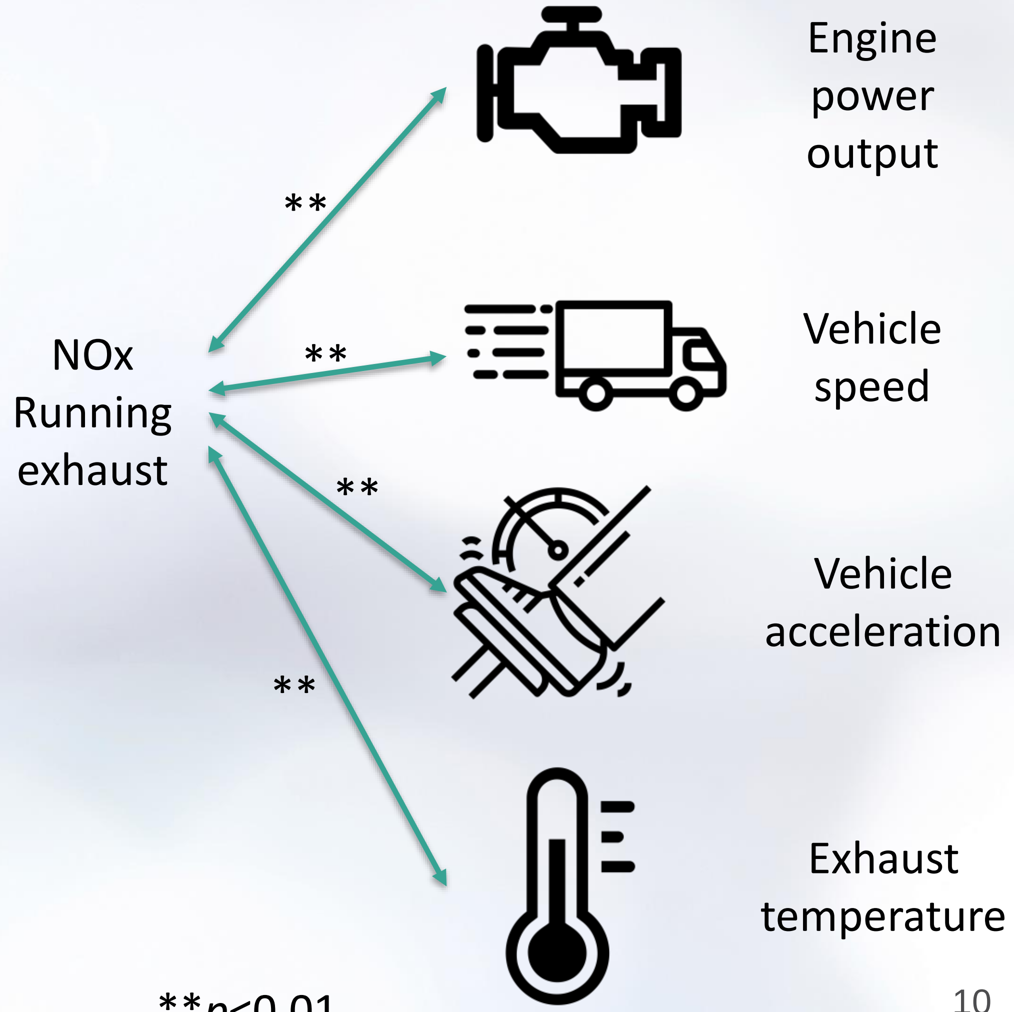
Data Source of HDIUT PEMS

- Heavy-Duty In-Use Testing (HDIUT): a manufacturer-run program reported PEMS testing to USEPA and CARB since 2005
- 776 vehicles from 19 manufacturers
  - 566 were used for analysis, the rest were filtered out for either ambiguous vehicle info or missing data
- Testing date range: 2006 – 2021
- Engine model year range: 2003 – 2017
- Data type: 1Hz
  - NOx (and other pollutants) emissions
  - Vehicle speed
  - Temperature (ambient, exhaust)
  - Engine status (RPM, torque)
- Data length: typically 1-2 days

Variables Correlated with Instantaneous NOx Emissions

PEMS Data
from 566 samples

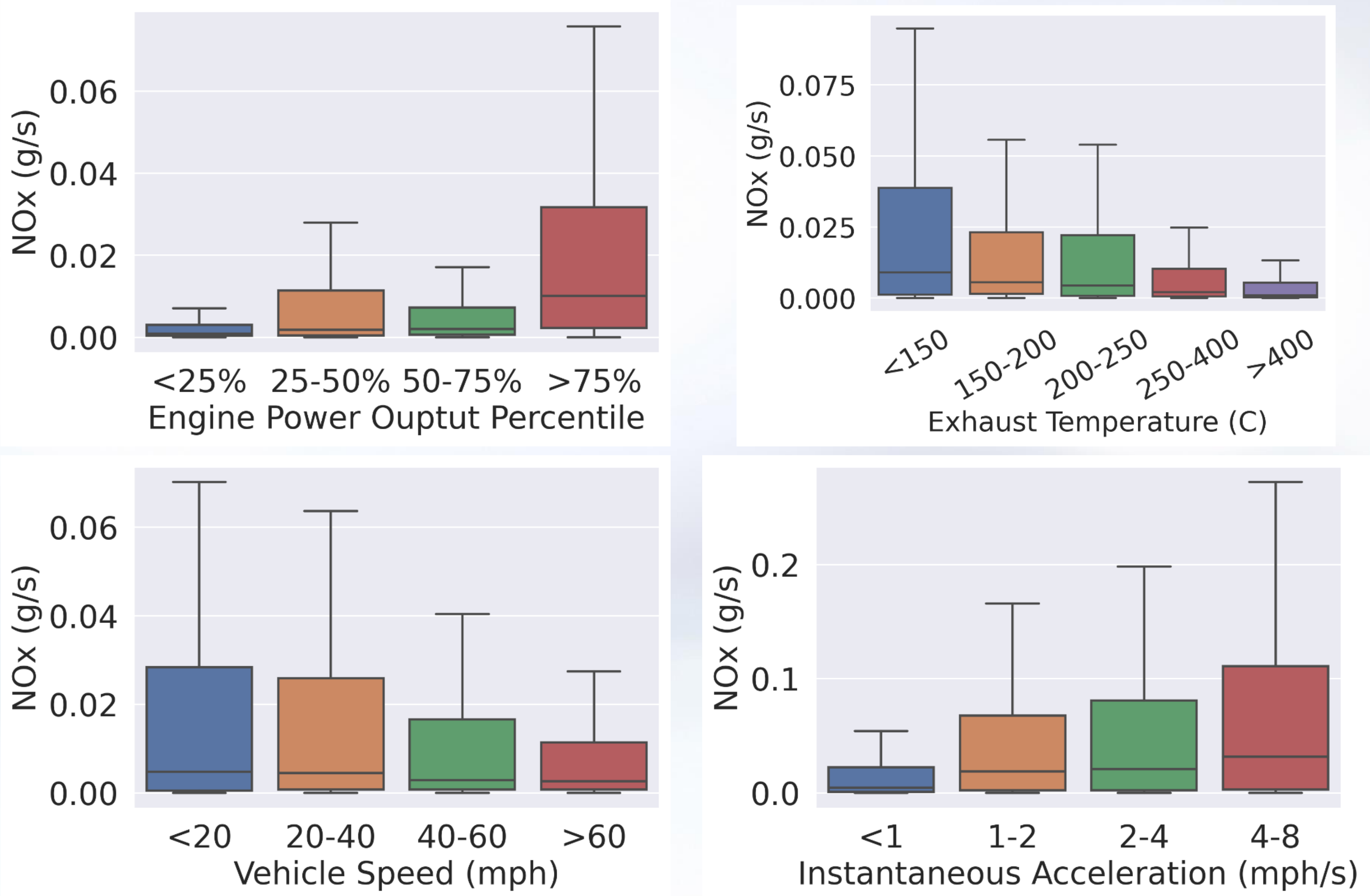
- Pre-2010 Model Year Class 4-7 Trucks
- 2010-2012 Model Year Class 4-7 Trucks
- 2013+ Model Year Class 4-7 Trucks
- Pre-2010 Model Year Class 8 Trucks
- 2010-2012 Model Year Class 8 Trucks
- 2013+ Model Year Class 8 Trucks



$^{**}p<0.01$

Variables Correlated with Instantaneous NOx Emissions

2013+ MY
Class 8 Trucks



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Multivariable Regression Experiments

$$\text{NOx}\,(g/s) = a \cdot \boldsymbol{HP} + b \cdot \boldsymbol{Speed} + c \cdot \boldsymbol{Acceleration} + d \cdot \boldsymbol{T_{exh}} + e$$

Subgroup	Pre-2010 MY Class 4-7	2010-2012 MY Class 4-7	2013+ MY Class 4-7	Pre-2010 MY Class 8	2010-2012 MY Class 8	2013+ MY Class 8
r^2	*0.58*	*0.20*	*0.08*	*0.50*	*0.17*	*0.14*

- Using linear regression, the four variables together can explain:
  - >50% of instantaneous NOx emissions for Pre-2010 Model Year trucks (no SCR equipped)
  - <20% of instantaneous NOx emissions for Post-2010 Model Year trucks (SCR equipped)

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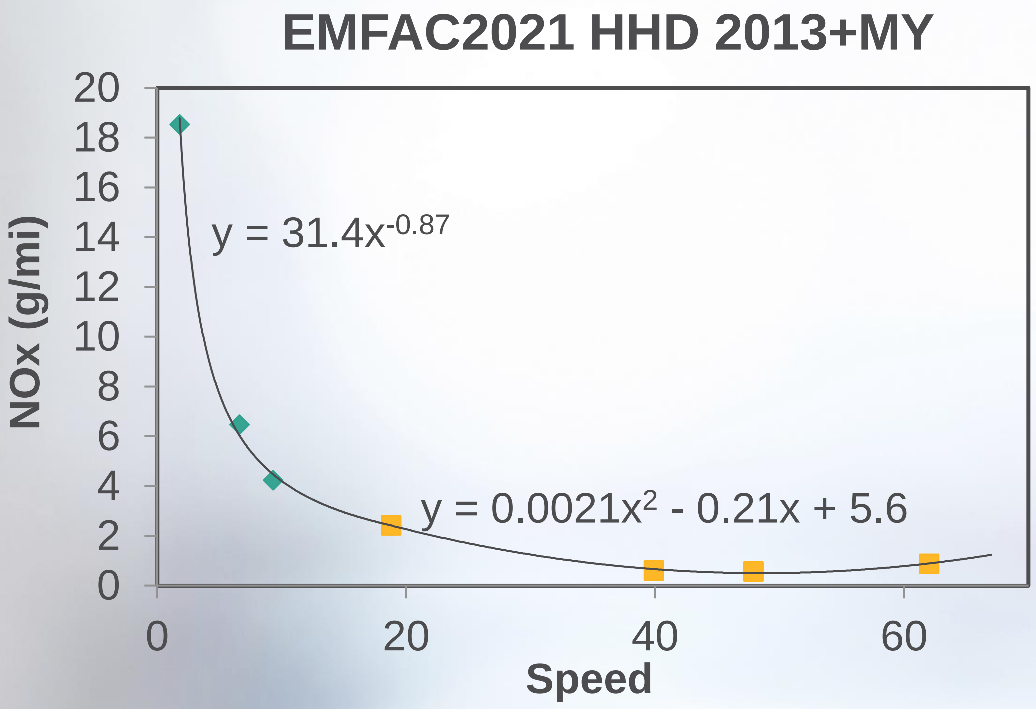
Informing Emission Rates by Speed using PEMS

Current SCFs Developed using Dyno data



Speed Bin Method

Local_Time	NOX_Mass_Sec_Final	Veh_Speed	Speed_Bins
183424	0.0375	6.773	10
183425	0.0419	8.987	10
183426	0.0361	10.693	15
183427	0.0346	12.076	15
183428	0.038	13.79	15
183429	0.0389	15.47	20
183430	0.0402	17.461	20

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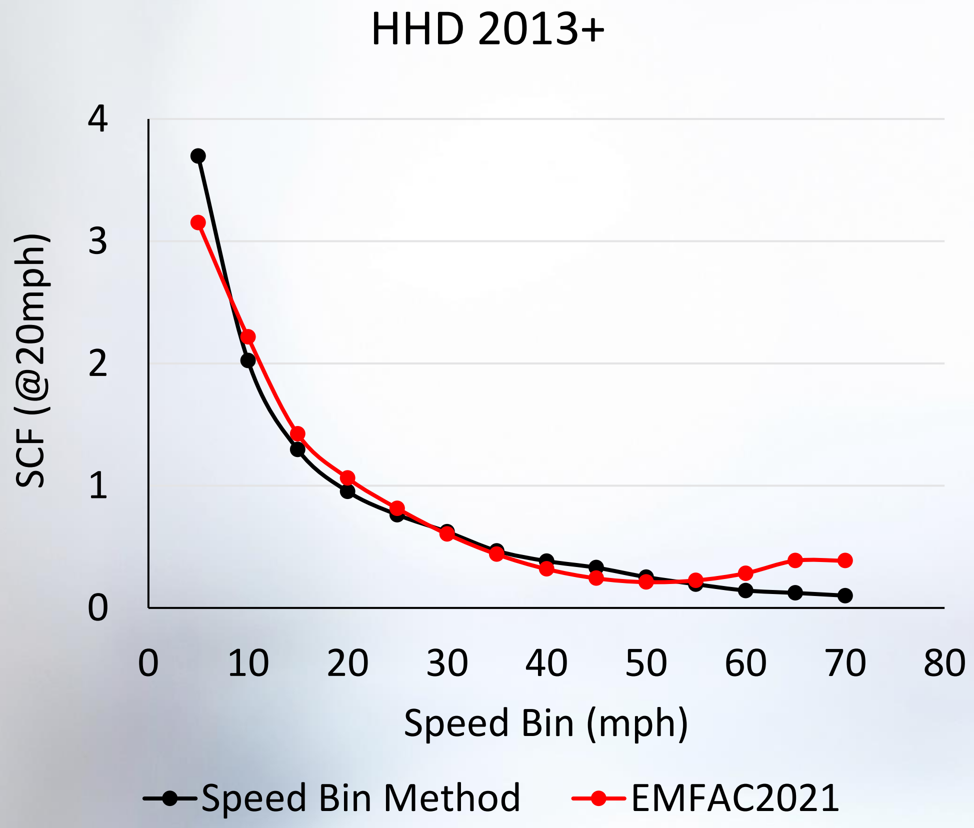
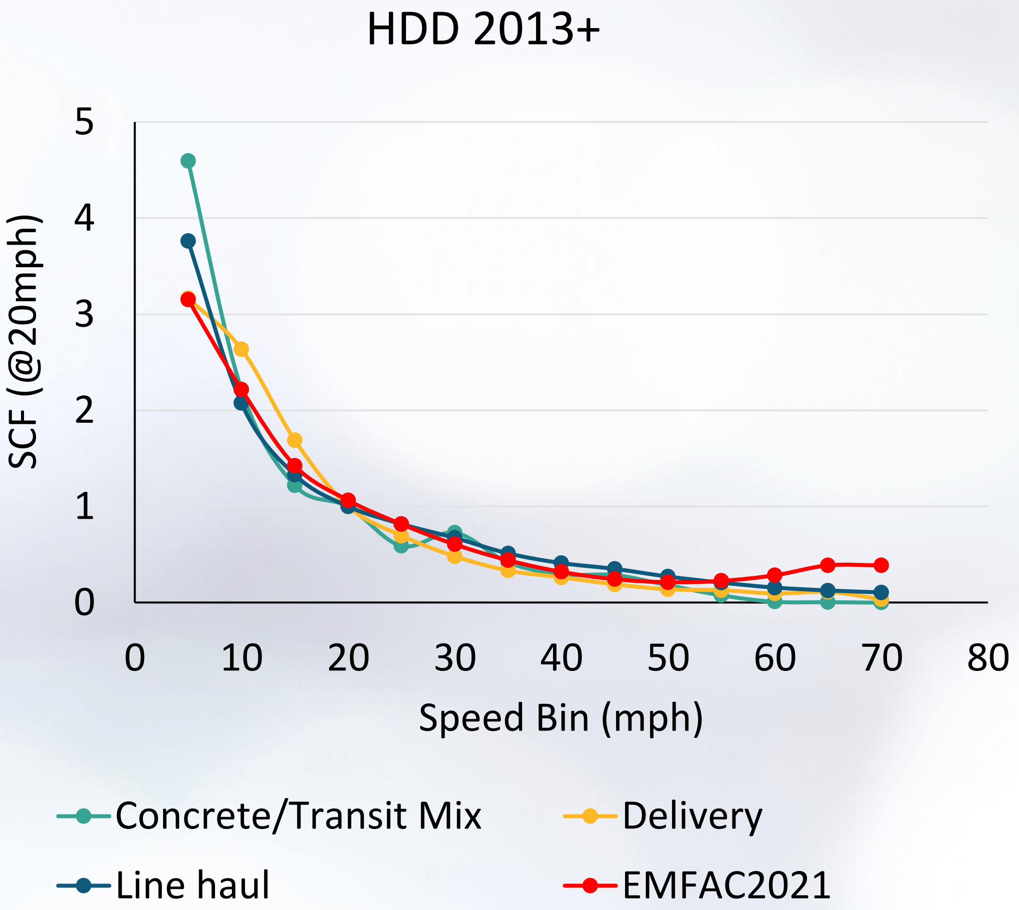
Speed Bin Method using PEMS



broken by vocations



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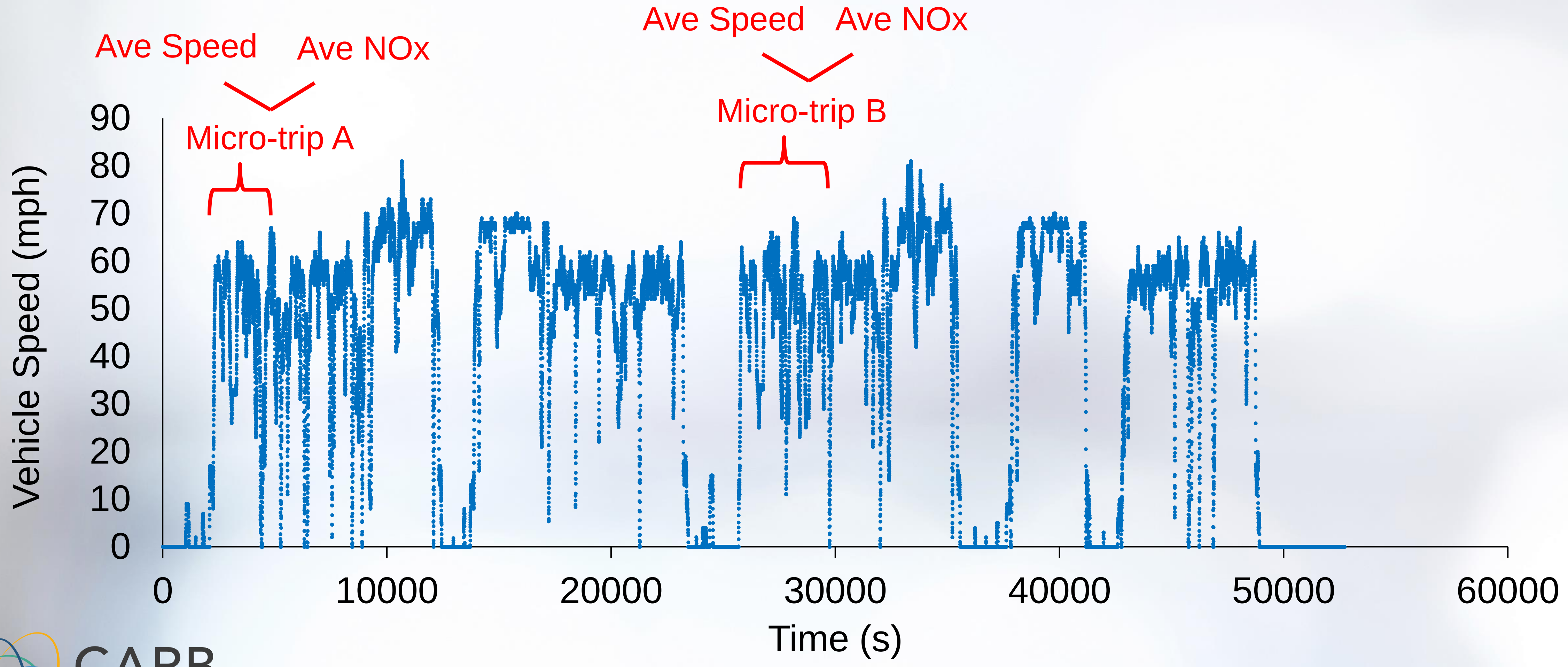
Micro-trip Method using PEMS



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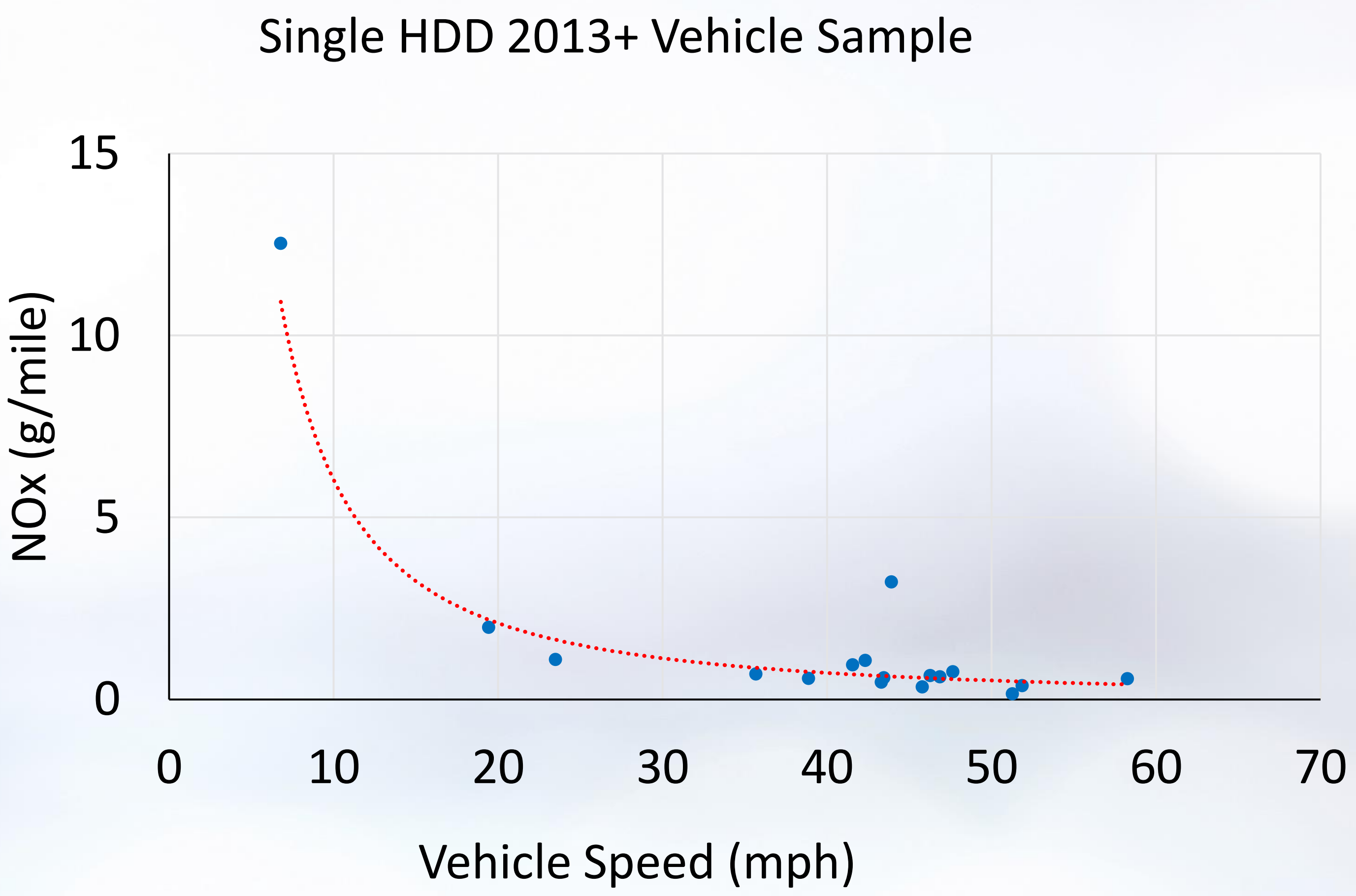
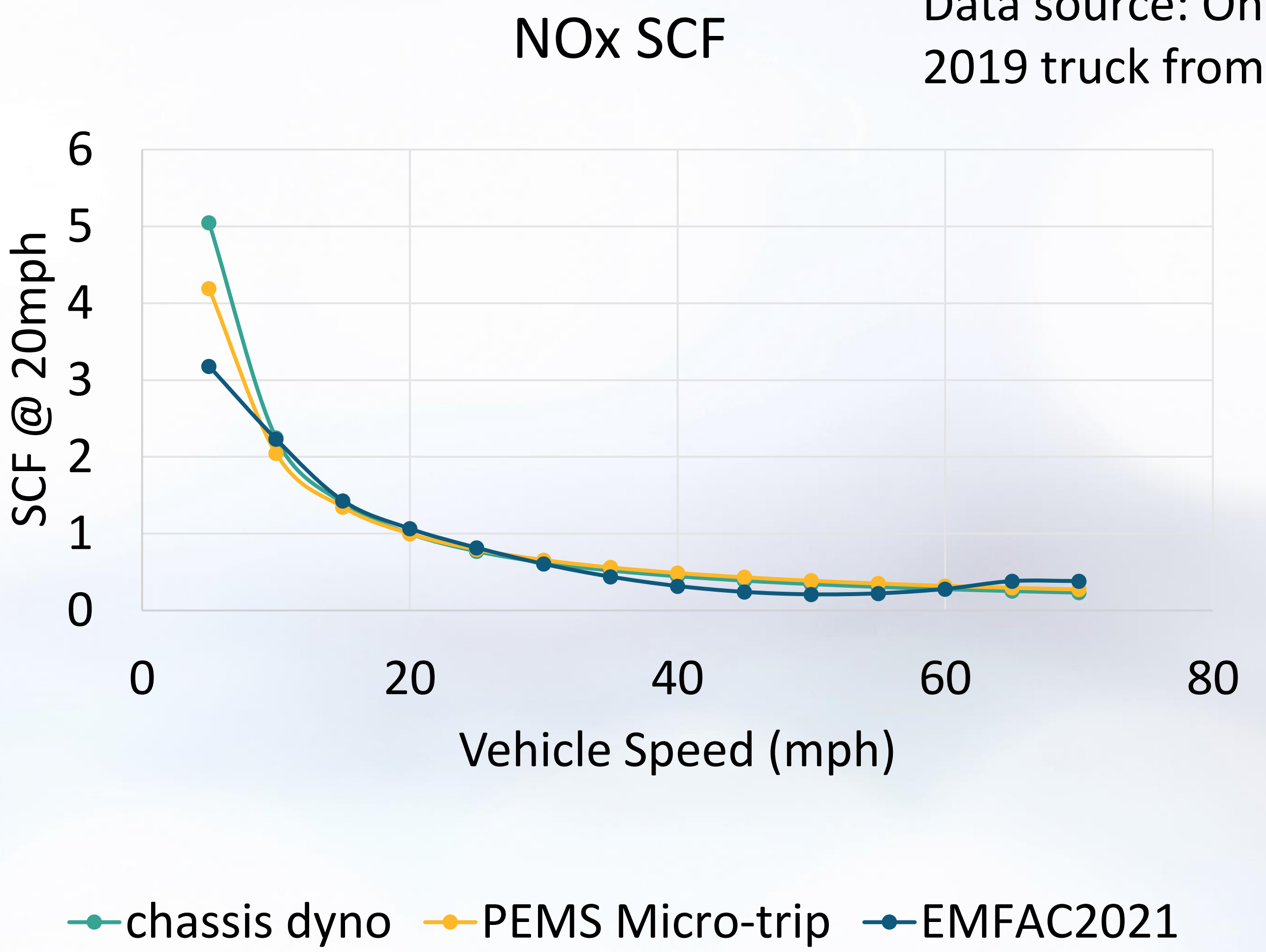
Micro-trip Method using PEMS



Comparing Micro-trip Method with Chassis Dyno Data



Data source: One sample HHD Engine MY 2019 truck from CARB TBSP*

*TBSP: Truck and Bus Surveillance Program

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Discussion of Micro-trip Method

- Need to refine micro-trip definition
  - e.g., min/max trip length, filter out idling
- Incorporate multiple PEMS routes' data (city, highway) to make SCF curve fitting more representative
- Increase vehicle sample size across weight and vocation categories

Summary

- **Engine power output (+)**, **vehicle speed (-)**, **vehicle acceleration (+)**, **exhaust temperature (-)** are correlated with instantaneous NOx emissions, across all engine MY and weight class groups in HDIUT dataset.
- Using micro-trip method to analyze PEMS can give similar speed correction factors as using chassis dynamometer data, while providing larger sample size and higher vocation resolution.

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Next steps

- Evaluate and apply the two new methods to develop SCFs for EMFAC202Y.
- Keep using chassis dyno data to develop HD base emission rates, with continuing efforts of comparing emission rates derived from PEMS and dyno.
- Acquire more PEMS data through CARB internal testing programs and extramural contracts for further analysis

Thank You!

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Multivariable Regression Experiments

Pre-2010 MY Class 4-7 Trucks	$\mathbf{r^2 = 0.58}$ $\text{NOx}\ (g/s) = 5.74 \times 10^{-4}\ HP - 1.59 \times 10^{-6}\ Speed + 1.22 \times 10^{-9}\ Acc - 2.43 \times 10^{-5}\ T_{exh}$
2010-2012 MY Class 4-7 Trucks	$\mathbf{r^2 = 0.20}$ $\text{NOx}\ (g/s) = 1.12 \times 10^{-4}\ HP - 5.98 \times 10^{-5}\ Speed + 1.59 \times 10^{-3}\ Acc - 1.8 \times 10^{-5}\ T_{exh}$
2013+ MY Class 4-7 Trucks	$\mathbf{r^2 = 0.08}$ $\text{NOx}\ (g/s) = 5.61 \times 10^{-5}\ HP - 6.91 \times 10^{-5}\ Speed + 1.29 \times 10^{-3}\ Acc - 9.48 \times 10^{-6}\ T_{exh}$
Pre-2010 MY Class 8 Trucks	$\mathbf{r^2 = 0.50}$ $\text{NOx}\ (g/s) = 5.05 \times 10^{-4}\ HP - 2.23 \times 10^{-4}\ Speed + 2.03 \times 10^{-3}\ Acc - 7.52 \times 10^{-5}\ T_{exh}$
2010-2012 MY Class 8 Trucks	$\mathbf{r^2 = 0.17}$ $\text{NOx}\ (g/s) = 9.7 \times 10^{-5}\ HP - 1.85 \times 10^{-5}\ Speed + 1.25 \times 10^{-2}\ Acc - 1.94 \times 10^{-5}\ T_{exh}$
2013+ MY Class 8 Trucks	$\mathbf{r^2 = 0.14}$ $\text{NOx}\ (g/s) = 8.68 \times 10^{-5}\ HP - 2.13 \times 10^{-4}\ Speed + 3.79 \times 10^{-3}\ Acc - 2.82 \times 10^{-5}\ T_{exh}$

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Multivariable Regression Experiments

$$\text{NOx}\ (g/s) = \boldsymbol{A} \cdot HP + \boldsymbol{B} \cdot Speed + \boldsymbol{C} \cdot Acceleration + \boldsymbol{D} \cdot T_{exh}$$

Subgroup	*A*	*B*	*C*	*D*	r^2
Pre-2010 MY Class 4-7	5.74×10^{-4}	-1.59×10^{-6}	1.22×10^{-9}	-2.43×10^{-5}	*0.58*
2010-2012 MY Class 4-7	1.12×10^{-4}	-5.98×10^{-5}	1.59×10^{-3}	-1.8×10^{-5}	*0.20*
2013+ MY Class 4-7	5.61×10^{-5}	-6.91×10^{-5}	1.29×10^{-3}	-9.48×10^{-6}	*0.08*
Pre-2010 MY Class 8	5.05×10^{-4}	-2.23×10^{-4}	2.03×10^{-3}	-7.52×10^{-5}	*0.50*
2010-2012 MY Class 8	9.7×10^{-5}	-1.85×10^{-5}	1.25×10^{-2}	-1.94×10^{-5}	*0.17*
2013+ MY Class 8	8.68×10^{-5}	-2.13×10^{-4}	3.79×10^{-3}	-2.82×10^{-5}	*0.14*

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Multivariable Regression Experiments

2013+ MY
Class 8 Trucks

$$\text{NOx}\ (g/s) = A \cdot HP + B \cdot Speed + C \cdot Accelaration + D \cdot T_{exh}$$

	A	*B*	*C*	*D*	r^2
Regular Linear Regression	8.68×10^{-5}	-2.13×10^{-4}	3.79×10^{-3}	-2.82×10^{-5}	*0.14*
Simple Moving Average Regression	4.84×10^{-5}	-1.19×10^{-4}	3.03×10^{-2}	-2.23×10^{-5}	*0.06*
Exponentially Weighted Moving Average Regression	7.95×10^{-5}	-1.97×10^{-4}	3.53×10^{-2}	-2.34×10^{-5}	*0.09*

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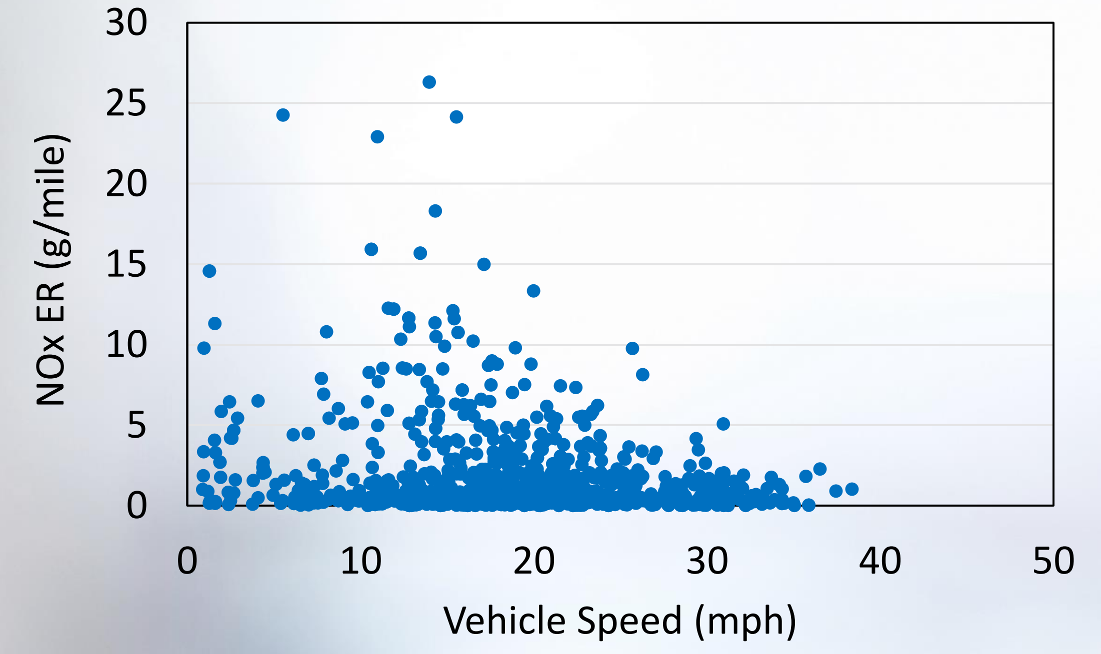
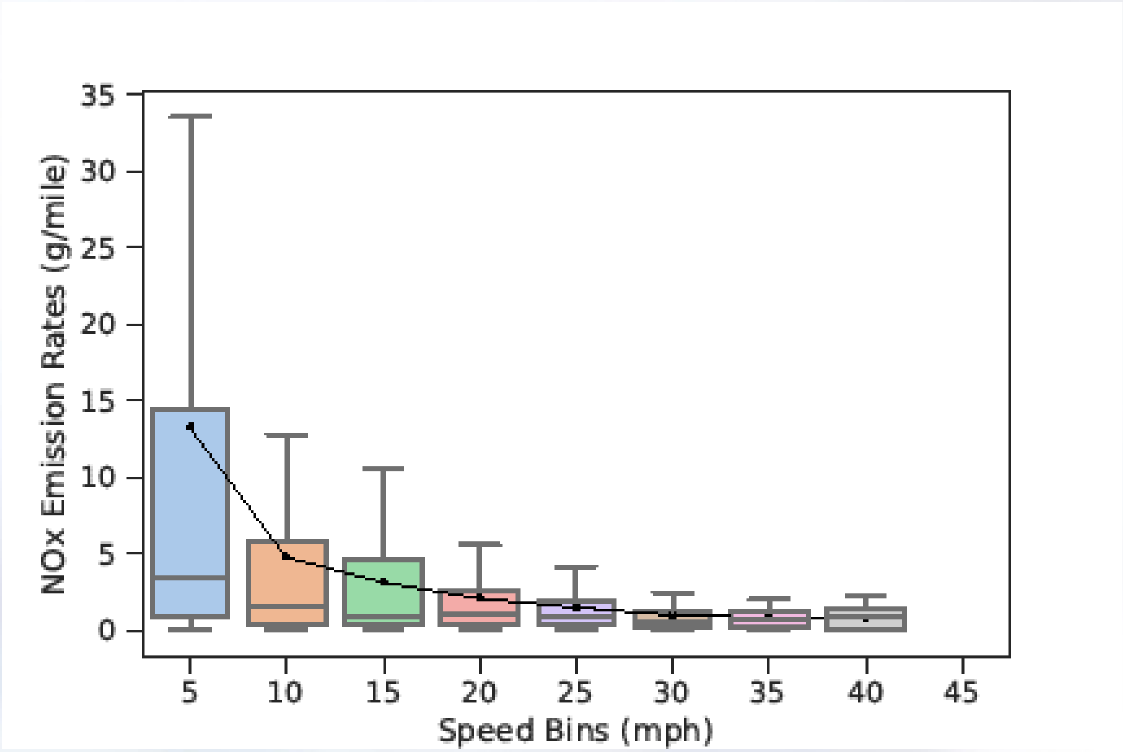
Micro-trip Method using PEMS





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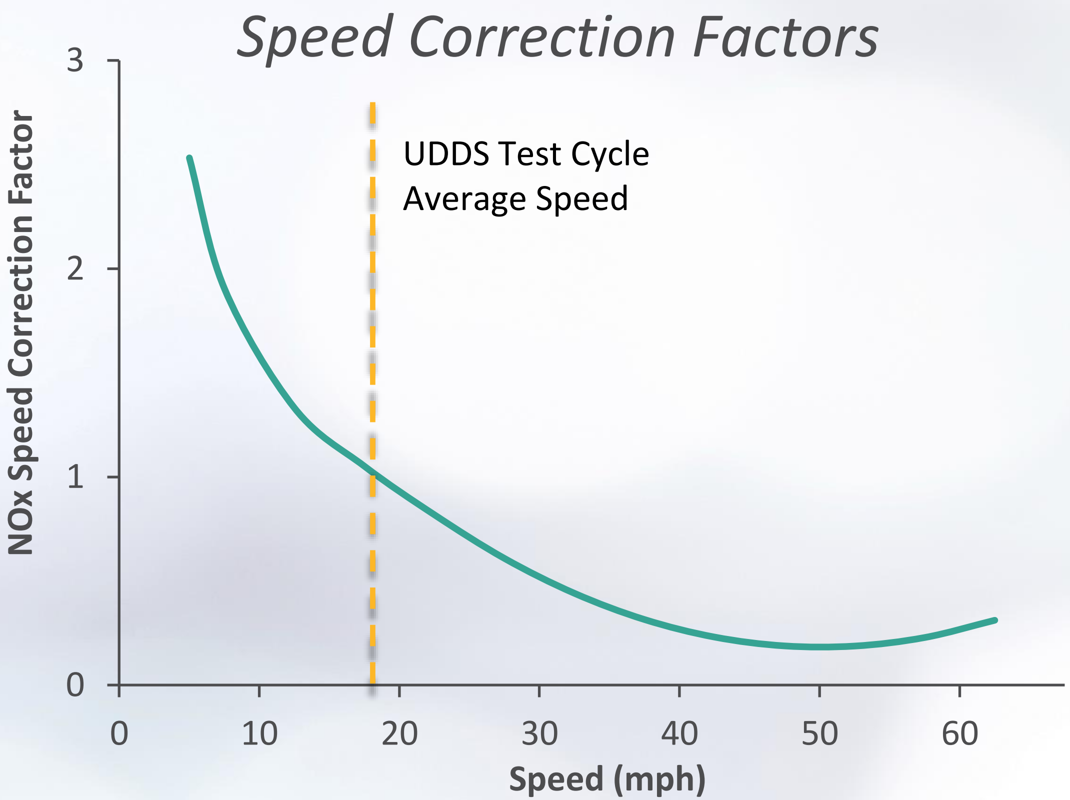
Modeling Heavy-Duty (HD) Emission Rates in EMFAC

$$Emission\ Rate\ (\frac{g}{mile}) = (ZMR + DR \times Odometer) \times SCF$$

Increasing percentage of high-emitting (up to 12X ZMR) vehicles w/ emissions after-treatment malfunction as the fleet ages → larger fleet-average emission rate



Speed correction factors (SCFs) account for variation of emissions for SCR*-equipped vehicles under different operating conditions (e.g., low load)

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*SCR=Selective catalytic reduction