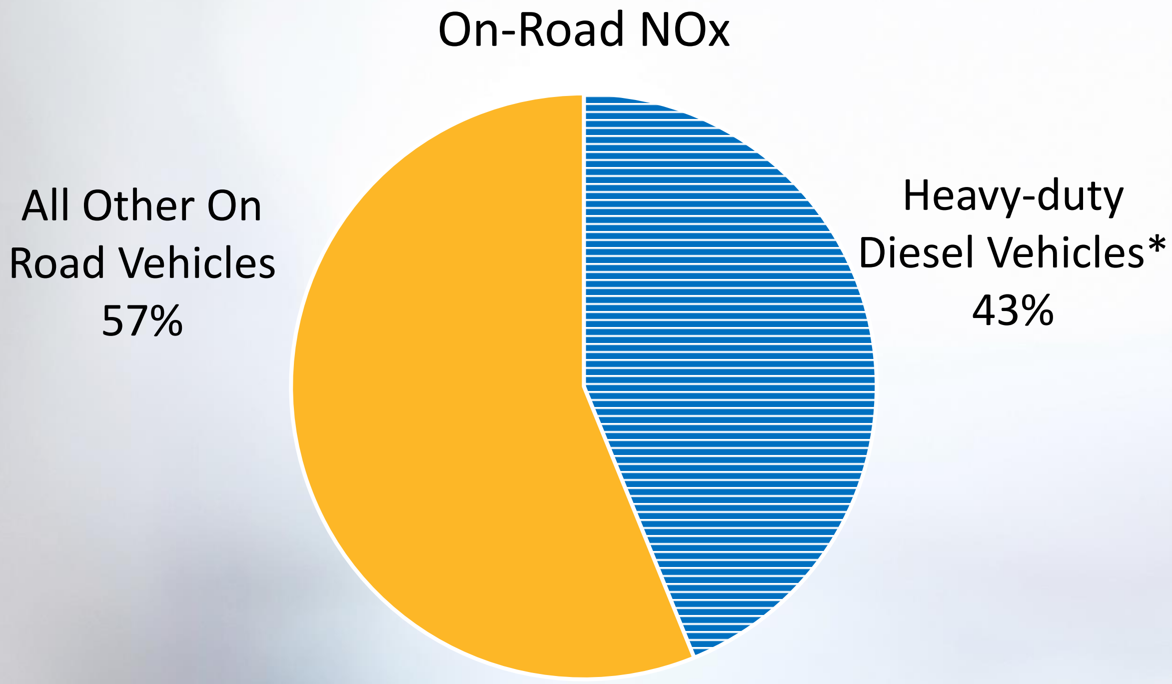
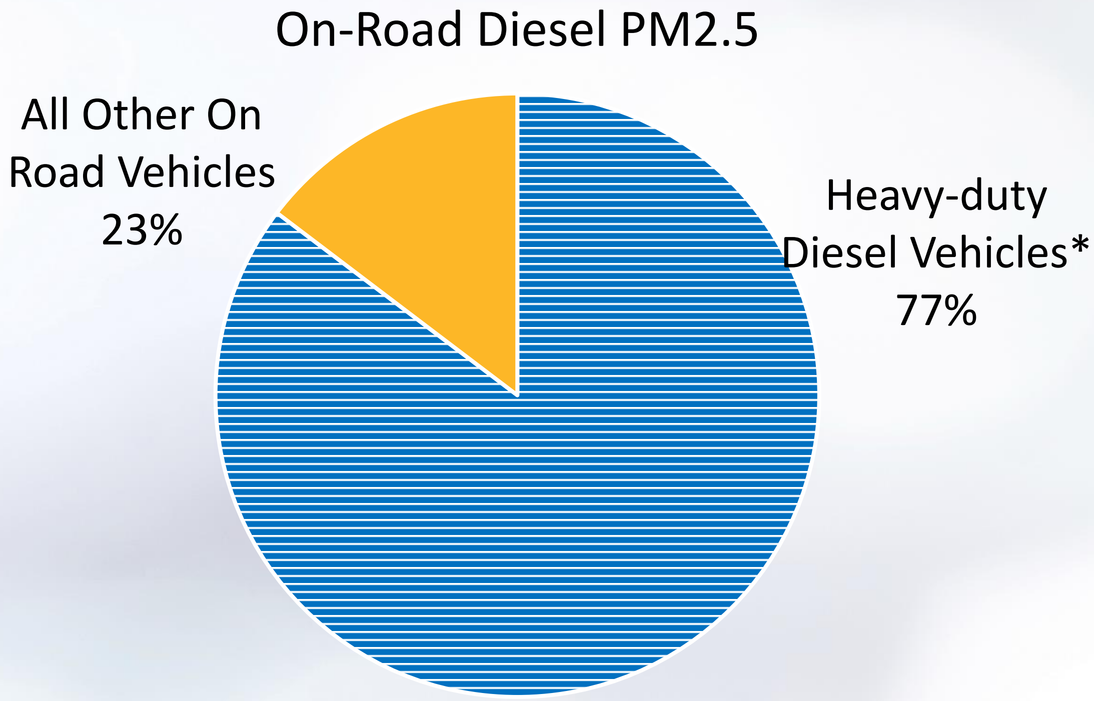
Applying Real-World Heavy-Duty Emissions Data to Inform Inventory Development

Presenter: Mo Chen
Mo Chen, Yirui Liang, Jiachen Zhang, David Quiros, Shaohua Hu, Tao Huai, Kevin Sothy, Belinda Chen, Shobna Sahni, John Karim
California Air Resources Board

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





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

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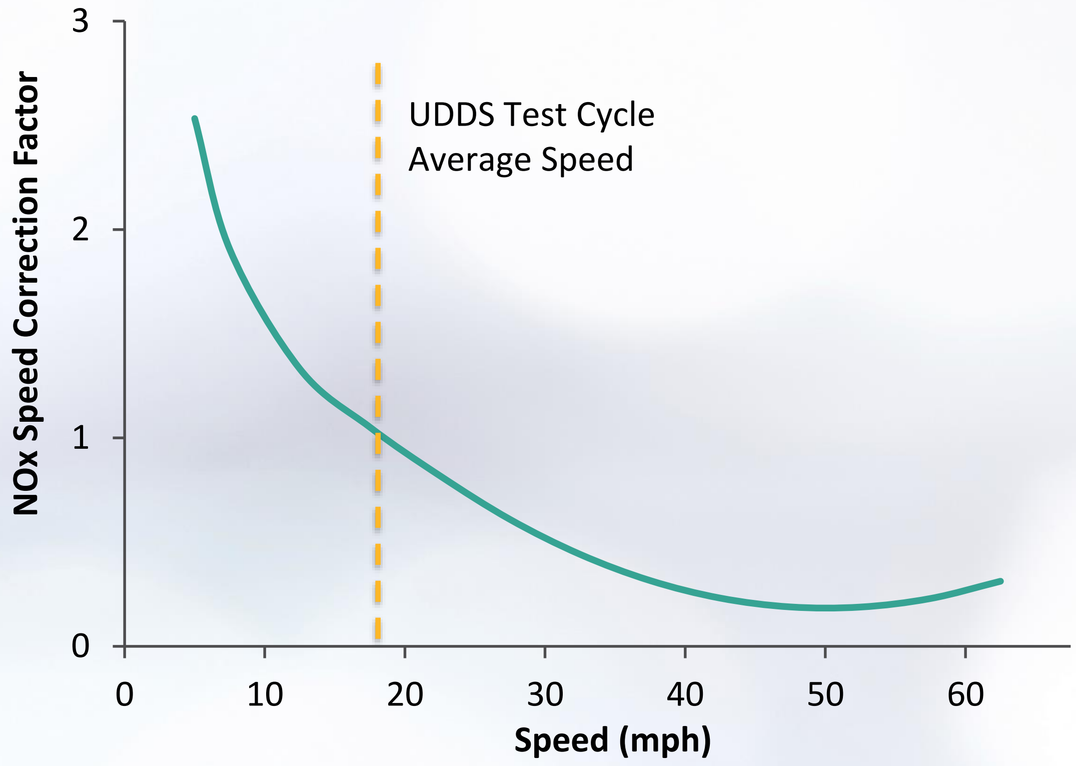
Modeling Heavy-Duty (HD) Emission Rates in EMFAC

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

- 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

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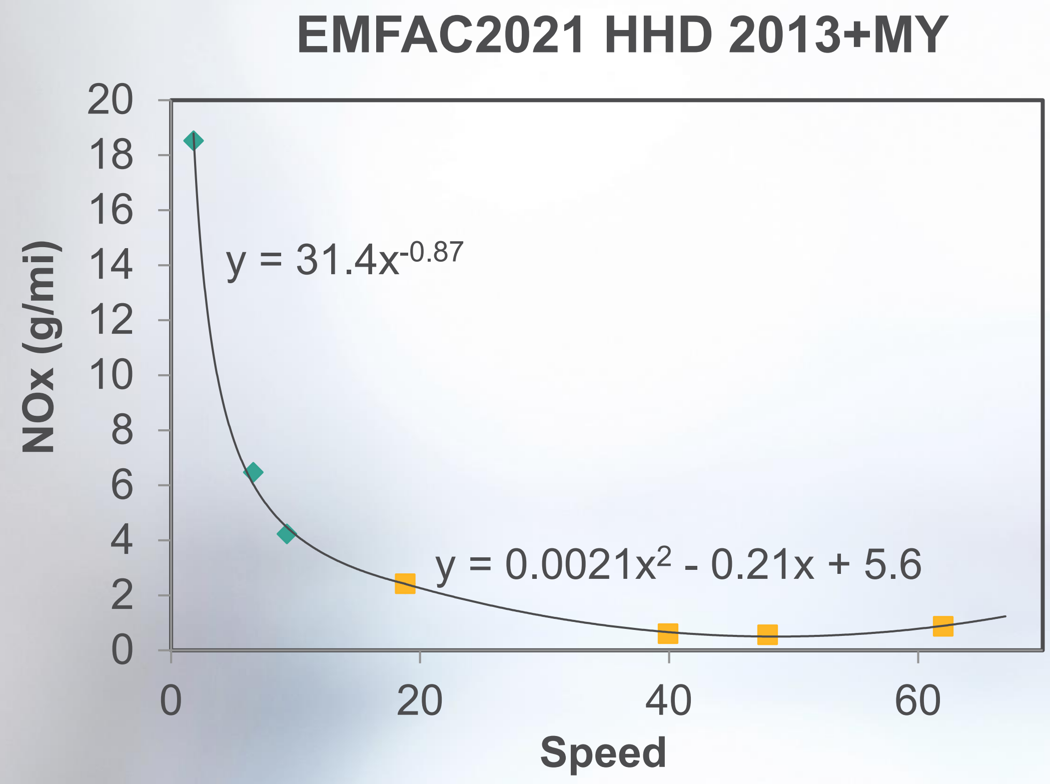
Heavy-duty Vehicle Speed Correction Factors (SCFs) Modeling in EMFAC

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

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

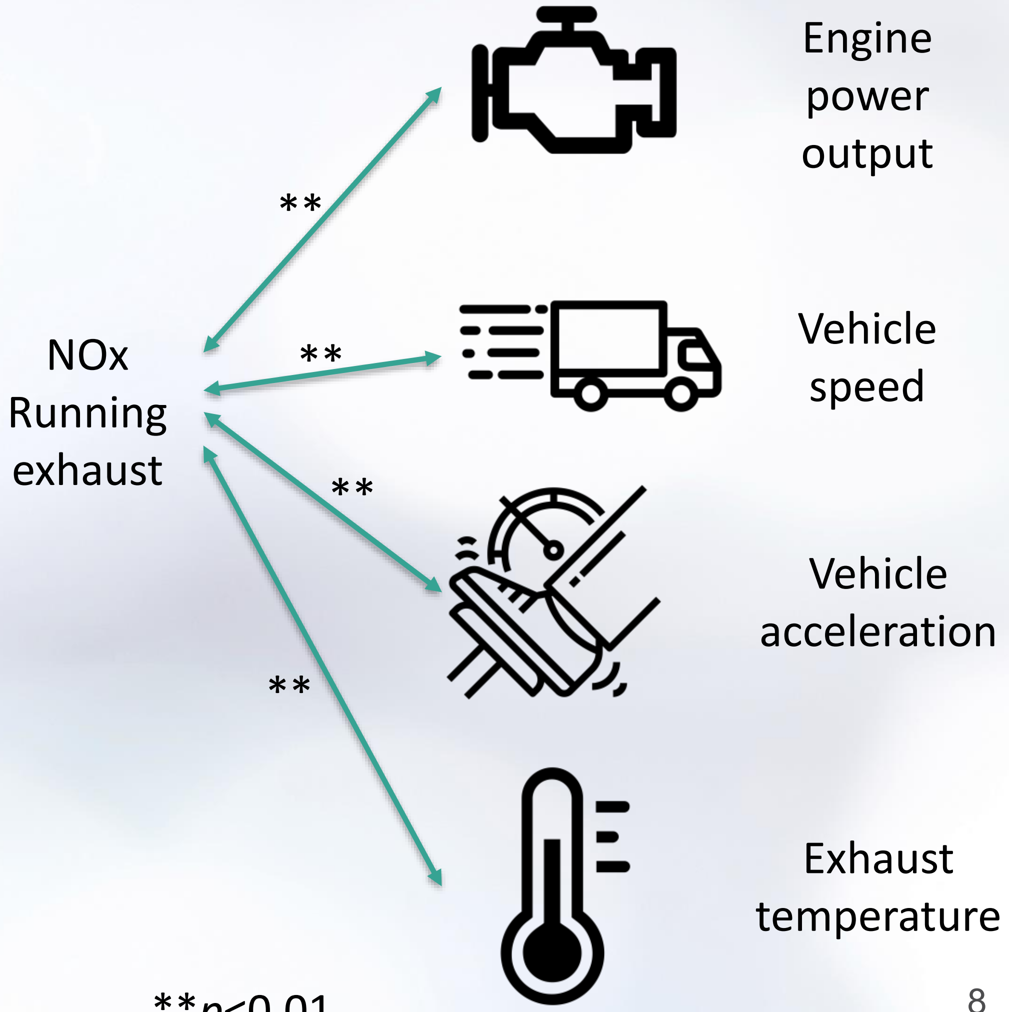
Data Source of HDIUT PEMS

- 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



**$p<0.01$

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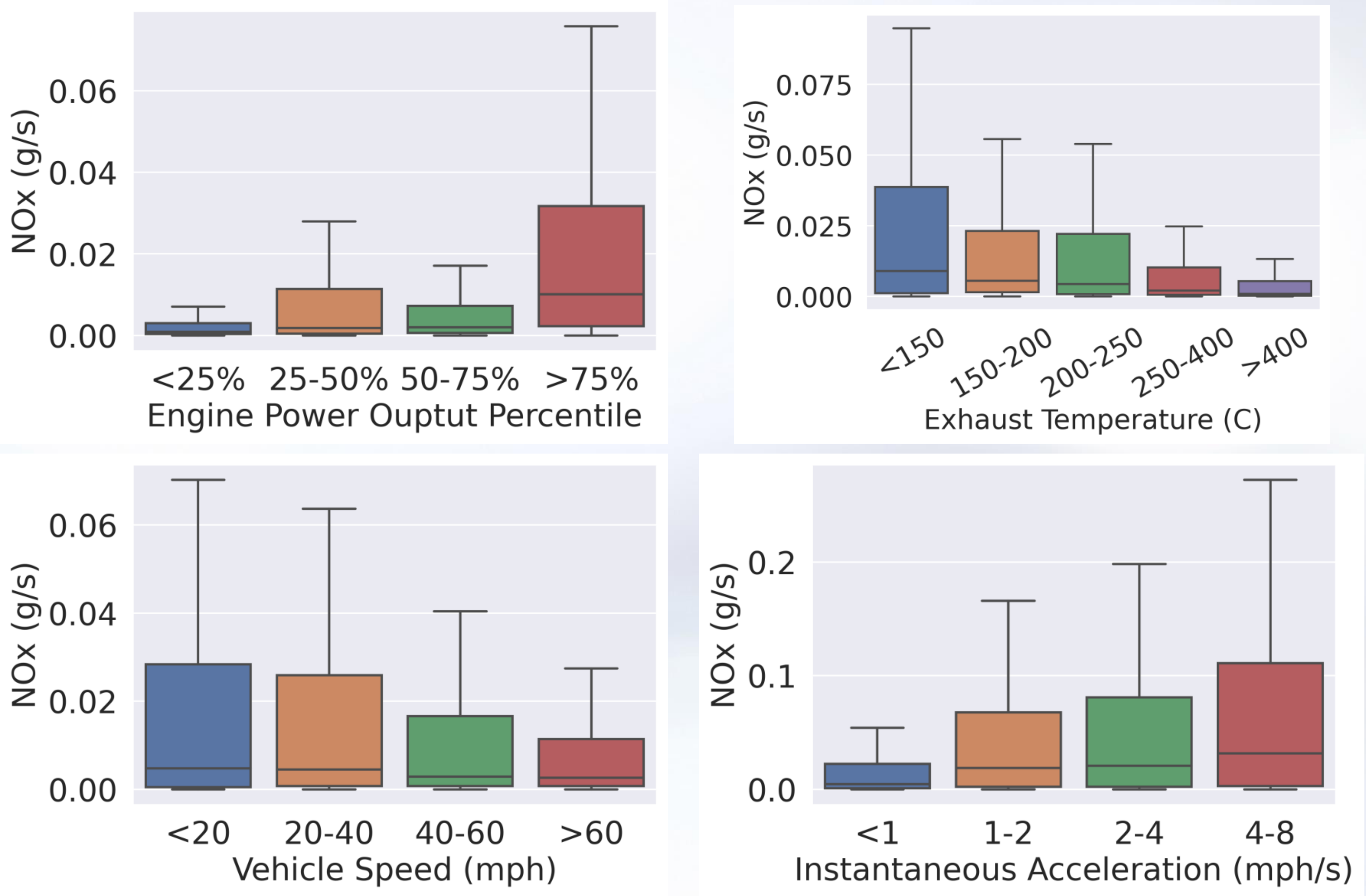
Variables Correlated with Instantaneous NOx Emissions

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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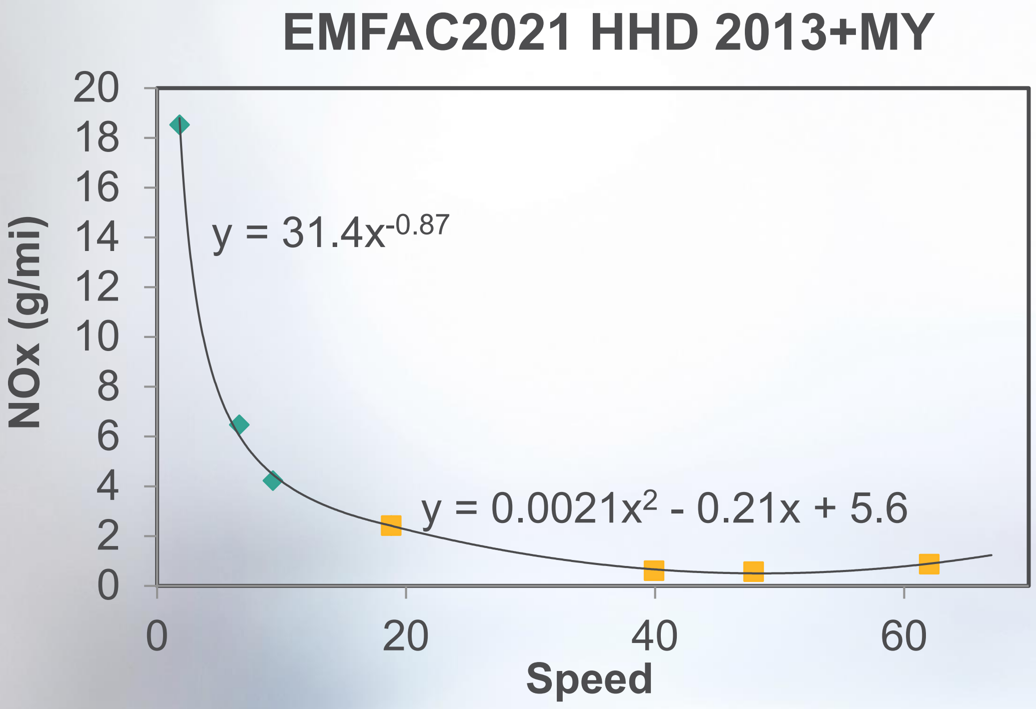
Informing Emission Rates by Speed using PEMS

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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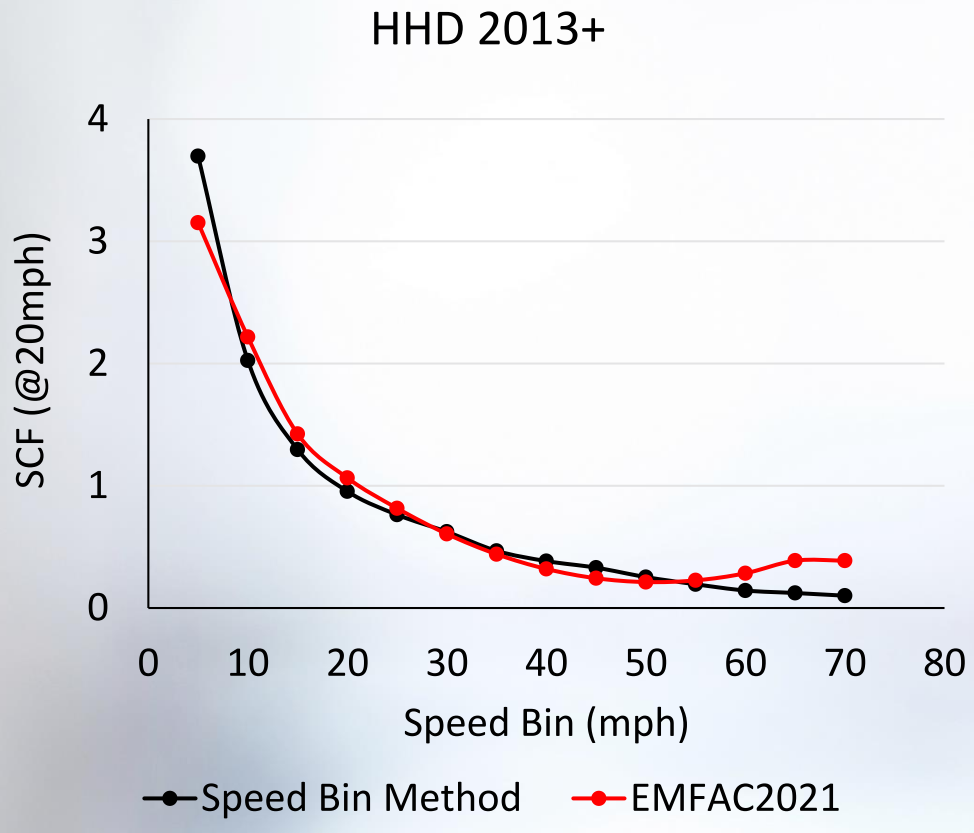
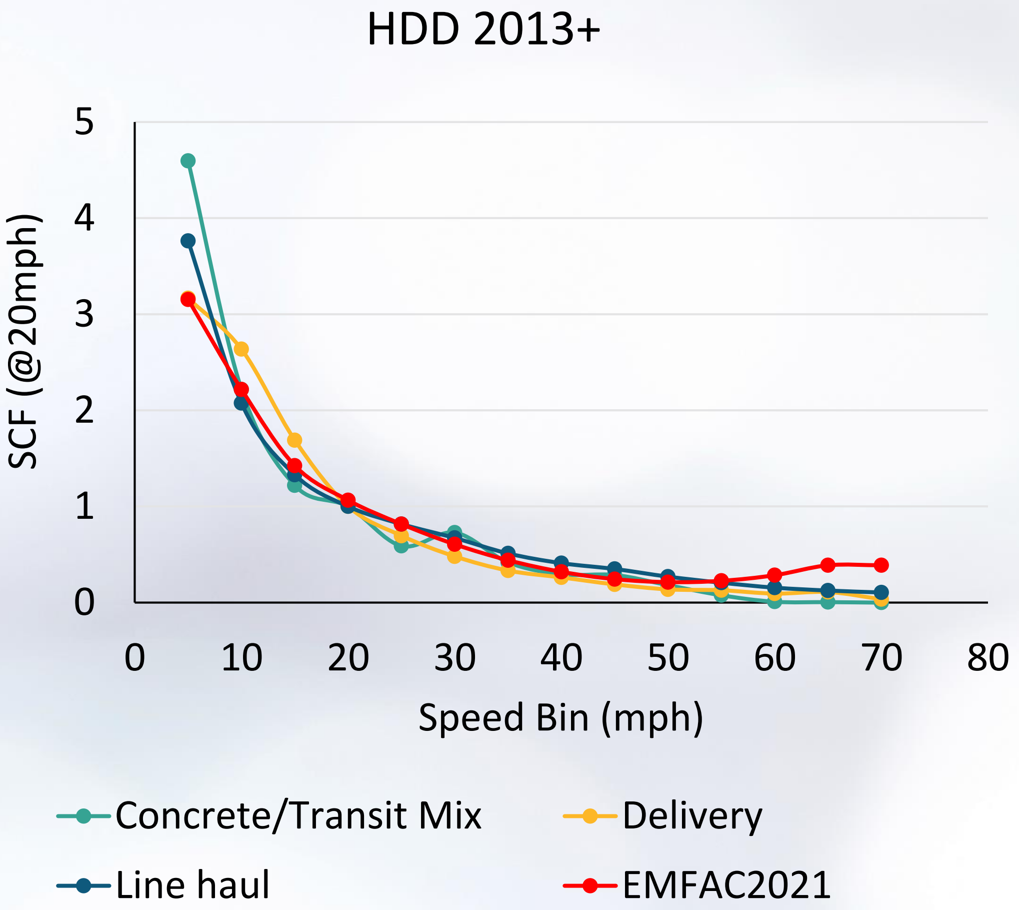
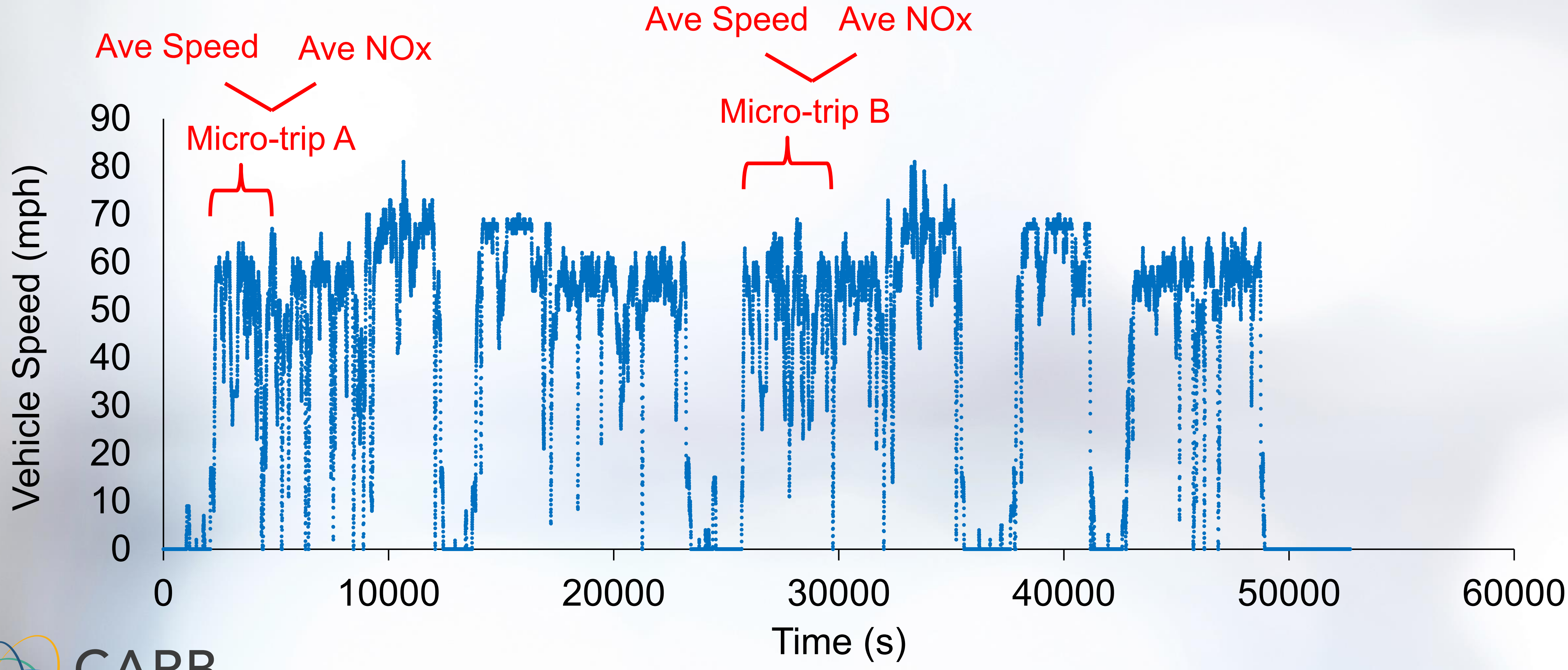
Speed Bin Method using PEMS



broken by vocations



Micro-trip Method using PEMS



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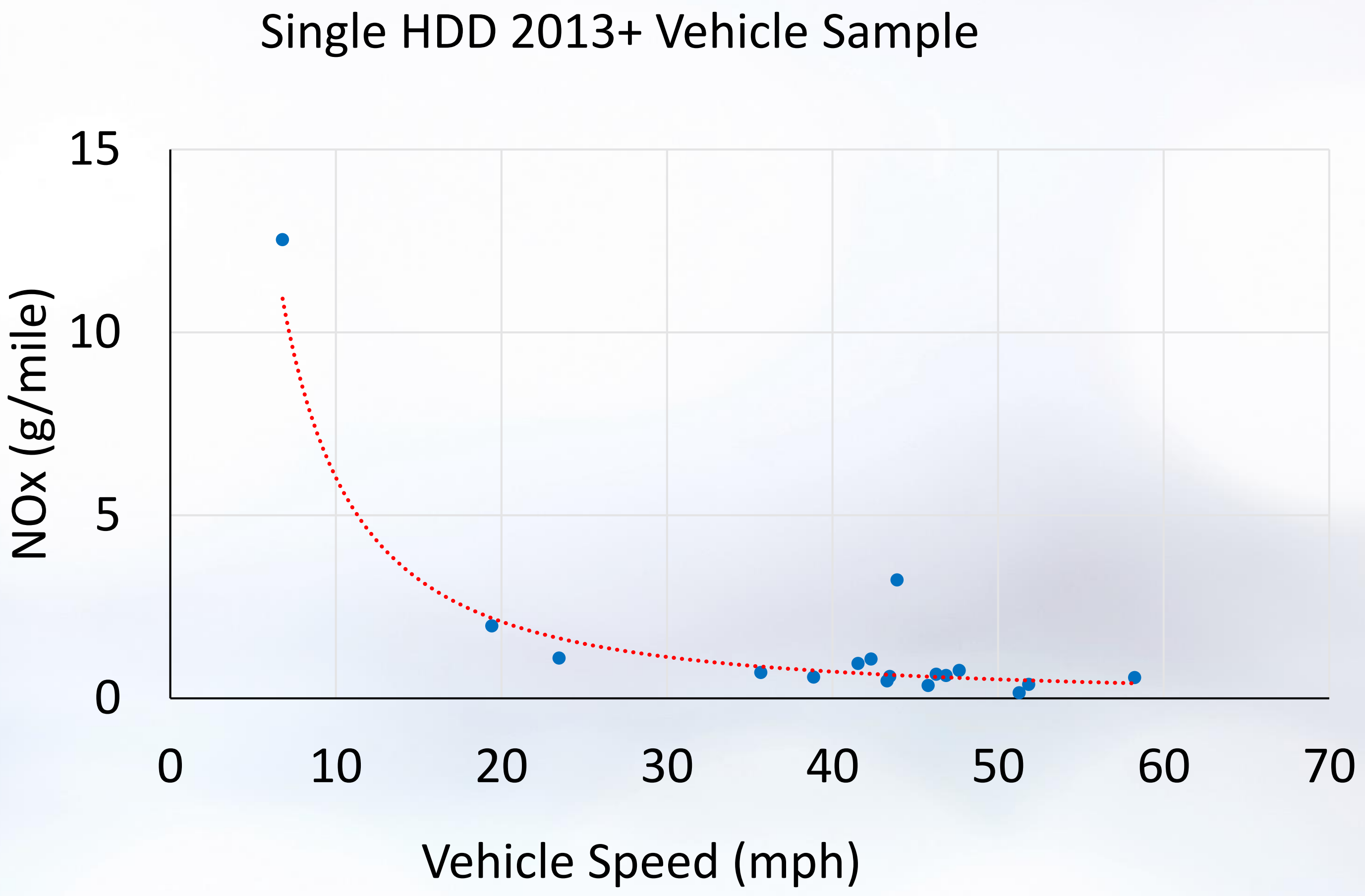
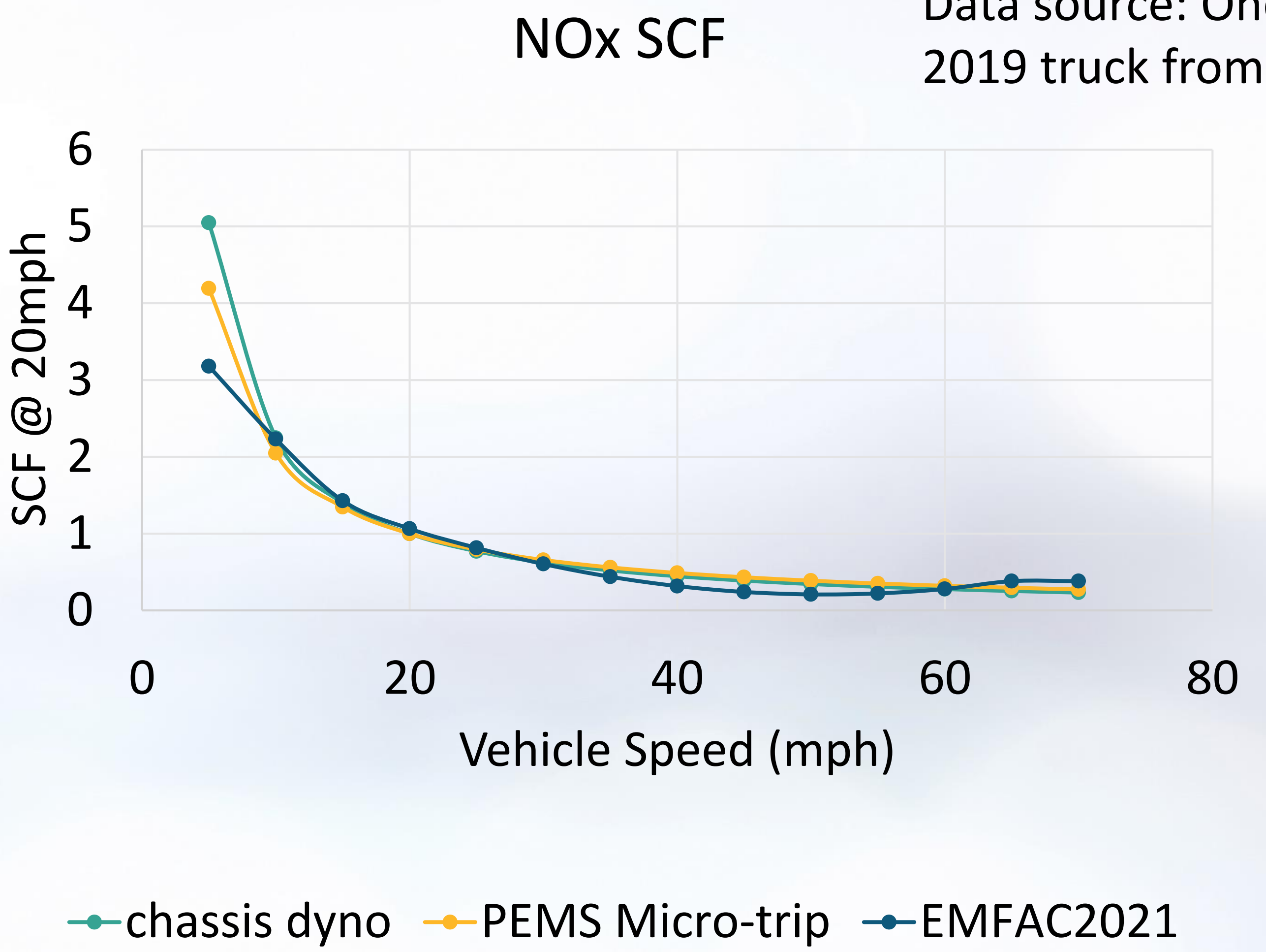
Micro-trip Method using PEMS



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

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!

Mo Chen, Ph.D.

Air Pollution Specialist

Mobile Source Technology Assessment and Modeling Section (MSTAMS)

California Air Resources Board

mo.chen@arb.ca.gov

Multivariable Regression Experiments

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

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*

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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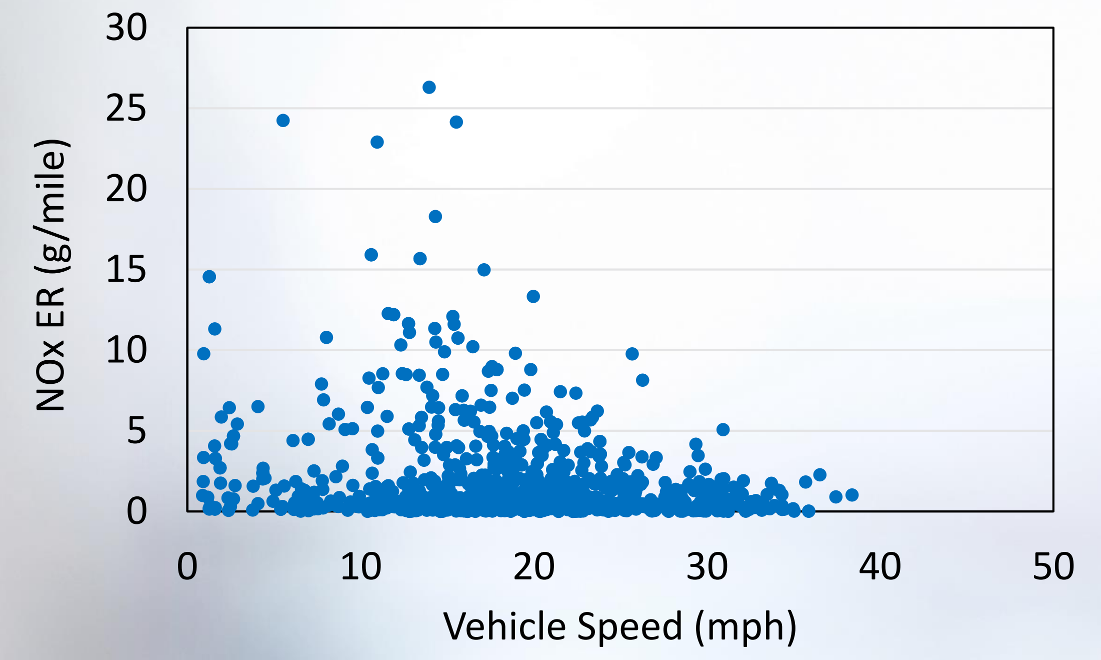
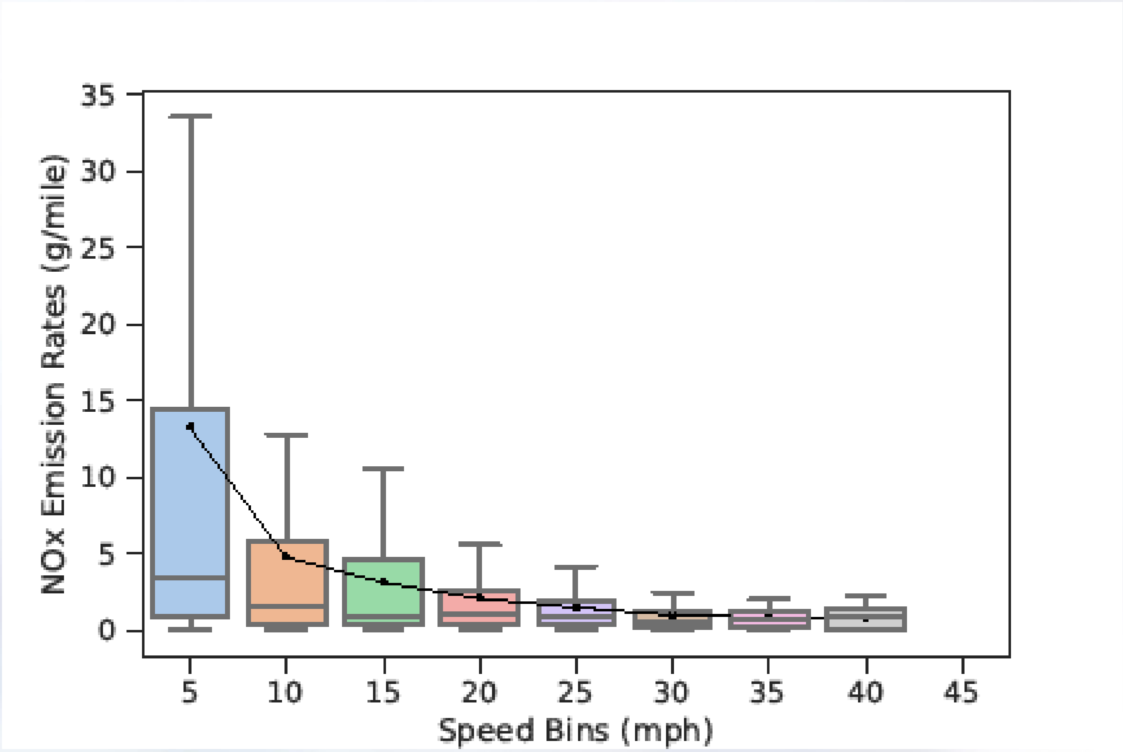
Micro-trip Method using PEMS





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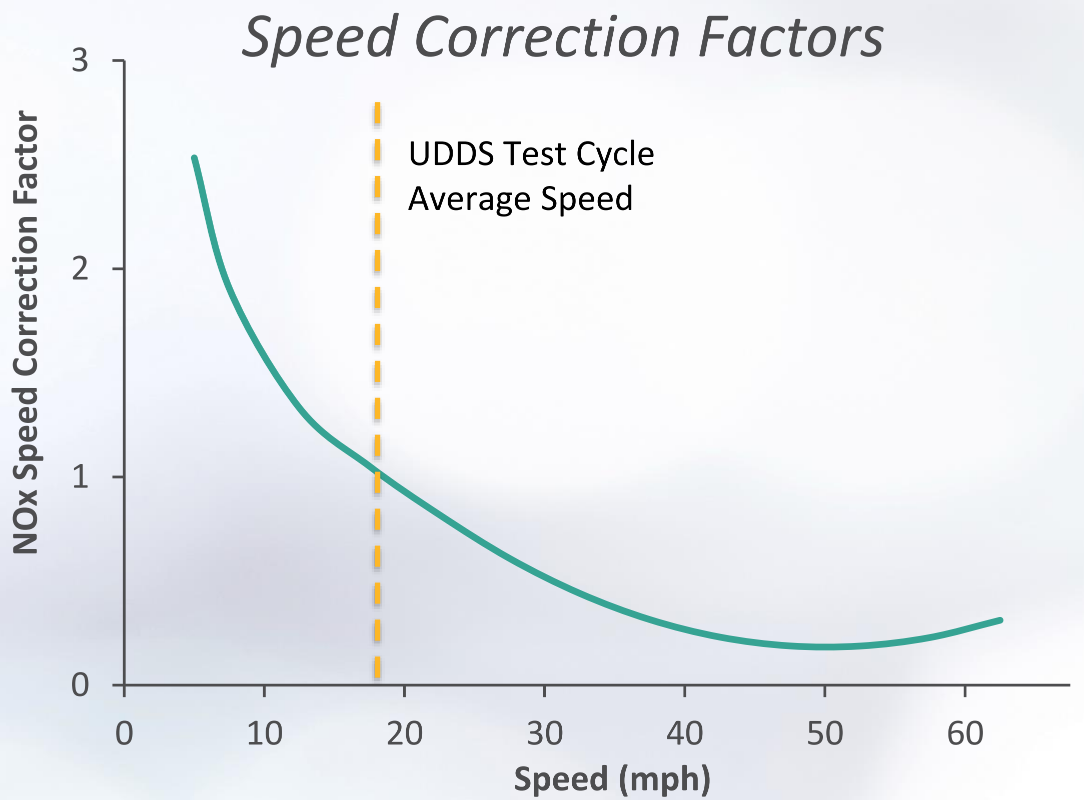
Modeling Heavy-Duty (HD) Emission Rates in EMFAC

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

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)

*SCR=Selective catalytic reduction