On-road comparison of early (model year 2010-11) and later (2013-14) Heavy-Duty Selective Catalytic Reduction

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Introduction

- On-road Heavy-Duty Diesel Engine NO_x certification standard lowered to 200 mg/bhp·hr in 2010
- By 2023, Truck & Bus Rule will require nearly all CA HDDVs to have EMY 2010 engines
- CARB's Mobile Source Strategy (2016) calls for continued reductions in NO_x emissions
  - South Coast Air Basin: reduce NO_x emissions to 90 tons/day by 2030 (80% below 2016 levels)
  - San Joaquin Valley: reduce NO_x emissions by 50% by 2031

2010: SCRs introduced

2016: baseline year for NO_x emissions

2023: SCRs required for all HDDEs in CA

2030: SCAB NO_x 80% below baseline

2031: SJV NO_x 50% below baseline

- ***Question: how does "early" (EMY 2010-11) SCR performance in controlling NO_x compare to "later" (2013-2014) SCRs?***

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Summary of Vehicles Tested

- One "early" (EMY 2010-11) and one "later" (EMY 2013-14) SCR-equipped HDDV selected with engines from three major OEMs
- Engine Control Module data and tailpipe emissions recorded at 1Hz w/PEMS

Vehicle			Engine			NO_x		Sample size	
ID	Make	Odometer (miles)	MY	Disp. (L)	Rated HP	Cert. Value (g/bhp-hr)	Cert. Standard (g/bhp-hr)	miles	hours
Veh-1	OEM 1	13,500	2010	14.9	450	0.25	0.35	491	14.1
Veh-2	OEM 1	44,635	2013	14.9	485	0.18	0.20	733	20.7
Veh-3	OEM 2	23,000 138,000	2011	12.8	410	0.13	0.20	695	19.3
Veh-4	OEM 2	135,000	2014	14.8	455	0.09	0.20	1,388	43.5
Veh-5	OEM 3	68,000	2010	12.8	405	0.11	0.20	303	8.9
Veh-6	OEM 3	62,000	2014	12.8	375	0.06	0.20	2,071	64.1

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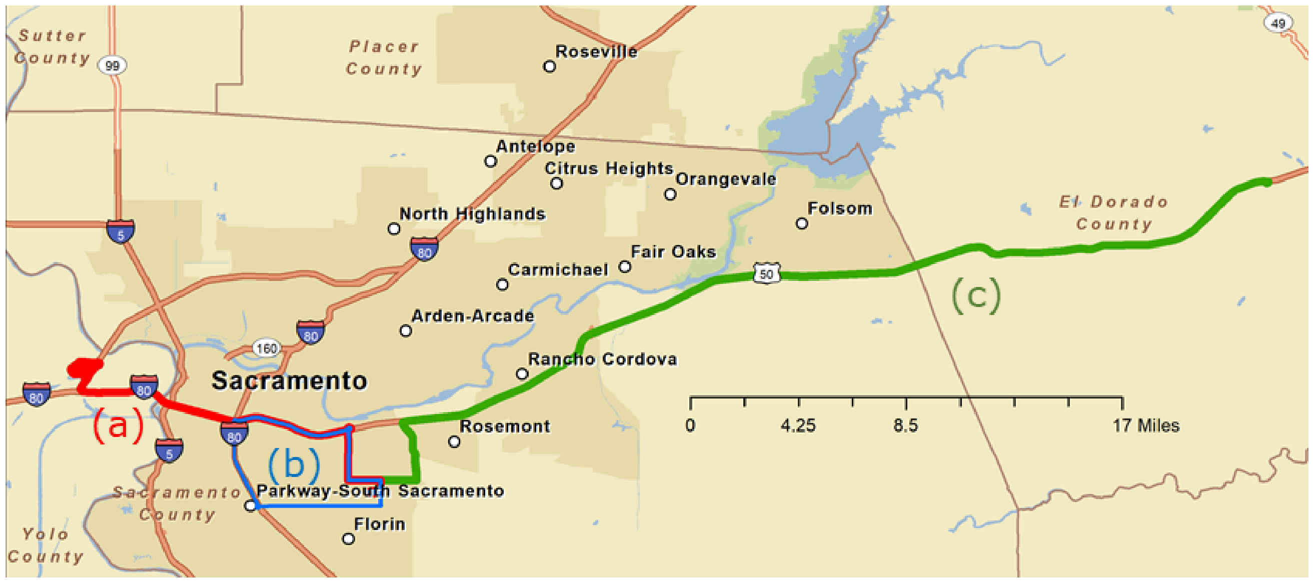
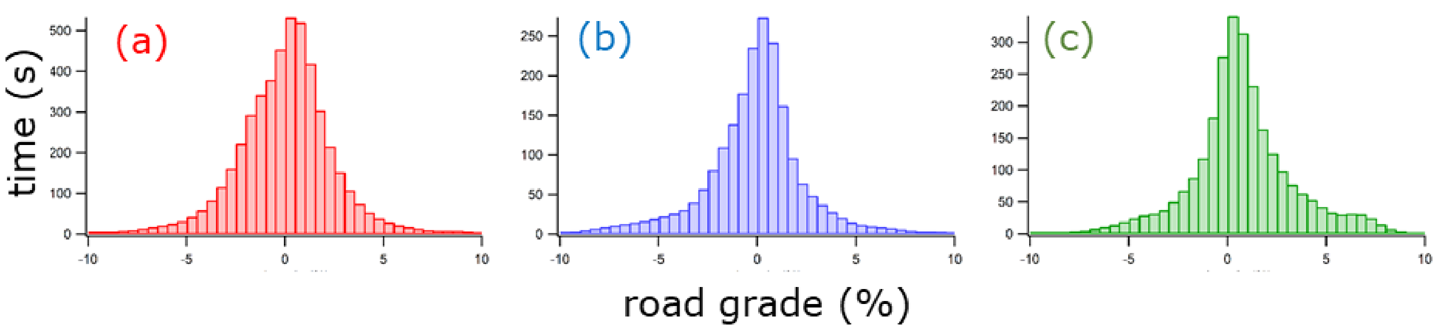
Description of Routes





- Each HDDV driven on 3 routes originating from CARB's Depot Park facility in Sacramento

a) "West Sacramento"

b) "City Streets"

c) "Placerville"

- Each HDDV had one of three payloads

1. "low" (40% of GVWR)
2. "medium" (70%)
3. "high" (90%)

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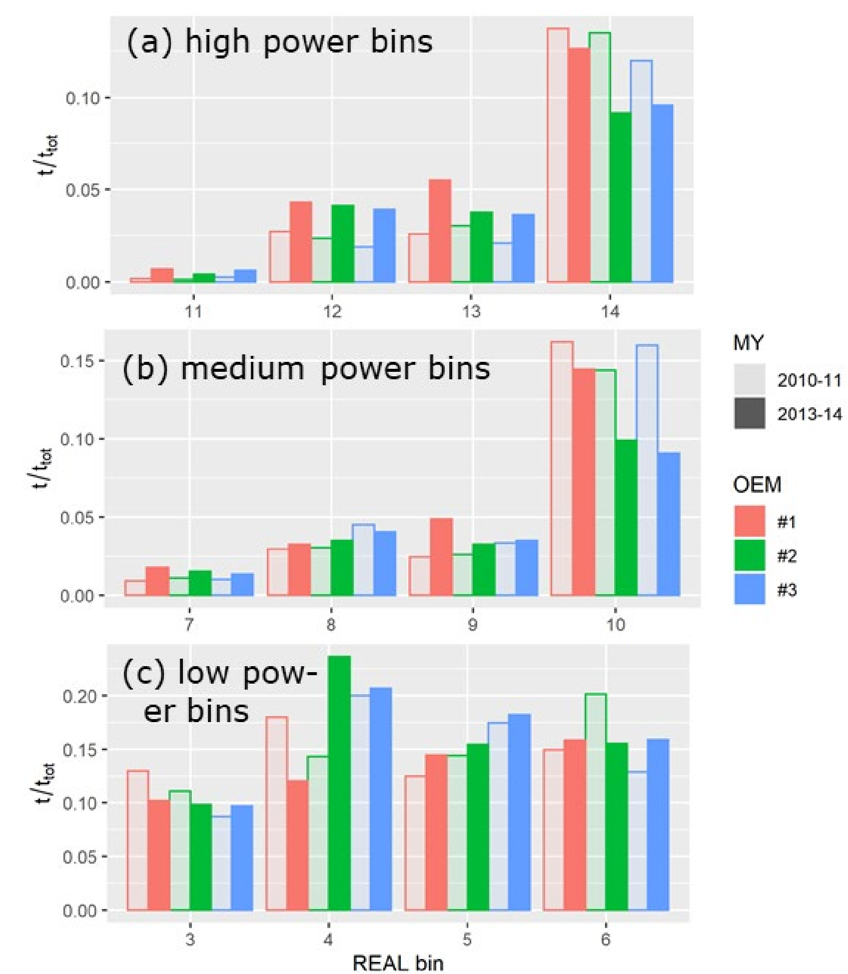
Real Emissions Assessment Logging (REAL) bins

REAL bins	Vehicle Speed (MPH)				
% of Rated Power	0	0 - 10	10 - 25	25 - 40	40 -
0 – 25%	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6
25 – 50%		Bin 7	Bin 8	Bin 9	Bin 10
50 – 100%		Bin 11	Bin 12	Bin 13	Bin 14

time fraction in each bin



- REAL bins: 12 vehicle speed-power bins defined by OBD regulations (Nov. 2018), used for data analysis
- EMY 2022+ engines will store total binned NO_x emissions data
- Not using Bin 2 (idling), 15 (NTE events), or 16 (DPF regeneration events)

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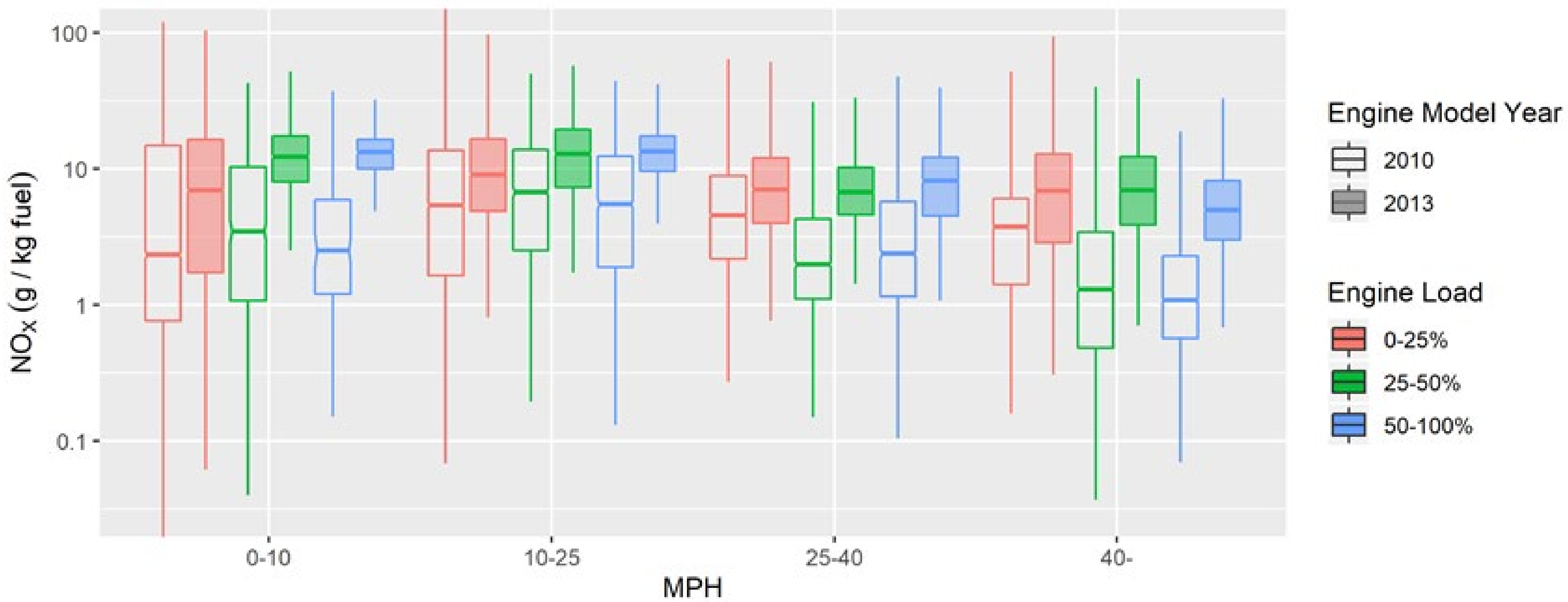
Results from early & later HDDV w/OEM #1 engine

Fuel-based NO_x emissions – not dependent on exhaust flow or reported engine power (only tailpipe $[NO_x]$ and $[CO_2]$)

- Large increase in NO_x emissions for all bins
- Overall mean NO_x increase of 58%
- *Why is the newer engine emitting so much more NO_x?*

fuel-based NOx emissions from OEM #1



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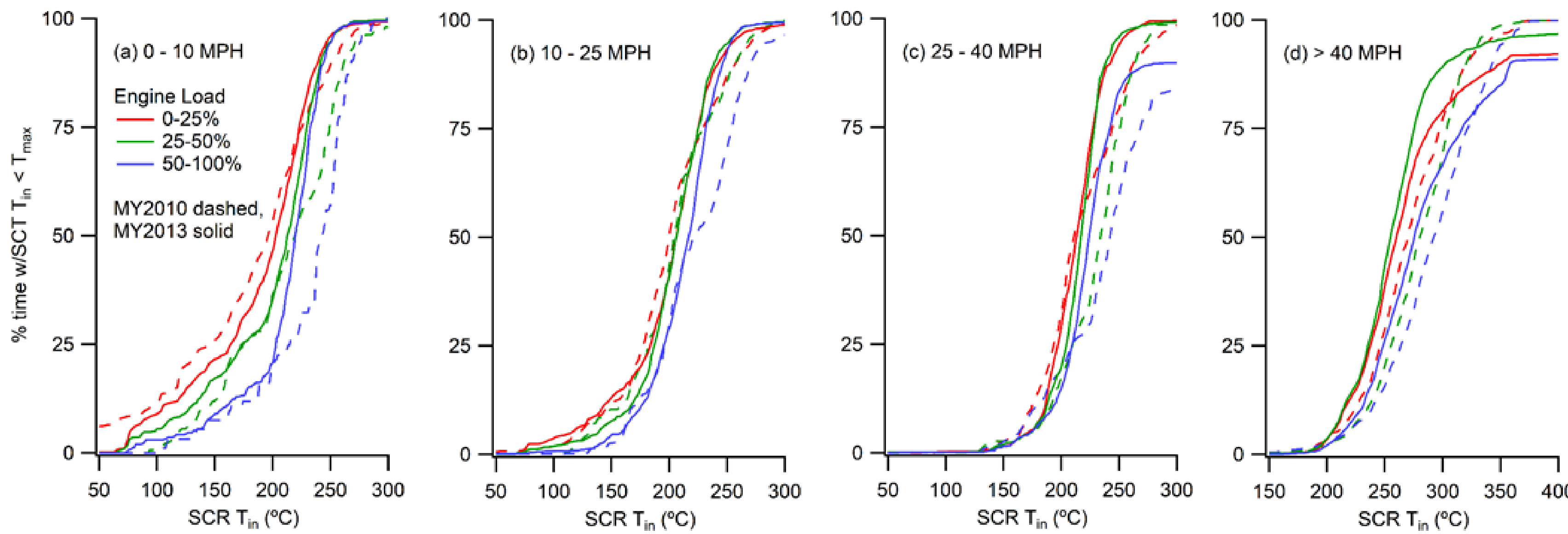
Results from early & later HDDV w/OEM #1 engine

Cumulative SCR inlet temperature distributions – older engine (dashed) is warmer than newer engine (solid)

- Dashed lines shift to the right (higher temperature)
- Difference most apparent for T from 200 to 250

OEM # 1



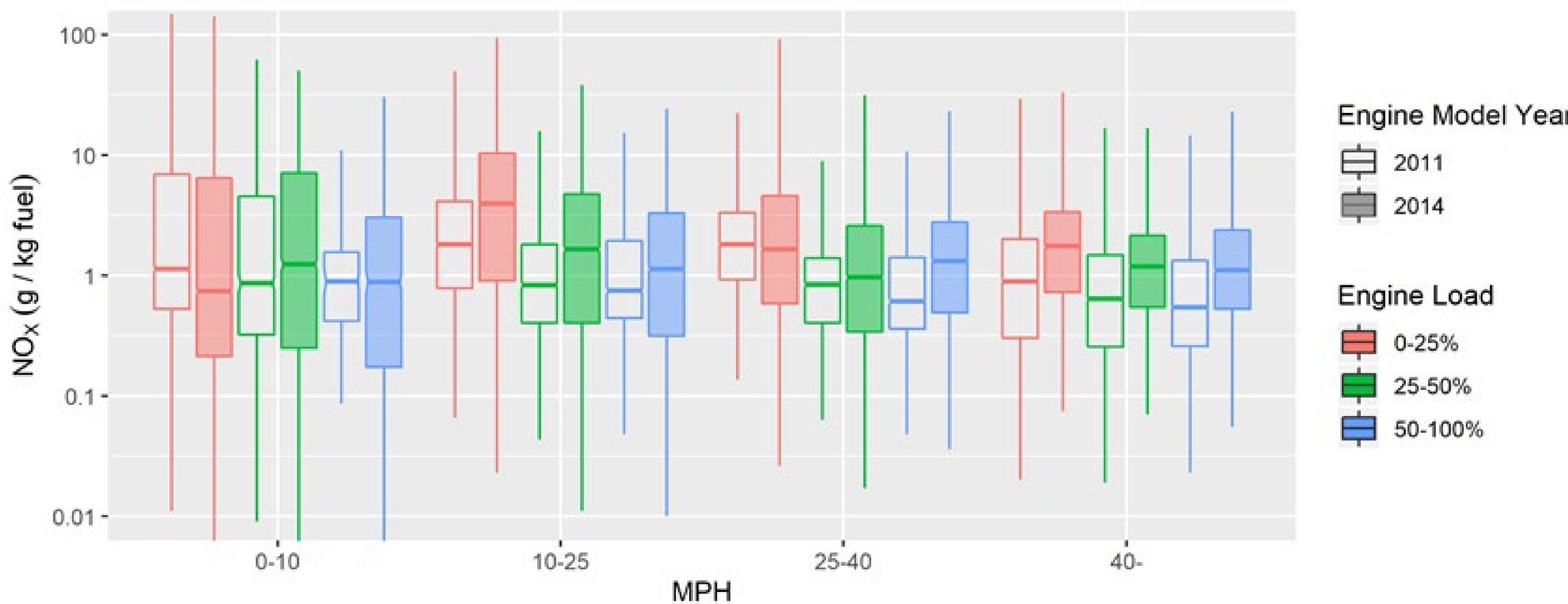
Results from early & later HDDV w/OEM #2 engine

Fuel-based NO_x emissions – not dependent on exhaust flow or reported engine power (only tailpipe [NO_x] and [CO_2])

- Increase in NO_x emissions for some bins, decrease for others

- overall increase from 2.4 to 3.3 g/kg fuel (38%)

fuel-based NOx emissions from OEM #2



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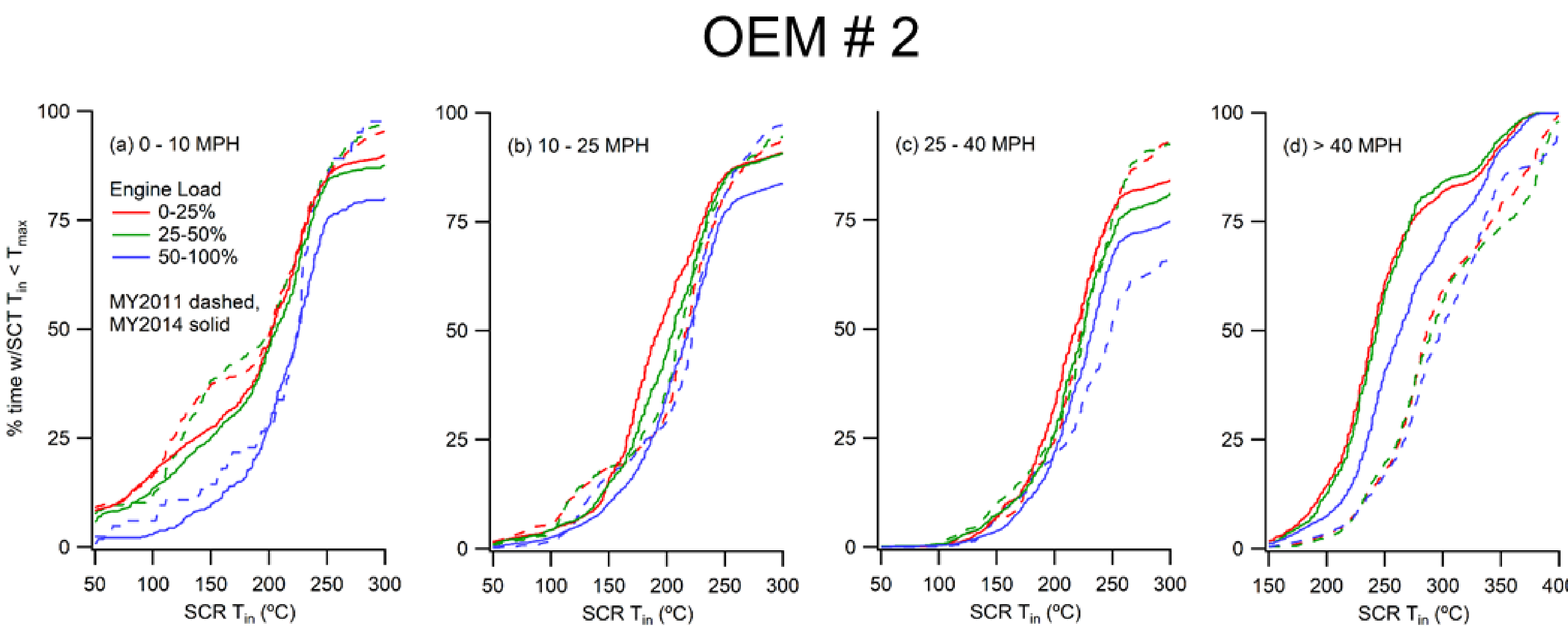
Results from early & later HDDV w/OEM #2 engine

- Temperature distributions more similar than for OEM #1
- Low-speed bins shifted to the right (warmer), high-speed bins to the left (cooler)



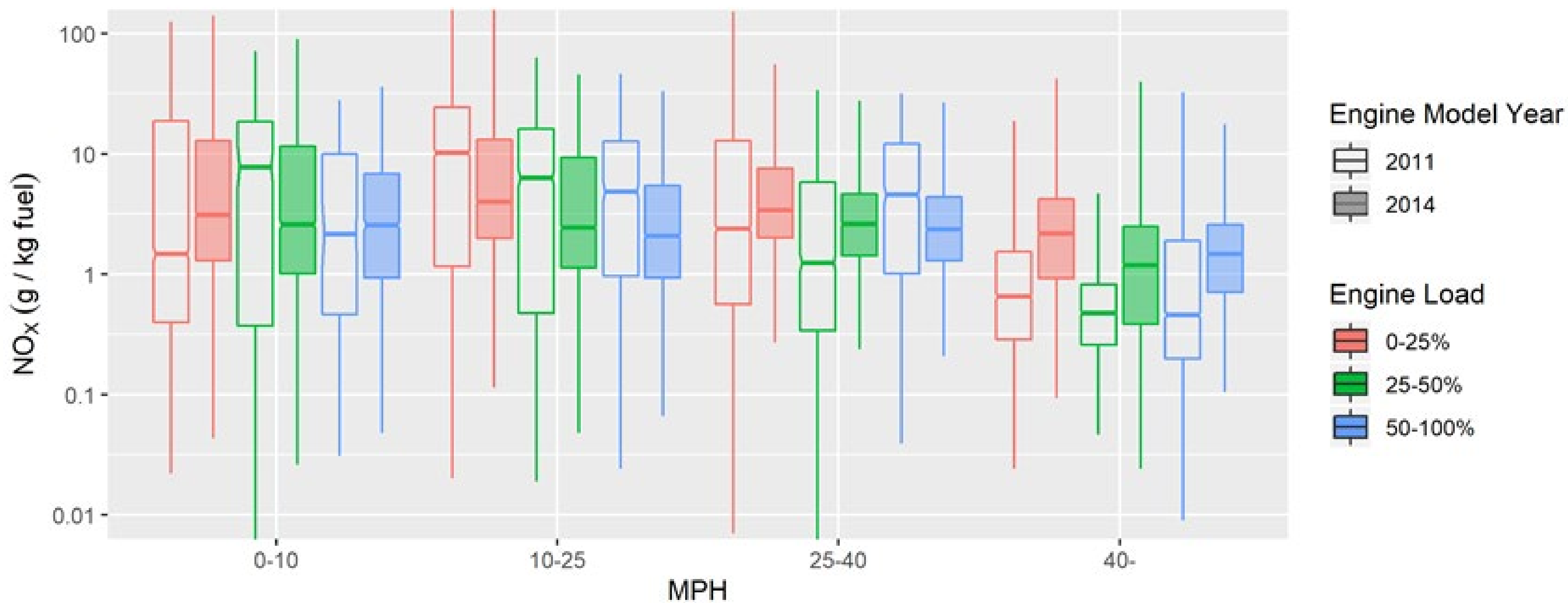
Results from early & later HDDV w/OEM #3 engine

Fuel-based NO_x emissions – not dependent on exhaust flow or reported engine power (only tailpipe [NO_x] and [CO_2])

- NO_x emissions decreased in low-speed, increase in high-speed bins

- overall decrease in mean NO_x of 23%

fuel-based NOx emissions from OEM #3



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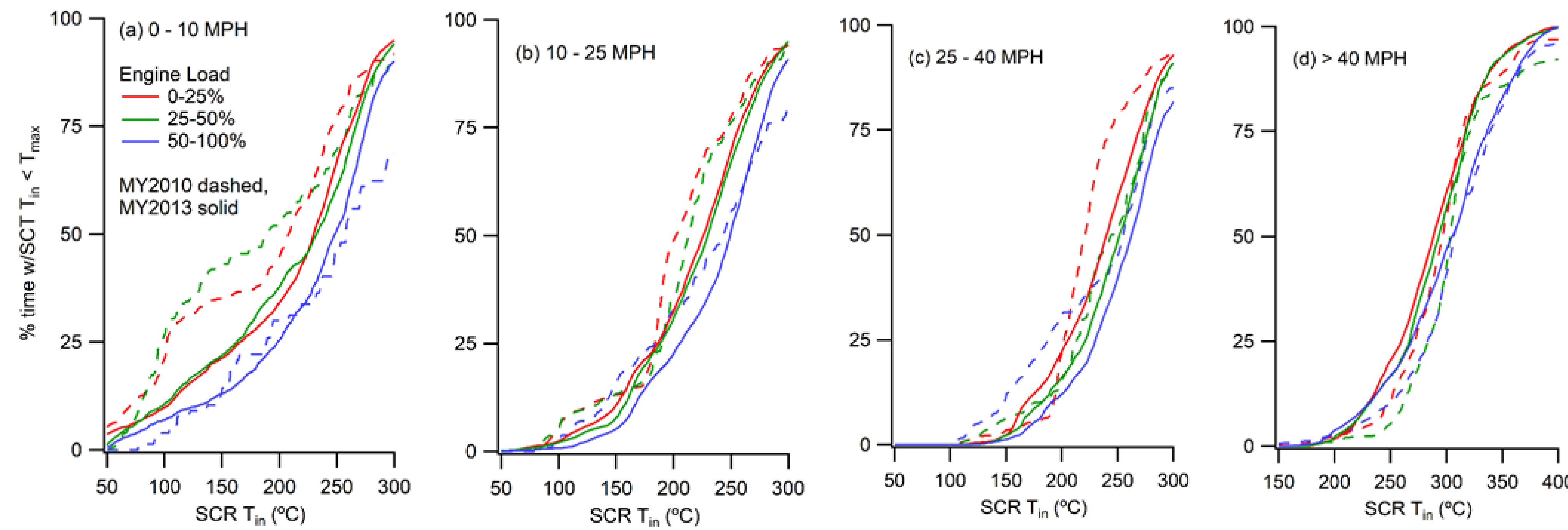
Results from early & later HDDV w/OEM #3 engine

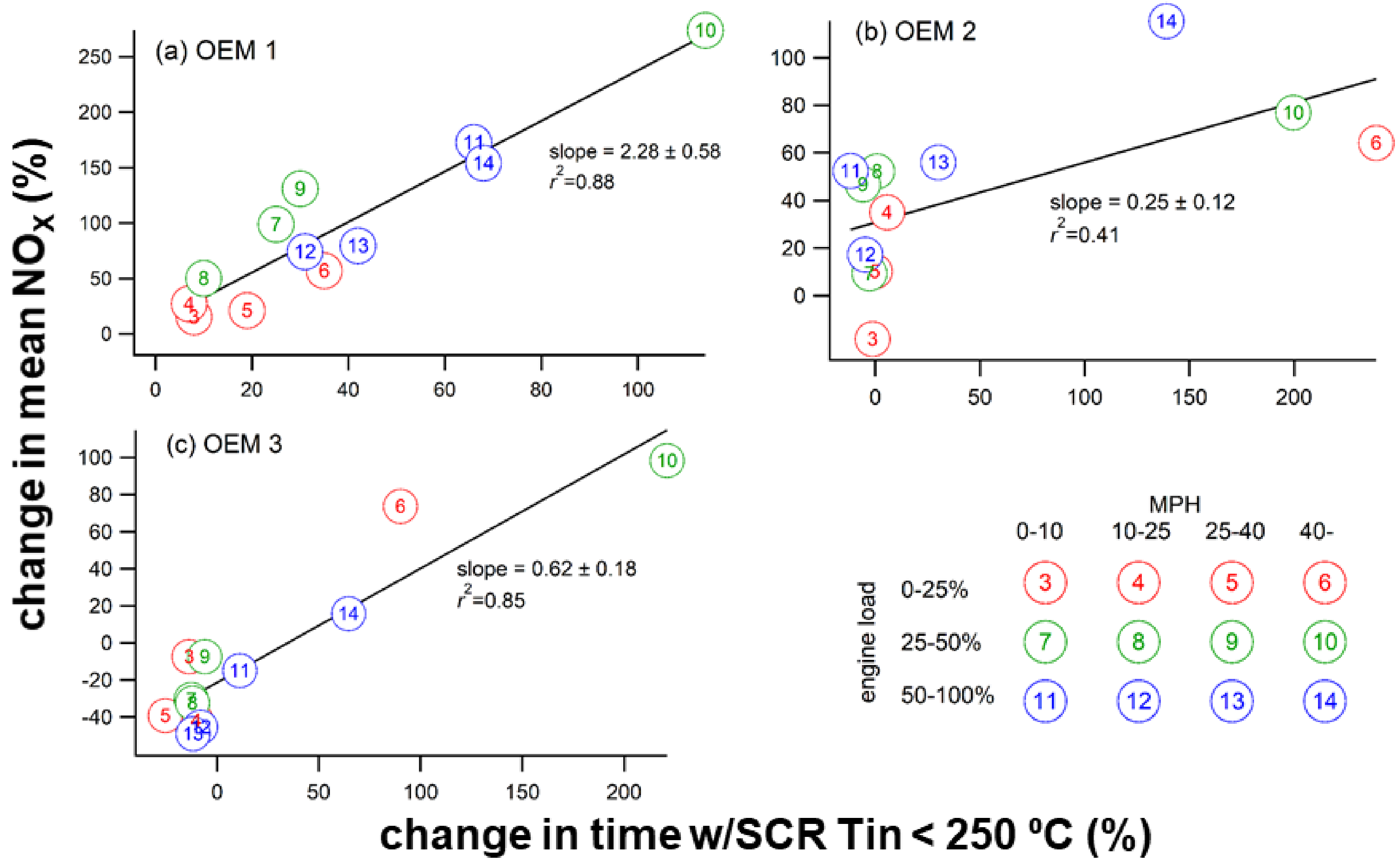
Newer (solid lines) SCR T similar at high speeds, hotter at low speeds

OEM # 3



How much of change in NO_x can be explained by SCR T?

- Regress the change in mean fuel-based NO_x from older to newer engine (ΔNO_x) onto change in fraction time w/SCR inlet T< 250
- For OEM #1, 88% of inter-bin variability in ΔNO_x can be predicted with $\Delta t_{SCR\ T<250}$
- For OEM #3, 85% (but overall $\Delta NO_x < 0$)



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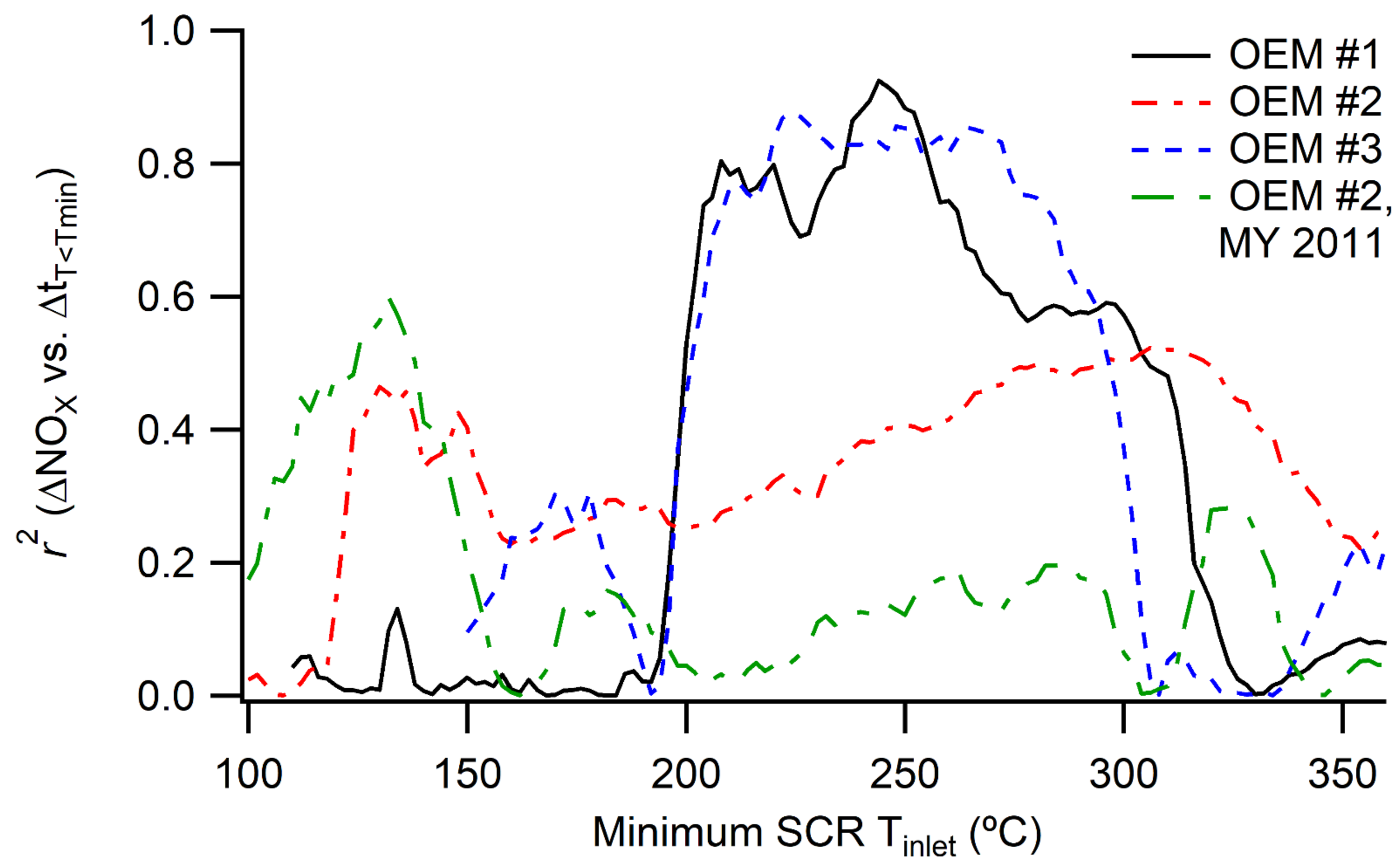
Which SCR T_{in} threshold best predicts ΔNO_x?

- High correlation for OEM #1 and OEM #3 begins at T_{in} ~ 200 °C
- Highest correlation around 250 °C
- Lower correlation for OEM #2
- Very low correlation for repeat measurement of older OEM #2



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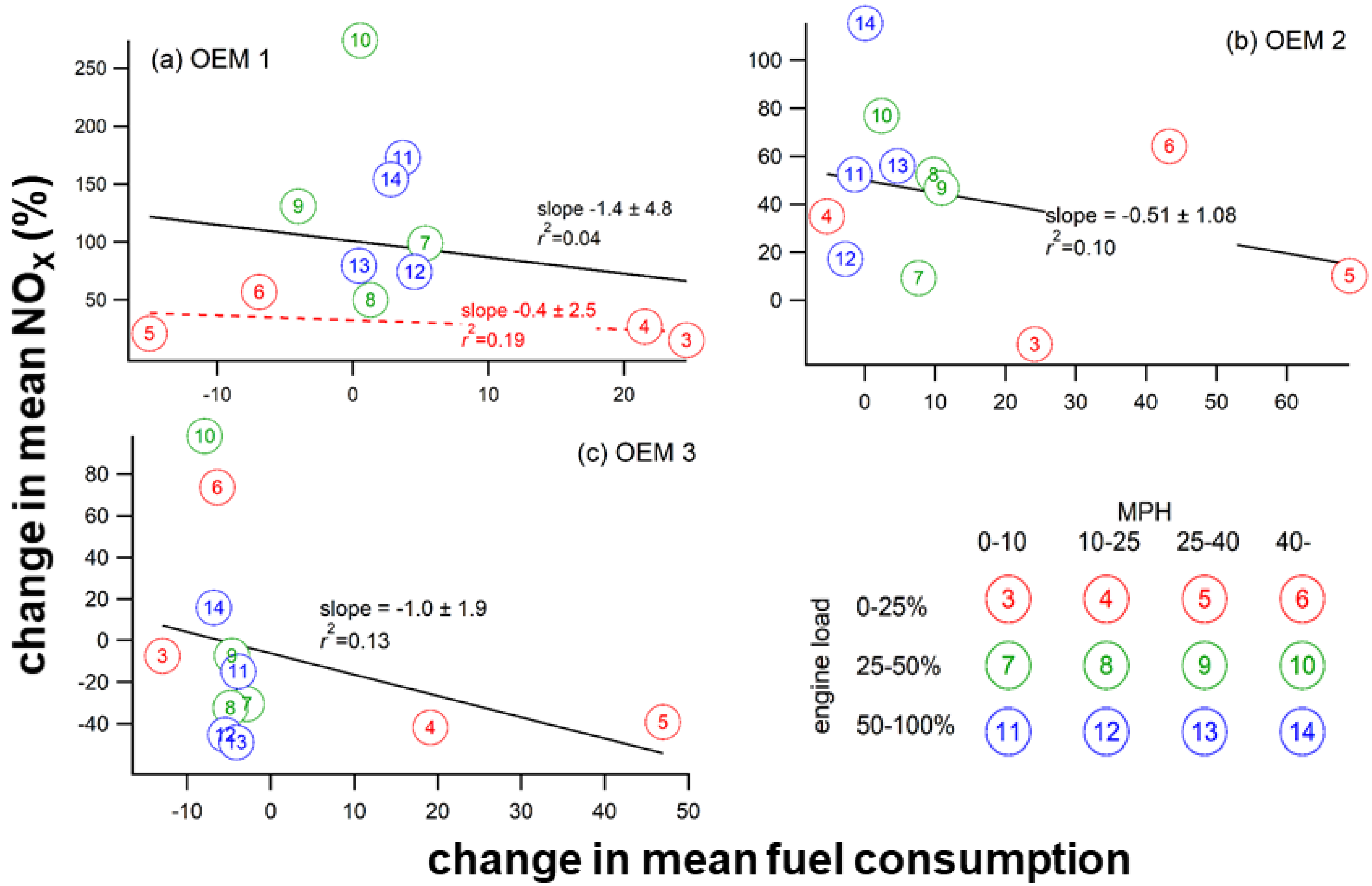
How much of Δ NOx can be explained by fuel consumption?

- Regress ΔNO_x onto change in work-normalized fuel consumption
- **All correlations much lower than for ΔNO_x vs. $\Delta t_{SCR\ T<250}$**
- Negative correlations for OEM #1 low-load and OEM #2, MY11 medium-load bins

  (i.e., ↑fuel → ↓ ΔNO_x)



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Conclusions

- SCR performance, compared for “early” (2010-11) and “later” (2013-14) SCR-equipped HDDEs made by three leading engine OEMs
- Fuel-based NO_x emissions increased for two OEMS, decreased for a third
- 88% of inter-bin variance in ΔNO_x can be explained by $\Delta t_{SCR\ T< 250}$ for OEM with larger NO_x increase
- 85% of inter-bin variance in ΔNO_x can be explained by $\Delta t_{SCR\ T< 250}$ for OEM with NO_x decrease
- ΔNO_x much less correlated to change in fuel consumption, but fuel could still explain some minor features (e.g., the decrease in NO_x emissions the second time OEM#2 MY2011 truck was tested)
- Future work will apply method to a larger sample size

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