THE RDE AND THE REAL-WORLD: A DIESEL HYBRID/ADVANCED BIOFUEL/PEMS CASE STUDY

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Background

Next-generation and transitional vehicle emission reduction strategies will likely employ a range of vehicle powertrain and fuel combinations. Governments are actively working to align incoming legislation to regulate vehicles on a fuel and technology neutral basis (e.g., EURO 7 in Europe).

https://ec.europa.eu/commission/presscorner/detail/en/ip_22_6495 [Press release / summary]
https://eur-lex.europa.eu/eli/reg/2024/1257 [Regulation (EU) 2024/1257]

Here, using data from an on-going PEMS study into the impact of advanced biofuels on diesel hybrid vehicle emissions, we consider one such benchmark, the Real Driving Emissions work package 4 (RDE-4) methods, the factors driving variability in associated metrics, and the likely real-world emissions outcomes during different activities and modes-of-vehicle operation.

NOTE: This is a short thought-piece on the sources of variability in on-road emissions.
It comes from discussions while analysing data from emissions studies at Leeds.
The case study is also part of larger body of work on biofuel/hybrid combinations.

REFERENCES:

Thomas et al, 2019. Investigating the engine behavior of a hybrid vehicle and its impact on regulated emissions during on-road testing, SAE Technical Paper, https://doi.org/10.4271/2019-01-2199

Thomas et al, 2022. Particle number and size distributions (PNSD) from a hybrid electric vehicle (HEV) over laboratory and real driving emission tests. Atmosphere, https://doi.org/10.3390/atmos13091510

Wiseman et al, 2023. Predicting the physical properties of three-component lignocellulose derived advanced biofuel blends using a design of experiments approach. Sus. Energy & Fuels. 7 https://pubs.rsc.org/en/content/articlelanding/2023/se/d3se00822c

Wiseman et al, 2025. Combustion and Emission Performance from the use of Acid-catalysed Butanol Alcoholysis Derived Advanced Biofuel Blends in a Compression Ignition Engine. SAE International, 2025. https://www.sae.org/publications/technical-papers/content/2025-01-8445/

Case Study

EURO 6 Medium Size Diesel Hybrid Car

Test Vehicle	Value
Vehicle Make and Model	Mercedes C300h
Registration Year (EU class)	2018 (EURO 6b)
Vehicle Weight	1,765 (2,065) kg
Number of Cylinders	4 in-line
Displacement	2,143 cm^3
Maximum Engine Power	150 kW
Maximum Torque	750 Nm
Transmission	7-speed automatic
Electric Motor Power	20 kW
Hybrid Battery Capacity	0.7 KWh
Emissions Management	DOC, DPF, SCR, EGR
Type Approval Test	NEDC
Pre-test Mileage (approx.)	150,000 km

… Running on (ULS) Diesel and Biofuel Blends

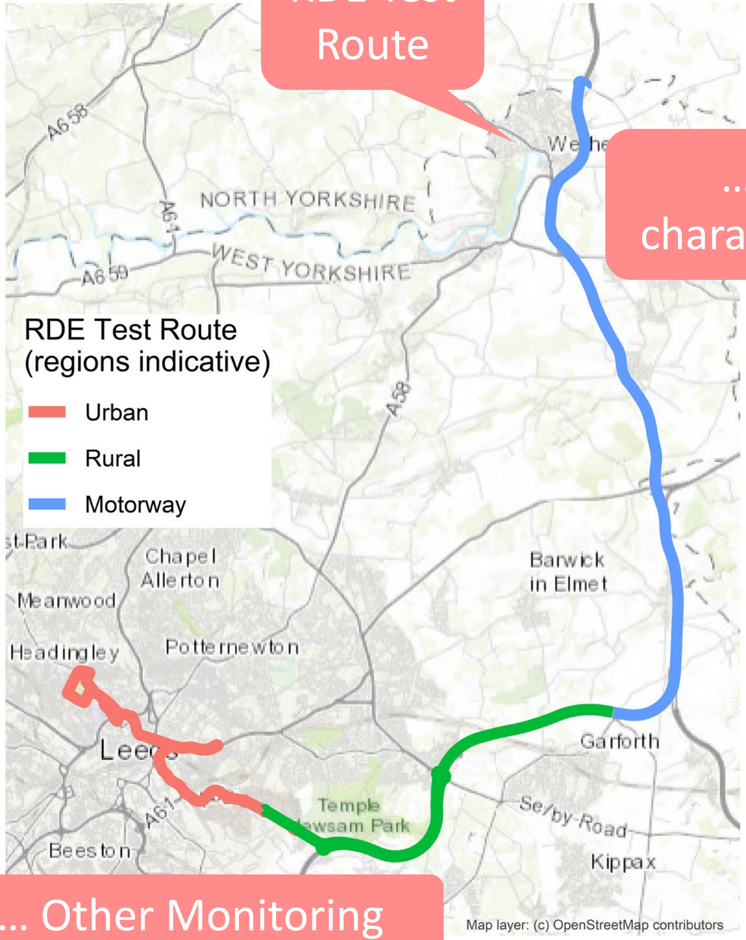
Test Fuels/Blend	Diesel : Biofuel Ratio (vol%)	nBL: DNBE : nBuOH* Ratio (vol%)	Calculated Lower Heating Value (MJ/kg)
D100	100 : 0	0	42.5 – 42.9
D90Bu10 – 65:5:30	90 : 10	65 : 30 : 5	41.4
D90Bu10 – 85:5:10	90 : 10	85 : 10 : 5	41.1
D75Bu25 – 85:5:10	75 : 25	85 : 10 : 5	38.8

* D Diesel; nBL n-butyl levulinate; DBNE di-n-butyl ether; nBuOH n-butanol

… Primary (RDE) Monitoring

OBS-ONE	Measurement Technique	Calibrated Range
CO	Non-Dispersive Infrared	0 – 10 vol%
CO_2	Non-Dispersive Infrared	0 – 20 vol%
NO_x	Chemiluminescence	0 – 3000 ppm
PN (23 - 1000 nm)	(IPA) Condensation Particle Counter	0 - 5×10^7 #/cm^3
Exhaust Flow Rate	Pitot Flow Meter	0.3 – 10 m^3/min

RDE Test Route



… Other Monitoring

Other Instruments /loggers	Measurement Technique	Typical Outputs
GASMET	Fourier Transform Infrared	40+ Species (and composites)
INFLUX	Engine Data Logger	Engine Diagnostics
Thermocouples	Thermocouples	Exhaust Temperatures

… and characteristics

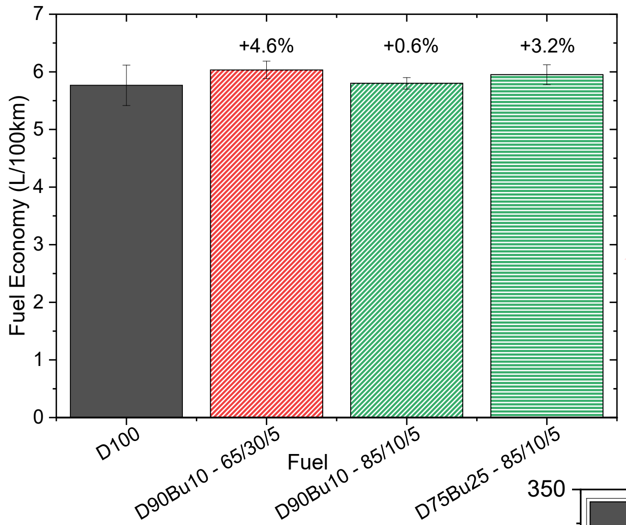
RDE Route Characteristics	Value
Total Trip Distance	97.2 km
Urban Distance Share	31.5 – 37.7 %
Rural Distance Share	29 – 35.6 %
Motorway Distance Share	29.6 – 35.2 %
Urban Speed Range	0 – 60 km/h
Rural Speed Range	60 – 90 km/h
Motorway Speed Range	>90 km/h
Average Test Duration	1 hr 54 min
Altitude Range	24 – 103 m
Cumulative Elevation Gain	563 m/100km

Data Processing:

- Fuel economy was calculated by carbon balance
- CO, NO_x, PN RDE emissions were calculated using Package 4 methods using Horiba's OBS-PP software
- Other monitoring (GASMET, INFLUX, Thermocouples) data time-aligned with primary (OBS-ONE) data using correlation alignment, and emissions calculated separately

Main RDE-4 Results

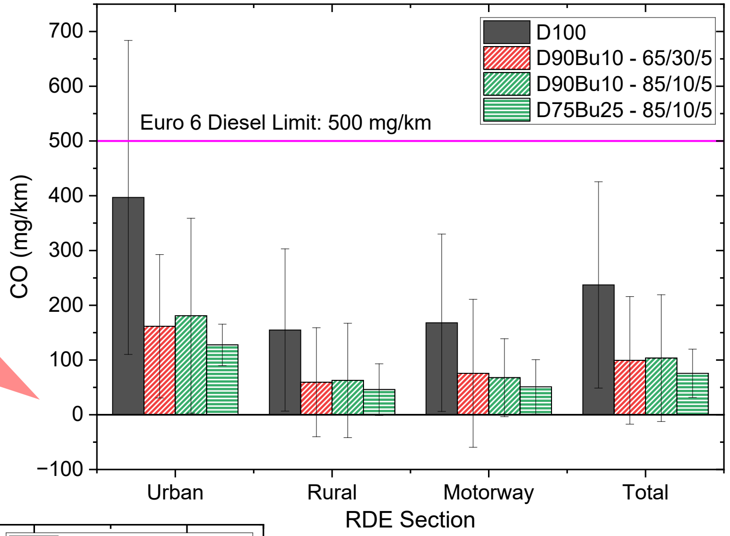
Exhaust emission trade-offs for one diesel hybrid vehicle when switching from a conventional Ultra Low Sulphur diesel (ULSD) to a 25% blend of an advanced biofuel (a butyl-based mixture derived from the acid catalyzed alcoholysis of lignocellulosic biomass) and the same diesel

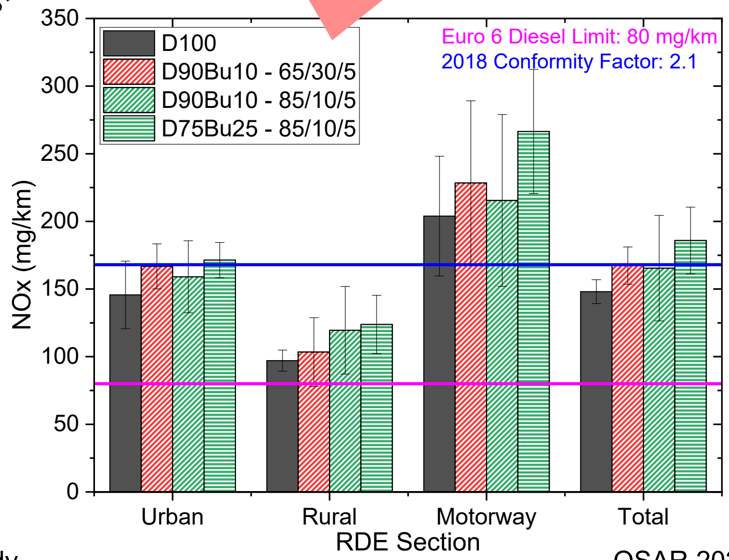


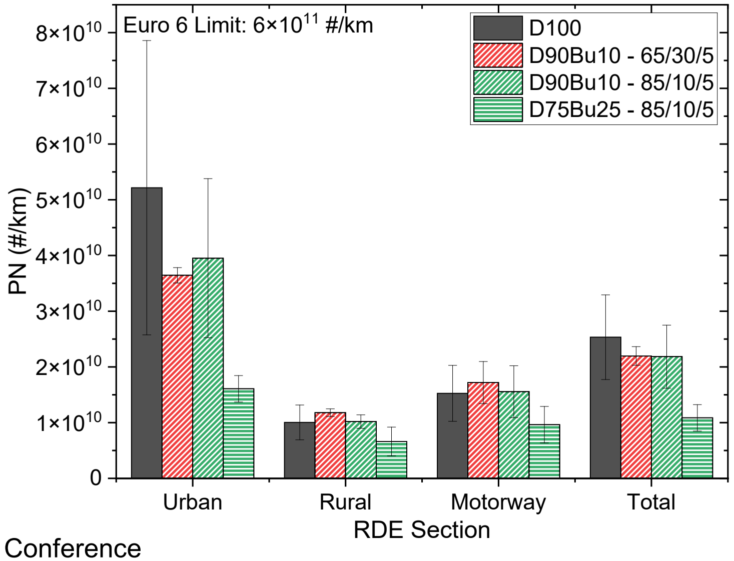
Fuel economy (and CO_2) increases of up to 5%

… NO_x increases of up to 25%

… CO decreases of up to 57%







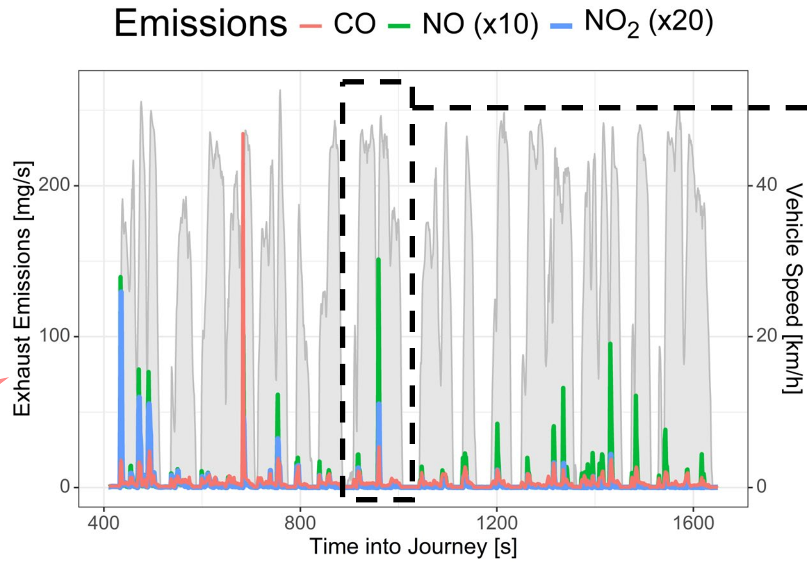
… and PN decreases of up to 72%

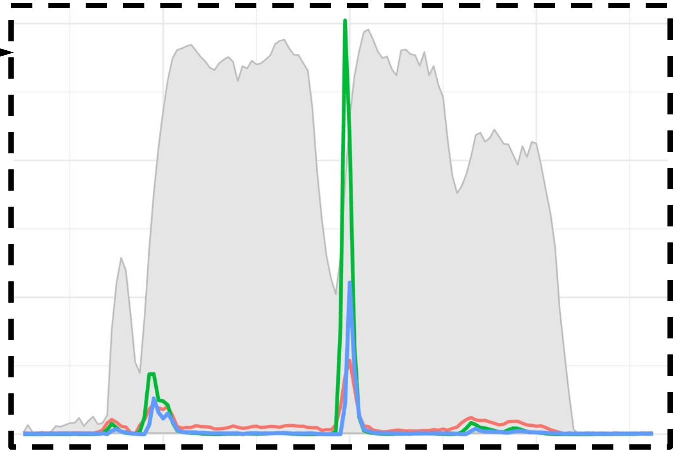
(NB: Scott's presenting more on the RDE analysis at European Combustion Meeting 2025)

The Challenge

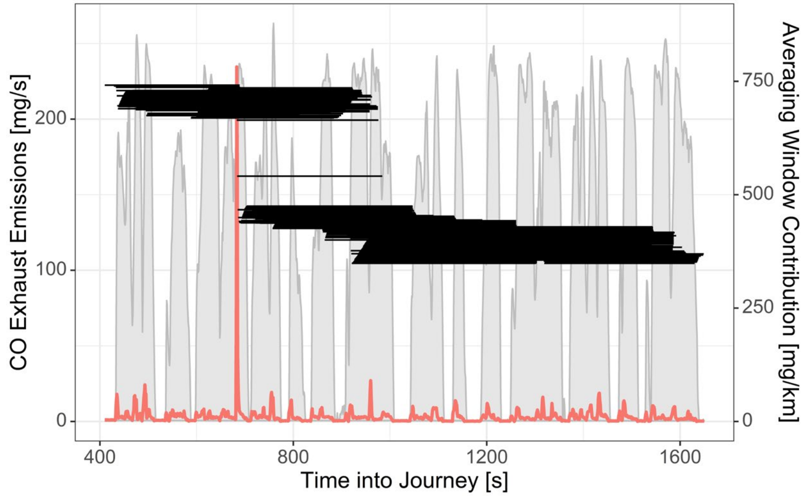
Looking at the sources of variance in the 1-Hz data used to calculate the RDE emission rates and associated error bars…

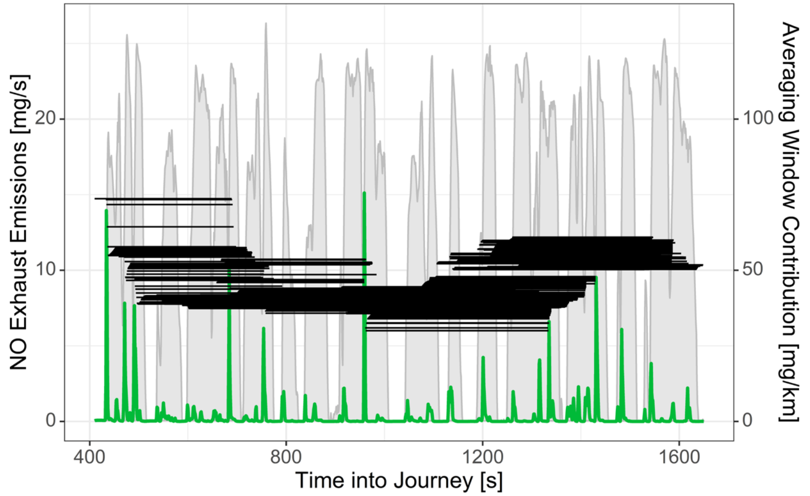
High emissions of most species associate with load events …

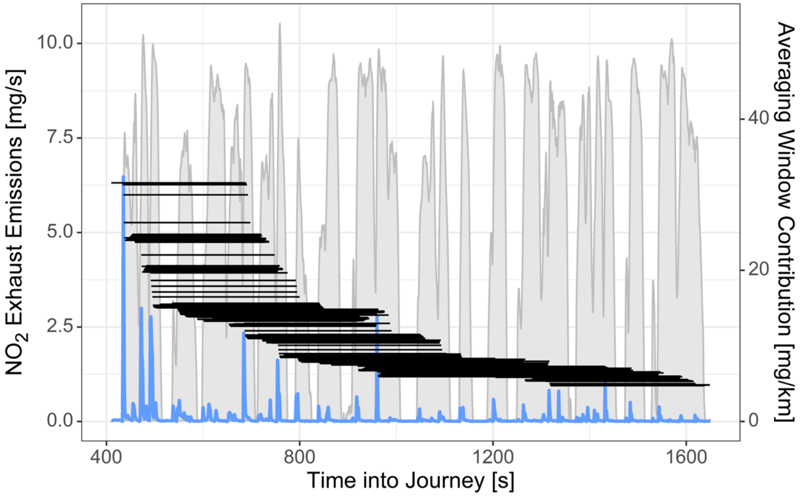




… Using moving-average windows to demonstrate how the frequency, intensity and duration of these events AND baseline all affect reported emissions







Applying a Source Contribution Approach

Using a conventional 'linear-combination of profiles' model BUT interpreting as indicative of exhaust-out emissions chemistry (and source/sink behavior) rather than a classical 'source'

Emissions time-series

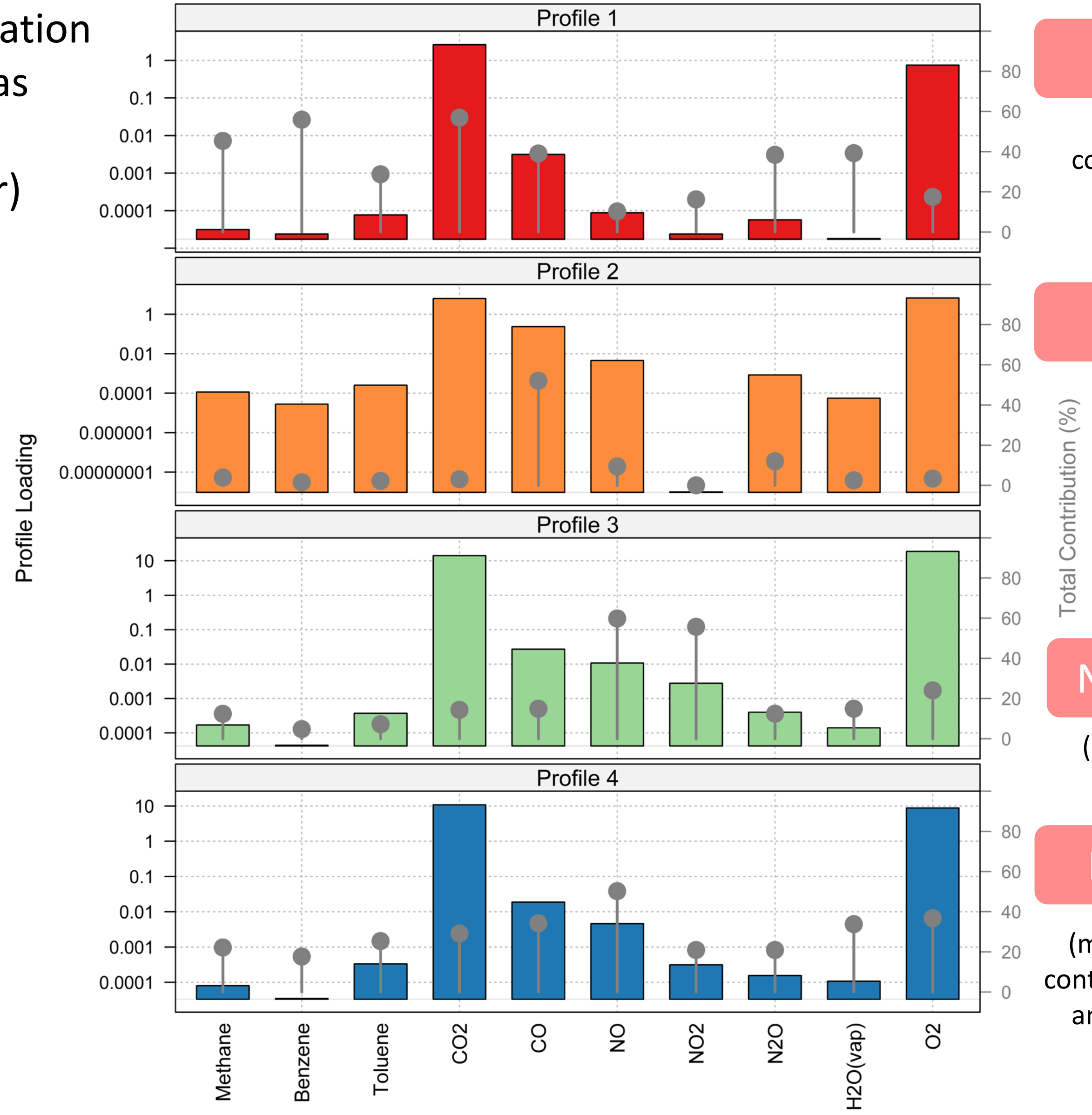
Their Contributions …

$$x_{ij} = \sum_{k=1}^{K} N_{ik} \times M_{kj} + e_{ij}$$

… and Contribution Profiles

Using EPA ESAT software and Positive Matrix Factorisation (PMF)-style 'multiple runs/random start-point' strategy to solve this…

https://quanted.github.io/esat/



Base Case

(main/major contributor to overall emissions)

CO-rich

(main CO contributor)

NO/NO_2-rich

(main NO and NO_2 contributor)

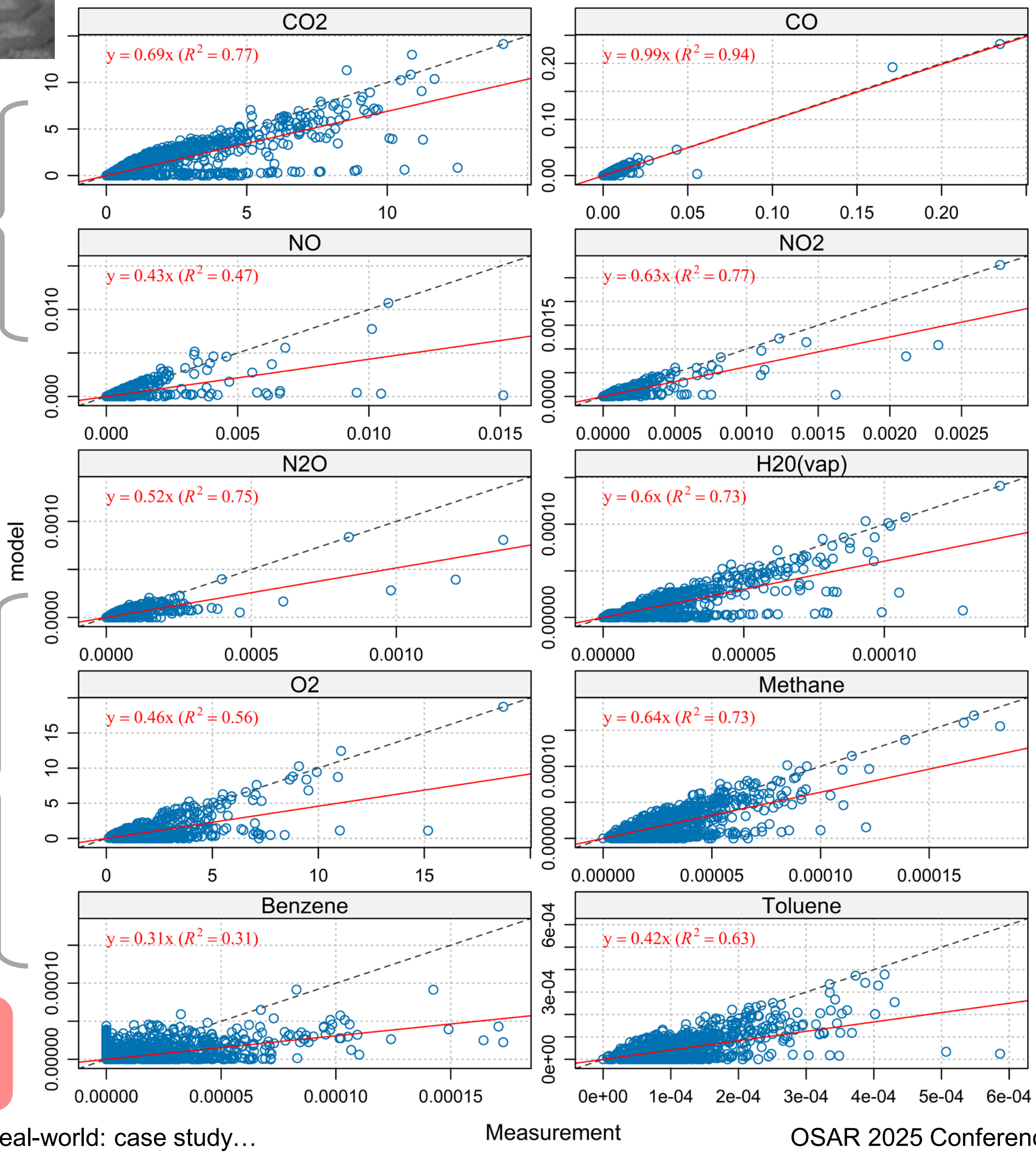
NO/NO_2 (2)

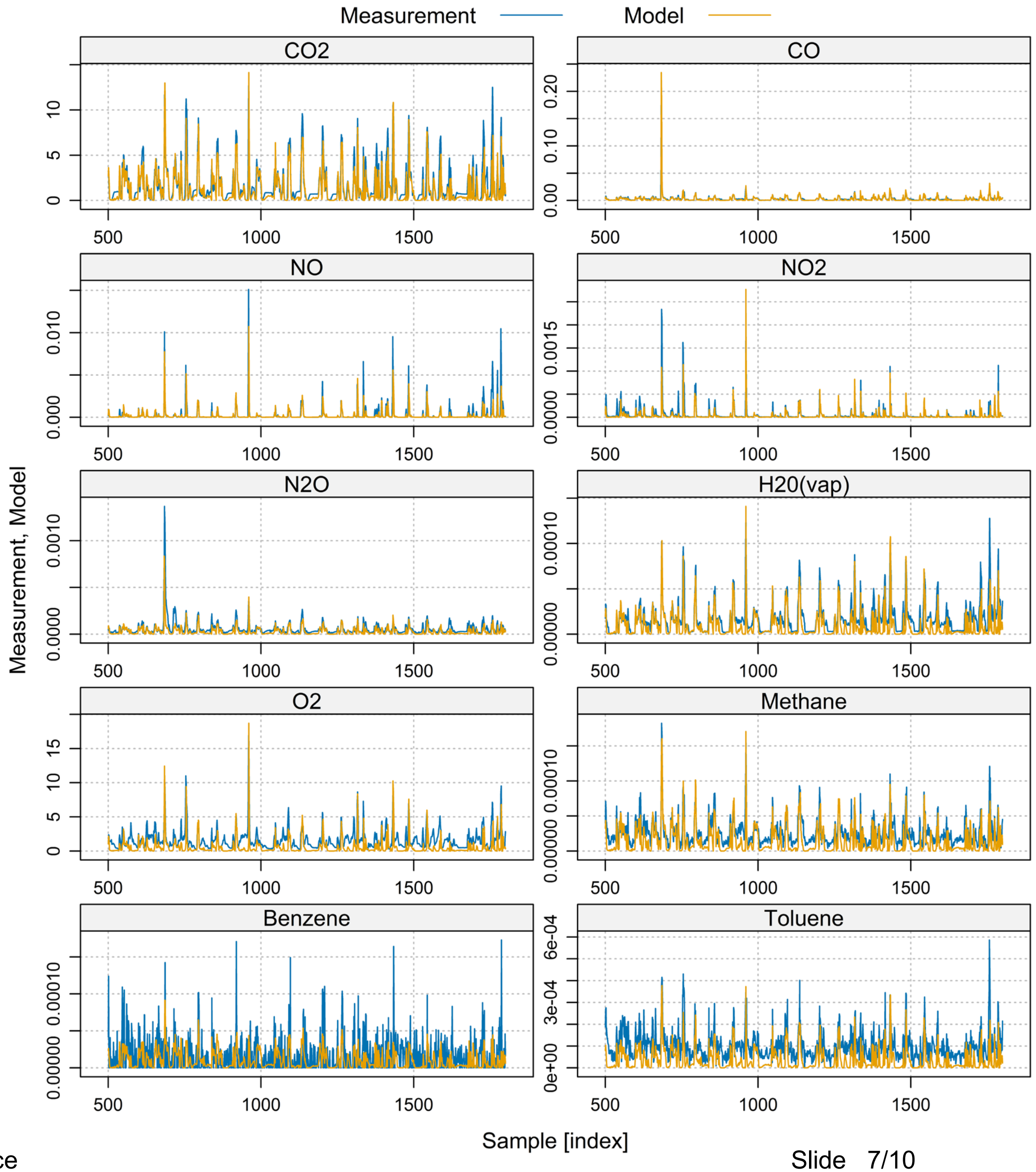
(major NO and NO_2 contributor but less NO and much less NO_2 than profile 3)

Model Validation

OBS-ONE

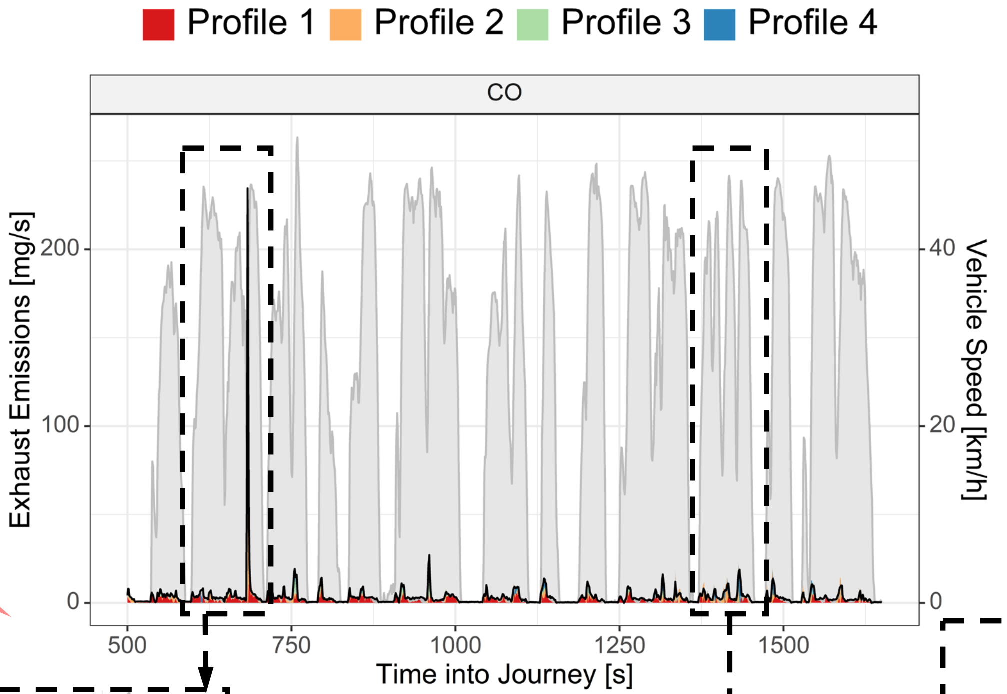
GASMET

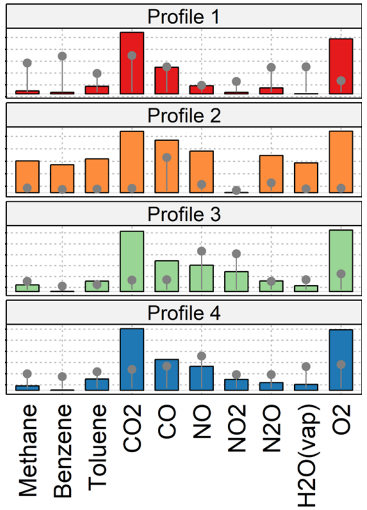




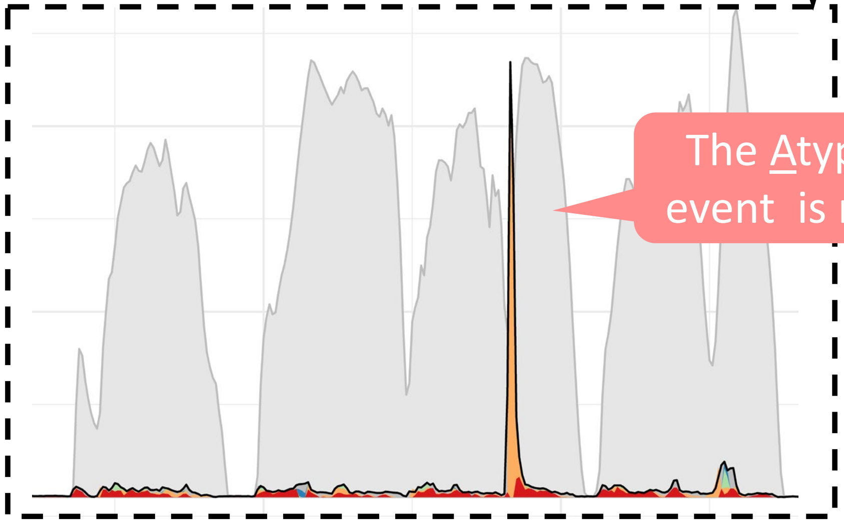
(caveat: work in progress)

Emission Events (1)

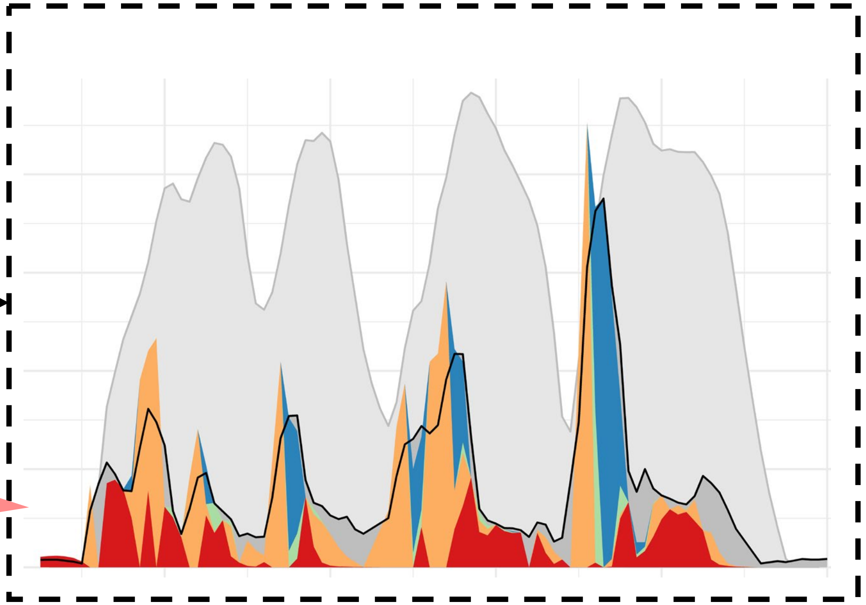




Baseline (idle and low load) dominated by Profile 1

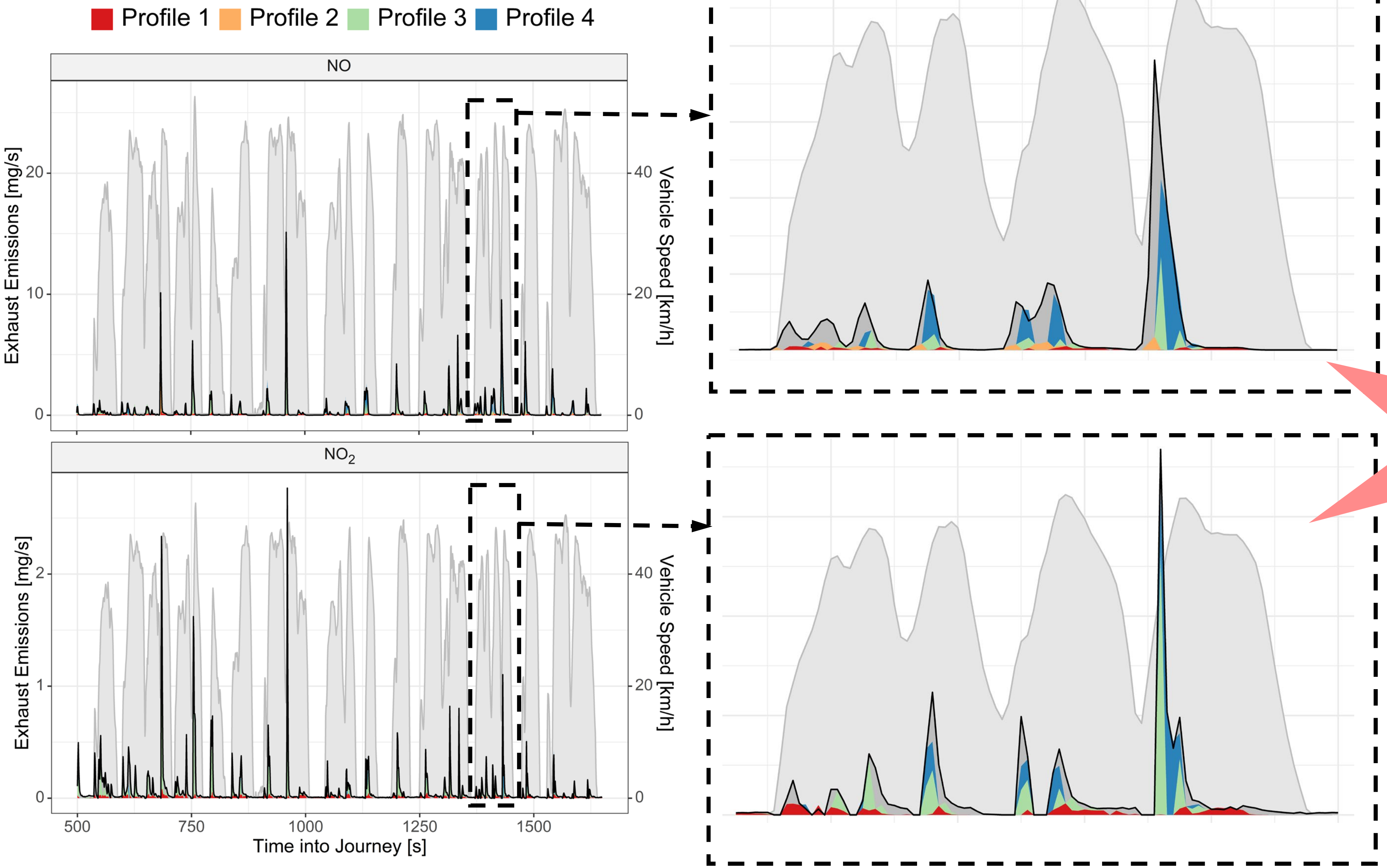


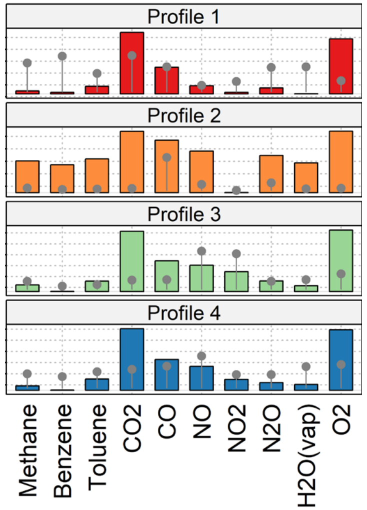
The Atypically large CO event is mostly Profile 2



… but other less extreme (more typical) load events move from Profile 2 to 3/4

Emission Events (2)





NO and NO_2 events typically involve Profile 3/4 combinations

(but still probably need to work on the time alignment ☺)

Conclusion and Comments

Key Points/Comments:

- RDE regulations provide a good benchmark for vehicle manufacturers and policy makers working at larger scales, and, being real-world, are a significant improvement on previous approaches, but are also a ‘blunt tool’ for anyone considering emissions on smaller scales
- The frequency, intensity and duration of the largest pollution events are obviously an important contribution to average emissions, but baseline levels can also be important
- There is obvious scope to use the raw data routinely collected during such regulatory testing to develop a range of additional non-regulatory outputs, e.g. for civil engineers, town planners, vehicle fleet operators, air quality modelers…

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