Heavy-duty brake wear emissions

an on-road measurement campaign using a novel fully open sampling system

Steinmetz, M.F.A. (Misja) | 28th ETH Nanoparticles Conference (Zürich)

19 June 2025

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PP012101 Pilot project
Feasibility study on reduction of traffic-related particulate emissions by means of vehicle-mounted fine dust filtration

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KTH Vetenskap och Konst — Kungl Tekniska Högskolan

LAT Laboratory of Applied Thermodynamics

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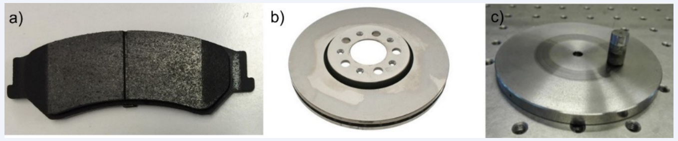
Introduction



Brake Wear Emissions project methodology

Light-duty

- Lab testing: brake dyno PMP methodology
- ↓
- On-road validation: On-road testing LD

Heavy-duty

- Lab testing: Scaled lab testing HD; Vehicle lab testing HD
- ↓
- On-road validation: On-road testing HD

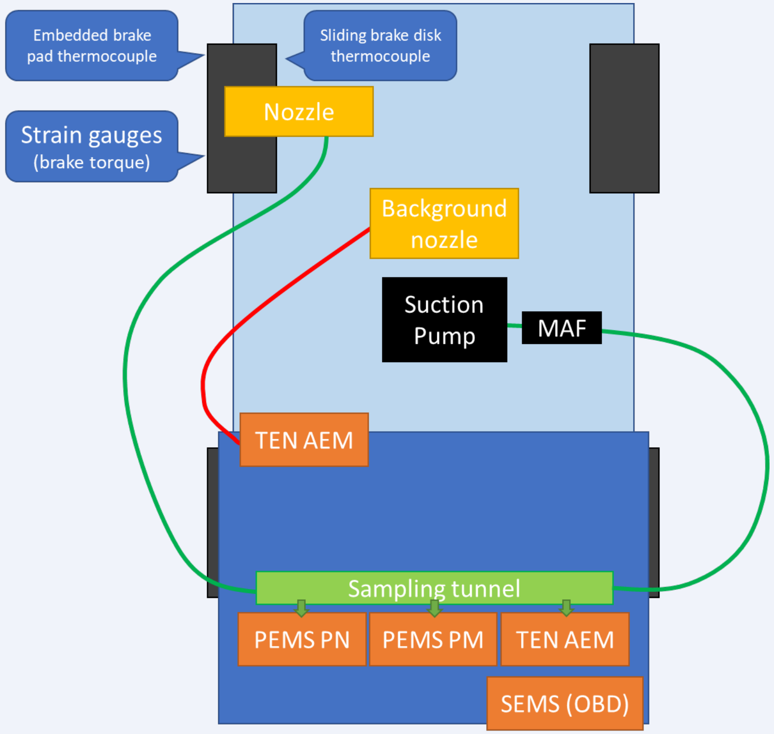
Heavy-duty full vehicle testing methodology

Development of full vehicle measurement methodology.

Important measurement parameters:

- Brake particle emissions (PN and PM)
- Brake temperature
- Braking torque
- Vehicle speed

Novel approach using open design brake wear emissions sampling.



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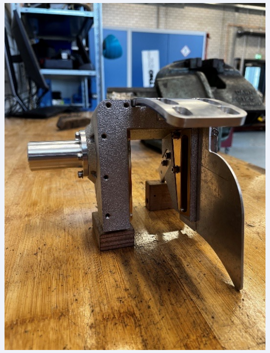
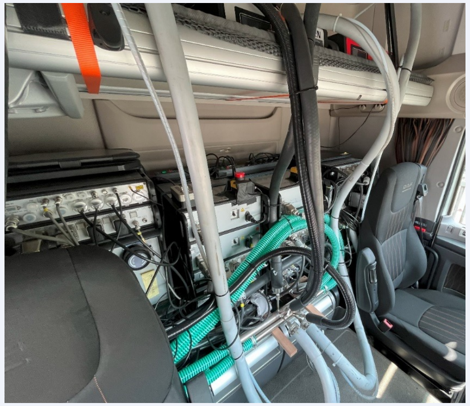
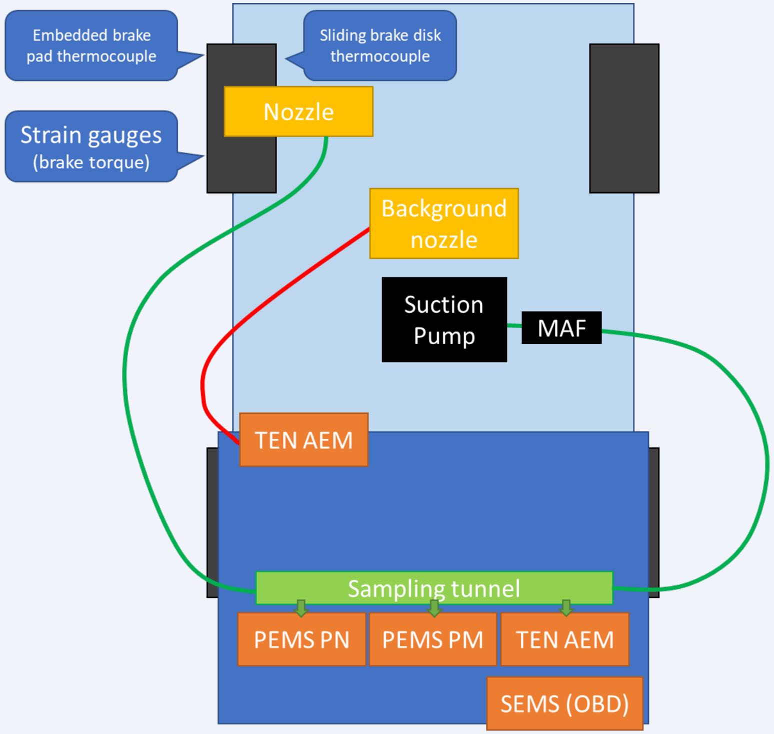
Heavy-duty full vehicle testing methodology

Version 1 (tractor)







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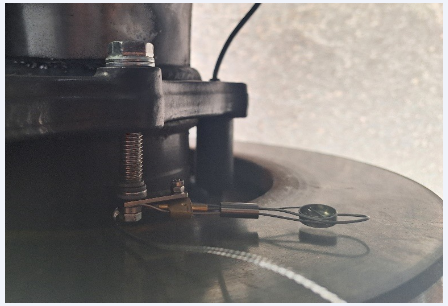
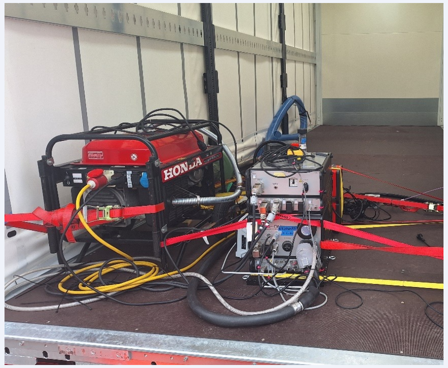
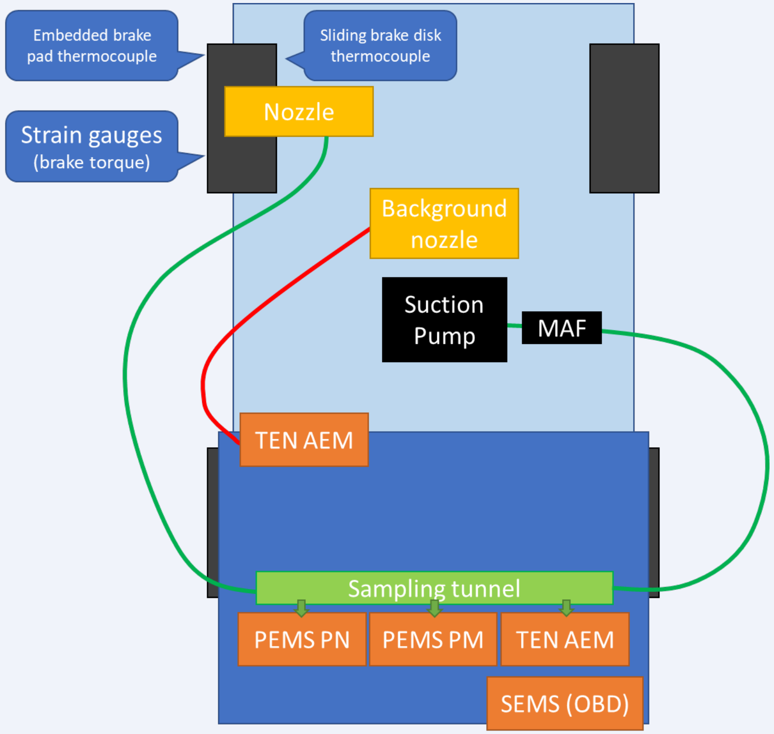
Heavy-duty full vehicle testing methodology

Version 2 (rigid truck)







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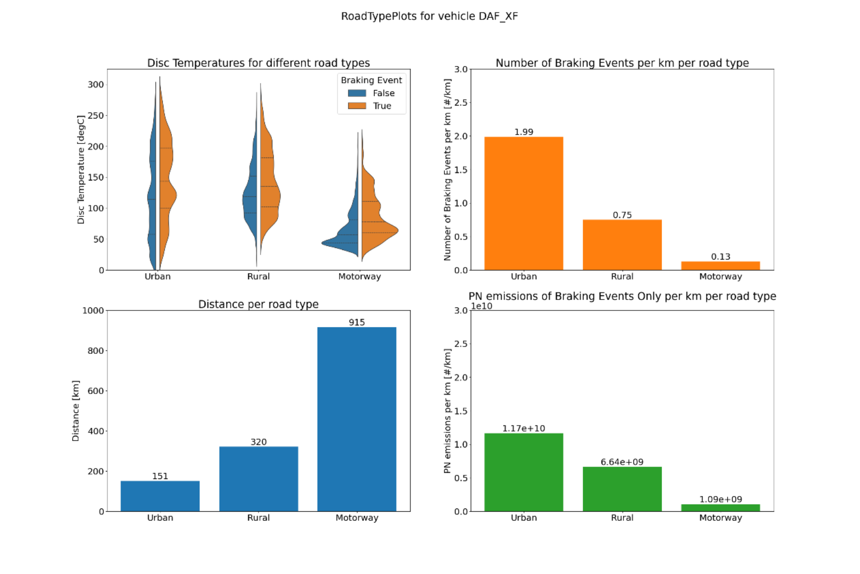
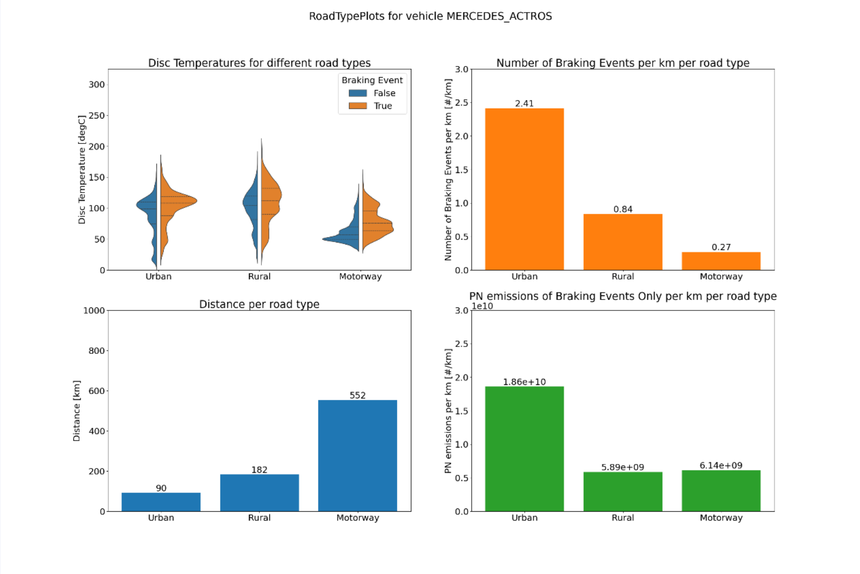
Results of tractor trailer and rigid truck testing





- Urban gives highest PN emissions per km and Motorway the lowest.
- Similar dominant temperatures, significantly higher peaks for the tractor.
- Higher pump speeds seem to collect more brake wear particles and more background particles.

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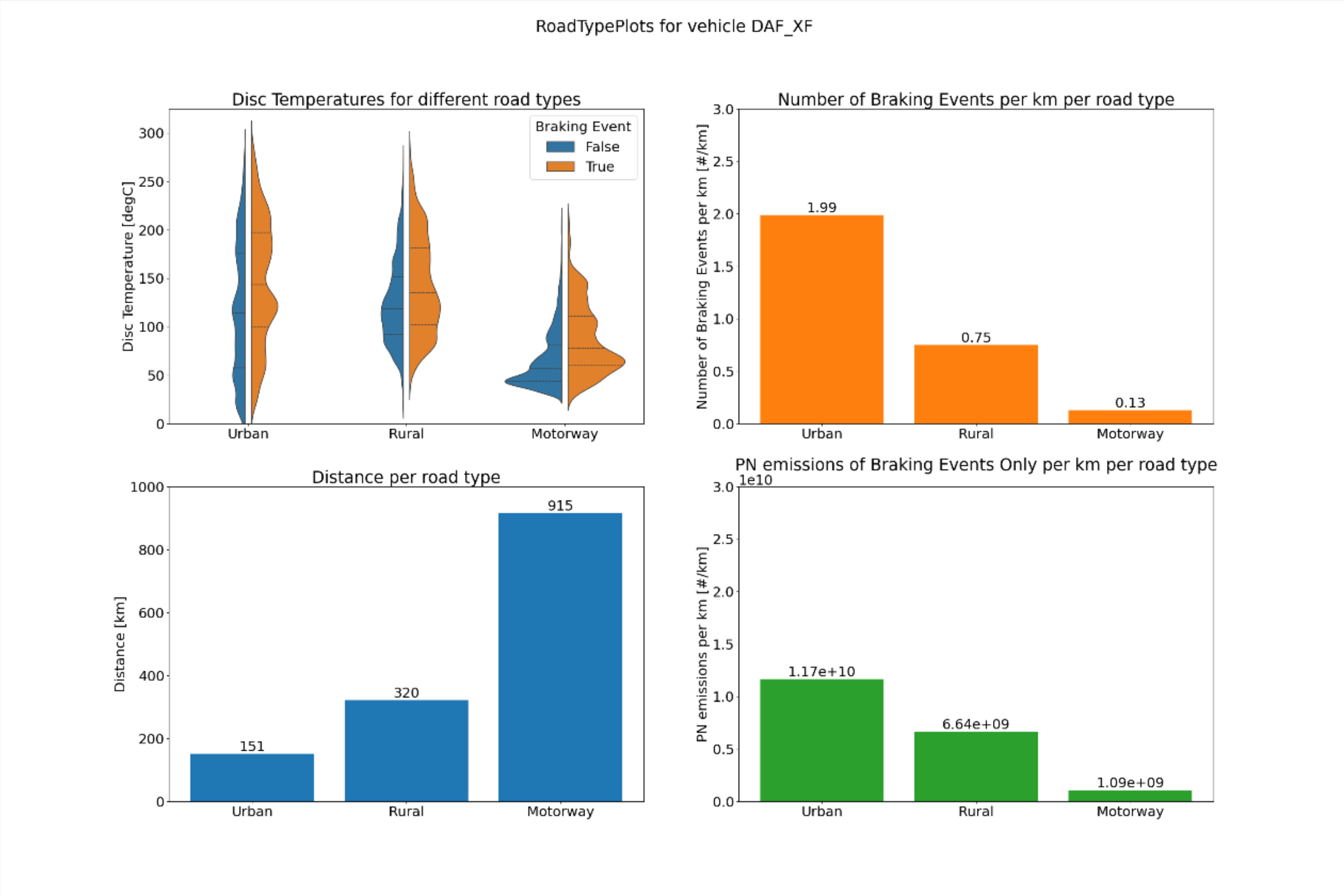

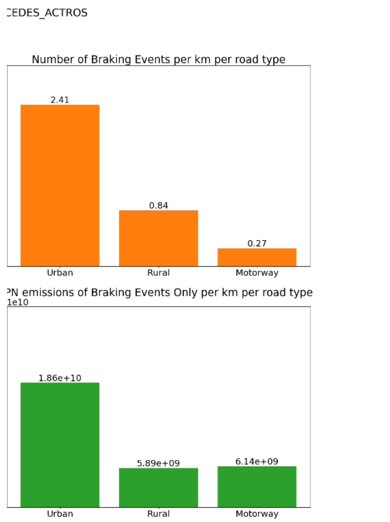

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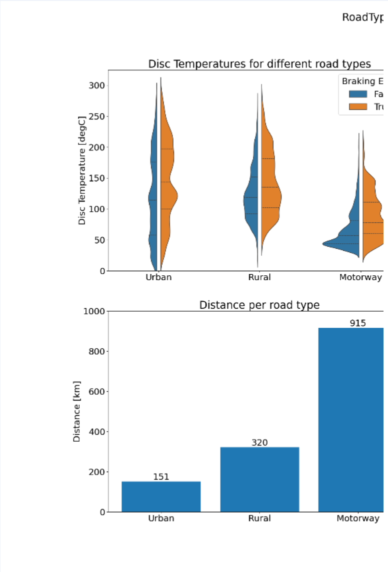

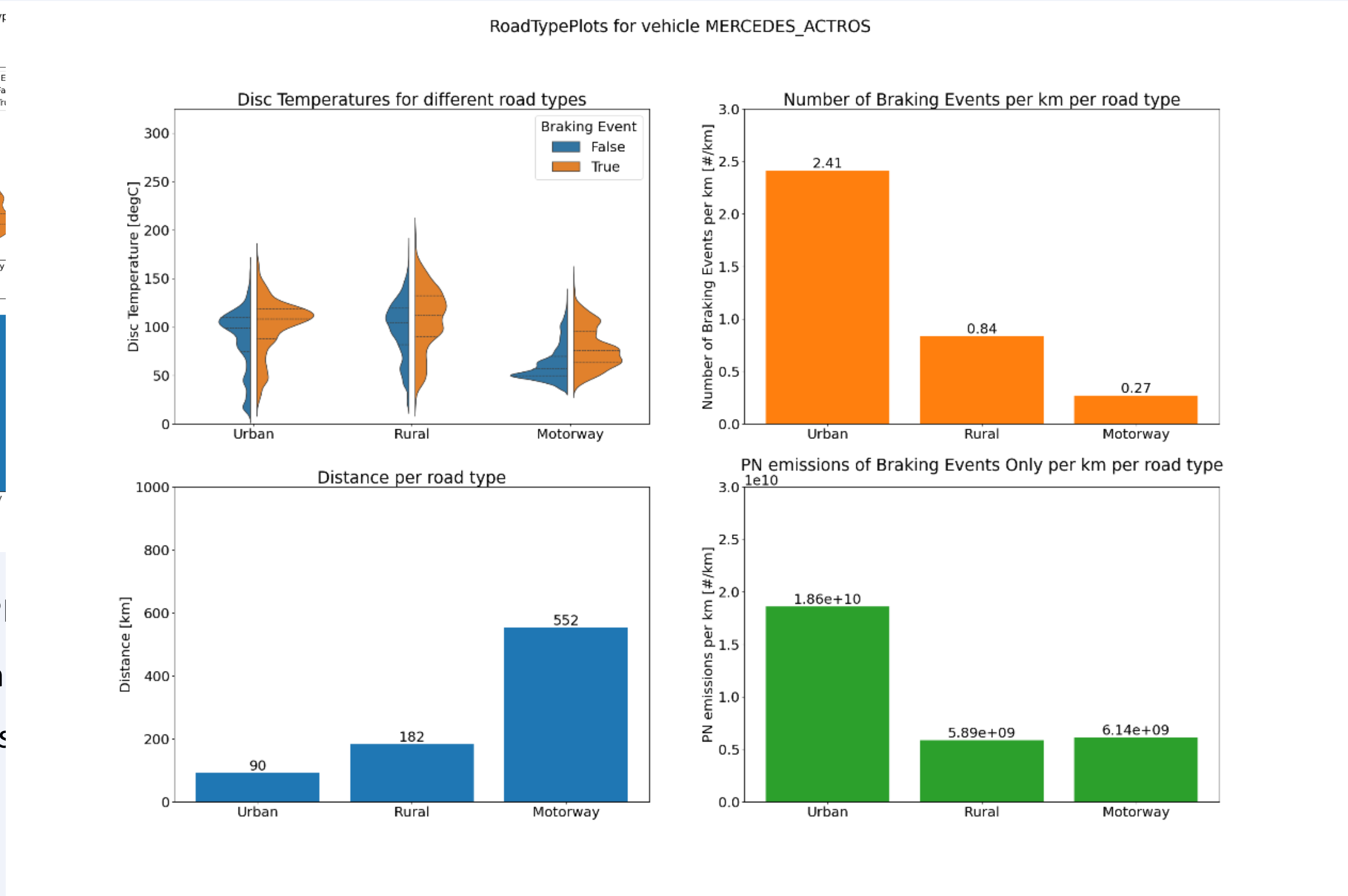

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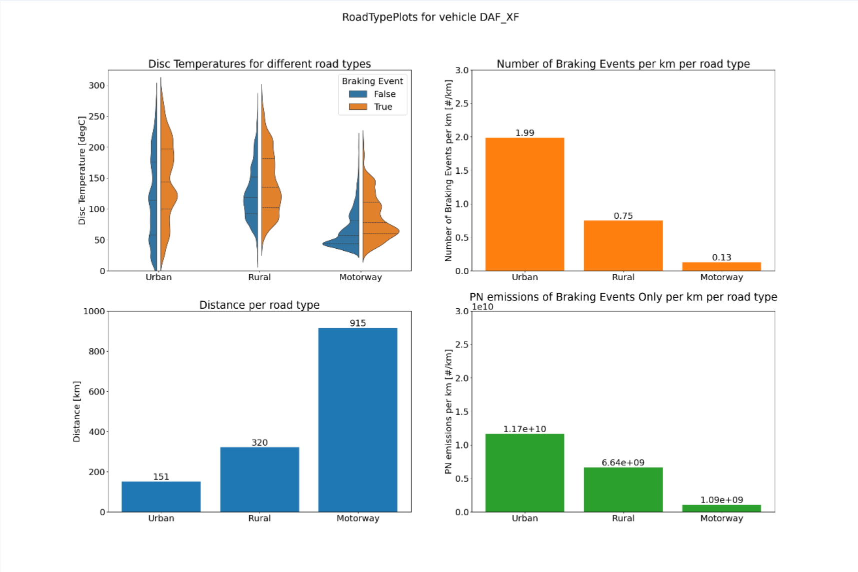
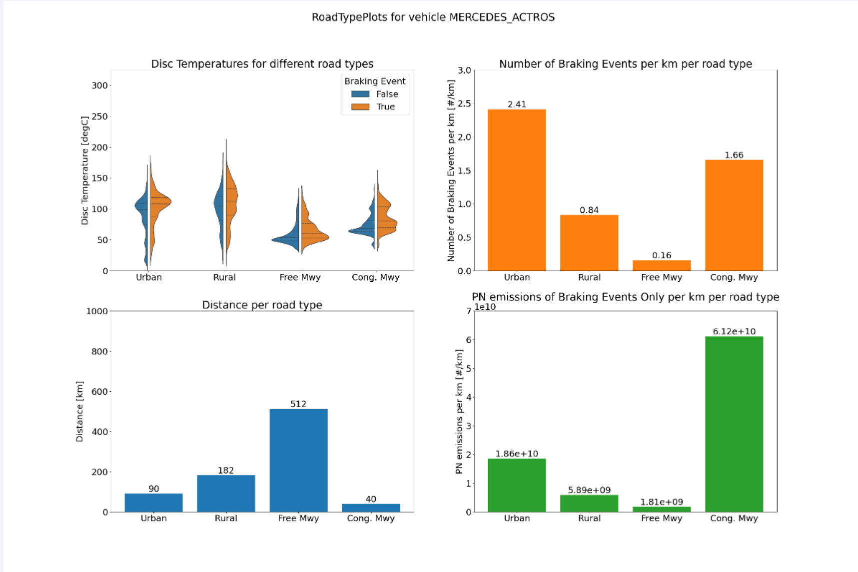




- Congested motorway driving is important for motorway figures

On-road Temperatures and Particles for Heavy-Duty Brake Wear

- Journal paper in MDPI’s Atmosphere
- More detailed analysis and modelling of the heavy-duty on-road brake wear data collected in the PP012101 Pilot project
- Fully open sampling system to minimize impact on airflow and brake temperature
- Detailed models of on-road brake temperatures and brake wear emissions for a measured heavy-duty tractor trailer
- Joint work with Jann Aschersleben and Aspasia Panagiotidou

atmosphere MDPI

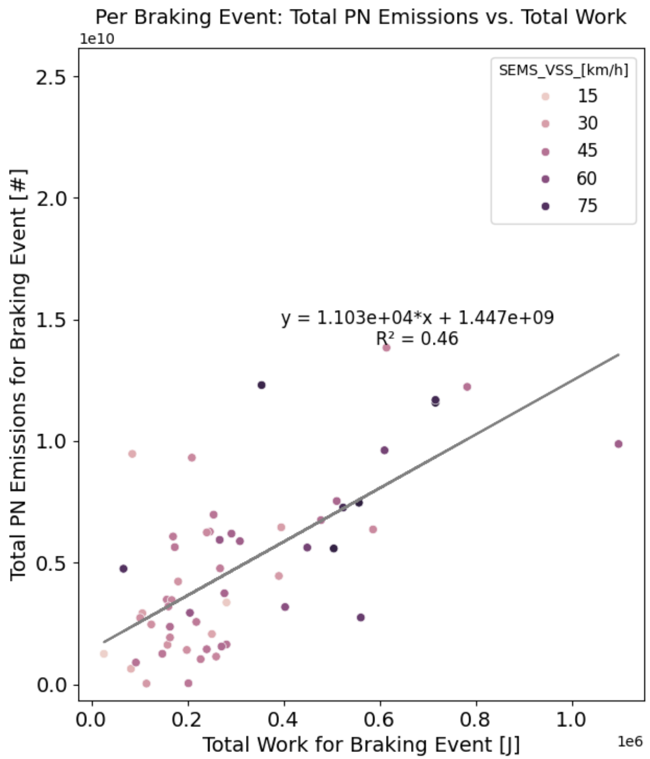
Article

On-Road Measurements and Modelling of Disc Brake Temperatures and Brake Wear Particle Number Emissions on a Heavy-Duty Tractor Trailer

Misja Frederik Alban Steinmetz *, Jann Aschersleben and Aspasia Panagiotidou

Results: Variable Correlations

- **Selection cuts** on braking force, temperature, and duration to filter data
- **Clear correlation between total PN emissions and total work**
  - Braking work: $W = \int P(t)dt$
  - Braking power: $P(t) = (F(t) \times r) \cdot \omega(t)$



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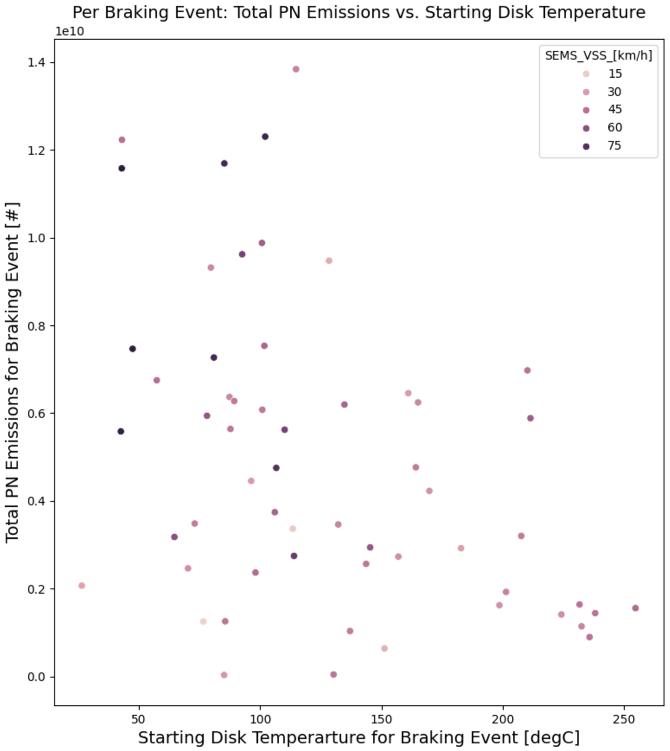
- In our measurement setup: **no correlation between total PN emissions and starting disk temperature**



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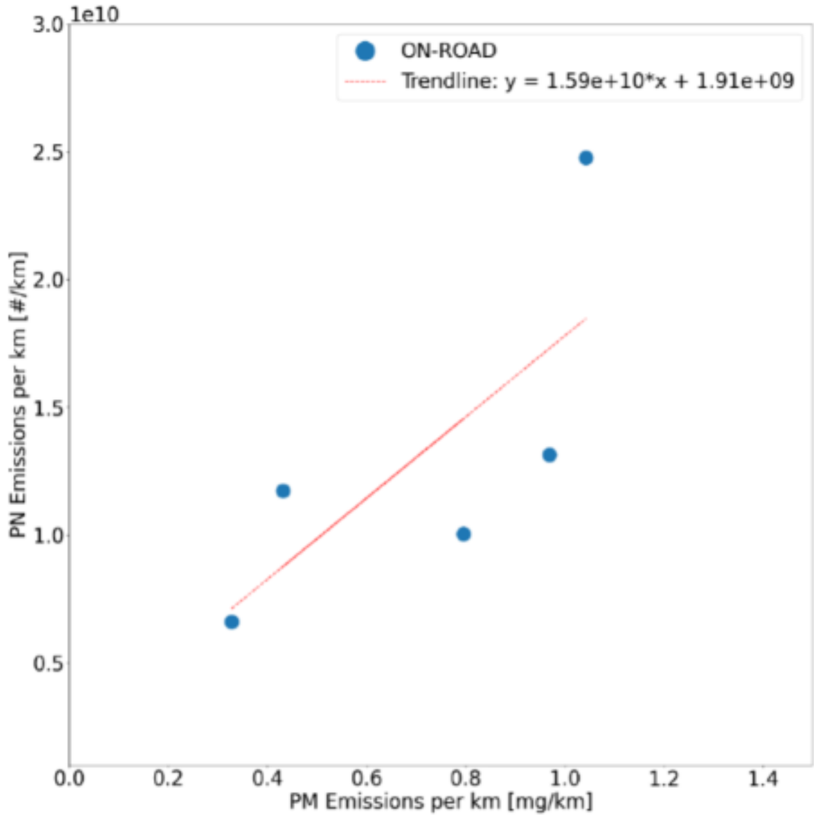
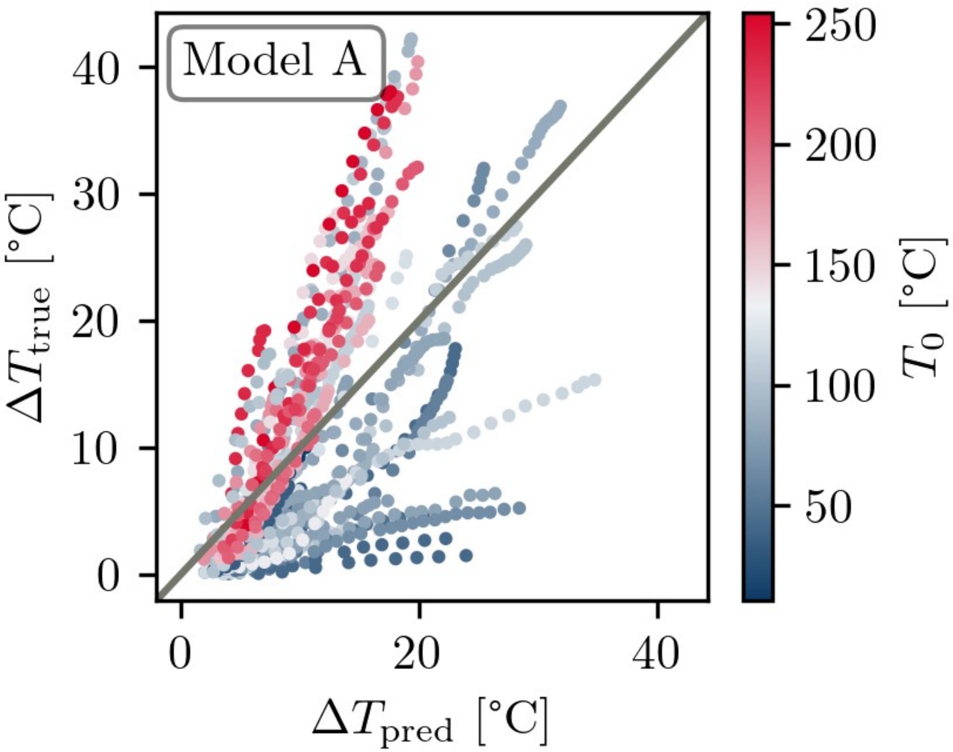
- **Correlation between PN emissions and PM emissions**



Results: Disk Temperature Heating

- **Model A*:**
  - $\Delta T(W) = a_1 W + a_2$
  - Braking work: $W = \int P(t)dt$
  - Mean absolute error: 5.4 °C

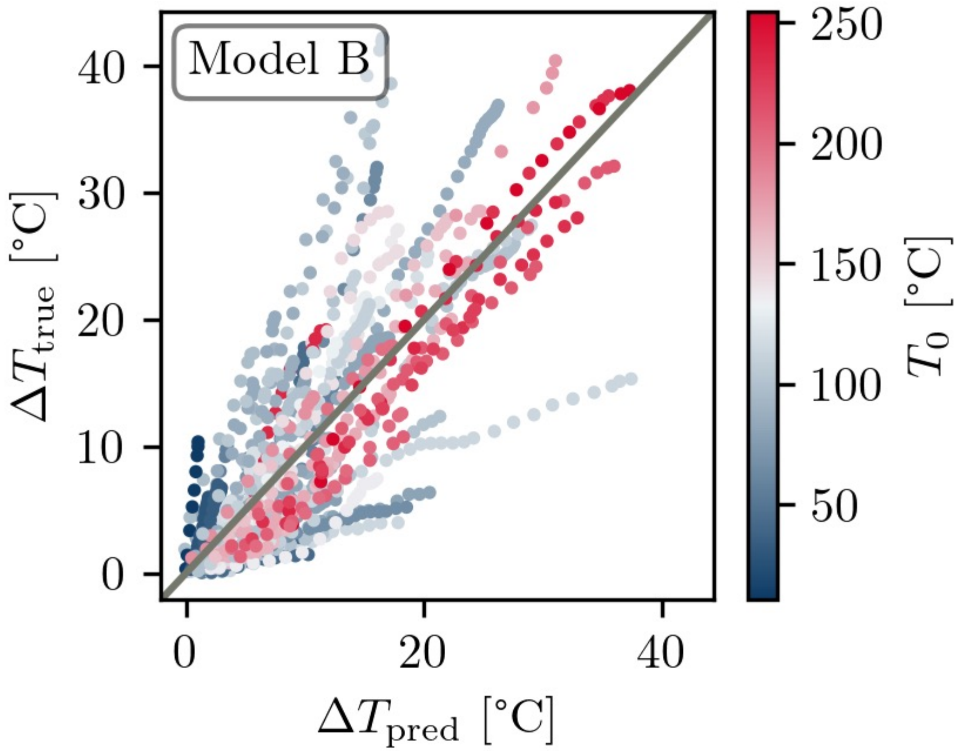
*Best fit parameters: $a_1 = (5.9 \pm 0.3) \times 10^{-5}$ °CJ^{-1}, $a_2 = (1.5 \pm 0.5)$ °C



Results: Disk Temperature Heating

- **Model A:**
  - $\Delta T(W) = a_1 W + a_2$
  - Braking work: $W = \int P(t)dt$
  - Mean absolute error: 5.4 °C
- **Model B×:**
  - $\Delta T\ (W, T_0) = a_1 T_0^{\alpha} W + a_2$
  - Starting temperature: T_0
  - Mean absolute error: 4.2 °C

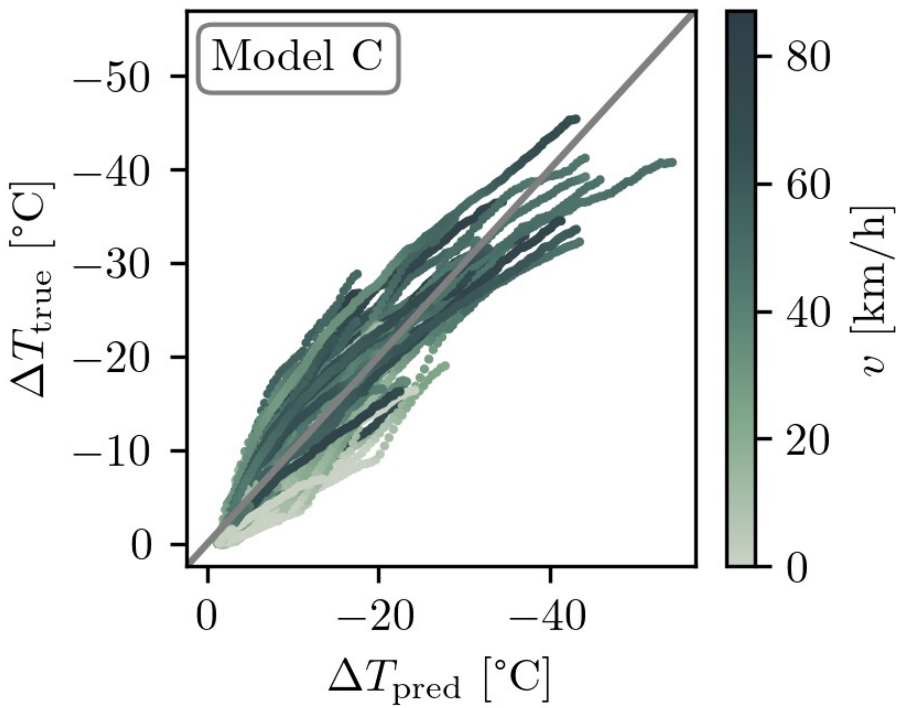
×Best fit parameters: $a_1 = (9.4 \pm 1.7)\times 10^{-7}$ °CJ^{-1}, $a_2 = (-0.2 \pm 0.3)$ °C, $\alpha = (9.0 \pm 0.3)\times 10^{-1}$



Results: Disk Temperature Cooling

- **Model C*:**
  - $\Delta T\ (Q) = \ b_1 Q\ \ + \ b_2$
  - Cooling term: $Q = \int \big(T(t) - T_{amb}(t)\big)dt$
  - Mean absolute error: 2.2 °C

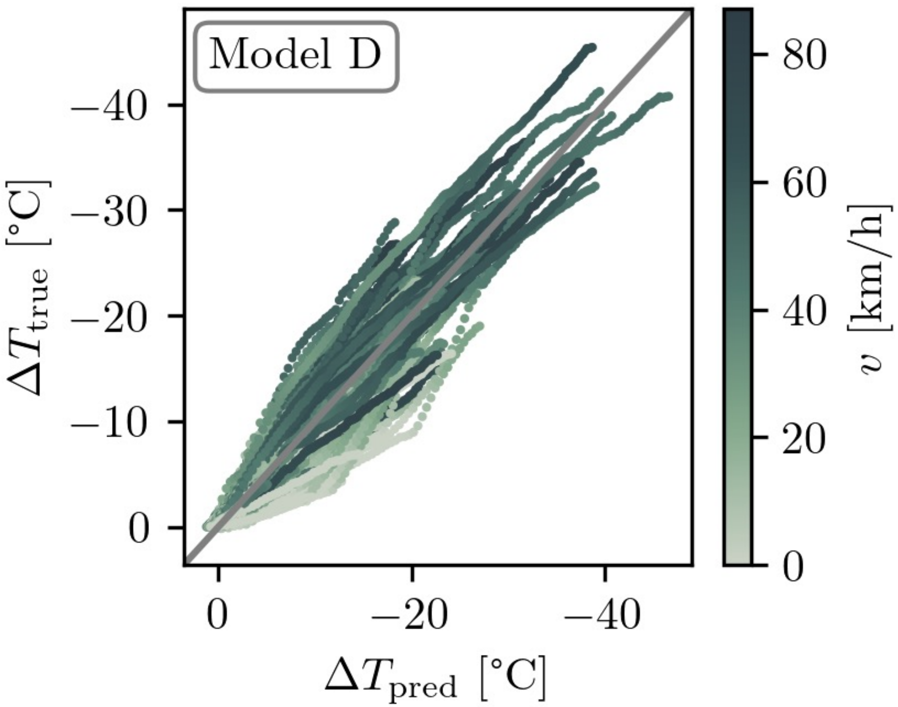
*Best fit parameters: $b_1 = (-2.05 \pm 0.01){\times}10^{-3}$ °CJ^{-1}, $b_2 = (-1.15 \pm 0.04)$ °C



Results: Disk Temperature Cooling

- **Model C:**
  - $\Delta T\ (Q) = \ b_1 Q\ \ + b_2$
  - Cooling term: $Q = \int \big(T(t) - T_{amb}(t)\big)dt$
  - Mean absolute error: 2.2 °C
- **Model D[x]:**
  - $\Delta T\ (Q) = \ b_1 Q^{\beta}\ + b_2$
  - Mean absolute error: 2.0 °C

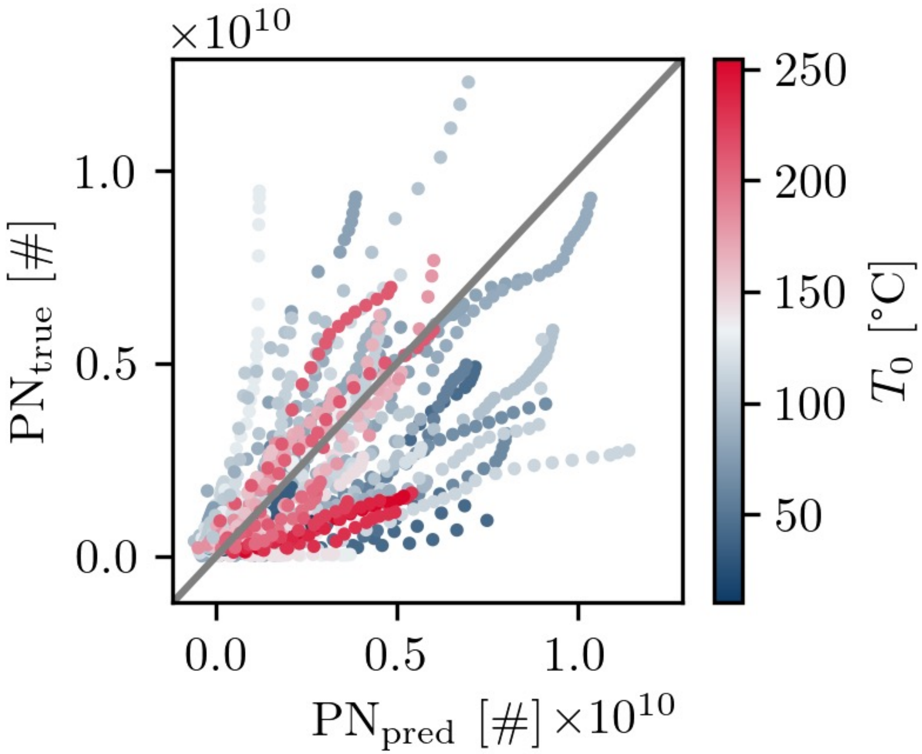
[x]Best fit parameters: $b_1 = (-2.05 \pm 0.01){\times}10^{-3}$ °CJ^{-1}, $b_2 = (-1.15 \pm 0.04)$ °C



Results: PN Emissions

- **Model*:**
  - $\text{PN}(W) = c_1 W + c_2$
  - Braking work: $W = \int P(t)dt$
  - Mean absolute error: 1.5×10^9 #

*Best fit parameters: $c_1 = (2.2 \pm 0.2) \times 10^4$ #/J, $c_2 = (-6.3 \pm 1.0) \times 10^8$ #



Conclusions

- Highest number of braking events and emissions per kilometre on urban roads, lowest on the motorway
- Congested motorway driving has a relatively high number of braking events and emissions per kilometre
- The higher the braking work applied on the disc, the higher the PN emissions
- Brake temperature increase depends on both the braking work and the initial temperature of the disc
- Non-linear behaviour in the cooling of the braking disc
- Successful proof of concept for on-road HD brake wear measurements