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Comparisons of Different RDE Measuring Systems

Commissioned by the Federal Office for the Environment (FOEN)

Project: Research on PEMS Testing Methodology and on Real Driving Emissions (ResRDE2) *)

BAFU contract nbr.: 19.0106.PJ / S081-0349, 2nd report, WP4

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This study/report was prepared under contract to the Federal Office for the Environment (FOEN).
The contractor bears sole responsibility for the content.

May 2020 R004

*) Abbreviations see at the end of report

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1. SUMMARY

The control of real driving emissions (RDE) by means of portable emission measuring systems (PEMS) is generally an accepted way to reduce further the air pollution of traffic.
In several research activities with different PEMS open questions resulted concerning the methodology of testing and of evaluation.
Additionally, there are questions about RDE from different types of vehicles, or on different routes with varying operating conditions, with different testing apparatus and with the use of recent evaluation method.

The project ResRDE(2) considers these objectives in 5 working packages (WP).

This 2nd report presents the results of the WP4 – comparisons of PN PEMS and GasPEMS: Horiba ↔ NM3 (CPC & NGK) examples on different vehicles (Diesel, gasoline), as well as the comparisons of data from HDV Euro VI (WVU).

The most important results are:

<u>Part 1</u>

- NM3 gives higher PN-concentrations readings, especially at very low concentrations. This is connected with the higher sensitivity of NM3 in the sub 23nm size range. The differences of integrated results were between 10% and 74%.
- Diesel engines equipped with DPF have very low PN-emissions. Sometimes, the average PN-values over a test are lower than the detection limit (the lower detection limit for both systems is at 10^3#/cc).
- Main PN-emissions occur during the cold start and / or DPF regeneration.

<u>Part 2</u>

- The PN-results obtained with CPC (PMP) and OBS-PN correlate very well.
- At higher PN-concentrations, there is a very good agreement between NM3 and OBS; at lowest PN-concentrations NM3 indicates higher PN due to the higher sensitivity of NM3 in the sub 23nm size range.
- The comparison of NCEM and OBS at higher PN-concentrations is relatively good; at lowest PN-concentrations the NCEM-PN-signal drifts away and there is no correlation.
- The average integral PN-emission level of GDI w/o GPF is by 2 to 3 orders of magnitude higher, than for Diesel with DPF.

<u>Part 3</u>

- The NCEM PN measuring device is not appropriate for the low PN-concentration control or monitoring.
- The NCEM NO_x sensor is a useful device for vehicles emissions control and screening except of low temperature range where the sensor cannot be operated.

2. OBJECTIVES OF ResRDE(2)

According to the project proposal from March 2019, the objectives of the working packages are:

<u>WP1</u>: Emission factors from non-driving situations with different vehicles.

Part 1: Analysis of present data

From the present data of RDE obtained with different vehicles, the specific situations of emissions like cold start, warm-up and stop&go, have to be found, analyzed and compared with the average cycle emissions.

Part 2: Reproduction of non-driving situations

It was proposed to investigate two gasoline and two Diesel passenger cars. The tests are performed in idling cold/warm, during the warm-up phase and in stop&go operation with a different portion of idling. The tests are performed on chassis dynamometer with measuring systems: CVS and PEMS (including HC_{FID} and PN).

After cold start, there are different options of operating profile to influence the warm-up phase. It is proposed to use two extreme variants: idling and high load (like highway). The cold start would be at 20-25°C. Other options of the cold start temperature are to be discussed.

To simulate the different portion of idling in stop&go operation, specific cycles have been created in order to repeat the same trials with all vehicles. Testing of stop&go operation will be carried out with warm engine.

WP2: RDE legislation package 4.

From January 2019, new amendments to the RDE-legislation was issued with new requirements of evaluation of results. It is necessary to deepen the new regulation, to perform the new evaluation procedure and to compare it with the previous one.

WP3: Extended RDE conditions – examples and comparisons of RDE for: winter/summer driving, mild/aggressive driving and altitude.

WP3(a): RDE – winter/summer – examples on two vehicles (passenger cars: Diesel, gasoline).

WP3(b): RDE with mild/aggressive driving behavior - examples on two vehicles (Diesel, gasoline).

WP3(c): RDE in “normal» legally valid circle compared with a high-altitude circle – examples on two vehicles (Diesel, gasoline).

WP4: Further comparisons of PN PEMS and GasPEMS: Horiba ↔ NM3 (CPC & NGK) examples on two vehicles (Diesel, gasoline), as well as the comparisons of data from HDV Euro VI (WVU).

The vehicles are tested with warm start on chassis dynamometer and on-road. Compared are: stationary CPC (PMP), PN PEMS Horiba, NM3 and NGK and gaseous components GasPEMS. The comparisons of results from the previous tests HDV Euro VI (WVU) are included.

WP5: RDE results on different RDE routes.

The same vehicle is measured on the test circuits of other associated institutes (EMPA, TCS, TFZ).

2.1. Research topics of present report

This 2nd report presents the results of WP4, which consists of three parts:

Part 1 - Comparisons of PN measured with OBS-ONE-PN and NanoMet (NM3) in WLTC and during RDE (two Diesel vehicles, V1 & V2).
Part 2 - Comparisons of PN measured with CPC, OBS-ONE-PN, NanoMet (NM3) and NCEM in WLTC (GDI and Diesel, V3 & V4).
Part 3 - Comparisons of PN & NO_x measured with OBS-ONE and NCEM during RDE (Diesel HDV, Euro VI, WVU).

3. TESTING MATERIAL, MEANS AND METHODS

3.1. Test vehicles, fuels and lubricants

The most important data of vehicles used for the investigations are listed in the table1.

Name	Type		Model	Fuel		EATS	Displ.	Power	Odometer
-	-		Year	-	-	-	ccm	kW	km
V1	LDV	VAN	2012	Diesel	Euro 5a	DOC/DPF	1.995	84	142'000
V2	LDV	VAN	2015	Diesel	Euro 6b	DPF/SCR	2.143	100	24'900
V3	LDV	PC	2012	Gasoline	Euro 5a	3WC	1.596	132	32'240
V4	LDV	VAN	2017	Diesel	Euro 6b	DPF/SCR	2.143	100	12'990
V5	HDV	Trailer	2015	Diesel	Euro VI	DPF/SCR	12.809	350	128'735

Table 1: Data of the vehicles used for the comparison tests.

All vehicles were operated with the Swiss market fuels and with the lubricating oils, which actually were present in each vehicle.

3.2. Test methods and instrumentation

3.2.1. Chassis dynamometer and standard test equipment

- roller dynamometer: AFHB GSA 200
- roller diameter: 502 mm
- driver conductor system: Tornado, version 3.3
- CVS dilution system: Control Sistem R03-700 with roots blower
- air conditioning in the hall automatic for intake- and dilution air
  temperature: 20 ÷ 30°C
  humidity: 5.5 – 12.2. g/kg

3.2.2. Test equipment for regulated exhaust gas emissions
(data not used in present report)

This equipment fulfils the requirements of the Swiss and European exhaust gas legislation.

- regulated gaseous components:
  exhaust gas measuring system Horiba MEXA-7100
  CO, CO_2… infrared analysers (IR)
  HCFID... flame ionisation detector for total hydrocarbons
  CH_4FID... flame ionisation detector with catalyst for only CH_4
  NO/NO_x... chemoluminescence analyser (CLA)

The dilution ratio DF in the CVS-dilution tunnel is variable and can be controlled by means of the CO_2-analysis.

3.2.3. PEMS

Most important data of the used Horiba GasPEMS are given in the table 2.

	Gas PEMS
	
Instruments	**Horiba PEMS OBS-ONE**
Exhaust concentrations	CO_2, CO, NO_x, NO_2
Measurement principle	heated NDIR*, CLD, heated line
Engine parameters	OBD
Vehicle speed & position	GPS
Exhaust flow	EFM
Ambient parameters	p, T, H
Electrical power	> 300 W (> 800 W with FID and PN)
Dimensions	500 x 500 x 500 mm + Pitot tube + heated line + batteries

* OBS one: H_2O is monitored to compensate the H_2O interference on CO and CO_2 sample cell heated to 60°C.

Table 2: Data of the applied GasPEMS

3.2.4. PN PEMS

For measurements of nanoparticles different portable systems were used:

- Horiba OBS-ONE-PN PEMS working on CPC-principle, for further information of manufacturer, see annex A1.
- Testo NanoMet (NM3) working on DC-principle, for further information of manufacturer, see annex A2.
- NCEM (NTK Compact Emissions Meter) a sensor-based Gas & PN PEMS. This system is very easily portable, is recognized for emissions monitoring, but not for certification purposes. The PN-measurement is based on the ejector, corona discharge & escaping current method (like Pegasor) and the NO_x-measurement uses the automotive Zirconia Oxide Sensor, [1]. For further information, see annex A3.

As a stationary, PN measuring system on the chassis dynamometer, a CPC 3790 from TSI was used.

3.3. Test procedures

The vehicles were tested on a chassis dynamometer in a WLTC cycle, figure 1.

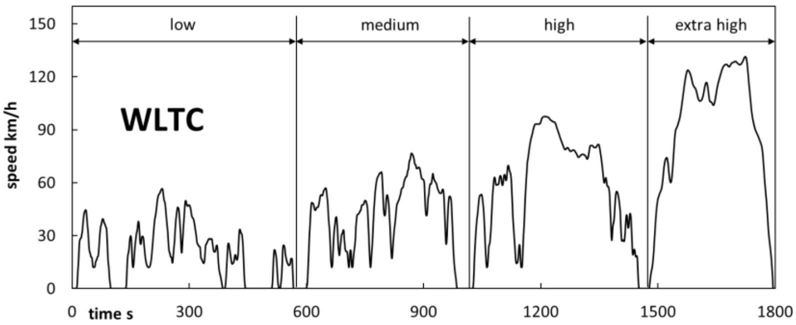

Figure 1: The World Light-Duty Transient Cycle (WLTC)

The driving resistances were set for a horizontal road, according to the legal directive.

Great part of testing was performed on the road in real driving conditions. An example of a road trip for RDE is given in annex A4.

4. RESULTS

The results and comparisons are graphically represented in the attached figures (see chap. 6) and are tabulated in annexes A5-A7).

4.1. Part 1: OBS-ONE-PN and NM3

In this part of work, the two PN-measuring systems (Horiba OBS-ONE-PN and NanoMet3) were compared on two Diesel vehicles – V1 Euro 5 and V2 Euro 6 – both with DPF. The vehicles were tested 3 times in WLTCc (with cold start) and 3 times in RDEw (with warm start).

Figures 2 and 3 show the time-plots of PN emissions and correlations of results obtained with both systems on vehicle V1. It can be remarked that due to the DPF regeneration at the end of RDE1 and at the beginning of the following WLTC2, there is a significant increase of PN. Nevertheless, the PN-level in normal DPF operation is very low and often below the ambient level (which can be, supposedly, in the range of 10^4#/cc) - like in WLTC1, or RDE3.
Both measuring systems show similar shapes of signals and the correlations are very good (except of RDE3) with the R^2-values between 0.90 and 0.95. There is a tendency of NM3 showing higher PN-concentration readings. A reason for that can be the higher sensitivity of NM3 in the lowest particle size range (down to 10 nm), while the OBS-ONE has a “cut-down” at 23nm.
For RDE3, there is no correlation between the results from both measuring systems. This means that there are for example concentrations like $3 \cdot 10^4$ indicated by NM3 and not recognized at all by OBS-ONE and vice versa.
There is, at this stage of work, no clear explanation for this fact and the physico-chemical structure of the nanoaerosol at these very low concentrations, is considered as a main reason.

Figures 4 and 5 show similar results obtained on the vehicle V2. There is a DPF regeneration at the end of RDE1 (highway part). NM3 shows as tendency higher PN-readings. In the very low-emitting cases, especially RDE2 and RDE3, there are weak correlations of PN-results, since NM3 indicates certain concentrations (of lowest particle sizes) and OBS-ONE is not sensitive to the lowest sizes (<23nm).

Figure 6 gives a summary overview of the integrated results in [#/cm³] and in [#/km]. For the results per km, the exhaust mass flow was determined for both measuring systems with the EFM of OBS-ONE. The numeric values are given in annex A5.

The conclusions from this working part are:

- NM3 gives higher PN-concentrations readings, especially at very low concentrations. This relates to the higher sensitivity of NM3 in the sub 23nm size range. The differences of integrated results were between 10% and 74%.
- Diesel engines equipped with DPF have very low PN-emissions. Sometimes, the average PN-values over a test are lower than the detection limit (the lower detection limit for both systems is at 10^3#/cc).
- Main PN-emissions occur during the cold start and / or DPF regeneration.

4.2. Part 2: CPC, OBS-ONE-PN, NM3, NCEM

In this working package, four PN-measuring systems (CPC/PMP, OBS-ONE-PN, NM3 and NCEM) were compared on two vehicles – GDI, Euro 5 (V3) and Diesel, Euro 6 (V4). The comparison tests were performed only on chassis dynamometer in WLTC with simultaneous use of all PN-measuring systems. There were 4 tests on vehicle V3 and 3 tests on vehicle V4. The first test was performed respectively with cold start, the further tests were completed with warm engine.
Examples of time-courses of PN-emissions in WLTC cold and the correlations of results for the investigated measuring systems are given for vehicle V3 (no GPF) in figure 7 and for vehicle V4 (with DPF) in figure 8.

Regarding CPC and OBS, there is a very good conformity of time-plots and good correlations both: with higher (V3) and with lower (V4) PN-concentrations.

Comparing NM3 and OBS at higher PN-concentrations (V3) a very good agreement of reading can be remarked. At very low PN-concentrations (in the range 10^3, V4) NM3 indicates higher PN-level, than OBS and the correlation of results is quite weak. This last finding is similar as in the part 1 with other DPF-equipped Diesel cars.

The comparison of NCEM and OBS shows for V3 (higher PN-concentrations) a relatively good correspondence and correlation of results, which nevertheless are the worst of all comparisons with this vehicle (V3). With the lowest PN-concentrations (vehicle V4) the NCEM-PN-signal drifts away after 600 s of the cycle. This is a repetitive effect in all performed WLTC's with this vehicle and is most probably triggered by the increasing exhaust temperature during the cycle. As a result, there is no correlation between the readings of NCEM and OBS for vehicle V4.

Figure 9 summarizes the integral average results of this working part both: as count concentrations in [#/cm³] and as distance-specific emissions in [#/km]. For exhaust mass flow of NM3 and NCEM the EFM of OBS-ONE was used. The numeric values are given in annex A6. The representation is without the 1st phases of the cycles in order to eliminate the differences from cold start / warm-up and to enable a better comparability of the investigated measuring systems.
From this figure, the big difference of PN emission levels of these two aftertreatment technologies (2 to 3 orders of magnitude) can be remarked.
The results indicated by NCEM deviate the most from the average level indicated by the other systems.

4.3. Part 3: OBS-ONE and NCEM, PN & NO_x

The tests of this working part were performed on a Mercedes Actors HD truck Euro VI, together with a team from WVU. Some pictures showing the installation of the measuring systems on the vehicle are given in annex A7. The results are also presented in [1], chap. 6.

Figures 10, 11 and 12 show the time-plots of PN-concentrations and the correlations of results between OBS and NCEM in different RDE trials.

In the driving periods when the exhaust system is warm and with a higher dynamic of driving (stronger accelerations and decelerations) NCEM shows significantly higher PN-concentrations, than OBS. These magnitudes of solid PN-concentrations are not possible after a good quality DPF, which is here the case, confirmed by OBS. The higher sensitivity of NCEM in the sub 23nm size range (mentioned in [1]) has for the differences, here indicated, supposing solid nanoparticles, only a marginal significance. Another bigger difference between both systems is the sample preparation: the NCEM-PN-sensor receives the sample directly from the exhaust pipe (see picture in annex 7-2), while the OBS has a PMP-conform sample preparation with dilution and thermoconditioning. In this way, the NCEM-PN-sensor can measure the spontaneous condensates of the nanoaerosol, which in contrary are eliminated before entering the OBS-CPC.

An interesting effect is demonstrated in figure 11-2, where during coasting there is no fuel used, there are no PN-emissions (OBS), but NCEM shows quite high PN-concentrations, which slightly decrease with the time. This indicates an artefact, which most probably depends on temperature of the NCEM sensor. This drifting away of the NCEM-signal was repetitively remarked in the 2nd working part (figure 8).
Finally, it must be stated that NCEM PN measuring device is not appropriate for PN-control of the modern, low emitting vehicles. The question, if the reasons of the discrepancies are mostly in the sample preparation or are there other sensor-internal artefacts, can be a subject of further investigations.

Figures 13, 14 and 15 represent the NO_x emissions measured with both systems in the three RDE trials as previously shown for PN.

The Zirconia-sensor of NCEM is not active in cold operation (below approx. 140°C of sensor temperature) in order to be protected against the condensing humidity.

It can be remarked that there is a very good conformity of time-plots and a good correlation of NO_x-values measured with NCEM and OBS.

Except of cold operation the NCEM NO_x sensor is a useful devise for vehicles emissions control and screening.

5. CONCLUSIONS

The comparisons of results obtained with different PEMS were performed in three working parts. Following statements can be made:

Part 1

- NM3 gives higher PN-concentrations readings, especially at very low concentrations. This is connected with the higher sensitivity of NM3 in the sub 23nm size range. The differences of integrated results were between 10% and 74%.
- Diesel engines equipped with DPF have very low PN-emissions. Sometimes, the average PN-values over a test are lower than the detection limit (the lower detection limit for both systems is at 10^3#/cc).
- Main PN-emissions occur during the cold start and / or DPF regeneration.

Part 2

- The PN-results obtained with CPC (PMP) and OBS-PN correlate very well.
- At higher PN-concentrations, there is a very good agreement between NM3 and OBS; at lowest PN-concentrations NM3 indicates higher PN due to the higher sensitivity of NM3 in the sub 23nm size range.
- The comparison of NCEM and OBS at higher PN-concentrations is relatively good; at lowest PN-concentrations the NCEM-PN-signal drifts away and there is no correlation.
- The average integral PN-emission level of GDI w/o GPF is by 2 to 3 orders of magnitude higher, than for Diesel with DPF.

Part 3

- The NCEM PN measuring device is not appropriate for the low PN-concentration control or monitoring.
- The NCEM NO_x sensor is a useful device for vehicles emissions control and screening except of low temperature range where the sensor cannot be operated.

6. LIST OF FIGURES

Figure in text:

Figure 1: WLTC

Figures in attachment:

Part 1:
Figure 2: OBS-ONE-PN vs. NM3, vehicle V1, WLTC
Figure 3: OBS-ONE-PN vs. NM3, vehicle V1, RDE

Figure 4: OBS-ONE-PN vs. NM3, vehicle V2, WLTC
Figure 5: OBS-ONE-PN vs. NM3, vehicle V2, RDE

Figure 6: Comparisons of PN-PEMS-results, V1&V2, WLTC & RDE

Part 2:
Figure 7: OBS-ONE-PN vs. CPC, NCEM, NM3, vehicle V3, WLTC
Figure 8: OBS-ONE-PN vs. CPC, NCEM, NM3, vehicle V4, WLTC
Figure 9: Comparisons of PN-PEMS-results, V3 & V4, WLTC

Part 3:
Figure 10: OBS-ONE-PN vs. NCEM, vehicle V5 HD, RDE1
Figure 11: OBS-ONE-PN vs. NCEM, vehicle V5 HD, RDE2
Figure 12: OBS-ONE-PN vs. NCEM, vehicle V5 HD, RDE3

Figure 13: OBS-ONE NO_x vs. NCEM NO_x, vehicle V5 HD, RDE1
Figure 14: OBS-ONE NO_x vs. NCEM NO_x, vehicle V5 HD, RDE2
Figure 15: OBS-ONE NO_x vs. NCEM NO_x, vehicle V5 HD, RDE3

7. ANNEXES

A1 Data of Horiba OBS-ONE-PN PEMS
A2 Data of NanoMet3 PN PEMS
A3 Data of NCEM Gas & PN PEMS
A4 Road trip of RDE (example)
A5 Comparisons of PN results, part 1
A6 Comparisons of PN results, part 2
A7 HDV Mercedes Actros equipped with NCEM
A8 Comparisons of PN/NO_x results, part 3

8. REFERENCES

[1] Leathermann, J.; Besch, M. C.; Ryskamp, R.; Thiruvengadam, A.; Demirgok, B.: Comparison of emissions measurement between a sensor-based compact emissions meter and a standard PEMS. Department of Mechanical and Aerospace Engineering West Virginia University, 2018

9. ABBREVIATIONS

AFHB	Abgasprüfstelle FH Biel, CH
AGR	Abgasrückführung
CLD	Chemoluminescence Detector
CPC	condensation particles counter
DC	diffusion charging
DI	Direct Injection
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particle Filter
EATS	exhaust aftertreatment system
EFM	Exhaust Flow Meter
EU	European Union
FID	Flame Ionization Detector
FOEN	Federal Office of Environment, CH
GPF	Gasoline particulate filter
GPS	Global Positioning System
HD	Heavy Duty (Nutzfahrzeuge)
HDV	Heavy Duty Vehicles
LD	Light Duty (Personenfahrzeuge)
LDV	Light Duty Vehicles
NCEM	NTK Compact Emissions Meter
NDIR	Non-Dispersive Infrared
NM3	NanoMet3
OBD	On Board Diagnosis
OBS	Horiba on board system
PC	passenger car
PEMS	Portable Emissions measurement system
PFI	port fuel injection
PMP	Particle Measuring Program of ECE GRPE
PN	Particle Number / Partikelanzahl
R^2	coefficient of determination
RDE	Real Driving Emission
ResRDE	research of RDE
SCR	Selective Catalytic Reduction
TP	tailpipe
TPA	Tailpipe Attachment / Endrohraufsatz
TWC	Three-way catalyst
V	vehicle
WHTC	World Heavy-Duty Transient Cycle
WLTC	World Light-Duty Transient Cycle
WP	working package
WVU	West Virginia University

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Figures

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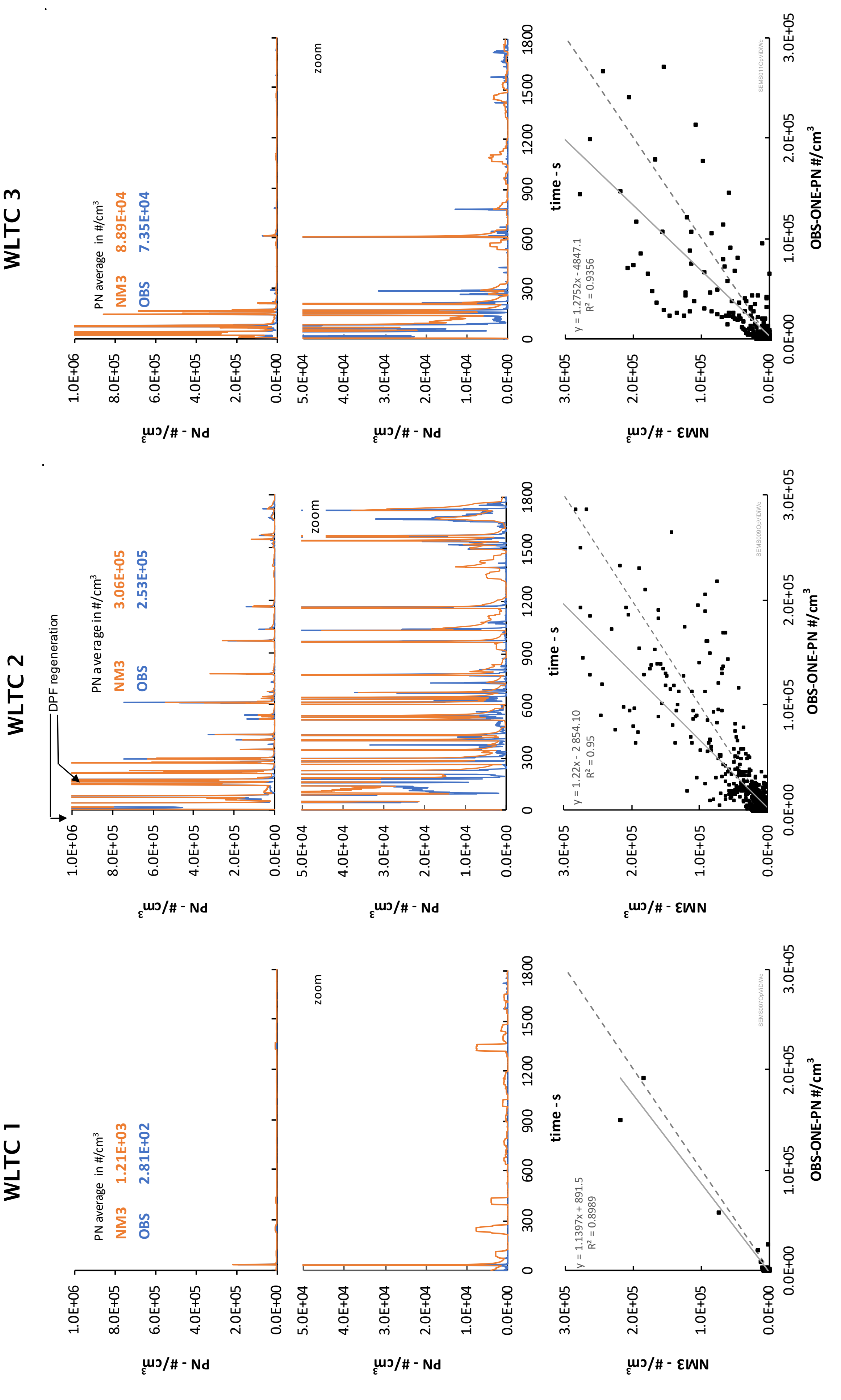
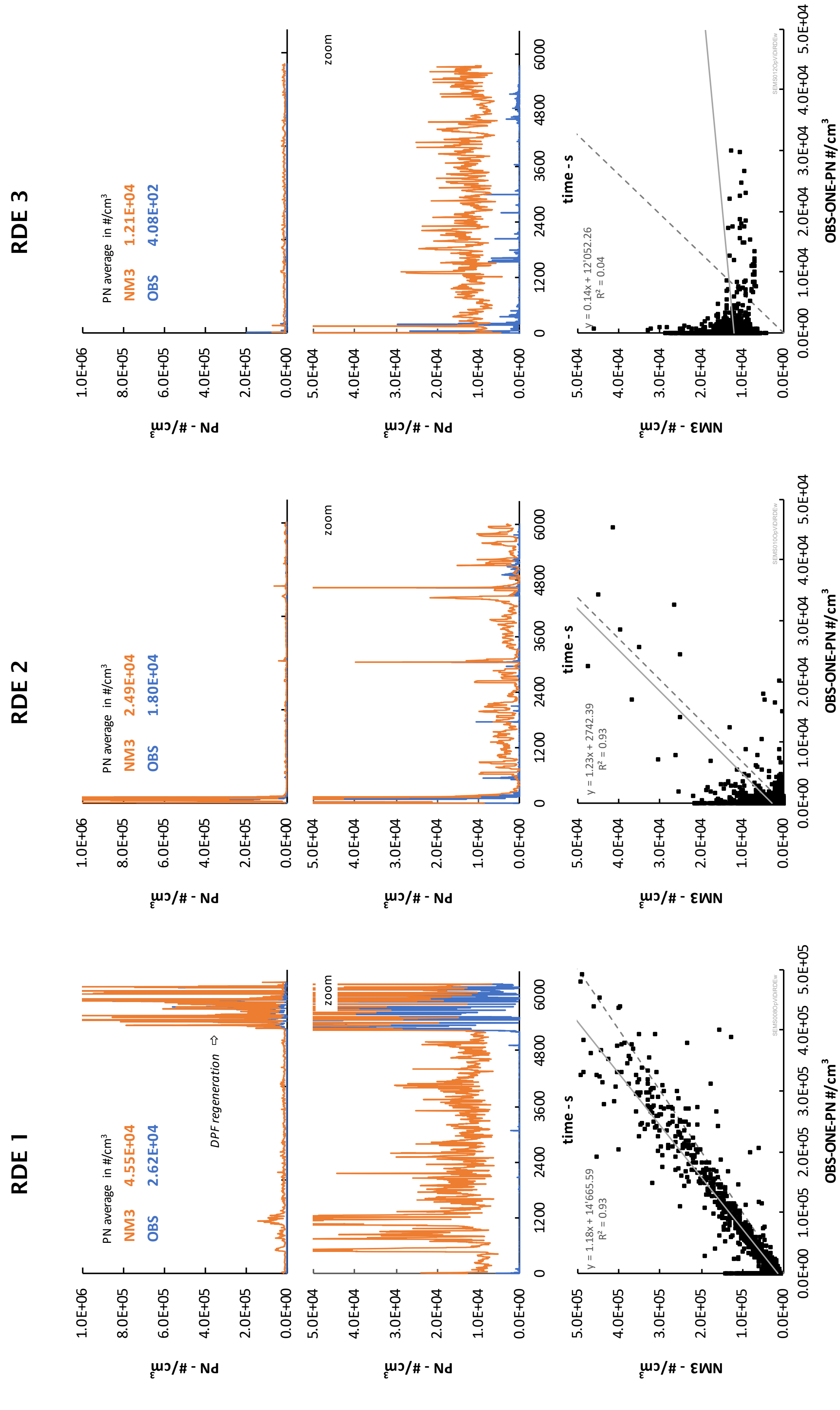
*) Abbreviations see at the end of report

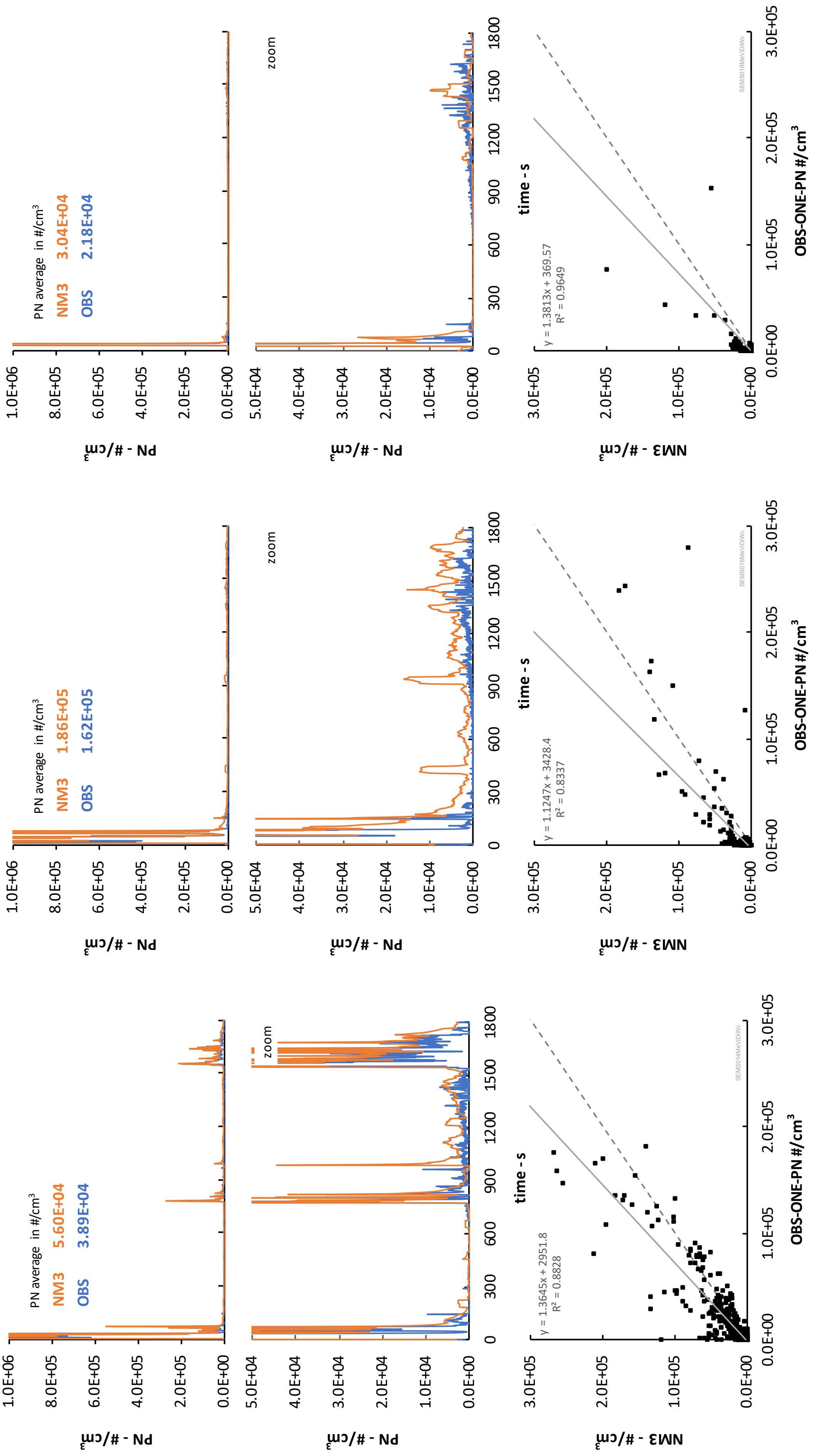
PN-PEMS Measurements with Vehicle 2 | Euro 5 Diesel (DPF)



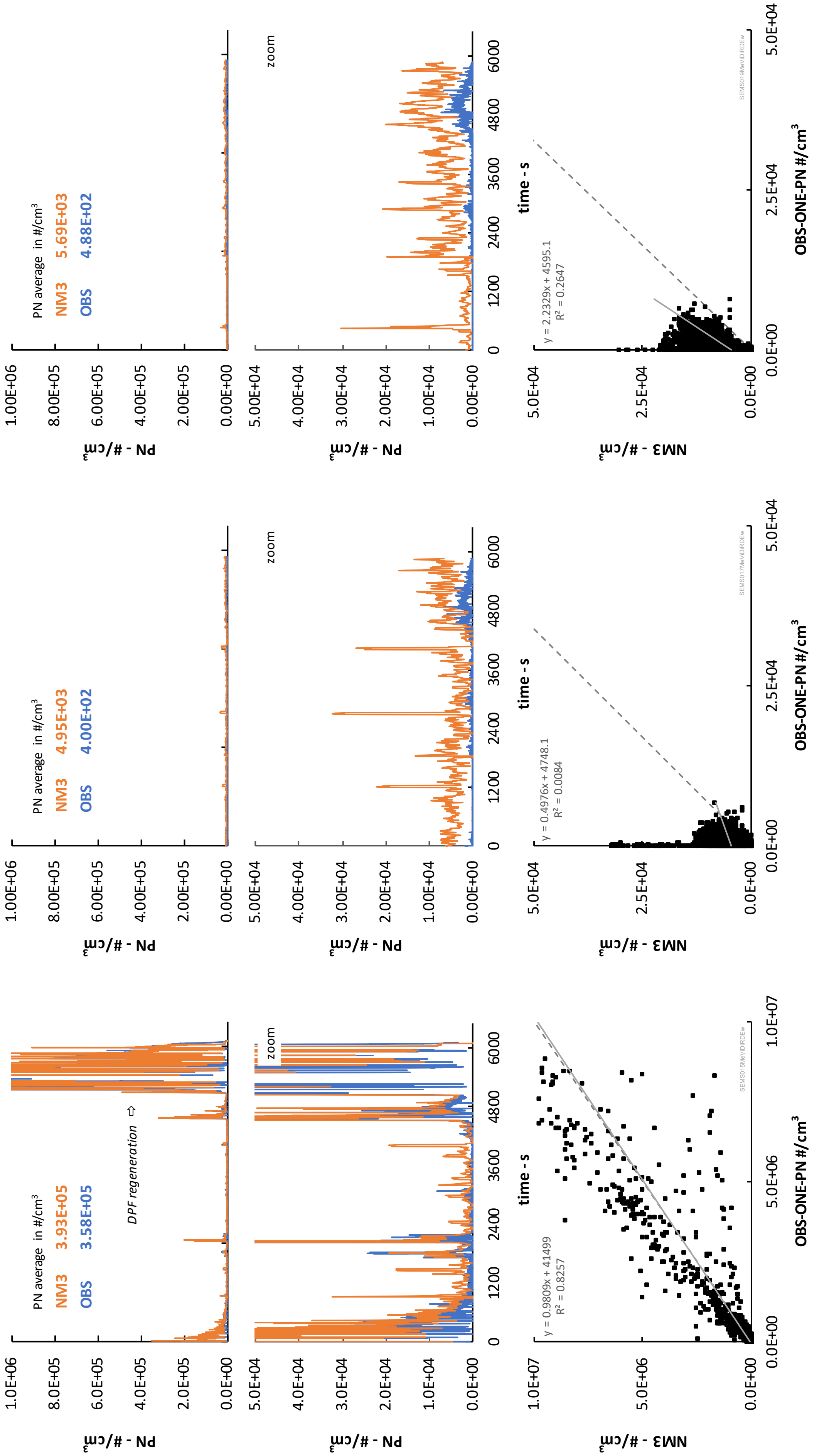
PN-PEMS Measurements with Vehicle 1 | Euro 5 Diesel (DPF)



PN-PEMS Measurements with Vehicle 2 | Euro 6 Diesel (DPF/SCR)



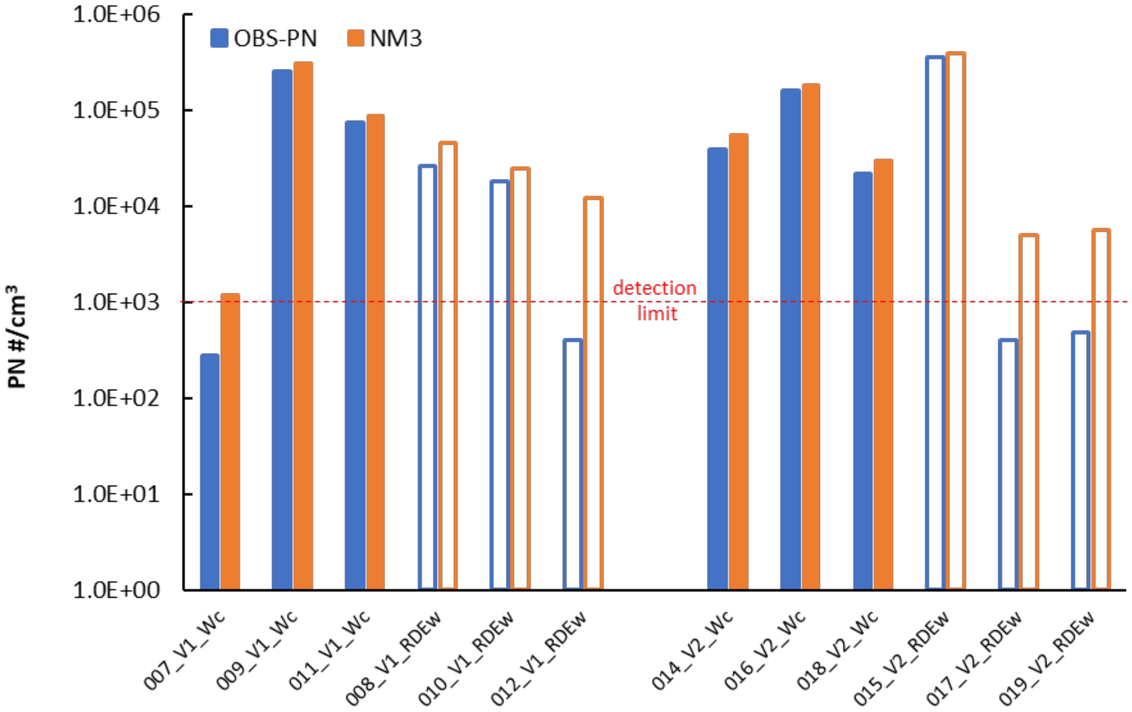
PN-PEMS Measurements with Vehicle 2 | Euro 6 Diesel (DPF/SCR)

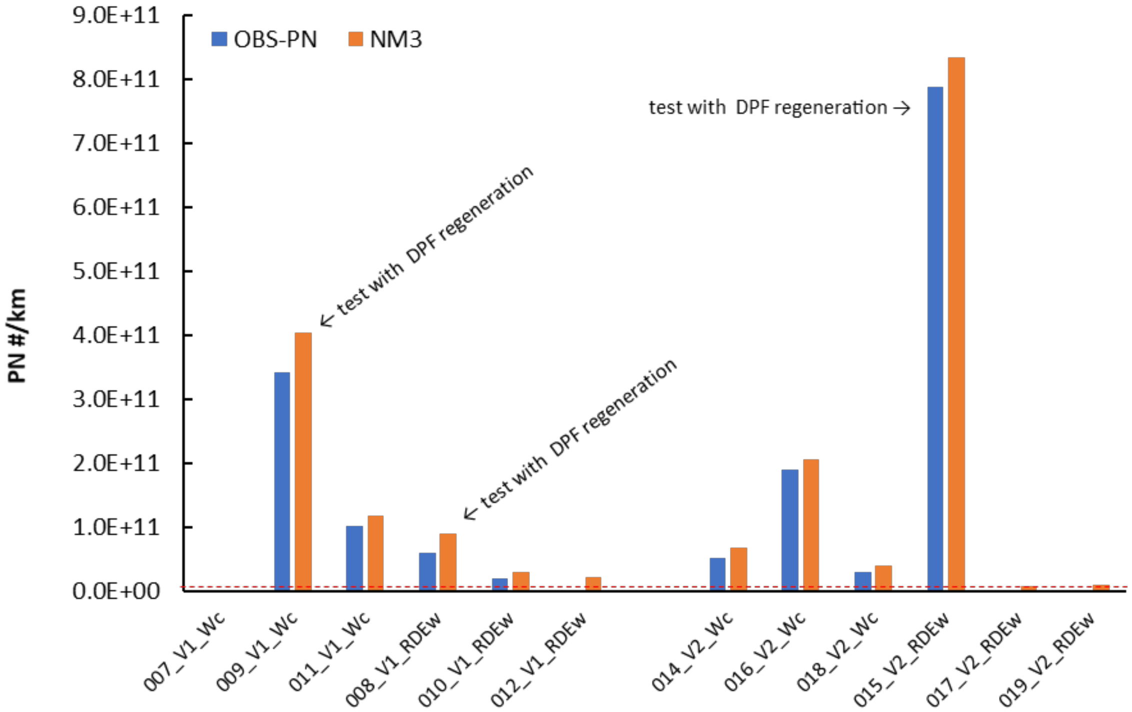


Comparisons of PN-PEMS-Results during WLTC and RDE

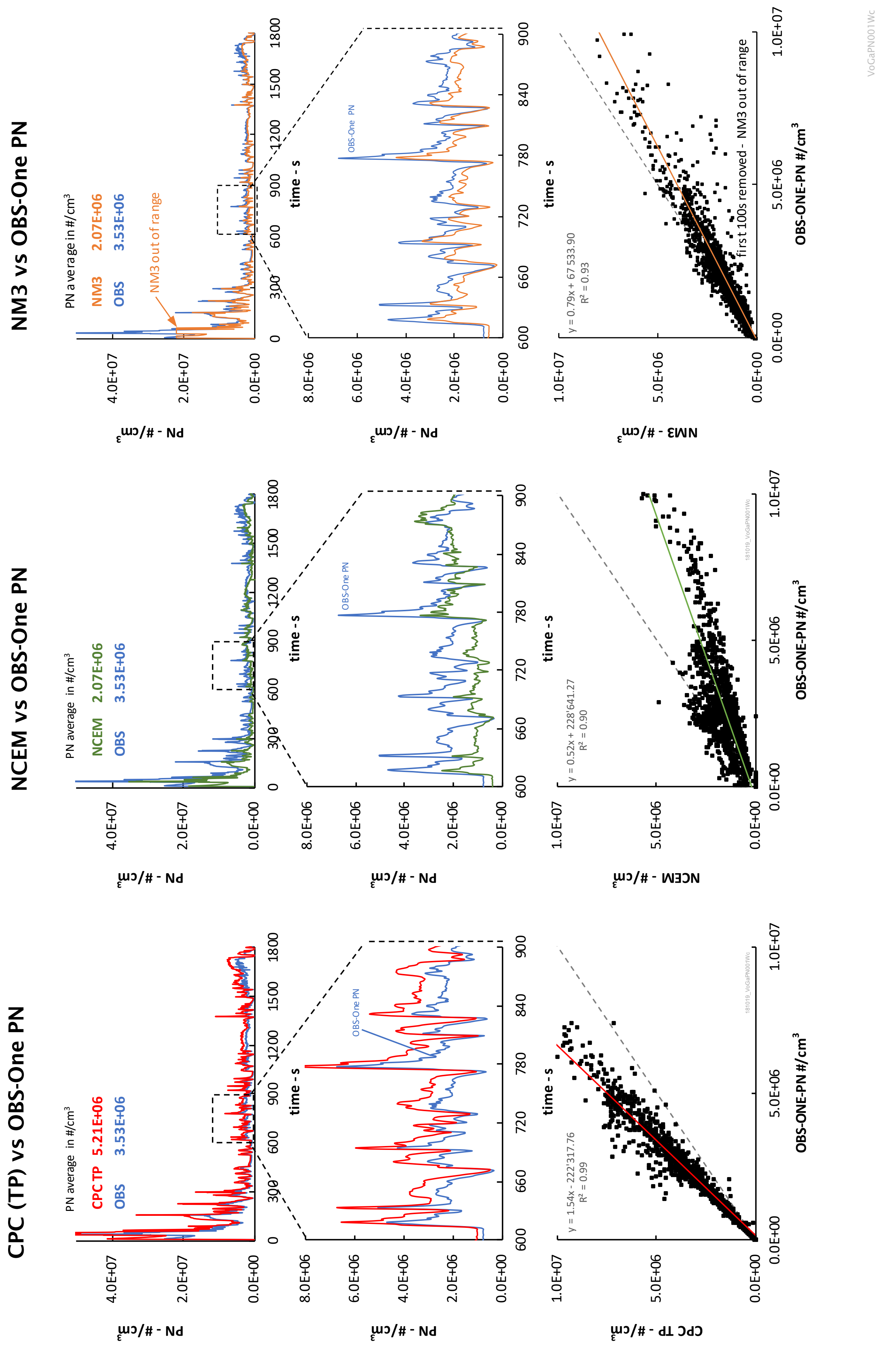
With V1 (Euro 5) and V2 (Euro 6) Diesel Vehicles

(RDE : integrated results, no MAW)

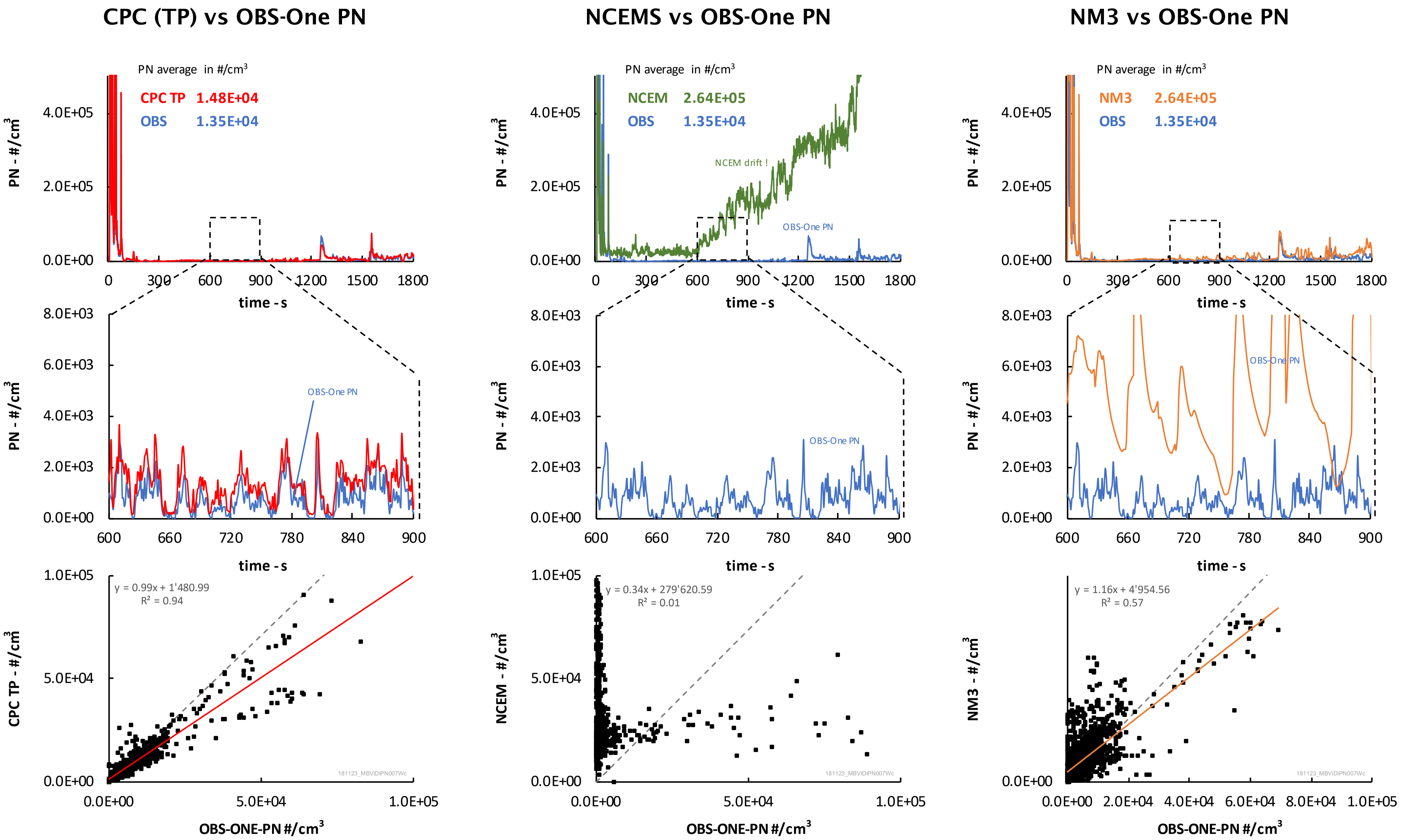




Exemple of PN-PEMS Measurements Results – vehicle 3, GDI (w/o GPF), $WLTC_{cold}$



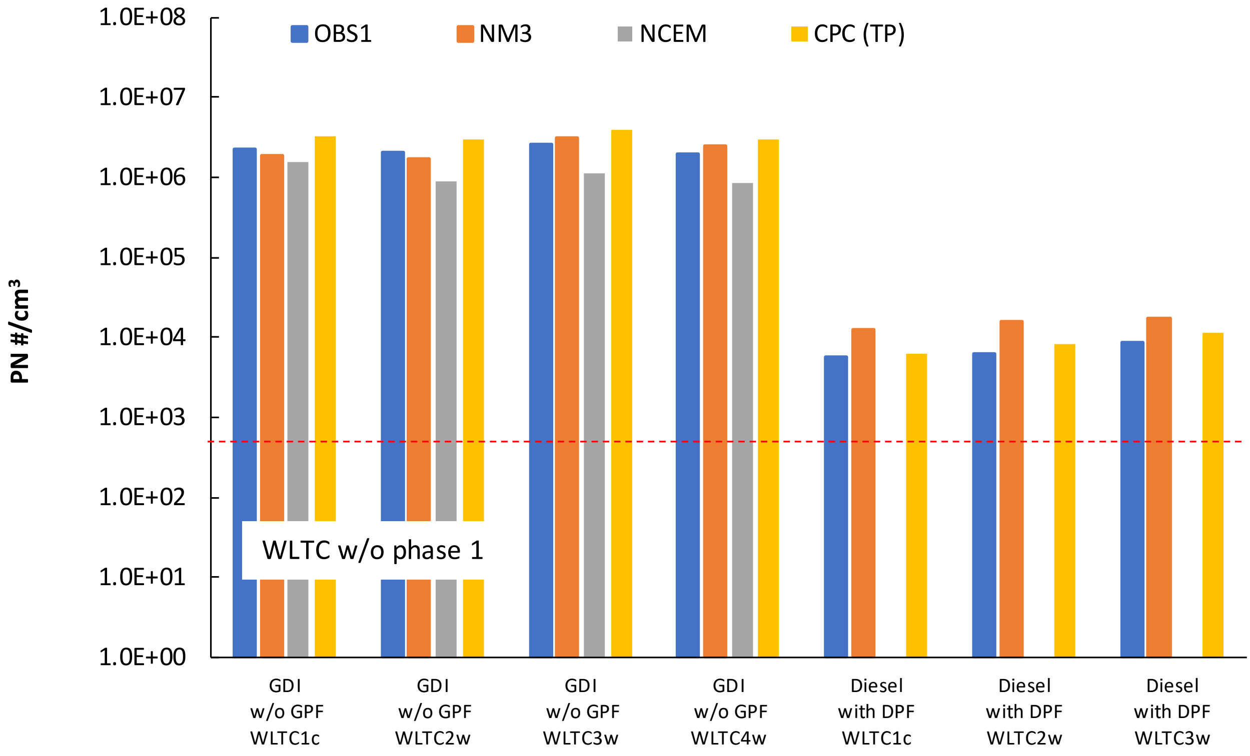
Exemple of PN-PEMS Measurements Results – vehicle 4, TDI (with DPF), $WLTC_{cold}$

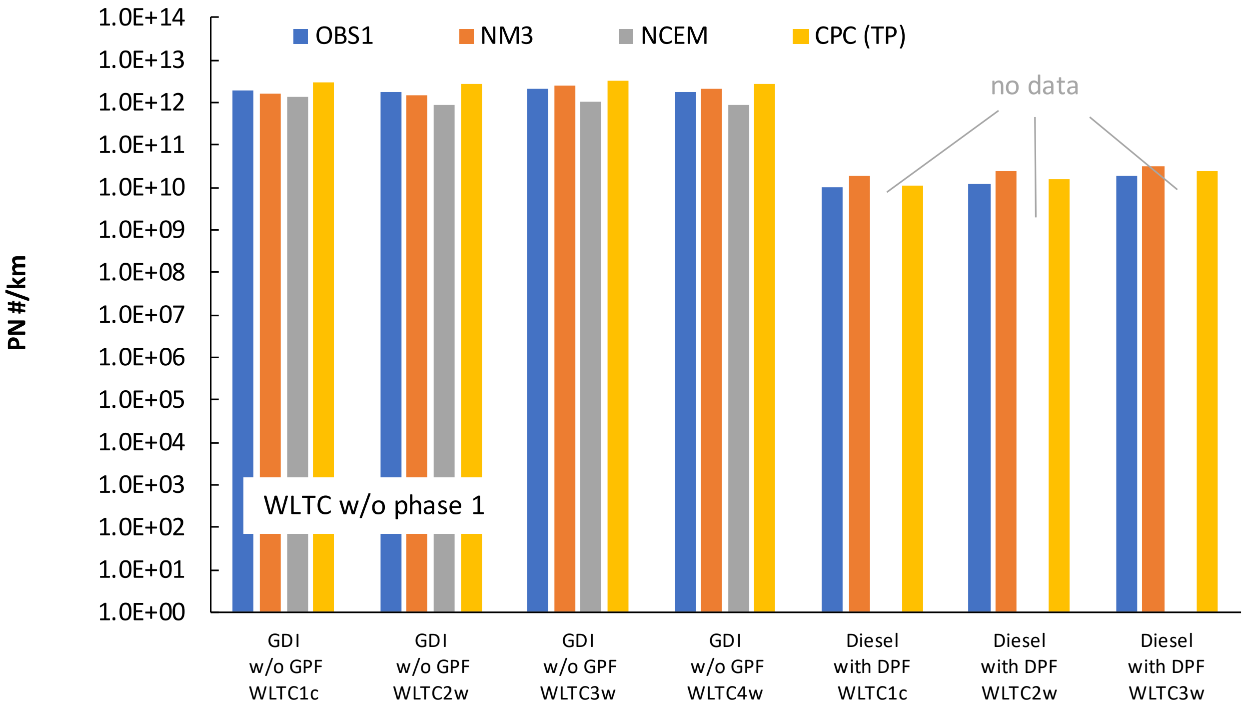


Comparisons of PN-PEMS-Results during WLTC

V3 (GDI w/o GPF) and V4 (Diesel with DPF/SCR)

(WLTC w/o phase 1)



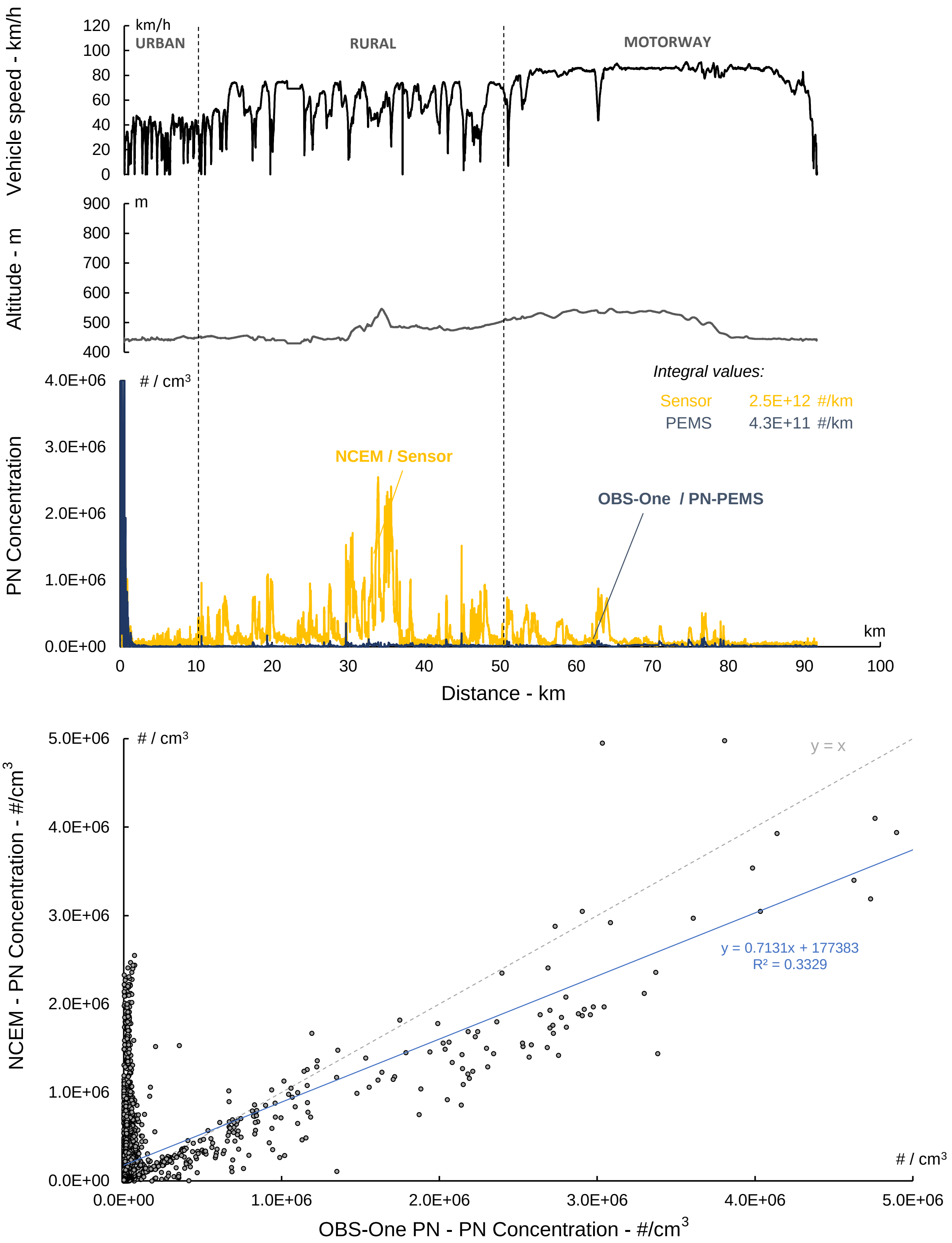


Real Driving Measurements

Comparison of PN Measurements during RDE

Mercedes Actros 1848, OM 471, Euro VI, (V5)

RDE 1: mix of urban, rural and motorway parts (cold start included)

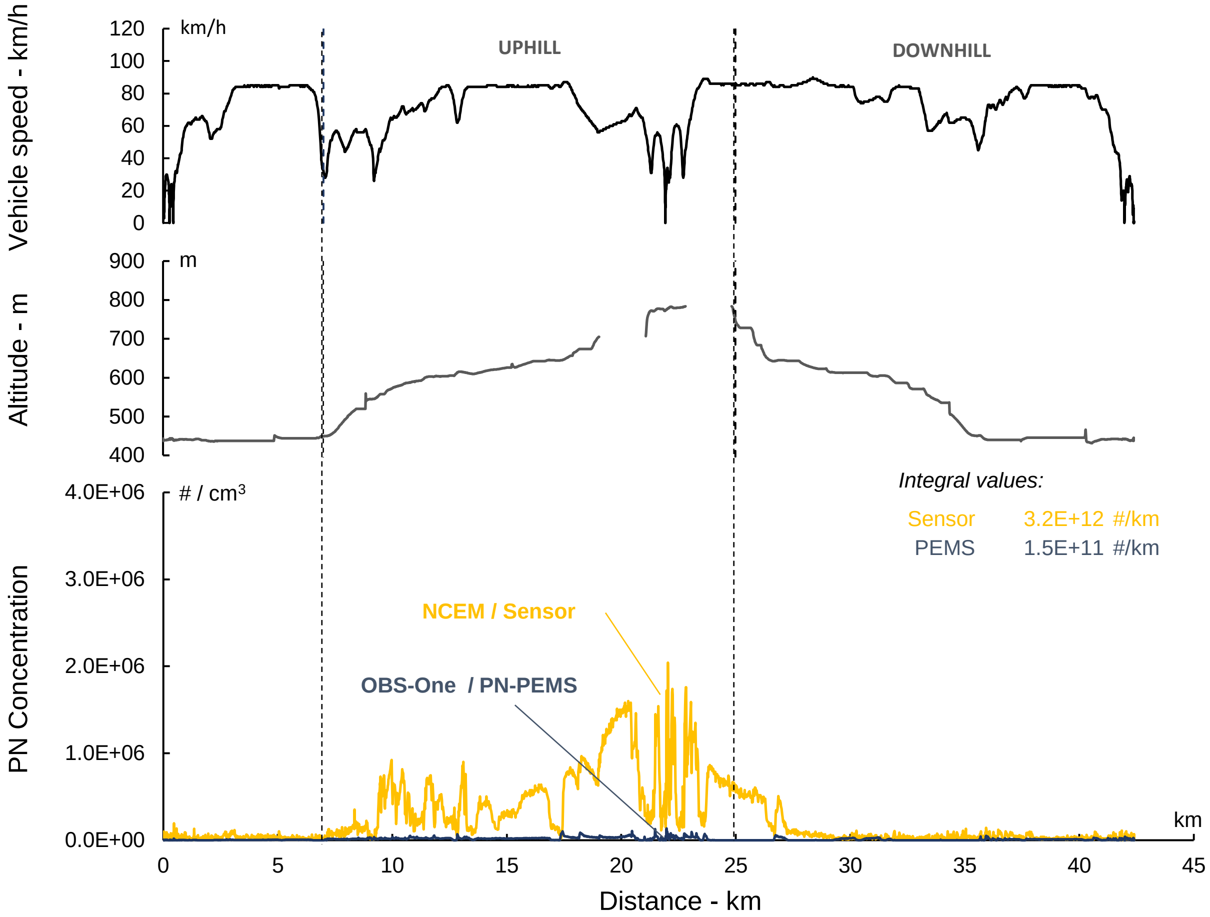


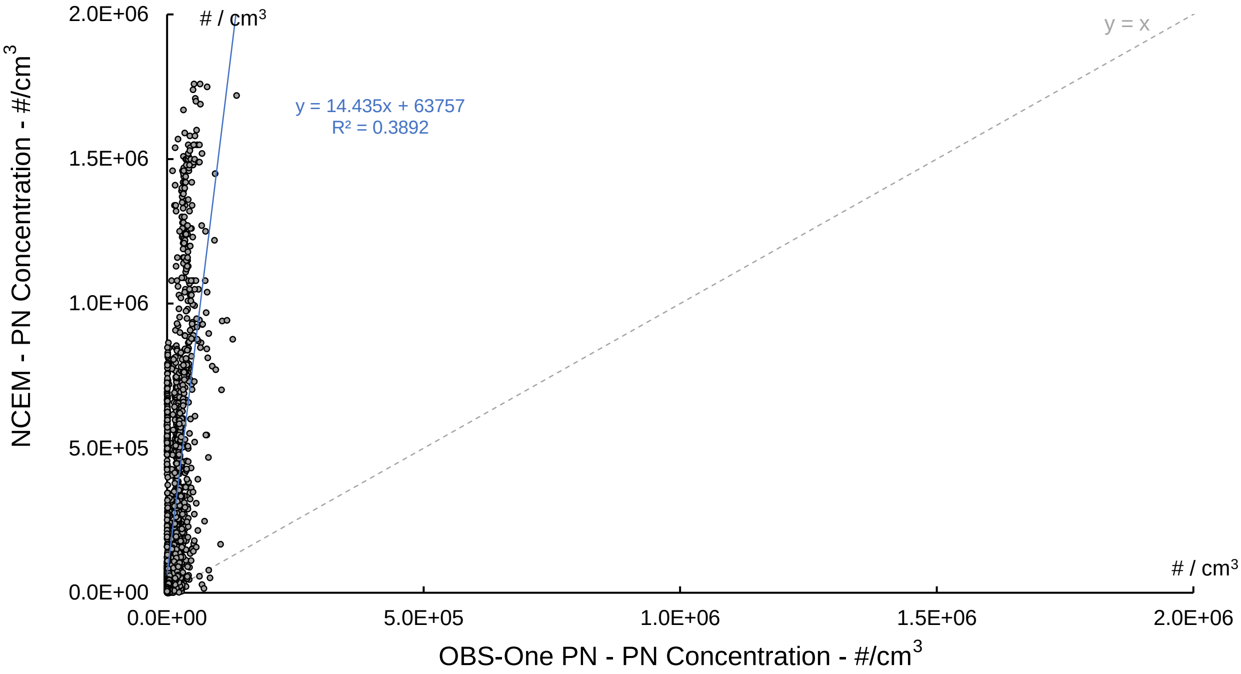
Real Driving Measurements

Comparison of PN Measurements during RDE

Mercedes Actros 1848, OM 471, Euro VI, (V5)

RDE 2: motorway with up- and downhill (warm start)



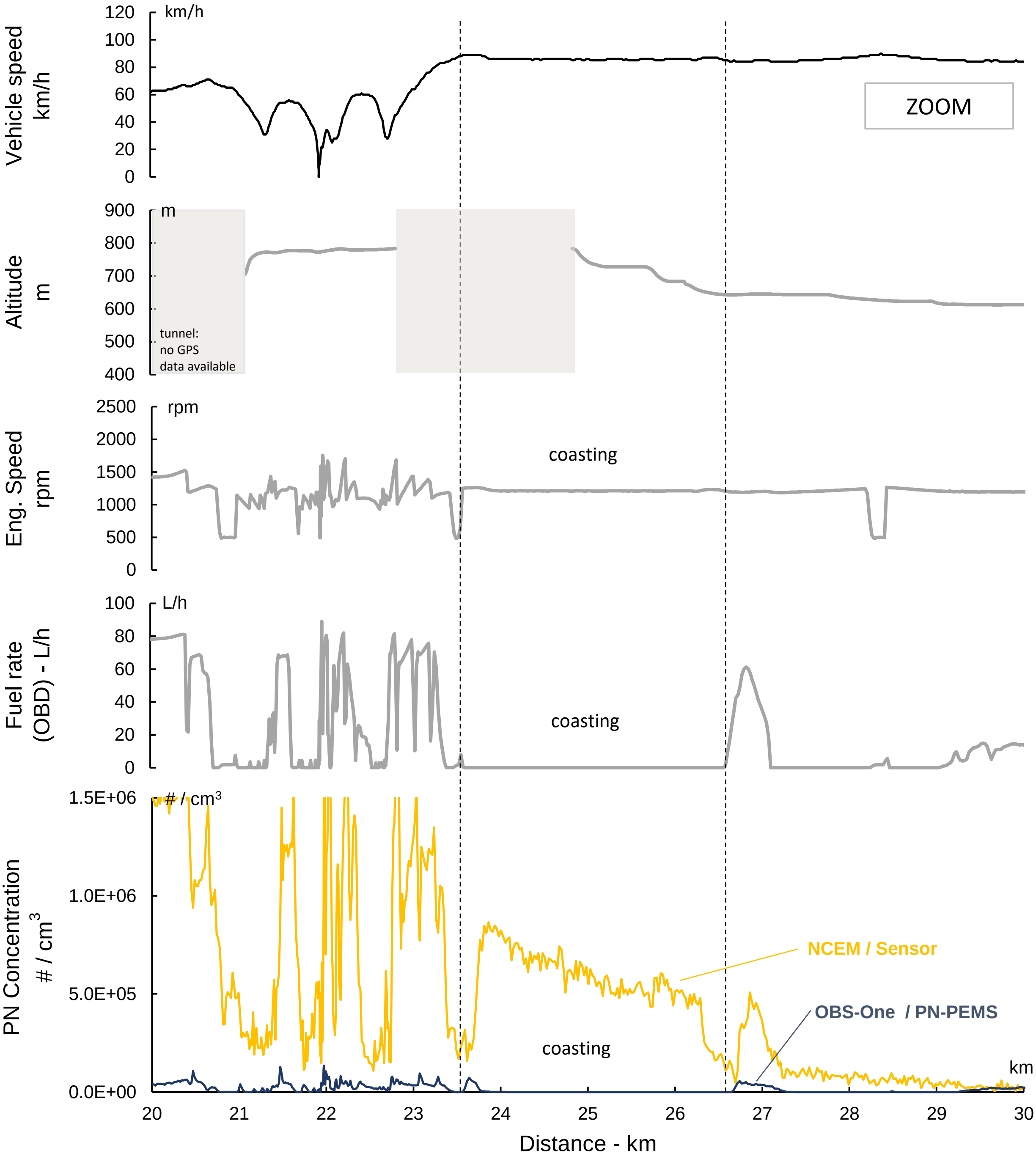


Real Driving Measurements

Comparison of PN Measurements during RDE

Mercedes Actros 1848, OM 471, Euro VI, (V5)

RDE 2: motorway with up- and downhill (warm start)

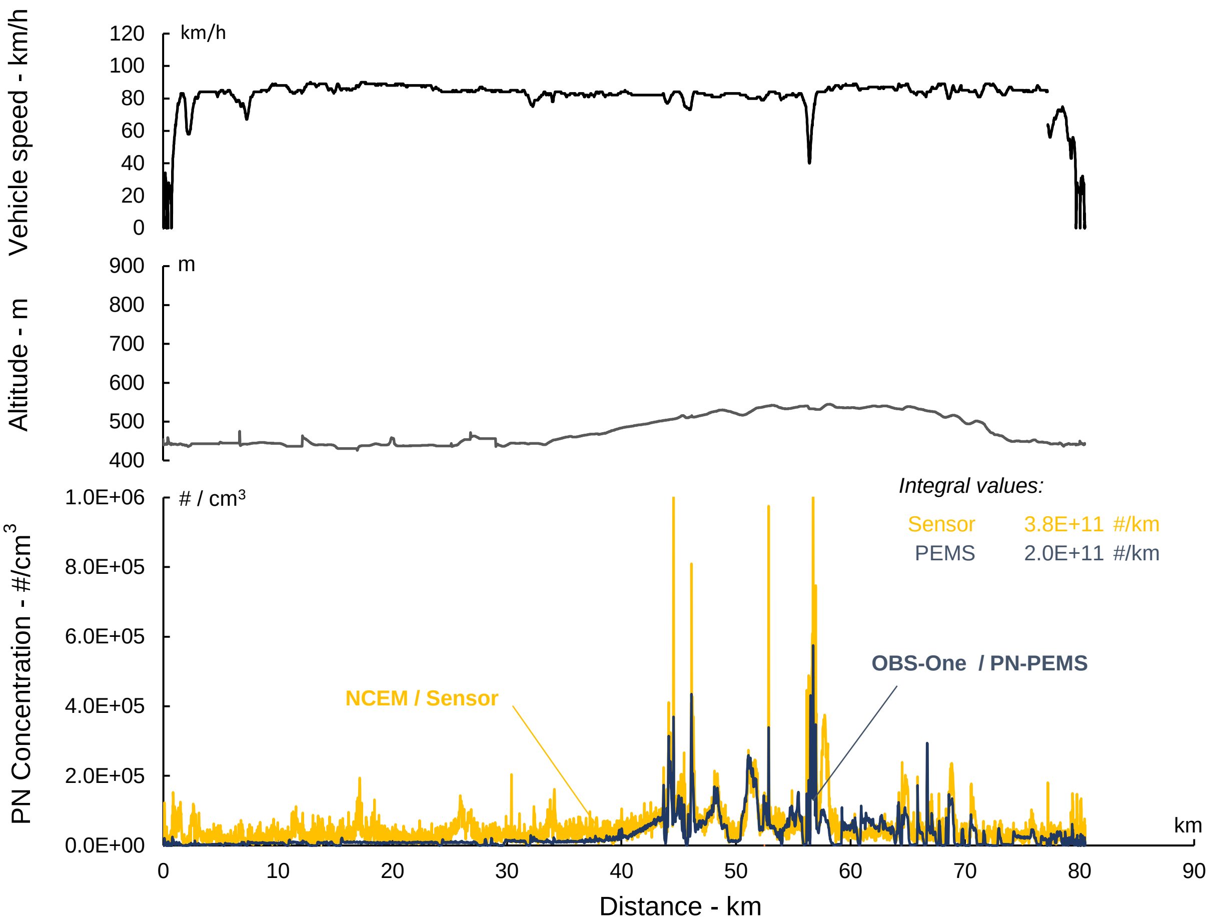


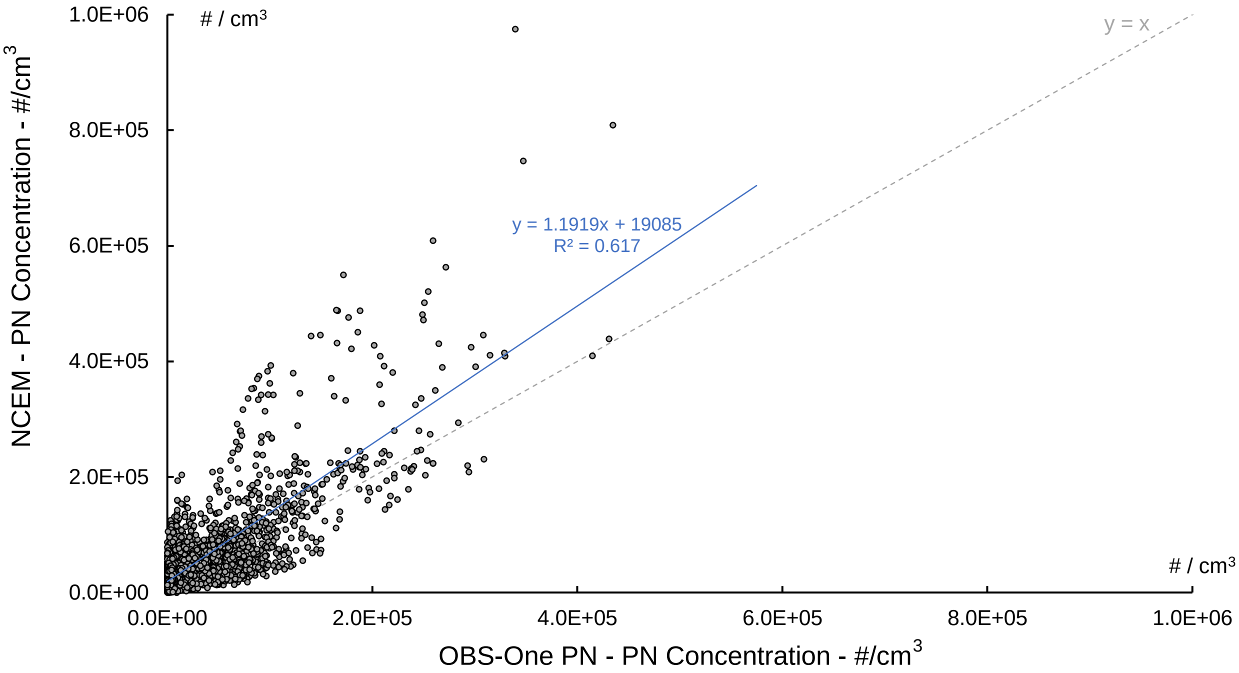
Real Driving Measurements

Comparison of PN Measurements during RDE

Mercedes Actros 1848, OM 471, Euro VI, (V5)

RDE 3: motorway (warm start)



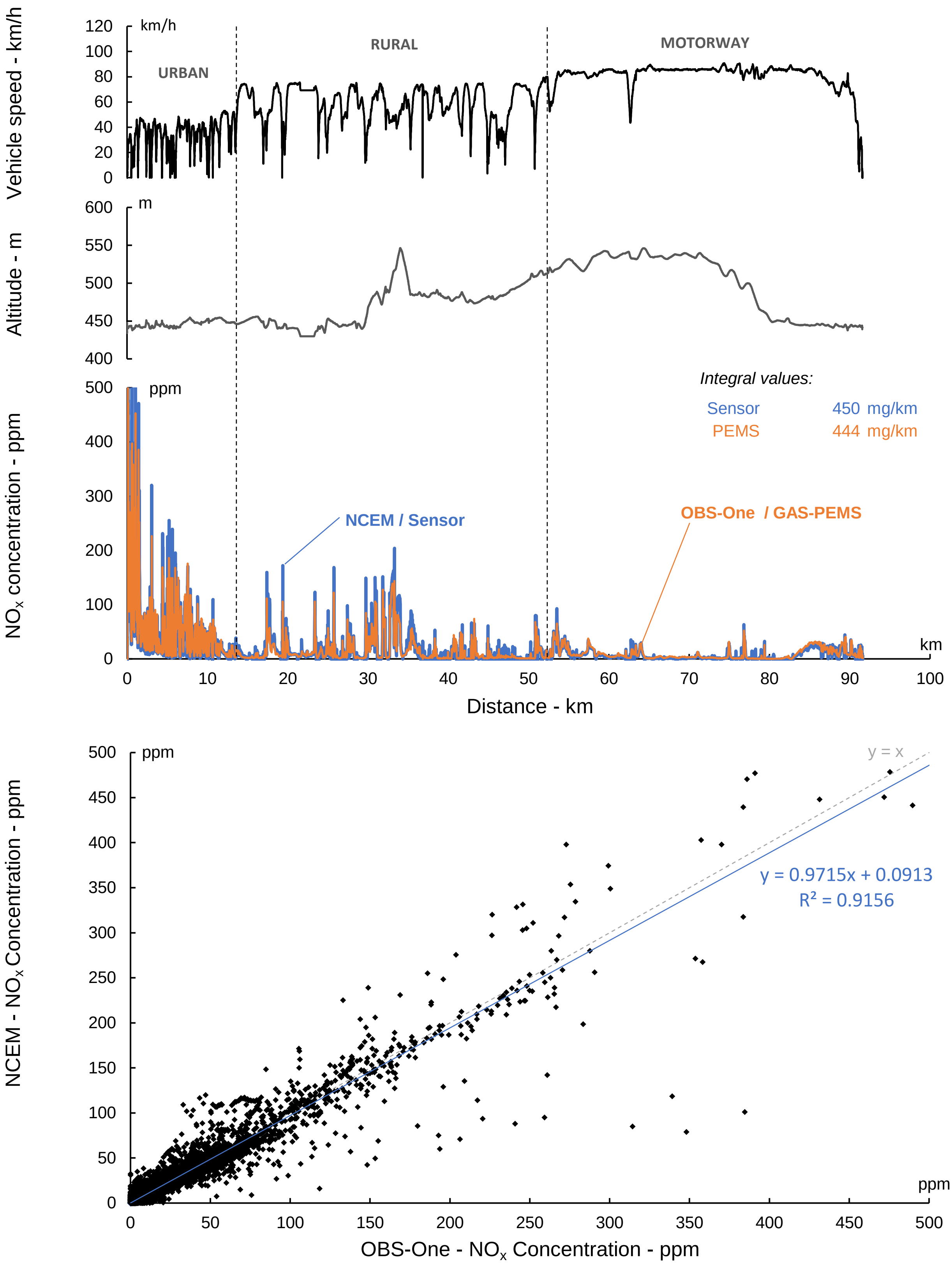


Real Driving Measurements

Comparison of NO_x Measurements during RDE

Mercedes Actros 1848, OM 471, Euro VI, (V5)

RDE 1: mix of urban, rural and motorway parts (cold start included)

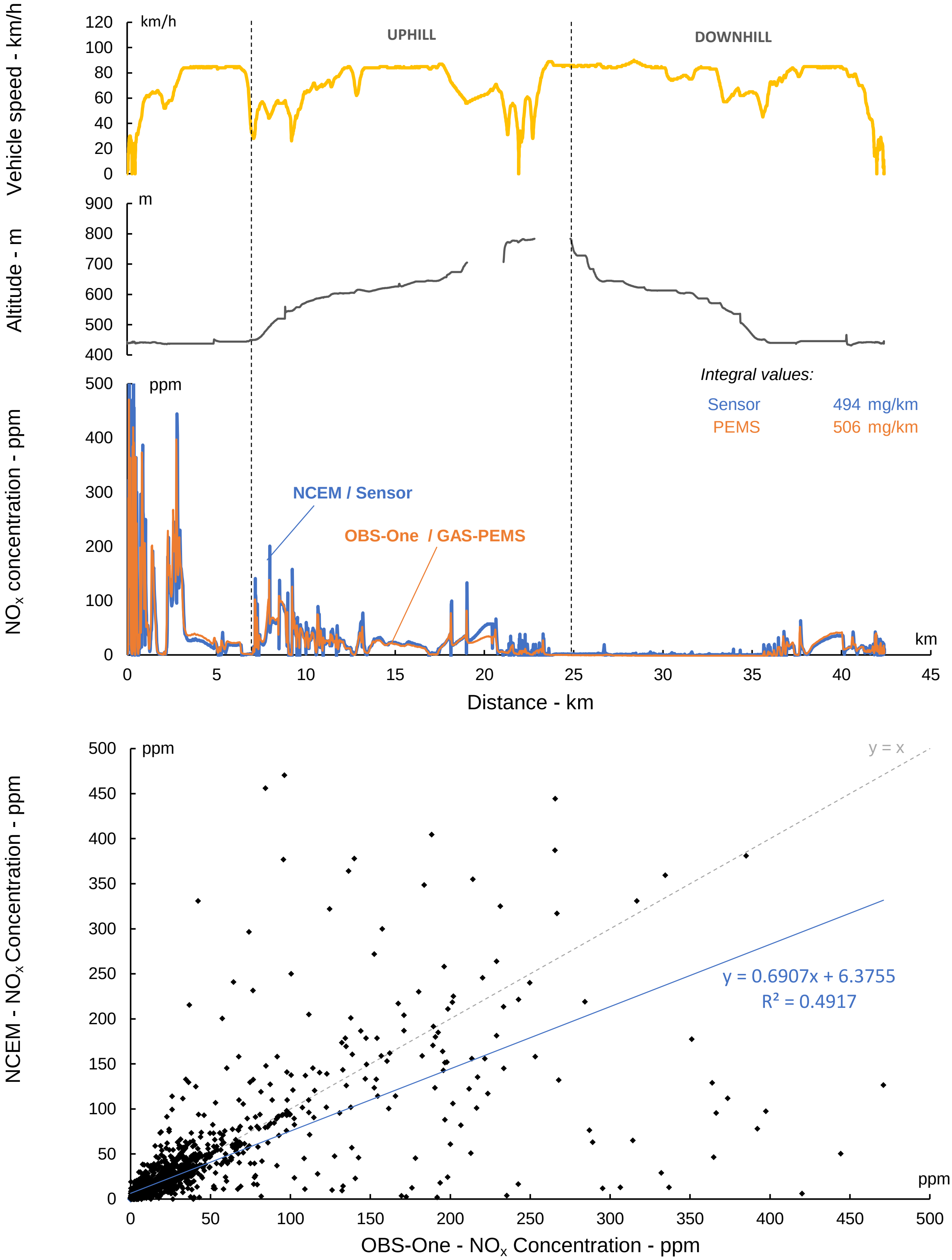


Real Driving Measurements

Comparison of NO_x Measurements during RDE

Mercedes Actros 1848, OM 471, Euro VI, (V5)

RDE 2: motorway with up- and downhill (warm start)

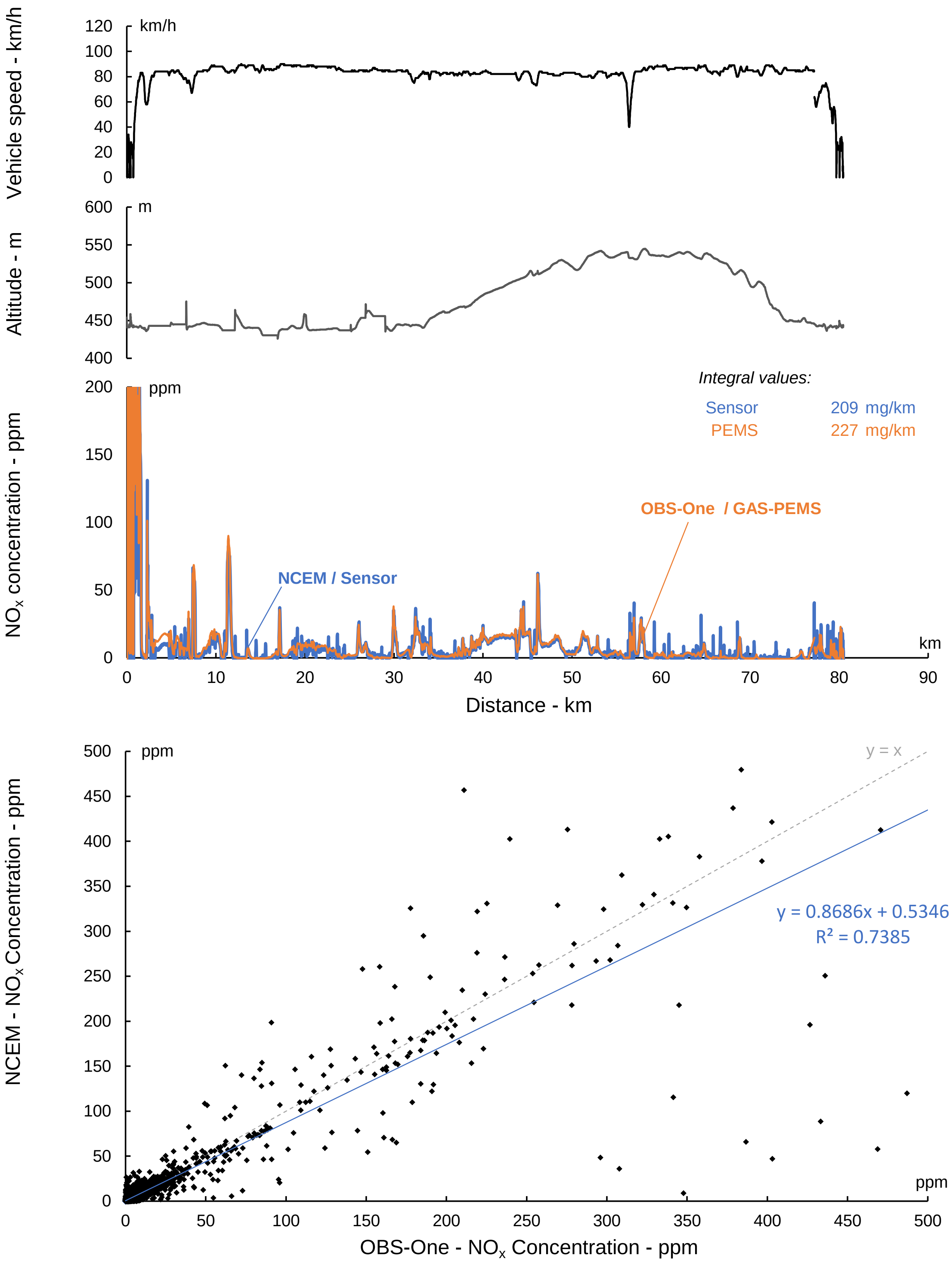


Real Driving Measurements

Comparison of NO_x Measurements during RDE

Mercedes Actros 1848, OM 471, Euro VI, (V5)

RDE 3: motorway (warm start)



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Comparisons of Different RDE Measuring Systems

Commissioned by the Federal Office for the Environment (FOEN)

Project: Research on PEMS Testing Methodology and on Real Driving Emissions (ResRDE2) *)

BAFU contract nbr.: 19.0106.PJ / S081-0349, 2nd report, WP4

Annexes

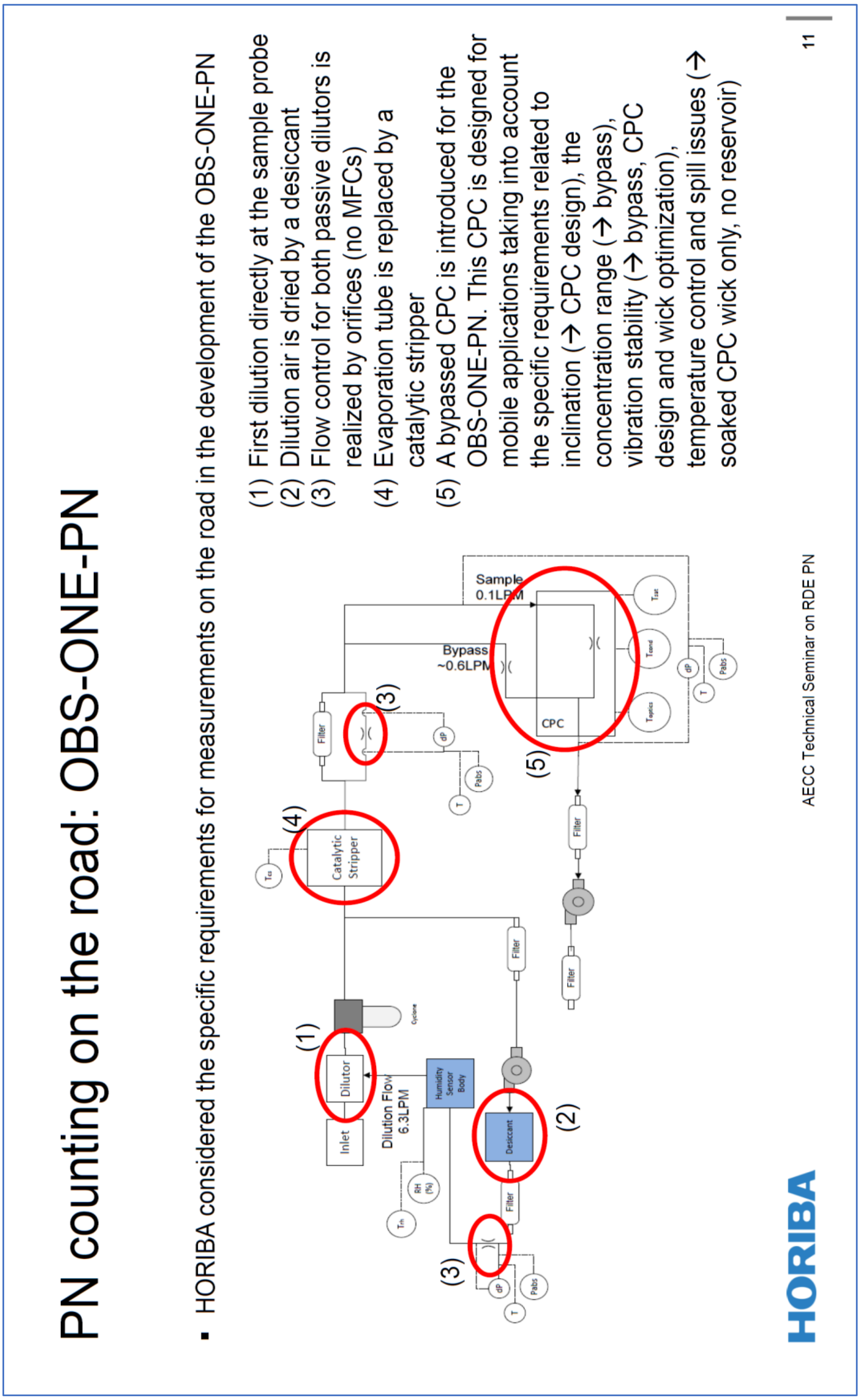
May 2020 R004

*) Abbreviations see at the end of report

Real Driving Measurements

PN-PEMS Flow Schematics

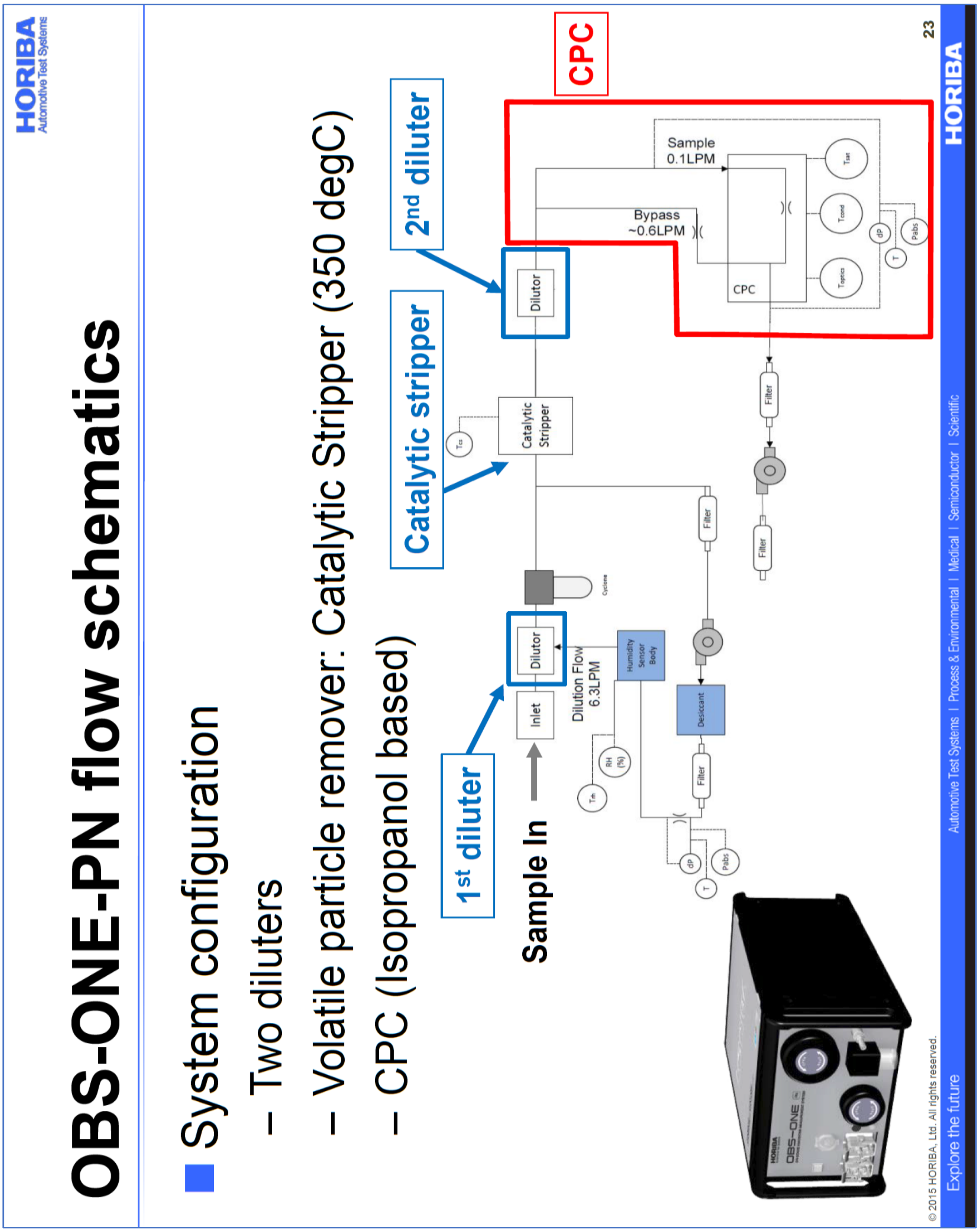
HORIBA OBS ONE PN



Real Driving Measurements

PN-PEMS Flow Schematics

HORIBA OBS ONE PN



Real Driving Measurements

Testo NanoMet 3 | PN-PEMS

Instrument Description

source: www.testo.com

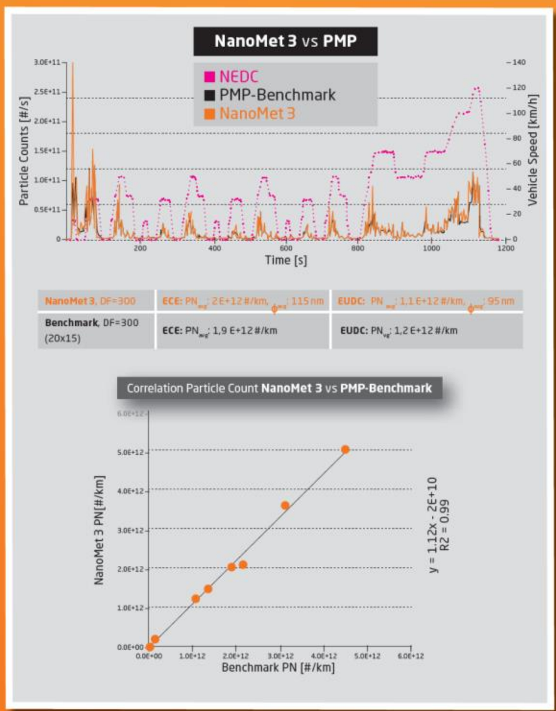
Real Driving Measurements

Testo NanoMet 3 | PN-PEMS

Instrument Description

Technical Specifications

aerosol	primarily diluted exhaust gases or air which contains nanoparticles
raw gas particle concentration range	1e³ ... 3e⁸ pt/ccm
particle size	10 ... 700 nm = 0.01 ... 0.70 µm (within mode diameter of 10 ... 300 nm)
inlet gas flow	4.0 lN/min, actively fed to the diluter and returning from there
dilution factor	10, 100, 300 (optional customised dilution factors)
power supply	12 VDC - 24 VDC / 100 VAC - 240 VAC
power consumption	300 W under standard ambient conditions
evaporation tube temperatures	ambient ... 300 °C / 572 °F; accuracy +/- 2 °C/4 °F
assembly	19" case with handles evaporation tube mounted inside of 19" case
weight	18 kg; with complete connections: ca. 23 kg
operating conditions	Tamb: 10 ... 40 °C 0 ... 80% relative humidity, max. 80 % @ 30 °C, linearly degrading to 50 % @ 40 °C, non-condensing
calibration	standard calibration with CAST soot particles, 80 nm



Benchmark measurements on NEDC cycles show 90-99% correlation* between NM3 and PMP systems.
*(under regular conditions)

Main features

- Particle number concentration and average particle size plots versus time, total counts provided by software interface
- PMP compliant VPR (sampling & conditioning)
- Fast response to rapid changes in aerosol concentration
- Butanol-free operation
- Embedded PC and pre-installed software
- Built-in data logging and storage capability with removable memory card or internal hard disk
- Matter Aerosol's quick change sensor cartridge
- Rotating disk with easy maintenance
- Long-life disk coating
- Low maintenance, 1000 operation hours of diluter between recommended service

source: www.testo.com

NCEM - 8016 | NTK Compact Emissions Meter

Sensor based portable Exhaust Gas Measurement System

source : www.ntk-ncem.com

Main specifications :

Item	Specifications
Electric supply source	AC 100 to 240 V or DC 12 to 28 V
Power consumption	AC: about 400 VA (Maximum actual power) DC: about 300 VA (Maximum actual power)
External dimensions	348 (W) × 283 (D) × 284 (H) mm
Main-unit weight	About 9.5 kg
Usage environment	Ambient temperature: -10 to 40°C Humidity: relative humidity of 85% or less absolute humidity of less than 30 g/m3, Non condensing
External I/F	CAN (Complies with ISO11898) USB (PC connection), OBD2 (ISO15765, SAEJ1979), GPS, Analog input (1ch)

Module	Range	
NOx/O2	NOx O2	0 to 1500ppm 0 to 21%
AFR (O2)	O2 A/F	0 to 21% 9 to 20
PM/PN	PM PN	0 to 60mg/m^3 0 to 1.0×10^8 #/cm^3
PM/PN EX	PM PN	0 to 300mg/m^3 0 to 1.0×10^9 #/cm^3

General description :

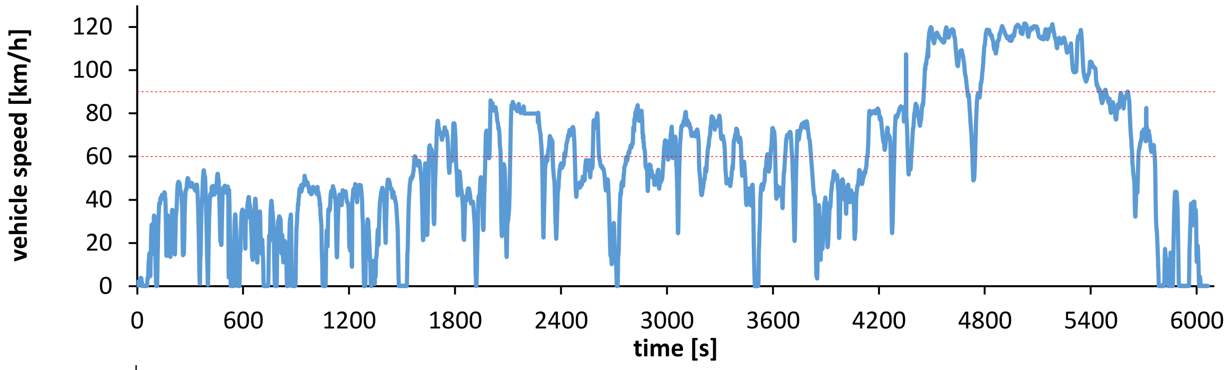
source : www.ntk-ncem.com

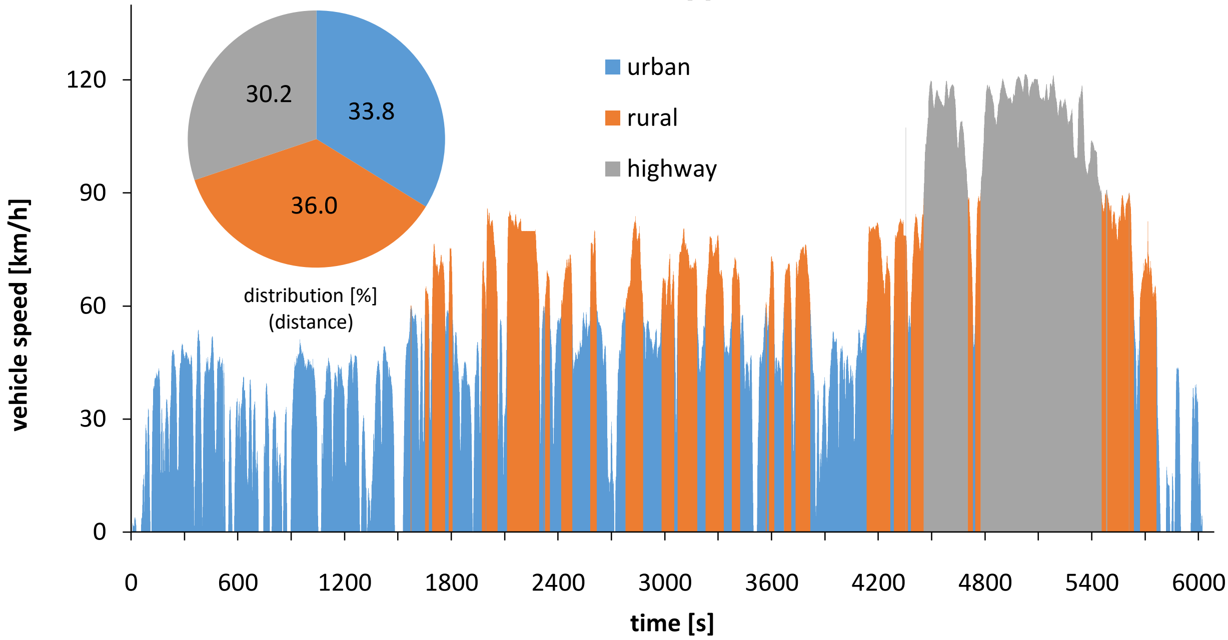
Real Driving Measurements

Road Trip for RDE

with Volvo V60 FlexFuel (LDV)

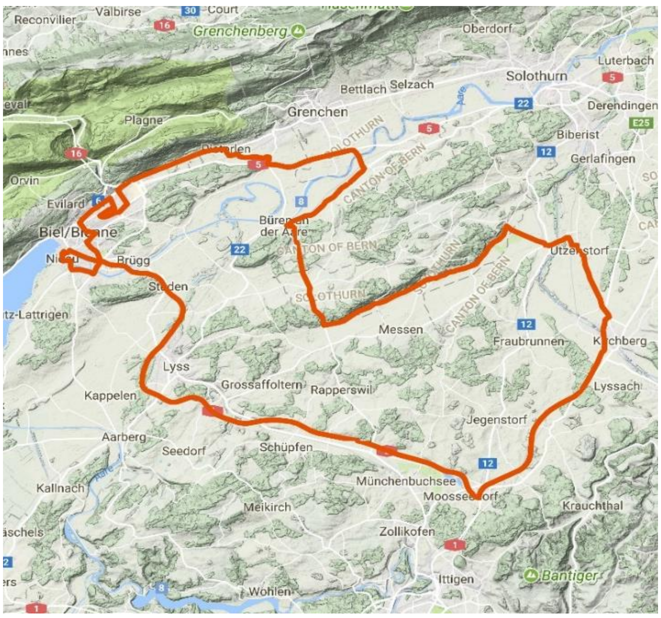
Mix of urban, rural and motorway parts





distance		
urban	32.4	km
rural	34.6	km
highway	29.0	km
total	**96.0**	**km**
time		
urban	51.1	min
rural	27.9	min
highway	15.6	min
stops	6.5	min
total	**101.1**	**min**
average speed		
urban	38.1	km/h
rural	74.2	km/h
highway	111.7	km/h
max	121.0	km/h

AFHB road-test route (AFHB06f)



Comparisons of PN-PEMS-Results during WLTC and RDE with V1 (Euro 5) and V2 (Euro 6) Diesel Vehicles

(RDE: integral values, no MAW)

average values

vehicle		test	NM3	OBS	NM3	OBS	Δ *)	meas. name	comments
-		-	#/cm3	#/cm3	#/km	#/km	%	-	
V1	Eu5	wltc	1.2E+03	2.8E+02	1.8E+09	4.8E+08	*low limit*	007_V1_Wc	*PN detection limit*
V1	Eu5	wltc	3.1E+05	2.5E+05	4.0E+11	3.4E+11	*21*	009_V1_Wc	
V1	Eu5	wltc	8.9E+04	7.4E+04	1.2E+11	1.0E+11	*21*	011_V1_Wc	
V1	Eu5	rde	4.5E+04	2.6E+04	9.0E+10	6.0E+10	*74*	008_V1_RDEw	*DPF regeneration*
V1	Eu5	rde	2.5E+04	1.8E+04	2.9E+10	2.0E+10	*38*	010_V1_RDEw	
V1	Eu5	rde	1.2E+04	4.1E+02	2.1E+10	4.1E+08	*low limit*	012_V1_RDEw	*PN detection limit*
V2	Eu6	wltc	5.6E+04	3.9E+04	6.8E+10	5.1E+10	*44*	014_V2_Wc	
V2	Eu6	wltc	1.9E+05	1.6E+05	2.1E+11	1.9E+11	*15*	016_V2_Wc	
V2	Eu6	wltc	3.0E+04	2.2E+04	4.0E+10	3.0E+10	*40*	018_V2_Wc	
V2	Eu6	rde	3.9E+05	3.6E+05	8.3E+11	7.9E+11	*10*	015_V2_RDEw	*DPF regeneration*
V2	Eu6	rde	4.9E+03	4.0E+02	7.2E+09	8.5E+08	*low limit*	017_V2_RDEw	*PN detection limit*
V2	Eu6	rde	5.7E+03	4.9E+02	9.4E+09	1.1E+09	*low limit*	019_V2_RDEw	*PN detection limit*

■ average value is lower than detection limit

■ average value is near to the instrument detection limit

*) Δ: NM3 vs OBS-One PN

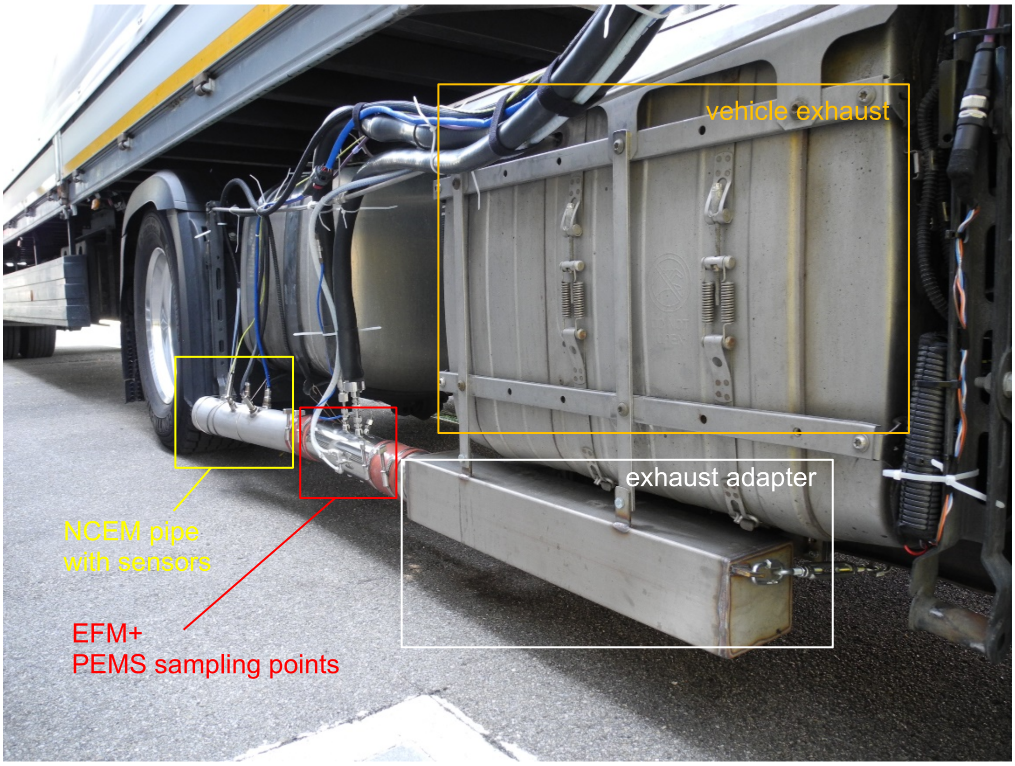
Comparisons of PN-PEMS-Results during WLTC with V3 (GDI w/o GPF) and V4 (Diesel with DPF/SCR)

			Particle Number (PN) in WLTC (w/o phase1)									
vehicle			NM3	OBS1	NCEM	CPC (TP)	dist.	NM3	OBS1	NCEM	CPC (TP)	meas. name
-			p/ccm	#/cm3	#/cm3	#/cm3	km	#/km	#/km	#/km	#/km	-
V3	Eu5	GDI w/o GPF	1.8E+06	2.2E+06	1.6E+06	3.3E+06	19.8	1.6E+12	1.9E+12	1.3E+12	3.0E+12	VoGaPN001Wc
V3	Eu5	GDI w/o GPF	1.7E+06	2.0E+06	8.9E+05	2.9E+06	19.8	1.4E+12	1.8E+12	9.0E+11	2.7E+12	VoGaPN002Ww
V3	Eu5	GDI w/o GPF	3.0E+06	2.5E+06	1.1E+06	3.8E+06	19.9	2.4E+12	2.1E+12	1.0E+12	3.2E+12	VoGaPN003Wc
V3	Eu5	GDI w/o GPF	2.4E+06	2.0E+06	8.4E+05	2.9E+06	19.8	2.1E+12	1.8E+12	8.8E+11	2.7E+12	VoGaPN004Ww
V4	Eu6	Diesel with DPF	1.3E+04	5.6E+03	-	6.3E+03	20.7	1.9E+10	1.0E+10	0.0E+00	1.1E+10	MBViDiPN007Wc
V4	Eu6	Diesel with DPF	1.6E+04	6.3E+03	-	8.2E+03	20.8	2.4E+10	1.2E+10	0.0E+00	1.5E+10	MBViDiPN008Ww
V4	Eu6	Diesel with DPF	1.8E+04	8.6E+03	-	1.1E+04	20.7	3.0E+10	1.8E+10	0.0E+00	2.4E+10	MBViDiPN009Ww

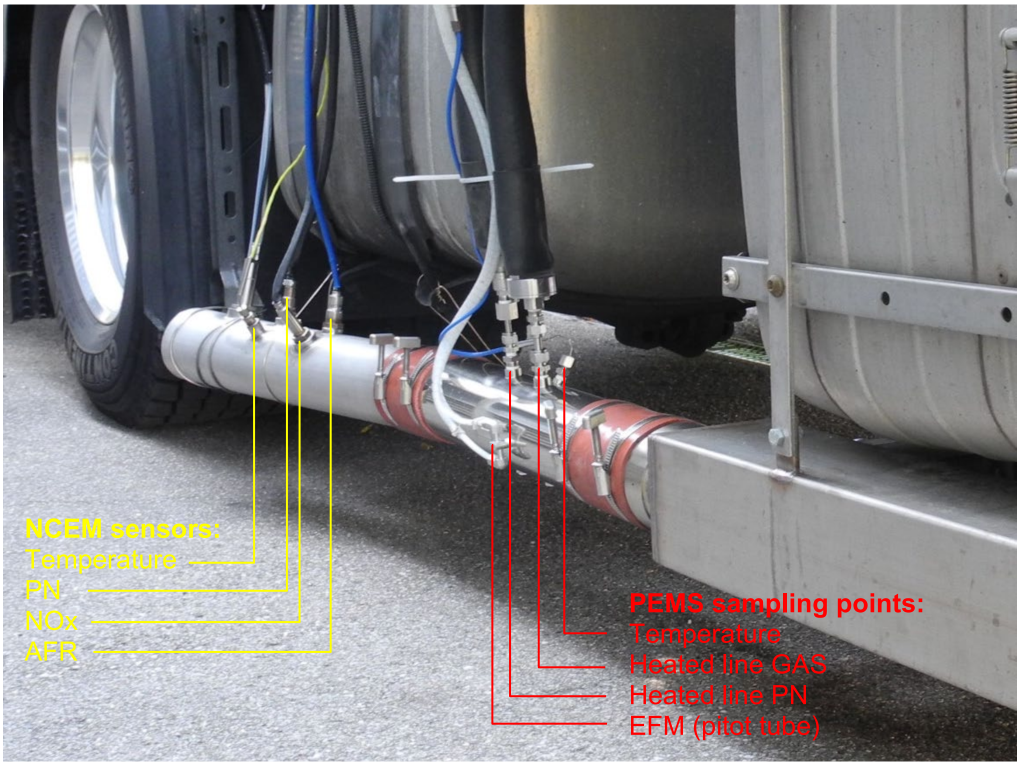
Example of a Vehicle equipped with the NCEM Instruments and Sensors

Mercedes Bens Actros (V5)

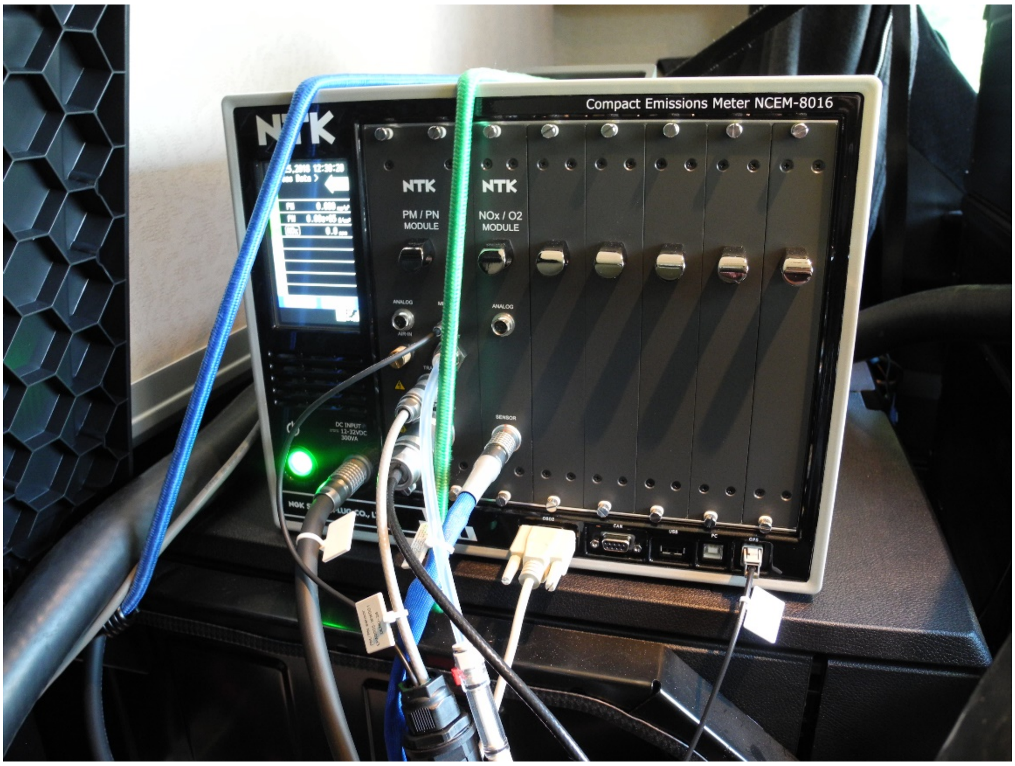
Vehicle moving on the road during real drive exhaust emissions measurement



Vehicle exhaust adapted for PEMS and NCEM measurements



Positions of the different sampling points and sensors



NCEM installed in the driver cabin

Comparisons of PN / NO_x - Results during RDE with Mercedes Actros 1848, OM 471, Euro VI

	Particle Number (PN)		**NO_x**		
	OBS1	NCEM	OBS1	NCEM	**meas. name**
	#/km	#/km	mg/km	mg/km	-
RDE 1	4.3E+11	2.5E+12	444	450	MBADi003RDE1c
RDE 2	1.5E+11	3.2E+12	506	494	MBADi005RDE2w
RDE 3	2.0E+11	3.8E+11	227	209	MBADi009RDE3w

RDE1: mix of urban, rural and motorway parts (cold start included)
RDE2: motorway with up- and downhill (warm start)
RDE3: motorway (warm start)