11th ETH Conference
on Combustion Generated Nanoparticles

Tail-Pipe Measurements of Emissions from LD Vehicles with Diesel Engines:

A Direct Comparison of Five Different Measurement Methods

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Overview

- Comparison of different measuring principles applied to diesel engine exhaust measurements
  - Campaign program, scope and setup
  - Using non-counting instruments for particle number measurements
  - Using non-gravimetric methods for particle mass measurement
- Conclusions
- Q & A

Campaign Program and Scope

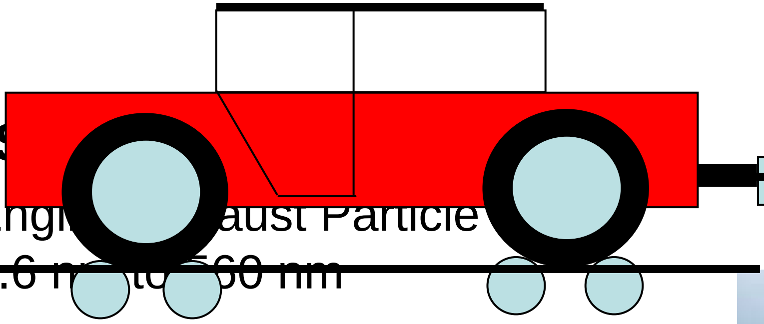
- Test program (in cooperation with DEKRA and TÜV Nord, other instrumentation manufacturers and developers also participated)
  - 31 test runs during one week on a chassis-dynamometer at DEKRA Technology Center in Klettwitz (Germany)
  - 3 different diesel engine vehicles (all Euro 4, one w/o DPF)
  - Adjustable DPF-bypass in several tests to simulate DPF malfunction
  - European drive cycle tests as well as steady state test cycles were run
- Scope: Demonstrate that tail pipe measurements can identify DPF malfunctions which OBD can‘t

Experimental Setup

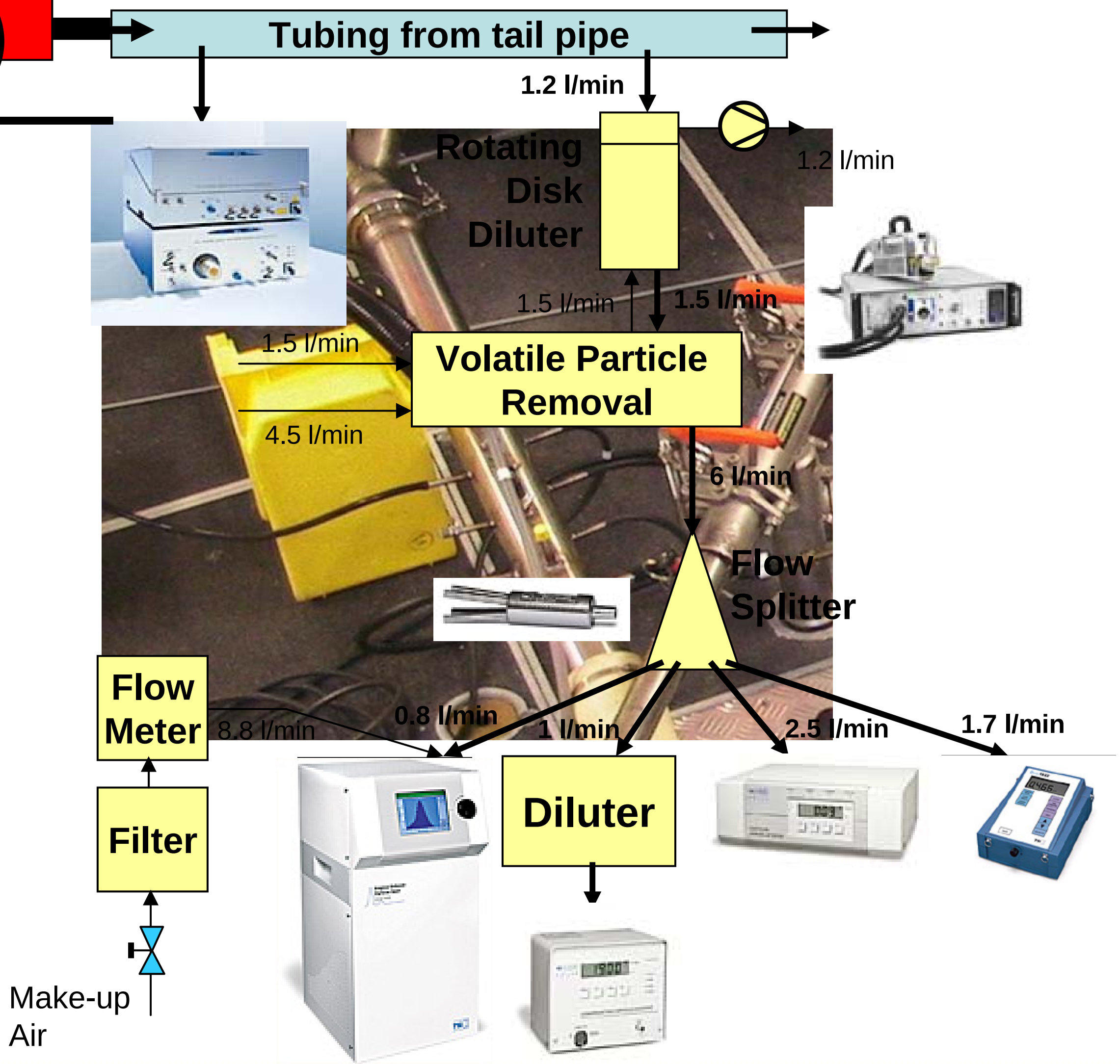
Climatic Chassis Dynamometer at DEKRA Klettwitz

Experimental Setup

- **EEPS**
  - Engi aust Particle
    5.6 n to 560 nm

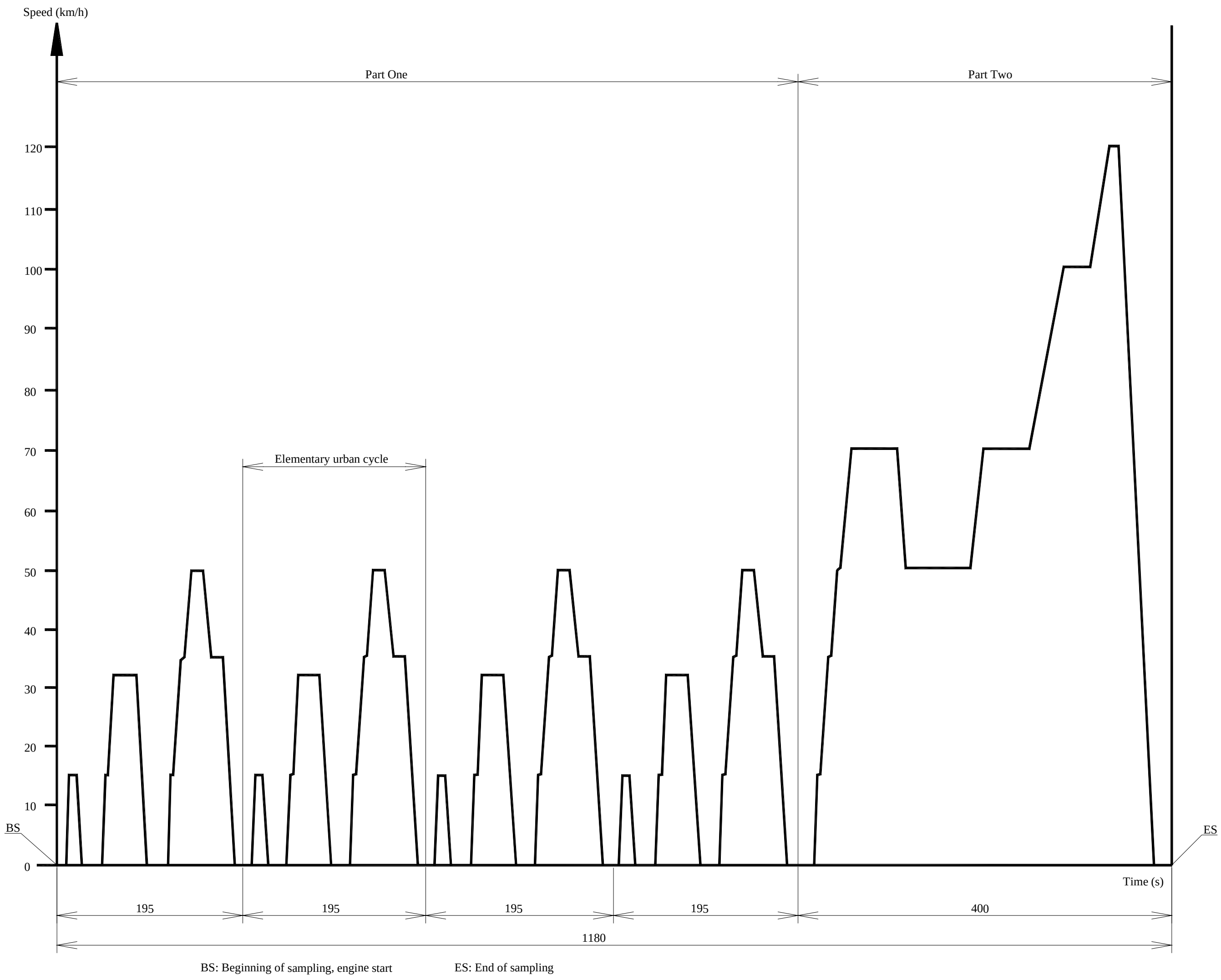


- **CPC 3010D:**
  - Engine Exhaust CPC, 23 nm to 3 µm
- **EAD 3070A:**
  - Diffusion Charger & Electrometer, 10 nm to 1 µm
- **DustTrak 8520:**
  - Light Scattering Photometer, 0.1 to 10 µm
- **AVL MSS:**
  - Photoacoustic Micro-Soot Sensor, total soot mass concentration



Experimental Setup

Operating cycle for the Type I test



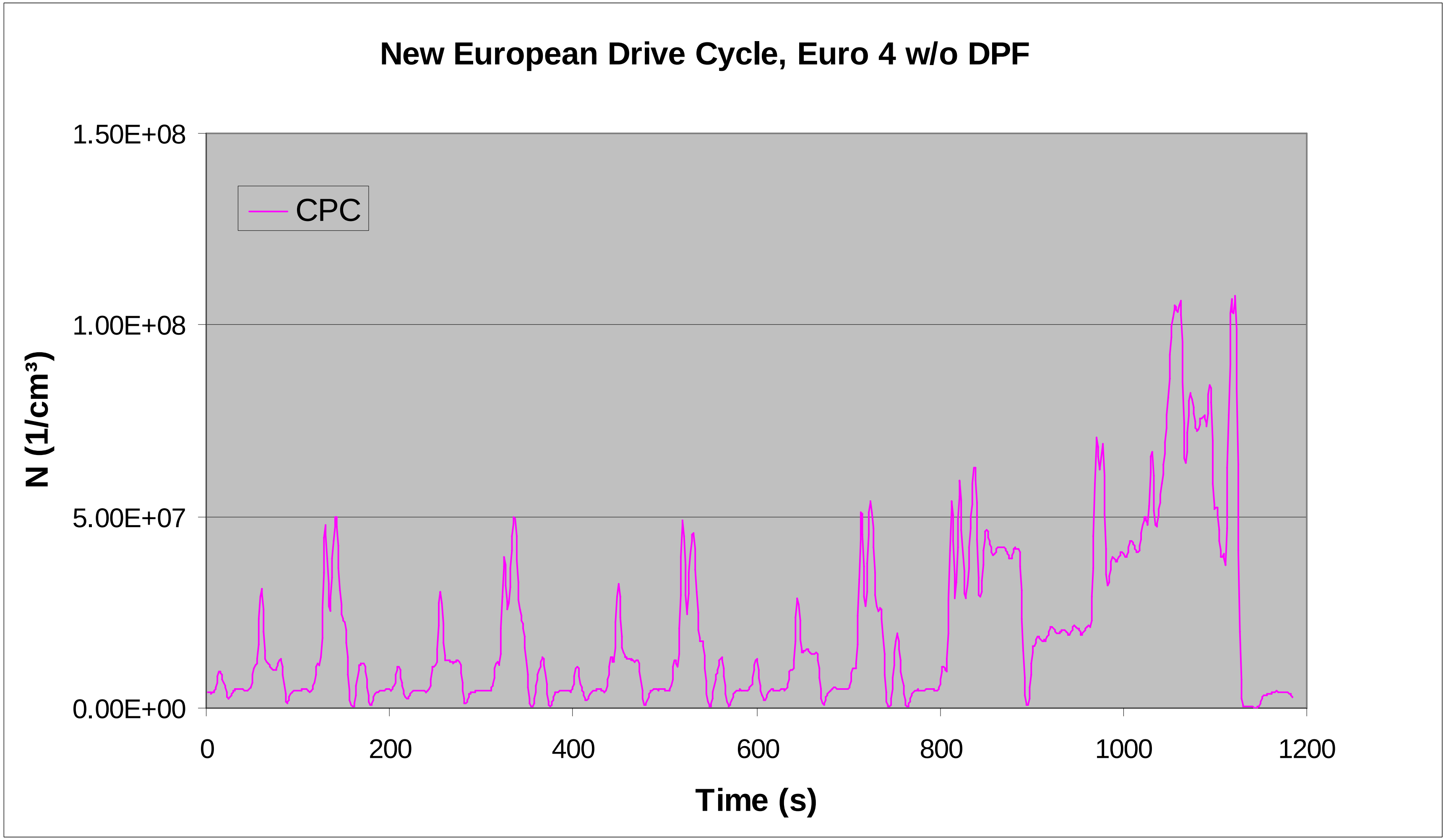
Example Results

– European test cycle
– Euro 4 diesel engine LD vehicle without DPF
– Particle number measurements with CPC 3010D, EEPS 3090 and EAD 3070A
– Particle mass measurements with EEPS 3090, EAD 3070A and DustTrak 8520
– Soot mass measurement with AVL MSS

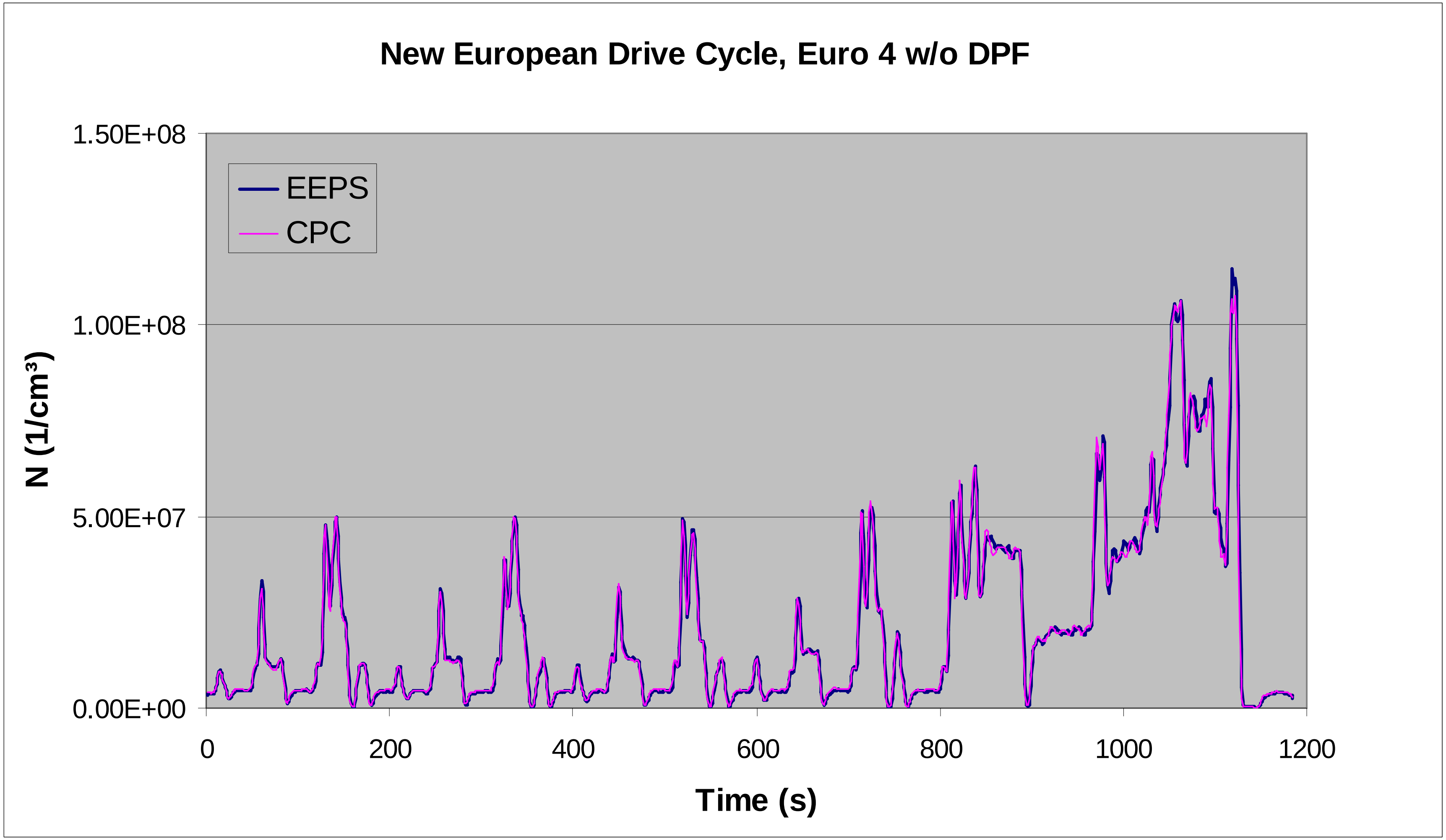
Data Analysis

- Step 1:
  Synchronize all instrument data (using the first prominent peak)
- Step 2:
  Apply a 5 seconds running average to all data sets to minimize the influence of instrument response time
- Step 3
  Integrate each data set and normalize all number (mass) measurements to the integrated data of the CPC 3010D (EEPS 3090)
- Step 4
  Compare dynamic concentration range and data correlation based on second by second data

Particle Number



Particle Number



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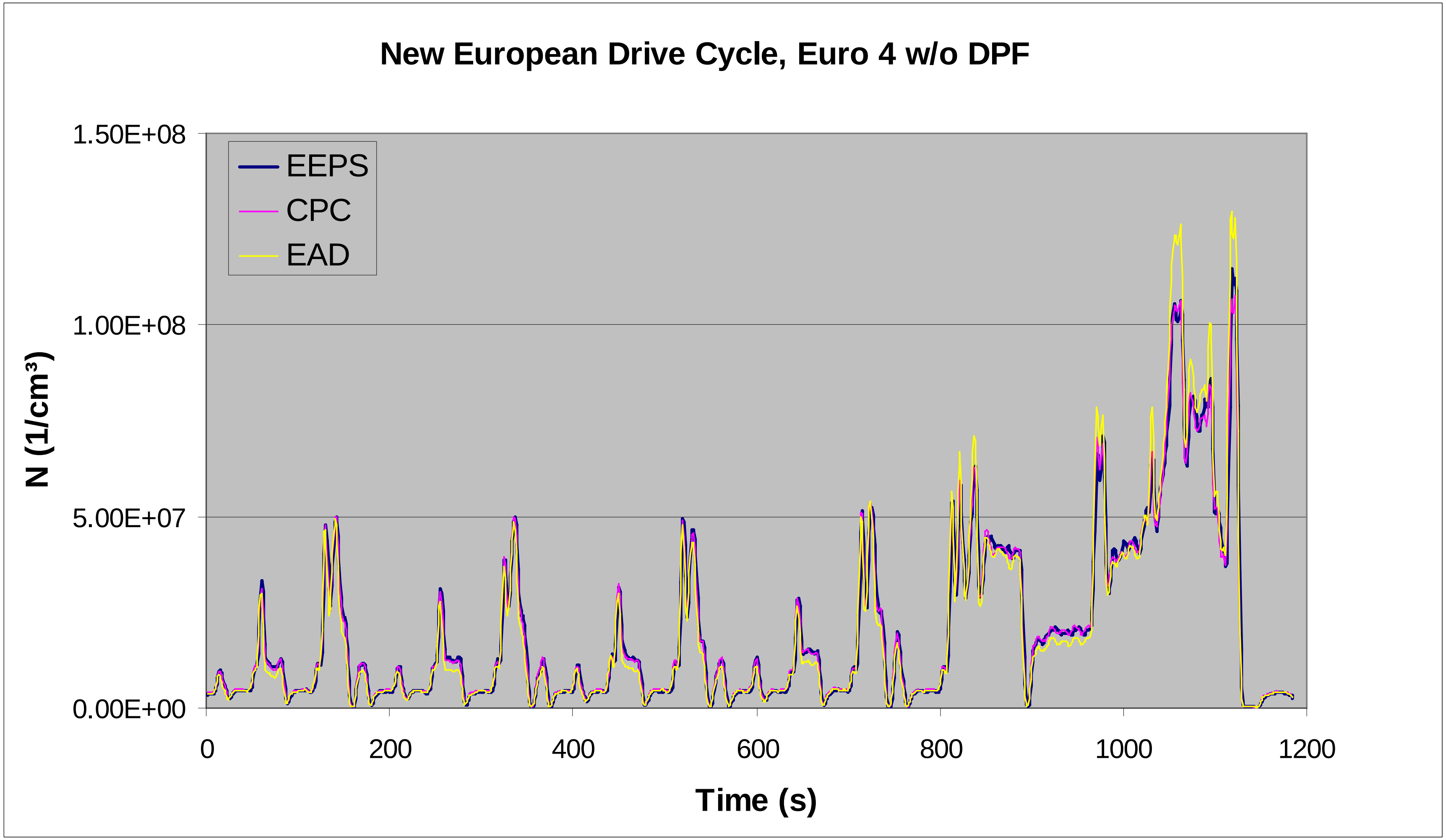

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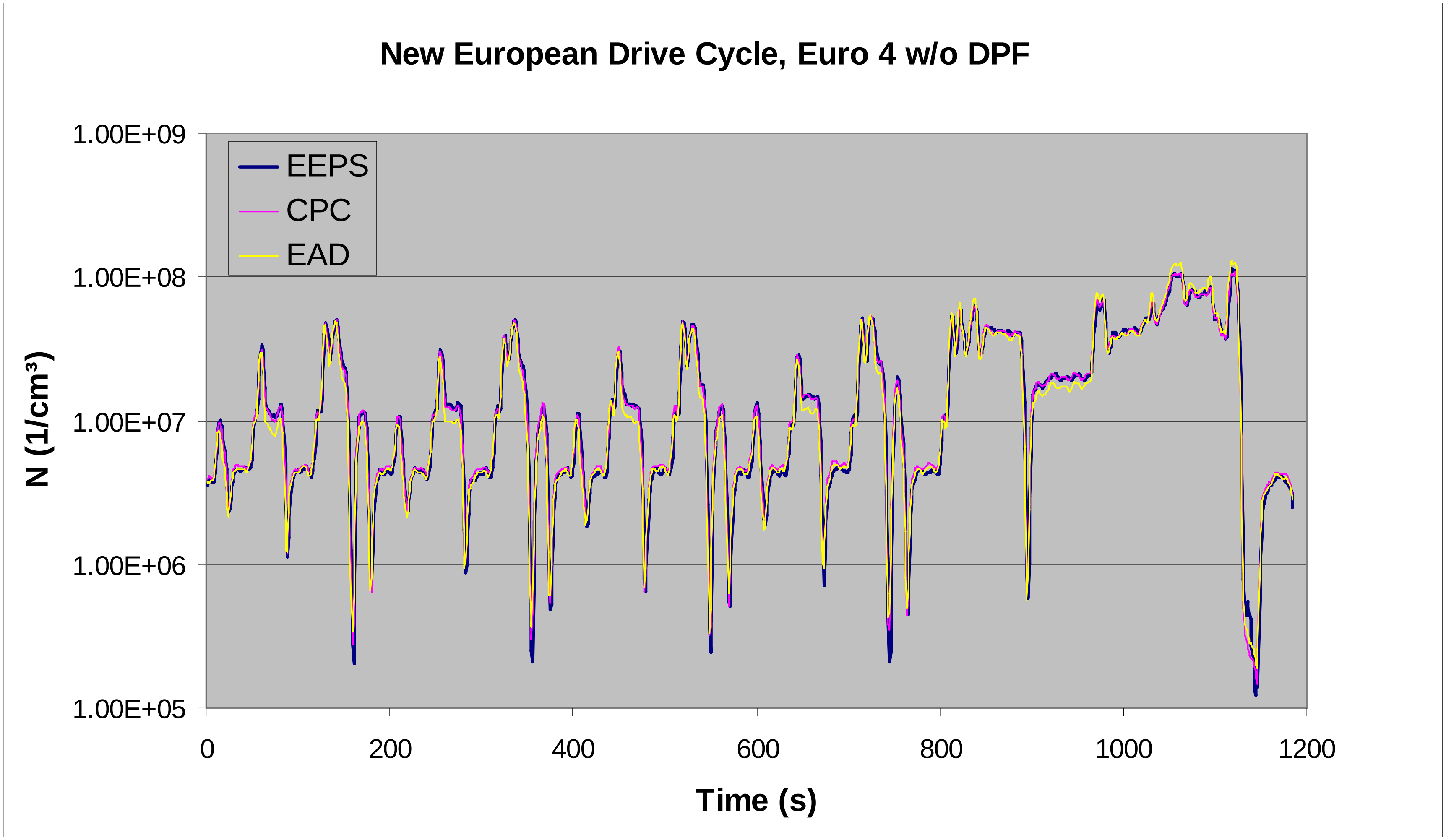
Particle Number



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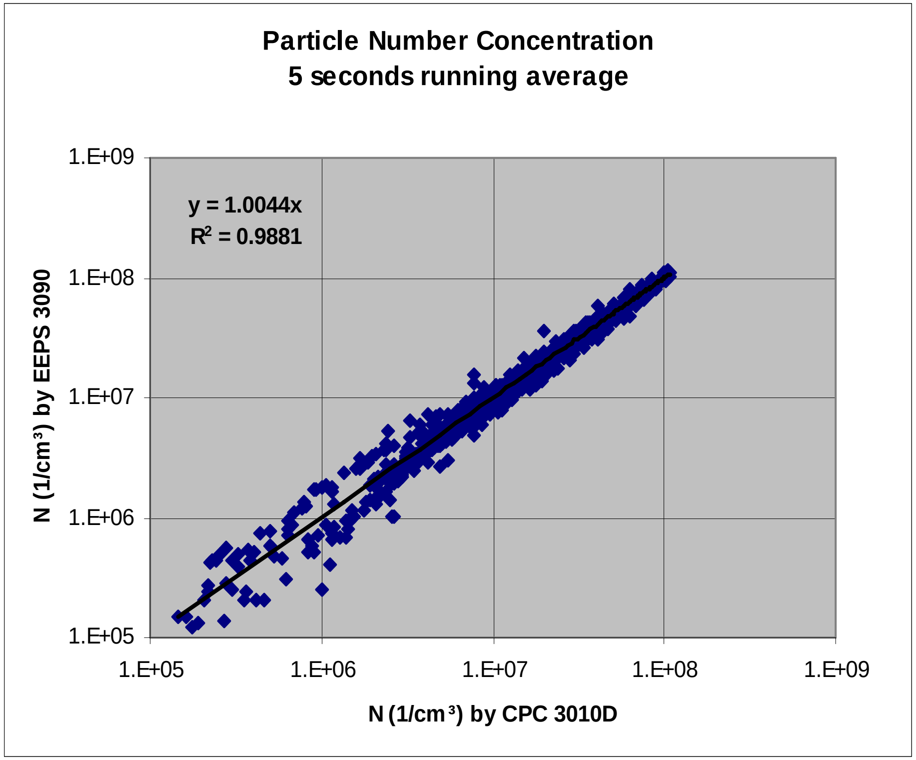
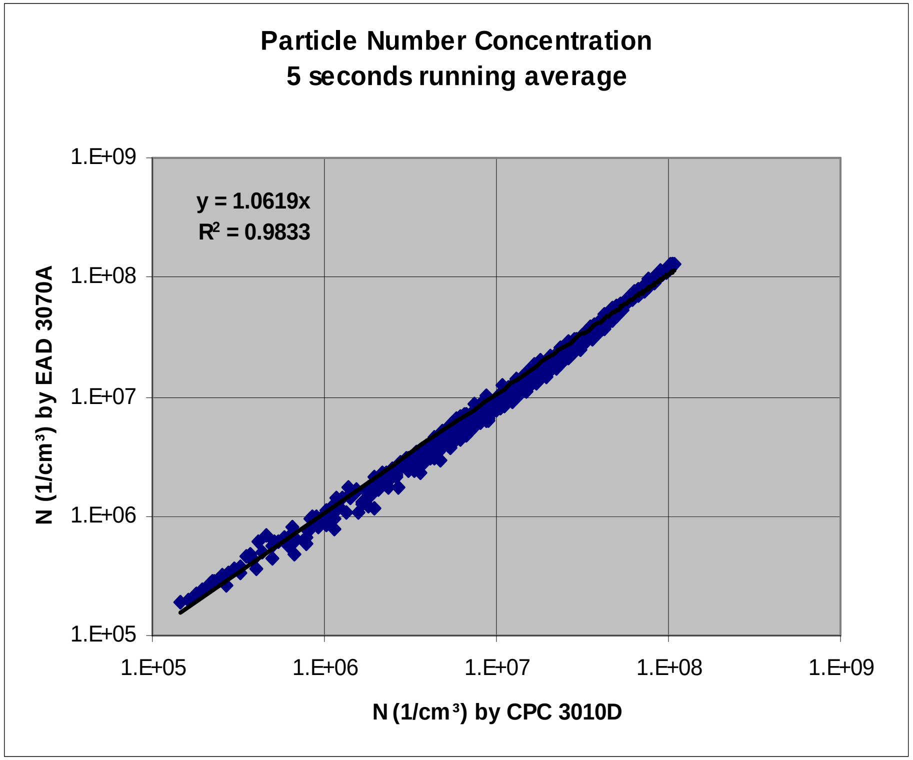
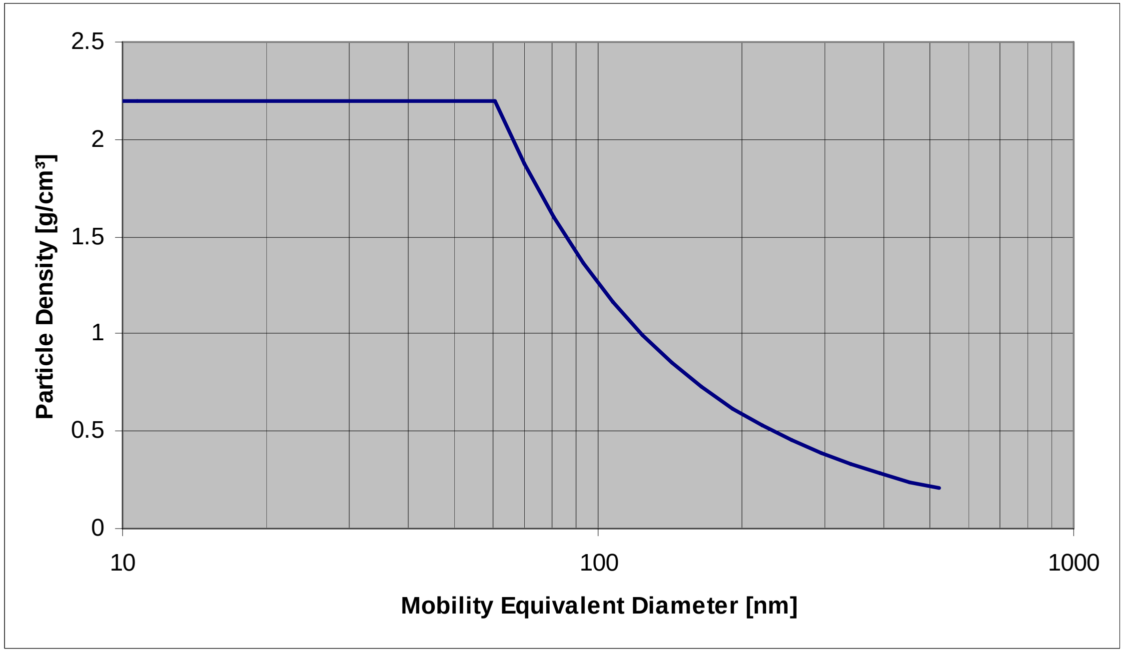
Number Correlation





EEPS Mass Calculation



Fractal density function for EEPS mass calculations:

$\rho_{p'}$ (g cm^{-3})= C D$_p$(nm) $^{Df-3}$; C = 200; Df = 1.9

ρ_p< 2.2 g cm^{-3} estimated density of primary soot particles

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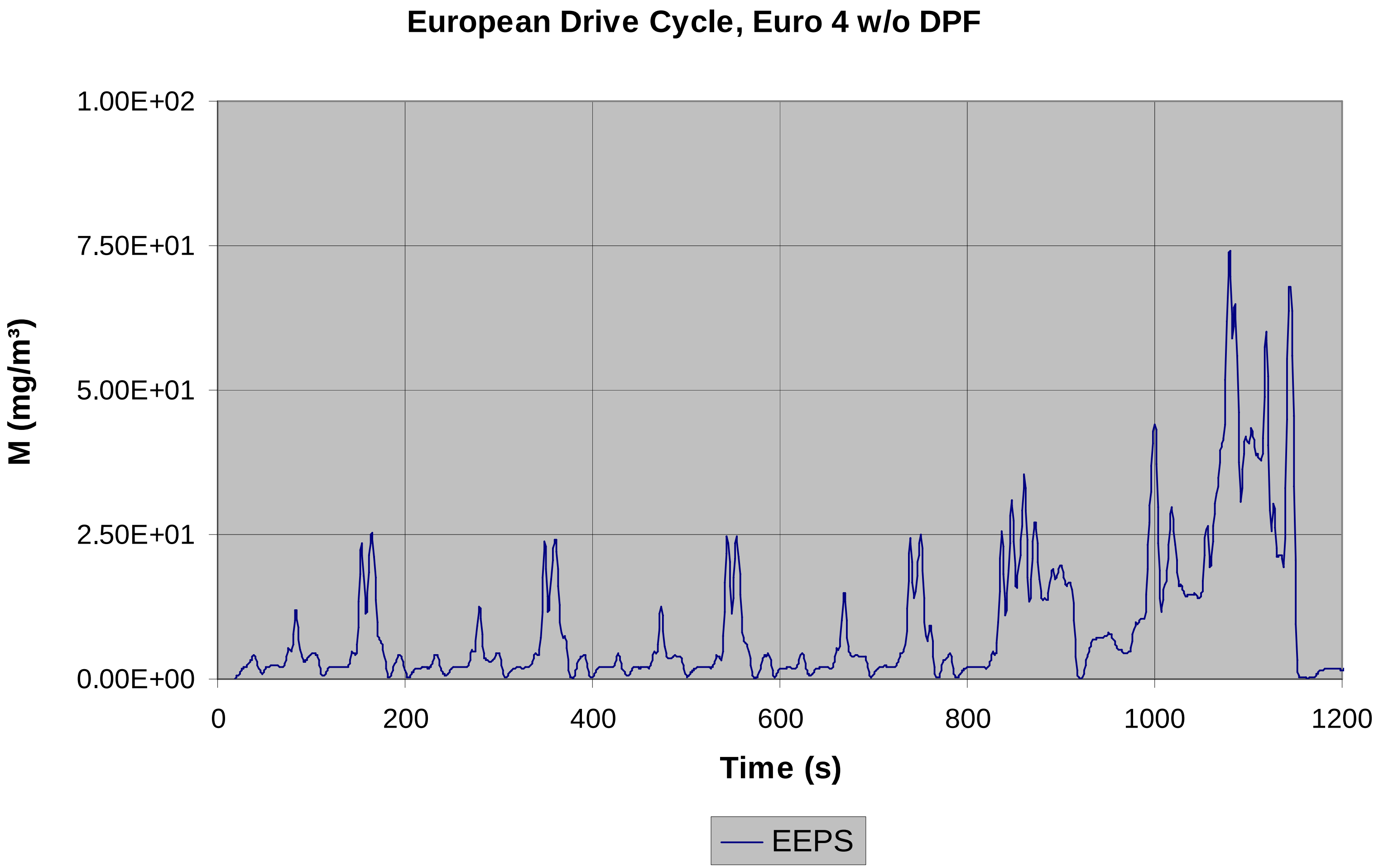
Particle Mass



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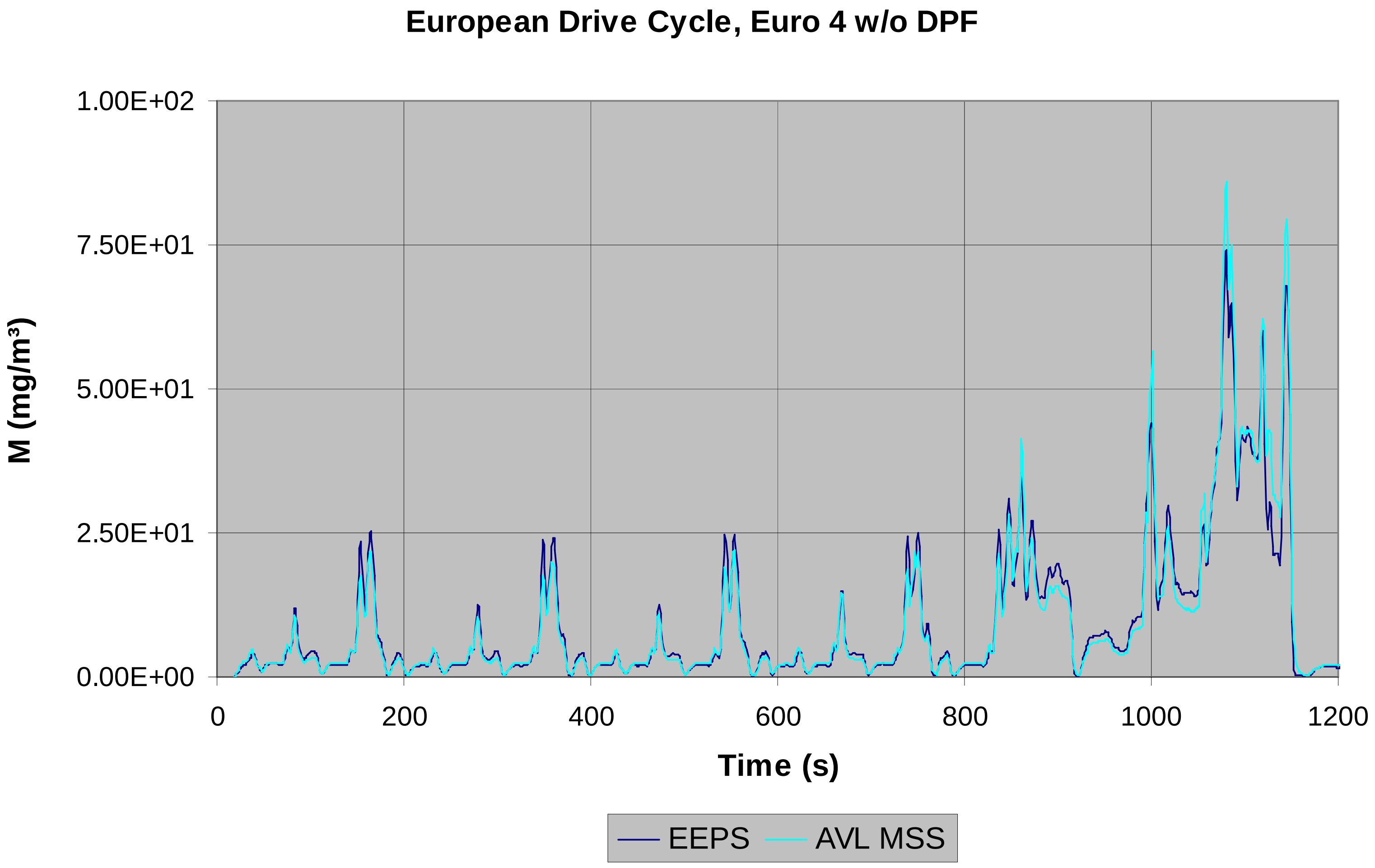
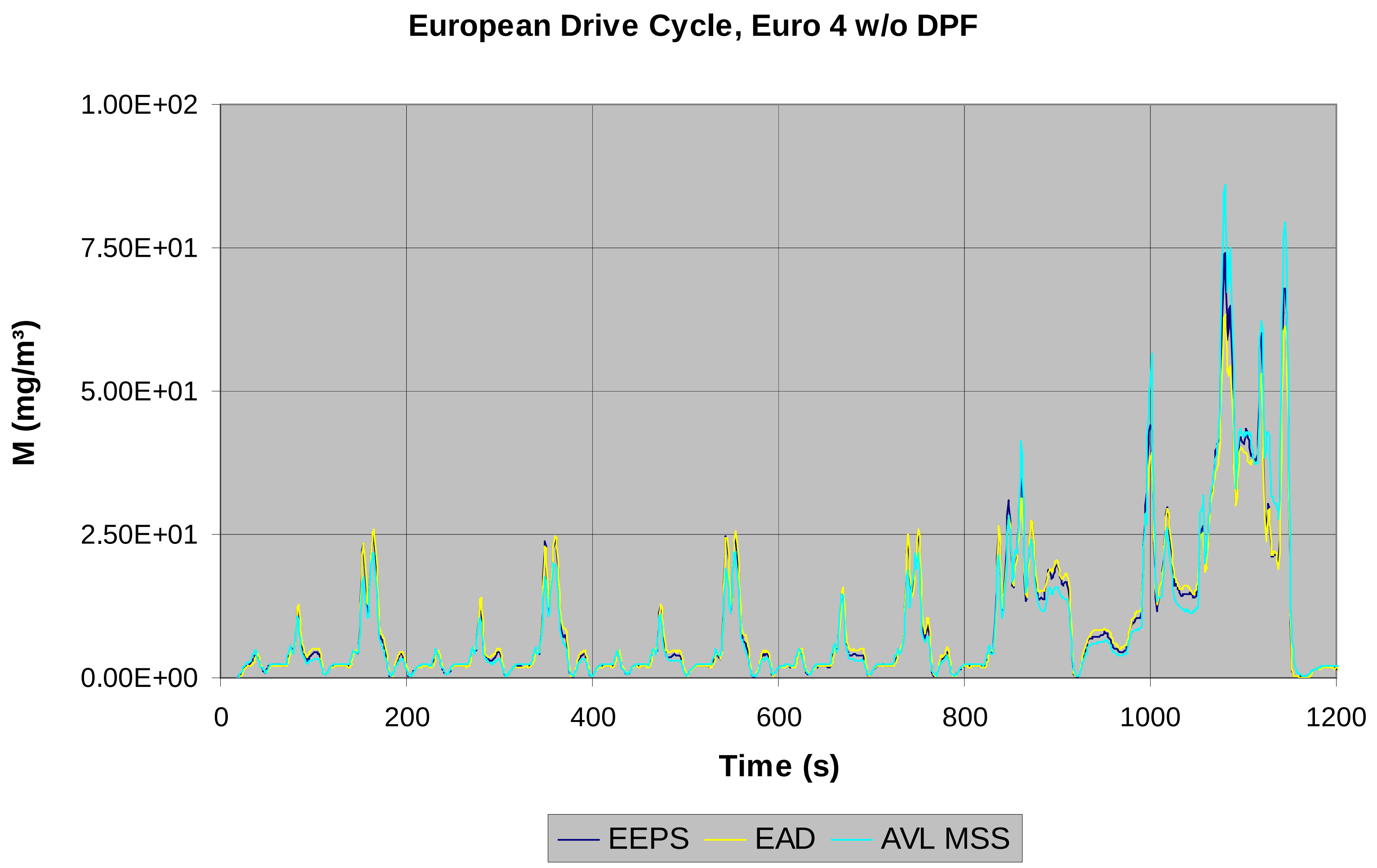
Particle Mass



Particle Mass



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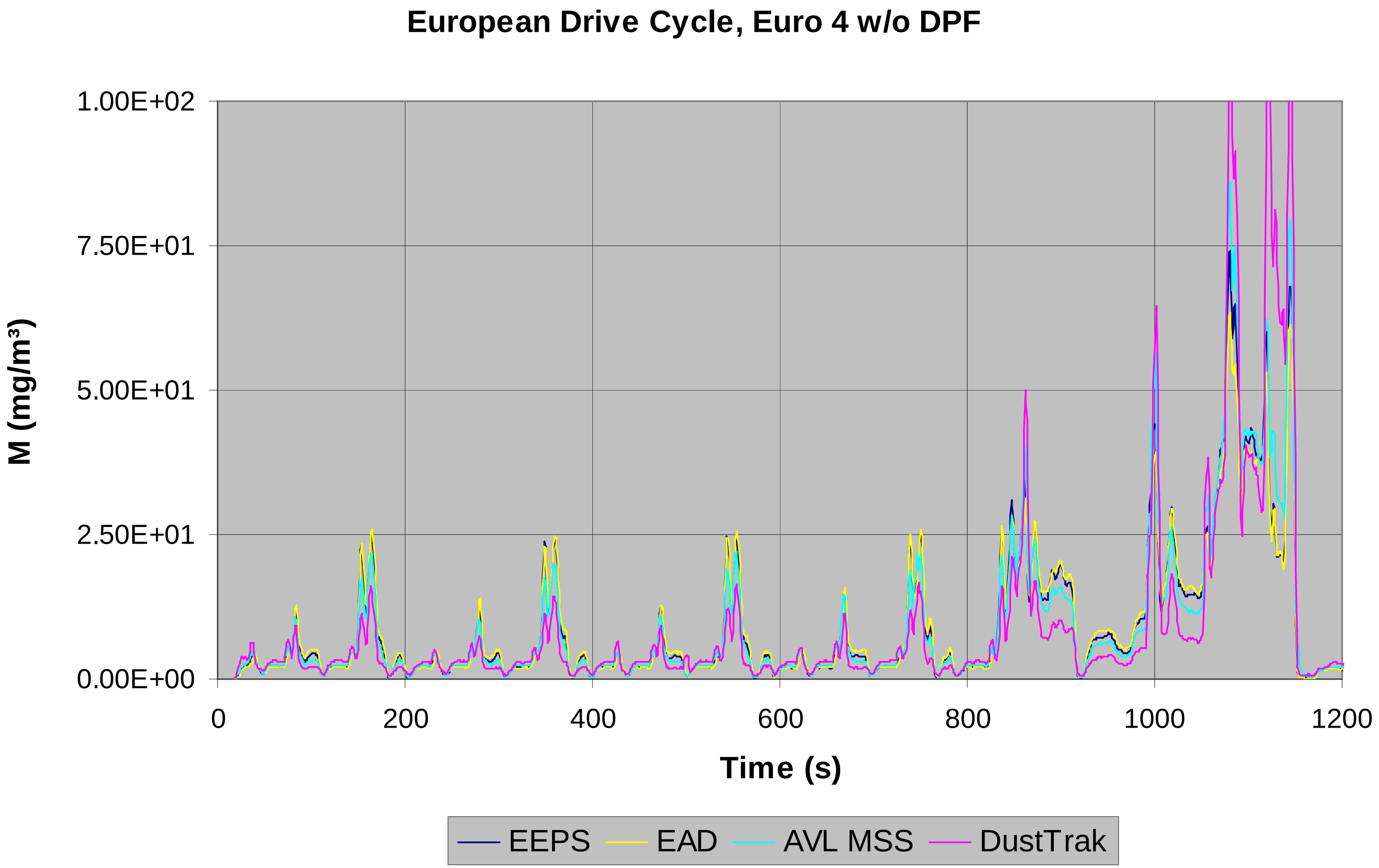
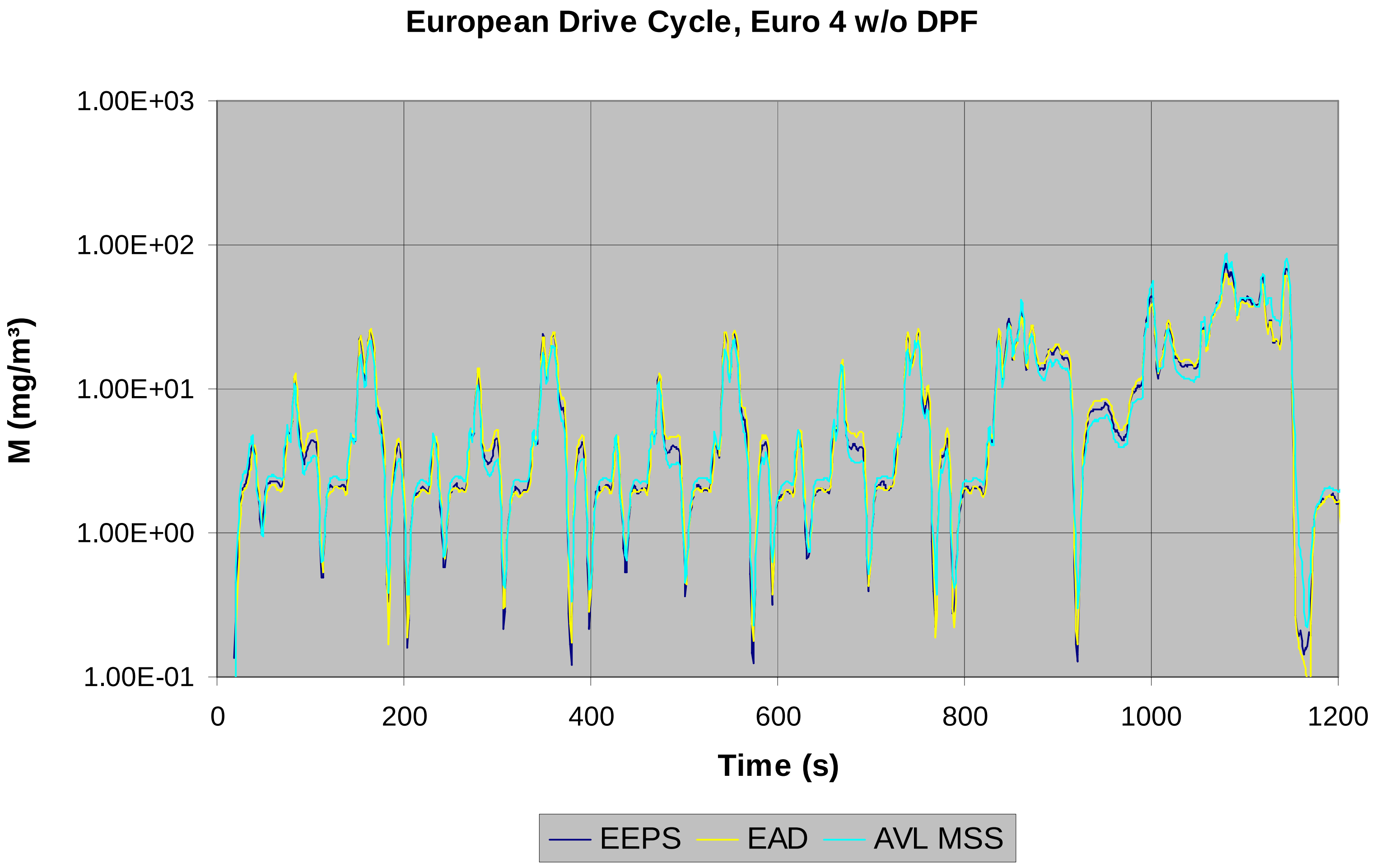
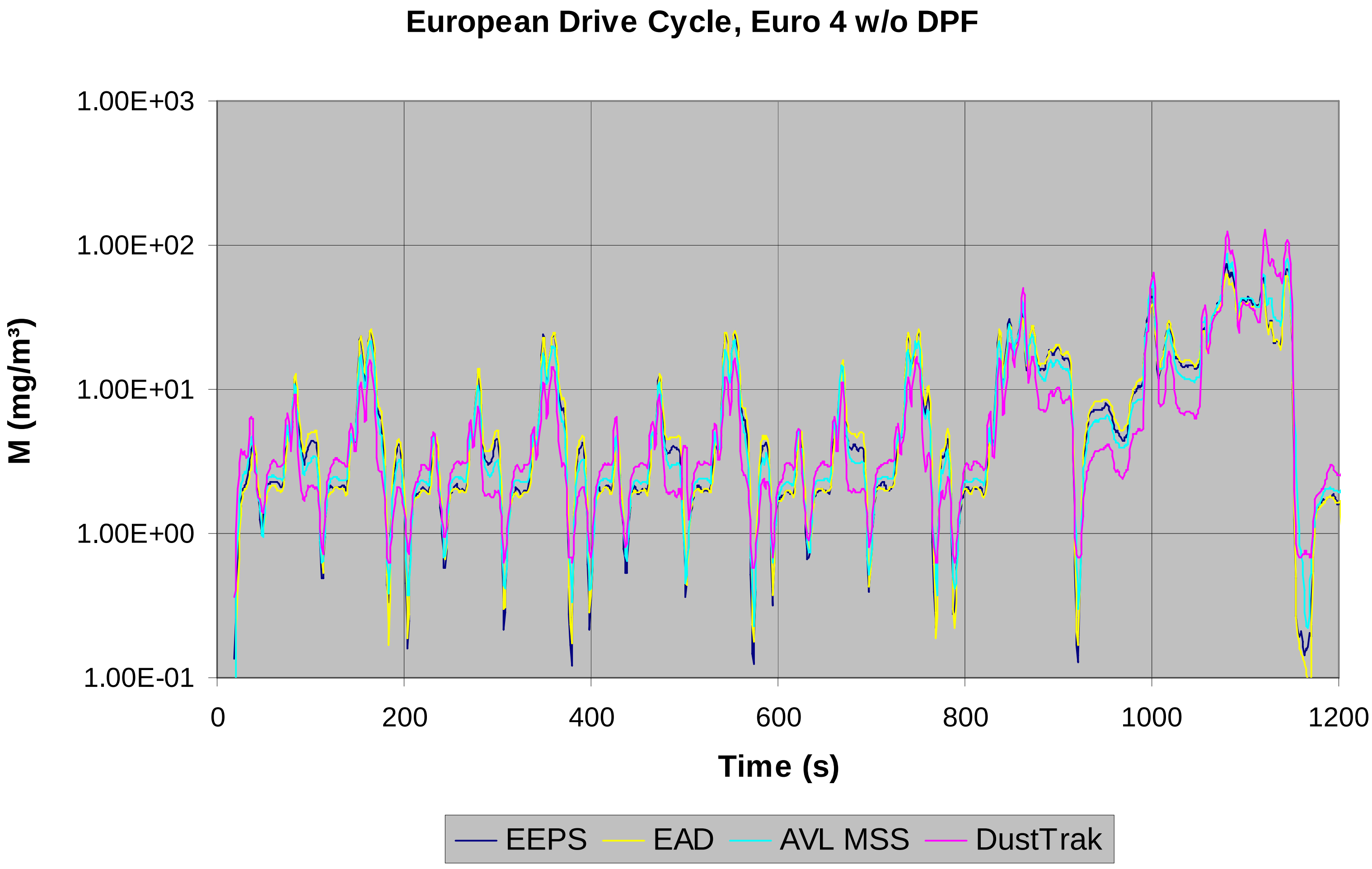
Particle Mass



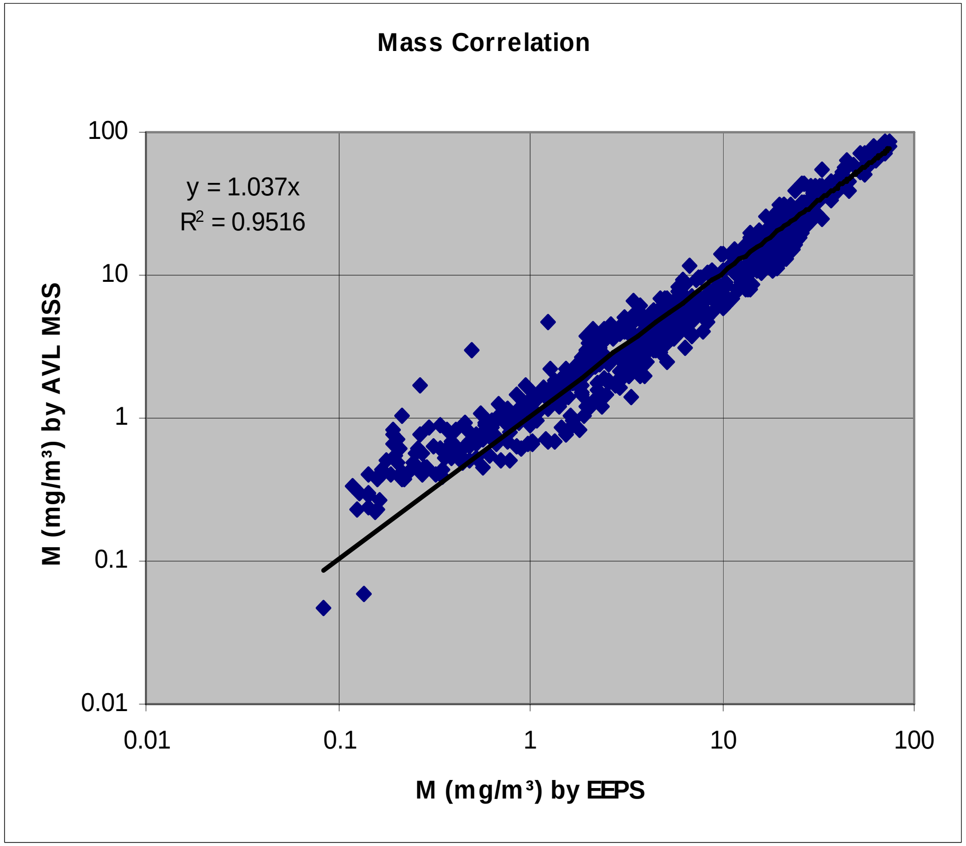
Particle Mass

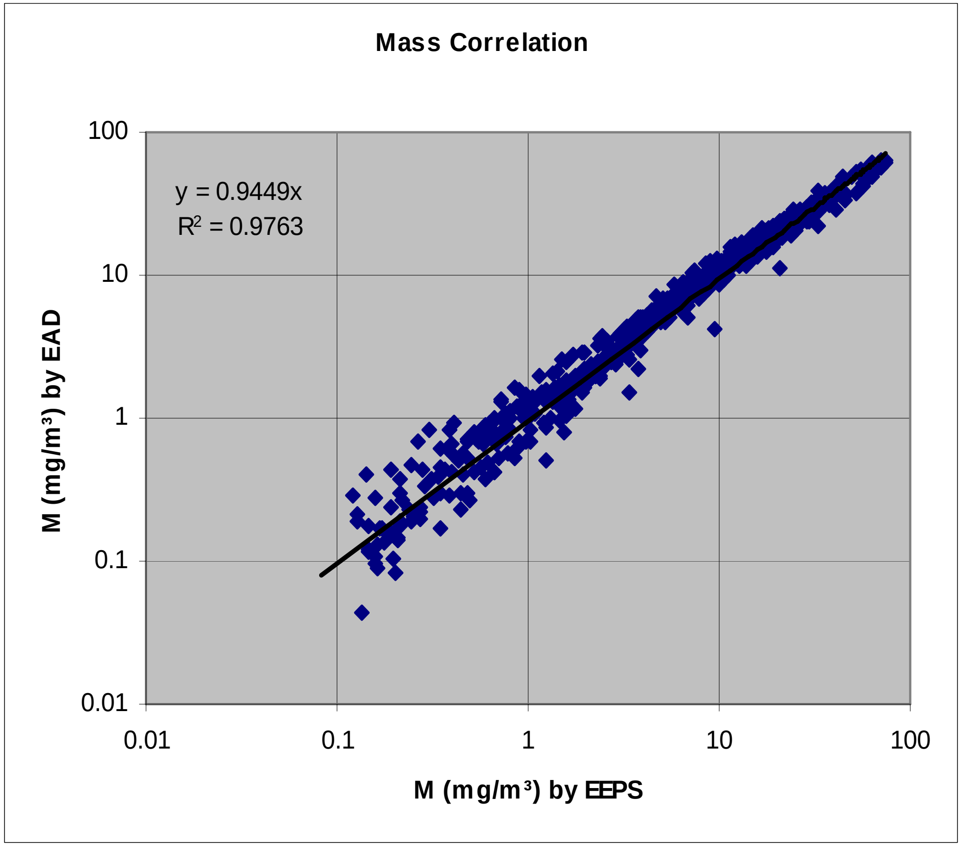


Particle Mass

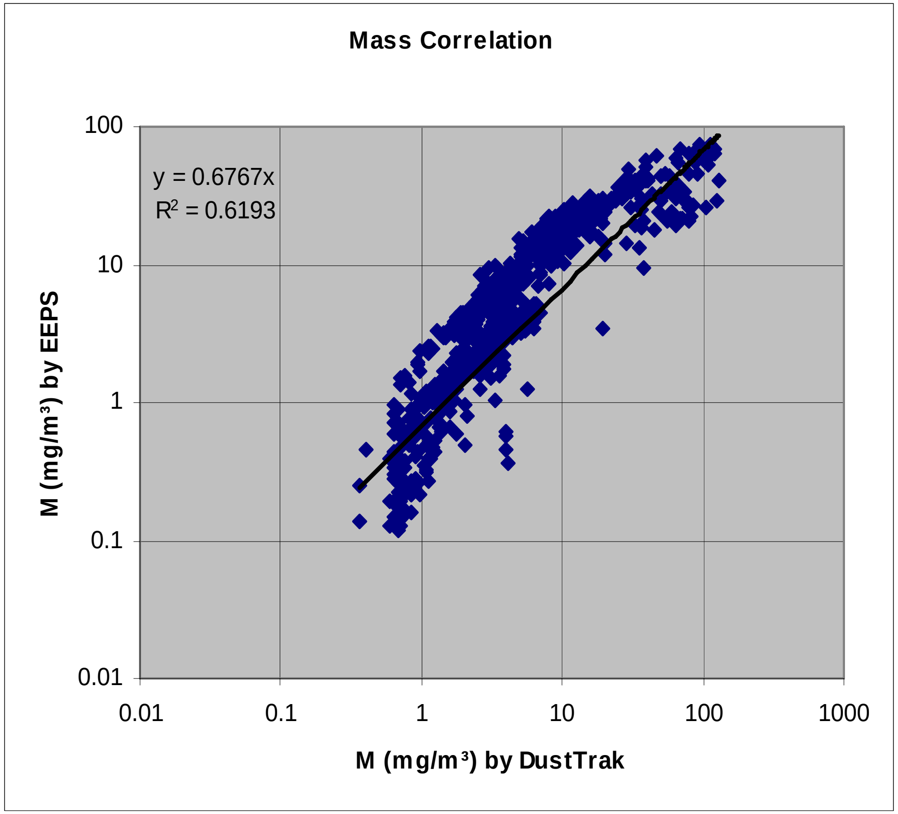


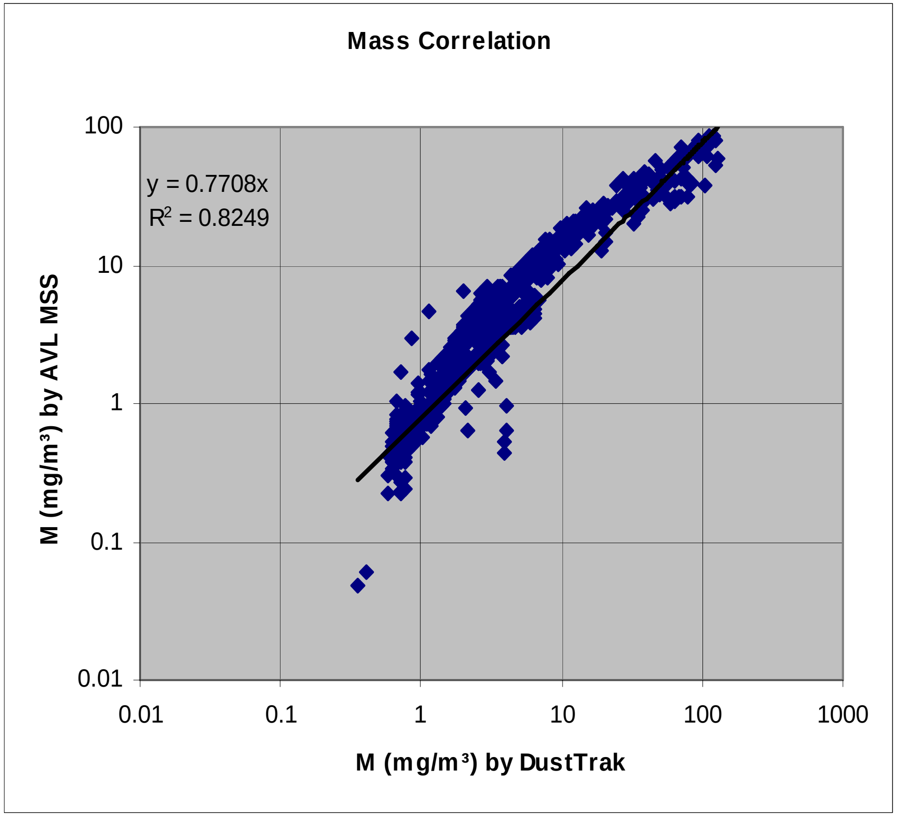
Mass Correlations





Mass Correlations





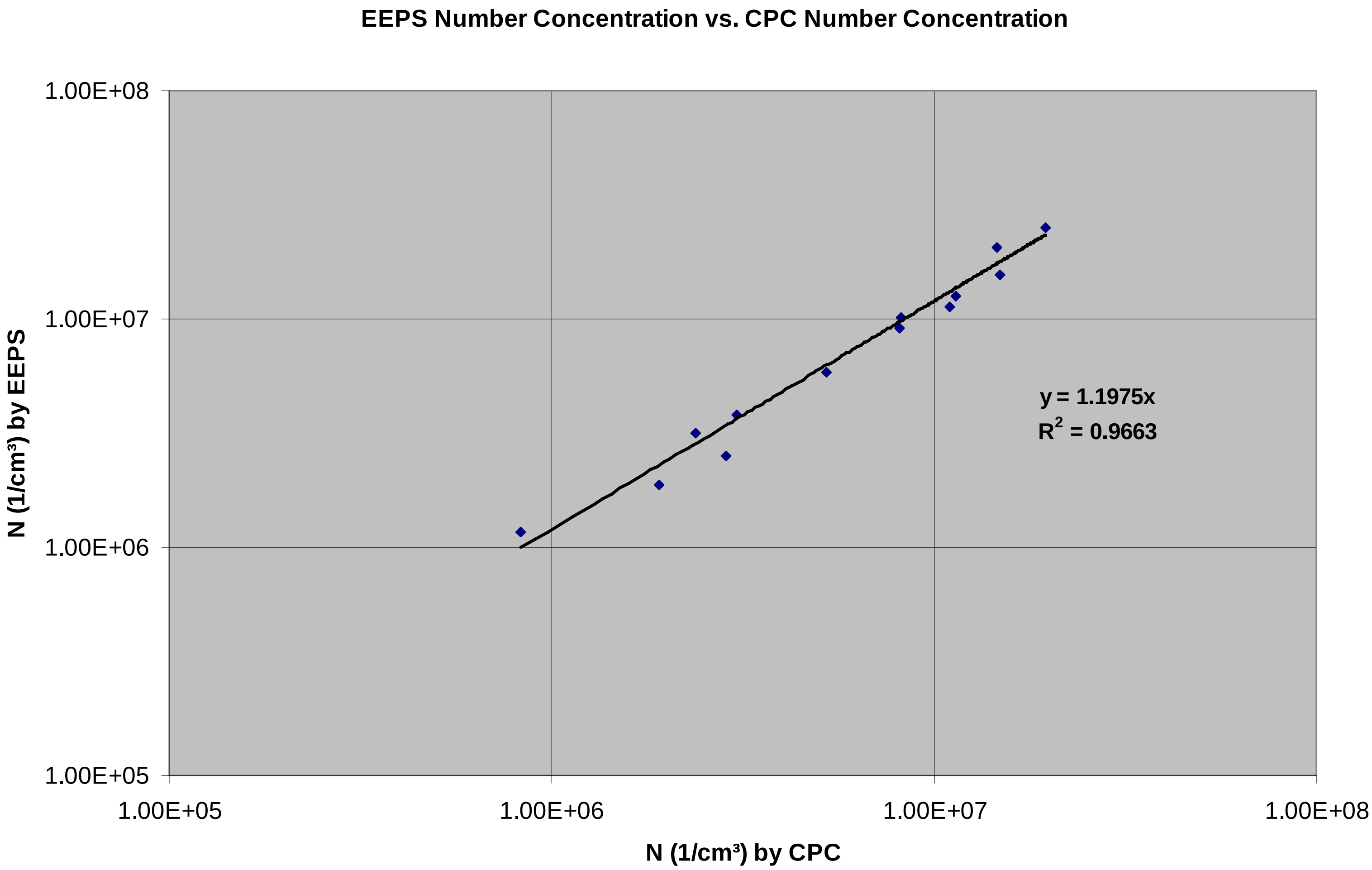
Overall Correlation

- Average number concentration and mass concentration was calculated for each test run

- Instruments used in the test runs were then correlated based on these average values

Overall Correlations

based on average data of all test runs



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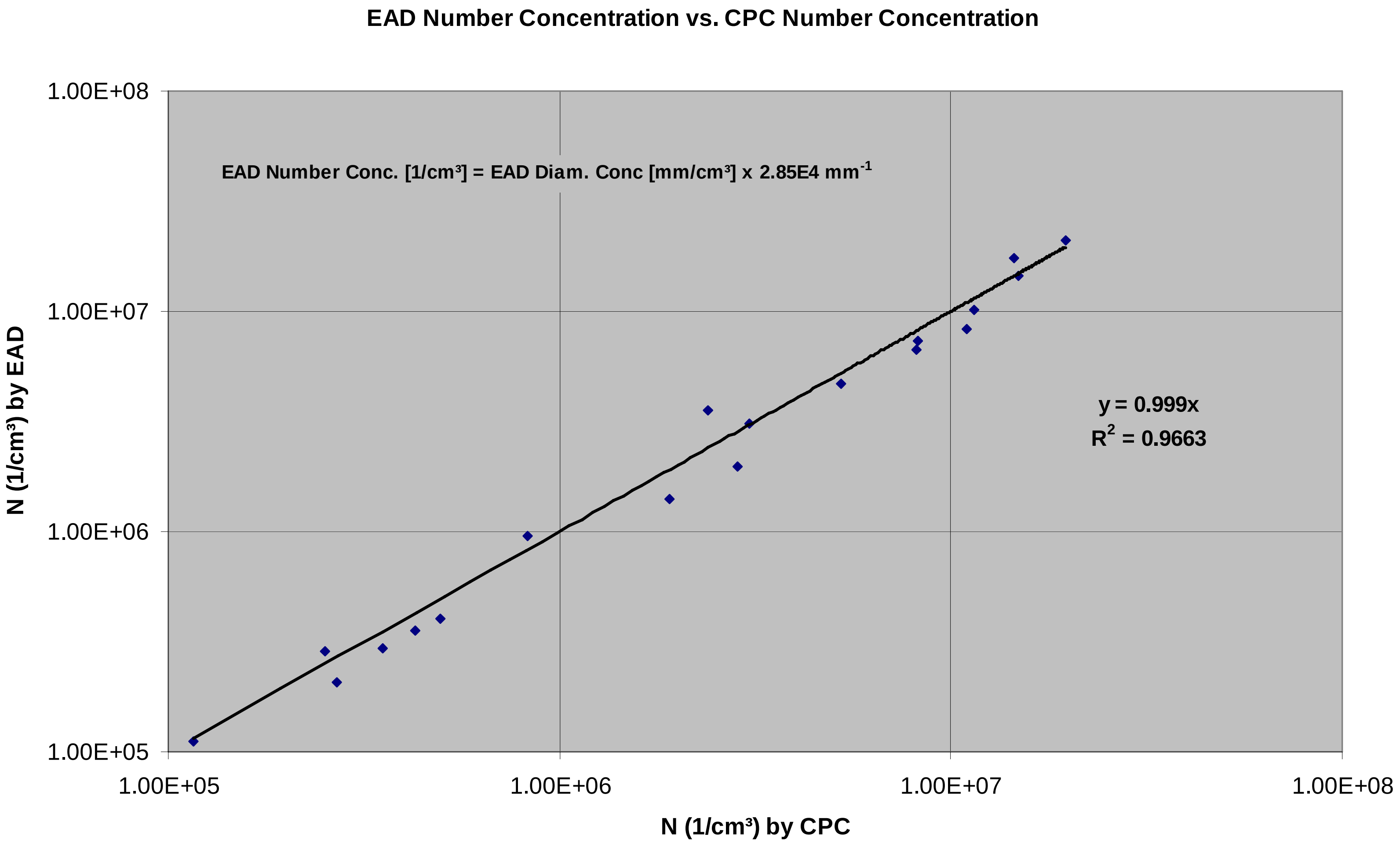
Overall Correlations

based on average data of all test runs



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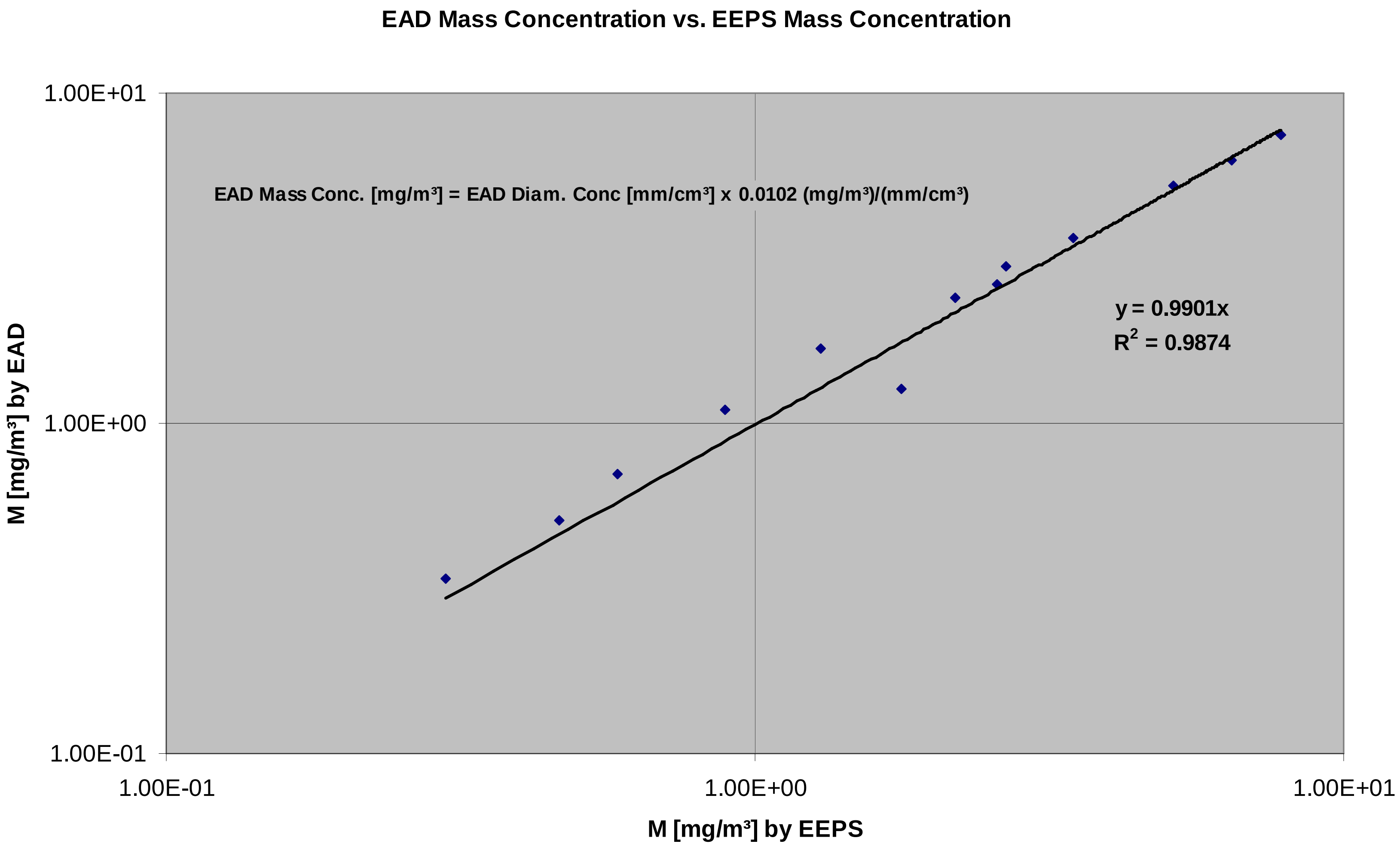
Overall Correlations

based on average data of all test runs



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Overall Correlations

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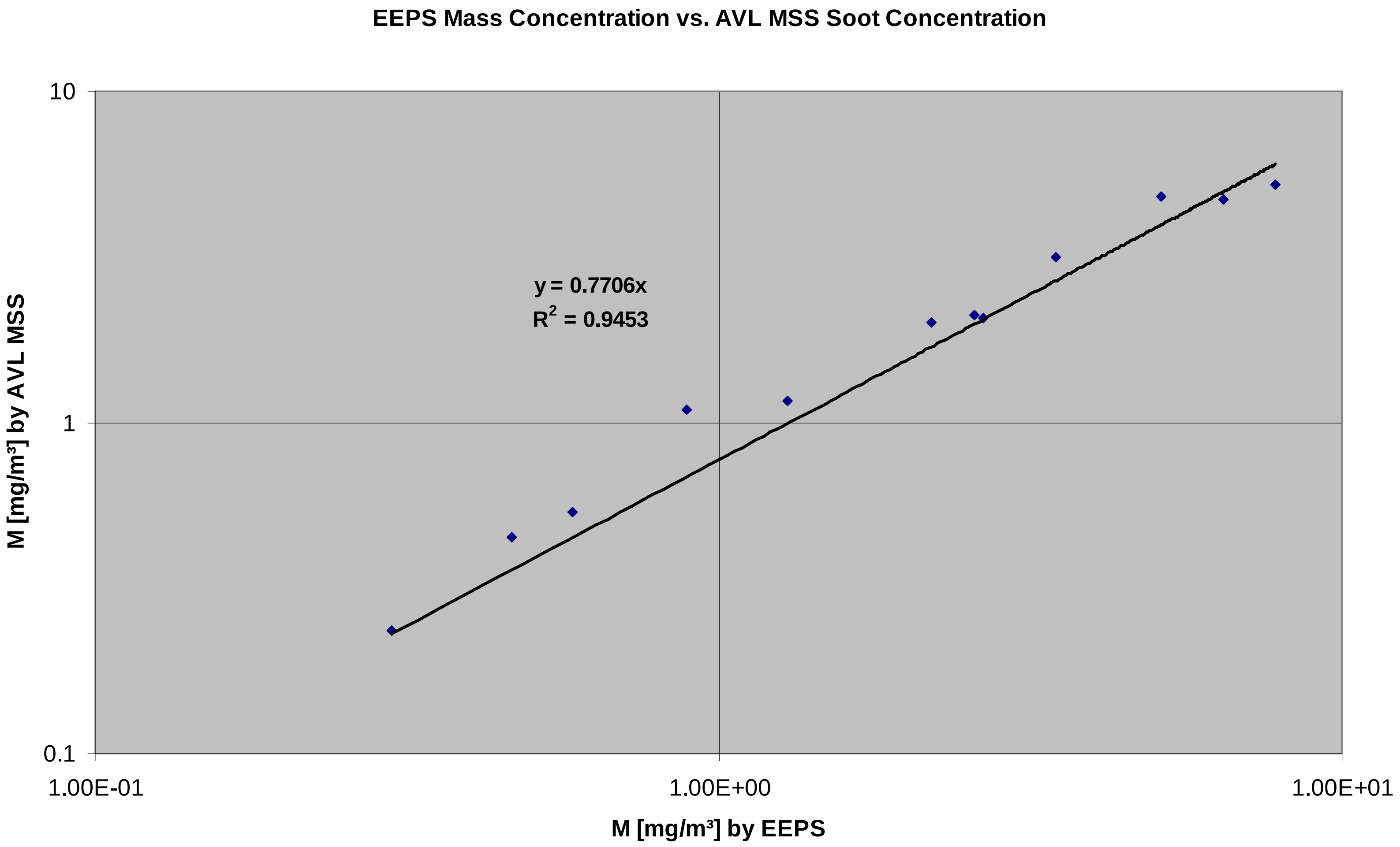

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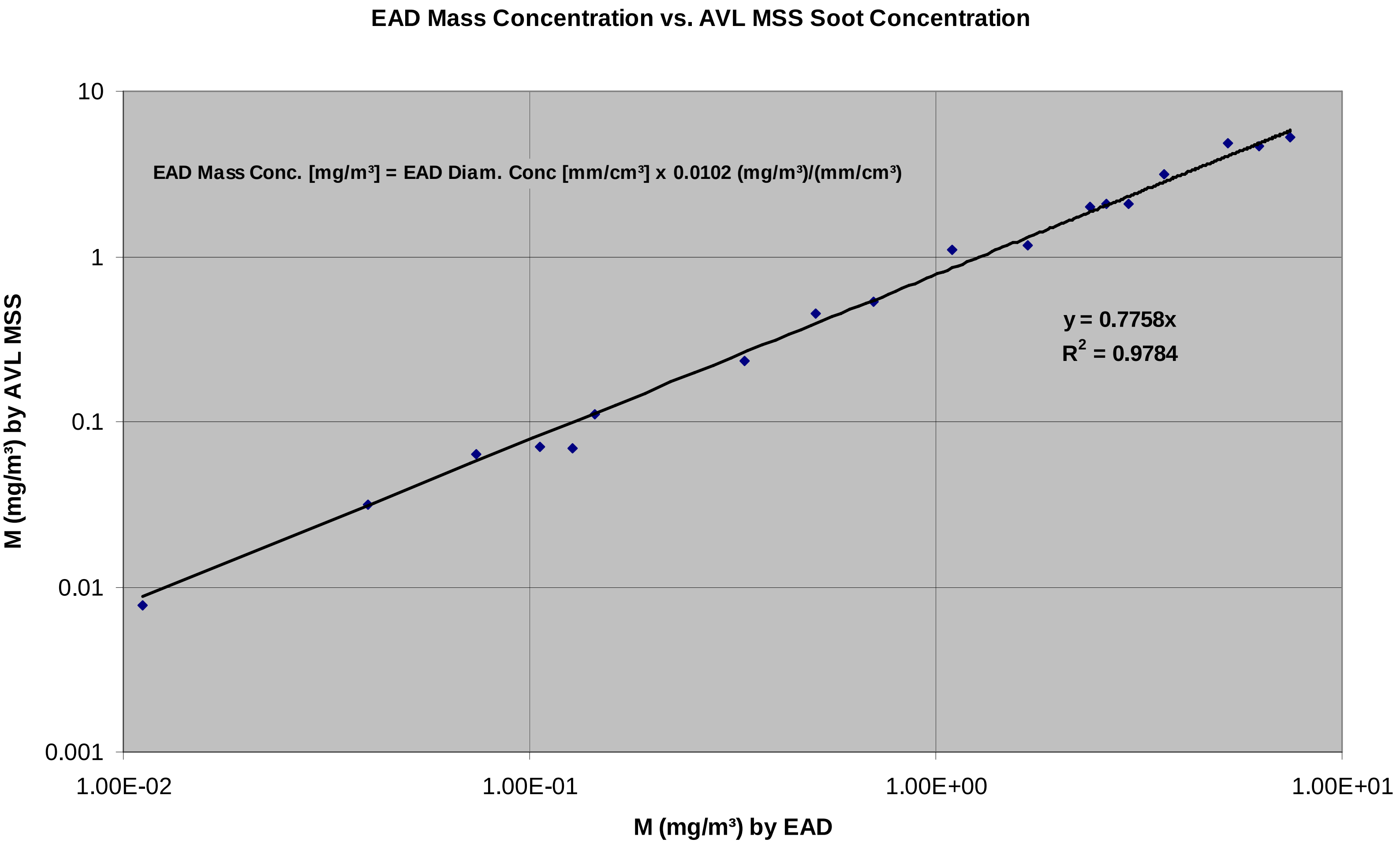
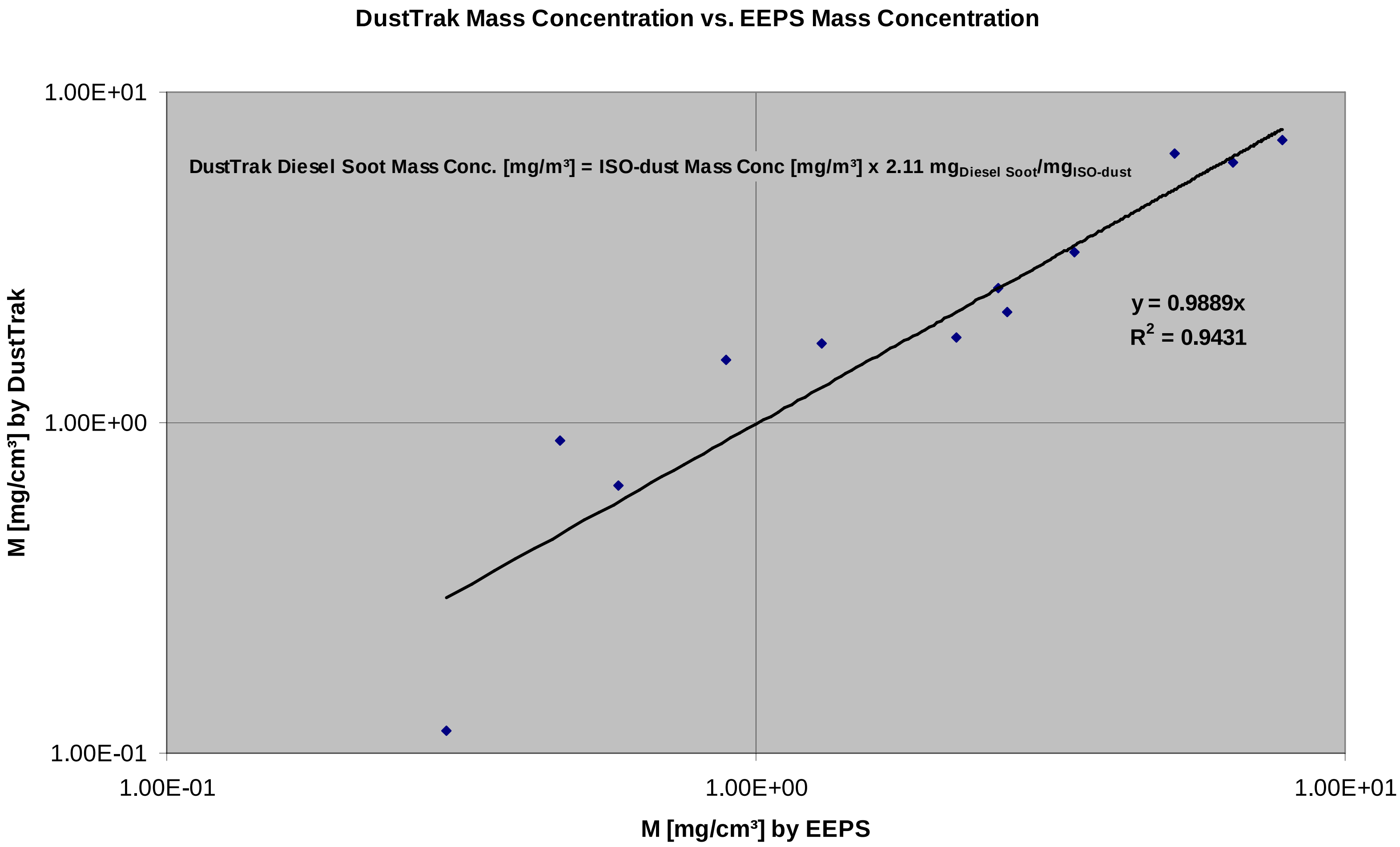
Overall Correlations

based on average data of all test runs



Overall Correlations

based on average data of all test runs



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Overall Correlations

R^2	Number Concentration			Mass Concentration			
	CPC	EEPS	EAD	EEPS	EAD	DustTrak	AVL MSS
CPC	-	0.966	0.966	N.A.	N.A.	N.A.	N.A.
EEPS		-	0.989	-	0.987	0.943	0.945
EAD			-		-	0.951	0.978
DustTrak	N.A.	N.A.	N.A.			-	0.961
AVL MSS	N.A.	N.A.	N.A.				-

Conclusions – Particle Number

- Considering the applied high dilution, CPC, EEPS and EAD demonstrated the necessary sensitivity and dynamic concentration range for particle number measurments
- Particle number correlations were good for CPC vs EEPS and CPC vs EAD, respectively
- For the typically stable soot size distributions, EAD can be calibrated for number measurement

Conclusions – Particle Mass

- Considering the applied high dilution, EEPS, EAD and MSS demonstrated the necessary sensitivity and dynamic concentration range for particle mass measurments
- Particle mass correlations were acceptable for MSS vs EEPS and MSS vs EAD, respectively
- For the typically stable soot size distributions, EAD can be calibrated for mass measurement
- DustTrak measurements were strongly influenced by relatively small changes in particle size distribution

The End

Thank you very much for your attention!

Questions?