

**French Institute
of Science and Technology
for Transport, Development
and Networks**



**23rd TAP Conference
Thessaloniki 2019**

Euro 3 and Euro 5 Diesel vehicles' particles evolution in ageing chamber

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Wednesday, May the 15th

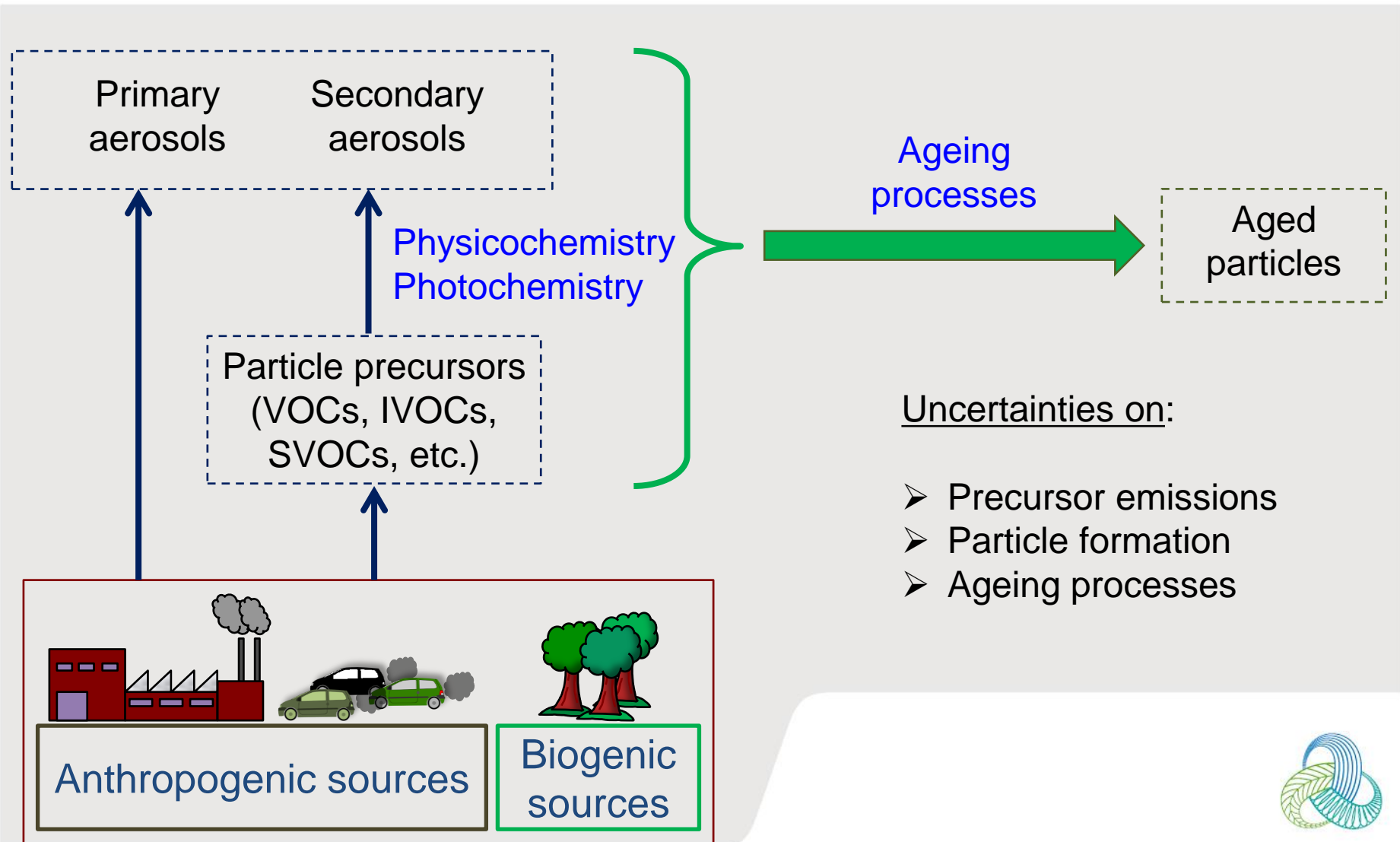
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IFSTTAR

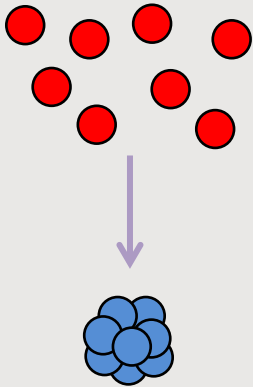
Context



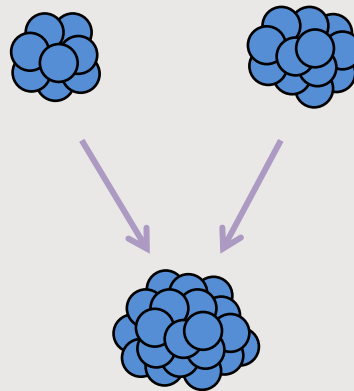
Context

→ Understanding contribution of transports on atmospheric particle formation and ageing through physical phenomena

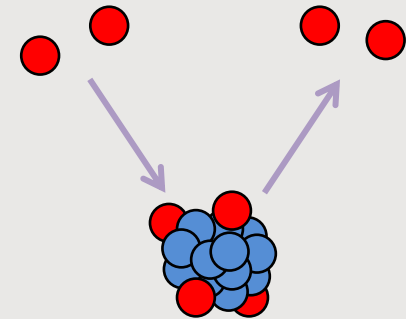
Nucleation



Coagulation



Condensation /
evaporation



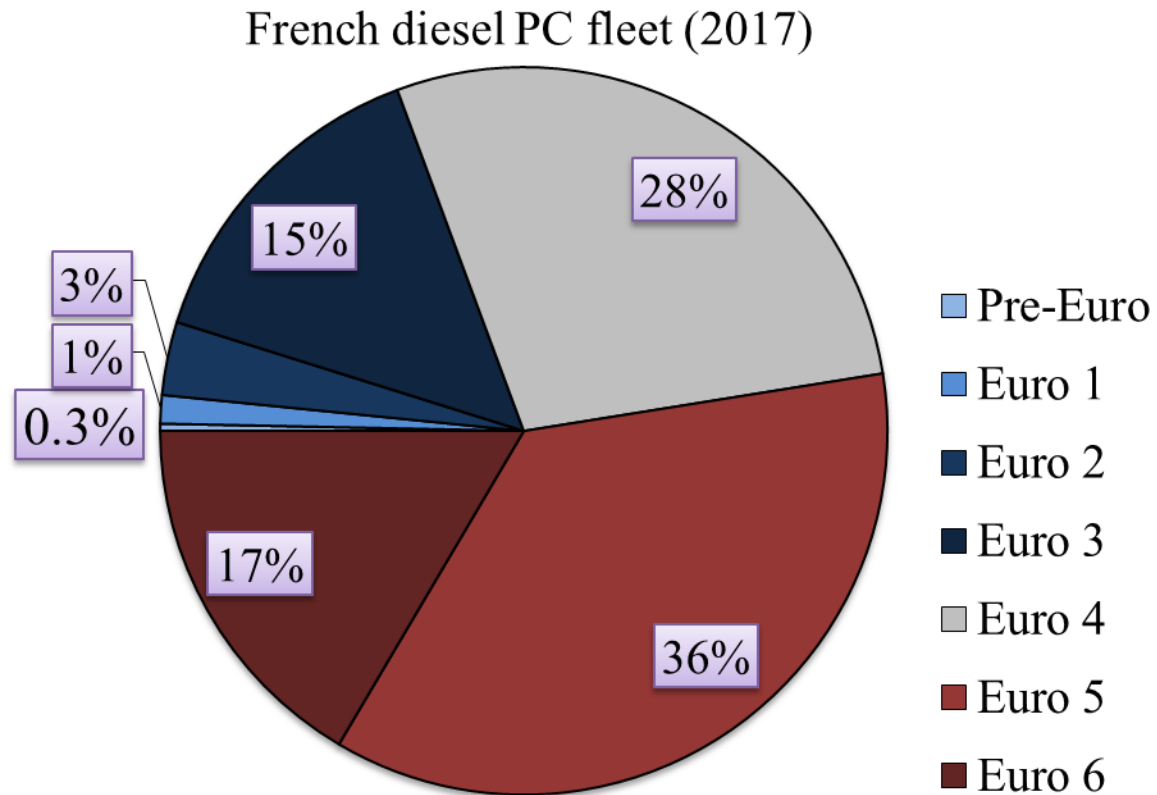
 Gas phase precursors

 Particle phase



Objectives

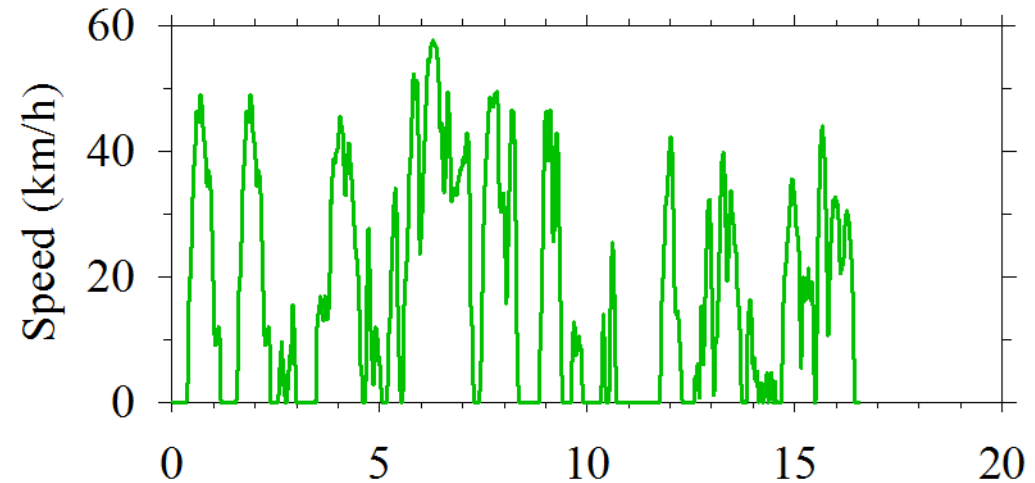
- **Diesel vehicles = 67% of the French PC fleet**
 - Pre-Euro - Euro 3 → 20 %
 - Euro 5 - 6 → 53 %
- **SOA formation and ageing with physical processes**
 - Impact of the exhaust after-treatment technologies
 - Impact of the driving conditions



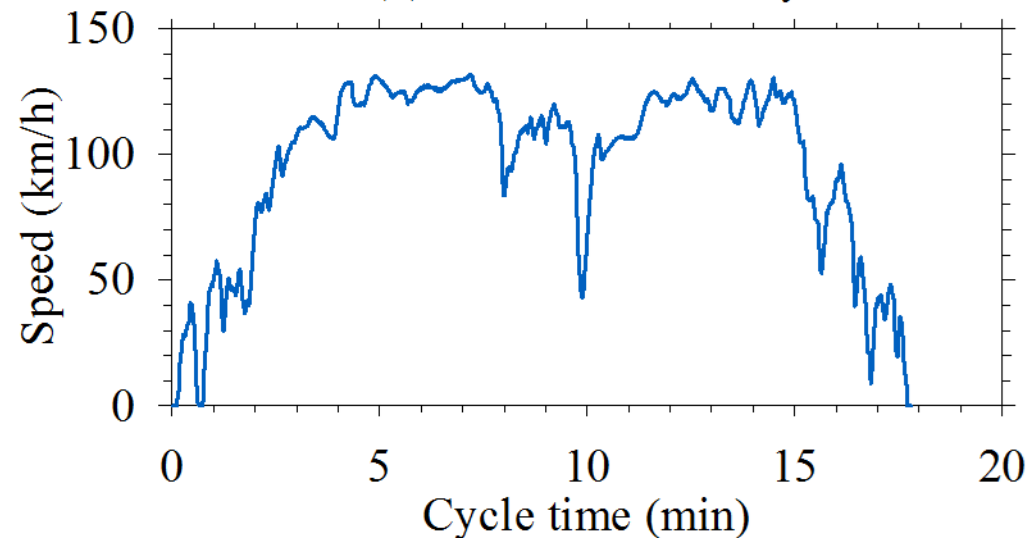
Vehicles and driving conditions

	Vehicle #1	Vehicle #2
Engine	1.3 VCDI	1.9 JTD
Energy	Diesel	Diesel
European norm	Euro 5	Euro 3
Catalyst	DOC	DOC
Filter	Cat. DPF	

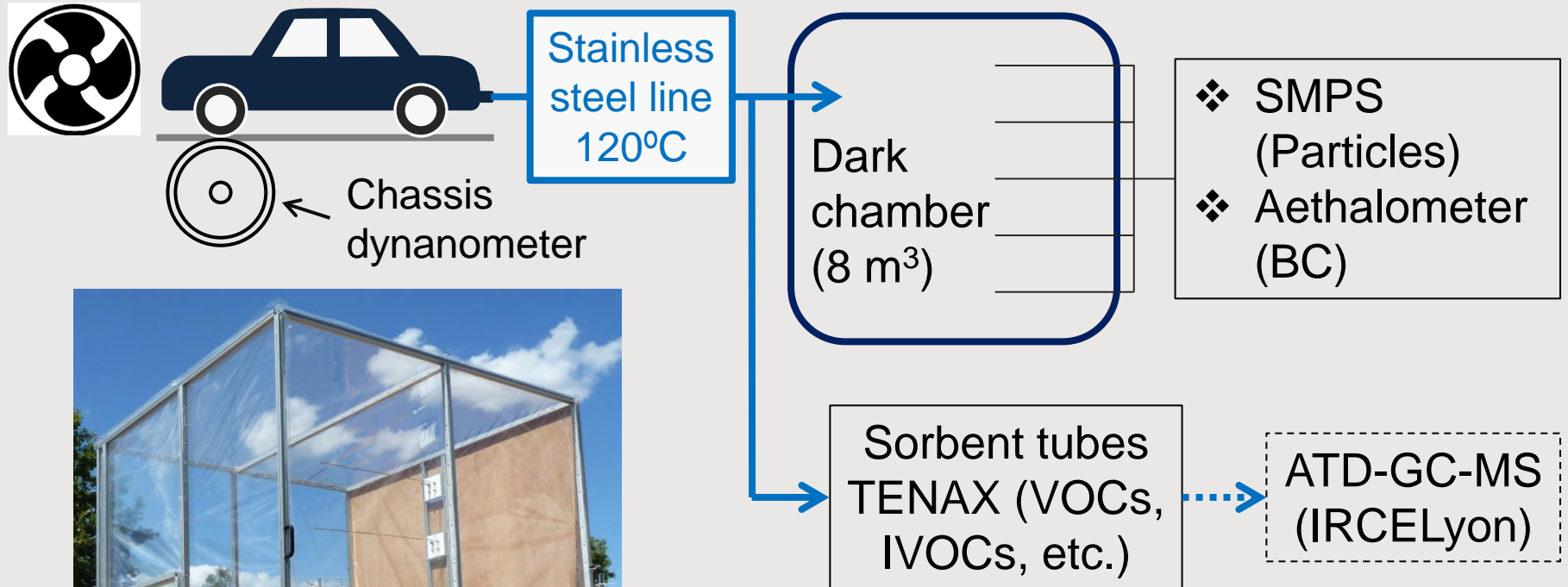
(a) Artemis Urban



(b) Artemis Motorway



Experimental setup



Experimental conditions

Vehicle	Cycle	Injection time (min)	Global dilution ratio	Repetitions
Diesel Euro 5	Urban cold start	16	97	2
	Motorway	25	65	2
Diesel Euro 3	Urban cold start	16	97	2
	Motorway	25	65	3



Chamber characterization

Total [PM] correction

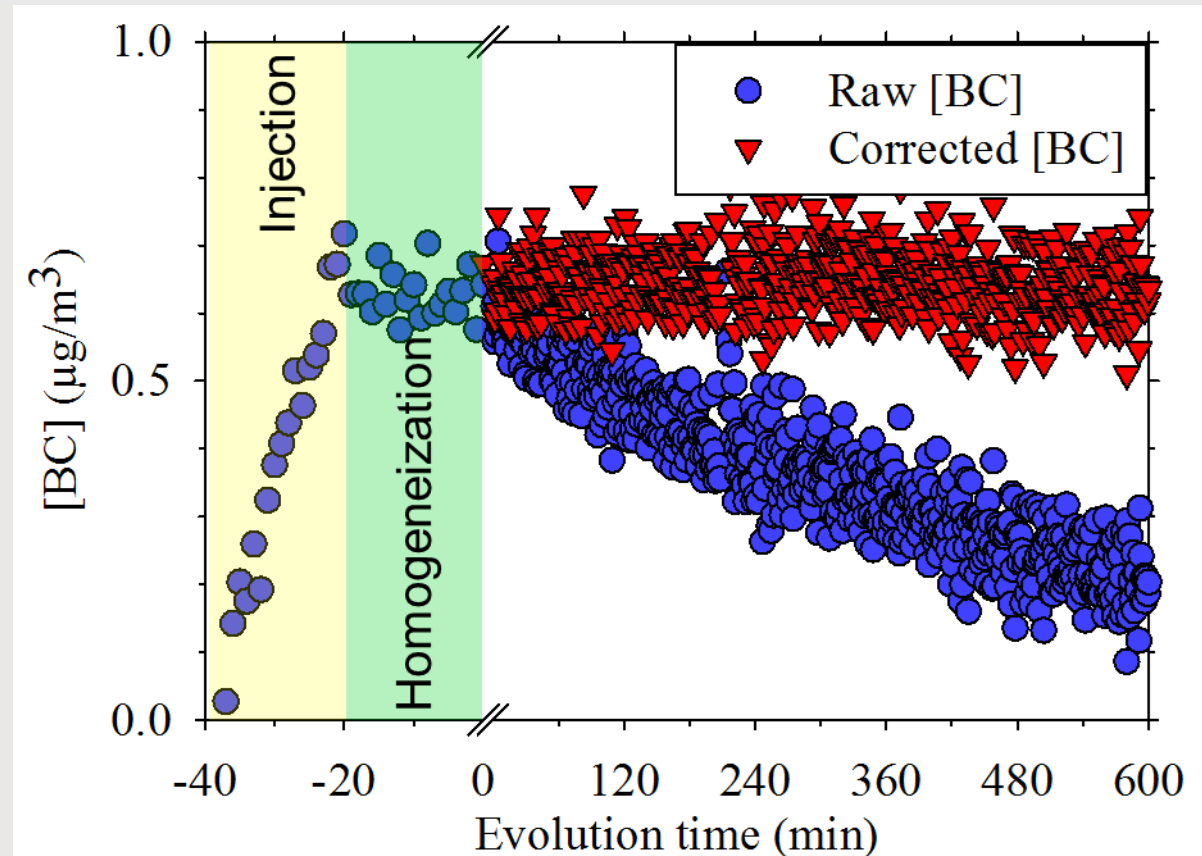
$$[BC]_t = [BC]_0 \times \exp(-kt)$$

BC

- Leakage
- Dilution
- Wall-losses

Particles

- Leakage
- Dilution
- Wall-losses
- **Physical processes**



Chamber characterization

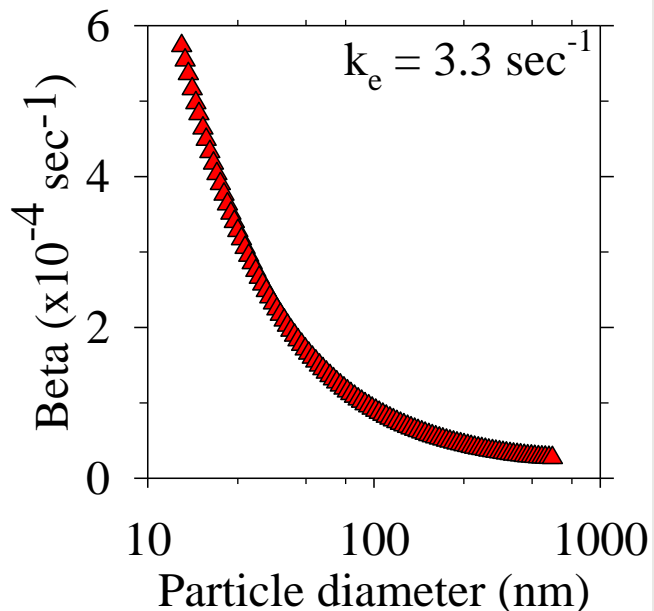
[PN] correction

Deposition coefficient (Crump and Seinfeld, 1981, Journal of Aerosol Science)

$$\beta(D_p) = \frac{1}{L} \times \left[\frac{8 \times \sqrt{k_e D(D_p)}}{\pi} + v(D_p) \times \coth \left(\frac{\pi v(D_p)}{4 \sqrt{k_e D(D_p)}} \right) \right]$$

Dilution and leakage:

$$\alpha = \dot{V}/V$$



L Side of the chamber

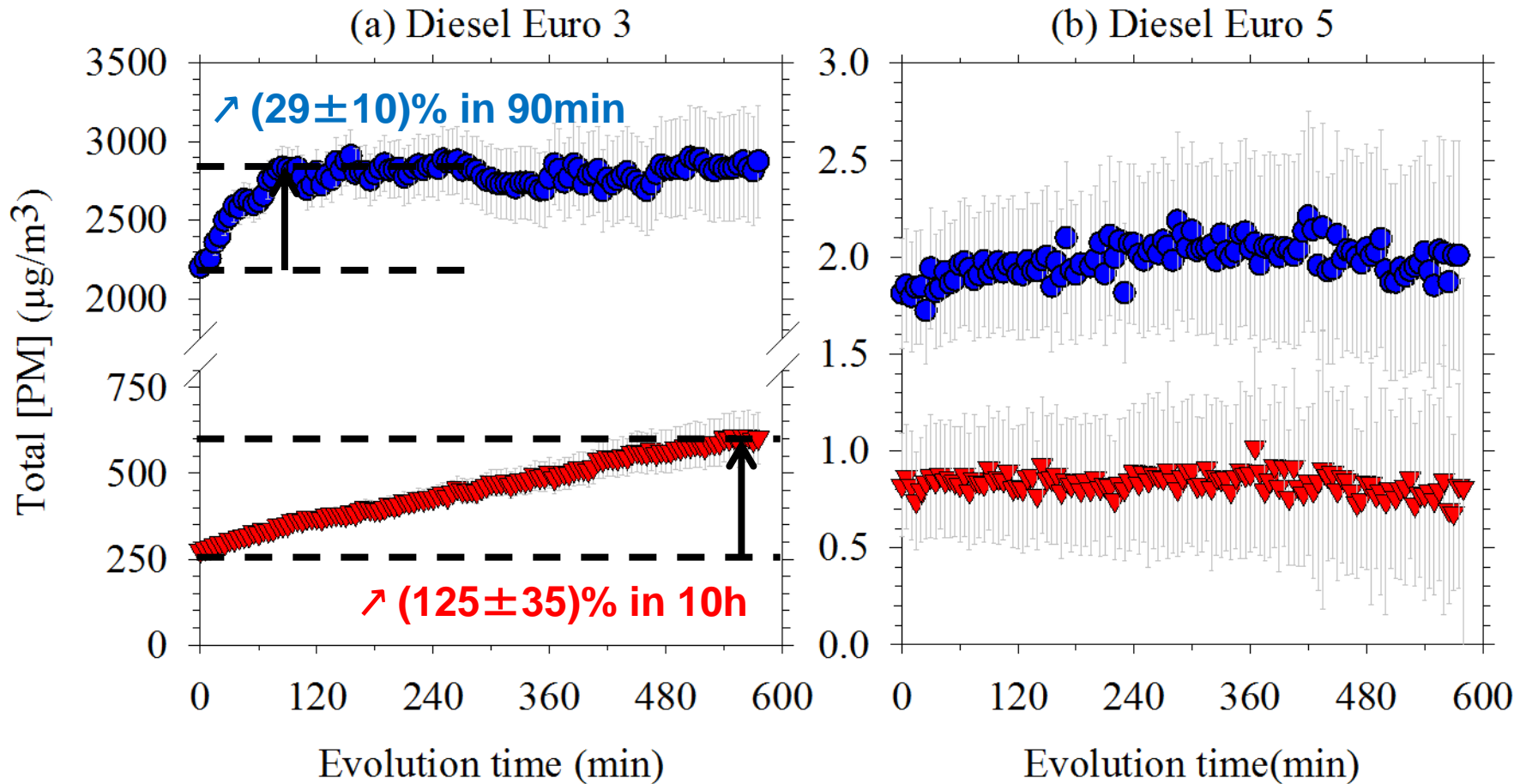
k_e Eddy diffusivity

$D(D_p)$ Brownian diffusivity

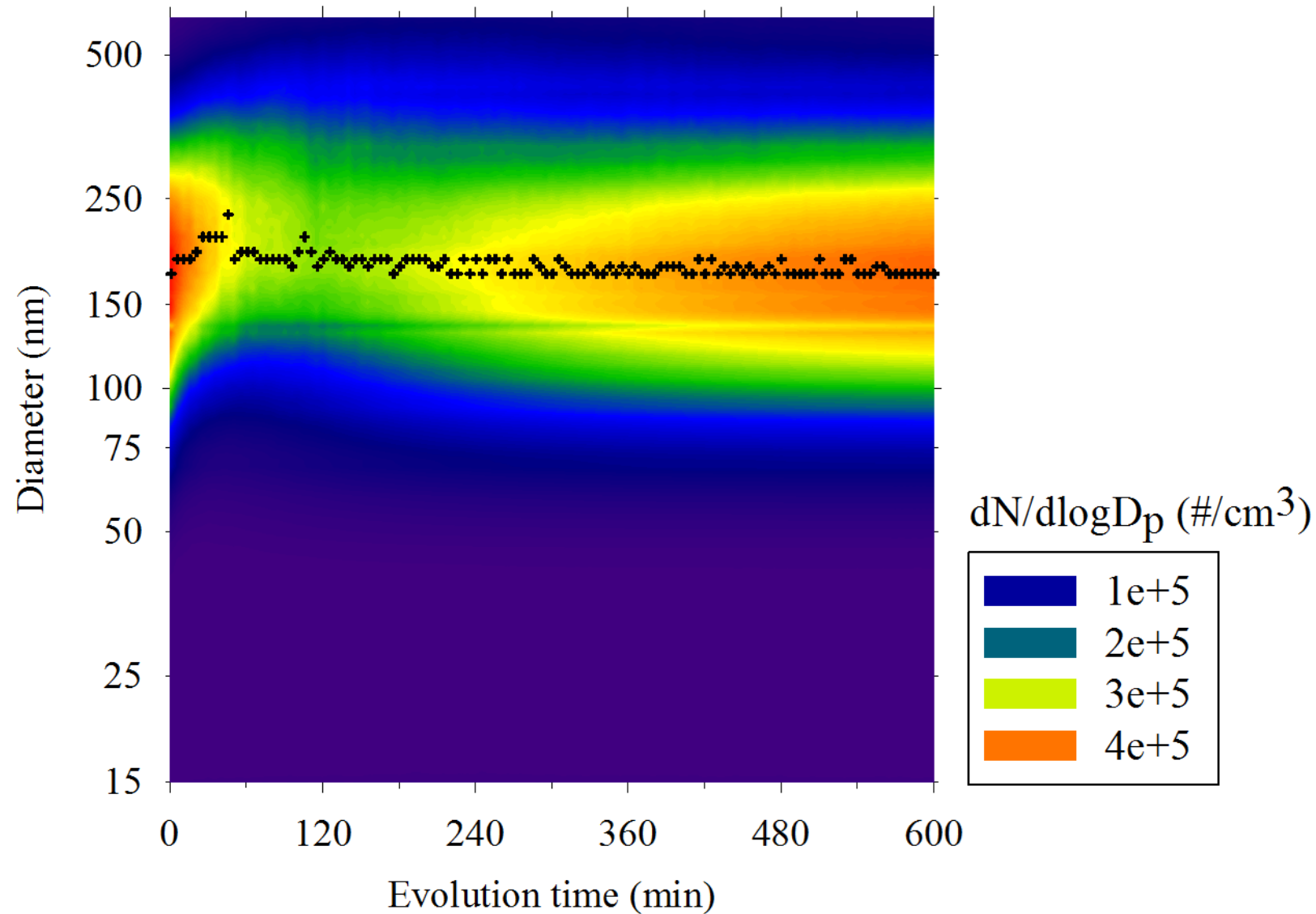
$v(D_p)$ Terminal particle settling velocity



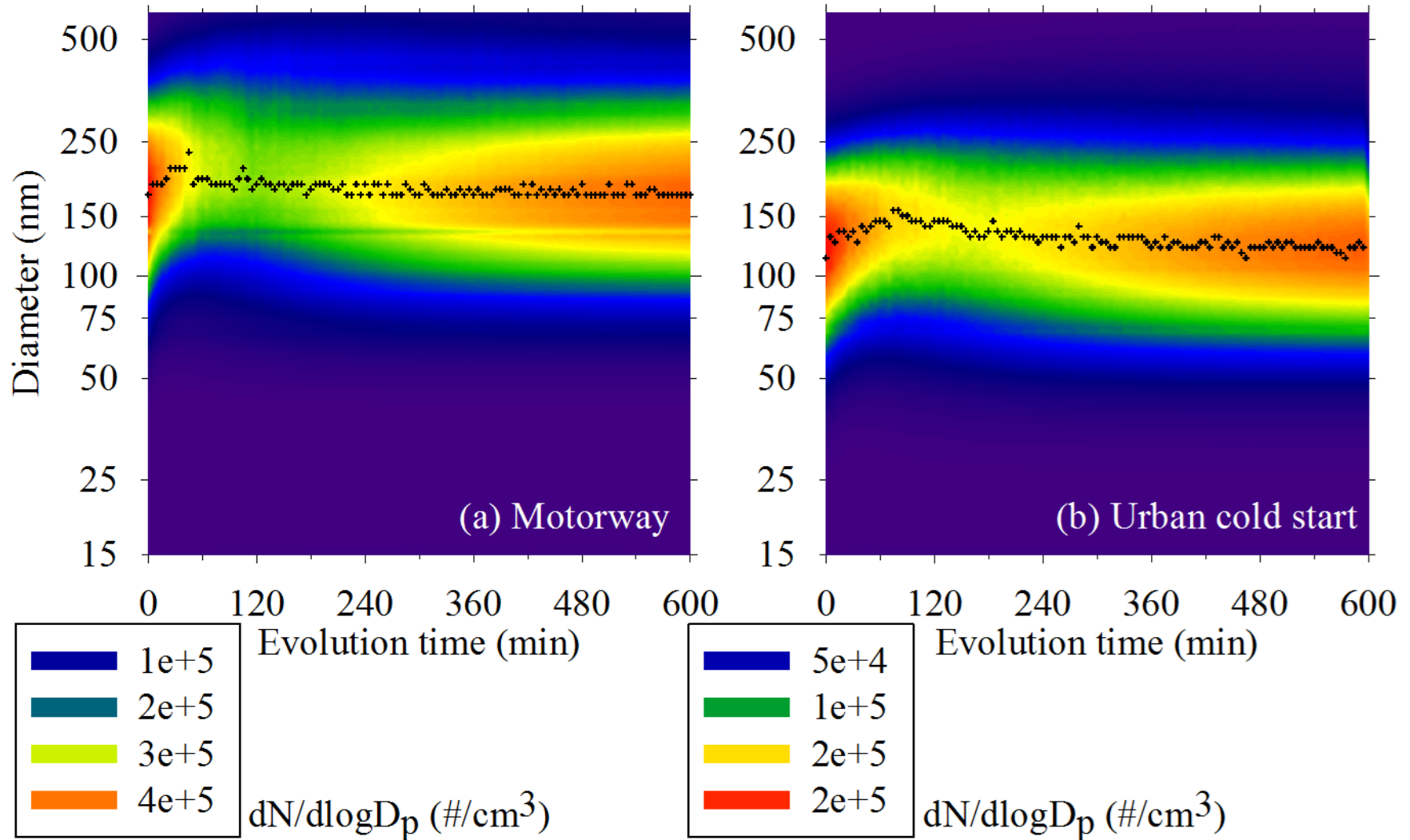
Total [PM] evolution



Results: Euro 3 MW

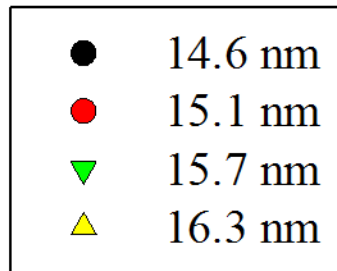
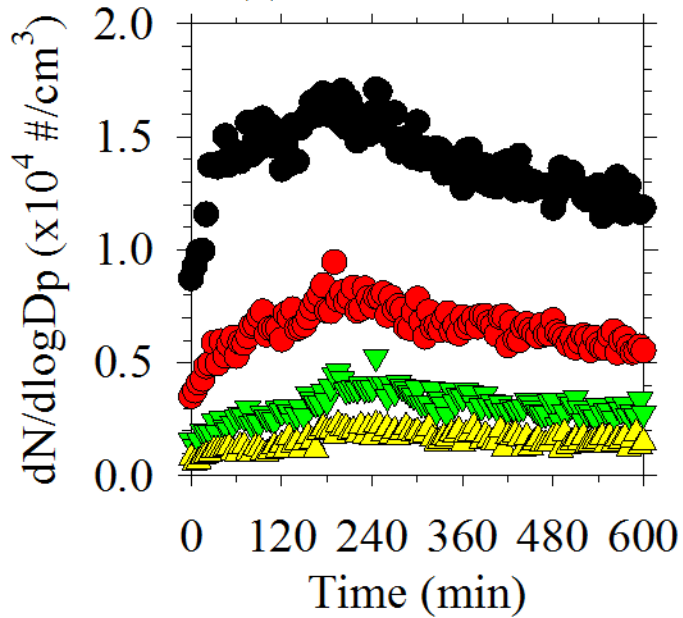


Results: Euro 3 MW and UC

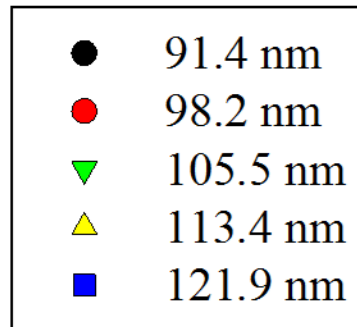
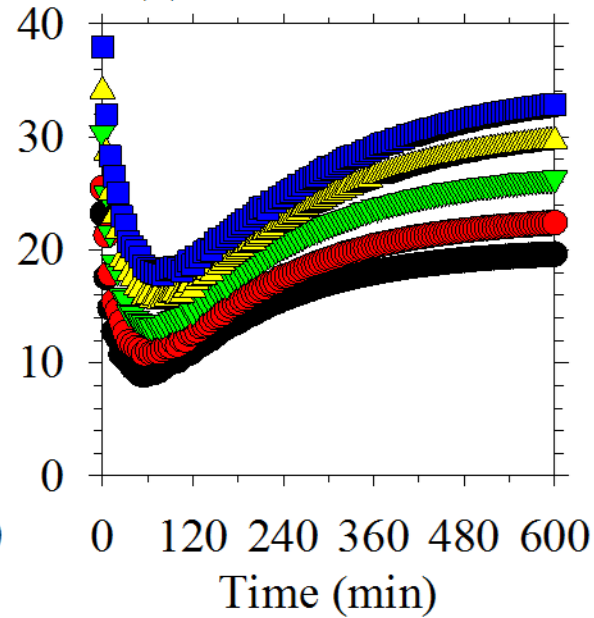


Results: Euro 3 MW

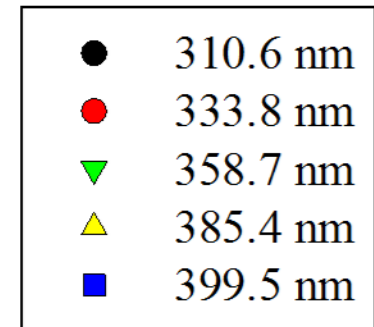
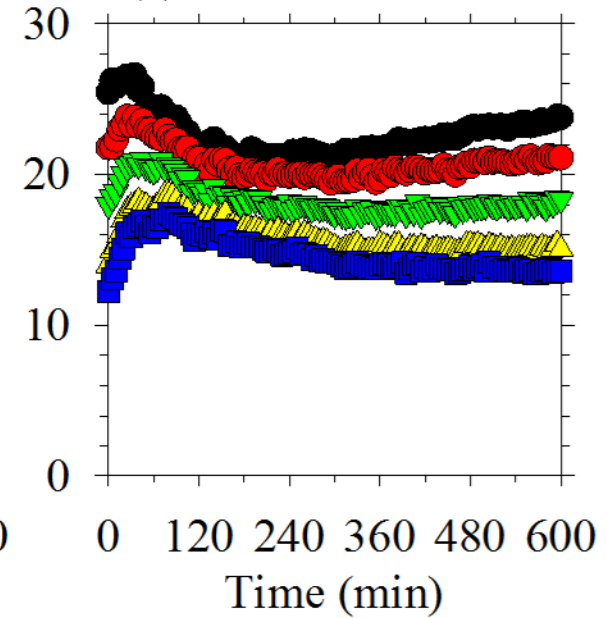
(a) 14.6 to 16.3 nm



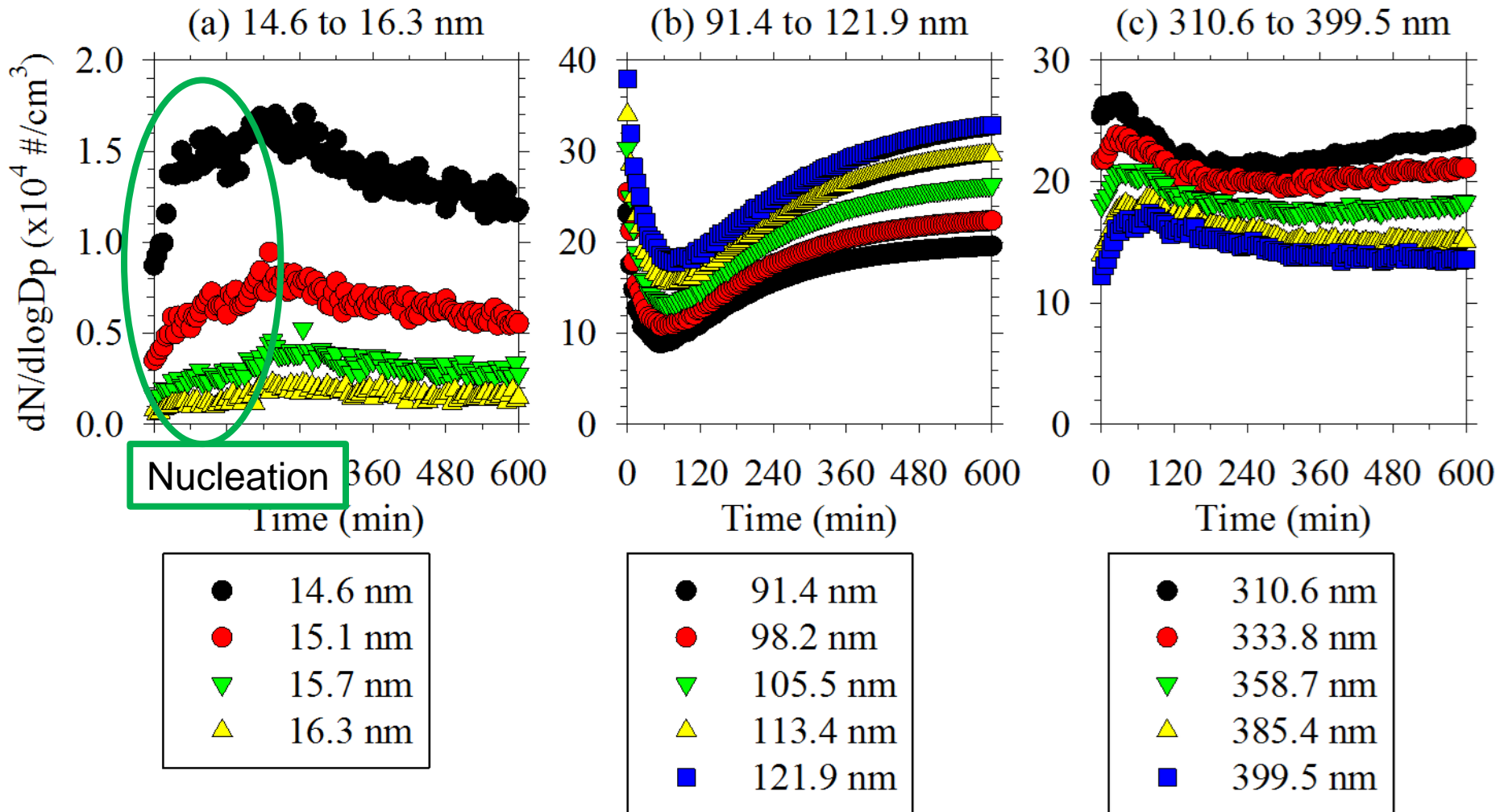
(b) 91.4 to 121.9 nm



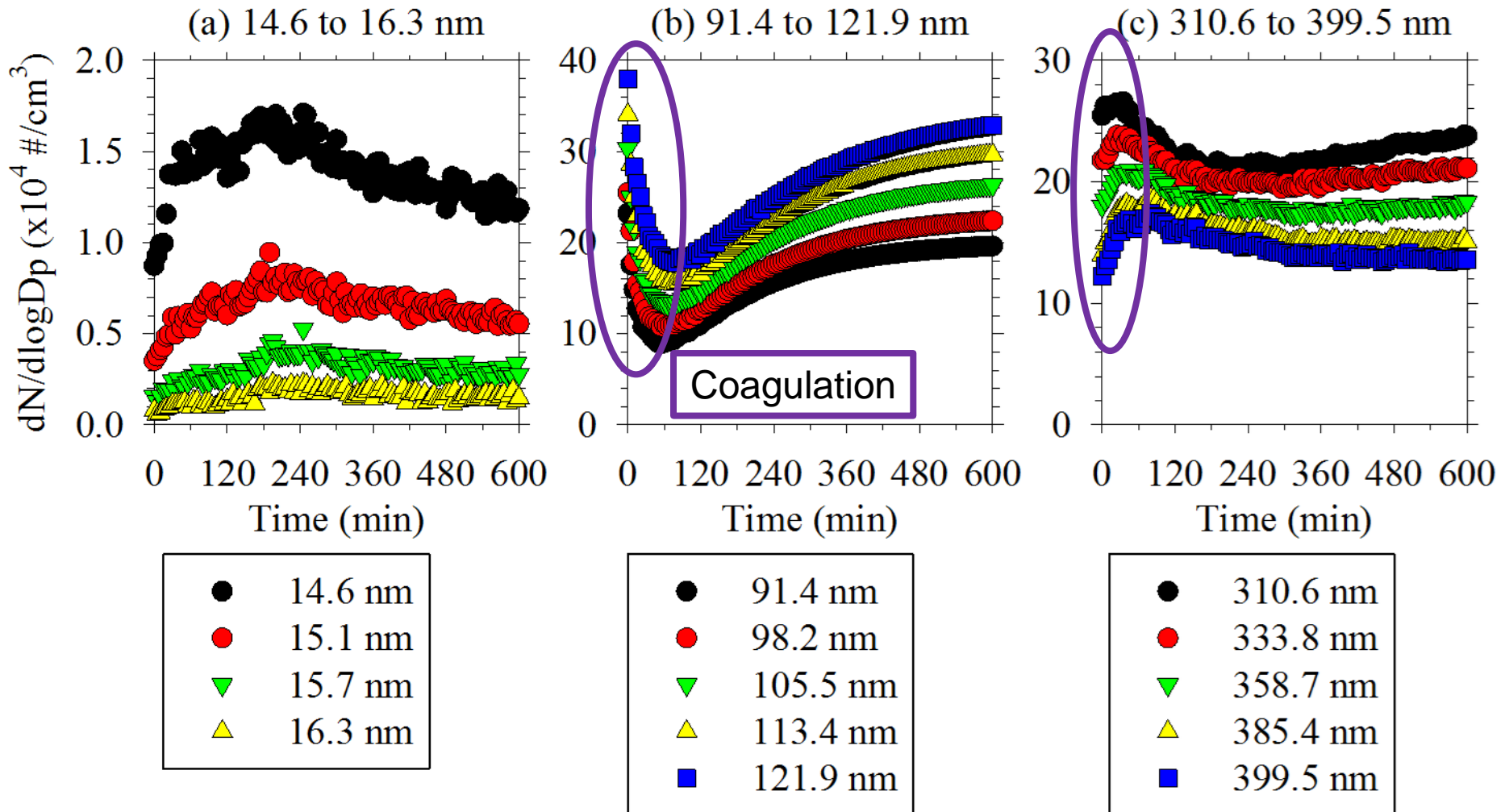
(c) 310.6 to 399.5 nm



Results: Euro 3 MW

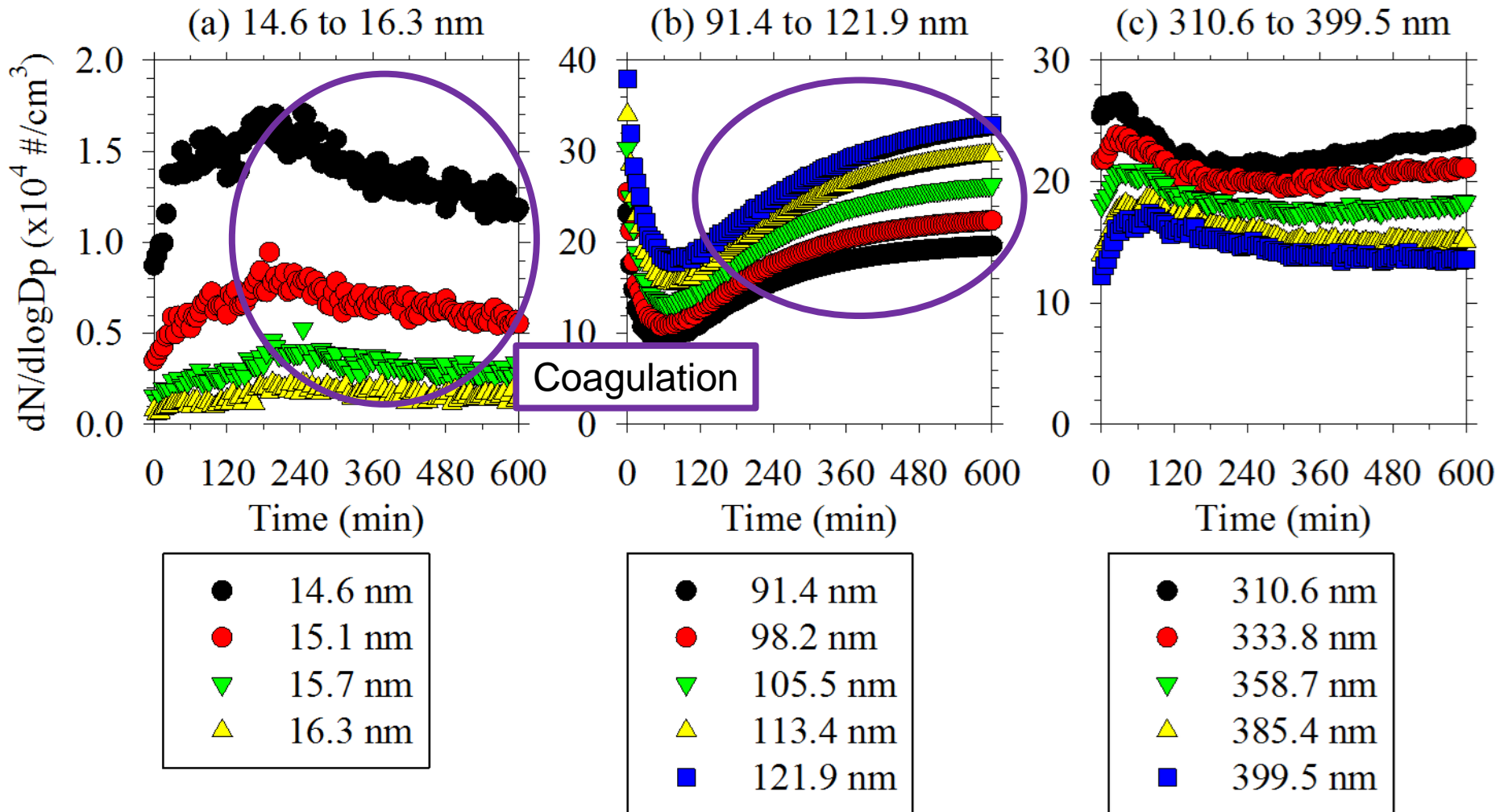


Results: Euro 3 MW



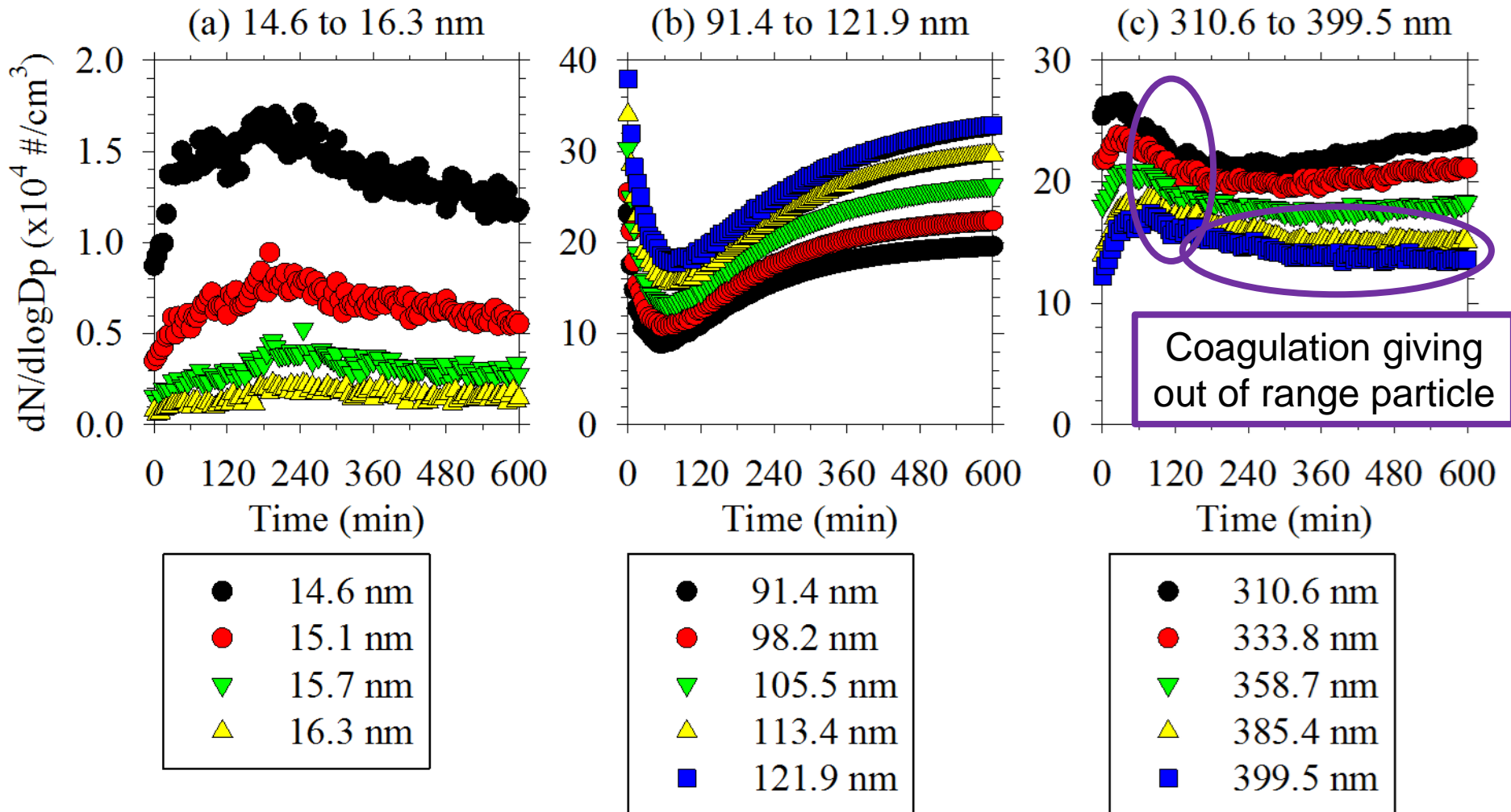
→ Nucleation and coagulation

Results: Euro 3 MW



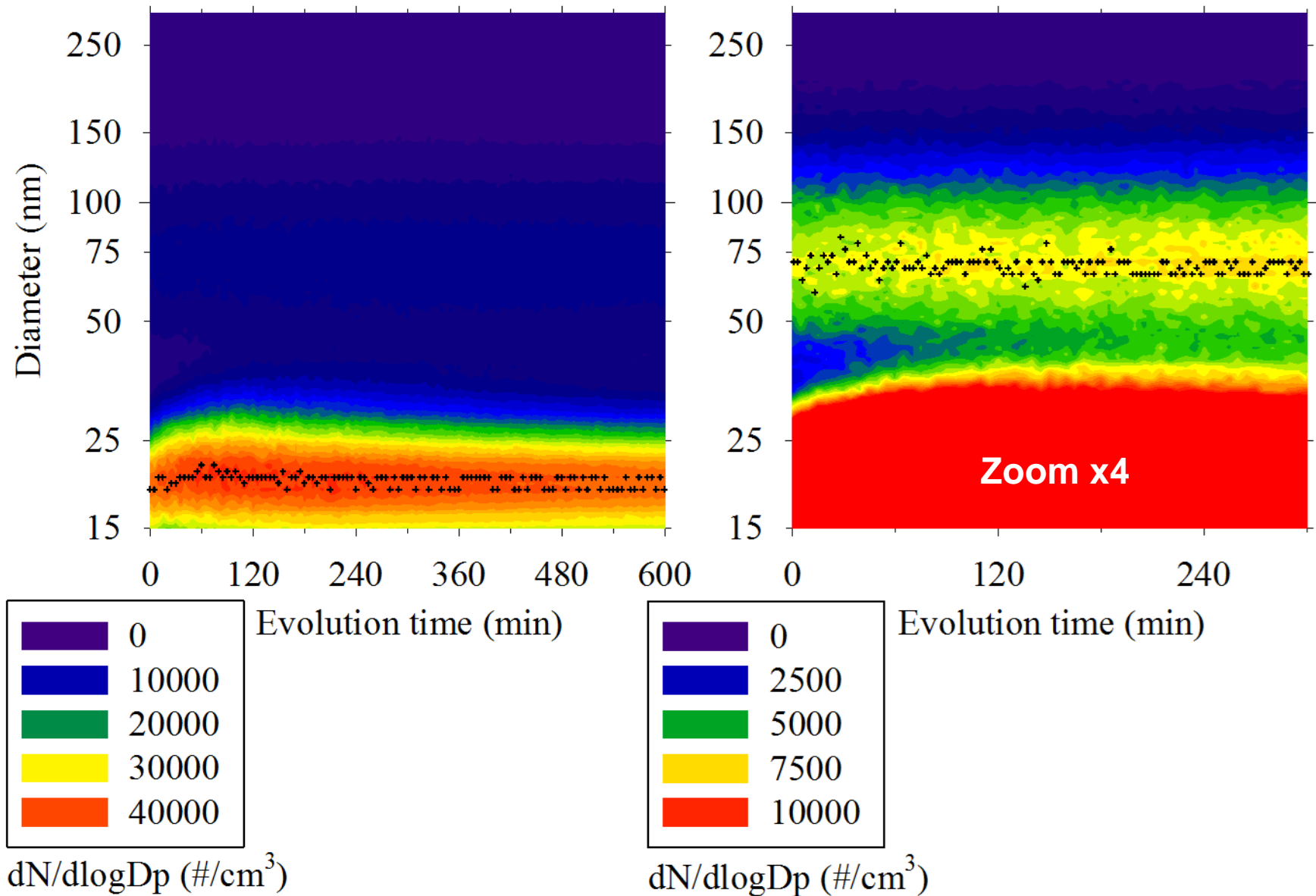
→ Nucleation and coagulation

Results: Euro 3 MW

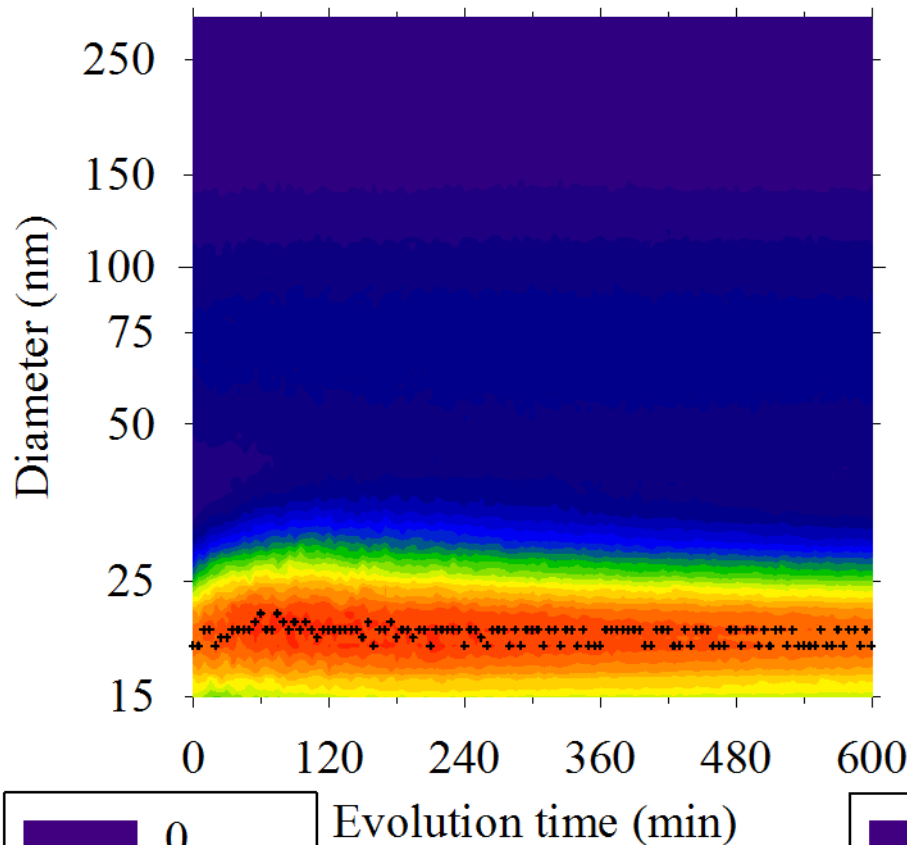


→ Nucleation and coagulation

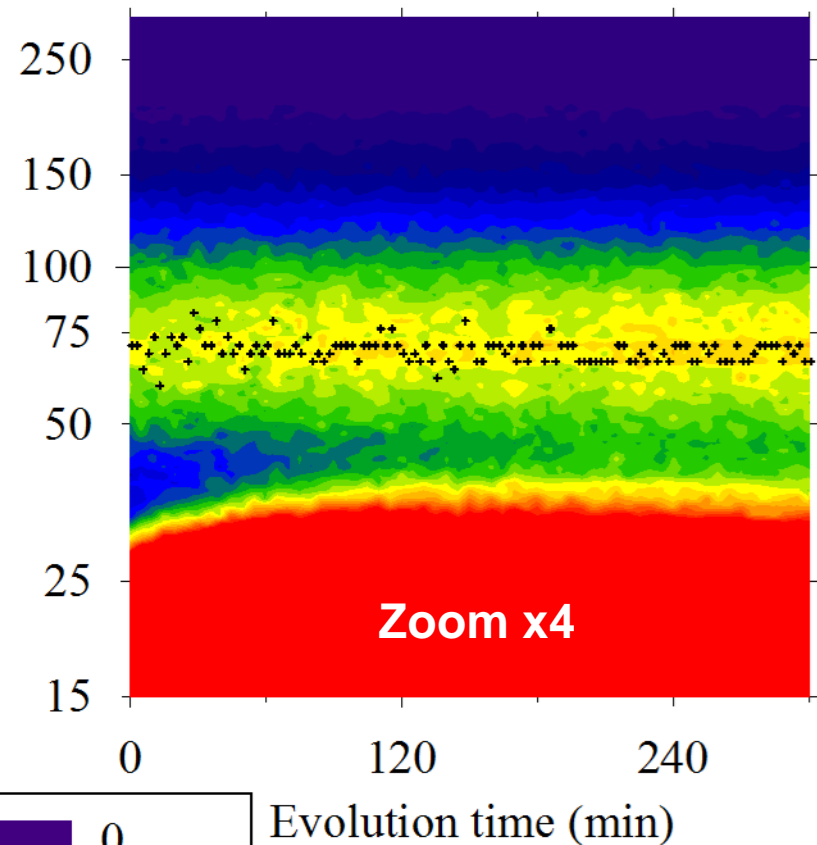
Results: Euro 5 MW



Results: Euro 5 MW



→ Coagulation
predominant



→ Small effects of
nucleation and/or
condensation

$dN/d\log D_p$ ($\#/cm^3$)

$dN/d\log D_p$ ($\#/cm^3$)

Particle precursor emission factors

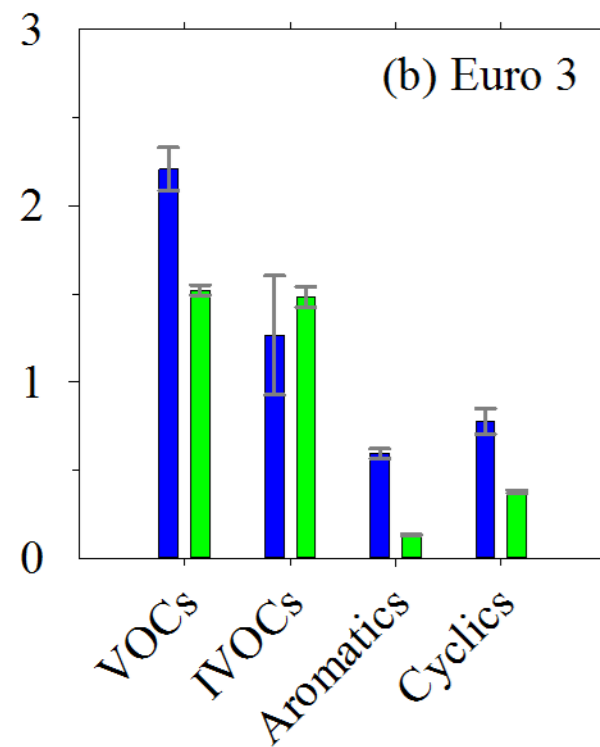
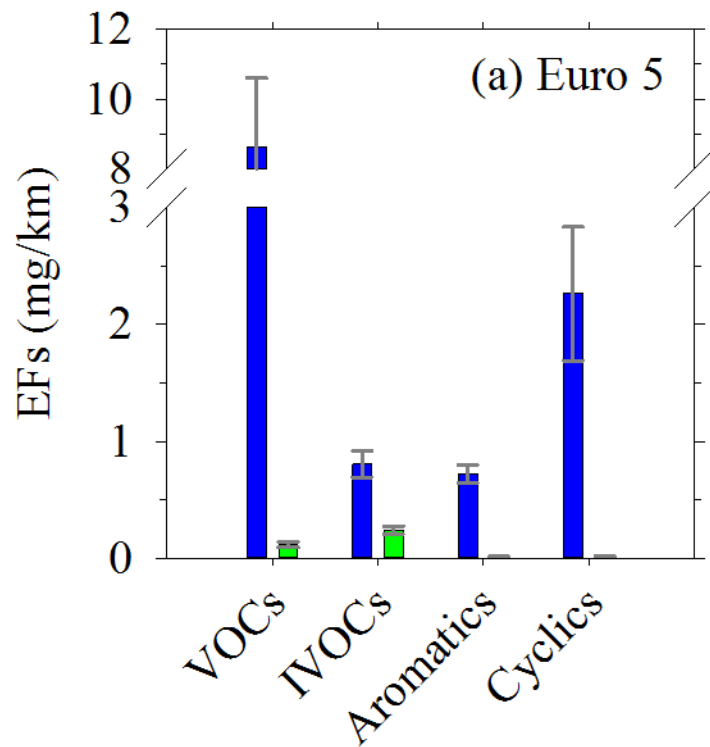
IVOC EFs

Urban cold start

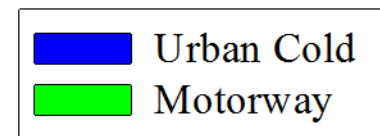
Motorway

Euro 3 = 1.6 x Euro 5

Euro 3 = 6.2 x Euro 5



VOC: C6 - C11
 IVOCs: C12 - C22
 Single-ring aromatics



Particle precursor emission factors

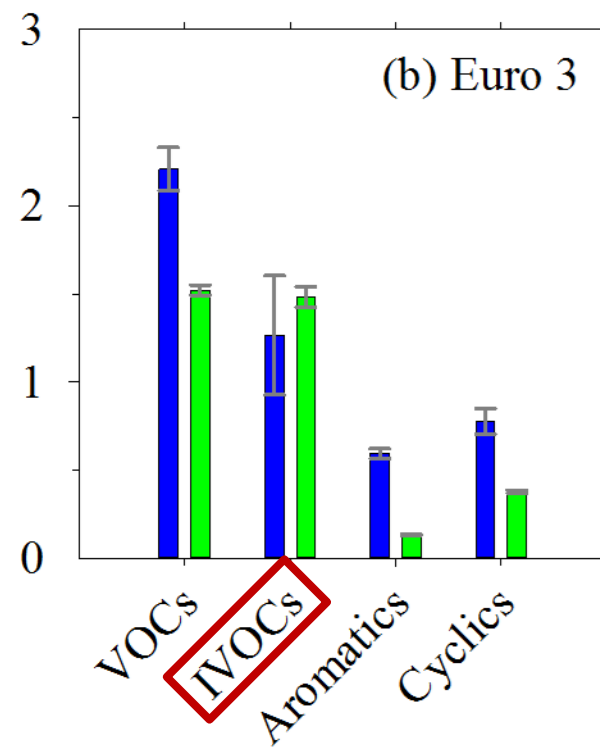
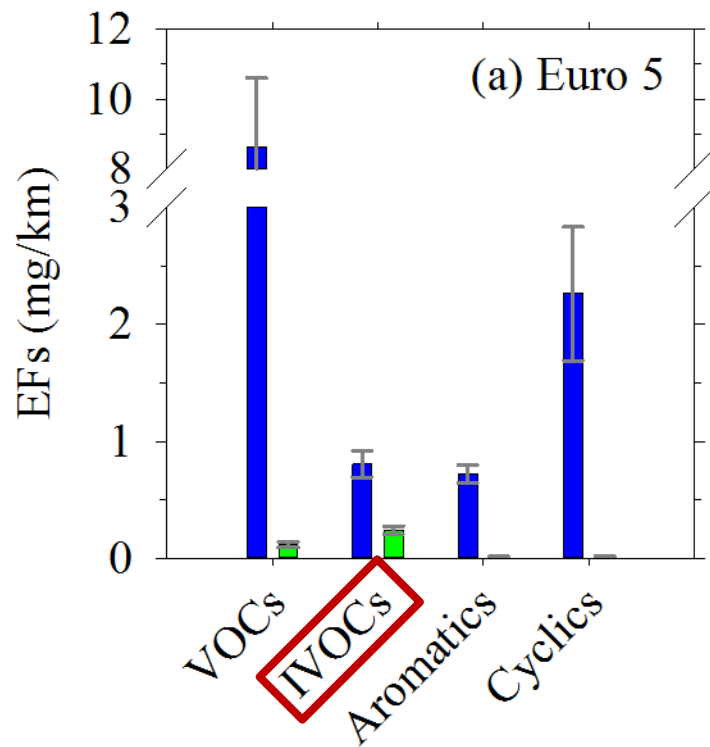
IVOC EFs

Urban cold start

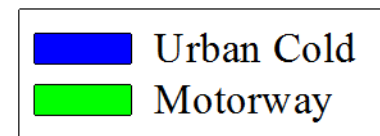
Euro 3 = 1.6 x Euro 5

Motorway

Euro 3 = 6.2 x Euro 5



VOC: C6 - C11
 IVOCs: C12 - C22
 Single-ring aromatics



Conclusions and prospects

- **Investigation on particle evolutions for Euro 3 and Euro 5 diesel vehicles**
- **Physical processes in a dark chamber**
- **Euro 3 less present than Euro 5**
- **Euro 3 emits more**
 - PM (200x UC and 1000x MW)
 - Precursors (IVOCs 1.6x UC and 6.2x MW)
- **Euro 3 forms SOA**
 - +125 ± 35% (UC)
 - +29 ± 10% (MW)
- **Prospects**
 - Euro 5 emits more VOCs than Euro 3
 - Effect of light on SOA formation??



Thank you for your attention!

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Thanks to:

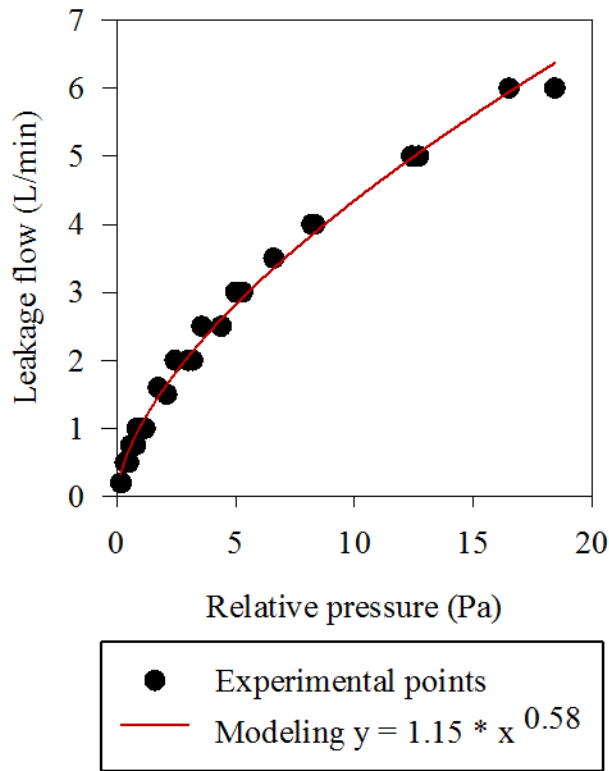


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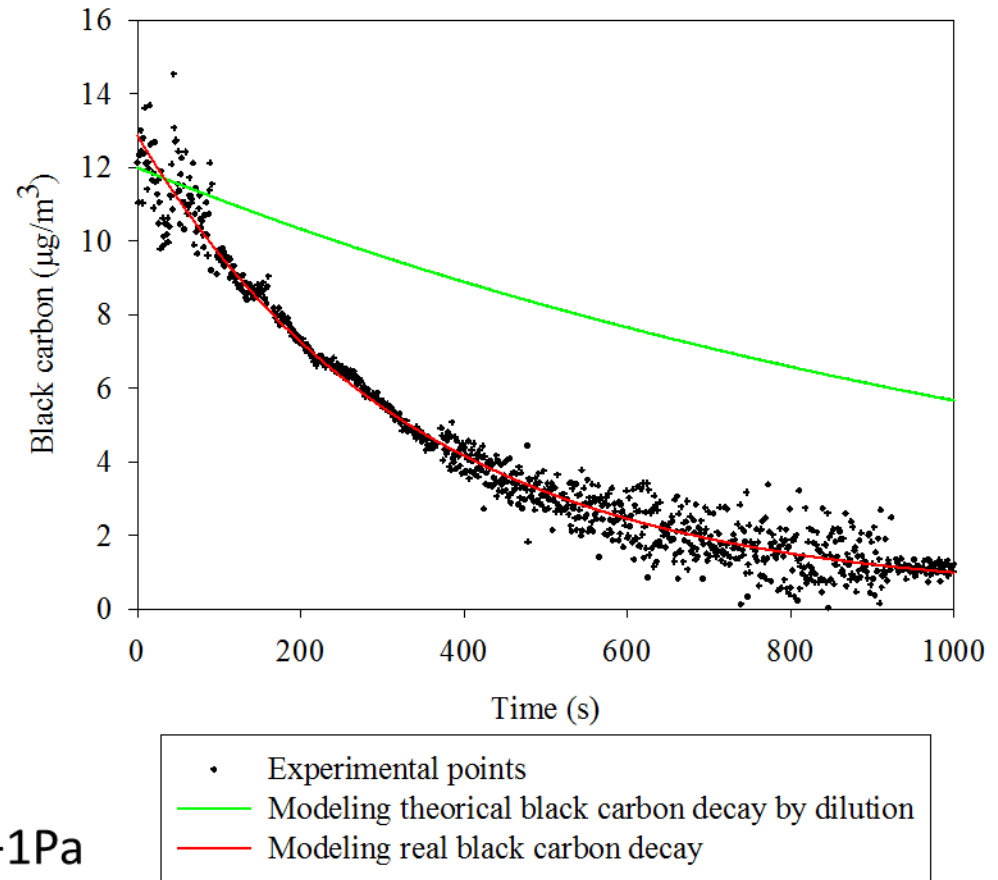


Appendix 1: Leakage characterization

Leakage flow as function of the relative pressure



Black carbon decay in the reactivity chamber



Leak flow 1L/min at relative pressure +1Pa

Leak rate < 1 %vol.h⁻¹

Particulate wall loss deposition in progress

Appendix 2: Crump and Seinfeld 1981

$$\beta = \frac{1}{L} \times \left\{ \frac{8 \times \sqrt{k_e D}}{\pi} + v \times \coth \left(\frac{\pi v}{4 \times \sqrt{k_e D}} \right) \right\}$$

With expressions found in (Seinfeld and Pandis, 2016):

$$D = \frac{kTC_c}{3\pi\mu D_p} \text{ the Brownian diffusivity (9.73)}$$

$$v = \frac{D_p^2 \rho_p g C_c}{18\mu} \text{ the terminal particle settling velocity (9.42)}$$

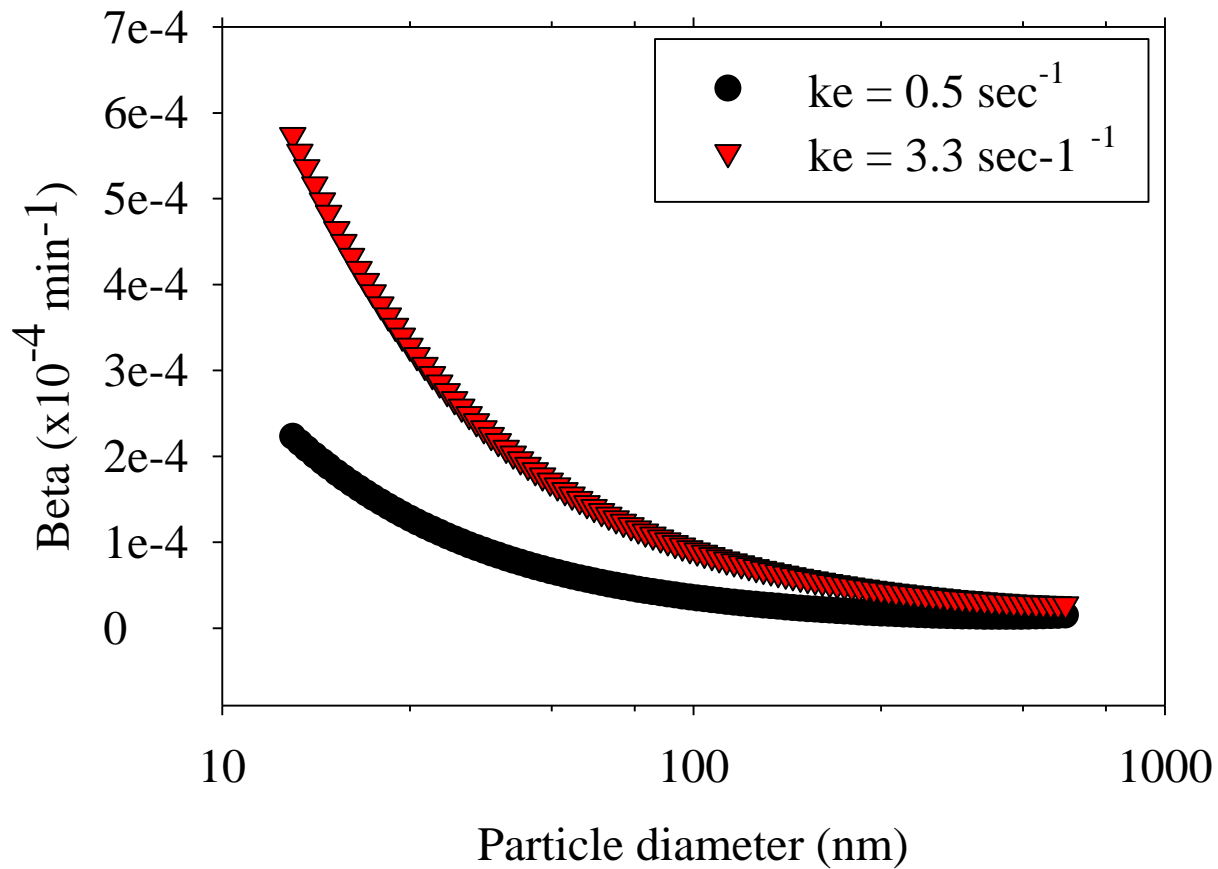
$$C_c = 1 + \frac{2\lambda}{D_p} \left[1.257 + 0.4 \exp \left(-\frac{1.1 \times D_p}{2\lambda} \right) \right] \text{ the Cunningham slip-correction factor (9.34)}$$

The following constants are given in (Seinfeld and Pandis, 2016):

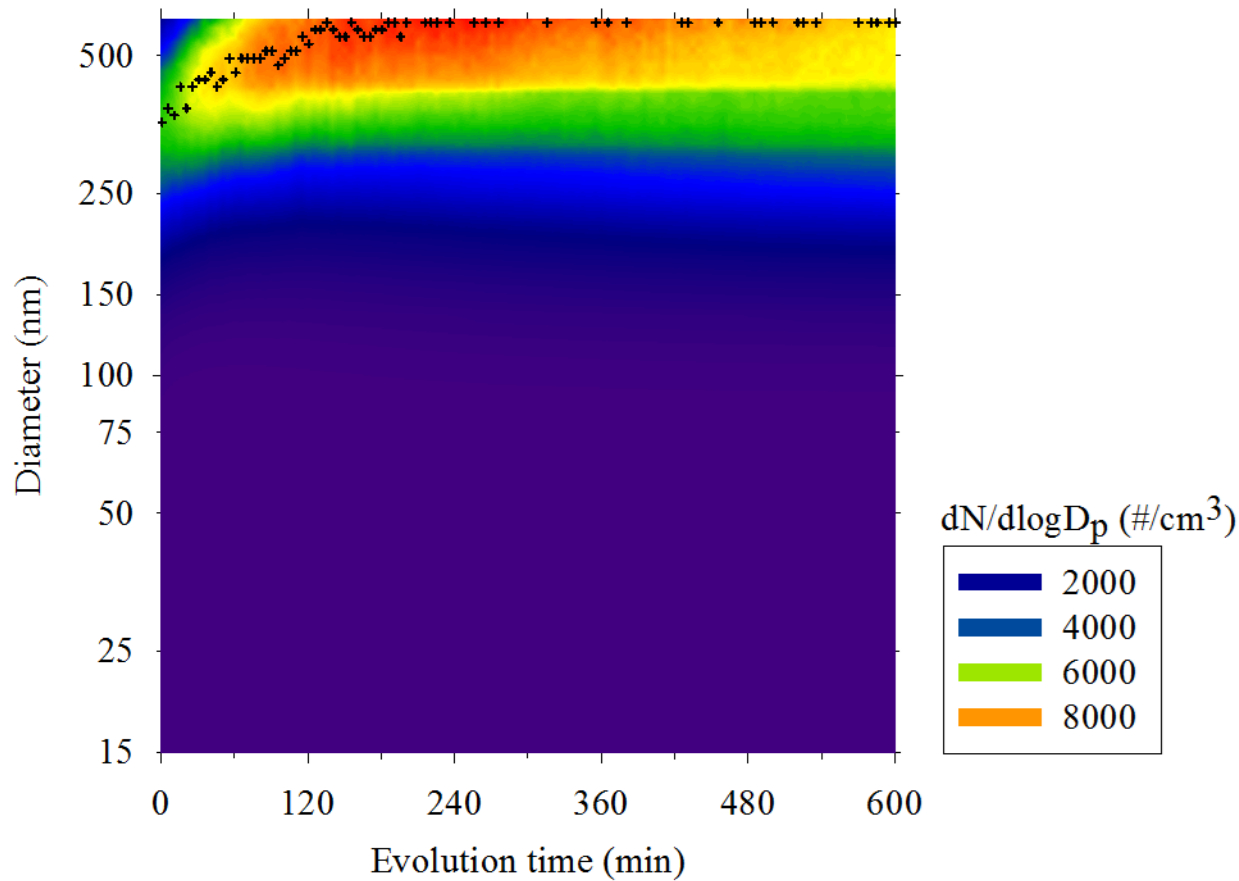
$$g = 9.81 \text{ m} \cdot \text{s}^{-2} ; \lambda_{\text{air}}(298 \text{ K}, 1 \text{ atm}) = 0.0651 \text{ } \mu\text{m} ;$$

$$\mu_{\text{air}} = 1.8 \times 10^{-5} \text{ kg} \cdot \text{m}^{-1} \text{s}^{-1}$$

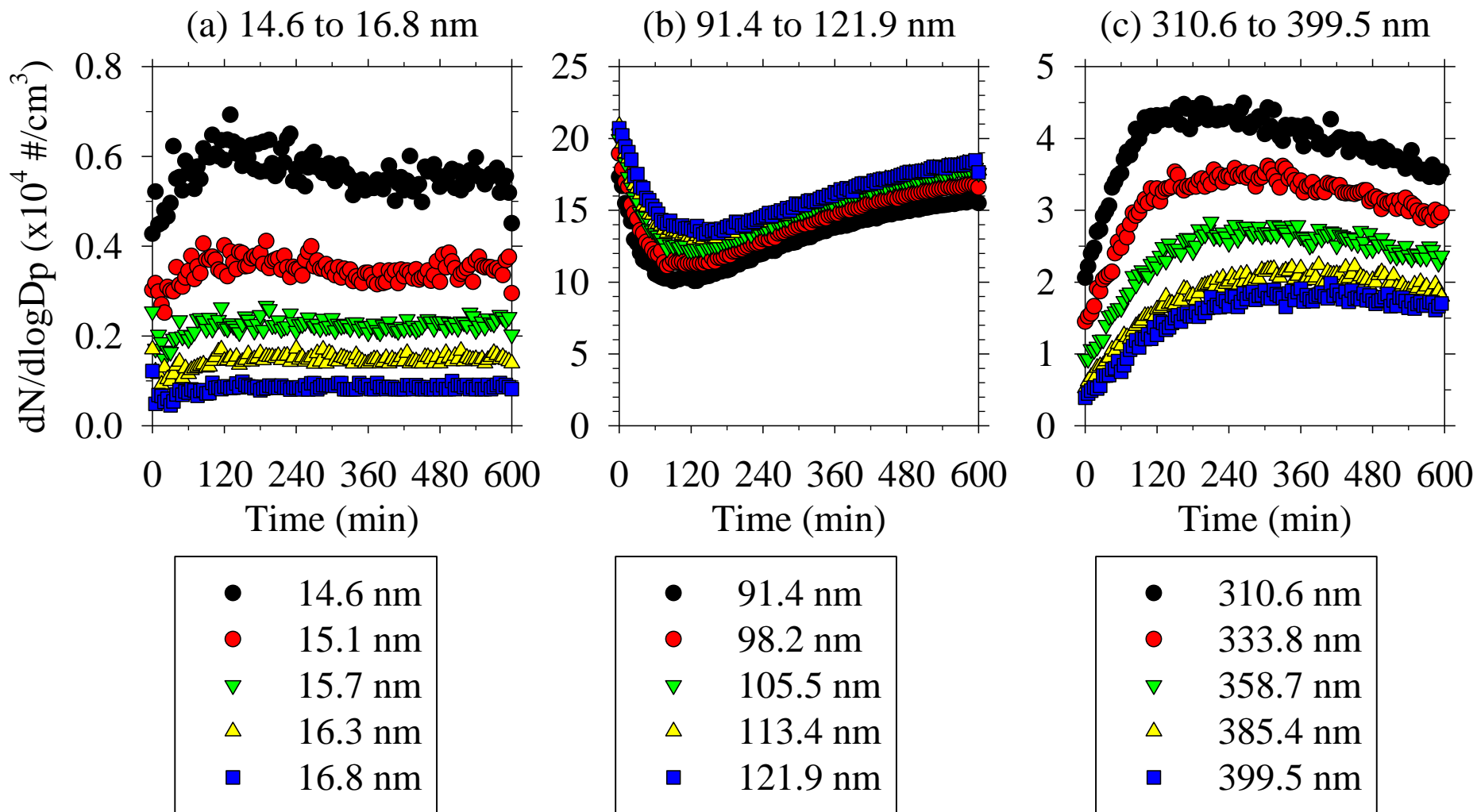
Appendix 3: Beta(D_p) for several k_e



Appendix 4: Euro 3 MW PM distribution



Appendix 5: Euro 3 UC



Appendix 6: Euro 5 MW

