TAMPERE UNIVERSITY OF TECHNOLOGY

Vehicles are a major source of atmospheric sub-3-nm particles

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Outline

- Introduction
- Experimental methods
- Measurement campaigns
- Results
- Conclusions

PNAS

Traffic is a major source of atmospheric nanocluster aerosol

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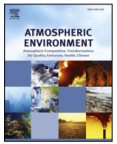
Edited by John H. Seinfeld, California Institute of Technology, Pasadena, CA, and approved June 1, 2017 (received for review January 16, 2017)

Contents lists available at ScienceDirect

Accepted to Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv



ELSEVIER

Diurnal variation of nanocluster aerosol concentrations and emission factors in a street canyon

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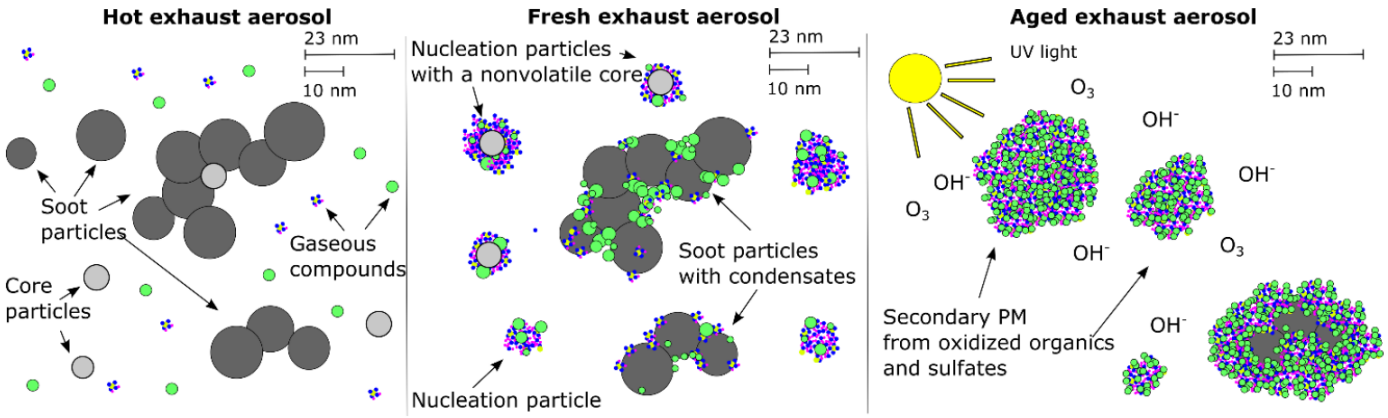
Manuscript in preparation: Järvinen et al., real-world particle emissions of city buses.

Exhaust aerosol



In engine and tailpipe

In exhaust plumes and roadside environments

Urban background

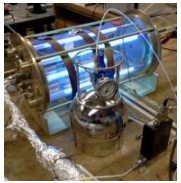
Figure: Panu Karjalainen

Time scale

Seconds → Seconds to minutes → Hours to days

Methods in emission studies

Engine and vehicle laboratories	PEMS	Chasing vehicles on road	Roadside / on-road in traffic	Chamber studies
Highly controlled environment and test conditions, repeatability	Realistic driving conditions	Realistic driving conditions and exhaust dilution and cooling	Emissions of whole vehicle fleet	Atmospheric ageing taken into account



Research question:

What is the role of sub-3-nm particles in the emissions of motor vehicles?

NCA = Nanocluster aerosol (particles 1–3 nm in diameter, *sub-3-nm particles*)

Experimental methods

Airmodus PSM (*particle size magnifier*)
- Concentration of particles larger than 1 nm
- Diethylene glycol (DEG) as a working fluid
- Used together with A20 CPC (*condensation particle counter*) or CPC 3775 in different campaigns
- Operated in fixed mode, step mode or scan mode in different campaigns

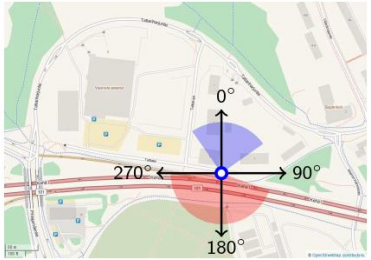
TSI Ultrafine CPC 3776
- Concentration of particles larger than 3 nm
- Butanol as a working fluid
- Comparison to the concentration measured by the PSM -> NCA concentration

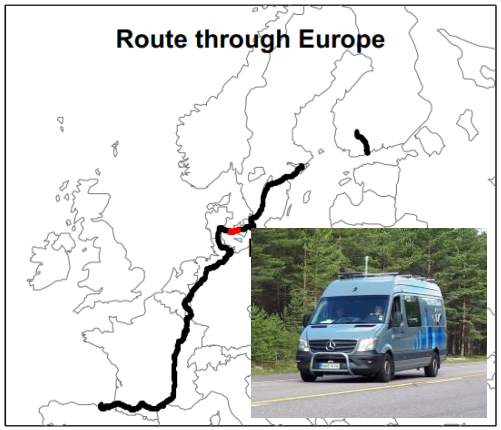
Sample dilution
- Bridge diluter before the PSM and CPC's
- Two-stage dilution in engine laboratory tests mimicking real-world dilution (*delayed primary particles + primary particles*)

CO_2 analyzers
- Used for calculating emission factors for the NCA
- LICOR LI-7000 or SIDOR SICK

Measurement of larger particles
- SMPS (*scanning mobility particle sizer*) or DMPS (*differential mobility particle sizer*) for the size distribution
- Airmodus A20 CPC for the concentration of particles larger than 7 nm

Measurement campaigns





Atmospheric measurements

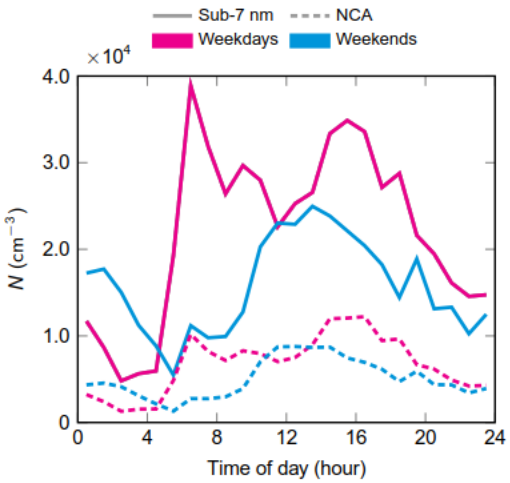
1. Semiurban roadside (Helsinki, Malmi, Ring I)
   Two weeks in Oct 2012, PSM in fixed mode + CPC 3776
2. Urban street canyon (Helsinki, Mäkelänkatu)
   Three months in 2015 (Apr – Jun), PSM in step mode
3. On-road measurement through Europe
   Six days in May 2015, PSM in fixed mode + CPC 3776
4. Urban street canyon (Helsinki, Mäkelänkatu)
   Four weeks in May 2017, PSM in fixed mode + CPC 3776 + A20 CPC
5. Chasing measurement on road for different buses
   Carried out in February 2016, PSM in fixed mode + CPC 3776

Engine laboratory measurements

1. A modern heavy-duty diesel engine equipped with a DOC + DPF + SCR exhaust aftertreatment system
   Carried out in 2013, PSM in scan mode

Results: Diurnal variation and size distribution

Street canyon, May 2017



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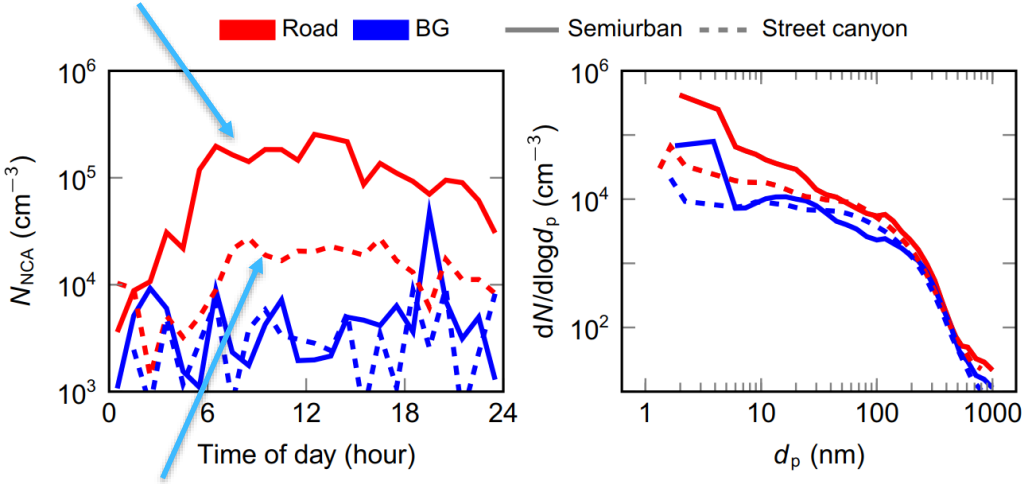
Semiurban, roadside, October 2012

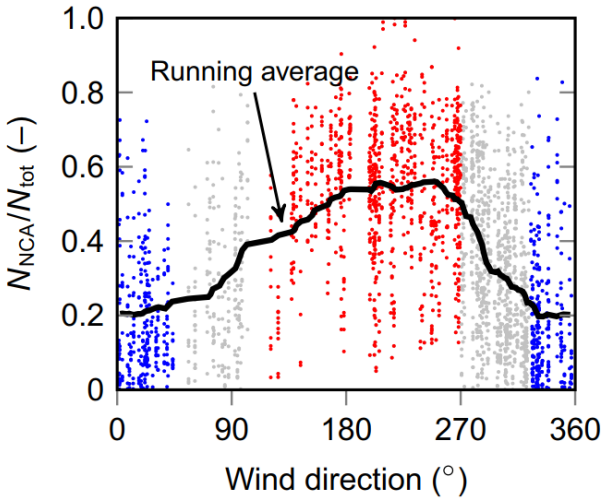


Street canyon, May 2015

Rönkkö et al., 2017

Results: The fraction of NCA

Semiurban roadside



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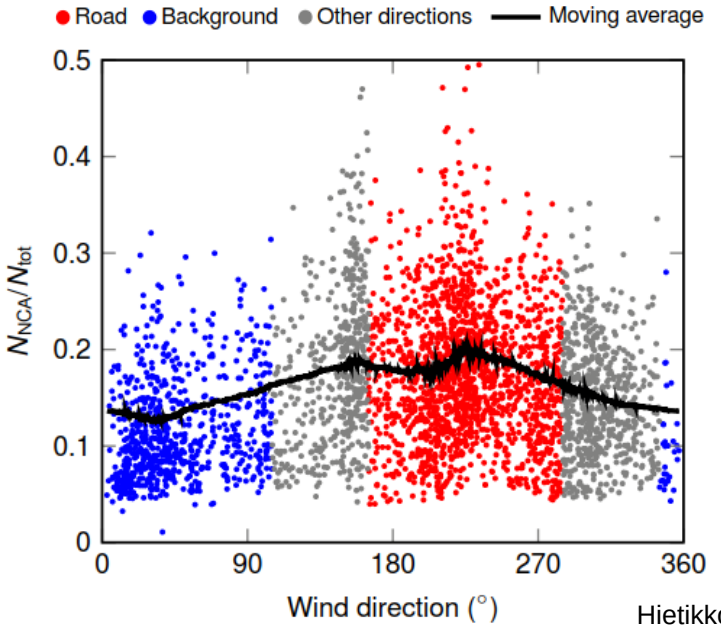
Street canyon



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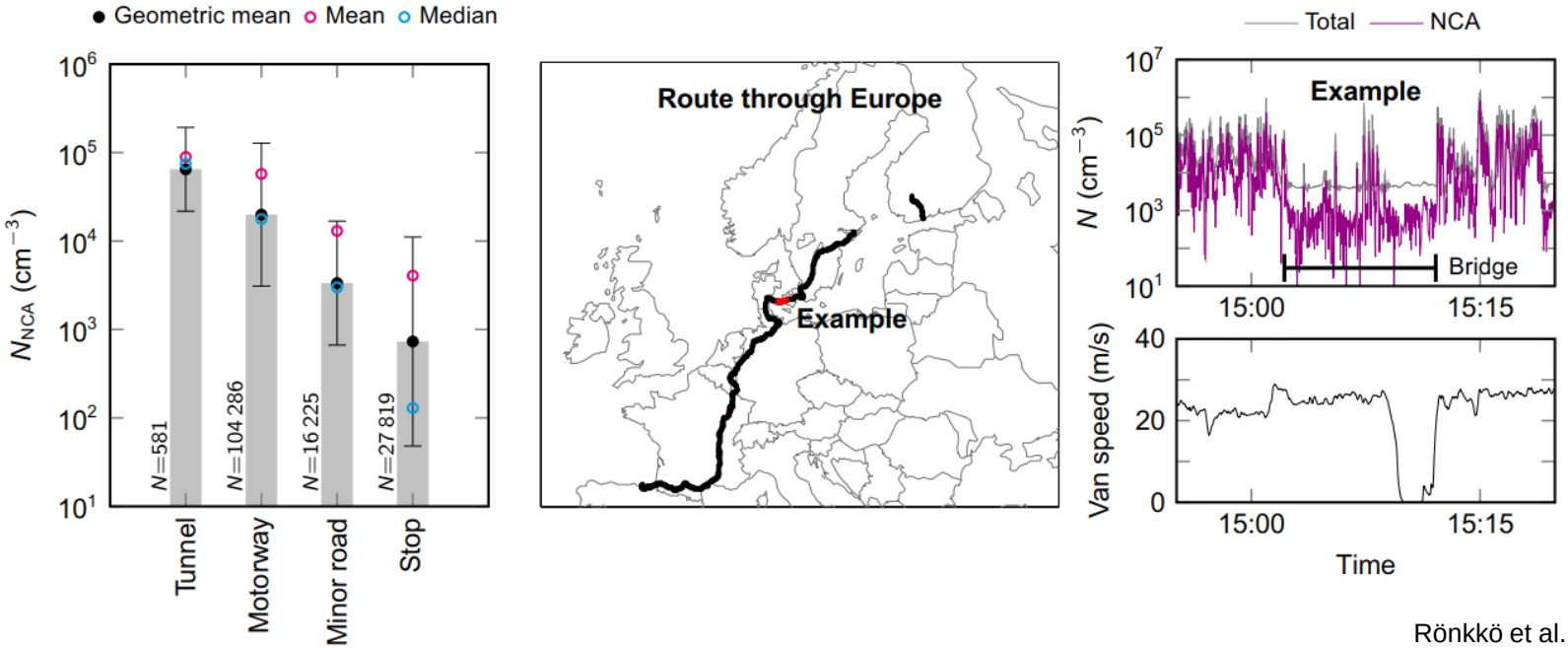
Results: NCA in different environments



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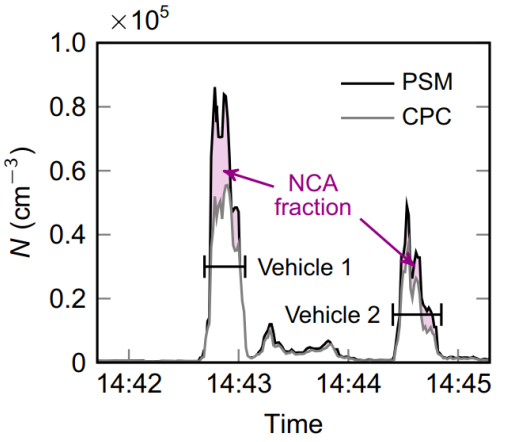
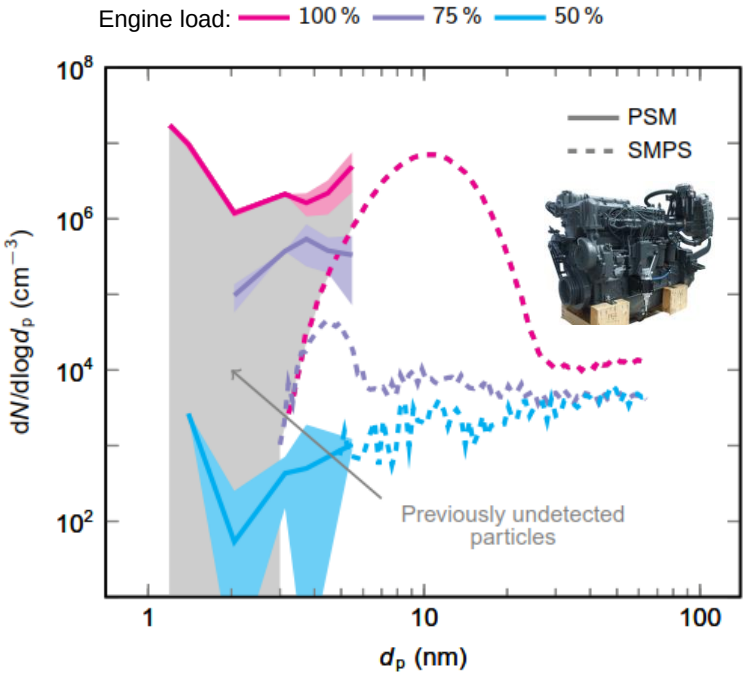
Results: on the variation of the NCA emissions

Street canyon



Engine laboratory



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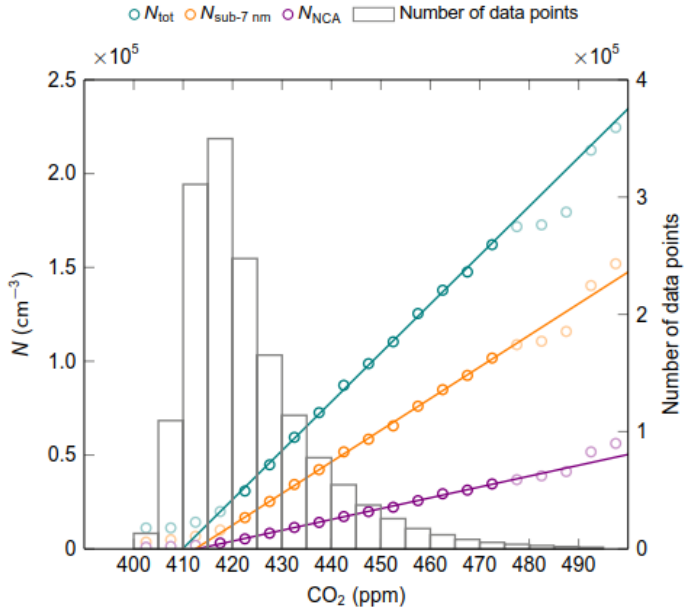
Results: Emission factor analysis



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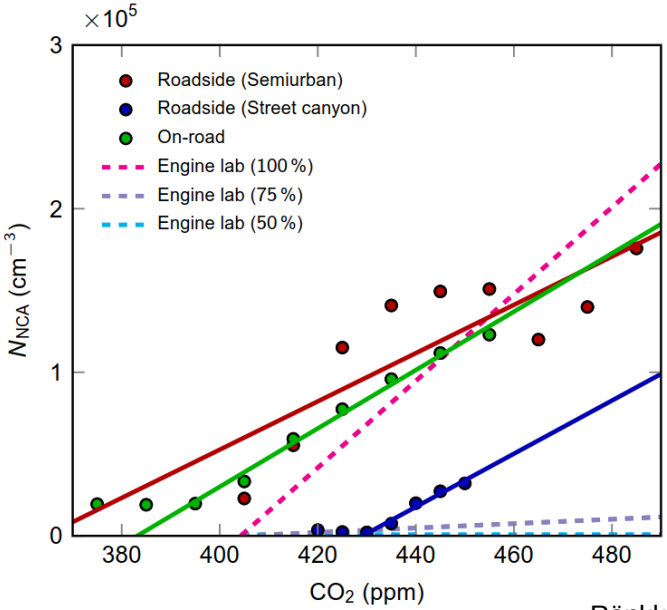
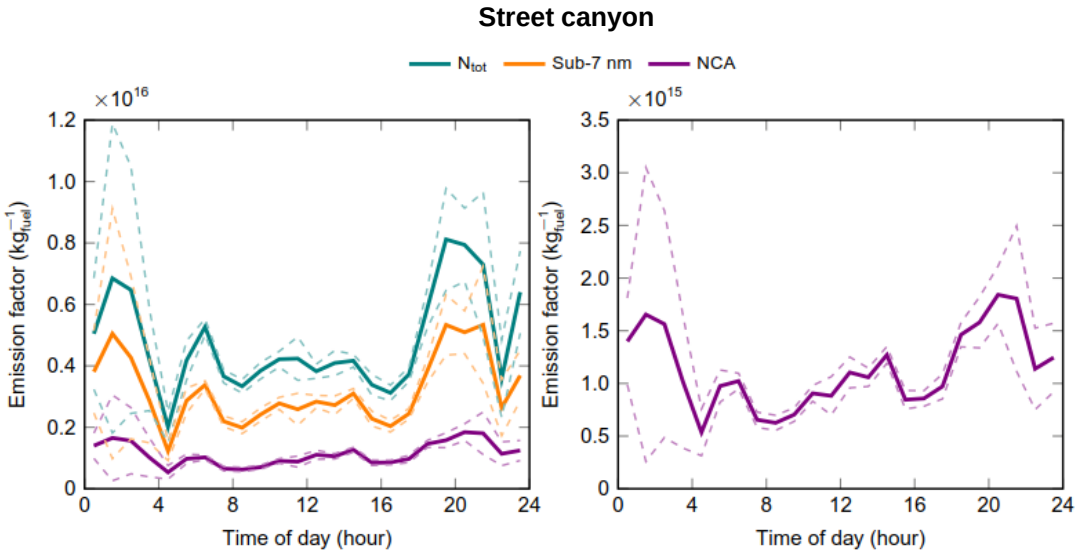


Rönkkö et al., 2017

Results: Emission factors (EF)

Environment	NCA EF (#/kg_{fuel})
Semiurban roadside	$2.4 \cdot 10^{15}$
Street canyon	$2.6 \cdot 10^{15}$ / $0.94 \cdot 10^{15}$
On-road (Eurotour)	$2.9 \cdot 10^{15}$
Engine laboratory	$1.6 \cdot 10^{12}$ ... $4.3 \cdot 10^{15}$



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Results: real-world NCA emissions of city buses

	Exhaust aftertreatment	Number of buses	N_{TOT} EF (10^{15}/kg_{fuel})	NCA EF (10^{15}/kg_{fuel})
Scania, 2013, EEV	EGR	12	1.1± 1.4	0.30±0.70
Scania, 2015, Euro VI	EGR-DPF-SCR	2	0.7±0.6	0.09±0.33
Volvo, 2015, Euro VI	DPF+SCR	3	0.3±0.4	Very low
Scania, 2013, EEV, retrofitted in 2015	DPF+SCR	1	4.6	2.65
Scania, 2013, EEV, retrofitted in 2016	EGR+DPF+SCR	2	0.9±1.7	Very low

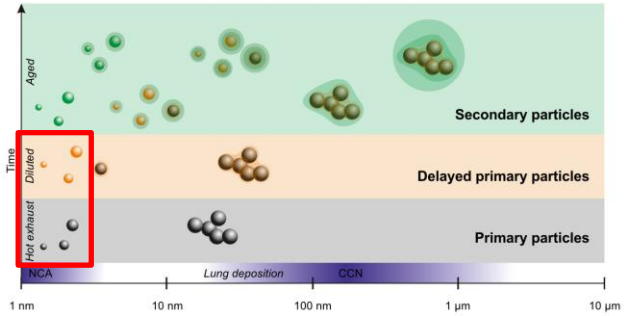
Conclusions

A significant amount of particles in the size range of 1–3 nm in urban areas

This nanocluster aerosol (NCA) was shown to be directly emitted by road traffic

Vehicle/engine type, fuels and lubricant oils, exhaust after-treatment, driving conditions and environmental conditions may affect the emissions

In roadside environment, the NCA emission of traffic was $0.94 \cdot 10^{15}$ - $2.9 \cdot 10^{15}$ #/kg_{fuel}

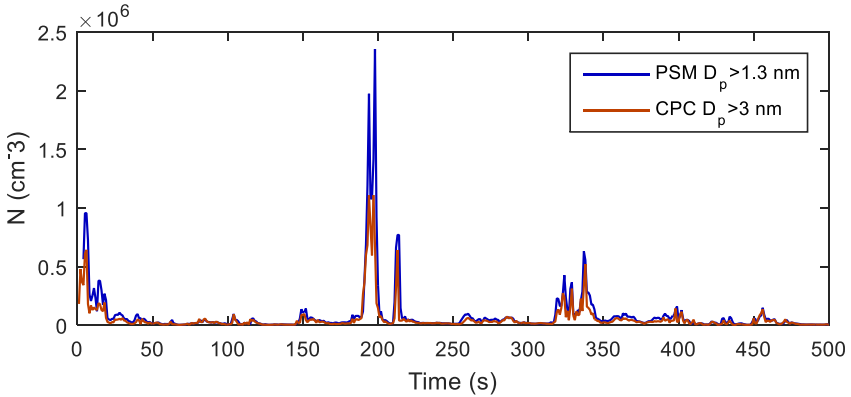


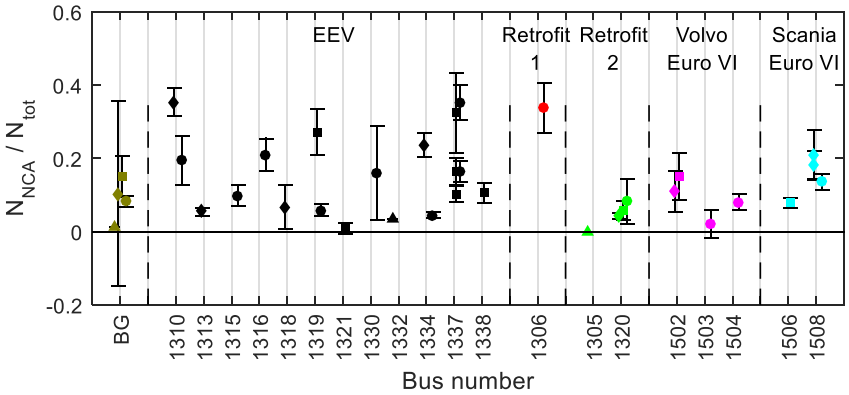
Thank you for your attention!

This work was funded by Tekes–the Finnish Funding Agency for Innovation (TREAM and Cityzer projects), Academy of Finland Grants 283455, 259016, and 293437, Cleen Ltd. (MMEA project), Dinex Ecocat Oy, Neste Oyj, AGCO Power, Ab Nanol Technologies Oy, Helsinki Region Environmental Services Authority HSY and Pegasor Oy.

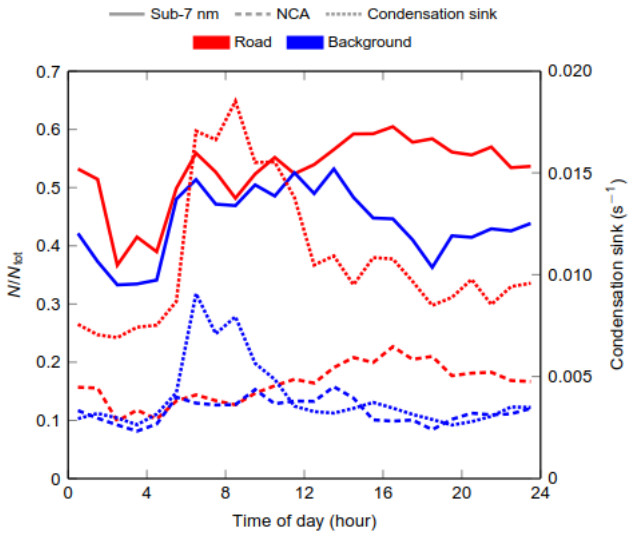
Results: NCA concentrations in city bus exhaust plumes

- NCA concentrations had temporal (and thus spatial) variation
- Highest concentrations for EEV and EEV+retrofit 1





Results



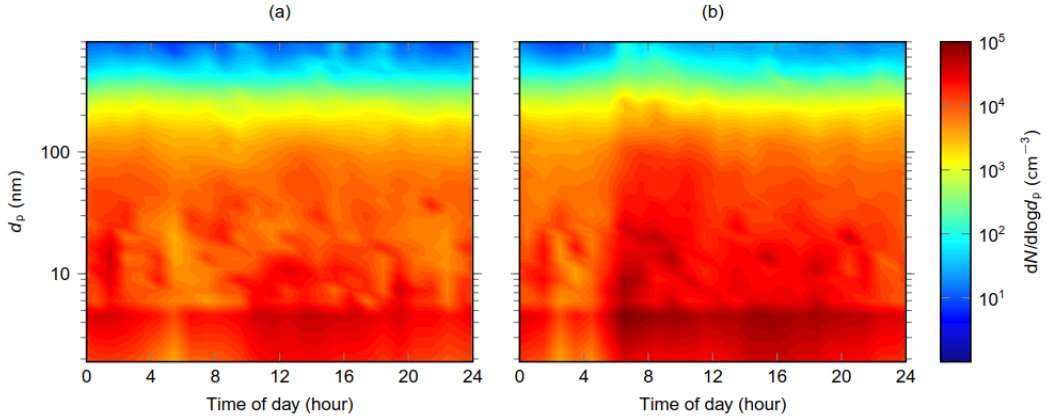


Figure 8: Diurnal variation of particle size distributions (a) at weekends with all wind directions included and (b) on weekdays with wind blowing from the road.

Results

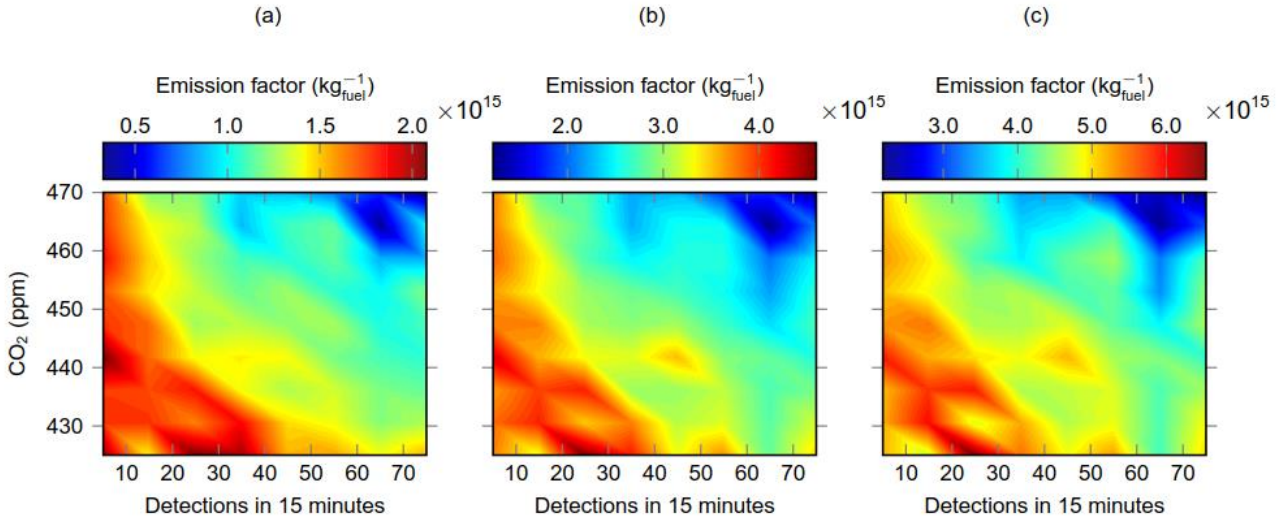


Figure 11: Emission factors of (a) nanocluster aerosol (NCA), (b) sub-7 nm and (c) all particles as a function of CO_2 concentration and the number of detections in 15-minute time periods. Note different scales in color axis.