In-field verification of particulate emission factors of road traffic

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ABSTRACT

Extended field measurements of PM10 and PM1 concentrations at the kerbside of several streets with different traffic regimes were performed in Switzerland using a comprehensive set of instruments. Besides PM1 and PM10, concentrations of total number, surface area, and black carbon along with full size distributions were determined. From the differences between up- and downwind concentrations (or differences between kerbside and background concentrations for urban sites), "real-life" emission factors were derived using NO_x concentrations to calculate dilution factors.

INTRODUCTION

The research project "Verification of PM10 emission factors of road traffic" was jointly realised by the Swiss Federal Laboratories for Materials Testing and Research (EMPA) and the Paul Scherrer Institute (PSI). The goal of this project was to characterise and quantify the road-traffic induced particle emissions for different traffic regimes and different processes (exhaust pipe emissions, emissions from abrasion and resuspension). Concentration measurements of the ambient air were performed on both sides of busy roads. During meteorological conditions with an approaching air flow perpendicular to the street, it is possible to determine the contribution of the local traffic from downwind-upwind differences. At the urban sampling sites, where this concept could not be realised, these contributions were calculated from the differences of the kerbside and nearby background sites.

RESULTS

Emission factors were determined by an indirect approach because the dilution rate was not known from the measurement configuration. Hourly dilution factors were calculated from the measured concentration differences of nitrogen oxides (NO_x), the number of vehicles, and the NO_x emission factors published for the Swiss vehicle fleet and for different traffic regimes. The emission factors for particles were then computed from the measured concentration differences, assuming that these undergo the same dilution as nitrogen oxides. Two vehicle categories were distinguished: LDV (light-duty vehicles < 6 m, i.e., gasoline and diesel passenger cars, vans, motor cycles) and HDV (heavy-duty vehicles > 6 m, i.e., lorries and coaches).

In order to distinguish between exhaust pipe emissions and emissions from abrasion and resuspension the PM10 and PM1 fractions were measured separately. PM1 was interpreted as direct exhaust pipe emissions, and PM10 as total particulate traffic emissions. The difference PM10-PM1 thus represents the emissions from abrasion and resuspension. Particle size spectra with high temporal and size resolution in the diameter range 18 nm < D < 10 µm were obtained, focussing on a detailed characterisation of fine particle emissions up to 1 µm. Particle number emission factors shown in this presentation were calculated for the particle size range from 18 to 50 nm (N0.05) representing the nuclei mode particles of exhaust gas emissions as well as for the total particle number (N_{tot}), i.e. number concentration of particles with D > 7 nm. The particle volume emission factor V0.3 (size range D = 18 to 300 nm, assuming that every particle has a spherical shape) is dominated by soot emissions, because condensation particles (D < 50 nm) are too small to significantly contribute to the volume concentration.

Table 1: Particle emission factors calculated for two traffic regimes (Birrhard: Freeway, 4 lanes, speed limit 120 km/h; Zürich-Weststrasse: Urban main road, 2 lanes, speed limit 50 km/h, traffic lights).

Sampling site		N0.05	N_{tot}	V0.3	PM10	PM1
		#/km	#/km	cm^3/km	mg/km	mg/km
Birrhard	LDV	4.10E+13	6.50E+14	0.02	63	16
	All	1.40E+14	1.34E+15	0.03	83	33
	HDV	8.10E+14	6.90E+15	0.16	267	193
Zürich-Weststrasse	LDV	2.50E+13	1.00E+14	0.03	49	11
	All	6.70E+13	4.50E+14	0.08	104	29
	HDV	7.40E+14	5.40E+15	0.94	703	342

CONCLUSIONS

Direct mass measurements of PM1 and PM10 showed relatively high measuring uncertainties. The differences between downwind and upwind of these parameters were quite small, which resulted in emission factors with high standard deviations. Therefore the distinction between LDV and HDV turned out to be difficult.
The measured particle size spectra have a lower measuring uncertainty. Due to the fact that the traffic contribution to particle number concentrations was much higher than the background value, particle number emission factors could be computed with smaller error bars. However, the conversion of a number into a mass concentration results in high uncertainties, because one has to assume the effective particle density, which depends on the mobility diameter and the chemical composition of the particles.
The emission factors (N0.05, V0.3, PM1 and PM10) found for HDV were about 10 times higher than for LDV. Abrasion and resuspension processes represent a significant part of the total primary PM10 emissions of road traffic.

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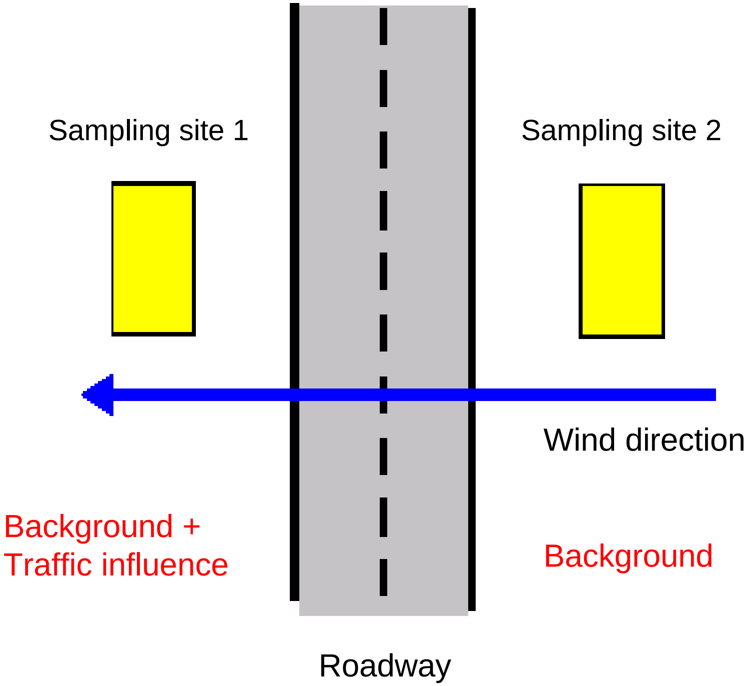
7th ETH Conference on Combustion Generated Nanoparticles

Motivation

- Emission factors of motor vehicles are well-known from test stand measurements.
- For real-life conditions, differences are expected because of maintenance and age of the vehicles as well as other dilution factors and rates of the exhaust gas in ambient air.
- Only little is known about emission factors of ultrafine particles.

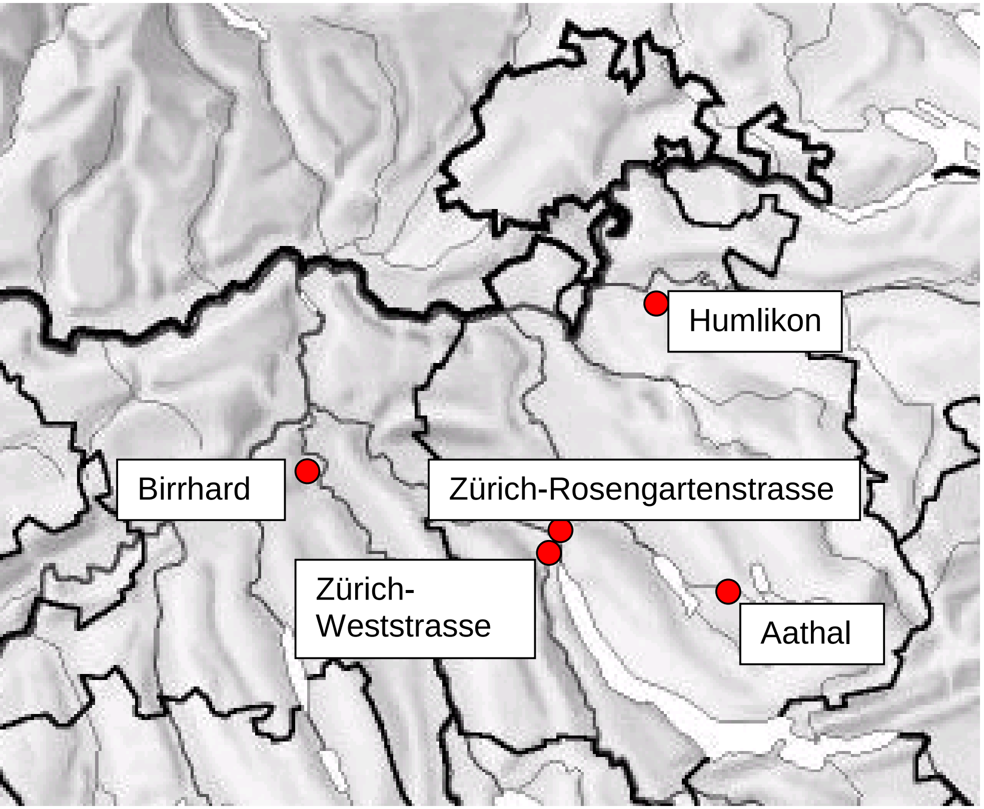
➔ In a field project real-life emission factors were determined for various traffic situations.

Concept and measured parameters



Instrument	Parameter
SMPS (DMA + CPC, TSI 3010)	Size distribution: 7 - 300 nm
Optical Particle Counter (Grimm 1.108)	Size distribution: 0.3 - 20 μm
CPC (TSI 3022A)	Number concentration N (D > 7 nm)
Betagauge (Eberline FH 62-I-R, Andersen)	Mass concentration PM 10
Betagauge (Eberline FH 62-I-R, Andersen)	Mass concentration PM 1
Aethalometer (AE10, Magee Scientific)	Black Carbon
Diffusion Charger (LQ 1-DC)	Particle surface area concentration
NO_x analyzer (ML 8841)	NO, NO_x
CO analyzer (APMA 350E)	CO

Sampling sites in the area of Zürich



Sampling site	Traffic situation
Aathal (only PM measurement)*	Main road (50 km/h)
Birrhard	**Freeway (4 lanes, 120 km/h)**
Humlikon	Highway (2 lanes, 80 km/h)
Zürich-Rosen-gartenstrasse*	Urban main road (50 km/h, slope 8%)
Zürich-Weststrasse*	**Urban main road (50 km/h, traffic lights)**

*) Background station is represented by a nearby sampling site

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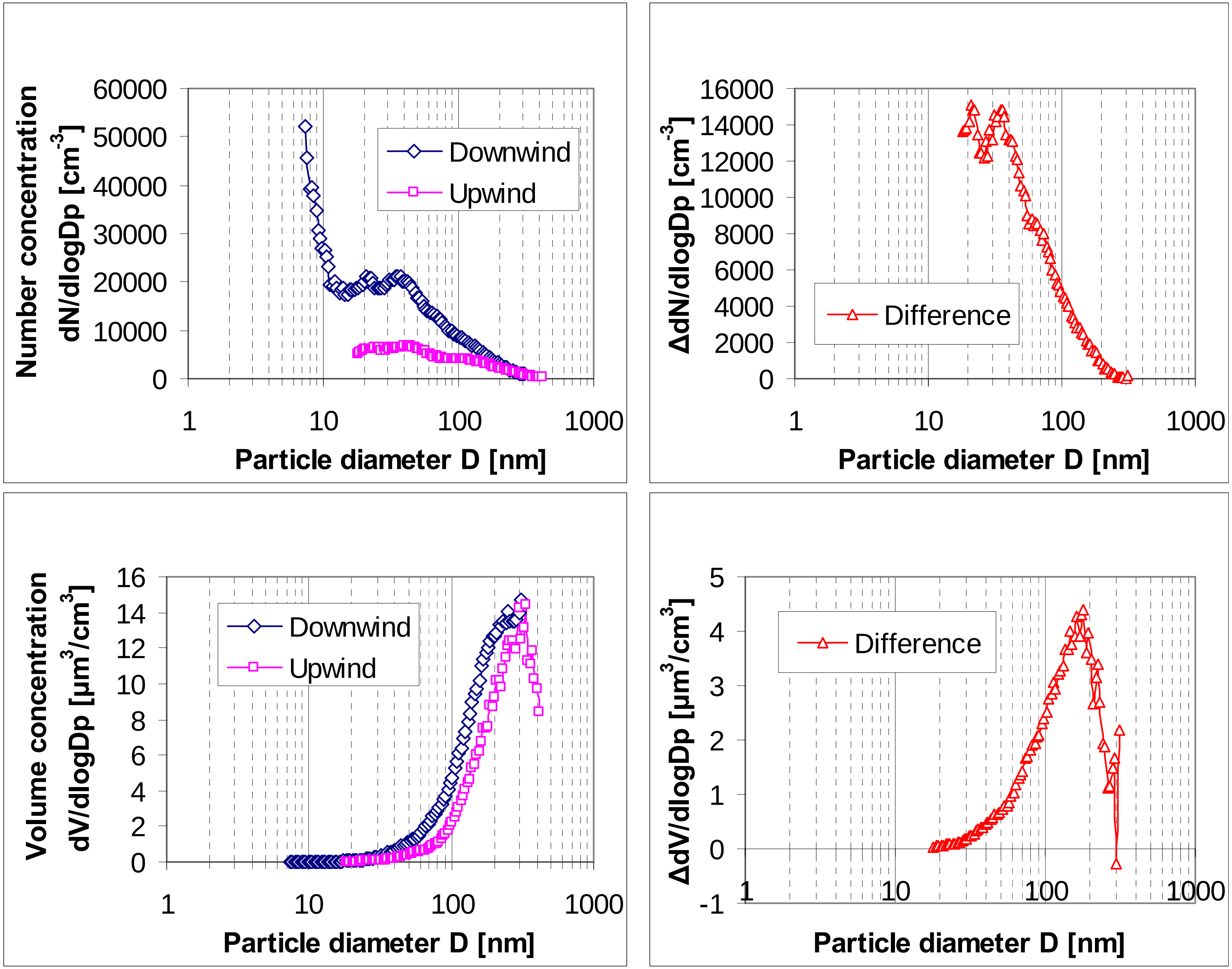
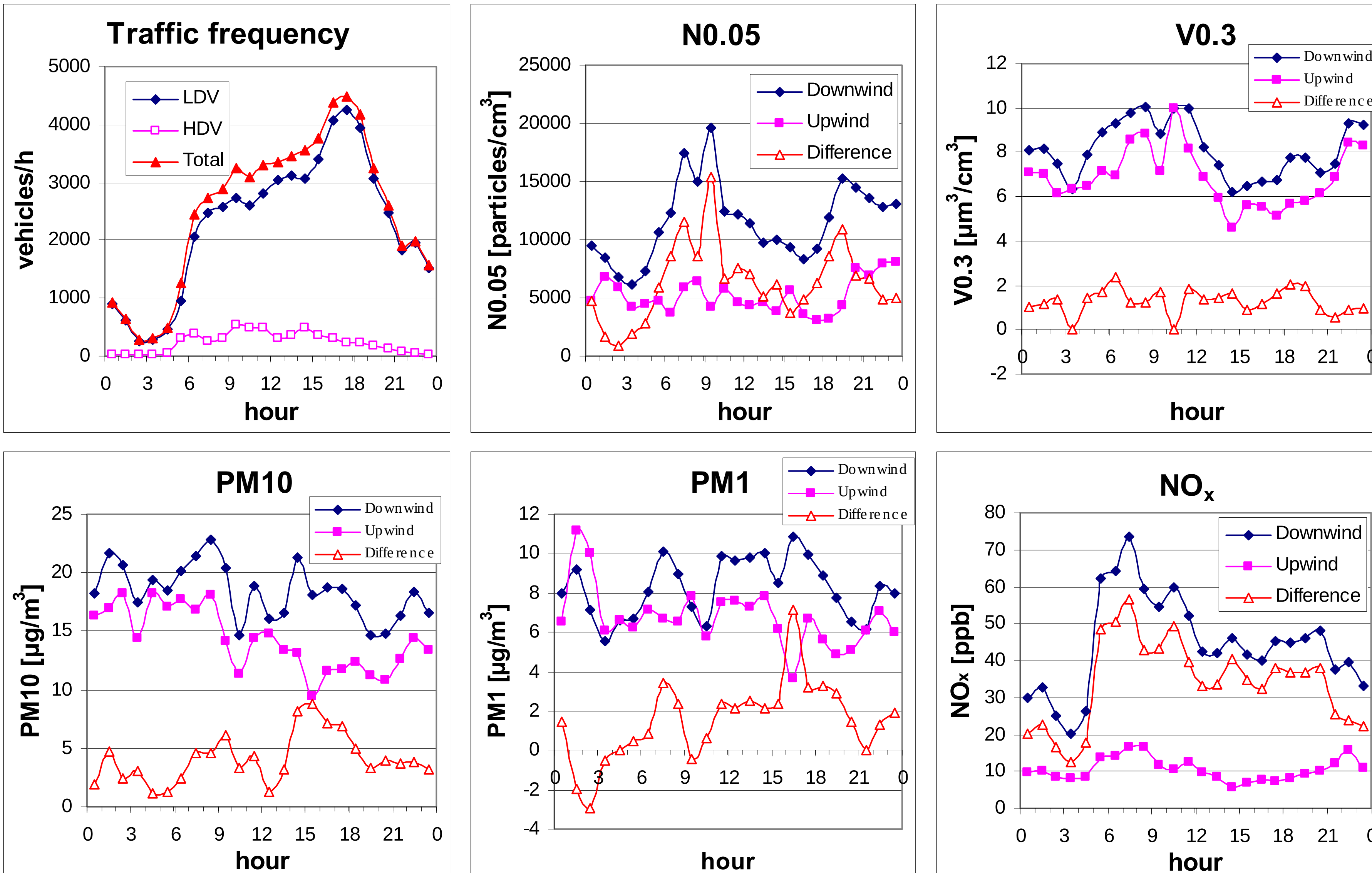
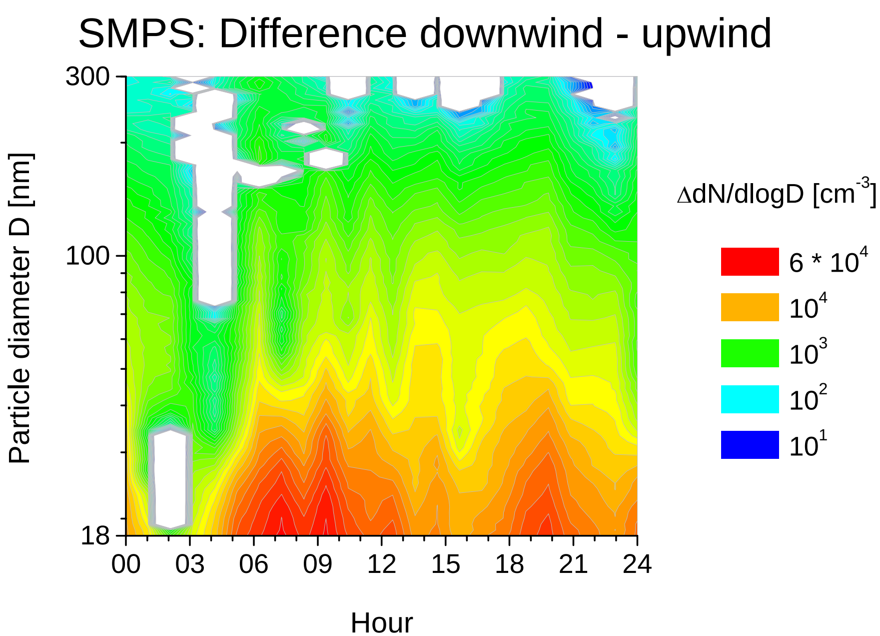
Particle number and volume size distribution close to a motorway

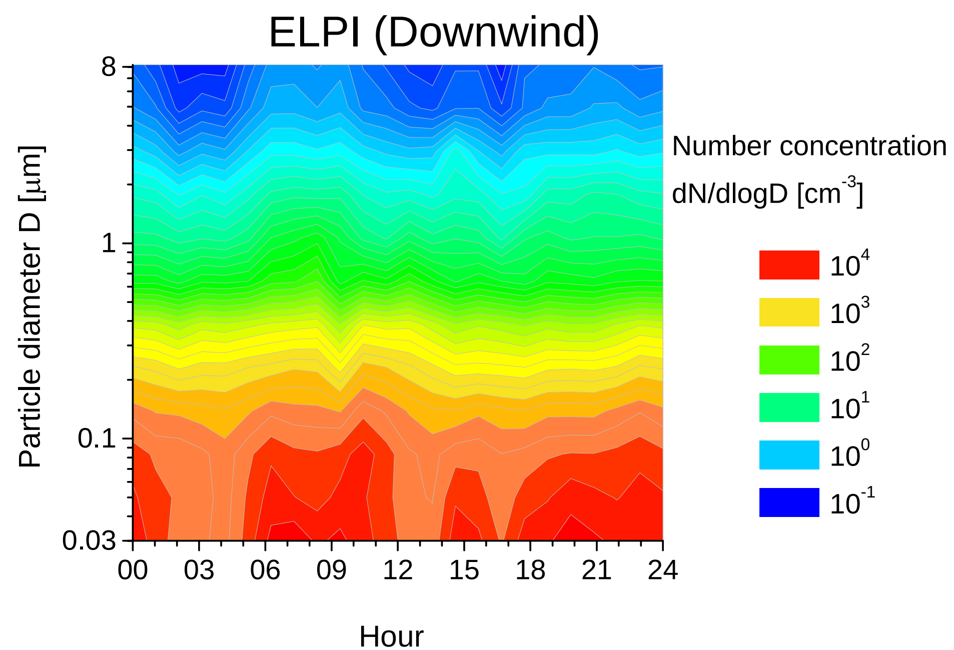


Average diurnal variation (I)



Average diurnal variation (II)





Calculation of emission factors

$$\Delta NO_x = \frac{EF_{NOx(LDV)}}{D} \cdot n_{LDV} + \frac{EF_{NOx(HDV)}}{D} \cdot n_{HDV}$$

$$D = \frac{EF_{NOx(LDV)} \cdot n_{LDV} + EF_{NOx(HDV)} \cdot n_{HDV}}{\Delta NO_x}$$

$$\Delta C_i = \frac{EF_{(LDV)}}{D} \cdot n_{LDV} + \frac{EF_{(HDV)}}{D} \cdot n_{HDV}$$

ΔNO_x:	Concentration difference of NO_x [$\mu g/m^3$]
$EF_{(LDV)}$:	Emission factor of light-duty vehicles [mg/km]
$EF_{(HDV)}$:	Emission factor of heavy-duty vehicles [mg/km]
n:	Vehicle number [1/h]
D:	Dilution [m^2/h]
ΔC_i:	Concentration difference of species I [x/m^3]

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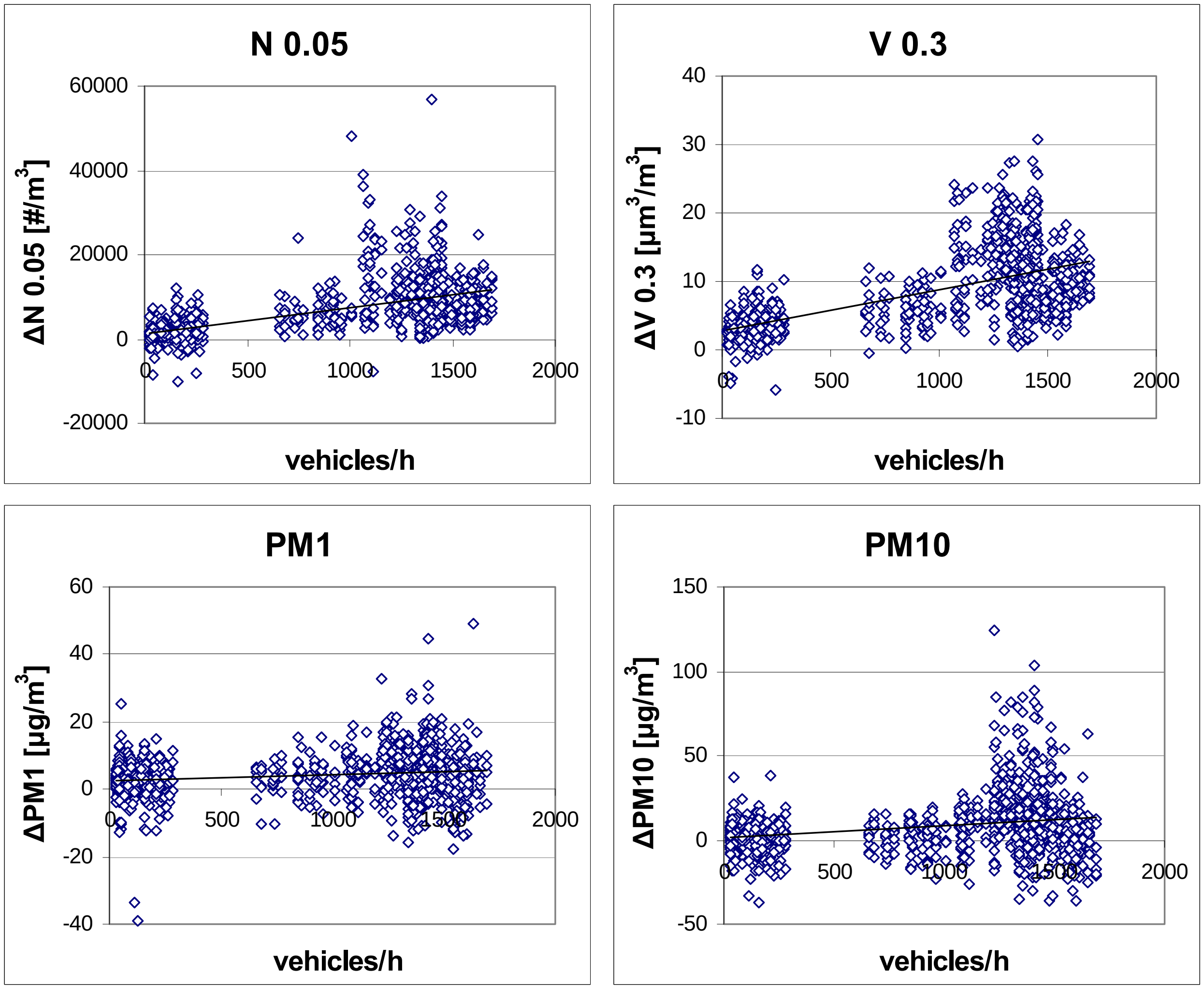
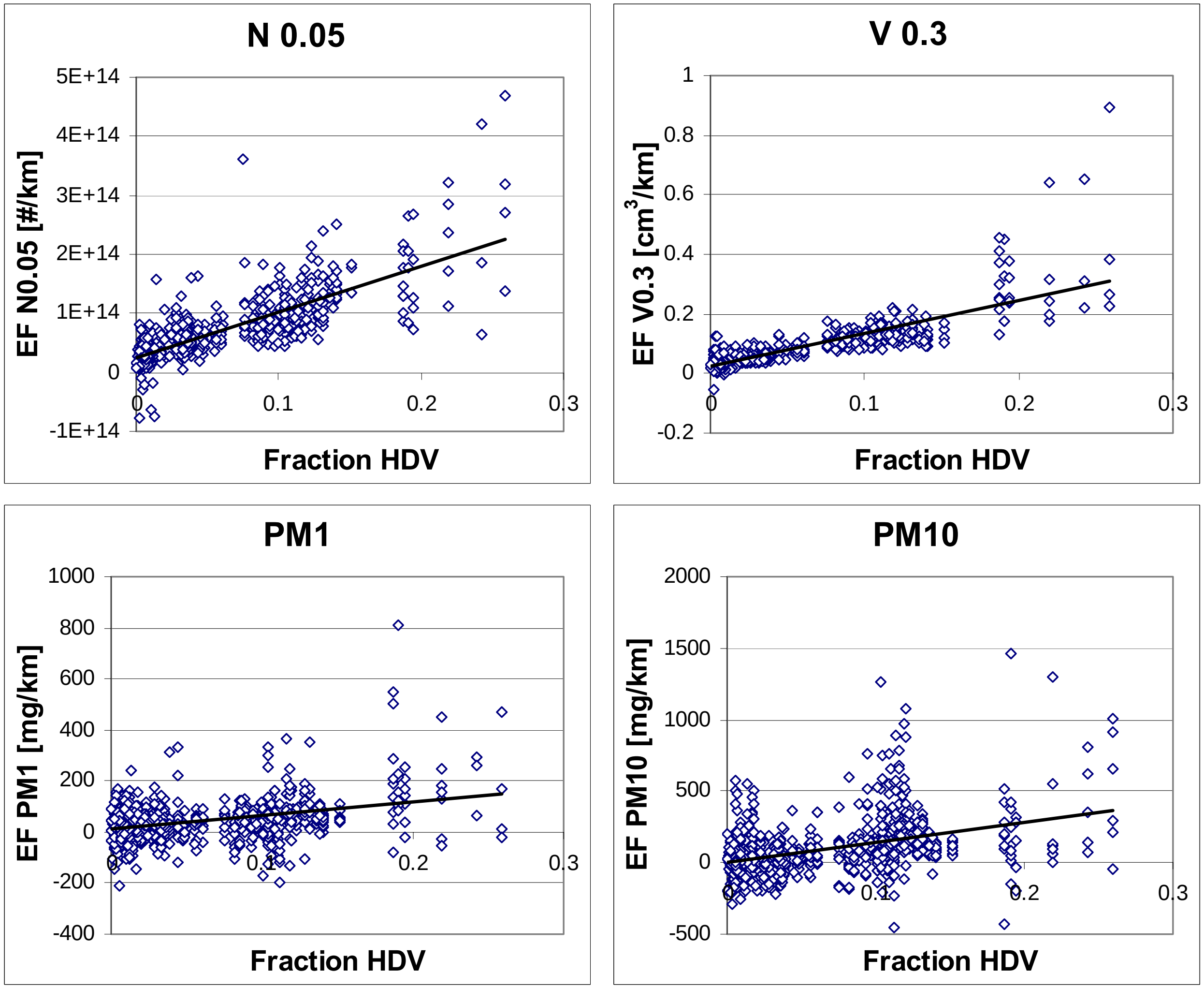
Concentration difference vs traffic frequency

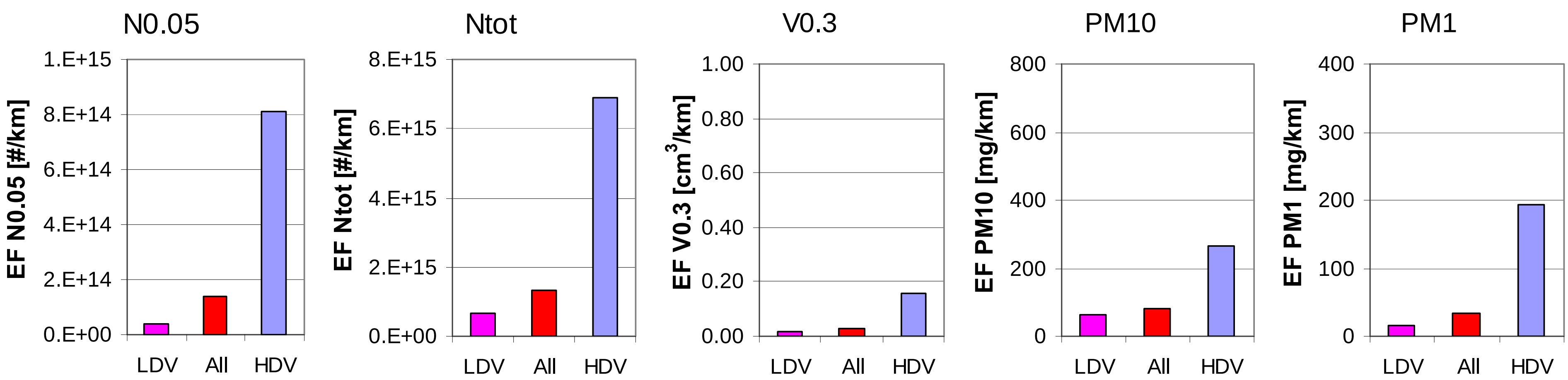


Emission factor per vehicle vs HDV fraction

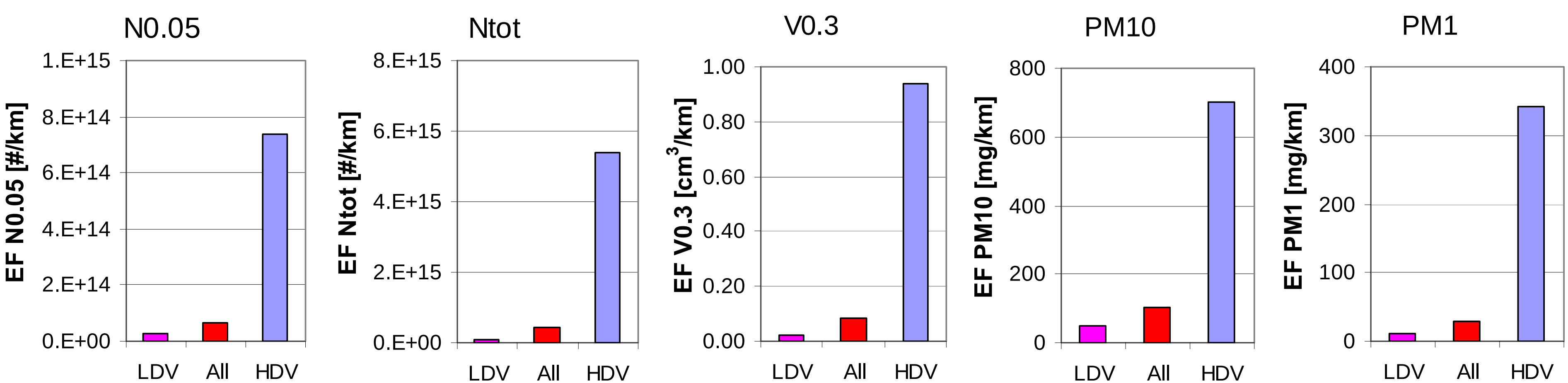


Emission factors

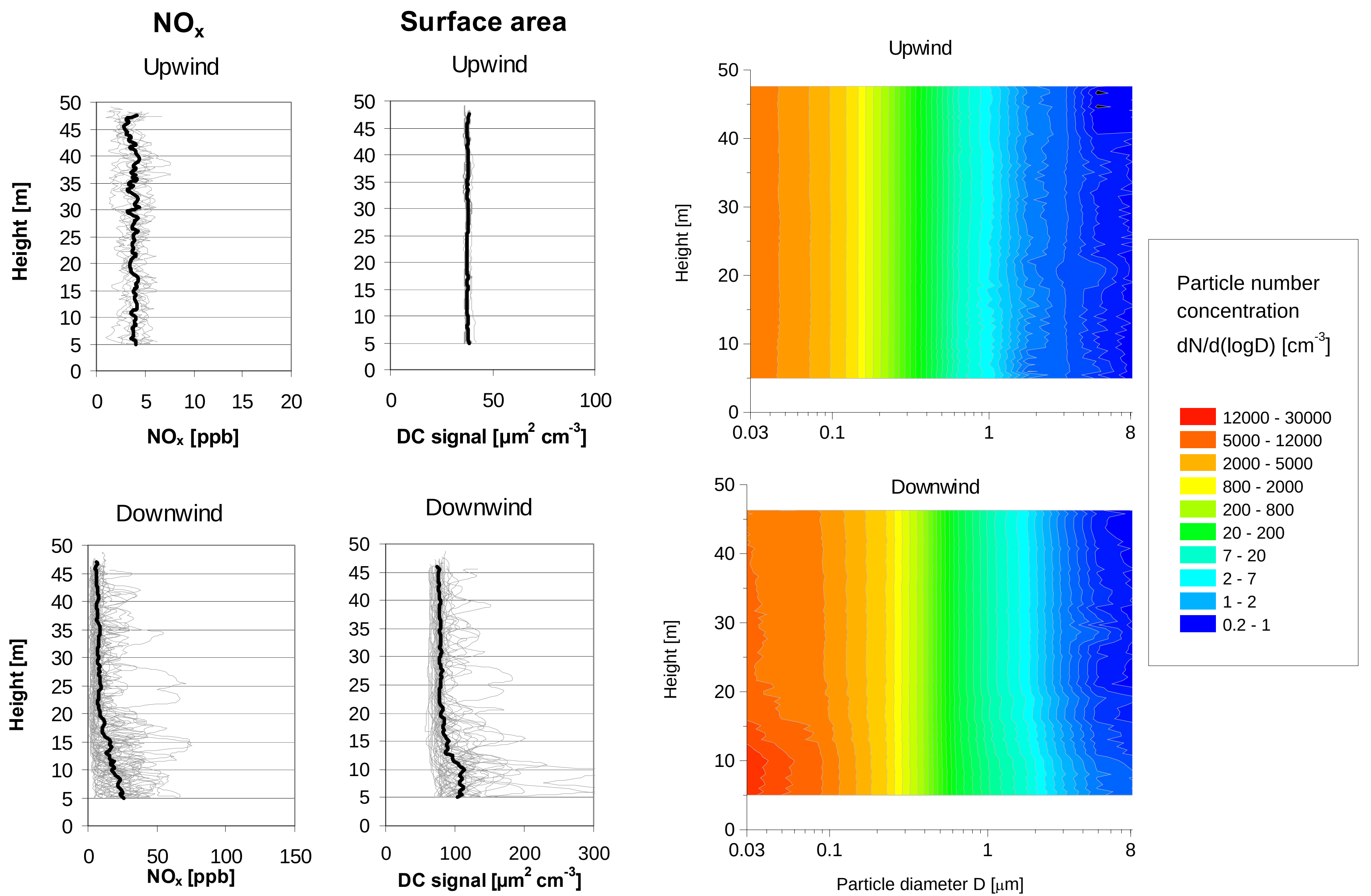
BIRRHARD



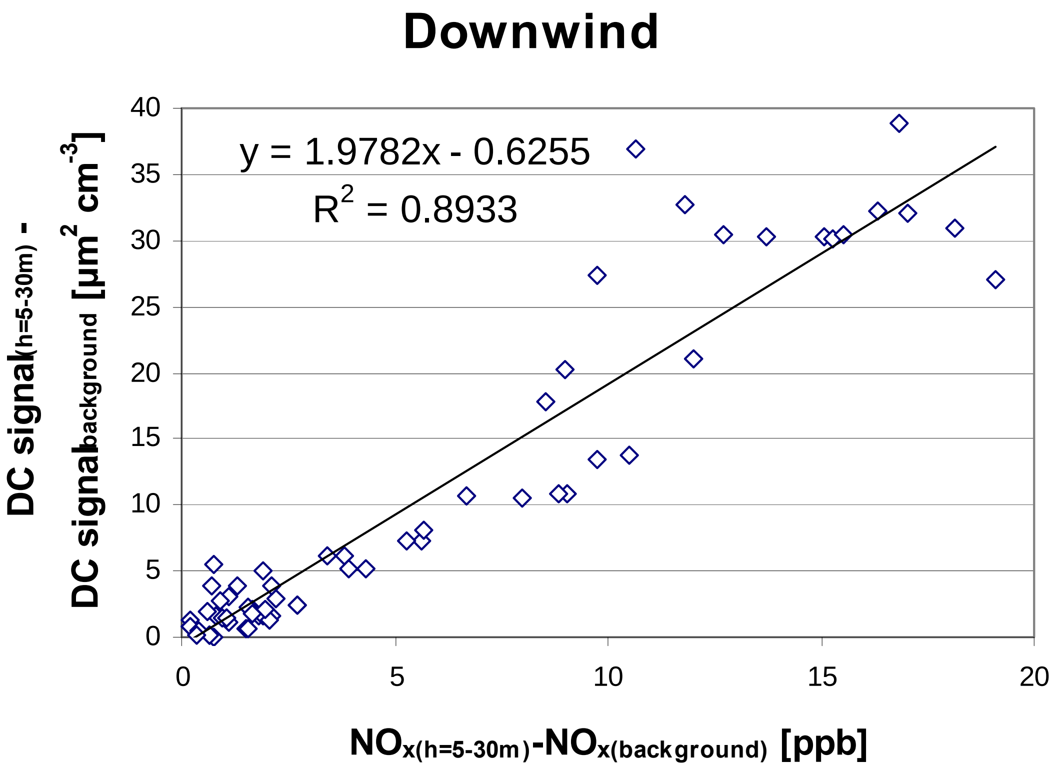
ZUERICH-WESTSTRASSE

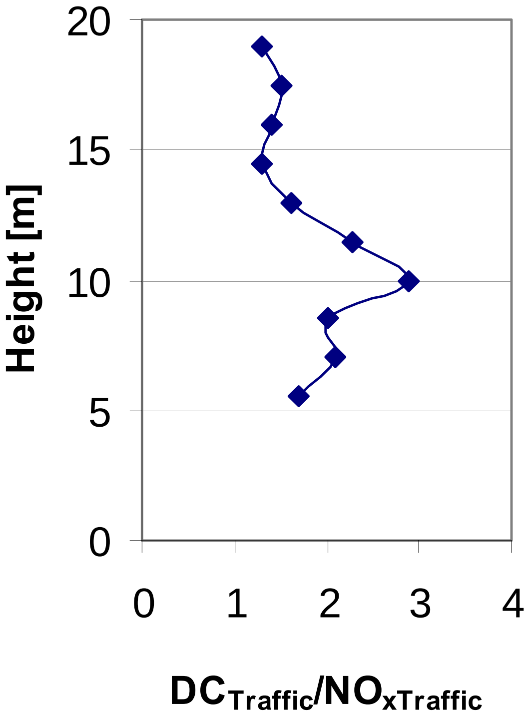


Vertical profiles of NO_x, particle surface area concentration and particle number size distribution



Correlation particles - NO_x

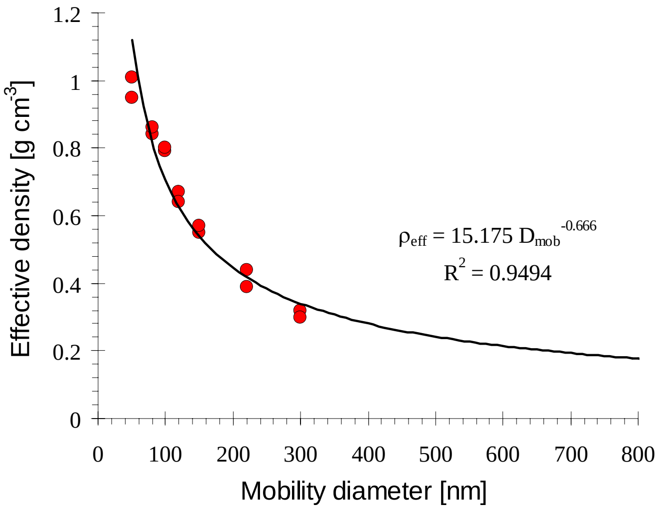




Conclusions

- PM10 and PM1 are determined by direct mass measurements which show relatively high measuring uncertainties.

- SMPS data have a low measuring uncertainty, but the conversion into a mass concentration will result in high uncertainties.



(Park et al., 2003)

- Emission factors (N0.05, V0.3, PM1, PM10) found for HDV are about 10 times higher than for LDV.

- Our results correspond well to findings in other field studies with similar traffic situations.