MONITORING AND MODELING OF ULTRAFINE PARTICLES IN A STREET CANYON IN STOCKHOLM, SWEDEN

L. Gidhagen[a,b], C. Johansson[b], J.Langner[a] and G. Olivares[b]
[a] Swedish Meteorological and Hydrological Institute, Norrköping, Sweden
[b] Air Pollution Laboratory, Institute of Applied Environmental Research, Stockholm University, Sweden
correspondance: lars.gidhagen@smhi.se

1. Introduction

During 1.5 years total particle number concentrations (ToN<7nm) have simultaneously been measured at roof level and at one side of the heavily trafficked street canyon Hornsgatan. For a shorter period, the street level station was complemented with a DMPS system, including a DMA (14 size bins 20-450 nm) and a CPC registering ToN>10nm. Hornsgatan also constitutes one of the fixed monitor stations of the Stockholm air quality network, that includes e.g. NOx, continuously measured at both sides of the street, as well as at roof level.

Street width:	24 m
Building heights (both sides similar):	24 m
Traffic intensity (yearly average):	35 500 veh day^{-1}
NOx (yearly average, street level):	181 µg m^{3}
NOx (yearly average, urban background level):	22 µg m^{3}
ToN (yearly average > 7 nm, street level):	63 900 #cm^{-3}
ToN (yearly average > 7 nm, urban background level):	9 900 #cm^{-3}

Table 1 Characteristics of Hornsgatan street canyon

2. Ambient conditions strongly influence particle number

NOx and particle number concentrations at street level are both completely dominated by emissions from the vehicles passing the monitors (see Table 1). Since NOx is inert on the street canyon scale, the ratio ToN/NOx can be used as a way to normalize ToN for variations in both traffic intensity and meteorological dilution. Fig. 1 shows that ToN/NOx ratios are much higher during cold ambient temperatures. ToN emissions may be as much as three times higher during winter, as compared to summer. This temperature dependence has also been shown in London (Charron and Harrison, 2003).

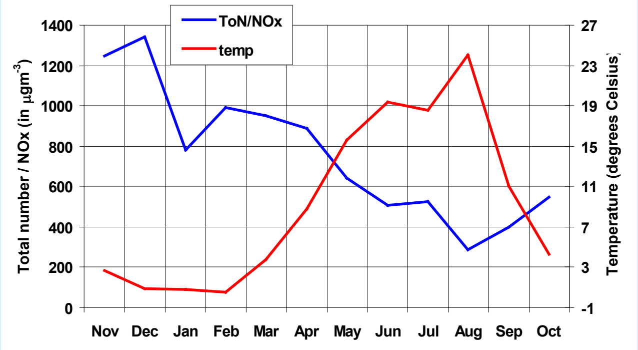


Fig. 1 Monthly levels of ToN/NOx ratios (weekdays 07-18 hours, background values excluded). Period: Nov 2001 - Oct 2002)

ToN is dominated by the nucleation size mode (diameter <30 nm), particles presumably formed from semivolatile organics during the early dilution and cooling of vehicle exhaust. Condensation on existing aerosols is a competing process to the formation of new particles. High ambient surface area concentrations will thus imply less particle formation and will also increase coagulation of the nucleation size mode particles (Fig. 2).

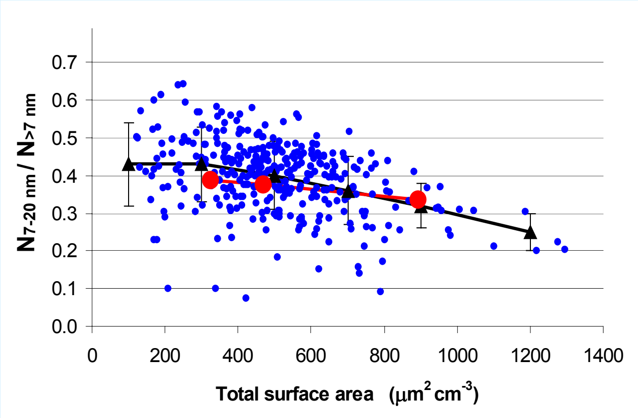


Fig. 2 Monitored hourly data of the ratio particles 7-20 nm to total number (blue dots). The black line show average ratios for surface area increments of 200. The red line is a model result (see Section 5). Weekdays and Saturdays 07-19 hours, Nov 2001 - Oct 2002, ambient temperature 0 to +5 °C.

3. Aerosol model

A simplified street canyon geometry has been set up for a CFD model coupled to the monodispersive dynamic model MONO32. The model system handles dispersion, coagulation, dry deposition and water uptake of four monodispersive size modes as decribed in Gidhagen et al. (2003). The Hornsgatan particle size distribution peaks at about 20 nm (Fig. 4). This is similar to the particle size distribution found earlier in the car tunnel.

Name	Diameter range (nm)	Initial dry diameter (nm)	Final[1] wet diameter (nm)
nucleation	< 10	6.8	7.2
Aitken 1	10 – 29	18.8	20.2
Aitken 2	29 – 109	45.0	48.2
accumulation	109 – 900	153.4	162.4

[1] Low wind speed case

Table 2 Size modes for the aerosol model.

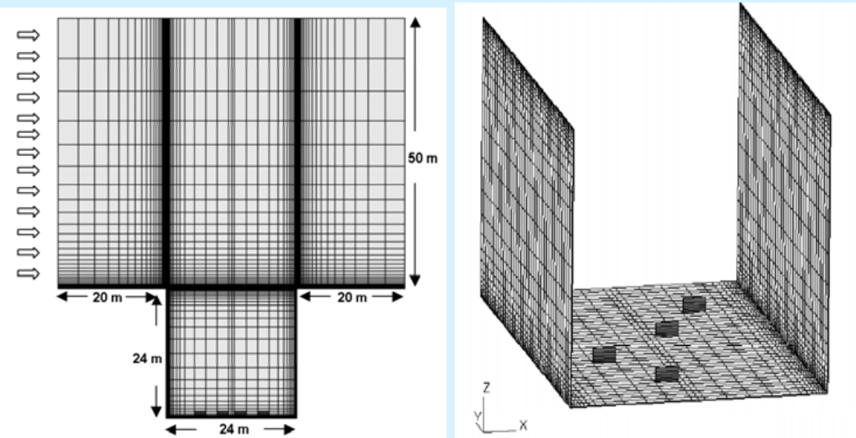


Fig. 3 Model grid and vertical plates used for the simulation of vehicular turbulence

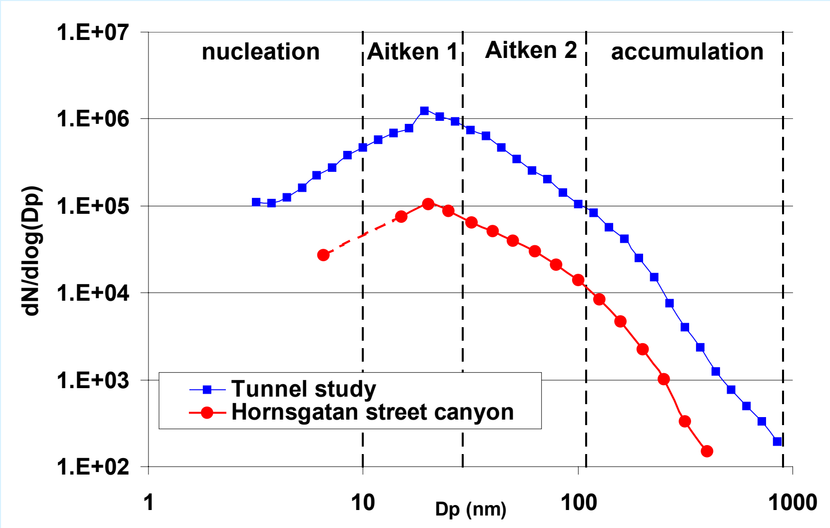


Fig. 4 Monitored size distribution during workdays at Hornsgatan (red) and in a car tunnel (blue). *Note: Data point for the smallest size at Hornsgatan is extrapolated based on the tunnel distribution.*

4. Hydrodynamics within the street canyon

A wind perpendicular to the street canyon generates a vortex that advects the vehicular exhausts towards the leeward side (left in Fig. 5a). The movements of the cars have been simulated in an inverted way by assuming fix vehicles (vertical plates, see Fig. 3) and boundaries moving with the speed of the cars. The velocity field created by the vehicle movements is thus unidirectional and will therefore somewhat underestimate the true mixing of a bidirectional traffic flow. The two velocity fields of Fig. 5 a and b are superimposed and solved for turbulence (RNG k-ε model), Fig. 5c. Three alternative wind speeds (2, 5 and 8 ms^{-1}) were used.

The enhanced mixing created by the vehicle movements is exemplified by the difference between Fig. 5 d and e.

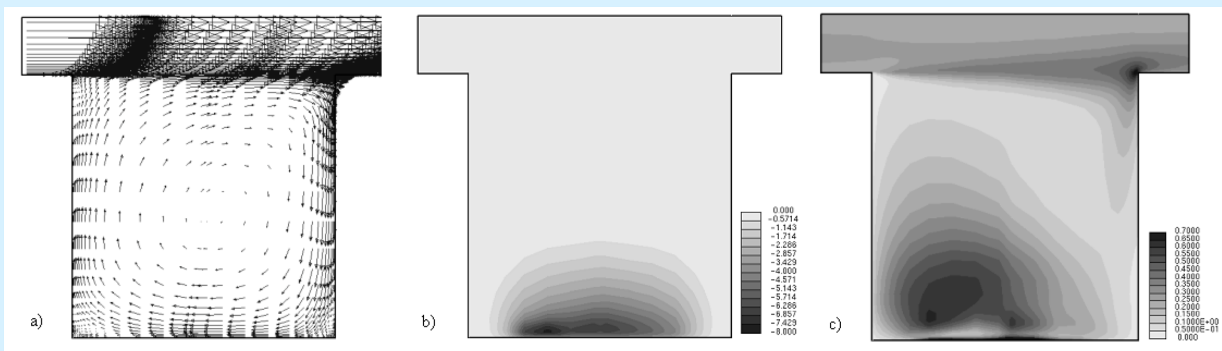
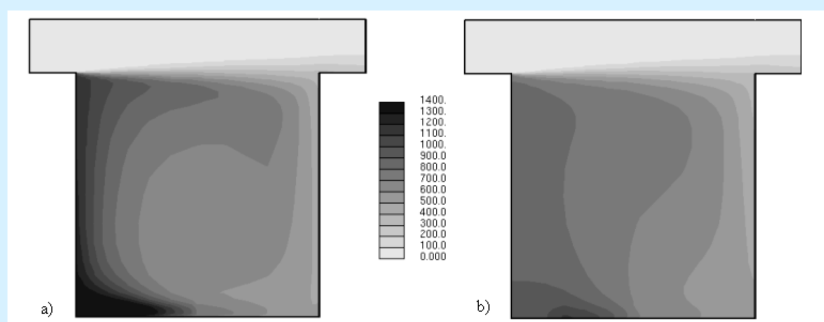


Fig. 5 a) Wind driven circulation
b) Longitudinal circulation driven by moving vehicles
c) Turbulent kinetic energy due to superimposed velocity fields. Unit: m^2s^{-1}
d) Distribution of inert tracer for pure wind driven circulation (low wind case)
e) Distribution of inert tracer for superimposed velocity and turbulence fields (low wind case)



5. Aerosol dynamics

The dispersion model was evaluated for NOx concentrations, for which the emission factors are known, and later applied to particle number. Particle emissions were tuned to output a size distribution similar to the monitored (Fig. 4). Although of slightly less importance than in the car tunnel, coagulation and deposition yields significant ToN losses for low wind speeds, 28% for 2 ms^{-1} wind speed (Fig. 6) and about 50% for the nucleation mode (Fig. 7a). For higher wind speeds and larger size modes (Fig. 7c) the effect of coagulation and deposition is small.

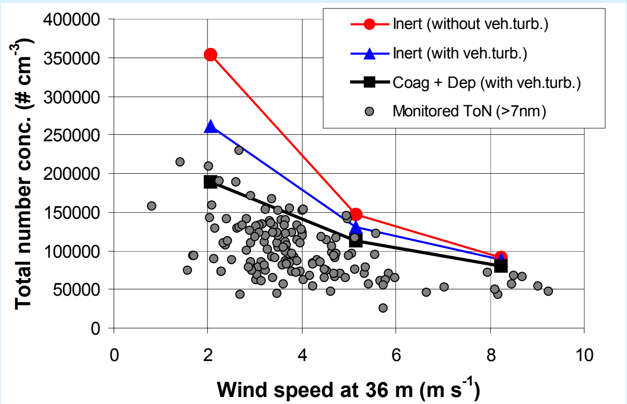


Fig. 6 Monitored (perpendicular wind, weekdays, 07-18 hours, urban background excluded) and simulated ToN concentrations as a function of wind speed. Simulated levels are expected to coincide with the highest monitored values, as the model uses peak hour traffic intensity.

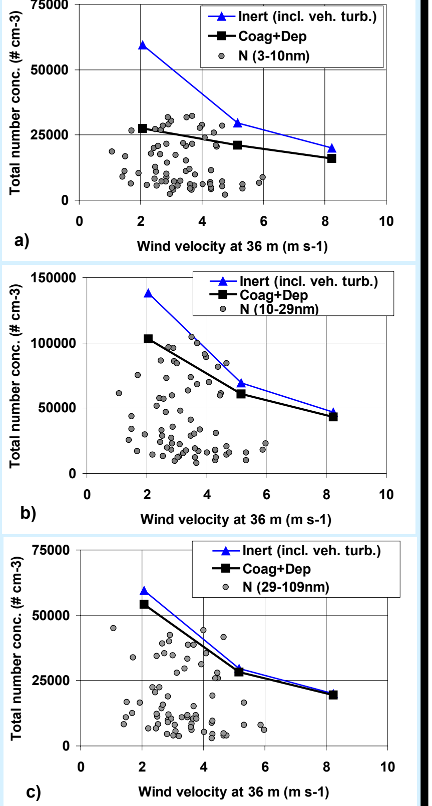


Fig. 7 Monitored (weekdays, 07-18 hours) and simulated concentrations of different size modes as a function of wind speed:
a) nucleation size mode (3-10 nm) (*note: monitored only down to 7 nm, estimated concentrations of 3-7 nm*).
b) Aitken 1 mode (10-29 nm)
c) Aitken 2 mode (29-109 nm)
Simulated levels are expected to coincide with the highest monitored values, as the model uses peak hour traffic intensity

Model results are plotted (red points) in Fig. 2, with the lowest wind speed case corresponding to highest number concentrations and also largest surface area. The effect on the size distribution of coagulation and deposition - i.e. the slope, with inert particles the line will be horizontal - seems to be smaller than actually monitored. Fig. 2 indicates that increased surface area available will imply both more effective losses due to coagulation and a smaller amount of particle formation (condensation instead) . Emission factors for ToN are thus functions of both temperature and ambient surface area concentration, which complicate their use in dispersion models.

6. Conclusions

• Ambient temperature has a strong influence on ToN concentrations at street level.

• The CFD model allows the inclusion of effects of vehicle generated turbulence within the traditional street canyon circulation.

• The aerosol model show that for low wind speeds, coagulation and deposition can deplete ~30% of emitted ToN, with small effects for winds > 5 ms^{-1}.

• Coagulation and deposition can not fully explain the observed lowered ratio of nucleation size mode particles for increased particle surface area. Increased particle surface area is likely to favour condensation instead of formation of new particles, thus contributing to an additional lowering of the ToN concentrations.

References

[1] Charron and Harrison (2003). Primary particle formation from vehicle emissions during exhaust dilution in the roadside atmosphere. *Atmos.Env.*, 37, pp. 4109-4119.

[2] Gidhagen et al. (2003). Model simulations of ultrafine particles inside a road tunnel. *Atmos.Env.*, 37, pp. 2023-2036.