VARIATION OF PARTICLE NUMBER CONCENTRATIONS AND NOISE ON THE
LOCAL URBAN SCALE

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Abstract

Mobile measurements of ambient noise and particle number concentrations were carried out within an urban residential area in Essen, Germany, during summer 2008. A busy major road with a traffic intensity of about 44,000 vehicles 24 h⁻¹ was situated within the study area. The spatio-temporal distribution of noise and particles was closely coupled to road traffic on the major road. Number concentrations and sound levels at measurement points in proximity to the road were more than double-fold in comparison to the urban residential background. At a 50 m distance off the road particle number concentrations were decaying to about 50 % of the initial value. The measurements were characterised by close spatial correlation between total particle number concentration and ambient noise.

Key words: urban aerosol, turbulence, noise

1. INTRODUCTION

Urban areas are prone to significant concentrations of different environmental stressors due to the large number of potential emission sources, e.g. traffic, industry and households. Two stressors receiving increased attention during recent years are particulate air pollution and environmental noise. In a number of studies both were associated with significant effects on human health (e.g. Oberdörster and Utell, 2002, Babisch et al., 2005, Muzet, 2007).

In terms of particulate air pollution, recent health related research indicated not particle mass but number concentrations to be the metric with significant impact on human health (Borm et al., 2006). This is of particular interest within cities due to the abundance of ultrafine particles (< 100 nm) in urban atmospheres (Costabile et al., 2008, Morawska et al., 2008). Therefore assessment of spatio-temporal variation in exposure of people towards urban particle number concentrations is an important topic in health related research.

While studies suggest traffic to be a major source of particles and noise due to road traffic as a common emission source (e.g. De Kluizenaar et al., 2007), there is little insight into a potential spatio-temporal covariation of both on the urban scale. In a former study Weber and Litschke (2008) studied the variation of noise and submicrometer particle mass on the urban local scale. Only moderate correlation between noise and submicrometer particle mass was found.

The intention of the present research is to study the spatio-temporal variation of particle number concentrations and ambient noise on the local scale within an urban residential environment close to a busy major road.

2. STUDY AREA

Measurements were performed within a busy urban street canyon and its surrounding neighbourhood in Essen, Germany during four consecutive days from Monday 28 July to Thursday 31 July, 2008. With a period of four days the study period is relatively short, however, it gives first insight into the important spatio-temporal characteristics of noise and urban aerosol by 'manpower' intensive mobile measurements at about 50 measurement points.

The study area covers about 20 ha. The street canyon ‘Gladbecker Straße’ (federal road B224) is characterised by a long-term average daily traffic intensity (ADT) of about 49,000 vehicles 24 h⁻¹. Mean building height of the symmetric canyon H = 17 m and mean width W = 21.6 m result in an H/W ratio of 0.8. The street canyon axis is northwest – southeast aligned (135° - 310°). Further details on the street canyon geometry can be found in Weber et al. (2006).

The surrounding neighbourhood is characterised by residential houses generally comprised of 4 to 5 floors. ADT intensity as estimated by the city authorities is less than 1000 vehicles 24 h⁻¹ on the neighbourhood streets. In the south-west of the study area an urban park is situated (measurement points 45 to 47). More details on the study area are provided in Weber and Litschke (2008).

3. MATERIAL AND METHODS

3.1. Instrumentation

To study the spatio-temporal variability of particle number concentration and ambient noise both quantities were gathered at 50 fixed measurement points (MP) along the 3.5 km measurement route. This results in a spatial
resolution of about one measurement every 70 m. During the study period 12 repeated measurement-runs each lasting about 70 to 80 min were conducted. Total particle number concentration (TNC) was measured by a handheld condensational particle counter (CPC, TSI Inc., USA, Model 3007). According to the manufacturer the CPC is able to measure particles above a cut-off of 10 nm. The CPC measures the total number concentration with a time resolution of 1 s. Ambient noise was evaluated by a handheld noise level meter (Norsonic, Norway; Mod. Norsonic 118). The device is able to sample the noise level with a resolution of 1 s. The equivalent sound power level (Leq) was A-weighted by the instrument software and stored for post-processing. The noise meter was calibrated on each measurement day. Additionally a measurement container was installed at B224 housing equipment to gather meteorological quantities and particle size distributions. A sonic anemometer (USA-1, Metek, Germany ) placed at a height of 3.75 m above ground level (agl) measured horizontal and vertical wind vectors at a time resolution of 10 Hz. From this data turbulence properties were calculated. The particle number concentration was estimated by a Scanning Mobility Particle Sizer (SMPS, TSI Inc., USA). Air was sampled from a height of 3.10 m agl. The system consisted of a Differential Mobility Analyser Model 3080 and a CPC Model 3785. During the measurement campaign the SMPS was able to measure the particle size distribution and number concentration in the size range 18 < Dp < 780 nm every 5 min.

4. RESULTS AND DISCUSSION

The temporal variation of particle number concentrations in urban atmospheres, e.g. the day-to-day variability, is generally large as a consequence of changes in background concentrations and dependence on time of day (e.g. traffic intensity, atmospheric stability). The diurnal course of TNC at the container site is characterised by a clear peak during the morning rush-hour with concentrations of up to 32,000 cm⁻³ on average (not shown here). Distinct morning rush-hour peaks of particle number caused by the combination of the daily peak in traffic intensity and stable atmospheric stratification during the early morning hours were reported from a number of street canyon and kerbside studies (e.g. Wehner et al., 2002, Morawska et al., 2008). Afterwards, in consequence of a growing atmospheric mixing layer and decline in number of passing vehicles, TNC concentrations decrease to about 13,000 cm⁻³ at noon. Average particle number concentrations measured by handheld CPC during twelve mobile measurements vary between 12,500 cm⁻³ and 29,500 cm⁻³ on average (Tab. 1). However, the 20 s maximum TNC along the measurement route can reach concentrations of more than 100,000 cm⁻³ (Tab. 1). These estimates are comparable to measurements conducted in Montreal, Canada (Weichenthal et al., 2008). During walking along a busy two-lane road, average particle number concentration in the size range 0.02 < Dp <1 µm of 25,000 cm⁻³ with a maximum of 89,000 cm⁻³ were observed during the morning hours. Higher particle numbers were reported from a study conducted in London, UK (Kaur et al., 2005). The personal pedestrian exposure along a major road was 80,000 cm⁻³ on average with a maximum of 163,000 cm⁻³. However, local effects such as walking past a school bus can result in short-term concentrations of more than 300,000 cm⁻³ (10 s average in Weichenthal et al., 2008).

Tab. 1: Average and median values of TNC and L_{eq} for the 12 measurements based on the 20 s measurements at 50 MP. Spearman R denote rank-correlation coefficients for TNC vs. L_{eq} respectively.

<table>
<thead>
<tr>
<th>Meas.</th>
<th>TNC [# cm⁻³]</th>
<th>L_{eq} [dB(A)]</th>
<th>Spearman R</th>
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</table>

Tab. 1: Average and median values of TNC and L_{eq} for the 12 measurements based on the 20 s measurements at 50 MP. Spearman R denote rank-correlation coefficients for TNC vs. L_{eq} respectively.

Average values of L_{eq} during the 12 measurements vary by about 5.3 dB(A) (range of medians = 5.5 dB(A)). In relation to the human sense of hearing which perceives a 10 dB noise increase as a doubling of loudness the estimated range of 5.3 dB corresponds to approximately one-third of a doubling of loudness on the logarithmic dB-scale. It becomes obvious that background variability and dependence on time of day (e.g. traffic intensity) seem to have a higher impact on variations in TNC than L_{eq}.
The spatial distribution of both quantities is significantly coupled to road traffic on B224 (Fig. 1). The values at every single MP in the vicinity of the major road (MP 15, 21, 25, 29, 49, 50) as well as the contiguous MP along the street canyon (MP 33 to 43) are considerably elevated above those located at some distance to B224. The classified average number concentrations (Fig. 2) of MP situated at some distance to B224 fall within the lowest concentration class (12,000 to 19,000 cm$^{-3}$). Within the street canyon TNC reaches maxima of up to 40,000 cm$^{-3}$. On average the street canyon TNC are larger by a factor of up to 2.4 in comparison to the local background within the residential neighbourhood streets. Since road traffic is a significant source of (ultrafine) particles it is obvious that the exposure towards high concentrations is closely coupled to the proximity of measurements to roads (e.g. Weichenthal et al., 2008, Morawska et al., 2008).

The spatial distribution of TNC closely corresponds to significant elevations of ambient noise at the near-road measurement points. All MP close to B224 are characterised by average noise levels above 70 dB(A) while those in the built neighbourhood are between 50 and 55 dB(A).

The close spatio-temporal covariation of both quantities is supported by a correlation analysis (Tab. 1). Except measurement day 2 (29 June 2008) significant positive correlations between TNC and noise are demonstrated by
Spearman rank-correlation coefficients. The correlation coefficients are principally larger than 0.5 indicating a strong positive relationship between TNC and $L_{eq}$ on the local urban scale.

5. SUMMARY AND CONCLUSIONS

Ambient noise and particle number concentrations were measured within an urban residential area. A major road with a traffic intensity of about 44,000 vehicles $24 \, h^{-1}$ was situated within the study area. It turned out that the spatio-temporal distribution of noise and particles was closely coupled to road traffic emissions. Future research should tend to verify the present results in a long-term campaign with a number of fixed measurement sites placed within an urban/suburban setting. Generally, it would be advantageous to incorporate effects of ambient noise in future cohort studies on particle health effects in urban atmospheres since the present results indicate that both stressors are characterised by a similar spatio-temporal variation on the local urban scale.

References


