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Spatio-temporal covariation of urban particle number concentration and ambient noise

Stephan Weber*

Department of Applied Climatology and Landscape Ecology, Institute of Geography, University of Duisburg-Essen, Campus Essen, Schützenbahn 70, 45127 Essen, Germany

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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 per day was situated within the study area. The spatio-temporal distribution of noise and particles was closely coupled to road traffic on the major road. Total particle number concentrations in proximity to the main road were on average between 25,000 cm^{-3} and 35,000 cm^{-3} while sound levels reached 70–78 dB(A). These estimates were more than double-fold (factor 2.4) 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 with correlation coefficients of up to $r = 0.74$. However, during one measurement day coupling between both quantities was weak due to higher turbulent mixing within the canopy layer and a change in ambient wind directions. Enhanced dilution of particle emission from road traffic by turbulent mixing and 'decoupling' from the influence of road traffic are believed to be responsible.

1. Introduction

Urban areas are prone to significant concentrations of different environmental stressors as a result of the large number of emission sources, e.g. traffic, industry and households. Due to their significant effects on human health, two quantities receiving increased attention recently are particulate air pollution and environmental noise. Road traffic is a major common source of particles and noise in cities (De Kluizenaar et al., 2007; Beelen et al., 2009; Davies et al., 2009). However, the potential spatio-temporal covariation of both stressors on the urban scale as well as confounding effects of noise for particle related health effects are still unclear.

Health endpoints of particulate air pollution are mainly associated with cardiovascular and respiratory diseases (e.g. Oberdörster and Utell, 2002; Brunekreef and Holgate, 2002; Hoffmann et al., 2007; Pope and Dockery, 2006). Recent findings in epidemiological and toxicological research also point to neurological effects of ultrafine particles by mechanisms of oxidative stress and modification in autonomous functions (Sunyer, 2008). While the prevailing number of research on health effects of particles is based on epidemiological evidence regarding the mass fractions PM_{10} and $PM_{2.5}$ (Pope and Dockery, 2006) current results indicated not particle mass but number concentrations to be the metric associated with most significant health impacts (Borm et al., 2006; Stölzel et al., 2007). 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).

The impact of environmental noise on human health was related to stress hormone dysregulations, hypertension, ischaemic heart diseases and elevated risk of myocardial infarction (Ising and Kruppa, 2004; Lusk et al., 2004; Bluhm et al., 2007). A cohort study in Berlin, Germany, indicated noise levels >70 dB(A) during the day to be associated with ischaemic heart diseases in males. A 65–70 dB(A) daytime noise level likely marks a threshold value for health effects (Babisch et al., 2005). In a Dutch cohort study increased road traffic noise was related to a higher risk of hypertension in males (De Kluizenaar et al., 2007).

So far exposure assessment of particles or noise was conducted on different spatial scales within cities. The exposure of pedestrians and commuters towards particles in different transport environments (cycling, driving by car, public transport) was studied by Kaur et al. (2007) and Weichenthal et al. (2008). Maximum average daily particle number concentration alongside major roads might reach 90,000 cm^{-3} (Weichenthal et al., 2008). However, a large degree of spatio-temporal variability in number concentrations was found depending on traffic intensity and the actual distance of the

* Tel.: +49 (0) 201 183 3387; fax: +49 (0) 201 183 3239.
E-mail address: stephan.weber@uni-due.de

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measurement site to traffic emissions (Morawska et al., 2008). Spatial variability in noise exposure is evaluated by questionnaires, manual measurements or modelled noise maps based on road, rail and airport traffic (Babisch, 2004; Jarup et al., 2005; Lipfert and Wyzga, 2008). However, simultaneous estimates of noise and particle exposure in cities are scarce so far.

Recently first studies were conducted in Europe and the US (Weber and Litschke, 2008; Allen et al., 2009; Beelen et al., 2009; Davies et al., 2009). Motor traffic was demonstrated to be an important source of both noise and particles (Beelen et al., 2009; Davies et al., 2009). Moderate correlations between air pollutants and noise indicating possible confounding effects were found by Allen et al. (2009) for NO_x and ultrafine particles and Weber and Litschke (2008) for PM mass. However, Beelen et al. (2009) reported traffic related air pollutants to the associated with cardiovascular mortality in a Dutch cohort study while the contribution of noise exposure was less clear. Certainly more research is needed to verify the picture of confounding effects of environmental noise. Once significant relations are established an important future application might be to model air pollution exposure based on the spatial distribution of noise in cities. First steps in that direction were reported by Tirabassi et al. (1998) and Tirabassi (1999). Noise measurements will usually be cheaper and easier to obtain in comparison to ultrafine particle number concentration data.

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 (Fig. 1). The street canyon 'Gladbecker Straße' (federal road B224) is characterised by a long-term average daily traffic intensity (ADT) of about 44,000 vehicles per day during the measurement period (summer holidays). B224 is a hot-spot of particulate air pollution in Essen with yearly average concentrations of about 36 μg m^{-3} PM_{10} in the years 2005–2007 (Lanuv NRW, 2007, 2008). 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°, cf. Fig. 1). 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 4–5 floors. ADT intensity as estimated by the city authorities is less than 1000 vehicles 24 h^{-1} on streets in the neighbourhood. In the south-west of the study area an urban park is situated (measurement points 45–47). 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 (Fig. 1). This results in a spatial resolution of about one measurement every 70 m. During the study period 12 repeated measurements each lasting about 70–80 min were conducted (Table 1).

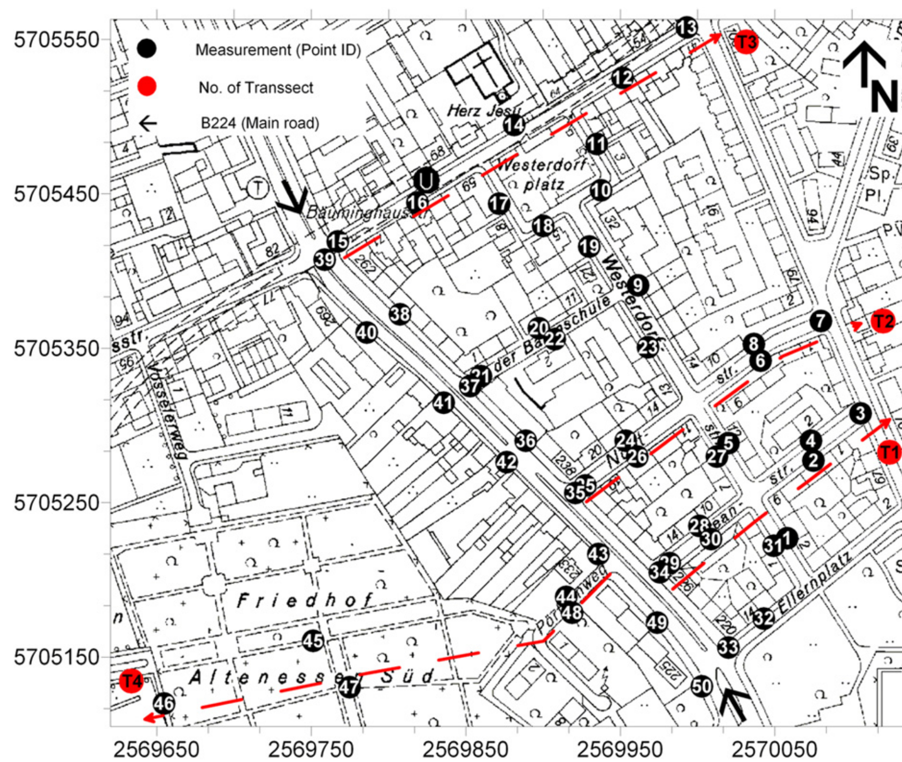

Fig. 1. Overview of the study area in Essen, Germany. Black spots indicate the 50 measurement points along the measurement route. The black arrows indicates the federal road B224, while the red lines depict horizontal transects T1–T4 referred to in a later part of the paper.

Table 1
Averages of different meteorological quantities during the study period measured at 3.75 m agl within the street canyon (φ_{Sodar} denotes average wind direction measured at a height of 100 m agl at the regional airport site).

Meas	Measurement Period [CET]	φ_{Sodar} [°]	σ_w [m s^{-1}]	U [m s^{-1}]	σ_w/U [1]
1	28.07.2008, 12:09–13:30	143	0.42	0.87	0.49
2	28.07.2008, 13:39–14:55	198	0.37	0.69	0.54
3	29.07.2008, 07:18–08:29	201	0.37	0.39	0.97
4	29.07.2008, 09:08–10:34	251	0.51	0.52	1.01
5	29.07.2008, 10:43–11:46	257	0.64	0.90	0.76
6	30.07.2008, 08:00–09:16	99	0.44	1.11	0.40
7	30.07.2008, 09:29–10:46	98	0.45	1.12	0.41
8	30.07.2008, 12:08–13:16	98	0.46	1.14	0.41
9	30.07.2008, 13:31–14:33	78	0.42	1.15	0.36
10	30.07.2008, 14:40–15:46	82	0.46	1.06	0.48
11	31.07.2008, 06:53–08:02	160	0.36	0.57	0.64
12	31.07.2008, 08:04–09:01	159	0.31	0.90	0.35

Total particle number concentration (TNC) was measured with a handheld condensational particle counter (CPC, TSI Inc., USA, Model 3007). 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 (L_{eq}) was A-weighted by the instrument software and stored for post-processing. The noise meter was calibrated on each measurement day.

Close to MP 36 at B224 a container was installed housing equipment to measure 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 $20 < D_p < 750$ nm every 5 min.

The traffic intensity in number of vehicles per unit time was automatically sampled by induction loops installed in close vicinity to the container at B224 (traffic data was provided by the North-Rhine Westphalia State Agency for Nature, Environment and Consumer Protection, LANUV NRW).

In the south-western part of Essen a Sodar was installed near a regional airport to evaluate atmospheric boundary layer mixing and its potential influence on near-surface aerosol concentrations. The measurement site was situated at a distance of about 10 km south-west of the study site. The Sodar (Scintec AG, Germany, Mod. MFAS) measures horizontal and vertical wind vectors and turbulence characteristics by sound pulses that are backscattered by atmospheric temperature inhomogeneities (e.g. Glickman, 2000). 10 m layer averages were stored at a time resolution of 30 min.

3.2. Data handling

3.2.1. Noise and aerosol data

At every MP ambient noise was measured over a period of 20 s. An average equivalent sound power level (L_{eq}) was calculated by the instrument software. At the beginning and end of each 20 s period TNC was measured by CPC and averaged. Additionally TNC was continuously logged along the route and averaged over 5 s periods (TNC_5). During post-processing the TNC_5 concentration was synchronised to the TNC measurements at the 50 MP. With the comparison of both approaches it should be verified that both methods provide reliable estimates of TNC over the 20 s period. TNC_5, because logged continuously might be advantageous since it measures about the whole 20 s cycle but might also be affected by local effects (e.g. passing motorcycles) along the route. Both methods resulted in similar estimates with correlation coefficients of $0.7 < r < 0.97$. Only two measurements showed correlation coefficients <0.7. The difference in TNC during the 12 measurements between both approaches was small with a mean deviation of about 6% and a standard error of 218 cm^{-3}. The subsequent data analysis is based on the TNC concentration data.

Recent studies conducted in the vicinity of particle line sources (freeways and major roads) reported a significant decrease of particle concentrations with increasing distance from the road (e.g. Weijers et al., 2004; Zhu et al., 2006). To study the decay of TNC between near-road and residential area measurement points particle concentrations along horizontal transects were extracted from the data set for further analysis in Section 4.3 of this paper (cf. Fig. 1).

3.2.2. Sodar data

Due to noise exposure of residents the Sodar had to be operated with limited sound power. Data availability at measurement heights $z > 250$ m agl was therefore constricted. In this study only data from height levels $30 < z < 200$ m agl will be presented.

4. Results and discussion

4.1. Meteorological situation during the study period

The synoptic situation during the study period was characterised by high pressure centred over Fennoscandia (High Fennoscandia, DWD, 2008). During mostly non-overcast conditions noon maximum values of shortwave downward radiation within the street canyon B224 reached 700–800 W m^{-2} while noon air temperatures were between 28 and 30 °C (data not shown here). On the second measurement day, 29 July 2008, a frontal passage was affecting the study area. Air temperatures and radiation were lower, after measurement No. 5 some precipitation occurred. Wind directions which were mainly from easterly and southerly directions during the study period turned to south/south-westerly directions on 29 July, 2008 (Fig. 2, Table 1). Higher turbulent mixing in the urban canopy layer as demonstrated by a maximum in the standard deviation of vertical wind speed σ_w in comparison to the other measurement days was likely affecting the distribution of canopy layer pollutant concentrations (Fig. 3 top). This will be discussed in more detail in Section 4.4.

4.2. Spatio-temporal variation of particle number concentration and noise

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 (Fig. 4). Distinct morning rush-hour peaks of particle number caused by the combination of the 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; Ketzel et al., 2004; Kumar et al., 2008; Morawska et al., 2008). Afterwards, in consequence of a growing atmospheric mixing layer and decline in number of passing vehicles, TNC

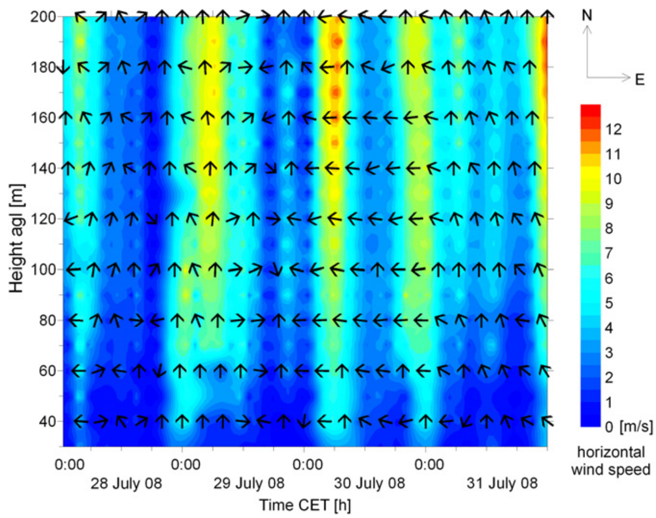

Fig. 2. Horizontal wind speed (contour shading) and wind direction (arrows) within the boundary layer as evaluated by Sodar measurements at a rural site in Essen, Germany during the study period from July 28 to July 31, 2008. Wind speed was averaged from 30 min values while the wind direction is depicted a 4 h intervals for different height levels.

concentrations decrease to about 13,000 cm^{-3} at noon. The afternoon rush-hour though indicated in traffic intensity is not clearly identifiable by a peak on the diurnal course. Due to the near-traffic measurement aerosol number size distributions peak at sizes

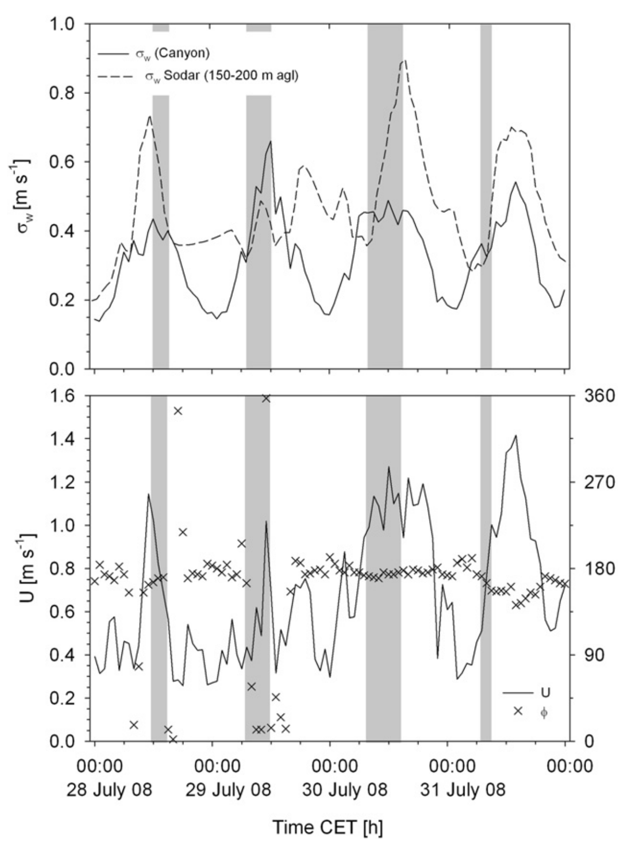

Fig. 3. Standard deviation of vertical wind speed σ_w from the sonic at 3.75 m agl in the canyon and from Sodar measurements at the rural site (top) and mean wind speed and wind direction at 3.75 m agl in the canyon (bottom). The Sodar σ_w represents a layer average of height levels between 150 m and 200 m agl. Grey shadings indicate the time periods of mobile measurements.

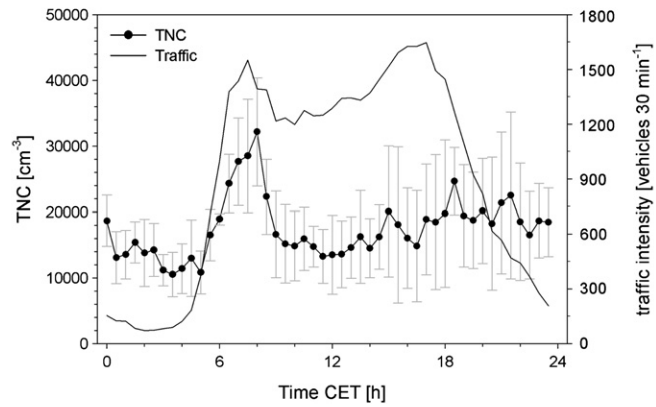

Fig. 4. Average diurnal course of TNC (circles) and traffic intensity (solid line) from the container site for the study period from 28 to 31 July, 2008. The vertical error bars indicate standard deviations.

$<$30 nm (Fig. 5, Table 2). This is indicative for fresh nucleation mode particles from road traffic tailpipe emissions (Morawska et al., 2008). Although absolute concentrations of TNC and the characteristics of the size distributions (e.g. mean and median diameter) are slightly changing between the measurement days, the overall shape of the size distributions are similar during the course of the study period (Fig. 5).

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 (Table 3). However, the 20 s maximum TNC along the measurement route can reach concentrations of more than 100,000 cm^{-3} (Table 3). 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 $0.02 < D_p < 1$ 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).

When comparing the 12 measurements conducted in Essen a range of about 17,000 cm^{-3} (range of median = 12,000 cm^{-3}) is

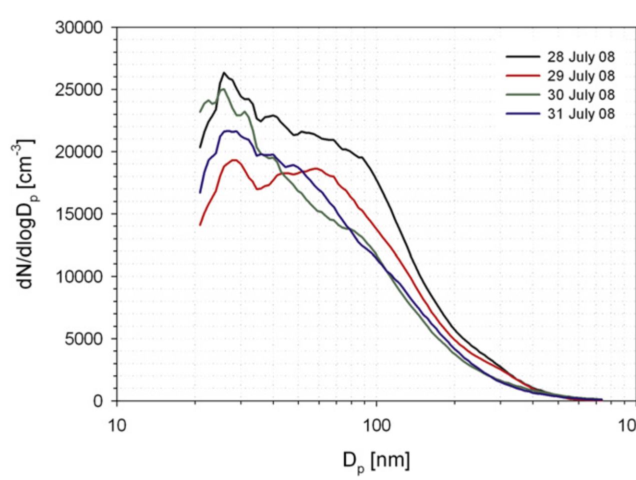

Fig. 5. Daily average aerosol number size distribution from the container site for the study period from 28 to 31 July 2008.

Table 2
Daily average statistics for aerosol number size distributions measured within the street canyon.

Day	TNC (±std dev) [cm^{-3}]	Median TNC [cm^{-3}]	Mean D_p [nm]	Median D_p [nm]	Mode D_p [nm]
28 July 08	19,876 (±7416)	18,023	75	53	26
29 July 08	15,867 (±7015)	14,890	78	55	28
30 July 08	15,897 (±6601)	15,151	69	46	26
31 July 08	15,518 (±7302)	12,454	70	50	27

covered. The significant difference between median and average values indicates the degree of spatial variability of number concentrations between and within measurements.

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 (Ministry of Economics of Baden-Württemberg, 2007) the estimated range of 5.3 dB corresponds to approximately one-third of a doubling of loudness on the logarithmic dB-scale. 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. 6). The values at every single MP in the vicinity of the major road (MP 15, 21, 25, 29, 49, 50, cf. Fig. 1) as well as the contiguous MP along the street canyon (MP 33–43) are considerably elevated above those located at some distance to B224. The classified average number concentrations (Fig. 7) of MP situated at some distance to B224 fall within the lowest concentration class (12,000–19,000 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 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 (Fig. 8). 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 (Table 3). Except measurement day 2 (29 July 2008) significant positive correlations between TNC and noise are demonstrated by Pearson and 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.

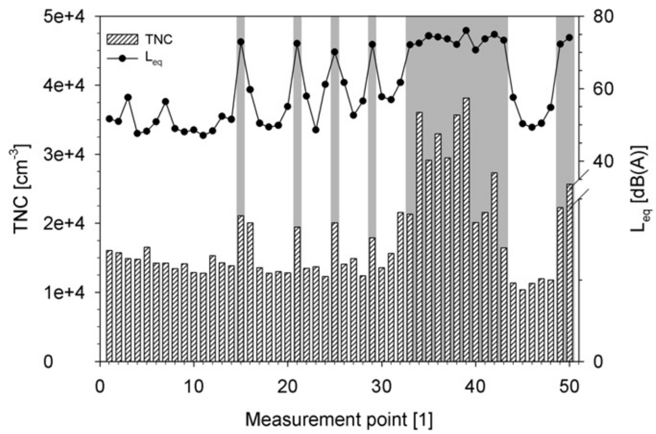

Fig. 6. Median TNC and L_{eq} at the 50 measurement points along the route. Grey shadings indicate the points that are situated in close proximity to road traffic on B224.

The non-significant correlation coefficients on 29 July 2008 are attributed to increased turbulent mixing on that day and will be referred to in more detail in Section 4.4.

4.3. *Decay of particles and noise at some distance from the street canyon*

As has been stated earlier a clear difference between large number concentrations in the vicinity of B224 and those at some distance to the road is apparent. A significant decay of particle concentrations with increasing distance from the source has also been reported by others (e.g. Hitchins et al., 2000; Weijers et al., 2004; Zhu et al., 2006; Kaur et al., 2006).

At all transects T1–T4 (Fig. 1) particle number concentrations rapidly decrease with increasing distance from the road. Assuming a linear concentration gradient the decline in number concentrations from the MP in proximity to traffic on B224 results in 433 cm^{-3} m^{-1} at T1, 170 cm^{-3} m^{-1} at T2, 403 cm^{-3} m^{-1} at T3 and 179 cm^{-3} m^{-1} at T4. At transects T1–T3 a 50% decrease of TNC relative to the concentration at the near-road MP can be observed at the second MP at a distance of about 50 m off B224 (Fig. 9). This corresponds to an average 8.5% drop in ultrafine particles per 10 m distance from major roads as reported in Hagler et al.

Table 3
Average and median values of TNC and L $_{eq}$ for the 12 measurements based on the 20 s measurements at 50 MP. Pearson and Spearman R denote correlation and rank-correlation coefficients for TNC vs. L_{eq} respectively. In case of Pearson correlation log(TNC) vs. L_{eq} was used.

Meas.	TNC [# cm^{-3}]			L_{eq} [dB(A)]			Pearson	Spearman *R*
	Average	Median	Max.	Average	Median	Max.		
1	15,902	10,549	63,568	70.6	57.3	85.7	0.64	0.57
2	18,511	11,798	62,026	72.3	58.9	86.1	0.72	0.69
3	22,953	18,823	60,976	69.4	58.0	90.4	0.14#	0.28#
4	20,773	16,964	48,952	70.3	58.5	80.5	0.52	0.54
5	17,393	18,101	30,423	68.7	60.6	77.9	−0.18#	−0.21#
6	15,724	9714	78,670	69.2	56.4	77.1	0.59	0.28
7	12,459	8574	53,963	69.5	59.3	79.2	0.71	0.73
8	15,240	11,809	63,785	68.9	56.1	79.3	0.59	0.40
9	19,878	16,362	56,596	73.1	59.8	84.1	0.41	0.30
10	21,899	20,402	52,637	67.8	59.5	76.4	0.53	0.52
11	29,479	19,512	110,648	69.9	55.1	79.2	0.73	0.64
12	21,401	14,212	79,341	70.1	57.5	80.1	0.81	0.74

#Not significant for $p < 0.05$.

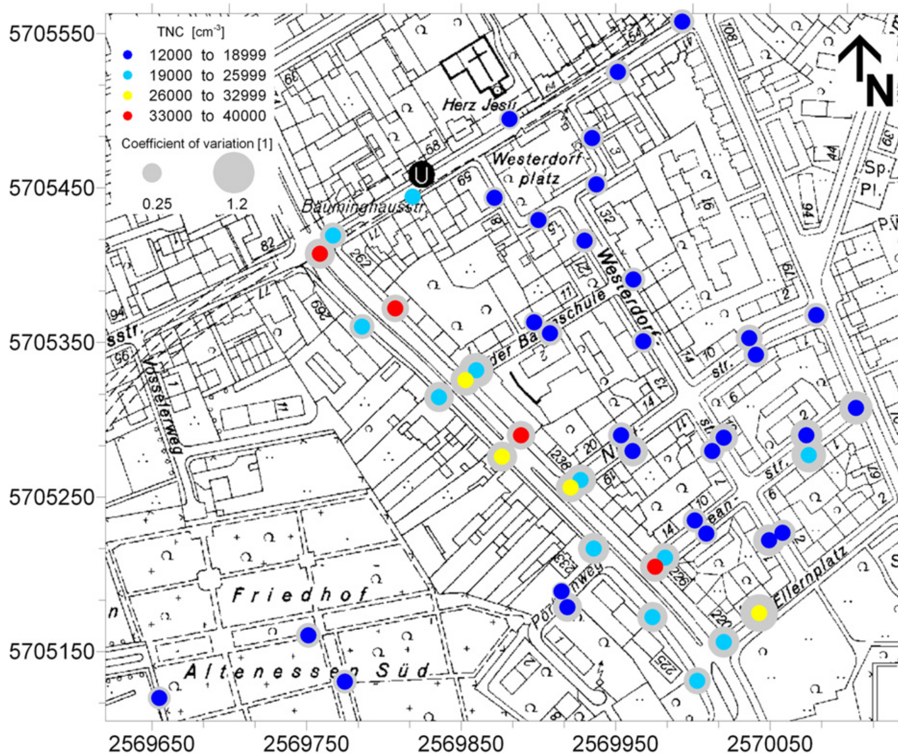

Fig. 7. Spatial distribution of TNC in the study area binned into different concentration classes.

(2009). At transects T2, T3, and T4 the decay of concentration with increasing distance to the road can be best-fitted by functions of exponential decay (Fig. 9). This behaviour was observed in a number of studies (e.g. Weijers et al., 2004; Zhu et al., 2006; Morawska et al., 2008; Hagler et al., 2009). The exponential-decay function does not give plausible results at T1 due to an unknown concentration increase of TNC at some distance to the road (cf. Fig. 9).

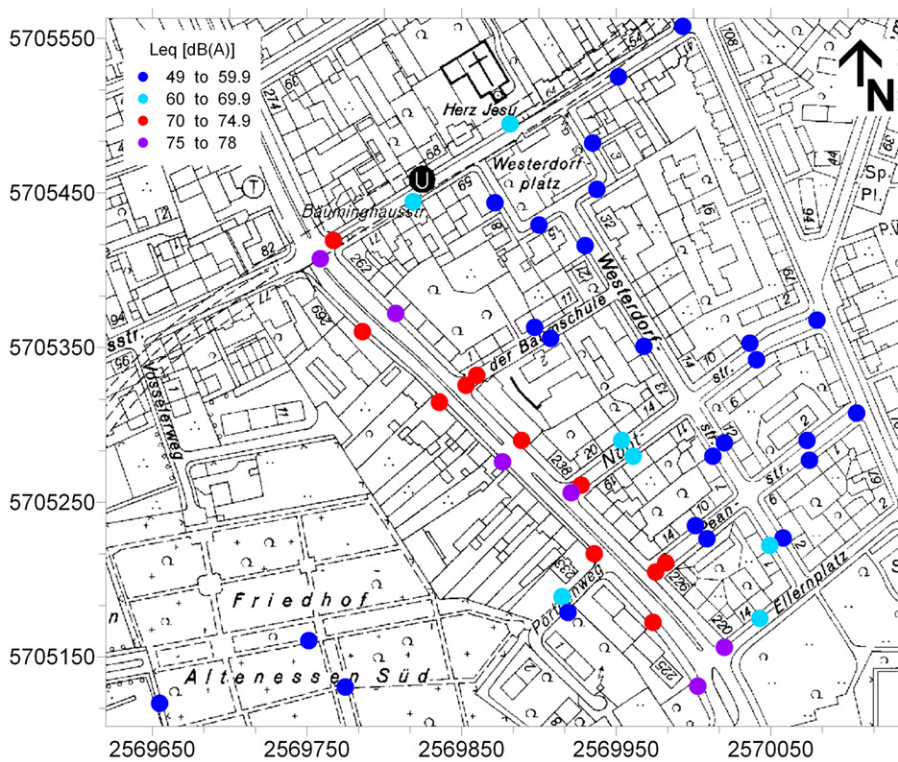

Fig. 8. Spatial distribution of L_{eq} in the study area binned into different noise level classes.

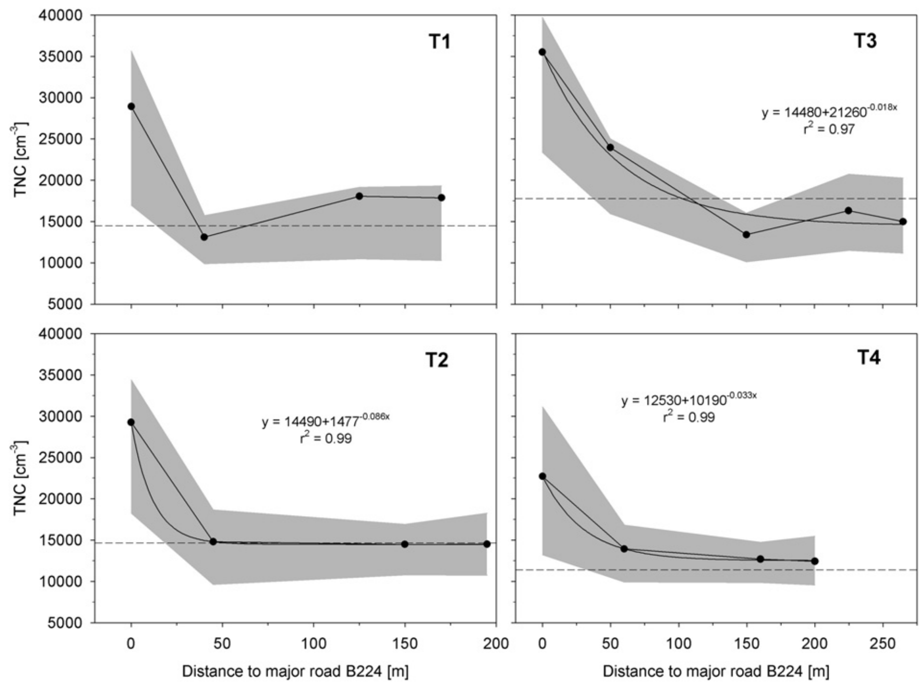

Fig. 9. Decay of TNC with increasing distance to major road B224 along transects T1–T4. Then grey shadings indicate the inter-quartile range between the 25th and 75th percentile. The dashed horizontal line indicates 50% of TNC in relation to the initial near-road measurement.

4.4. Influence of micrometeorology

The present research indicates a positive spatio-temporal correlation of particles and noise in 10 out of 12 measurements. However, during the third and fifth mobile measurement on 29 July 2008 (Table 3) correlation was low and statistically non-significant. The data was checked for any inconsistencies, but no unreliable data was found. The reason for this behaviour is believed to be attributed to the characteristics of the atmospheric boundary layer on that day. Wind directions were changing from south to south-west (Table 1, Fig. 2). While atmospheric boundary layer mixing in the 150–200 m agl level as evaluated by Sodar measurements was weaker in comparison to the other days of the study period (cf. Fig. 3 top) turbulent mixing within the urban canopy layer reached a maximum during the measurement period on that day (Fig. 3 bottom, Table 1). Turbulence intensity σ_w/U within the canyon was about a factor 2 in comparison to the other days of the campaign (Table 1). However, both TNC and L_{eq} were not considerably lower or higher in comparison to the other measurements (Table 1). Also the time period of measurement (07–12 CET) was comparable to the other days.

In earlier measurements it was shown that the canyon circulation (e.g. vortex-circulation within street canyons) has distinct influence on the distribution and dispersion of pollutants (Weber et al., 2006; Weber and Weber, 2008). At the study site a vortex circulation under flow being perpendicular to the street canyon axis was observed (Weber et al., 2006), while under flow being directed at some angle to the canyon axis helical vortex circulations are indicated in literature (e.g. Kastner-Klein et al., 2004). Under easterly wind directions on measurement days 1, 3 and 4 wind directions in the canyon were from 180° indicating some deflection from the opposite wall of the canyon (Fig. 3 bottom). On measurement day 2 with south-westerly wind directions the canyon flow is from north/north-easterly directions indicating a vortex circulation. We believe the different circulation regimes and the maximum in turbulent mixing on measurement day 2 to be responsible for the different picture in the spatio-temporal covariation of noise and TNC. It is known that stronger mixing leads to enhanced dilution of ultrafine particles (Ruuskanen et al., 2001; Harrison and Jones, 2005). This would lessen the effect of road emissions on the near-road MP in comparison to the other measurement days by 'decoupling' induced by turbulent mixing. This is supported by correlation matrices calculated for L_{eq} and TNC from all 12 measurements (data not shown here). The spatial distribution of L_{eq} is similar during all 12 measurements on four consecutive days with rank-correlation coefficients >0.62 indicating the distribution of noise to be somewhat robust across the study area (cf. Weber and Litschke, 2008). However, correlation for TNC is smaller with rank-correlation coefficients varying between $0.18 < r < 0.70$. This supports the concept that meteorology has a significant impact on particles but little influence on ambient noise.

Despite the modifying influence of micrometeorology the spatio-temporal distribution of L_{eq} and TNC in the fourth mobile measurement on 29 July 2008 was similar to the other measurements; this picture is not fully understood. A long-term campaign of noise and particle number concentration measurements at multiple sites within the urban environment would be helpful to get better insight into the distribution of both quantities under different weather regimes.

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 per day was situated within the study area. The spatio-temporal distribution of noise and particles was closely coupled to road traffic emissions. Number concentrations and sound levels at measurement points in proximity to the road were significantly elevated above the urban residential background. In 10 out of 12 measurements a close correlation between TNC and L_{eq} was found. However, during measurement day 2 which was characterised by higher turbulent mixing and a change in wind directions the spatio-temporal coupling between TNC and L_{eq} was weak. We believe stronger dilution of particles by turbulent mixing and 'decoupling' from the influence of road traffic to be responsible for this picture. A correlation analysis showed the similar spatial distribution of ambient noise even between measurements on different days while particle number concentrations are more prone to changes introduced by micrometeorology.

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.

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