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Short communication

Variation of particle concentrations and environmental noise on the urban neighbourhood scale

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ABSTRACT

Particulate air pollution and environmental noise received increased attention within the environmental health community during recent years due to their potential impacts on human health. In this study the spatio-temporal variation of noise and particles was estimated by a short set of mobile measurements within an urban neighbourhood in Essen, Germany. Particle concentrations (PM_1 and $PM_{coarse} = PM_{10} - PM_1$) were measured by an optical particle counter continuously along the measurement route while environmental noise was measured at fixed points on the same route. Additionally, wind and turbulence parameters were gathered above rooftop height and within an urban street canyon.

The spatial distribution of noise was very homogeneous while the distribution of particle concentrations turned out to be rather inhomogeneous. The spatial correlation between noise and particles was found to be poor for PM_{coarse} during all measurements. However, for PM_1 and noise a moderate positive correlation ($r \sim 0.5$) emerged under conditions of weak turbulent atmospheric mixing. The spatio-temporal covariation between particles and noise is believed to be more evident for ultrafine (<100 nm) particles.

1. Introduction

People living in urban areas are exposed to a complex mixture of environmental pollutants. Due to the heterogeneous spatial distribution of emission sources, different source types, complex urban geometry and differences in meteorology the people's exposure towards pollutants is characterised by a significant spatio-temporal variability.

In order to study the variation of urban pollutants with a high spatio-temporal resolution mobile measurements were conducted across different spatial scales recently. These mobile investigations have focussed on gaseous and particulate pollutants (e.g. Bukowiecki et al., 2002; Pirjola et al., 2004; Weijers et al., 2004; Kolb et al., 2004; Tang and Wang, 2006) or environmental noise (Tang and Wang, 2007). These measurements were performed on the urban scale, the neighbourhood scale and within street canyons. The results demonstrated the mobile measurement technique to be a powerful method to map urban pollutant concentrations and to assess main factors influencing variation of pollutants on the different spatial scales.

Particulate air pollutants and environmental noise received increased attention during recent years due to their relevance to human health (Klaeboe et al., 2000; Tobias et al., 2001; Lusk et al., 2004; Babisch et al., 2005; Pope and Dockery, 2006; Muzet, 2007). Based on single spot measurements in two Italian cities a close relation between carbon monoxide concentrations and traffic noise was stated experimentally (Tirabassi et al., 1998; Tirabassi, 1999). This is related due to the emission of both stressors from the same source, motorised traffic in urban areas. However, the variation of both quantities within both cities was not taken into account.

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Here we try to investigate the spatial variability of both noise and particle concentrations by a short set of mobile measurements on the urban neighbourhood scale. The data was also analysed for influence of meteorological conditions on the distribution of noise and particles.

2. Study area

Measurements were performed within a busy urban street canyon (average daily traffic (ADT) = 49,000 vehicles 24 h^{-1}) and its surrounding neighbourhood in Essen, Germany. The study area covers about 20 ha. The street canyon 'Gladbecker Straße' (federal highway B224) is a hot-spot of particulate air pollution in Essen with yearly average concentrations of about 36 $\mu g\,m^{-3}$ PM_{10} in 2005 and 2006. 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. Further details on the street canyon and its geometry can be found in Weber et al. (2006).

The surrounding neighbourhood is characterised by residential houses generally comprised of 4–5 floors. ADT data is estimated by the city authorities to be less than 1000 vehicles 24 h^{-1}. Manual short-term traffic counts during the field campaign yielded traffic amounts of around 1% the vehicle number at B224.

The 3.5 km mobile measurement route was subdivided into 45 similar subsections (SU) along which spatial averages of particle concentrations and fixed-point measurements of noise and meteorology were gathered in the centre of each section (see Section 3.2 for details). Besides the western area of the route (urban park) the measurements were conducted within street canyons to the NE of B224.

3. Material and methods

3.1. Instrumentation

Particle concentrations were measured by optical particle counters (OPC_{Can}, Grimm Aerosol, Model 1.107, Germany) which offer a sufficient temporal resolution for mobile applications (measurements every 6 s). At B224 the OPC was installed within a container at a height of 3.4 m above ground level (agl). OPC measures particle size distributions in the range $0.3 < D_p < 32\,\mu m$ by a light scattering technique (see Weber and Weber, 2008; Weber et al., 2006 for details of the OPC). Size distributions are converted into particle mass by the instruments software assuming constant densities for different size ranges. A comparison with on-site TEOM readings performed by the North-Rhine Westphalia State Environment Agency (LANUV NRW, comparison period 24 March–14 June 2007) showed an underestimation of average 24 h TEOM PM_{10} concentrations by 20% on average ($r^2 = 0.85$).

At the container a sonic anemometer (Metek USA-1, Germany) was installed at a height of 3.75 m agl to measure horizontal wind speed u_{Can} and turbulence parameters.

The same OPC model was installed at a height of 1.1 m agl on a trolley for mobile measurements (OPC_{Mob}). Particle concentrations were measured continuously while walking along the measurement route with a speed of about 1 m s^{-1}. During two consecutive days (13 and 14 June 2007; labelled day 1 and 2 hereafter) nine repeated mobile measurements of approximately 75 min duration were conducted in the time period from 11.00 to 16.30 CET on day 1 and 06.00 to 13.30 CET on day 2 covering a data-set of $n = 405$ measurement points in total.

Additional wind data above the urban canopy layer (UCL) was measured at a rooftop at 35 m agl by a sonic anemometer (Metek USA-1, Germany). This measurement gives a good estimation of the undisturbed wind above roof level (Weber et al., 2006).

Environmental noise was measured by a handheld noise level meter (Mod. Norsonic 118, Norsonic, Norway). At every SU we measured a time-averaged sound power level over a period of 15 s. The averaged equivalent sound power level (L_{eq}) was A-weighted by the instrument software and stored for post-processing. The noise meter was calibrated prior to each measurement.

3.2. Data handling

During post-processing OPC_{Mob} data was quality checked and averaged into 45 SU. Spatial averages of particle data were calculated for a coarse ($PM_{coarse} = PM_{10} - PM_1$) and a fine size fraction (PM_1). The mobile data was corrected for any 'time-trend' in urban background particulate matter during the measurements. Hence, OPC_{Can} data was first smoothed by a locally weighted least square regression approach (Cleveland, 1981). Afterwards the 'time-trend' during beginning and end of the mobile measurement was subtracted from OPC_{Mob}. Generally, this procedure had larger impact on the coarse fraction which exhibits a higher degree of time variation in comparison to PM_1. Corrected values deviated from raw data by on average 15% for PM_1 and 26% for PM_{coarse}.

4. Results and discussion

4.1. Meteorological conditions during the measurement period

Both measurement days were characterised by distinct differences in meteorological conditions (Table 1, Fig. 1).

Table 1
Daily averages of different meteorological quantities during day 1 and 2 (daily sum for precipitation, standard deviation in brackets)

Quantity	Day 1	Day 2
$u_{rooftop}$ [m s^{-1}]	3.11 (±0.84) *3.32 (±0.54)*	1.81 (±0.95) *1.96 (±0.66)*
$\phi_{rooftop}$ [°]	234 (±21) *225 (±45)*	123 (±51) *141 (±52)*
P [mm]	0 0	9.4 0
PM_{10} [$\mu g\,m^{-3}$]	50.6 (±23.3) *30.26 (±9.7)*	35.9 (±19.6) *36.59 (±22.3)*
PM_1 [$\mu g\,m^{-3}$]	33.7 (±19.0) *16.97 (±7.8)*	22.4 (±16.4) *21.08 (±17.7)*

Data for u, ϕ 35 m agl is from the rooftop sonic while the other data were measured at the container installed at B224. The values in italics indicate the averages during the measurement periods from 11 to 16.30 CET on day 1 and from 06.00 to 13.30 CET on day 2.

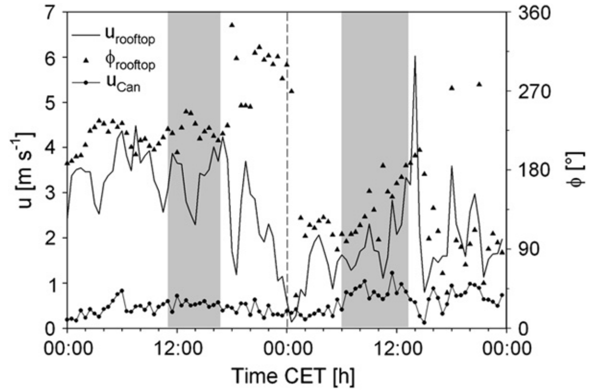

Fig. 1. Time series of different meteorological quantities on 13 and 14 June 2007. The grey shadings indicate time periods of mobile measurements.

While day 1 was characterised by higher average rooftop wind speeds from SW, day 2 showed weaker wind speeds blowing from south-easterly directions. On day 2 a frontal passage with precipitation was observed in the afternoon (Table 1). However, during both periods of mobile measurements no precipitation occurred.

Average particle concentrations of OPC_{Can} were higher during the measurement period on day 2 (Table 1), mainly due to higher background aerosol and a larger percentage of stably stratified situations covered during the morning hours on day 2.

4.2. Temporal and spatial variability of particles and noise

During the nine mobile measurements spatial variation of L_{eq} across the study area amounted to about 32 dB(A) while particle concentrations varied between 14 $\mu g\, m^{-3}$ (PM_{coarse}) and 9 $\mu g\, m^{-3}$ (PM_1), respectively (Fig. 2). However, the relative variation of noise is evenly distributed when comparing the nine mobile measurements. This is indicated by a nearly constant coefficient of variation (CV) of about $CV = 0.14 \pm 0.02$, calculated as the ratio of standard deviation divided by the arithmetic mean of the

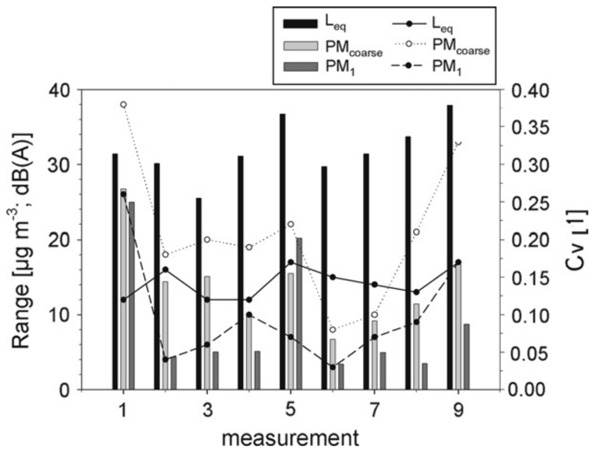

Fig. 2. Ranges (vertical bars) and coefficients of variation (CV, line plots) for L_{eq}, PM_{coarse} and PM_1 during nine mobile measurements on 13 and 14 June 2007.

45 SU. Relative variation of particles is on average larger for PM_{coarse} ($CV = 0.21 \pm 0.1$) but smaller for PM_1 ($CV = 0.1 \pm 0.07$). However, both particle fractions exhibit large temporal variation when comparing the nine measurements (Fig. 2).

Independent of meteorological conditions and time of day environmental noise appears to have a very consistent spatial distribution (Fig. 3). The maximum average noise levels of about 70–75 dB (A) are associated to the immediate vicinity of B224, while side streets are characterised by noise levels between 50 and 60 dB(A). This indicates traffic to be the major source of noise in the study area. Contrarily, average particle concentrations PM_{coarse} and PM_1 did not show a consistent picture in terms of spatial distribution within the study area (data not shown here). Both coarse and fine particles were unevenly distributed within the study area. While coarse particles were spatially not related to the major road on the short time scale, fine particles were shown to be related during specific meteorological circumstances (see Section 4.3).

On longer time scales canyon geometry (e.g. vortex circulation during wind perpendicular to the canyon) can have significant impact on pollutant concentrations within street canyons (e.g. Boddy et al., 2005). To look into any influence imposed by canyon geometry and wind flow within the UCL data was checked for significant spatial differences between day 1 and 2. Due to the change in wind direction between day 1 and 2 some effects of wind flow along and perpendicular to the canyon might be possible. Canyon geometry was taken into account based on the street being orientated along or perpendicular to the mean wind direction. Data analysis did not reveal any clear relationship between canyon geometry and particulate matter. However, this conclusion might change when looking into data from a larger number of measurements. This is subject to ongoing research.

Correlation between L_{eq} and particle concentrations is generally weak. Especially for the coarse fraction the relationship is statistically not significant (Table 2). There is slightly enhanced relationship between PM_1 and noise. On day 2 correlation coefficients r are between $0.31 < r < 0.53$ demonstrating a moderate positive correlation. Since L_{eq} is spatially fixed to the main source of noise emission, traffic on B224, the correlation between PM and L_{eq} enhances as soon as PM_1 represents the L_{eq} distribution.

4.3. Influence of meteorology

Enhanced relationship between PM_1 and noise on day 2 is believed to be coupled to the state of turbulent mixing within the UCL. Canopy layer wind speeds were slightly elevated during mobile measurements on day 2 with an average of 0.8 $m\, s^{-1}$ in comparison to 0.5 $m\, s^{-1}$ on day 1 (Fig. 1). However, the dispersion of particles was limited due to the decrease in turbulent mixing (Fig. 4). In comparison to day 1 σ_w was considerably lower during measurements 5–8 on day 2 (Fig. 4). However, it increased during the afternoon due to the frontal passage as described in Section 4.1.

In a previous paper submicrometer particles were demonstrated to be negatively correlated to turbulent

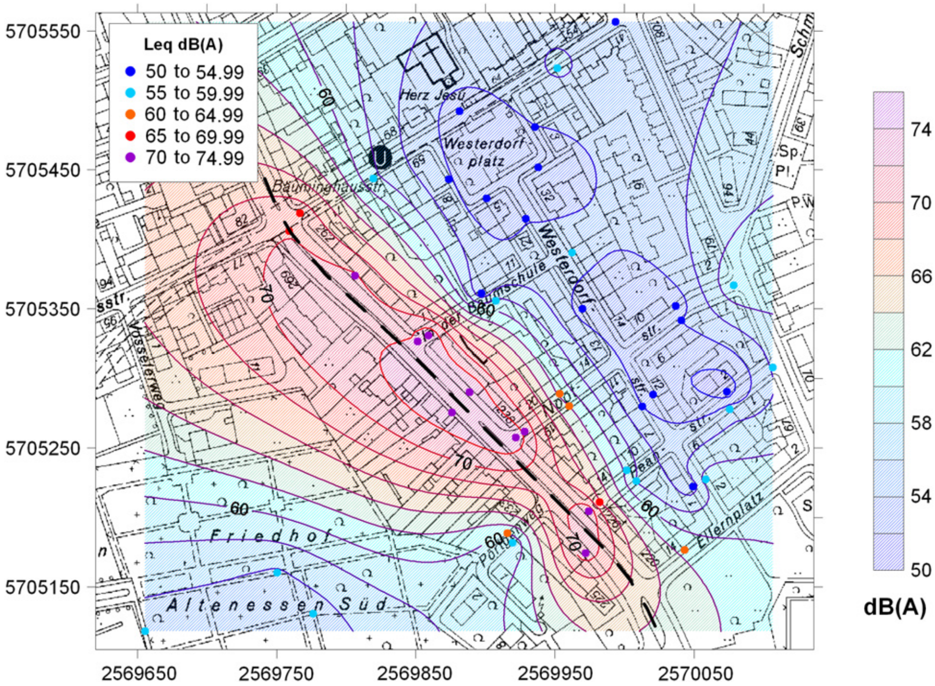

Fig. 3. Average spatial distribution of environmental noise L_{eq} during nine mobile measurements on 13 and 14 June 2007. Circles mark spot measurements of L_{eq}, isopleths indicate interpolated noise levels L_{eq} according to a kriging interpolation approach. The different symbols indicate the locations at which spot measurements of L_{eq} were performed. B224 is sketched by the thick dashed line.

mixing within a street canyon (Weber et al., 2006). Therefore higher mixing tends to disperse particles more significantly and blurs spatial differences across a study area, e.g. concentration differences between major and side roads.

5. Summary and conclusions

Mobile measurements of noise and particle concentrations were carried out within an urban study area. The distribution of noise was shown to be spatially very consistent and ‘fixed’ to the main source of environmental noise (traffic) on a major road. However, particle concentrations were spatially very inhomogeneous. On the short time scale the distribution of particle concentrations was not notably related to either canyon geometry or meteorological conditions. The correlation between noise and PM_1 tended to be moderate ($r \sim 0.5$) only for situations of weak turbulent mixing and limited dispersion.

For health related research no direct information of possible confounding effects of noise due to spatio-temporal covariation with particles could be deduced. However, a future campaign is planned to study the spatial distribution of ultrafine particles <100 nm on the local urban scale for a longer period. Ultrafine particles are not only related to adverse health effects, but also high emissions are directly related to road traffic. The covariation between particles and noise is likely to increase when measuring ultrafine particle sizes.

Table 2
Correlation coefficients for L_{eq} vs. PM_1 and PM_{coarse} for nine measurements on day 1 and 2

Measurement		L_{eq} vs. PM_1	L_{eq} vs. PM_{coarse}
Day 1	11.00–12.15	0.37	0.34
	12.30–13.45	0.06*	0.01*
	14.00–15.15	0.23	−0.18
	15.30–16.45	0.03*	−0.19*
Day 2	06.00–07.15	0.47	0.01*
	07.30–08.45	0.31	0.21*
	09.00–10.15	0.52	0.25*
	10.45–12.00	0.53	0.02*
	12.15–13.30	0.14*	0.10*

*Not significant at the $p = 0.05$ level.

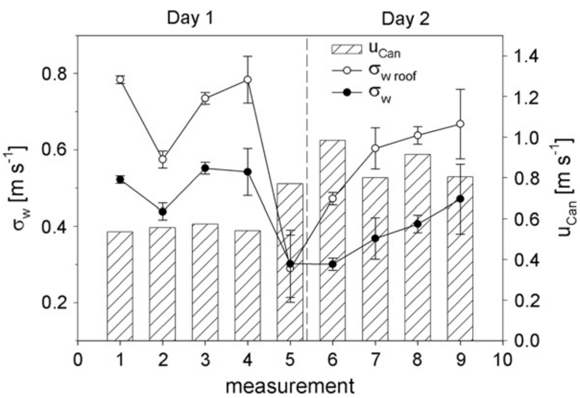

Fig. 4. Standard deviation of vertical wind speed measured at rooftop ($\sigma_{w\ roof}$, 35 m agl, open circles) and within the street canyon (σ_w, 3.75 m agl, black circles). Bars indicate the ratio between horizontal wind speed in the canyon (3.75 m agl) and at rooftop height (35 m agl).

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References

Babisch, W., Beule, B., Schust, M., Kersten, N., Ising, H., 2005. Traffic noise and risk of myocardial infarction. Epidemiology 16, 33–40.
Boddy, J.W.D., Smalley, R.J., Dixon, N.S., Tate, J.E., Tomlin, A.S., 2005. The spatial variability in concentrations of a traffic-related pollutant in two street canyons in York, UK – part I: the influence of background winds. Atmospheric Environment 39, 3147–3161.
Bukowiecki, N., et al., 2002. A mobile pollutant measurement laboratory-measuring gas phase and aerosol ambient concentrations with high spatial and temporal resolution. Atmospheric Environment 36, 5569–5579.
Cleveland, W.S., 1981. LOWESS: a program for smoothing scatterplots by robust locally weighted regression. The American Statistician 35, 54.
Klaeboe, R., Kolbenstvedt, M., Clench-Aas, J., Bartonova, A., 2000. Oslo traffic study – part 1: an integrated approach to assess the combined effects of noise and air pollution on annoyance. Atmospheric Environment 34, 4727–4736.
Kolb, C.E., et al., 2004. Mobile laboratory with rapid response instruments for real-time measurements of urban and regional trace gas and particulate distributions and emission source characteristics. Environmental Science and Technology 38, 5694–5703.
Lusk, S.L., Hagerty, B.M., Gillespie, B., Ziemba, R.A., 2004. Acute effects of noise on blood pressure and heart rate. Archives of Environmental Health 59, 392–399.
Muzet, A., 2007. Environmental noise, sleep and health. Sleep Medicine Reviews 11, 135–142.
Pirjola, L., et al., 2004. "Sniffer" – a novel tool for chasing vehicles and measuring traffic pollutants. Atmospheric Environment 38, 3625–3635.
Pope, C.A., Dockery, D.W., 2006. Health effects of fine particulate air pollution: lines that connect. Journal of the Air and Waste Management Association 56, 709–742.
Tang, U.W., Wang, Z.S., 2006. Determining gaseous emission factors and drivers's particle exposures during traffic congestion by vehicle-following measurement techniques. Journal of the Air and Waste Management Association 56, 1532–1539.
Tang, U.W., Wang, Z.S., 2007. Influences of urban forms on traffic-induced noise and air pollution: results from a modelling system. Environmental Modelling and Software 22, 1750–1764.
Tirabassi, T., 1999. New directions: listening out for urban air pollution. Atmospheric Environment 33, 4219–4220.
Tirabassi, T., Fortezza, F., Bassanino, M., Lavecchia, C., 1998. Carbon monoxide concentrations evaluated by traffic noise data in urban areas. Il Nouvo Cimento 21, 149–159.
Tobias, A., Diaz, J., Saez, M., Carlos Alberdi, J., 2001. Use of Poisson regression and Box-Jenkins models to evaluate the short-term effects of environmental noise levels on daily emergency admissions in Madrid, Spain. European Journal of Epidemiology 17, 765–771.
Weber, S., Kuttler, W., Weber, K., 2006. Flow characteristics and particle mass and number concentration variability within a busy urban street canyon. Atmospheric Environment 40, 7565–7578.
Weber, S., Weber, K., 2008. Coupling of urban street canyon and backyard particle mass and number concentrations. Meteorologische Zeitschrift 17, 251–261.
Weijers, E.P., Khlystov, A.Y., Kos, G.P.A., Erisman, J.W., 2004. Variability of particulate matter concentrations along roads and motorways determined by a moving measurement unit. Atmospheric Environment 38, 2993–3002.