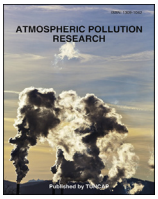
Atmospheric Pollution Research xxx (2016) 1–8

HOSTED BY

Contents lists available at ScienceDirect

Atmospheric Pollution Research

journal homepage: http://www.journals.elsevier.com/locate/apr



Original Article

# Using ambient noise measurements to model urban particle number size distributions at a traffic site

Janko Löbig [a, b, 1], Stephan Weber [a, *]

[a] *Climatology and Environmental Meteorology, Institute of Geoecology, Technische Universität Braunschweig, Langer Kamp 19c, 38106 Braunschweig, Germany*
[b] *GEO-NET Umweltconsulting GmbH, Große Pfahlstraße 5a, 30161 Hannover, Germany*

## ARTICLE INFO

*Article history:*
Received 1 June 2016
Received in revised form
19 October 2016
Accepted 21 October 2016
Available online xxx

*Keywords:*
Aerosol
Size distribution
Environmental noise
Noise frequency
Street canyon
Regression model

## ABSTRACT

Urban road traffic is a major joint emission source for particles and ambient noise. This study explores the relationship between both environmental stressors at an urban traffic site and analyses the potential to model particle number size distributions (NSD) from measurements of ambient noise frequency levels. Thus, a measurement campaign was conducted within an urban street canyon covering a period of 50 days. First, noise frequency levels were used to successfully model traffic intensity at the street canyon site on a half-hourly basis ($R^2 = 0.78$). Thereafter, two multiple linear regression models were built to calculate NSD using noise frequency levels in combination with meteorological quantities (wind speed and air temperature) and air pollutant data ($NO_2$) as explanatory variables. Implementation of meteorological quantities in Model 1 captured the diurnal variation of measured NSD. However, total particle number concentration (TNC) as derived from modelled NSD underestimated observed TNC. Implementation of $NO_2$ led to higher model performance for TNC ($R^2 = 0.57$) but not for particle NSD. Detailed information about urban background particle concentrations as a proxy for local conditions and about boundary layer conditions (e.g. atmospheric stability, mixing layer height) might help improving the model. The spatial characteristics of the site and their acoustical effects were not considered in the present approach (e.g. distance to road or buildings, road surface), hence, the results should be transferred to other sites with some caution.

## 1. Introduction

Epidemiologic studies indicate air pollution by particulate matter (PM) to negatively impact human health, e.g. triggering respiratory or cardiovascular diseases (Allen and Adar, 2011; Araujo, 2011). Health risks from PM exposure are well understood (Pope et al., 2004; WHO, 2013), resulting in air quality standards in the European Union member states for $PM_{10}$ (mass concentration of particles with aerodynamic diameter $< 10$ µm) and $PM_{2.5}$ ($<2.5$ µm) (Directive 2008/50/EC; European Union, 2008). However, there is growing evidence that the number of small particles, i.e. ultrafine particles (UFP; diameter $D_P < 0.1$ µm), is strongly associated with effects on human health (Breitner et al., 2011; Perez et al., 2009; Stölzel et al., 2007). This is due to the size-dependent respiratory tract deposition probability of particles which shows a U-shaped relationship with minimum deposition probability for $D_P \approx 200–300$ nm and highest deposition probabilities for $D_P < 10$ nm and $2$ µm $< D_P < 10$ µm, respectively (based on the International Commission on Radiological Protection deposition model; ICRP, 1994).

Ambient noise is another important urban environmental stressor which is reported to cause annoyance, sleep disturbance and to trigger the release of stress hormones (Ising and Kruppa, 2004; WHO, 2011). In addition, chronic noise disturbance can produce physiological stress symptoms (Babisch et al., 2005; Gan et al., 2012). In urban areas, road traffic is a major joint emission source of particles and noise (Allen and Adar, 2011; Liu et al., 2014; Pey et al., 2009; Weber, 2009). Several studies address possible confounding effects between traffic noise and air pollution (Allen and Adar, 2011; Gan et al., 2012; Klæboe et al., 2000).

---

[*] Corresponding author. Fax: +49 (0)531 391 5617.
*E-mail addresses:* j.loebig@tu-bs.de, loebig@geo-net.de (J. Löbig), s.weber@tu-bs.de (S. Weber).

Peer review under responsibility of Turkish National Committee for Air Pollution Research and Control.

[1] Fax: +49 (0)511 3887201.

http://dx.doi.org/10.1016/j.apr.2016.10.008

Please cite this article in press as: Löbig, J., Weber, S., Using ambient noise measurements to model urban particle number size distributions at a traffic site, Atmospheric Pollution Research (2016), http://dx.doi.org/10.1016/j.apr.2016.10.008

Road traffic mainly emits particles in the UFP-size range, i.e. diesel-powered vehicles predominantly in the range 20 nm < $D_P$ < 130 nm and petrol-powered vehicles between 20 nm < $D_P$ < 60 nm (Kumar et al., 2014; Morawska et al., 2008). Thus UFP, contributing only small amounts to urban $PM_{10}$ and $PM_{2.5}$ mass concentrations, accounts for the major part of total urban particle number concentration (TNC; Lonati et al., 2011; Morawska et al., 2008).

Particle number size distributions (NSD) can be used to infer different emission sources from measured concentrations and to convert the NSD into other particle and exposure metrics, i.e. volume or surface area (Liu et al., 2014; von Bismarck-Osten and Weber, 2014; Wegner et al., 2012). According to von Bismarck-Osten et al. (2013) specific particle size ranges can be classified into nucleation mode (NUC; $D_P$ < 30 nm), Aitken-mode (AIT; 30 nm ≤ $D_P$ < 100 nm) and accumulation mode (ACC; $D_P \geq$ 100 nm). At roadsides, particle NSD usually shows maxima in NUC and AIT, caused by two different types of emission (Wegner et al., 2012). Primary particles are emitted directly by the engine predominantly in the size range between 30 nm < $D_P$ < 500 nm (Morawska et al., 2008). Secondary particles generated from condensation of hot exhausts in the colder atmosphere are mainly in the range $D_P$ < 30 nm.

Road traffic noise results from engine noise and rolling noise, i.e. due to contact and friction between tire and street, and air pumping noise generation in tire grooves. Except during acceleration, engine noise is rather independent from traffic speed, while rolling noise increases with driving speed (Sandberg and Ejsmont, 2002). Hence, engine noise dominates at lower speeds and during acceleration and corresponds to low noise frequencies of about 100 Hz. Rolling noise prevails at higher speeds from approximately >30–45 km $h^{-1}$ for cars and >45–50 km $h^{-1}$ for heavy-duty vehicles. This corresponds to medium and high noise frequencies around 1 kHz (Can et al., 2011b; Dekoninck et al., 2013; Ouis, 2001; Sandberg and Ejsmont, 2002).

Different relationships between ambient noise and particles were reported from urban areas (Allen and Adar, 2011). While no significant correlation between noise and particle mass was observed (Shu et al., 2014; Weber and Litschke, 2008), there is evidence for correlation with particle number concentrations (Can et al., 2011b; Shu et al., 2014; Weber, 2009). These studies refer to the most common noise indicator $L_{Aeq}$, representing the average A-weighted equivalent continuous sound pressure level in a time period. Yet, there is a certain limit using $L_{Aeq}$ as it underestimates low frequencies due to the A-weighting (Can et al., 2011b; Ross et al., 2011). Several studies documented stronger correlation of traffic data (Can et al., 2011a) and air pollutants (Dekoninck et al., 2013; Ross et al., 2011) with specific noise frequency levels as they better reflect the local traffic situation (Can et al., 2011b). Recently, it was indicated that noise in comparison to traffic intensity is a more appropriate variable to describe the relationship with UFP (Morelli et al., 2015). Dekoninck et al. (2015) successfully applied their approach of estimating black carbon exposure using noise frequency levels to TNC. However, according to the authors' knowledge, studies that model particle NSD from measurements of ambient noise are not available, yet.

The aim of the present study is to model particle NSD by using noise frequency levels measured at a traffic site as explanatory variables in two different linear regression models.

## 2. Materials and methods

### 2.1. Study area

We took measurements from 2015-02-01 to 2015-05-15 at a busy street canyon site in the city of Braunschweig, Germany (52.26673° N, 10.54055° E). Within the street canyon, a measurement container of the Lower Saxony air quality monitoring agency (Lufthygienische Überwachung Niedersachsen; LÜN) was situated.

Instrumentation to measure ambient noise, particle NSD and equivalent black carbon concentrations (eBC) was placed on top of the container. We measured at 3.2 m above ground level (a.g.l.), particle and eBC concentrations at 3.4 m a.g.l., each 1.9 m off the street and 5.5 m off the closest building. Additional data on gaseous pollutant concentrations, meteorological quantities and road traffic data were measured at the LÜN container site.

The study site was a busy two by two-lane street canyon (height to width ratio = 0.5, average observed daily traffic intensity ≈ 52,000 vehicles), separated by a grass-covered centre strip with single trees. Traffic speed limit was 50 km $h^{-1}$. The street axis was directed NNW to SSE, the measuring container was located at the western kerbside. Up to ten buses from local public transport passed the measuring container per hour. The next bus stop was located about 150 m to the north of the site.

### 2.2. Instrumentation

Ambient noise was measured with 1 s time resolution by a sound level meter using a windscreen for outdoor measurements (Type 2250, Brüel & Kjær). Data were logged with the Enhanced Logging-Software for long time measurements (BZ7225, Brüel & Kjær). In addition to $L_{Aeq}$, the sound frequency spectrum $L_f$ was recorded by measuring the unweighted sound pressure level in 33 third-octave bands centred in the range 12.5 Hz–20 kHz (e.g. $L_{800\ Hz}$ the third-octave band centred around 800 Hz).

Particle NSD were measured with 1 min time resolution by the NanoScan scanning mobility particle sizer at a flow rate of 0.75 L $min^{-1}$ (TSI Inc., Model 3910). Particle NSD were estimated in eleven size bins over the range 11.5 nm ≤ $D_P$ ≤ 205.4 nm. The two larger size bins of NanoScan were not considered in this study ($D_P$ = 273.8 nm and 365.2 nm). TNC as defined in this study represents the sum of the particle number concentrations of each size bin, thus covering a size range of approximately 10 nm < $D_P$ < 240 nm. Particle concentrations were integrated over specific size ranges to define NUC, AIT and ACC (cf. Section 1).

Equivalent black carbon concentrations were measured using a mobile Aethalometer with 1 min time resolution and a flow rate of 50 mL $min^{-1}$ (microAeth® Model AE51, AethLabs). The Aethalometer estimates black carbon concentrations by measuring the rate of change in absorption of transmitted light (880 nm wavelength) due to continuous deposition of particles on a filter medium. When using an optical absorption method the measured concentrations could contain other absorbing material. Hence, Aethalometer mass concentrations readings are denoted eBC in this study as suggested by Bond et al. (2013). The filter was changed twice weekly. Both instruments, NanoScan and Aethalometer, were successfully applied in earlier studies to measure concentrations using a mobile approach on the local urban scale (Ghassoun et al., 2015; Ruths et al., 2014).

BELLIS GmbH, Braunschweig, provided traffic data with 30 min time resolution. All vehicles passing the measuring container in both driving directions were recorded using the TRAFFIC EYE Universal that detects number and speed of vehicles via passive infrared measurements (Siemens AG, Germany). Data were separated into different vehicle types: $Q_{AV}$, $Q_{LV}$ and $Q_{HV}$ define the number of all vehicles, light vehicles (such as cars or motorcycles) and heavy-duty vehicles (6 m length and above), respectively.

Meteorological quantities air temperature ($T_a$) and wind speed (WS) as well as nitrogen dioxide concentrations ($NO_2$) were provided by LÜN with 30 min time resolution.

Please cite this article in press as: Löbig, J., Weber, S., Using ambient noise measurements to model urban particle number size distributions at a traffic site, Atmospheric Pollution Research (2016), http://dx.doi.org/10.1016/j.apr.2016.10.008