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Methodology for setup and data processing of mobile air quality measurements to assess the spatial variability of concentrations in urban environments

Martine Van Poppel*, Jan Peters, Nico Bleux

VITO – Flemish Institute for Technological Research, Boeretang 200, 2400 Mol, Belgium

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ABSTRACT

A case study is presented to illustrate a methodology for mobile monitoring in urban environments. A dataset of UFP, $PM_{2.5}$ and BC concentrations was collected. We showed that repeated mobile measurements could give insight in spatial variability of pollutants at different micro-environments in a city. Streets of contrasting traffic intensity showed increased concentrations by a factor 2–3 for UFP and BC and by <10% for $PM_{2.5}$. The first quartile (P25) of the mobile measurements at an urban background zone seems to be good estimate of the urban background concentration. The local component of the pollutant concentrations was determined by background correction. The use of background correction reduced the number of runs needed to obtain representative results. The results presented, are a first attempt to establish a methodology for setup and data processing of mobile air quality measurements to assess the spatial variability of concentrations in urban environments.

1. Introduction

Traffic-related air pollution is one of the major concerns in urban environments. Fixed air quality monitoring stations have several limitations when used to assess people's real life exposure to (ultra)fine particles and other traffic-related air pollutants, due to the large spatial variability of these pollutants in urban environments. Mobile platforms are increasingly used to acquire air quality data at a high spatial and temporal resolution in a complex urban environment (e.g. Adams et al., 2012; Hagler et al., 2010; Wallace et al., 2009; Westerdahl et al., 2005; Weijers et al., 2004). Mobile measurements provide a solution to assess spatial variability of pollutants with a limited number of instruments and in a confined timeframe. Typically, measurements are performed in the area of interest by repeated runs (Peters et al., 2013). In this paper the term 'run(s)' is used to specify repeated measurements over the entire area at different days and/or different times of one day. In this way, mobile measurements can be used for air quality mapping, hot spot identification and exposure assessment. However, issues related to the data coverage requirements of mobile runs and to the variation in background concentrations are not yet solved.

Air pollutant concentrations contain a regional and an urban background component in addition to the street level component. The urban background component is the contribution to the measured concentration at street level, not coming from local sources in the street but originating from regional and urban sources. Temporal variations in the background concentration may mask the contribution of local sources to the air quality, and complicate the comparison of the air quality between measurements of different dates. The air quality measured on a day with a high background concentration at a street with low traffic intensity can exceed the concentration measured at a location with many local sources when background concentrations are low. Therefore, background concentrations need to be taken into account when comparing measurements on different days, especially in order to assess the local source contribution. Local contributions (from traffic) to air pollutants can be calculated by subtracting the measured concentration at an urban background station from the concentration measured at a kerbside station (Lenschow et al., 2001). Also distance to the traffic source affects the resulting concentration (Mishra et al., 2012).

This study focuses on mobile monitoring of the ultrafine particles (UFP), $PM_{2.5}$ and black carbon (BC) in urban environments.

* Corresponding author.
E-mail address: martine.vanpoppel@vito.be (M. Van Poppel).

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$PM_{2.5}$ is a complex mixture of solid and liquid particles with an aerodynamic diameter of less than 2.5 μm and originates from different sources. $PM_{2.5}$ mass concentrations are currently legislated by Air Quality Directive (2008/50/EC). Spatial variability of $PM_{2.5}$ and PM_{10} is rather limited (e.g. in Flanders (Vercauteren et al., 2011); between urban background and street locations in Europe (Keuken et al., 2012)).

UFP are strictly defined as particles with a diameter smaller than 100 nm, however some instruments that measure particle number concentrations have a somewhat larger size range (e.g. submicron). UFP contribute little to the mass of the total suspended particles but are highly abundant in number. Conventional-fuelled vehicles are currently the dominant anthropogenic source in urban environments (Kumar et al., 2010 and references). UFP concentrations decrease rapidly with distance from the emission sources (Zhu et al., 2002) inducing important differences, in space and time, between urban micro-environments (e.g. Mishra et al., 2012). BC is a component of PM, related to combustion processes. Elemental carbon and black carbon are both parameters to assess the combustion related fraction of PM. They are measured by different measurement principles relying on its optical properties for BC and its thermal properties for EC. Both terms are used in literature, however absolute values can differ significantly although they are often highly correlated (Hitzenberger et al., 2006).

Whereas in this study only BC is measured, also studies on EC are discussed to explain the relevance of this parameter, given their correlation and common origin. Keuken et al. (2012) showed that in Europe, the difference in concentration between urban background and street locations is larger for elemental carbon (EC) as compared to $PM_{2.5}$ and PM_{10}. They concluded that EC is a better indicator to evaluate traffic measures as compared to $PM_{2.5}$ or PM_{10}. In Flanders, increased concentrations of EC are observed at air quality monitoring stations exposed to traffic (monitoring site in a city at 30 m from a busy road: 2.04 μg/m^3) compared to rural sites (0.47–0.98 μg/m^3); whereas for PM_{10} mass concentrations, smaller differences were observed (33.7 μg/m^3 compared to 27.4–28.2 μg/m^3 at the traffic exposed and rural site respectively) (Vercauteren et al., 2011). The relatively small regional variation for PM_{10} is due to the relative large contribution of background concentrations.

Both UFP and BC are considered to cause adverse health effects (Atkinson et al., 2010; Peters et al., 1997; Kumar et al., 2011; Janssen et al., 2011). A recent review study has shown that BC is a valuable additional air quality indicator to evaluate the health risks of air quality dominated by primary combustion particles. Estimated health effects of a 1-μg/m^3 increase in exposure were greater for BC than for PM_{10} or $PM_{2.5}$. The study showed that the estimated increase in life expectancy associated with a hypothetical traffic abatement measure was four to nine times higher when expressed in BC compared with an equivalent change in $PM_{2.5}$ mass (Janssen et al., 2011). Given their considered health impact and high spatial variability, it is important to measure UFP and BC at a high spatial resolution (in addition to PM fractions) in order to get insight into people's exposure.

At VITO, a measuring bike – called Aeroflex – was developed for mobile measurements, as a complementary tool for policy makers and researchers. This bike was previously involved in air quality management studies (Berghmans et al., 2009; Int Panis et al., 2010) and an updated model was used in this study. The updated version was equipped with instrumentation for UFP, $PM_{2.5}$ and BC. In this paper, the results of a case study of the improved Aeroflex are presented. The objectives of this case study were threefold. The first objective was to investigate whether repeated mobile measurements could give insight in pollutant concentrations of urban zones with different exposure to direct traffic emissions. The zones were predefined based on street and traffic characteristics. A statistical comparison between the zones is made for the different pollutants. The second objective was to develop a method to estimate a representative background concentration for the time of measurements from the mobile data. The final objective was to assess the potential of the background concentration estimate for background correction, allowing a direct comparison of the local air quality component between different days.

2. Methods

2.1. The Aeroflex measurement bicycle

The measuring bicycle used in this study was developed at VITO as a complementary tool for policy makers and researchers (Berghmans et al. (2009)). Recently, improvements were made in relation to data synchronization and data transmission (Elen et al., 2013). The Aeroflex was equipped with a modified P-Trak (TSI model number 8525) for UFP measurements, a Micro-Aethalometer (AE51, Magee Scientific) for BC measurements and a Grimm Dust monitor (1.108) for $PM_{2.5}$ measurements. A GPS was used for location tracking. All synchronized data were logged as csv-files. UFP and BC were measured on a 1 s time resolution. The time resolution of the Grimm for $PM_{2.5}$ measurements was 6 s. BC and UFP concentrations were sampled at respectively 0.150 L/min and 0.70 L/min. $PM_{2.5}$ was sampled at 1.20 L/min. The Micro-Aethalometer measures the attenuation of light (880 nm LED) through a Teflon coated borosilicate glass fibre filter on which light absorbing particles are sampled continuously. The difference in attenuation (per time base) is converted to BC concentrations using a specific absorption coefficient $\sigma = 12.5$ m^2/g (at 880 nm) and the actual sample flow rate.

2.2. Study design and route

A case study was performed in Mol (a small city in Flanders with 34,000 inhabitants). A fixed sampling route was repeated 20 times on 10 different days between 07-04-2010 and 23-04-2010. The time of monitoring and the meteorological conditions are summarized in Table 1. The monitoring route is displayed in Fig. 1 and contained areas characterised by differences in the amount of traffic, the street layout and the building density. Six zones were differentiated based on the traffic characteristics: (1) access road outside the city centre, (2 and 3) major road in the city, (4) access road from ring road to city centre, (5) green space, and (6) road in the city centre. These zones were also characterised by differences in street lay-out: more 'open' zones (1, 5) and 'street canyon'-like zones (2, 3 and 6 (partly)). During the case study, zone 4 – that was originally characterised as an access road from the ring road to the city centre - had restricted traffic because of construction works at the ring road preventing access to the city from the ring road. An overview of the characteristics of the different zone is summarized in Table 2.

Zone 1 has the highest traffic density and traffic speed (Turnhoutsebaan, 70 km h^{-1}, approximately 10,000 vehicles per day). The biking lane is separated from the street by a parking lane. Zone 2 has also a high traffic density, but speeds are limited to 50 km h^{-1} and has buildings at both sides of the route which may result in

Table 1
Overview of the mobile runs and meteorological conditions during the measurements.

Date	Run	Start hour – stop hour	Duration (minutes)	T (°C)	WD	RH (%)
7/04/2010	1	14:00–14:43	43	17.9	S	44
	2	14:58–15:57	59			
8/04/2010	3	13:43–14:29	46	9.6	N	93
	4	14:30–15:18	49			
12/04/2010	5	14:41–15:29	48	13.0	NE	47
	6	15:33–16:20	47			
14/04/2010	7	11:57–12:38	41	15.1	NE	50
	8	12:41–13:25	44			
15/04/2010	9	12:11–12:55	44	16.5	NE	37
	10	12:56–13:41	45			
16/04/2010	11	12:23–13:12	49	11.9	NE	45
	12	13:15–14:04	49			
19/04/2010	13	13:54–14:44	50	15.6	NE	44
	14	14:46–15:40	54			
20/04/2010	15	10:17–11:06	49	14.7	W	51
	16	11:10–11:59	49			
22/04/2010	17	15:01–15:48	47	13.8	NE	35
	18	15:51–16:39	48			
23/04/2010	19	10:53–11:41	48	12.7	E	43
	20	11:44–12:28	44			