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Biomagnetic monitoring as a validation tool for local air quality models: A case study for an urban street canyon

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ABSTRACT

Biomagnetic monitoring of tree leaf deposited particles has proven to be a good indicator of the ambient particulate concentration. The objective of this study is to apply this method to validate a local-scale air quality model (ENVI-met), using 96 tree crown sampling locations in a typical urban street canyon. To the best of our knowledge, the application of biomagnetic monitoring for the validation of pollutant dispersion modeling is hereby presented for the first time. Quantitative ENVI-met validation showed significant correlations between modeled and measured results throughout the entire in-leaf period. ENVI-met performed much better at the first half of the street canyon close to the ring road ($r = 0.58$–0.79, RMSE = 44–49%), compared to second part ($r = 0.58$–0.64, RMSE = 74–102%). The spatial model behavior was evaluated by testing effects of height, azimuthal position, tree position and distance from the main pollution source on the obtained model results and magnetic measurements. Our results demonstrate that biomagnetic monitoring seems to be a valuable method to evaluate the performance of air quality models. Due to the high spatial and temporal resolution of this technique, biomagnetic monitoring can be applied anywhere in the city (where urban green is present) to evaluate model performance at different spatial scales.

1. Introduction

To date, particulate air pollution remains an important issue to tackle. Particulate matter (PM) comprises material in solid or liquid phase suspended in the atmosphere. It can be either primary or secondary and covers a wide range of sizes (WHO, 2006). The particles are identified according to their aerodynamic diameter, as either PM_{10} (particles with an aerodynamic diameter smaller than 10 μm), $PM_{2.5}$ (aerodynamic diameter smaller than 2.5 μm) or $PM_{0.1}$ (aerodynamic diameter smaller than 0.1 μm). The latter are more dangerous since, when inhaled, they may reach the peripheral regions of the bronchioles, and interfere with gas exchange inside the lungs (WHO, 2011). Health impacts associated with chronic PM exposure involve cardiovascular and respiratory diseases, as well as lung cancer and premature death (Donaldson et al., 2001; EEA, 2010; Remy et al., 2011). An estimated 5 million years of lost life per year are due to fine particles ($PM_{2.5}$) alone in Europe (EEA, 2010). While different emission sources of particles exist, such as power plants, airports, building demolition sites, tire and road surface wear and natural formation, gasoline- and diesel-fuelled vehicles and domestic heating remain the dominant sources in urban environments (Kumar et al., 2011; Pey et al., 2009). Considering the fact that more than half of the global population now lives in urban settings with even a much higher number (97.4%) for Belgium (WHO, 2010), a large exposure level to this emission source can be expected. From a population exposure point of view, street canyons are of major importance, since both emission sources and targets of impact (exposed city dwellers) are often concentrated in these kinds of streets (Hertel et al., 2001).

Due to the health effects, atmospheric PM concentrations are monitored meticulously by means of automated monitoring networks in many European cities. The spatial resolution of these stations is, however, limited due to high investment and maintenance costs. In addition to telemetric measuring stations, pollutant dispersion models or biomonitoring techniques can be used to obtain a higher spatial resolution. Currently, several simple to complex models addressing dispersion of gaseous and particulate pollutants at different urban scales are available. These models are developed to understand and forecast not only the magnitude of the air pollution problem but also the development of emission control policies and regulations (Nikolova, 2012). Doing so, they provide a sound scientific and technical basis for regulatory policies. However, the evaluation of model performance against measured data is essential for producing reliable modeled results (Kumar et al., 2011). In this regard, biomagnetic monitoring might offer a rapid, cost-effective and nondestructive indicator to obtain a measure of the spatial and temporal variations of urban dust loadings on leaves of roadside trees (Matzka and Maher, 1999; Zhang et al., 2012).

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Biomonitoring, which can be defined as the response of living organisms to changes in their environment (Nali and Lorenzini, 2007), has experienced increased interest in the last decades. Within the field of biomonitoring, magnetic properties of tree leaf deposited particles have proven to be good indicator of the ambient traffic derived PM concentration (Lu et al., 2008; Maher et al., 2008; Matzka, 1997; Matzka and Maher, 1999). The magnetizable PM fraction can be quantified by the *Saturation Isothermal Remnant Magnetization* (SIRM), which represents the magnetization retained by a sample after exposure to a large magnetic field, e.g. 300 mT or 1 T (Matzka and Maher, 1999). Recently, biomagnetic monitoring studies have identified significant magnetic property variation of urban tree leaves at both intra-urban (Kardel et al., 2012; Moreno et al., 2003) and intra-street/tree canopy level (Hofman et al., 2013; Langner, 2007). A comparative analysis between the modeled results and magnetic tree leaf properties might, therefore, provide important information about the performance of a model.

One of the main differences between the modeling and biomagnetic monitoring approach is the integration time over which the sample is taken. Biomagnetic monitoring represents long response times (several weeks, months or even years, depending on species and the time of sampling) since the magnetic signal accumulates throughout the entire growth season (Kardel et al., 2011), while pollutant concentration and environmental parameters are being most frequently modeled with short timesteps (e.g. hourly) since they vary very rapidly, and for shorter time periods (e.g. a day) because of the calculation time. Long response times might be preferable when sampling substances whose impact on human health is due to cumulative exposure (Vardoulakis et al., 2003). Doing so, we obtain information about the integrated exposure, defined as the exposure over a period of time (Hertel et al., 2001), to a certain pollutant. To cope with these differences in representation time between the measurements and the model, this paper provides an integrated model analysis over the entire in-leaf season, i.e. the period for which the magnetic signal might be representative.

As previously suggested by Hofman et al. (2013), magnetic biomonitoring might be a suitable validation tool for pollutant dispersion models. The objective of this study is to test this hypothesis by validating the PM distribution modeled by a pollutant dispersion CFD-model (ENVI-met) by means of magnetic biomonitoring analysis of tree leaf deposited particles in a typical urban street canyon. To the best of our knowledge, the application of biomagnetic monitoring for the validation of pollutant dispersion modeling is hereby presented for the first time.

2. Materials and method

2.1. Location

This study focuses on the same study area as previously used in Hofman et al. (2013), a typical street canyon, Kunstlaan (5°2′26.22″N, 3°43′27.11″E), located in the densely populated city center of Ghent. The Kunstlaan consists of two opposing traffic lanes separated by two rows of London plane (*Platanus acerifolia*) trees. It has a typical street canyon geometry with a width (W) of 24 m, a height (H) of 10 m and a length (L) of 200 m. According to the geometry rules described by Vardoulakis et al. (2003), the street can thus be described as a long (L/H > 7) avenue street canyon (aspect ratio (H/W) < 0.5). The street canyon is continuous, except for a crossing street (Kattenberg) in the middle of the street canyon.

2.2. Biomonitoring campaign

As described in Hofman et al. (2013), a biomonitoring campaign was conducted in the Kunstlaan on August 29th, 2011. Eight trees with similar crown dimensions were sampled throughout the street canyon by means of a boom lift (Fig. 1).

From the 8 sampled trees, T1, T4, T5 and T8 were regarded as edge trees (e) since they were positioned at the edges of the street canyon, while T2, T3, T6 and T7 were regarded as canyon trees (c) since they were positioned inside the street canyon and completely surrounded by other tree crowns and street walls. For each tree crown, leaf sampling occurred at the crowns outer surface at three heights (5, 8 and 12 m) and four different wind directions parallel and perpendicular to the

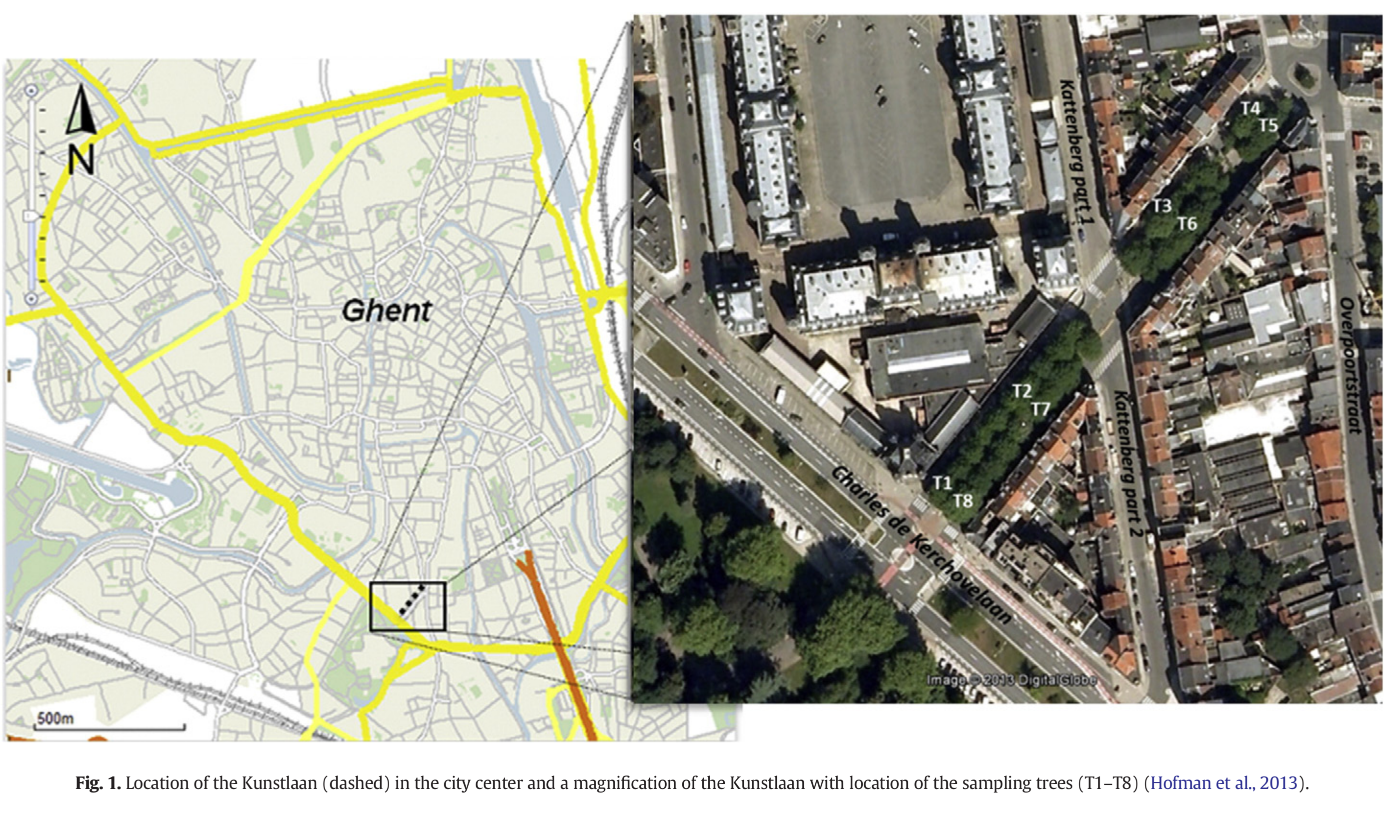

Fig. 1. Location of the Kunstlaan (dashed) in the city center and a magnification of the Kunstlaan with location of the sampling trees (T1–T8) (Hofman et al., 2013).