Enhanced Land Use Regression models for ultra-fine particle concentrations using 2D, 3D and pseudo dynamic parameters

Yahya Ghassoun, Marc-O. Löwner

Yahya Ghassoun, Institute for Geodesy und Photogrammetry, Technische Universität Braunschweig, Germany, y.ghassoun@tu-bs.de
Marc-O. Löwner, Institute for Geodesy und Photogrammetry, Technische Universität Braunschweig, Germany, m-o.loewner@tu-bs.de

Abstract

Many studies have widely discussed and reported strong relationship of the concentration of ultrafine particles (UFP) <100 nm in diameter with negative health effects (e.g. Heal et al., 2012; HEI, 2013; WHO, 2013). As an example, epidemiological and toxicological research demonstrated associations between daily average UFP concentrations measured at central locations and daily cardiorespiratory mortality, respiratory symptoms, and hospital admissions (Ibald-Mulli, et al., 2002). In this context urban areas are of special interest because of significant emissions of fine and ultra-fine particles from stationary and mobile sources in combination with high population density. Thereby, air pollution, especially from traffic has been considered as the most significant factor of premature death where numerous toxic materials produced by combustion processes are in the ultrafine size range (Burtscher, 2012). Therefore, detailed assessment of exposure by measurement and modelling of fine dust distribution is necessary in the field of urban planning, traffic management and city system modelling.

UFP concentrations can be estimated from measurements of the particle number distribution. At street canyon scale or near traffic sites, the number of UFP generally accounts for the majority of total particle number concentration, i.e., greater than 80 % to 90 % (Weber et al., 2013). Since measuring capacity is limited, different kinds of aerosol models have been developed in order to explain the spatio-temporal variation of urban ultrafine particulate (Kumar et al., 2011; Di et al., 2016). However, these models often require quite a lot of variables or complex input data and are computationally expensive. Therefore, the application of these models for particle exposure studies and short-term traffic management is limited.

Land Use Regression (LUR) models were developed as an alternative to dispersion models (Brauer et al., 2003, Beelen et al., 2013). LUR models are multiple linear regression approaches that assume independent residuals and use spatially explanatory variables extracted within zones of influence around each monitoring site to predict pollutant concentrations at certain locations (Mercer et al., 2011). They can be applied to predict long-term and local-scale variation in traffic pollution and to obtain accurate, small scale air pollutant concentrations without a detailed pollutant emission inventory (Zhang, 2015; Ghassoun et al. 2015A).

Ghassoun et al., 2015A applied and extended an LUR model approach to predict particle number concentrations on urban microscale. They introduced a 'process chain' representing emission, dilution/dispersion and deposition as the main processes that reveal in an integral value of particle numbers. Results showed that this extended LUR approach was able to explain the spatial distribution of urban UFP concentrations and, further, to model the intra-urban variations in number size distributions. Furthermore, this approach was able to explain the variance of UFP concentrations and the full size distribution in different microenvironments.

Since dilution is depended on the local wind field that is influenced from urban morphology the third dimension has to be taken into account. Few studies used 3D spatial data to enhance the representation of land use and the dispersion field in LUR (Tang et al., 2013; Ghassoun et al., 2015B). Ghassoun et al. 2015B and Ghassoun et al., 2016 described parameters that represent the 2D and 3D urban morphology, f.i. volumetric building and tree density, ratio of height and width of the street canyon. They further introduced porosity, i.e. the chance for the air to pass through a building block to enhance their approach of the process chained LUR approach. Thereby, they used OSM data and a CityGML based 3D city model.

They were able to predicted total number concentrations and to explain the variance of total number concentration for Berlin. They proved that the 3D-LUR showed better results than the 2D-LUR (Ghassoun et al., under review). However, since main wind direction seems to have major influence on short time fine dust distribution, static parameters describing the urban morphology are still not sufficient.

Here we present first results of the definition and application of pseudo dynamic parameters (PDPs) to further enhance the above described modeling approach. Since urban morphology is static but interacts with dynamic factors like the main wind direction and wind speed, some parameters affects the UFP concentration in a dynamic way. Therefore, new urban roughness parameters, f.i. frontal area index and aerodynamic roughness length that can be operationalized for both, 2D and 3D data have been defined. Accurate definitions and descriptions of these pseudo dynamic parameters (PDPs) help to compute them from different geodata sources like OSM and CityGML. The main advantage of PDPs is that current wind data may be introduced to the modelling approach. The pseudo dynamic parameters have been categorized and applied to the process class of dilution. The final LUR model led to a significant enhancement of modeling results. At this level of study the PDPs enhanced modelling approach shows better description of the urban morphology's impact on the distribution of the UFP concentrations.

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