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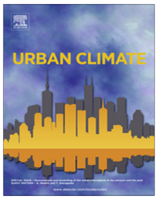

Influence of mixing layer height on air pollutant concentrations in an urban street canyon

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ABSTRACT

Urban areas often suffer from high air pollutant concentrations. To study the influence of the mixing layer height (MLH) on concentrations of important pollutants in an urban street canyon of a busy road, a long-term measurement campaign was performed at the kerb site of an arterial road in Essen, Germany, during the winter 2011/2012 and the early spring in 2012. Considered pollutants were NO, NO_2, PM_{10}, benzene, toluene and isoprene. The MLH was detected continuously using a ceilometer.

To study the impact of MLH on pollutant concentrations, the classification scheme of Sturges was applied for the first time for this purpose.

It is found that even in the immediate vicinity (kerbside) to a busy road the concentrations of air pollutants are strongly affected by MLH. It is a new result that high quantiles of concentrations decrease stronger with increasing MLH than low quantiles. The strongest correlations between concentrations and MLH are obtained for maximum concentrations with coefficients r from -0.84 to -0.95. In general, maximum concentrations of air pollutants in a street canyon provide stronger correlations with MLH than mean concentrations. NO_2 is the pollutant whose concentration is affected least by MLH because it is mainly a secondary pollutant.

1. Introduction

Urban regions are frequently influenced by enhanced air pollution, mainly due to strong emissions and chemical transformation processes. But, high air pollutant concentrations are not only a result of strong emissions but also of meteorological conditions. Wind speed and wind direction as well as mixing layer height (MLH) are important factors which influence exchange processes and distribution of ground-level emissions (Schäfer et al., 2006, 2011; Alföldy et al., 2007; Rost et al., 2009; Tandon et al., 2010; Pal and Devara, 2012; Pal et al., 2014; without MLH: Elminir, 2005; Gupta et al., 2008; Tai et al., 2010; Xu et al., 2011; Lee et al., 2015; Zhang et al., 2015). The mixing layer is defined as the atmospheric layer adjacent to the ground over which pollutants or any constituents emitted within this layer or entrained into it become vertically dispersed by convection or mechanical turbulence within a time scale of about an hour (Seibert et al., 2000). Within the mixing layer, the compounds are well-mixed. At the MLH which is the upper limit of the mixing layer, strong vertical gradients of humidity and other unreactive air compounds can be found (Stull, 1988).

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Because MLH is linked to temperature inversion, strong vertical wind shear and strong vertical decrease in moisture as well as pollutant concentrations, remote sensing techniques are suitable to monitor the MLH: lidar or mini-lidar like ceilometer (Wiegner et al., 2014), Sound Detection and Ranging (SODAR), Radio Acoustic Sounding System (RASS) (for comparisons see Emeis et al., 2004, 2007, 2009, 2012) or passive methods like microwave radiometers (Cimini et al., 2013) can be used for this purpose. Each technique has its pros and cons (Seibert et al., 2000). In this study, a ceilometer is deployed to determine the MLH. In the absence of low clouds and precipitation, ceilometers can estimate the MLH fairly well. These instruments, originally developed to monitor the cloud base height, are easy to handle, frequently available today and do not pollute the surroundings with sound or light. Furthermore, ceilometers have advantages over other ground-based remote sensors like most of the available high-power lidars. In general, ceilometers have lower heights of full overlap of a few tens of meters so that shallow MLH can be detected which is a challenging task for lidars which attain full overlap in a few hundreds of meters. Recently, the advantages of ceilometers have been discussed in detail in a review paper (Pal, 2014).

Previous air pollution studies in urban and sub-urban areas (Hanover, Munich, Budapest; see Schäfer et al., 2006, 2011; Alföldy et al., 2007) and at airports (e.g. Athens International Airport; see Helmis et al., 2011) revealed significant correlations between air pollutant concentrations and continuously monitored MLH. Schäfer et al. (2006) showed that the MLH can account for more than 50% of the variation in the near-surface concentrations of pollutants, especially in winter and at sites which represent urban background. If the MLH is located near to the ground, air pollution in urban areas can be high due to accumulation of emitted pollutants within the shallow mixing layer. Unlike Schäfer et al. (2006) who did not find a significant correlation between pollutant concentrations and MLH in a street canyon of a busy road on the basis of daily averages, Wagner and Kuttler (2014) illustrated a strong correlation between them grouping MLH values into intervals of 200 m and correlating classified MLH with maximum and mean concentrations of each MLH class. Because of other meteorological factors like wind speed strongly affecting concentrations (Xu et al., 2011; Wagner and Kuttler, 2014; Zhang et al., 2015), the best approach to derive the impact of MLH from statistical analyses seems to be the use MLH classes for correlation analysis. Rost et al. (2009) also applied 200 m classes of MLH for correlation analysis between MLH and PM_{10} concentration in four cities in Germany. Therefore, the approach applied by Wagner and Kuttler (2014) is stated more precisely by performing detailed analysis in this study. The classification method of Sturges (1926) is applied to establish an appropriate class width and class number, respectively. It is studied if differences exist in the dependency of mean, median, maximum, minimum and different quantiles of concentration of various pollutants on MLH.

Pollutants considered in the present study are NO, NO_2, PM_{10} and volatile organic compounds (VOCs). As VOCs benzene, toluene and isoprene are chosen because they are important organic substances and differ largely in reactivity. Benzene is emitted by road traffic and its concentration is limited by Directive 2008/50/EC because it is carcinogenic. Toluene is also originated from anthropogenic sources, mainly road traffic and the application of solvents, and is one of the most abundant VOCs in the urban atmosphere with regard to concentration. Finally, isoprene, which is emitted both by anthropogenic and biogenic sources, is of special interest in urban areas considering ozone formation because of its high reactivity (Wagner, 2013; Wagner and Kuttler, 2014). All concentrations were measured in a street canyon of a busy arterial road in Essen, Germany.

At first, the measurements campaign and the applied methodologies are introduced. Before the correlation between MLH and concentrations is analysed, the validity of the MLH values determined from ceilometer measurements is surveyed by plausibility check and comparison with MLH values obtained from radiosonde profiles. Finally, results of correlation analyses between MLH and different quantiles and mean concentrations of measured pollutants, respectively, are discussed and conclusions are drawn.

2. Material and methods

2.1. Measurement locations and period

To study the influence of MLH on pollutant concentrations, a measurement campaign was performed in Essen, Germany, during the winter 2011/2012 and early spring in 2012. Essen is located in the central part of the Ruhr conurbation (a metropolitan area with a population of about 5.2 million) in western Germany. Essen itself has approximately 570,000 residents (IT.NRW, 2013).

The MLH was determined with a ceilometer which was installed at the meteorological station on the university campus (operated by the Department of Applied Climatology and Landscape Ecology, University of Duisburg-Essen). The station is located 1.0 km northwest of the city centre of Essen. MLH was measured from 21 December 2011 until 15 April 2012.

The MLH determined from ceilometer measurements is compared to the MLH determined from radiosonde data. The radiosonde ascents are performed by the German National Meteorological Service called Deutscher Wetterdienst (DWD) at its station in Essen which is situated in the southern part of the city, in a distance of about 7 km to the meteorological station on the university campus at which the ceilometer was operated. Radiosonde ascents start at an altitude of 147 m asl (above sea level), whereas the campus station is located on an elevation of 56 m asl.

NO, NO_2, PM_{10} and VOC concentrations were measured at a kerb site of a busy four-lane arterial road named Gladbecker Straße (40,000–50,000 vehicles d^{-1}; City of Essen, 2009). The measurement site is situated in a street canyon formed by the

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