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An alternative conception of PM₁₀ concentration changes after short-term precipitation in urban environment

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ABSTRACT

In the article, a linear model is presented which describes a reduction of PM₁₀ mass concentration in relation to the type of precipitation and water vapour content in the air. The model was built using covariance analysis. In studies of PM₁₀ concentration changes, the results of 247 observations were used, which were carried out in the urban area. Concentration changes were archived during short-term (30 min) convection and large-scale rainfalls. For the determination of PM₁₀ mass concentration, the reference method was used.

To describe changes in PM₁₀ concentration in the air after precipitation, a series of linear models were created, in which the explanatory variables were: the level of PM₁₀ before precipitation, absolute humidity of the air and the precipitation type. The criteria for the best model selection were its linearity, zero mean residual value and high coefficient of determination. Additionally, normality and homoscedasticity of the model residuals were tested.

The formulated linear model is a useful tool for predicting changes in the concentration of particulate matter following short-term precipitation in urban areas. There is a need to check the utility of models for other fractions of suspended particles.

1. Introduction

Particulates are the main pollutants of the troposphere, and one of their qualitative indicators is the mass concentration of PM₁₀ (Wu, Liu, & Fan, 2015). Suspended particles, enriched with a number of elements, substances and chemical compounds with toxic influence, have proven to have a negative impact on human health (Bravo & Bella, 2011; Moja, Mnisi, Nindi, & Okonkwo, 2013; Seaton, Godden, MacNee, & Donaldson, 1995; Yoo et al., 2015). Most of practical and theoretical researches dealing with the issue of air pollution are mainly focused on presenting data on air quality in urban areas (Amador-Muñoz et al., 2013; Clements, Hannigan, Miller, Peel, & Milford, 2015; Makra et al., 2013; Tian, Qiao, & Xu, 2014; Wu et al., 2014), where the concentration of pollutants depends not only on the amount and activity of emission sources, but also on meteorological mechanisms, including scavenging from the atmosphere.

Solid particle scavenging processes take the form of dry and wet deposition. Wet deposition is atmospheric pollution capturing by clouds and/or precipitation droplets in liquid or solid form. Captured contaminants are then delivered to the ground. Dry deposition brings down particles directly to the surface of the litho- or hydrosphere without precipitation (Seinfeld & Pandis, 2006). Wet deposition is divided into two types, classified by the place at which the process occurs. Namely in-cloud (rainout) and below-cloud

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(washout) processes (Connan et al., 2013; Santachiara, Prodi, & Belosi, 2013). Washout (below-cloud) is a very efficient process for particles with aerodynamic diameter bigger than $1\ \mu\text{m}$ (Andronache, 2004; Bae, Jung, Kim, & Woo, 2012; Kim et al., 2007; Zhao, Gong, Zhang, & McKendry, 2003), which, as noted by Aikawa and Hiraki (2009), are intercepted by rain at the beginning of the process. Researchers in this area claim that this process can lead to scavenging of up to 30% of aerosols from the troposphere (Murakami, Kimura, & Magono, 1983; Schumann, Zender, & Waldvogel, 1988). The mechanisms of this process include the microphysical interactions between the solid particles and hydrometeors. The impact and the share of direct collision, the effect of inertia, Brownian diffusion, thermophoresis, diffusiphoresis and electro-scavenging have been thoroughly recognised and described (Andronache, 2004; Bae, Jung, & Kim, 2009; Chate et al., 2003; Chate, Murugavel, Ali, Tiwari, & Beig, 2011; Feng, 2009; Goldsmith, Delafield, & Cox, 1963; Pruppacher & Klett, 1997; Seinfeld & Pandis, 2006; Tinsley, Rohrbaugh, & Hei, 2001; Zhang, Michelangeli, & Taylor, 2004). Wet below-cloud purification involves all of the phenomena by means of which particles are removed from the air through various types of precipitation e.g. rain, snow, fog and ice (Bae, Jung, & Kim, 2006; Widziewicz, Rogula-Kozłowska, Rogula-Kopiec, Majewski, & Loska, 2017). Below-cloud scavenging is strongly dependent on rain drop and solid particle size distribution, precipitation intensity and the efficiency of collisions between the droplets and the atmospheric aerosol (Laakso et al., 2003).

There are a number of parameterizations needed to determine the effectiveness of wet deposition in below-cloud processes of troposphere purification. The most popular is scavenging coefficient $\Lambda\ [\text{s}^{-1}]$, which indicates the relative change in the aerosol number concentration per second for particles of a given diameter (Volken & Schumann, 1993; Pruppacher & Klett, 1997; Seinfeld & Pandis, 1998; Laakso et al., 2003; Pryor, Joerger, & Sullivan, 2016; Zikova & Zdimal, 2016). Scavenging coefficient Λ could be also recognised as a function of fallout intensity for different types of precipitation (Brandt, Christensen, & Frohn, 2002; Nickovic, Kallos, Papadopoulos, & Kakaliagou, 1966). It was also found that, Λ is dependent on the relative humidity of air for hygroscopic particles (Chate et al., 2003). Parameterization of solid particles scavenging based on the change of relative humidity during rainfall was proposed by Pudykiewicz (1989). In a previous article (Paramonov, Groenholm, & Virkkula, 2011), a new parameterization of scavenging coefficient was developed. The authors took into account both particle diameter and relative humidity.

In the literature, others methods of scavenging efficiency for suspended particles can be found. Seinfeld and Pandis (1998) introduced the removal coefficient $S_c\ [\text{s}^{-1}]$, which may define changes in the concentration of particles of a given size occurring after precipitation. Authors often use the scavenging coefficient SR (Cerqueira et al., 2010; Kasper-Giebl, Kalina, & Puxbaum, 1999; Kulshrestha, Reddy, Satyanarayana, & Kulshrestha, 2009), which expresses a relation between pollutant concentration in precipitation water and pollutant concentration in the air (Granat, Norman, Leck, Kulshrestha, & Rodhe, 2002; Hicks, 2005) and can also be used to evaluate the effectiveness of wet deposition (Jaffrezo, Colin, & Gros, 1990; Türküm, Pekey, Pekey, & Tuncel, 2008).

The concentration of PM_{10} is still an important indicator characterizing the quality of the troposphere. Throughout the world, urban and background air quality monitoring stations provide information on the mass concentration of PM_{10} . Announcements regarding the potential to exceed permissible concentrations are also presented in the form of mass concentration. At the same time, parameterization of the dust concentration changes used often refers to the concentration quantity of particles of a fixed size. This causes problems in the interpretation and prediction of potential improvements of aerosanitary conditions following precipitation events.

The principal objective in this project was to determine the relationship between PM_{10} mass concentration before (c_0) and after a predetermined time of precipitation (c_1) and to create a model describing a change in the concentration of PM_{10} during the process of wet deposition in an urban area. The additional aim was to determine potential differences in the relationship between mass concentration of c_0 and c_1 resulting from different types of precipitation observed, i.e. liquid convective (K) and liquid large scale (W) and solid large scale (S) precipitation.

2. Materials and methods

2.1. Site of observation and sampling procedure

The measurements were carried out in the suburban area of Opole city (Poland, $50^{\circ}41'13''\text{N}$; $17^{\circ}56'44''\text{E}$). Analysing the city for environmental nuisance, the function it plays, character of building and terrain have a significant impact on the formation and accumulation of air pollutants. Road traffic, and emissions from households and industry are the main primary factors, which are responsible for the state of air quality. The measurement point was situated 20 m away from a medium traffic urban road, close to compact households with individual heating systems. The weather station was located 10 m away from dust sampler. The procedure by which the measurement of the concentration of PM_{10} was performed conformed to the European standard (BS EN 12341, 1999). The reference gravimetric method, which is often relied on (Chate et al., 2003; Connan et al., 2013), was also applied in this case. The aspiration of outdoor air was carried out by a MicroPNS HVS16 sequential dust sampler. Similarly to the case of sensors in the weather station, the aspiration header was installed 2 m above ground level. The flow rate was $68\ \text{m}^3\ \text{h}^{-1}$. The particulate matter separators applied Whatman GF/A fibreglass air filters with a diameter of 150 mm. Prior to and after aspiration, the filters were seasoned for over 24 h in conditions of constant temperature and humidity and their weight was subsequently determined by a differential scale (RADWAG XA 52/2 $\times$). The aspiration at a constant time interval of 0.5 h was conducted directly before and during the occurrence of precipitation. The expanded concentration measurement uncertainty (U) did not exceed 3.2%. The mass concentration of PM_{10} was calculated on the basis of formula (1).

$$C = \frac{(m_1 - m_0)}{V} \quad (1)$$

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