ARTICLE IN PRESS

Atmospheric Pollution Research xxx (xxxx) xxx–xxx

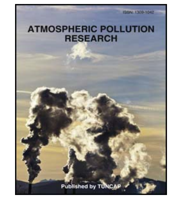
HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

Atmospheric Pollution Research

journal homepage: www.elsevier.com/locate/apr



Comparison of particle concentration vertical profiles between downtown and urban forest park in Nanjing (China)

Fan Liu, Xiaohong Zheng*, Hua Qian

Jiangsu Provincial Key Laboratory of Solar Energy Science and Technology, School of Energy and Environment, Southeast University, Nanjing, 210096, China

ARTICLE INFO

Keywords:
Particle
Vertical profiles
Unmanned aerial vehicle (UAV)
Meteorological parameters
Correlation analysis

ABSTRACT

This study attempts to characterize and compare the vertical distributions of the $PM_{2.5}$ and PM_{10} concentrations in downtown and surrounding national forest park. A contrastive measurement was performed using the portable particle sampler in Nanjing (China), from Apr. 22, 2016 to Jan. 24, 2017. The particle concentrations were found to be negatively associated with height in the forest park. The same but slighter phenomena were also found in the downtown in most time, however, peak values were observed at the height of roadside tall tree (25 m) instead of at the ground level at most of the sampling time. At 100 m, particle concentrations decreased by about 30% in the forest park, and only a 20% attenuation was found in the downtown. An unmanned aerial vehicle (UAV) measurement was conducted under the hypothesis that the roadside trees can limit the vertical diffusion of particles. It was found that the interception of trees could reduce 24% and 26% of the $PM_{2.5}$ and PM_{10} concentrations above the road, respectively. The correlation analysis between the particle concentrations and five meteorological parameters (temperature, relative humidity, air pressure, solar energy and precipitation) showed higher correlations in the downtown than in the forest park. Both the temperature and the relative humidity contributed to the variation of the particle concentrations at different heights. This work serves to better understanding of particles dynamic characteristics in urban areas and has a significant implication for assessment of indoor air quality in high-rise buildings.

1. Introduction

With rapid economic development, China is now experiencing major public health challenges due to environmental changes (Editoral, 2014; Chang et al., 2017). A particular issue is the decline of air quality, caused by the rising resource utilization and energy consumption (Van Donkelaar et al., 2015; Xie et al., 2016a, b). In addition, meteorological disasters, such as frequent sandstorms in East Asia, are also attributed to the air pollution. Studies revealed that the dust aerosols originated from the Taklimakan Desert and other deserts in northwest of China were also transported to free atmosphere and to eastern China (Iwasaka et al., 2003). Epidemiological studies have consistently showed an association between particles (e.g. $PM_{2.5}$ and PM_{10}) and pathogenesis due to a series of chemical reactions in air (Herbarth, 1995; Franck et al., 2011). Short-term and long-term exposures to ambient air pollution are found associated with a wide range of adverse health outcomes, such as respiratory and cardiovascular diseases (Bremner et al., 1999; Davidson et al., 2005; Samet and Krewski, 2007). The properties and concentrations of indoor particles that occupants are exposed to are closely related to those of outdoor particles (Ando et al., 1994; Brauer et al., 2002; Franck et al., 2006). Outdoor particles can penetrate the building envelope via doors, windows, building structure leakages, and mechanical ventilation systems, which is detrimental to human health (Ando et al., 1994; Brauer et al., 2002; Li et al., 2005; Franck et al., 2006; Kalaiarasan et al., 2009). Hence, it is of significance to study the vertical dispersion of particles surrounding high-rise buildings to better understand their impacts on indoor environment and occupant health. Furthermore, it is hopeful to help people select the proper location for fresh air inlets of air conditioning system in high-rise buildings.

In recent years, the findings of investigating vertical particle profiles around high-rise buildings (e.g. office buildings or residential buildings) seemed not to be consistent. Numerous studies found that concentrations decreased with height, for example, Rubino et al. (1998) reported that particle concentrations showed a linear decrease with height below 80 m while no significant correlation was found with higher height. Chan and Kwok (2000) found that in urban areas, decreases in total suspended particle (TSP), PM_{10} and $PM_{2.5}$ concentrations from ground to 14 m were about 48%, 37% and 35%, respectively.

Peer review under responsibility of Turkish National Committee for Air Pollution Research and Control.
* Corresponding author.
E-mail address: xhzheng@seu.edu.cn (X. Zheng).

https://doi.org/10.1016/j.apr.2018.02.001
Received 13 August 2017; Received in revised form 1 February 2018; Accepted 3 February 2018

Please cite this article as: Liu, F., Atmospheric Pollution Research (2018), https://doi.org/10.1016/j.apr.2018.02.001

Wu et al. (2002) found that the relationship between decreasing concentrations and height was exponential in a street canyon while linear for open sites. At the height of 79 m, the concentrations of PM_{10}, $PM_{2.5}$ and PM_1 near major roads decreased to about 60%, 62% and 80% of the maximum occurring at 2 m, respectively. Li et al. (2005) also reported a negative correlation between $PM_{2.5}$ concentrations and heights, and the attenuation decreased with height. However, many observations around building envelopes found that peak particle concentration was found in specified height, especially in street canyon. Park et al. (2004) used the tracer gas in a wind tunnel (3 m) to simulate the dispersion of vehicle emissions in the street canyon and found the concentration reached the maximum at a certain height, which was related to the aspect ratio of the street. Kumar et al. (2008) observed that the concentration peaked at about 4 m (with highest height of 7.37 m). The reduction in concentrations at the bottom of the street canyon was due to dry deposition while the reduction in concentrations in the upper part was attributed to the mass exchange between the street canyon and the wind above. Similar findings of fine particles were reported by Longley et al. (2004)and Kalaiarasan et al. (2009).

In addition to the quantified vertical profiles, relationships between the vertical variation of particle concentrations and meteorology have also been studied. The impact of meteorological conditions on the particle distributions, including particle transportation, diffusion and accumulation stage has been universally recognized (Bhaskar and Mehta, 2010; Pateraki et al., 2012; Kim et al., 2015; Li et al., 2017). Inversion layer and atmospheric stability were regarded as two key factors influencing the uneven vertical distribution. Linearly decreasing in concentrations with height were found when the atmospheric layer was stable, while exponential or power declines appeared in the existence of inversion layer (Li et al., 2007; Liu et al., 2009; Babu et al., 2011; Xiao et al., 2012; Peng et al., 2015). Wind was observed to make a major contribution to the dilution and transmission of pollutants in atmosphere. Pollutant concentrations were proportional to source emission while inversely proportional to wind speed, especially at a high altitude (Federico et al., 1998; Kumar et al., 2008; Wu et al., 2002; Xiao et al., 2012). Vertical patterns were found to be depended on the joint effect of the dominant wind direction and the street aspect ratio in urban canyons (De Paul and Sheih, 1985; Qin and Kot, 1993; Chan and Kwok, 2000; Wu et al., 2002; Kumar et al., 2008). Besides, removals in the form of dry and wet depositions, such as rainfall flushing, also affected seasonal variations of vertical pollutant profiles (Liu et al., 2009; Sun et al., 2013; Minguillon et al., 2015).

In contrast to urbanized areas with poor air quality, it is widely believed that forest ecosystems can mitigate the urban air pollution due to the absorption and capture of air pollutants by large leaf area (Beckett et al., 2000; Nowak et al., 2014; Uni and Katra, 2017). Nowak et al. (2014) reported that the total PM_{10} removal by trees in 55 U.S cities reached 214,900 tons and the total removal of $PM_{2.5}$ in 10 cities varied from 4.7 tons to 64.5 tons annually. In addition, the air quality improvement ranged between 0.05% and 0.24%. Fares et al. (2016) found that the urban vegetation could make a 20% attenuation on PM_1 concentrations in polluted ambient air. Nguyen et al. (2015) compared five commonly cultivated kinds of urban forest types and noted that shrubs and broadleaf trees captured $PM_{2.5}$ most effectively especially when leaves have fully developed, while the conifer and mixed trees made main contributions to the removal of $PM_{2.5}$ concentrations in the leafless season. Except the particulate matter, gaseous air pollutants from local emissions, such as NO_2 (Takahashi et al., 2005; Nowak et al., 2006), O_3 (Harris and Manning, 2010; Yli Pelkonen et al., 2017) and volatile organic compounds (Doty et al., 2007; Calfapietra et al., 2013) are also affected by trees and vegetation. It was found that the lower gaseous pollutant concentration levels in green areas were attributed to the leaf, where gases were absorbed through the stomata into the leaf interior. Although all these studies yielded valuable information on the mechanism and the capacity of removing pollutants by trees, there were mostly conducted at one sampling site, and only horizontal and temporal variations of pollutants were investigated.

Very little work has been done on contrasting the urban and forest particle concentrations, especially on vertical patterns in urban forests that are also health-related with dwellers in the downtown. Moreover, existing researches on vertical patterns in the downtown were scarce compared with those measured in green areas, from which the suspected pollutant sources could not be verified or excluded. Well-documented observations of particle variations are required for better understanding of particle distribution characteristics. For this season, a field study was accomplished throughout four seasons (from Apr. 22, 2016 to Jan. 24, 2017) in Nanjing, the capital of Jiangsu Province in China. In recent years, accumulating industrial and vehicular emissions have caused worse air quality in downtown. Nanjing boasts the Zijin Mountain forest park, the only national urban forest park in China, which facilitated the comparative study on particle vertical distributions between polluted and clean areas. Therefore, two monitoring sites were chosen: a high-rise office building in the downtown, representing the downtown area, and Zijin Mountain forest park, representing the green area. The present study was set out to measure vertical profiles of the $PM_{2.5}$ and PM_{10} concentrations at both sites, and to investigate the relationship between concentrations and meteorological parameters, including temperature, relative humidity, solar energy, air pressure and rainfall. The Spearman correlation coefficient (r_s) was used to analyze the strength of correlation between these variables. This work also intends to contribute to the understanding of particles dynamic characteristics and the optimization of fresh air inlet positions to reduce particle penetrations into high-rise buildings.

2. Methodology

2.1. Monitoring sites

Nanjing is the capital of Jiangsu Province in East China (32°03′ North, 118°46′ East), with an area of 6587 km^2 and a resident population of 8.18 million by the end of 2013 (Nanjing Bureau of Statistics, 2014). Located at the western part of the affluent Yangtze River Delta, Nanjing is well known as a national transportation hub as well as the economic, cultural and educational center of eastern China. The amount of particles in the urban atmosphere is mainly influenced by vehicle exhaust emissions during traffic peak hours and industrial emissions (Wang et al., 2002). Moreover, Nanjing is surrounded by mountains on three sides, which is not conducive to the dispersion of particles, and consequently particle concentrations measured in Nanjing area are relatively higher than the national average (MEP, 2016).

Two sampling sites were strategically chosen for this field-monitoring study: (1) High-rise building (Site 1), representing the polluted area. The targeted building is a 33-storey office building (100 m), adjacent to a busy road with heavy traffic load at the heart of Gulou business district. Local dominant particle sources are traffic-related emissions, residential discharge and ground dust (Quang et al., 2012); (2) Zijin Mountain forest park (Site 2), the only national urban forest park in China. It is covered with dense plants and stands at an altitude of 448.9 m in the hinterland of Nanjing. This site was chosen to exclude the influence of human activities and industrial emissions. The locations of the two sampling sites are shown in Fig. 1.

2.2. Instrumentation

An air sampler, DustTrak, II Model 8532 (TSI Inc., Shoreview, MN, USA) was used to sample the $PM_{2.5}$ and PM_{10} concentrations, which is widely used in measuring the vertical profiles (Hitchins et al., 2002; Egondi et al., 2016). As a portable sampler, DustTrak uses a 90° light scattering technique in which the amount of scattered light is proportional to the volume concentration of an aerosol. Light emitted from the laser diode is scattered by particles drawn through the unit as a