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# Concentrations and personal exposure to black carbon particles at airports and on commercial flights

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ABSTRACT

The volume of passengers carried by airlines increased by 57% globally in the period 2005–2014. This value is more outstanding when observed regionally, especially in developing countries (for example, Brazil experienced a rise of 121% over the same period). This large growth of civil aviation enhances air pollution levels and poses health risks to passengers, airport workers and the population living close to airfields. We measured black carbon (BC) particle concentrations using hand-held devices within different microenvironments of 12 airports and on 41 non-smoking commercial flights, totalling 154 h of data. The largest BC concentrations were found during boarding and disembarking (mean 3.78 $\mu g\ m^{-3}$), followed by large concentrations at the airport concourse (mean 3.16 $\mu g\ m^{-3}$) and inside parked aircraft with open doors (mean 2.78 $\mu g\ m^{-3}$). BC levels were remarkably low when the aircraft were on the ground with the doors closed (mean 0.81 $\mu g\ m^{-3}$), with incidental relatively high concentrations (BC at 95th percentile = 2.82 $\mu g\ m^{-3}$) suggesting that exhaust plumes from the apron enter the cabin through the ventilation system. The lowest BC concentrations were found during the flights (mean 0.20 $\mu g\ m^{-3}$, 95th percentile = 0.52 $\mu g\ m^{-3}$). The data show that the concourse and the transit to/from the aircraft contributed disproportionally to the personal exposure and accounted for an average of 52% and 19% of the total exposure during a journey, respectively. The results suggest that these two microenvironments should be targeted to reduce exposure of passengers and airport workers to BC particles.

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## 1. Introduction

In recent years, studies on air quality have gained increased attention due to well-established links between exposure to air pollutants and adverse short- and long-term effects on human health (e.g., Beelen et al., 2014; Carey et al., 2013; Crouse et al., 2012). The World Health Organisation (WHO) estimates that only about one in ten people breathe clean air and, as a consequence, outdoor air pollution accounts for 3 million deaths yearly in all regions of the world due to noncommunicable diseases (NCDs), such as cardiovascular and chronic respiratory diseases (WHO, 2016). These figures may be even larger since the WHO estimates only include particulate matter (PM). The health impacts of other pollutants such as nitrogen oxides (NOx) or ozone ($O_3$) have not been factored in. In view of the economic burden to public health systems for treating air pollution related diseases, governments have raised public awareness of the dangers of elevated air pollution concentrations,

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especially those related to on-road vehicle emissions. This led to successful strategies to reduce emissions in areas where population and traffic densities are high, such as the introduction of low emission zones in many European cities (*e.g.*, London, Milan, Munich and Stockholm) with positive outcomes on air pollution levels (Holman et al., 2015; Johansson et al., 2009).

Despite the large number of people exposed to air pollution at airports, studies within this environment received comparatively much less attention. Instead, most research focuses on the characterisation of emissions from aircraft engines (e.g., Petzold and Schröder, 1998; Spicer et al., 1992) and the assessment of air pollution levels at monitoring sites surrounding airports (Hsu et al., 2012; Amato et al., 2010; Westerdahl et al., 2008). The civil aviation sector has grown rapidly worldwide and between 2005 and 2014 the index of revenue passenger kilometres (RPK) – a measure of the volume of passengers carried by an airline – increased 57% globally (ICAO, 2014). Regionally, the numbers can be more dramatic. For example, in Brazil the RPK index increased 121% in the same period, reflecting a 68% rise in the flight volume (ANAC, 2014). This large growth of civil aviation has immediate effect on the enhancement of air pollutant levels at and near airports due to the exhaust emissions from aircrafts and ground service equipment (GSE) responsible for logistics. Airport GSE include diesel-fuelled passenger buses, baggage vehicles, aircraft refuelers, supply trucks, as well as ground power units (GPUs) which provide energy when the auxiliary power units (APUs) on-board the aircraft are not operating (Schäfer et al., 2003).

Aircraft exhaust emits carbon dioxide ($CO_2$), carbon monoxide (CO), NOx, volatile organic compounds (VOCs) including polycyclic aromatic hydrocarbons (PAHs), non-methane hydrocarbons, ultrafine particles (UFP, with diameter less than 100 nm) and black carbon (BC) (e.g., Timko et al., 2010; Herndon et al., 2008; Schürmann et al., 2007; Anderson et al., 2006; Spicer et al., 1992). Hu et al. (2009) found concentrations of 60 s average particle-bound PAHs, BC and UFP of 440 ng $m^{-3}$, 30 $\mu g\ m^{-3}$, and $2.2 \times 10^6$ particles $cm^{-3}$, respectively, matching aircraft arrival and departure times at Santa Monica Airport (California), resulting in ratios of about 90, 100 and 440 times the background levels, respectively. Aircraft emissions also include non-exhaust sources, such as PM from tyres that get worn and burnt during takeoff and landing. Other air pollution sources at airports are due to airport maintenance (*e.g.*, cleaning agents and building repairs) and road traffic in and out of the airport. For example, Ryley et al. (2013) showed that 97% of passenger surface access to Manchester Airport (UK) in 2009 was made by cars and buses. Depending on the proximity to the urban areas and weather conditions, the city's anthropogenic plumes can also enhance pollution levels around airfields.

The complex matrix of air pollutants commonly found at airports poses a health hazard to workers, residents and travelers. A study conducted in the Netherlands (Staatsen et al., 1994) reported that people living near Amsterdam Schiphol Airport complained about coughing and shortness of breath. Tunnicliffe et al. (1999) studied the effect of jet stream pollutants on a sample of employees (baggage handlers, operational engineers, engineering technicians, among others) of Birmingham International Airport (UK) and found that cough with phlegm and a runny nose were significantly associated with occupational exposure to aircraft fumes. However, probably the most compelling evidence of the detrimental effect of airport air pollution on workers' health was the first case of bladder cancer of a Copenhagen Kastrup Airport baggage handler recognised as an occupational disease in 2008. The case triggered actions to measure the air pollution within the airport and the results showed significant differences in exposure levels of UFP among the groups of workers, with baggage handlers exposed to sevenfold higher average concentrations than employees working indoors (Møller et al., 2014). This is partly due to the fact that particulate emission factors for diesel-powered GSE are up to fourfold larger than on-road trucks and buses (Danish Eco Council, 2012) which yield considerably larger UFP concentrations. Despite the small mass of UFP, they pose potential health risks since their size and number – rather than the mass – have been implicated in numerous negative health outcomes (Oberdörster et al., 2005; Nel et al., 2006).

PM is a heterogeneous mix of particles in which the predominance of certain toxic substances are size-dependent and thus, when treated as a bulk, the specific constituents responsible for acute health outcomes remain uncertain. Chung et al. (2015), Rohr and Wyzga (2012) and Kelly and Fussell (2012) advocate that identifying the PM species that are most harmful is of utmost importance to prioritise strategies to abate NCDs. From this standpoint, there has been a consensus within the scientific community to focus on BC particles, since they make up a substantial fraction of ultrafine carbonaceous particles in urban ambient air. For example, Krecl et al. (2015) found correlations greater than 80% between BC concentrations and particle number concentrations in the size range 60–100 nm within a busy street canyon in Stockholm. With regard to aircraft emissions, BC is the primary form of non-volatile PM emitted by jet engines (Timko et al., 2010) and in terms of ambient concentrations, Herndon et al. (2008) found a mode at 65 nm in diameter comprised of BC associated with takeoff plumes and a mode at 25 nm associated with idle plumes at Hartsfield-Jackson Atlanta International Airport.

BC particles consist of fractal-like chain aggregates of small carbon spherules in the 10–50 nm range, are refractory and insoluble in water, have a volatilisation temperature near 4000 K and absorb radiation in the spectral range of visible light (Petzold et al., 2013). The resulting morphology of BC particles offers a greater surface area for adsorption of toxic species than an equivalent solid sphere (Highwood and Kinnersley, 2006). BC is classified as carcinogenic and is also one of the most prominent indicators of negative health effects of airborne particles (Silverman et al., 2012; Ostro et al., 2015). Like any inhaled nanoparticle, BC particles can potentially enter the brain directly through the olfactory nerve (Maher et al., 2016).

We measured BC concentrations using hand-held devices in different microenvironments of 12 airports and on 41 commercial flights, totalling 154 h of data. The purpose of this research was to quantify the variability of BC concentrations at airport areas most commonly visited by passengers during their journeys and calculate the personal exposure for nonsmoking airline users. To the best of the authors' knowledge, BC concentrations have never been measured within these kinds of microenviroments in such detail.

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