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Exposure to airborne particulate matter in the subway system

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HIGHLIGHTS

- Higher PM concentrations were found on platforms compared to outdoor.
- Air quality was better in the new lines with PSDs.
- PM concentrations were higher in the colder than in the warmer period.
- Ventilation and air conditioning systems improve air quality in the subway system.
- Time commuting in the subway contributes substantially to the personal exposure.

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ABSTRACT

The Barcelona subway system comprises eight subway lines, at different depths, with different tunnel dimensions, station designs and train frequencies. An extensive measurement campaign was performed in this subway system in order to characterise the airborne particulate matter (PM) measuring its concentration and investigating its variability, both inside trains and on platforms, in two different seasonal periods (warmer and colder), to better understand the main factors controlling it, and therefore the way to improve air quality. The majority of PM in the underground stations is generated within the subway system, due to abrasion and wear of rail tracks, wheels and braking pads caused during the motion of the trains. Substantial variation in average PM concentrations between underground stations was observed, which might be associated to different ventilation and air conditioning systems, characteristics/design of each station and variations in the train frequency. Average $PM_{2.5}$ concentrations on the platforms in the subway operating hours ranged from 20 to 51 and from 41 to 91 μg m^{-3} in the warmer and colder period, respectively, mainly related to the seasonal changes in the subway ventilation systems. The new subway lines with platform screen doors showed $PM_{2.5}$ concentrations lower than those in the conventional system, which is probably attributable not only to the more advanced ventilation setup, but also to the lower train frequency and the design of the stations. PM concentrations inside the trains were generally lower than those on the platforms, which is attributable to the air conditioning systems operating inside the trains, which are equipped with air filters. This study allows the analysis and quantification of the impact of different ventilation settings on air quality, which provides an improvement on the knowledge for the general understanding and good management of air quality in the subway system.

1. Introduction

Citizens usually spend a considerable amount of their daily time commuting. Considering that in urban areas road traffic is a major emission source of air particles (Viana et al., 2008), travelling by public transportation saves energy and produces less pollution than travelling in private vehicles. The subway, being an electrical system and one of the cleanest public transport systems in large urban agglomerations, is considered to be the most appropriate public transport since it diverts the burdens of superficial traffic congestion. Its high capacity in terms of number of daily commuters makes it an environmentally friendly alternative. The energy efficiency and reduced urban atmospheric emissions make this kind of public transport a powerful tool to reduce energy demands and improve air quality in urban environments.

However, prior studies in subway systems of several cities worldwide indicate, with few exceptions, that particulate matter (PM)

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concentrations are generally higher in these environments than those measured in ambient air (Nieuwenhuijsen et al., 2007). The underground subway system is a confined space that promotes the concentration of contaminants entering from the outside atmosphere in addition to those generated inside. The subway aerosol particles are mainly generated by the abrasion of rail tracks, wheels, catenary and brake pads produced by the motion of the trains, and the movement of passengers which promotes the mixing and suspension of PM (Querol et al., 2012). PM levels have been reported in many subway systems, such as in Milan (Colombi et al., 2013), Barcelona (Querol et al., 2012; Moreno et al., 2014), Taipei (Cheng et al., 2008, 2012; Cheng and Lin, 2010), Seoul (Kim et al., 2008, 2012; Park and Ha, 2008; Jung et al., 2010), Mexico City (Mugica-Álvarez et al., 2012; Gómez-Perales et al., 2004), Los Angeles (Kam et al., 2011a,b), New York (Wang and Gao, 2011; Chillrud et al., 2004, 2005), Shanghai (Ye et al., 2010), Sydney (Knibbs and de Dear, 2010), Buenos Aires (Murruni et al., 2009), Paris (Raut et al., 2009), Budapest (Salma et al., 2007), Beijing (Li et al., 2006, 2007), Prague (Braniš, 2006), Rome (Ripanucci et al., 2006), Helsinki (Aarnio et al., 2005), London (Seaton et al., 2005; Adams et al., 2001), Stockholm (Johansson and Johansson, 2003), Hong Kong (Chan et al., 2002a), Guangzhou (Chan et al., 2002b), Tokyo (Furuya et al., 2001), Boston (Levy et al., 2000), and Berlin (Fromme et al., 1998). However, results are not always directly comparable because of differences in sampling and measurement methods, data analysis, duration of the measurements and the type of environment studied (Nieuwenhuijsen et al., 2007). There are important factors influencing PM concentrations in underground railway systems around the world, which include differences in the length and design of the stations and tunnels, system age, wheel and rail-track materials and braking mechanisms, train speed and frequency, passenger densities, ventilation and air conditioning systems, cleaning frequencies, among other factors (Moreno et al., 2014 and references therein).

Despite the number of studies on PM in underground subway systems, the main focus of most of them has been to monitor variations in mass concentration of PM on platforms and in a reduced number of stations. Therefore, there is a need for extensive studies of entire subway systems, covering the vast diversity of lines, trains and stations and providing an overview of the overall exposure to PM in this environment.

With this in mind, this work is the first study that presents a large dataset from an extensive campaign, able to characterise 24 stations in the Barcelona subway system and providing valuable information for human PM exposure studies in such environment, considering its possible adverse health effects (Pope et al., 2004; Seaton et al., 2005; Karlsson et al., 2006, 2008; Gustavsson et al., 2008). For this, continuous PM measurements were carried out in 4 underground subway stations in Barcelona, on a daily basis during two months and supplementary samplings were also performed in a total of 20 additional stations. Measurements inside the trains were also carried out in 6 subway lines.

In order to gather information on the relationship between pollutant levels and the characteristics of the sampling sites, the measurements were obtained in several subway lines, including stations with different characteristics (design and ventilation of the station and tunnels, number and location of connections with the outdoor level, and train frequency). This monitoring scheme was designed to characterise the temporal and spatial variation of particles at each site and to identify their possible sources. Therefore, the four subway stations studied on daily basis have different characteristics; in particular, one of the stations is equipped with platform screen doors (PSDs) for commuters' safety but also resulting in less mixing of air between the platform and tunnels. The influence of the installed PSDs on aerosol characteristics is also investigated in this work.

2. Methodology

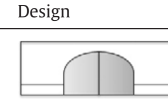
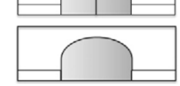
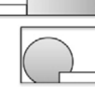
2.1. Field study

The subway system in the city of Barcelona (managed by Transports Metropolitans de Barcelona, TMB) is one of the oldest underground transport systems in Europe, with its first line beginning operation in 1924. By the present decade, the Barcelona subway system comprises 8 lines (3 of them in operation over the last five years) with a total length of 102.6 km and including 140 train stations. The new stations have platforms separated from the tunnel by a wall with mechanical doors (PSDs) that are opened simultaneously with the train doors. Trains run from 5 a.m. until midnight every day, with additional services on Friday nights (finishing at 2 a.m. of Saturday) and Saturday nights (running all night long), with a frequency between 2 and 15 min, depending on the day (weekend or weekday), subway line and time of day. The Barcelona subway absorbs around 50% of the urban commuting load, transporting 1.25 million commuters on weekdays, with the most frequent average journey time being 35 min (Querol et al., 2012).

In all subway systems, two main types of environments are connected: the platform station and the inside of the train. Both types of environments were investigated in this study. Four underground stations with distinct designs belonging to different lines were selected for continuous monitoring in two one-month periods: Joanic on the yellow line (L4), Santa Coloma on the red line (L1), Tetuan on the purple line (L2), and Llefià on the new light blue line (L10). The architecture of the stations and tunnels is different for each station: one wide tunnel with two rail tracks separated by a middle wall in Joanic station and without middle wall in Santa Coloma, a single narrow tunnel with one rail track in Tetuan, and a single tunnel with one rail track separated from the platform by a wall with PSDs in Llefià (Table 1).

The study was conducted in the warmer (2 April–30 July 2013) and colder (28 October 2013–10 March 2014) periods (Table 1), according to TMB ventilation protocols to ascertain seasonal differences. In total, the air quality at each station was measured continuously for 30 days

Table 1
Features of the subway stations and measurement periods.

Subway station (line)	Measurement period		Station	
	Warmer	Colder	Depth	Design
Joanic (L4)	2 Apr–2 May 2013	28 Oct–25 Nov 2013	−7.6 m	
Santa Coloma (L1)	1 Jul–30 Jul 2013	10 Feb–10 Mar 2014	−12.3 m	
Tetuan (L2)	2 May–31 May 2013	25 Nov–20 Dec 2013	−14.8 m	
Llefià (L10)	31 May–1 Jul 2013	13 Jan–10 Feb 2014	−43.6 m