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Screening of short-lived climate pollutants in a street canyon in a mid-sized city in Brazil

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ABSTRACT

Black carbon (BC) and tropospheric ozone (O_3) are two main short-lived climate pollutants also linked to health effects. They are ubiquitous in street canyons, since this environment is a hotspot for traffic-related pollutants due to their particular airflow characteristics, location within the cities and the high density of vehicles and population.

We report on BC and O_3 concentrations measured in a Brazilian city in November 2014. Measurements of BC at 880 nm wavelength were conducted in a street canyon on the north and south façades and at rooftop level (7 wavelengths, including 880 nm) whereas O_3 was recorded only on the south façade. Concurrent meteorological data were gathered at a suburban and a rooftop sites.

Clear diurnal patterns were found for BC related to traffic emissions and atmospheric mixing conditions. Ozone peaked in the afternoon in response to maximum photochemical production and at night most likely linked to vertical and/or horizontal transport. By using conditional bivariate probability functions, we identified on-road traffic as the main local source for BC during daytime, and at night an intermittent signal was associated with local waste and biomass burned on the city's outskirts. A complementary air backward trajectory analysis helped conclude that locally produced O_3 was enhanced by regional transport from large cities and/or biomass smoke.

Mitigation strategies for BC and O_3 depletion should target the vehicle fleet, particularly diesel buses, reduction of biomass and waste burning at local level, and decrease of open biomass burning in large areas in Brazil and neighbor countries.

1. Introduction

Short-lived climate pollutants (SLCP) are species with relatively limited residence time in the atmosphere (from a few days up to a few decades) and contribute directly to global warming due to their strong absorption of electromagnetic radiation in the infrared spectrum. The main SLCP are black carbon (BC) particles, tropospheric ozone (O_3) and methane, and the two former have furthermore direct effects on human health. BC is emitted by incomplete combustion processes (e.g., vehicle and industrial combustion, and biomass burning), whereas O_3 is a secondary pollutant produced by photochemical oxidation of carbon monoxide and volatile organic compounds in the presence of nitrogen oxides (Birks, 1998).

Since O_3 has limited solubility in water, most of the inhaled O_3 reaches the lower respiratory tract leading to several detrimental health effects for short- and long-term exposures, such as reduction in lung function, inflammation of airways, aggravation of asthma and even premature death (Jerrett et al., 2009). Because of their small size (with diameters of the order of nanometers), BC particles can reach the alveolar region, carrying also toxic chemical species deposited onto their porous surface (Janssen et al., 2012). Moreover, the World Health Organization recently reclassified diesel fumes

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—known for containing a high load of BC— from ‘probably carcinogenic’ to ‘carcinogenic’. Hence, the reduction of BC and ozone levels benefit health very immediately and climate in the short term.

To quantify pollution levels and to identify hotspots, it is of utmost importance to monitor air pollutants, especially in urban centers where anthropogenic sources are ubiquitous and population density is larger than in rural areas. Engel-Cox et al. (2013) recommend establishing permanent monitoring networks in cities, with stations distributed across different landscapes in order to capture the effects of land uses on air pollution. However, many countries have unevenly distributed networks, with lower coverage and more information shortfalls in developing countries than in developed ones (Engel-Cox et al., 2013). For example, Denmark —which has a human development index (HDI) of 0.90 and is home to 5.7 million persons— established a national network composed by 18 stations, 6 of which are urban sites in 4 cities with population between 130 thousand and 580 thousand inhabitants (Ellermann et al., 2015). Brazil is the 5th most populated country in the world (204.8 million and HDI of 0.74) and has air pollution monitoring networks in only 9 of the 27 federal units, with most stations located in large metropolitan regions (population over 2 million). Besides the uneven spatial distribution of stations, shortfalls are very frequent due to the lack of maintenance, spare parts and technical expertise (Instituto de Energia e Meio Ambiente, 2014). Thus, the air quality in small and mid-sized Brazilian cities is usually unknown, except for a few dedicated short-term field works conducted to investigate specific aspects of atmospheric processes and pollutants (e.g., Targino and Krecl, 2016; Krecl et al., 2015a, b; Tavares et al., 2004).

Besides incomplete air quality datasets, Brazilian air quality standards date back to 1990 when thresholds values were very permissive compared to current legislation in developed countries. In Europe, air quality standards are more stringent and, for example, the daily maximum 8-h average O_3 concentration of 120 μg m^{-3} should not to be exceeded on more than 25 days per year averaged over 3 years, whereas in Brazil the hourly O_3 level is allowed to exceed the limit value of 160 μg m^{-3} once per year. BC limit values in ambient air are not included in air quality standards (Bond, 2007), but the concentrations are measured at some European sites routinely or within research projects (European Environment Agency, 2013). In Brazil, black smoke —which considers reflectance rather than absorption measurement methods— is regulated with very tolerant thresholds (mean daily value of 160 μg m^{-3}, and mean annual value of 60 μg m^{-3}), but monitoring occurs in just a few stations (11.7% of all stations in the country).

From the air pollution viewpoint, street canyon microenvironments are of particular interest because they present elevated concentrations of pollutants emitted by vehicular traffic under limited dispersion conditions (Rose et al., 2006). For example, measurements conducted in cities across Europe showed that air quality standards for particulate matter concentrations (PM_{10} and $PM_{2.5}$) are exceeded at curbside stations, and especially in canyon configurations (Putaud et al., 2010). Krecl et al. (2014) investigated the spatial distribution of BC across Stockholm using platforms mounted on a taxi fleet, and found the largest concentrations in tunnels and heavily-trafficked highways (median of 62,000 vehicles day^{-1}), followed by canyon streets. Regarding O_3 production, street canyons in central areas of the city have large abundance of O_3 precursors emitted by traffic exhausts which contribute to produce O_3 downwind of the area. Paradoxically, O_3 levels can be depleted inside the canyon due to reactions with nitrogen oxide freshly emitted from traffic (Colette et al., 2011).

This work was conducted in Londrina —a city with 548 thousand inhabitants in Paraná State (southern Brazil). Londrina is considered mid-sized for Brazilian standards, however there is no air monitoring network in the city. Targino and Krecl (2016) showed that BC concentrations across the city have a large spatial variability and are due to local and remote sources, such as traffic and long-rang transport (LRT) of smoke, respectively. This study focuses on BC and O_3 concentrations within a busy street canyon and uses ancillary measurements of traffic data and meteorology to help characterize their patterns, as well as BC data at a rooftop site. Because wind speed (WS) and wind direction (WD) are the most important factors influencing the flow, mixing processes and the pollutant concentrations in street canyons (Krecl et al., 2015a, b; Longley et al., 2003; Ketzel et al., 2003), we also investigated the influence of these variables on the concentrations and explored the possible pollution sources.

2. Methodology

2.1. Study area

The sampling campaign was conducted in Londrina's city center between 05 and 25 November 2014. The city is located in the northern part of Paraná State (latitude: 23.29° S, longitude: 51.17° W) and has a gentle relief with altitudes ranging between 520 and 610 m above mean sea level. Its climate is humid subtropical (Cfa in the Köppen-Geiger classification) with an annual mean temperature of 21.0 °C, annual mean precipitation of 1630 mm and abundant rainfall in summertime (December to February). Londrina has plenty of sunshine throughout the year (average of 2600 h), with a daily mean energy dose of 20.2 MJ m^{-2} in summer and 14.2 MJ m^{-2} in winter. South (29–34%) and southeast (20–25%) winds dominate during autumn and winter (matching periods with frequent cold front passages) and southeast (21–26%) and east (18–20%) winds are typical in spring and summer.

The annual gross domestic product indicates that the service sector is the main economic activity (69%), followed by the industry (14.5%). According to the city's official emission inventory for the year 2011, which includes only industrial and traffic emissions (Grauer, 2013), on-road sources contribute with 99% of the carbon monoxide (31,935 ton/year) and 78% of the nitrogen oxides (2164 ton/year), whereas industries dominate particulate matter emissions (464 ton/year, 67%). The vehicle fleet grew 85% in the last decade, and is largely dominated by passenger vehicles (78%) with the following share according to fuel use: 52% gasoline-powered units, 33% flexible-fuel engines (that run on gasoline, hydrated ethanol or any blend of these fuels), 5% run on hydrated ethanol, and 7% burn diesel (mostly heavy-duty vehicles). To estimate the drivers' fuel choice in flexible-fuel vehicles (ethanol or gasoline), we employed the empirical relationship determined by Goldemberg et al. (2008) for Brazil that considers the ratio of prices for both fuels. In November 2014, this ratio was 67% for Londrina, indicating that 75% of the flex vehicles burned gasoline and 25% hydrated ethanol. In this way, the percentage of vehicles running on gasoline and hydrated ethanol was 78% and 14%, respectively. The automotive gasoline in Brazil was blended with 25% of anhydrous ethanol by volume (E25) in the study period, and the automotive diesel contains 7% of biodiesel since July 2014 with sulfur content of 500 ppm or 10 ppm, the latter for vehicles manufactured from 2012.

Other sources of air pollution are frequent and illegal fire activities to burn domestic waste, clear of leaves and crop residues (Targino and Krecl, 2016), restaurants and pizzerias that burn either charcoal or wood, and LRT of regional smoke, mainly from August to October matching the biomass burning season in South America (Rosário et al., 2013).

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