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Potential utilization for the evaluation of particulate and gaseous pollutants at an urban site near a major highway

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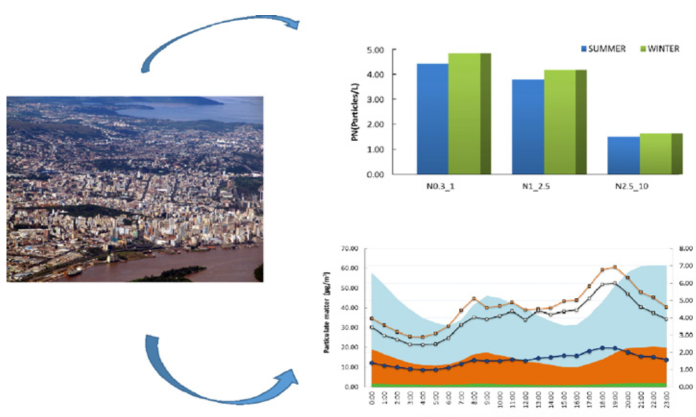
HIGHLIGHTS

- PN concentrations were higher for fine fractions 0.3–1.0 and 1.0–2.5 μm.
- Gases (NO_2, O_3) and PN concentrations were highest during the day.
- NO, NO_x and PM concentrations were highest at night.
- PN, PM and nitrogen oxide concentrations were higher on weekdays than weekends.
- Correlation of particles and gases with meteorological variables

GRAPHICAL ABSTRACT



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ABSTRACT

Works of particle number and mass concentration variability have a great importance since they may indicate better the influence of vehicle emissions in an urban region. Moreover, the importance of this work lies in the fact that there are few studies in Brazil, where the fuel used has unique characteristics. Consequently, this paper presents measurements of particle number (size range 0.3–10 μm), particle mass (PM_{10}, $PM_{2.5}$, PM_1), O_3 and NO_x (NO, NO_2), in a site near a major highway at the Metropolitan Area of Porto Alegre, south Brazil. Measurements were carried out during two years: 2012 and 2013. Particle number and mass concentrations were measured using an optical counter with a PM10 analyzer. Results showed that concentrations of $N_{0.3-1}$ (0.3–1 μm) were the highest, although similar to $N_{1-2.5}$ (1–2.5 μm). Daily variability of the analyzed pollutants followed the traffic pattern. Moreover, NO_2, O_3, and particle number were higher during the day, whereas NO, NO_x, and particle matter showed higher concentrations during nighttime. Traffic influence was evidenced by the mean concentrations of weekends and weekdays, being higher for the latter. Correlation of particles and gases with meteorological variables, together with the application of PCA confirmed the influence of vehicle exhaust discharges.

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1. Introduction

Currently, deterioration of urban air quality due to airborne particulate matter is receiving more attention. In recent years, the understanding of atmospheric particles has been an increasing concern because of their potential adverse human health effects caused by the change in visibility and global climate (Colette et al., 2008; Chen et al., 2010). Airborne particle matter is a complex mixture of many different chemical species (Herrmann et al., 2006) with different physical properties (Pastuszka et al., 2003). These particles originate from a variety of sources such as combustion and chemical reactions in the atmosphere. Between the main sources of particle matter are emissions from vehicles motors and industrial activities, thus the mass concentrations of suspended particulates can be a good indicator for a pollution alert. However, the size distributions and nature of these particles are important parameters for the determination of their potential impact on human health (Renard et al., 2010). The particle size depends on the multiplicity of sources and processes which lead to their formation, and, therefore, on the material from which these particles were formed (Morawska et al., 2008a). For example, particles with different aerodynamic diameters have different lifetimes in the atmosphere and those with size <1 μm (PM_1) can travel for days over distances of several hundred kilometers from the source (Spindler et al., 2010).

Emissions from gasoline and diesel fuelled vehicles remain the dominant source of atmospheric particle number in polluted urban environments (Morawska et al., 2008b). Although, heavy duty vehicles are the less in number in all cities, they contribute more than 50% of particle number and PM_1 emissions (Keogh et al., 2009). With regard to particles emitted by mobile sources, over 90% of the particle number concentrations belong to the <1 μm fraction. Therefore, most anthropogenic sources of pollution are combustion-related and generate PM_1 that represents most of the particle matter that is dispersed in urban environments in terms of particle number. On the other hand, PM_{10} has negligible contribution from combustion processes, although it provides information about the mechanical processes that produce coarse particles. Recent researches have found that both particle number and PM_1, and PM_{10} need to be introduced for to complement existing standards to adequately control particle emissions emitted by motor vehicles than the current standards of $PM_{2.5}$ and PM_{10} (Keogh et al., 2009).

Although automotive vehicles are the main source of fine particles in urban areas, the number and size distribution of particles can change rapidly due to the influence of transformation processes such as coagulation, condensation and turbulence, which improve mixing and dilution (Kumar et al., 2011). Moreover, vehicle emissions are a major source of nitrogen oxides (NO_x), especially in the form of NO (Gaffney and Marley, 2009), causing an almost direct emission in the boundary layer. Diesel engines produce five times more NO_x (by mass of fuel burned) than gasoline vehicles. Furthermore, the addition of biodiesel to diesel can slightly increase NO_x emissions (Coronado et al., 2009). Recent research shows that the proportion of NO_x in the form of NO_2 from diesel vehicle emissions has increased markedly over the past few years, significantly affecting ambient concentrations of NO_2 (Carslaw, 2005; Alvarez et al., 2008; Anttila and Tuovinen, 2010). The types of after treatment used on diesel vehicles result in the increased oxidation of NO to NO_2. These pollutants and atmospheric particles are capable of causing adverse effects on human health (WHO, 2006).

As explained above, current ambient air quality standards for controlling particulate matter pollution are mass-bases and restricted to $PM_{2.5}$ and PM_{10}. Consequently, the current regulations may be unable to effectively control submicron particles emitted from combustion sources such as motor vehicles, which have a much stronger impact on human health and a longer residence time (Aurangojeb, 2011). The current standards may be ineffective for controlling fine particles from mobile sources, which are very numerous in terms of their numbers, but have little mass (weight) (Tittarelli et al., 2008). Particle number provides data of particular importance in epidemiological studies for the evaluation of health effects of particles in ambient air (Slezakova et al., 2007; Tittarelli et al., 2008). Has been suggested by several authors that the number rather than the mass per unit volume of fine particles in air might be more closely correlated with adverse health effects, thus particle number may be an important indicator of air quality. So, current studies and standards needs to include both particle number and mass concentrations measurements to provide a comprehensive assessment of urban air quality, as well as to investigate associations between air pollution and adverse health outcomes (Keogh et al., 2009; Morawska et al., 2008b). For this reason, this work is part of an attempt to investigate the variability of particle number in size ranges $N_{0.3-1}$ (0.3–1 μm), $N_{1-2.5}$ (1–2.5 μm), and $N_{2.5-10}$ (2.5–10 μm) and mass concentrations (PM_{10}, $PM_{2.5}$, PM_1) and their relationship with gaseous pollutants (O_3, NO, NO_2, and NO_x) and meteorological parameters. For the first time, were measured both particle number and mass concentrations continuously for two years. Although, few studies exists analyzing the atmospheric particles number in Brazil, specifically in the area of study (Schneider et al., 2015; Agudelo-Castañeda et al., 2013).

2. Methods

2.1. Study area

The sampling site selected for this study was Sapucaia do Sul, located in the Metropolitan Area of Porto Alegre (MAPA) (Fig. 1). The area of study is the central-eastern part of the Brazilian state of Rio Grande do Sul. According to the Brazilian Institute of Geography and Statistics, this region covers an area of 9652 km^2, representing 3.76% of the state, and has a population of 4.12 million (IBGE, 2013), i.e., 37.21% of the total population of Rio Grande do Sul. The MAPA is the most urbanized area of the Rio Grande do Sul state and is characterized by different industries including several stationary sources: oil refineries, steel mills that do not use coke, coal-fired power plants, and wood burning (Teixeira et al., 2011). Among the 31 counties of the MAPA, Sapucaia do Sul is the major contributor of atmospheric emissions due to its large diesel and gasoline vehicular fleet (Teixeira et al., 2008).

The sampling site (Sapucaia do Sul) was located near the BR-116 and BR-290 highways, which are characterized by heavy traffic. This site was chosen for being located in the county with the highest vehicular influence. The sampling site has a strong vehicular influence characterized by light and heavy-duty fleet, traffic congestion, and slow vehicle speed. This site, too, has low industrial influence (oil refinery, coal-fired power plant, steel mills that do not use coke) upstream from the prevailing winds, as reported in other studies (Teixeira et al., 2012, 2013).

2.2. Equipments: particles, nitrogen oxides, ozone

Particles were measured using a PM_{10} analyzer model MP101M with an optical particle counter, the continuous particulate monitor (CPM) module. The optical counter uses a laser beam to measure the scattering intensity caused by atmospheric particles present in the air sample by applying the Mie scattering theory (Environnement, 2010). The CPM presents a new optical design for solid aerosols counters that detects particulates and classifies them by size ranges. The particulate that crosses the laser beam (635 nm) scatters the light into different directions. A photodiode located approximately 15° from the incident laser measures the intensity of the scattered radiation. At this angle, the intensity of the scattered light does not depend on the nature of the particles, but it is a function of their size (Renard et al., 2010). The calibration factor to convert the number of counted particles into mass concentration is calculated for each new measurement of the PM_{10} analyzer. This enables the adjustment of the value of the average density of the particles which is likely to change with time. Moreover, a temperature regulated sampling line was used for obtaining representative samples of the atmospheric dust to be analyzed. A sampling head PM10 US-