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The role of medium-sized cities for global tropospheric ozone levels

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Abstract

Brazilian medium-sized cities are those showing highest growing rates in the last decades, above 3 % annually. To call attention to the consequences of such strong urban growth on air quality, measurements of ozone concentrations were comparatively performed in Londrina (a growing medium-sized city), Curitiba (a big city) and São Paulo (a megacity). Particularly to the cities of Londrina and São Paulo, both are located at similar latitude (–23.5). Surprisingly, the findings of this study indicated that, there are periods of the year in which the average ozone concentration measured in Londrina can be even higher than those found in large urban areas like São Paulo. The average ozone concentrations at three medium cities are close to those found in São Paulo. It is suggested that the local meteorological conditions (temperature, cloud cover, relative humidity and wind speed), as well as the local chemical regime, could explain the differences in the observed ozone concentrations. As the number of medium-sized urban areas is increasing around the world, especially in South America, special attention should be given by policy makers when defining new air quality monitoring networks and the regulation of new areas planned for the purpose of industrial development.

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Keywords: pollution; radiation; urban area; air quality; medium and large cities

1. Introduction

The interactions among air quality, climate change and human activities are still not quantified and not totally known, in part due to missing local studies, measurements, personnel, budget, and efficient public policies, mainly in developing countries. In these countries, air quality and climate change are not government priority. In South America,

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for example, the network to measure even regulated air quality pollutants is still small and concentrated mainly in large cities as São Paulo, Rio de Janeiro and Belo Horizonte.

Tropospheric ozone is a secondary pollutant and produces harmful effects in health and vegetation, and it is a short-lived greenhouse gas [1–3]. Ozone is formed by photochemical reactions, which have carbon monoxide, volatile organic compounds and nitrogen oxides [4, 5] as chemical precursors. The large number of ozone precursor sources, the complex chemical reactions and the local topography and meteorological conditions (i.e. radiation, temperature and wind) are factors to be considered in ozone studies.

Ozone is a pollutant which has large coverage, due to its free tropospheric has about 22 days of life, and consequently it can be transported to other regions, such as the U.S, the air quality of which is influenced by ozone precursors and ozone coming from Asia [6]. Past studies showed that ozone increased in the North Hemisphere, but since the past few years, a slight decrease has been noted as a result of domestic precursor emissions control [7–9]. Changes in regional ozone levels are associated with transport from other regions and an increase of precursor emissions in complex and non-linear formation processes [9, 10]. Therefore, it is complicated to understand the origins of surface ozone and measurements are fundamental to better understand the regional ozone levels and their trends. As the number of medium-sized urban areas is increasing around the world, especially in South America, appropriate attention should be given by politicians when defining new air quality monitoring networks and the regulation of new areas planned for the purpose of industrial development. To call attention to the consequences on air quality of such strong urban growth, measurements of ozone concentrations have been performed in Londrina (a growing medium-sized city) and comparatively analyzed with the observed concentrations of other medium cities and the Metropolitan Area of São Paulo (MASP) (a megacity region). In addition, we analyzed the global average ozone trends and discussed the potential of medium cities of increasing global average ozone levels, which emphasizes the importance of measurements performed in South America to the improvement of ozone global trends assessment.

2. Methodology

The ozone data was obtained from six monitoring stations, of which three are located in MASP (Ibirapuera, Parque D. Pedro II and Diadema) and three located in medium cities called São José dos Campos, Sorocaba and Londrina. The measurements in Londrina started this year at the Technological Federal University of Paraná and were sponsored by public agencies (CNPq and CAPES). These are the first measurements performed in this region, which can be influenced by transport of pollutants from São Paulo and the Amazonian region [11, 12].

The ozone concentrations have been measured by ultraviolet photometry (Thermo Scientific, model 49i) and recorded with 1 minute resolution. The data for São Paulo (1-5 stations) was retrieved from São Paulo Environment Protection Agency (CETESB). The dataset is validated as follows: the daily average is valid only if at least 2/3 of the hourly averages in that day are valid; the monthly average is valid only if at least 2/3 of the daily averages in that month are valid; and for the annual averages, 1/2 of the daily averages in that year must be valid. The amount of invalid or missing data for the analyzed period is negligible.

According to CETESB, the air quality monitoring in the metropolitan region of São Paulo began in 1972 with the setting up of 14 stations. In 1981, the automated monitoring started and new stations were installed for the evaluation of various pollutants, including ozone. The locations of the stations are shown in Fig. 1.

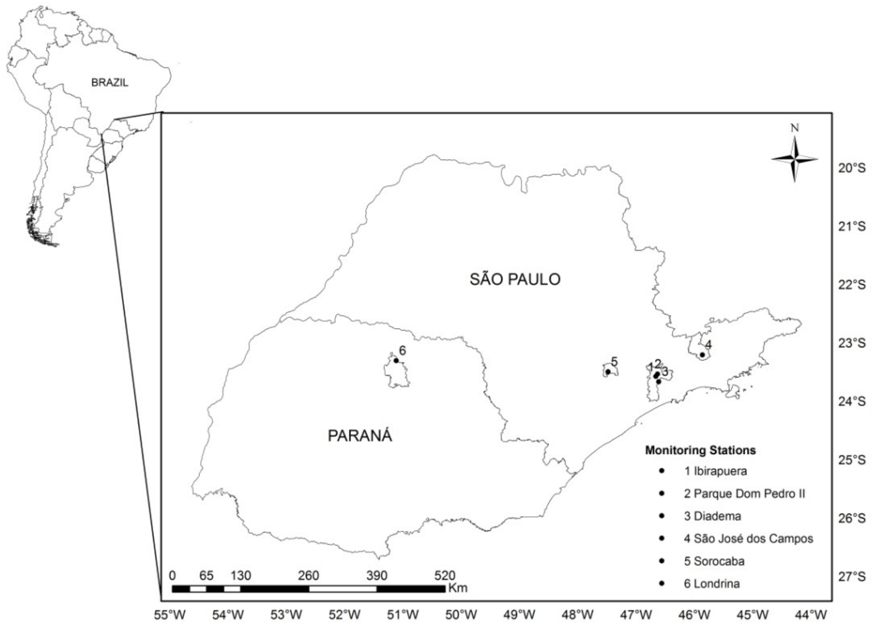

Fig. 1. Map showing the locations of monitoring stations, Brazil.

MASP is between the world's largest urban areas, with about 20 million people and more than 7 million vehicles, which are considered the main source of pollutant emission in this region [13]. The vehicles in Brazil use a large variety of fuels, which include gasohol (made up of 20–25 % anhydrous ethanol and 80–87 % gasoline), hydrated ethanol, compressed natural gas and diesel.

São José dos Campos and Sorocaba are medium cities with about 680 and 630 thousand inhabitants, respectively. They are considered as industrial parks, concentrating important Brazilian industries (food, automobile, aerospace and cement), with a vehicular fleet around 385 and 417 thousands, respectively.

Londrina has over half a million people and about 360 thousands vehicles. The main economic activities are services, trade, agriculture and industry [14].

The meteorological data was retrieved from three public agency databases for the same locations: INMET (National Institute of Meteorology), INPE (National Institute of Space Research) and SIMEPAR (Paraná Meteorological System).

The studied period for the comparison among stations was from 03/19/2015 to 05/05/2015. However, dataset from the last years for stations 1–5 were used to discuss the ozone levels. All data from CETESB used in this work had a resolution of one hour, from which average diurnal variations from ozone, radiation and temperature were calculated, along with daily averages.

In order to assess the correlation between the ozone concentration and meteorological variables, a Pearson correlation coefficient was calculated for each data group. Finally, we used hourly data of ozone surface concentrations measured at Mauna Loa Observatory (155.58 W; 19.54 N) from 1973–2014.

3. Results and Discussion

The number of medium cities, from 100,000 to 500,000 inhabitants, has been increasing in developing countries, especially in South America. Table 1 shows data concerning the population and Gross National Product (GNP) for Brazilian medium cities in 2000, 2010 and 2014.

Table 1. Medium cities population growth and their Gross National Product [14].

Parameters	Year 2000	Year 2010	Year 2014
Number of medium cities*	192	241	266
Population percentage in medium cities (%)	23	25	27
Gross National Product – medium cities	25		27**

Note: Medium cities – 100,000 to 500,000 inhabitants; ** 2012

A clear increase in the number of medium cities is observed in Brazil, which was accompanied by GNP. The growth was of 38 % in population and of 3.6 times for GNP in medium cities. São Paulo megacity presented the smallest population growth, with its average below the national rate.

The population and GNP growth also increase anthropogenic sources, like vehicular activities, industrial and biomass burning. Biomass burning is a critical cultural Brazilian problem, which is a common practice at peripheral areas of cities.

Analyzing the first measurements available for Londrina, we found periods with ozone concentrations higher than those found in large cities as Curitiba and megacity of São Paulo. Figure 2 shows daily average ozone concentrations observed in the six stations.

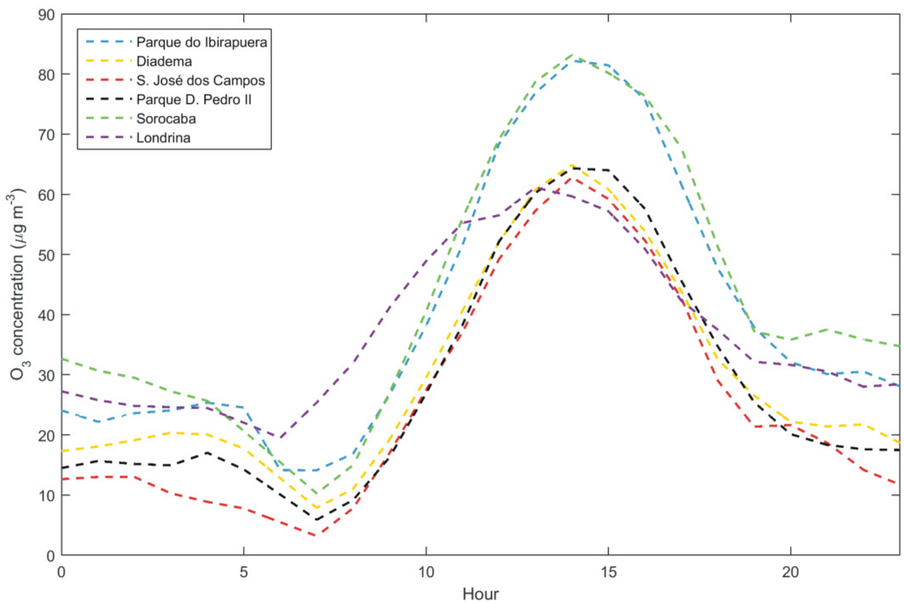

Fig. 2. Daily average ozone concentrations in the six stations.

The ozone profile from the six stations presented some differences in terms of intensity, time of peaks and shape. For stations 1 – 5, the shape and time are similar, but at Ibirapuera and Sorocaba presented higher intensity. Londrina station presented the most different profile when compared to stations 1 – 5. The peak is extended and shows relatively high ozone concentrations at night, probably influenced by transport of ozone from other places.

The typical average ozone concentration in MASP is around 32 μg m^{-3}, with a variation coefficient of 33 % (average for 2008 – 2011) and maximum values occurring in springtime [15, 16]. For Curitiba, the average values are 29 ± 23 μg m^{-3} (2010-2014).

Although the measurements are from a short period, we observed a clear influence of biomass burning, transport and the available radiation as a key to explain the relatively high ozone concentrations observed in Londrina. An important aspect is also the location of measurements stations, which is close to the emission of ozone precursors, except by Londrina that is in the city's peripheral area, which is significantly affected by pollutants from biomass and residues burning.

Table 2. Pearson's correlation between meteorological variables and ozone concentrations.

	Cities	Relative Humidity	Temperature	Radiation
Ozone	Londrina	-0.14	0.14	0.88
	Parque D. Pedro II	-0.75	0.73	0.94
	S. José dos Campos	-0.93	0.95	0.79
	Diadema	-0.19	0.18	0.91
	Parque Ibirapuera	-0.77	0.76	0.94
	Sorocaba	-0.96	0.94	0.91

Ozone has a negative correlation with relative humidity and positive with radiation and temperature as expected. For Londrina and Diadema the correlations are weak with relative humidity and temperature.

The daily profile exhibited for Londrina differs from that of Ibirapuera and Sorocaba; however, the average concentrations for the period are very similar, as shown in Figure 3. The average concentrations of medium cities S. José dos Campos, Sorocaba and Londrina are similar to Ibirapuera, which is located at São Paulo megacity, indicating that medium cities contributed significantly with ozone average levels as well São Paulo megacity.

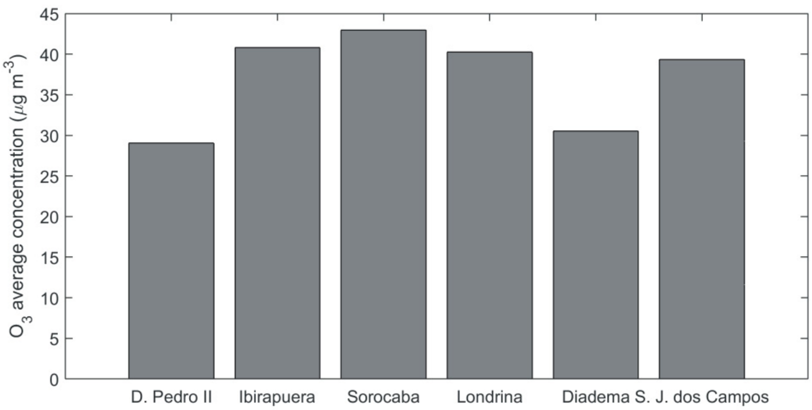

Fig. 3. Average ozone concentrations at six stations.

P. D. Pedro II and Diadema stations are in MASP, but presented lower average ozone concentrations due to the proximity with source of nitrogen oxide emissions (the station is close to a large bus station) and the influence of the sea breeze. Diadema is located in the SE of MASP and received early the influence of sea breeze as compared with Ibirapuera [15, 17]. The influence of meteorological variables, such as wind direction and cloud cover also contributed to the differences [18].

Tropospheric ozone has been increasing since pre-industrial times due to greater VOC and NOx emission by human activities. However, in urban areas these trends are not similar. In some large cities (i.e. Los Angeles, European cities) the urban tropospheric ozone is decreasing, but increasing in the developing countries like India, Brazil and China [1]. Figure 4 shows the ozone concentrations measured at Mauna Loa Observatory to infer about trends in global ozone concentrations. It presents a series of historical data for ozone concentrations, with a trend line indicating an overall increase of this pollutant [19].

A clear increase in ozone concentrations can be noted from 1973 to 2014 as pointed out in studies attributed to increase of ozone concentrations in developing countries, although in Europe and the United States, a decrease is observed [20, 21].

An important aspect that should be taken into account is the contribution of medium-large cities to the increase in global ozone tropospheric concentrations. In megacities like São Paulo, a smooth decrease of maximum values in ozone concentration is observed, as in other large cities in the U.S. and Europe [16]. Therefore, the increase in ozone concentrations in the last years can be due to the growing of medium-large cities in the developing countries of South America and Asia. Policies to support the transition to low carbon society are fundamental to improve the air quality [22, 23].

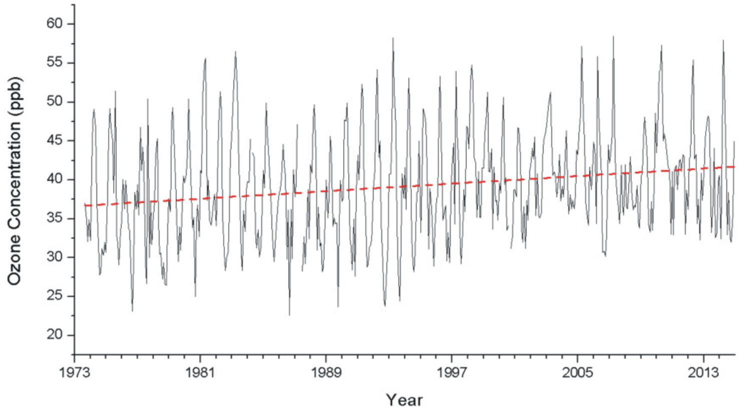

Fig. 4. Mauna Loa ozone concentration series throughout 41 years (1973 – 2014). The trend line is shown in red.

4. Conclusions

As the number of medium-sized urban areas is increasing around the world, especially in South America, proper attention should be given by policy makers when defining new air quality monitoring networks and the regulation of new areas planned for the purpose of industrial development, considering that these cities have been contributing with global ozone concentrations. Finally, more measurements should be performed in South America concerning air pollutants.

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