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COVID-19 pandemic: Impacts on the air quality during the partial lockdown in São Paulo state, Brazil

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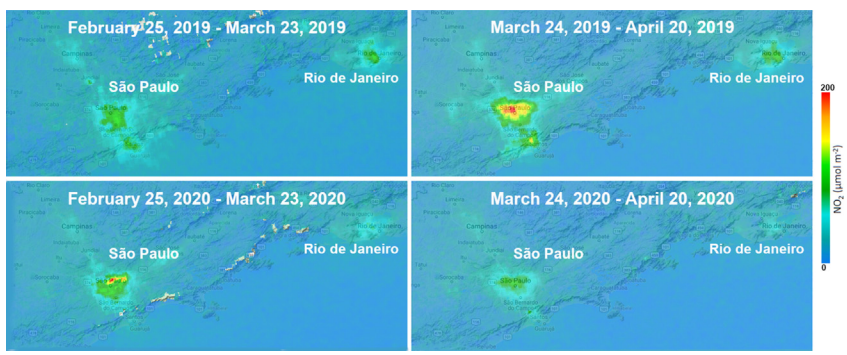
HIGHLIGHTS

- Up to 64.8% decrease in CO concentrations (ppm) were observed in city center
- Up to 77.3% decrease in NO concentrations (μg·m^{-3}) were observed in urban road
- Up to 54.3% decrease in NO2 concentrations (μg·m^{-3}) were observed in urban road
- Approximately 30% increase in O_3 concentrations (μg·m^{-3}) were observed

GRAPHICAL ABSTRACT



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ABSTRACT

In early March 2020, the World Health Organization declared the COVID-19 as a pandemic, and in late March 2020 partial lockdown was ordered by the São Paulo state government. The aim of this study was to assess impacts on air quality in São Paulo – Brazil, during the partial lockdown implemented to provide social distancing required due to the COVID-19 pandemic. We have analyzed data from four air quality stations in São Paulo, Brazil to assess air pollutant concentration variations during the partial lockdown. Data were compared to the five-year monthly mean and to the four-week before the partial lockdown. Overall, drastic reductions on NO (up to −77.3%), NO_2 (up to −54.3%), and CO (up to −64.8%) concentrations were observed in the urban area during partial lockdown compared to the five-year monthly mean. By contrast, an increase of approximately 30% in ozone concentrations was observed in urban areas highly influenced by vehicle traffic, probably related to nitrogen monoxide decreases. Although the partial lockdown has contributed to a positive impact on air quality, it is important to take into account the negative impacts on social aspects, considering the deaths caused by COVID-19 and also the dramatic economic effects.

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1. Introduction

On March 11, 2020, the World Health Organization (WHO) declared that the COVID-19 –disease caused by the new Coronavirus SARS-CoV-2 – had been characterized as a pandemic (WHO, 2020). In Brazil, the first

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case was confirmed on February 26, 2020, in São Paulo – SP. To date (April 26, 2020), there are 61,888 confirmed cases in all regions of Brazil, most of the cases (20,715) confirmed in São Paulo state (Brazil 2020), being São Paulo – SP, the city with most confirmed cases (13,513) (SEADE 2020).

On March 24, 2020, partial lockdown was ordered by São Paulo state government (São Paulo 2020a), closing shopping malls, restaurants, fitness centers, elementary, middle and high schools, and universities. Supermarkets and drugstores started working with restrictions concerning person-to-person distance, and public transportation started working with reduced hours. Since partial lockdown was first ordered, social isolation varied from 54% (March 24), achieving a minimum of 47% (April 09) and a maximum of 59% (several dates), with an average of 54% (São Paulo 2020b).

Recent researches have reported air quality improvements associated with social distancing measures, and consequent decrease of vehicle transit. For example, Zambrano-Monserrate et al. (2020) used the Copernicus Atmosphere Monitoring Service to analyze data of particulate matter ($PM_{2.5}$) in China and observed approximately 20–30% reduction in February 2020 (month average) when compared to monthly averages of February 2017, 2018 and 2019. Tobías et al. (2020) used the Copernicus Tropospheric Monitoring Instrument, and also data from one traffic station in Barcelona (Spain), provided by the local organization for atmospheric pollution monitoring, to assess air quality changes during the lockdown in the city of Barcelona. The authors observed 31% and 51% reduction of particulate matter (PM_{10}) and nitrogen dioxide (NO_2), respectively, during the lockdown compared to the month before the lockdown. Sharma et al. (2020) also analyzed local data from different regions in India, to assess effects of the lockdown on air quality. The authors observed 43% and 31% reduction of particulate matter ($PM_{2.5}$) and particulate matter (PM_{10}), respectively, during the lockdown compared to the same time period of the past four years.

The aim of this study was to assess impacts on air quality in São Paulo, Brazil, during the partial lockdown implemented to provide social distancing required due to the COVID-19 pandemic.

2. Materials and methods

São Paulo is the largest state in Brazil, with a population of 45,919,049 people, and a total of 29,057,749 vehicles. Its capital, São Paulo, is the largest city in Latin America, with a population of 12,252,023 people, and an urbanization rate of 99.1% (IBGE, 2019).

Data from three air quality stations in São Paulo – SP (Urban Road I: Marginal Tietê, Urban Road II: Marginal Pinheiros, and City center) and from one air quality station (Industrial) in Cubatão (an industrial city between São Paulo – SP and Santos Port, Santos – SP) made available by the São Paulo State Environmental Agency (CETESB, 2020) were used to assess the levels of: particulate matter with a diameter of less than 2.5 μm ($PM_{2.5}$), particulate matter with a diameter of less than 10 μm (PM_{10}), Carbon monoxide (CO), Nitrogen monoxide (NO), Nitrogen dioxide (NO_2), Nitrogen oxides (NOx), Sulphur dioxide (SO_2) and Ozone (O_3). For each station, daily data (24 h) from February, March and April of the years 2015, 2016, 2017, 2018 and 2019 were used to calculate the mean levels of each pollutant for each month, and therefore estimate a five-year monthly trend. Similarly, data from February 25, 2020 to March 23, 2020 (four-week before partial lockdown) and from March 24, 2020 to April 20, 2020 (four-week during partial lockdown) were used to calculate the mean levels of each pollutant both before and during the partial lockdown. Furthermore, the variations in mean concentrations (μg·m^{-3}, ppb or ppm) were calculated to assess relative change (%) comparing the partial lockdown period to the five-year monthly trend or to the four-week before partial lockdown.

Table 1
Mean concentration and relative change of: CO, PM_{10}, $PM_{2.5}$, NO, NO_2, NOx, O_3 and SO_2 in São Paulo, Brazil. Five-year monthly mean (2015–2019) and mean of the four-week before partial lockdown (February 25, 2020 - March 23, 2020) and the four-week during partial lockdown (March 24, 2020 - April 20, 2020).

Type of station / air pollutant	Five-year monthly mean (2015–2019)			Mean of the four-week before partial lockdown	Mean of the four-week during partial lockdown	Relative change (%)	
	Feb.	Mar.	Apr.			A	B
Industrial							
PM_{10} (μg·m^{-3})	24.1	24.2	26.1	17.6	22.8	−12.7	+29.4
NO (μg·m^{-3})	19.8	24.0	27.2	22.7	29.4	+8.1	+29.6
NO_2 (μg·m^{-3})	28.0	28.2	31.4	27.1	29.7	−5.6	+9.6
NOx (ppb)	31.0	34.4	38.9	32.9	40.0	+3.0	+21.7
O_3 (μg·m^{-3})	30.4	23.8	25.0	23.2	23.9	−4.3	+2.9
SO_2 (μg·m^{-3})	11.6	10.0	11.1	6.4	7.5	−32.7	+16.2
Urban road I							
CO (ppm)	0.7	0.7	0.6	0.5	0.4	−36.1	−15.8
PM_{10} (μg·m^{-3})	26.2	25.5	30.4	22.1	23.5	−22.8	+6.2
$PM_{2.5}$ (μg·m^{-3})	14.9	15.3	17.8	12.9	12.5	−29.8	−3.6
NO (μg·m^{-3})	56.3	51.1	45.4	28.7	23.3	−48.6	−18.8
NO_2 (μg·m^{-3})	51.3	50.5	50.3	40.6	35.1	−30.1	−13.6
NOx (ppb)	72.7	68.2	63.4	44.8	37.6	−40.7	−16.1
SO_2 (μg·m^{-3})	2.2	2.0	2.3	1.8	1.9	−18.1	+8.0
Urban road II							
CO (ppm)	0.5	0.5	0.6	0.3	0.3	−53.1	−21.8
NO (μg·m^{-3})	20.7	22.9	22.6	8.1	5.1	−77.3	−36.2
NO_2 (μg·m^{-3})	33.3	35.7	37.0	24.0	16.9	−54.3	−29.3
NOx (ppb)	34.5	37.6	38.1	19.3	13.2	−65.4	−31.7
O_3 (μg·m^{-3})	28.2	25.2	28.1	32.3	36.7	+30.3	+13.4
City center							
CO (ppm)	0.4	0.4	0.4	0.2	0.1	−64.8	−29.8
PM_{10} (μg·m^{-3})	21.5	21.8	–	18.9	20.4	–	+7.7
$PM_{2.5}$ (μg·m^{-3})	–	–	–	12.4	12.4	–	−0.3
NO (μg·m^{-3})	9.8	11.2	9.8	4.5	2.7	−72.7	−40.4
NO_2 (μg·m^{-3})	33.1	34.8	35.9	24.4	19.2	−46.5	−21.5
NOx (ppb)	25.6	27.6	27.0	16.6	12.4	−54.2	−25.5
O_3 (μg·m^{-3})	36.4	31.4	33.9	40.2	44.6	+31.5	+10.8

A: Four-week during partial lockdown *vs* Five-year monthly mean for April.
B: Four-week during partial lockdown *vs* Four-week before partial lockdown.
- Data not available.

Nitrogen dioxide (NO_2) data obtained by remote sensing and provided by the Copernicus Sentinel-5 Precursor Tropospheric Monitoring Instrument (S5p/TROPOMI), developed by the European Space Agency (ESA) were used to assess NO_2 levels (Tobías et al. 2020).

3. Results and discussion

Brazil is currently in the autumn season, and thus under good conditions to pollutant dispersion. During winter season São Paulo commonly faces the temperature inversion phenomena, when the air pollutants

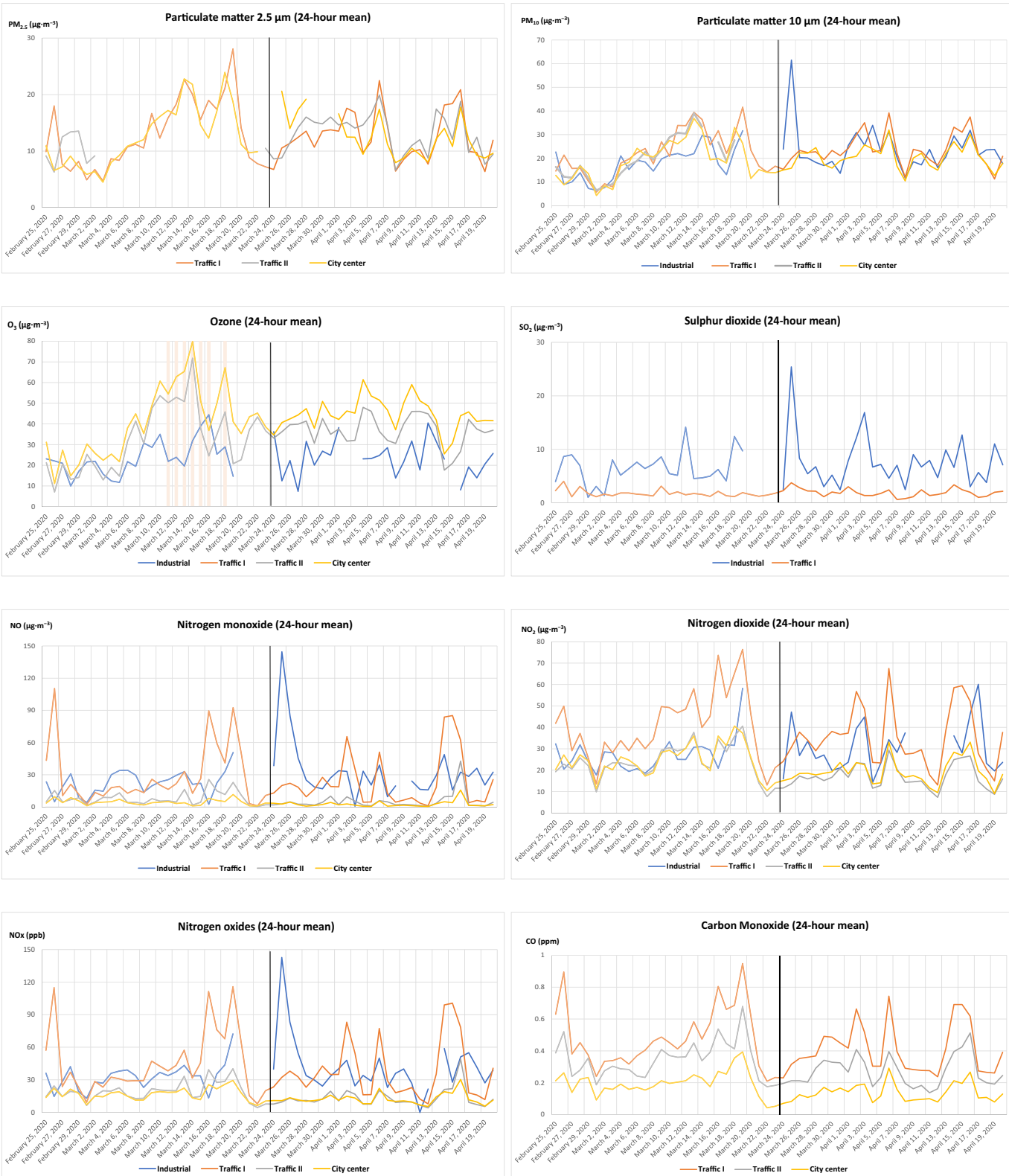

Fig. 1. Daily mean concentrations of air pollutants: $PM_{2.5}$ (µg·m^{-3}), PM_{10} (µg·m^{-3}), O_3 (µg·m^{-3}), SO_2 (µg·m^{-3}), NO (µg·m^{-3}), NO_2 (µg·m^{-3}), NOx (ppb), and CO (ppm) both in the four-week before and in the four-week during the partial lockdown in São Paulo, Brazil. Bars in the ozone graph indicate days with adverse conditions to ozone dispersion.

reach their peaks. Meteorological monitoring data bulletin made available by the São Paulo State Environmental Agency (CETESB, 2020) show that favorable conditions to pollutant dispersion were found both before partial lockdown (February 25 – March 23) and during partial lockdown (March 24 – April 20), therefore indicating that observed pollutant reductions were not highly determined by changes in dispersion conditions. Before partial lockdown, in a few days (March 11–17) adverse conditions to ozone dispersion were observed, and in the same period ozone peaks were detected.

In the industrial area we observed low levels of variation when compared to the five-year monthly mean (2015–2019), and also concentration increases of all analyzed pollutants when compared to the period before the partial lockdown (Table 1). It is important to mention that the industry was not ordered to lockdown, albeit some industrial sectors have been affected by decreasing demand.

In the urban area we observed significant air quality improvements considering decreases in air pollutants monitored in areas highly influenced by vehicle traffic (Urban Road I, Urban Road II and City center) (Table 1 and Fig. 1). High reductions of air pollutants concentration were found during partial lockdown compared to the five-year monthly mean (variation A), while significant reductions were found in comparison to the period before partial lockdown (variation B). Drastic reductions on NO (−48.6%, −77.3% and − 72.7% in Urban Road I, Urban Road II and City center, respectively), NO_2 (−30.1%, −54.3% and − 46.5% in Urban Road I, Urban Road II and City center, respectively) and CO (−36.1%, −53.1% and − 64.8% in Urban Road I, Urban Road II and City center, respectively) concentrations were observed in the urban area during partial lockdown compared to the five-year monthly mean. In São Paulo – SP, road traffic accounts for approximately 68% of NOx and 98% of CO emissions (Andrade et al. 2017). One recent research has demonstrated that traffic emissions from heavy-duty diesel trucks are major sources of NO (He et al. 2020). During the partial lockdown, vehicle traffic considerably decreased in all analyzed areas, positively affecting the air quality. Decreases in pollutant concentrations in Urban Road I were lower than in the other analyzed areas, probably because this urban road is the connecting route for several highways and also is the main route in São Paulo.

The NO_2 concentration reductions can be visualized by satellite measurements of background tropospheric NO_2 concentrations (Gorelick et al. 2017; Tobías et al. 2020) made available by the S5p/TROPOMI-ESA (Fig. 2). The S5p/TROPOMI NO_2 levels over the Metropolitan Area of São Paulo (2100 km^2) decreased during the partial lockdown: −45% compared to the same period in 2019, and − 27% compared to the four-week before the partial lockdown in São Paulo. In the four-week before the partial lockdown, an increase of 12% was calculated in comparison to the same period in 2019, therefore indicating an increasing trend for 2020, and corroborating that the observed reduction in pollutant concentrations were determined by the partial lockdown.

Overall, pollutant concentrations decreased in all analyzed areas. Our study shows a reduction of 29.8% in $PM_{2,5}$, similarly to findings reported by Zambrano-Monserrate et al. (2020). By contrast, we observed an increase of approximately 30% in ozone concentrations in urban areas highly influenced by vehicle traffic. This result is consistent with the recent literature, for example, Sharma et al. (2020) reported an increase of 17% in O_3 concentration in India, and Tobías et al. 2020 observed an increase of 57.7% in ozone concentration in Barcelona, Spain. Ozone concentration increases have been associated with the decrease of NO, which may cause a decrease in ozone consumption, thus leading to a higher ozone concentration (Andrade et al. 2017; Tobías et al. 2020).

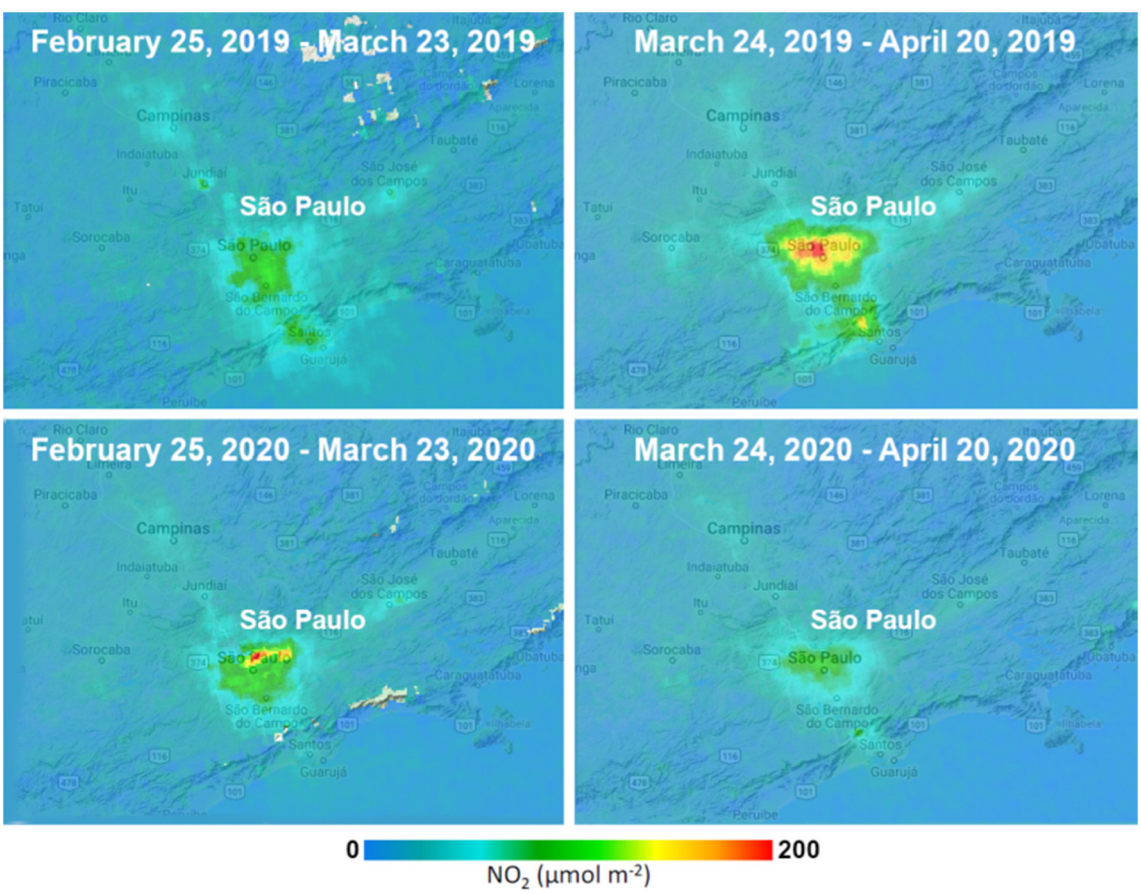

Fig. 2. Mean levels of tropospheric NO_2 measured by the S5p/TROPOMI-ESA both in the four-week before and in the four-week during the partial lockdown in São Paulo, Brazil, compared to the same period in 2019.

4. Conclusions

Even though Brazil is located in the southern hemisphere, and thus present relevant meteorological differences when compared to Europe and Asia, significant air quality improvements were observed during the partial lockdown in São Paulo. Favorable conditions to pollutant dispersion were found both before and during the partial lockdown, therefore indicating that observed pollutant reductions were not highly determined by changes in dispersion conditions. Although the partial lockdown has contributed to a positive impact on air quality, it is important to take into account the negative impacts on social aspects, considering the deaths caused by COVID-19 and also the dramatic economic effects. As a lesson learned, this pandemic brought to light the possible reduction of air pollutant emissions by increasing the use of technology in order to expand remote working.

Credit Author Statement.

Liane Y.K. Nakada: Conceptualization, Methodology, Investigation, Writing - Original Draft.

Rodrigo C. Urban: Conceptualization, Methodology, Investigation, Formal analysis.

Declaration of Competing Interests.

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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