Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Short Communication

Lightning during the COVID-19 pandemic in Brazil

Osmar Pinto Neto a,⁎, Iara R.C.A. Pinto b, Osmar Pinto Jr. b

a Center for Innovation, Technology and Education – CITE, Biomedical Engineering Department, Anhembi Morumbi University, São José dos Campos, 12247-016, Brazil
b Atmospheric Electricity Group (ELAT), Earth Science System Center (CCST), Brazilian Institute of Space Research – INPE, São José dos Campos, 12227-010, Brazil

ARTICLE INFO

Keywords:
Lightning
COVID-19
Brazil
Air pollution

ABSTRACT

This study is concerned with the effects of a decrease in the air pollution concentration on the lightning characteristics of two large Brazilian cities. The decrease in air pollution happened from March 20, till April 02, 2020, and it was caused by the social distancing effort to contain the COVID-19 spread in the cities. In São Paulo, the ratio between cloud-to-ground to intracloud flashes and the average peak current of negative cloud-to-ground flashes significantly decreased; whereas in Belo Horizonte, the ratio between positive and negative cloud-to-ground flashes significantly increased with respect to the values in previous years.

1. Introduction

COVID-19 (coronavirus disease 2019) is an infectious disease caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), previously known as the 2019 novel coronavirus (2019-nCoV). The first cases were seen in Wuhan, China, in late December 2019 before spreading globally. The current outbreak was officially recognized as a pandemic by the World Health Organization (WHO) on March 11, 2020. In Brazil, the first death by COVID-19 was in March 16, 2020 in the city of São Paulo, the largest city of the country, located in the Southeast region. A few days later, in March 19, social distancing of the population started in the largest cities of this region, among them São Paulo and Belo Horizonte, as shown in Fig. 1, considering that isolation can effectively reduce the potential peak number of COVID-19 infections and delay the time of peak infection (Kennedy et al., 2020). As a direct consequence of social distancing, the daily average concentrations of PM2.5 and PM10 decrease significantly in the cities of São Paulo and Belo Horizonte (Table 1). Similar reductions were observed in many cities worldwide (Urrutia-Pereira et al., 2020). This sudden drop in air pollution in consequence of social distancing provided an uncommon great window of opportunity to further study the effects of air pollution on lightning activity.

The effects of aerosol pollution on lightning have been observed in the past in association with smokes from fires (Lyons et al., 1998; Murray et al., 2000; Fernandes et al., 2006) and urban pollution (Nacarato et al., 2003; Mushtaga et al., 2018). Current results suggest a complex and nonlinear relationship between aerosols and lightning, which should be dependent on the concentration and type of aerosols (Farias et al., 2009). The significant reduction in pollution for more than 10 straight days in São Paulo and Belo Horizonte are not common and may help yield new insight into this relationship, which is important to better predict lightning in the future based on global climate models.

2. Material and method

The period chosen to run the analysis was from March 20 to April 02, because after April 02, no lightning was observed in the cities in most of the years. Data for the period from 2015 to 2020 were considered in the study.

The pollution data for São Paulo were provided by the Air Quality Open Data Platform Worldwide COVID-19 dataset project (https://aqicn.org/data-platform/covid19/pt/). With the COVID-19 spreading out all over the world, the World Air Quality Index project provides global data covering about 380 major cities in the world. The pollution data for Belo Horizonte were provided by the State Environment Foundation.

Because lightning depends on thermodynamics conditions, surface temperature and the dew point temperature from meteorological stations of the National Institute of Meteorology (INMET) in the cities of São Paulo and Belo Horizonte were used to compute the cloud base height (CBH). In a simplified way, CBH can be represented by the following equation: CBH = 122(T−Td), where T is the surface air temperature and Td is the dew point temperature. According to some studies (Williams et al., 2003, 2005; Samanta et al., 2020), CBH plays an
important role in controlling the Convective Available Potential Energy (CAPE) transformation into upward kinetic energy to produce thunderstorms and lightning.

Lightning data were provided by the BrasilDAT Dataset (Pinto and Pinto, 2018), a dataset combining data from multiple networks to obtain higher detection efficiency than individual networks.

Fig. 2 shows the infrared (channel 13) GOES 16 images of the thunderstorms responsible for most lightning flashes in the period from March 20 to April 02, 2020: for São Paulo, they occurred on March 29 and for Belo Horizonte, on March 21. In both cases, flashes are produced by thunderstorms associated with an oriented band of convection extending from the Amazon basin to Southeast region and connecting with a frontal system. These synoptic conditions are responsible for all thunderstorms in this period of the year (beginning of Autumn in Brazil) in the cities, as the mean temperatures in this period (between 21 °C and 23 °C) are not sufficient to induce local thunderstorms, common in the summer.

Additionally, Fig. 3 shows the location of the lightning flashes recorded in São Paulo and Belo Horizonte in the days with largest activity in the period from March 20 to April 02, 2020.

3. Results and discussion

Table 1 shows the average daily concentration of PM2.5 and PM10 and the average daily CBH during the period of March 20 to April 02 for the years with lightning from 2015 to 2020 for the cities of São Paulo and Belo Horizonte. It can be observed that the pollution has reduced considerably in 2020 with respect to previous years. In addition, CBH show an average value around 650 m in both cities, with variations by 100 m. In 2020, the value in São Paulo was above average, while in Belo Horizonte was below average. However, based on the results of Williams et al. (2005), these changes have no significant influence on lightning activity.

Table 2 shows a summary of the lightning activity in São Paulo and Belo Horizonte during the period from March 20 to April 02 for the years with lightning from 2015 to 2020 in terms of the total number of flashes, the percentage of cloud-to-ground (CG) flashes, the percentage of positive CG flashes, the average positive CG peak current and the average negative CG peak current. For some years there were no flashes in this period in both cities.

Three points are worth mentioning from Table 2. First, for the city of São Paulo the percentage of CG flashes (4%) is significantly lower than the values in the previous years (p < 0.001), assuming a Poisson distribution (Uitenbroek, 1997). Second, the average peak current of CG negative flashes (10 kA) in 2020 is significantly lower than the values in 2018 and 2016 (p = 0.034), comparing to the 2015 the difference approached significance (p = 0.068). Finally, for the city of Belo Horizonte the percentage of positive CG flashes is significantly higher than the values in the previous years (p < 0.001). All three variations suggest a strong influence of the decrease in pollution on lightning characteristics and that such influence may be different in the cities due to the large differences in the concentration of pollution in the cities. The differences in pollution between the cities are amplified by the fact that most flashes in São Paulo occurred in March 29, while in Belo Horizonte most flashes occurred in Mach 21. It must be observed that although the sudden drop in air pollution, caused by social distancing, enabled us to study the effects of air pollution on lightning activity in these cities, the

---

**Table 1**

Average daily concentration of PM2.5 and PM10 and the average daily CBH during the period of March 20 to April 02 for the years with lightning from 2015 to 2020 for the cities of: (a) São Paulo and (b) Belo Horizonte. The years of 2017 and 2019 were not considered because there were no lightning in the period. na - data are not available.

| YEAR | PM2.5 (µg/m-3) | PM10 (µg/m-3) | CBH (m) |
|------|----------------|---------------|---------|
| (a)  |                |               |         |
| 2015 | 53.5           | 23.9          | 627     |
| 2016 | 54.7           | 23.3          | 667     |
| 2018 | 50.8           | 19.1          | 596     |
| 2020 | 40.8           | 15.9          | 725     |
| (b)  |                |               |         |
| 2015 | na             | na            | 594     |
| 2016 | 9.8            | na            | 721     |
| 2018 | 8.0            | 26.0          | 661     |
| 2020 | 5.6            | 22.7          | 575     |

---

**Table 2**

Summary of the lightning activity in São Paulo and Belo Horizonte during the period from March 20 to April 02 for the years with lightning from 2015 to 2020 in terms of the total number of flashes, the percentage of CG flashes, the percentage of positive CG flashes, the average positive CG peak current and the average negative CG peak current. For some years there were no flashes in this period in both cities.

---

**Fig. 1.** Social distancing in percentage giving by Apple Driving (Apple Mobility Trends Reports, 2020, available from: https://www.apple.com/covid19/mobility) in the cities of São Paulo and Belo Horizonte, during the period from March 10 to April 09, 2020. Also shown in the figure are the values in São Paulo given by the São Paulo government (Available from: https://www.saopaulo.sp.gov.br/coronavirus/isolamento#gsc.tab=0). Data were low-pass filter filtered at 0.09 Hz (Butterworth 4th order), and changes from baseline were considered.
short-period of decreased pollution may introduce noise in the lightning-aerosol analysis that may influence the physical picture. Nevertheless, a decrease in the percentage of CG flashes and an increase in the percentage of positive CG flashes were also observed in a recent study made in China comparing between polluted and clean oceanic regions in the southern South China Sea (Liu et al., 2020). No information about peak current is available in the study in China.

An increase in the percentage of positive flashes has been observed for higher CBH (Carey and Buffalo, 2007; Albrecht et al., 2011), but this fact cannot explain the results found for Belo Horizonte, where a decrease in the CBH was observed in 2020 with respect to the previous years.

Although the details of the influence of the air pollution on lightning are still no clear, we expect that a decrease in the air pollution concentration should increase cloud effective particle radius of ice and liquid water, changing the graupel - ice crystal electrification process and causing the modification of the charge reversal temperature. The different effects observed in each city support previous results that these processes may be nonlinearly related to the concentration or type of pollution (Farias et al., 2009).

Future studies should consider investigating the cloud microphysics of the two cities to help determine the reason behind the reported differences.
Table 2

The lightning characteristics of flashes recorded in: (a) São Paulo and (b) Belo Horizonte in the period from March 20 to April 02 for 2015 to 2020. Three numbers mentioned in the text are highlighted in bold. Some years there were no lightning in this period. *Indicate significant statistical difference compared to previous years (p < 0.034).

| YEAR | Total Number of Flashes | Percentage of CG Flashes (%) | Percentage of Positive CG Flashes (%) | Average Positive CG Peak Current (kA) | Average Negative CG Peak Current (kA) |
|------|-------------------------|-------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|
| (a)  |                         |                               |                                      |                                      |                                      |
| 2015 | 1241                    | 45                            | 1                                    | 22                                   | 20                                   |
| 2016 | 2029                    | 40                            | 5                                    | 24                                   | 22                                   |
| 2017 | 14521                   | 63                            | 10                                   | 17                                   | 22                                   |
| 2020 | 1726                    | 4*                            | 7                                    | 15                                   | 10*                                  |
| (b)  |                         |                               |                                      |                                      |                                      |
| 2015 | 1446                    | 45                            | 3                                    | 28                                   | 18                                   |
| 2016 | 451                     | 59                            | 24                                   | 40                                   | 16                                   |
| 2018 | 275                     | 62                            | 4                                    | 11                                   | 16                                   |
| 2020 | 521                     | 62                            | 54*                                  | 35                                   | 21                                   |

4. Conclusion

This article presents results regarding the effects on the lightning characteristics of a significant decrease in the air pollution concentration (PM10 and PM2.5) of two large cities in the Southeast region of Brazil. The decrease occurred from March 20 March to April 02, 2020, caused by social distancing of the population to combat the COVID-19 pandemic. While in São Paulo the ratio between cloud-to-ground to intracloud flashes and the average peak current of negative cloud-to-ground flashes have significantly decreased compared with previous years, in Belo Horizonte these parameters did not show significant variation. On the other hand, in Belo Horizonte the ratio between positive and negative cloud-to-ground flashes has significantly increased with respect to the values in previous years, while in São Paulo it remained almost constant. Local and synoptic thermodynamic conditions were investigated and could not explain the variations in lightning characteristics. The results indicate that pollution can directly affect lightning characteristics and support previous findings that have suggested that nonlinear effects related to the concentration of pollution are relevant. Finally, future research should consider a detailed investigation of the cloud microphysics of the two cities to better understand the reason behind the differences observed.

Data availability

Lightning data used in this work are available under request to the corresponding author. Pollution data are available in https://aqicn.org/data-platform/register for São Paulo and in http://www.feam.br/.

Author contributions

All authors made substantial contributions to all of the following: (1) the conception and design of the study, or acquisition of data, or analysis and interpretation of data, (2) drafting the article or revising it critically for important intellectual content, (3) final approval of the version to be submitted.

Declaration of competing interest

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.

Acknowledgements

Thanks to Earle Williams of MIT for valuable discussions.

References

Albrecht, R.L., Morales, C.A., Silva Dias, M.A.F., 2011. Electrification of precipitating systems over the Amazon: physical processes of thunderstorm development. J. Geophys. Res. 116 https://doi.org/10.1029/2010JD014756.
Carey, L.D., Buffalo, K.M., 2007. Environmental control of cloud-to-ground lightning polarity in severe storms. Mon. Weather Rev. 135, 1227–1353.
Farias, W.R.G., Pinto Jr., O., Naccarato, K.P., Pinto, I.R.C.A., 2009. Anomalous lightning activity over the Metropolitan Region of São Paulo due to urban effects. Atmos. Res. 91, 405–490. https://doi.org/10.1016/j.atmosres.2008.06.009.
Fernandes, W.A., Pinto, I.R.C.A., Pinto Jr., O., Longo, K.M., Freitas, S.R., 2006. New findings about the influence of smoke from fires on the cloud-to-ground lightning characteristics in the Amazon region. Geophys. Res. Lett. 33 https://doi.org/10.1029/2006GL027744.
Kennedy, D.M., Zambrano, G.J., Wang, Y., Neto, O.P., 2020. Modelling the effects of intervention strategies on COVID-19 transmission dynamics. J. Clin. Virol. https://doi.org/10.1016/j.jcv.2020.104440.
Liu, Y., Guha, A., Said, R., Williams, E., Lapierre, J., Stock, M., Heckman, S., 2020. Aerosol effects on lightning characteristics: a comparison of polluted and clean regimes. Geophys. Res. Lett. https://doi.org/10.1029/2019GL086825.
Lyons, W.A., Nelson, T.E., Williams, E.R., Cramer, J., Turner, T., 1998. Enhanced positive cloud-to-ground lightning in thunderstorms ingesting smoke. Science 282, 77–81.
Murray, N., Orville, R., Huffines, G., 2000. Effect of pollution from Central American fires on cloud-to-ground lightning in May 1998. Geophys. Res. Lett. 28, 2597–2600.
Mushtaga, F., Lala, M.G.N., Anand, A., 2018. Spatio-temporal variability of lightning activity over I&K region and its relationship with topography, vegetation cover, and absorbing aerosol index (AAI). J. Atmos. Sol. Terr. Phys. 179, 281–292.
Naccarato, K.P., Pinto Jr., O., Pinto, I.R.C.A., 2003. Evidence of thermal and aerosol effects on the cloud-to-ground lightning density and polarity over large urban areas of Southeastern Brazil. Geophys. Res. Lett. 30, 1674–1677.
Pinto Jr., O., Pinto, I.R.C.A., 2018. BrasilDATDataset: Combining Data from Different Lightning Location Systems to Obtain More Precise Lightning Information. International Conference on Lightning Detection, Florida, USA.
Samanta, S., Tyagi, B., Vissa, N.K., Sahu, R.K., 2020. A new thermodynamic index for thunderstorm detection based on cloud base height and equivalent potential temperature. J. Atmos. Sol. Terr. Phys. 207 https://doi.org/10.1016/j.jastp.2020.105367.
Uitenbroek, D.G., 1997. SBS Binomial, Southampton, UK.
Urrutia-Pereira, M., Mello-da-Silva, C.A., Solé, D., 2020. COVID-19 and air pollution: a dangerous association? Allergol. Immunopathol. (in press).
Williams, E.R., Mushtak, V.C., Boccippio, D.J., 2003. Another look at the dependence of lightning flash rate on the temperature of boundary layer air in the present climate. In: International Conference on Atmospheric Electricity. Versailles, France.
Williams, E., Mushtak, V., Rosenfeld, D., Goodman, S., Boccippio, D., 2005. Thermodynamic conditions favourable to superlative thunderstorm updraft, mixed phase microphysics and lightning flash rate. Atmos. Res. https://doi.org/10.1016/j.atmosres.2004.11.009.