Lightning-induced wildfire in Serra do Cipó National Park

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Abstract. *Analysis was performed to search all CG lightning most likely to cause wildfires up to 72 h before the fire and within 1.5 km of ignition point detected from each active fire in remote sensing data. The results address some scientific aspects of lightning and wildfires and the connections between the two. The electrical characteristics of the lightning candidates showed negative polarity and peak current below 15 kA. The holdover time between lightning and fire detection was less than 10 h while the spatial distance between lightning candidates and active fires was less than 1 km. This approach provides a useful tool to support the local fire managers in decision-making regarding fire management and identifying the ignition sources of wildfires in protected areas.*

1. Introduction

Wildfire activity in Brazil has greatly increased in recent years, impacting the climate and ecosystems as well as the economy and population health (e.g., Libonati et al., 2020). In recent decades, natural fire regimes have been extensively modified by human activity, especially in Brazil, which is a country with intense use of fire associated with agricultural management and expansion (Schmidt and Eloy 2020; Pivello et al., 2021).

Fire effects can also be beneficial, depending on the sensitivity of the ecosystems to fire, being important for maintaining ecological processes, biodiversity, habitats, and landscape in fire-prone ecosystems (Myers 2006). The Brazilian cerrado biome is an example of a fire-prone ecosystem, which evolved from the development of dry forests under the influence of fire that shaped the species evolution for thousands of years (Ledru 2002; Berlinck and Batista 2020).

Cerrado is also characterized by the occurrence of natural fires by lightning (Ramos-Neto and Pivello 2000; Schumacher and Setzer 2021); although, in the last decades, anthropogenic fires are more frequent in both the fire-adapted cerrado and the fire-sensitive rainforest (Pivello 2011). However, under ongoing global warming, the chance of lightning-induced fire is likely to increase (Price 2009; Li et al., 2020).

The overall goal of this study is to search for lightning candidates and to describe some characteristics such as peak current (kA) and polarity (negative or positive) associated with lightning-induced wildfires in Serra do Cipó National Park, in Minas Gerais State – Brazil, between 2015 to 2020.

2. Data and methods

2.1 Lightning data

We used cloud-to-ground (CG) lightning data for the period 2015-2020 from the Brazilian Lightning Detection Network – BrasilDAT based on technology from Earth Networks (Naccarato et al., 2012). CG strokes included coordinates, date, time, peak current, and polarity information. In terms of accuracy, the BrasilDAT presents an average precision location of 500 m and detection efficiency of 90% for return strokes in some parts of Brazil, included a study area located in Serra do Cipó National Park, Minas Gerais (MG) state (Figure 1).

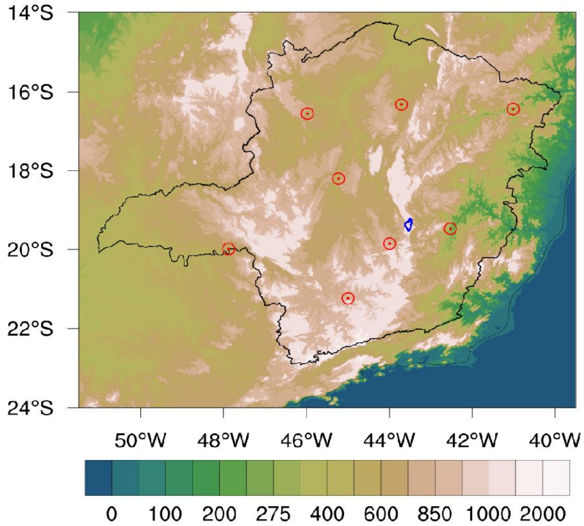

Figure 1. Sensor configuration of the BrasilDAT network with 8 installed sensors in MG state (red points), study region in Serra do Cipó National Park (blue polygon), and main topographic features (m).

2.2 Active fire data

Active fires used in this study were provided by four satellite sensors, namely: Moderate Resolution Imaging Spectroradiometer (MODIS) onboard the Earth Observation System (EOS) TERRA and AQUA polar-orbiting satellites, collection 6 version processed by the National Aeronautics and Space Administration (NASA), with a spatial resolution of 1 km (Giglio et al., 2016); Visible Infrared Imaging Radiometer Suite (VIIRS) of the Suomi National Polar-orbiting Partnership (S-NPP) with a spatial resolution 375 m (Schroeder et al., 2014); the Advanced Baseline Imager (ABI) on-board the Geostationary Operational Environmental Satellite-R (GOES-R) renamed GOES-16, with a spatiotemporal resolution of 2 km every 10 min (Schmit et al., 2017). All overpasses, at day and nighttime, were used and the data were downloaded from the Wildfire Monitoring Program of the Brazilian National Institute for Space Research (INPE), available at http://www.inpe.br/queimadas/.

2.3 Method

In order to select the igniting lightning among all CG lightning strokes, we searched for the probable lightning candidates that occurred up to 72 h (3 days) prior to active fires detection, considering a fixed buffer radius of 1.5 km around each active fire, accounting the location accuracy of both datasets. In the literature, the maximum buffer distance used is 10 km, and the maximum holdover time (phase between ignition and fire detection) of 14 days to account for large location errors of fire and lightning (e.g., Schults et al., 2019; Moriz et al., 2020).

Fire severity was estimated based on steps: i) selected imagery from Landsat 8 OLI imagery for pre-pos fire, according to the method applied by Santos et al., (2019); ii) subtraction of the delta Normalized Burn Ratio (dNBR) between the two scenes to account for the total amount of biomass consumed; iii) flammability index (Setzer et al., 2019). Fire severity was categorized ranging from 0 to 1: low severity < 0.5, median severity $= 0.5$ and high severity > 0.5. For more details about fire severity, see Barros and Macul (2021).

3. Results and discussion

Figure 2 shows the spatial distribution of active fires detected by S-NPP satellite and CG lightning in Serra do Cipó National Park, between 2015 and 2020. The region with the higher distribution of active fires is noted in the central and southwest of National Park, with up to 15 fires/km^2. CG lightning density varies between 10 to 15 lightning/km^2 most of the region, with a maximum of 30 lightning/km^2 in the south of National Park.

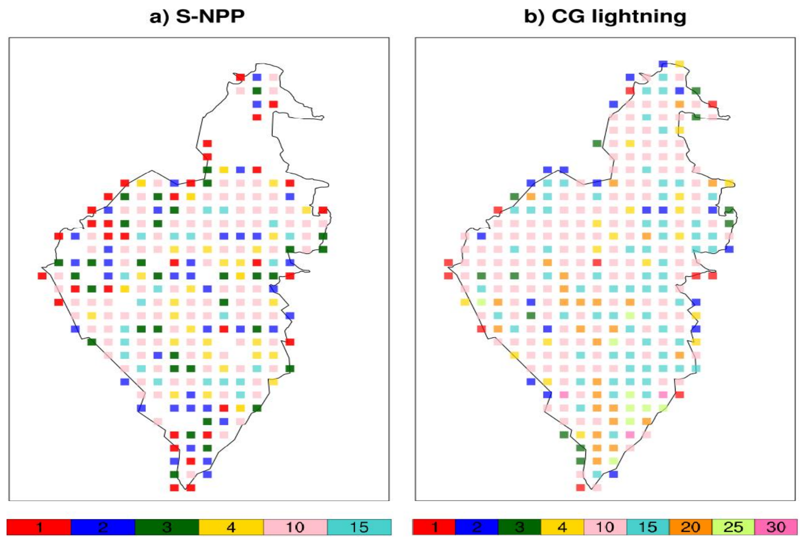

Figure 2. Spatial distribution of a) active fire from S-NPP satellite and b) CG lightning, with 1 km spatial resolution. Label bar values indicate the number of fires or lightning per km^2.

The annual distribution of active fires shows a significant increase in the year 2020, corresponding to 64% of all fires for the period (Figure 3a). The monthly distribution (Figure 3b) shows that the peak of fire occurs in September and October, marked by a transition period between the dry and wet seasons, in which dry weather conditions and litter accumulation favor the ignition and spread of fire (Collins et al., 2019). Alvarado et al., (2017) showed that the dry season length and the distribution of precipitation during the season are the main drivers for increasing fire occurrence at Serra do cipó.

Concerning the annual distribution of CG lightning shown in Figure 3c, there is no clear increase or decrease of lightning activities during the analyzed period. Between 2015 and 2017 there is a slight decrease in CG lightning, while 2018 presents the highest occurrence, decreasing until 2020. Monthly CG lightning activities follow the distribution of precipitation in the Minas Gerais State, occurring mostly during the wet season (Figure 3d).

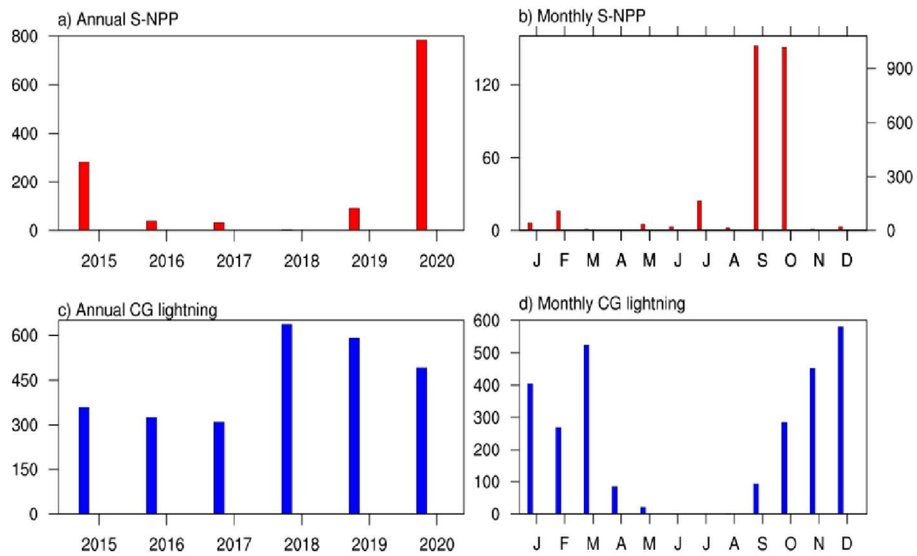

Figure 3. Temporal distribution of a-c) annual and b-d) monthly active fire from S-NPP satellite and CG lightning.

The search for lightning-causing ignition in Serra do Cipó National Park results in candidates associated with only one case of natural fire between 2015 and 2020. The case occurs in 2020, where electrical activity is registered on January 7th at around 4 pm, with a total of 16 CG lightning inside the National Park (Figure 4a). Active fires were detected about 9 h after electrical activity, on January 8th. The TERRA satellite detected one active fire at 1:35 am while the S-NPP five, at around 3:46 am, located in the southwest region of the National Park (Figure 4a). Note that the differences in fire incidence between the sensors are due to distinct spatial and radiometric resolutions. The VIIRS sensor onboard S-NPP detects up to ten times more active fires than the MODIS/AQUA-TERRA satellites.

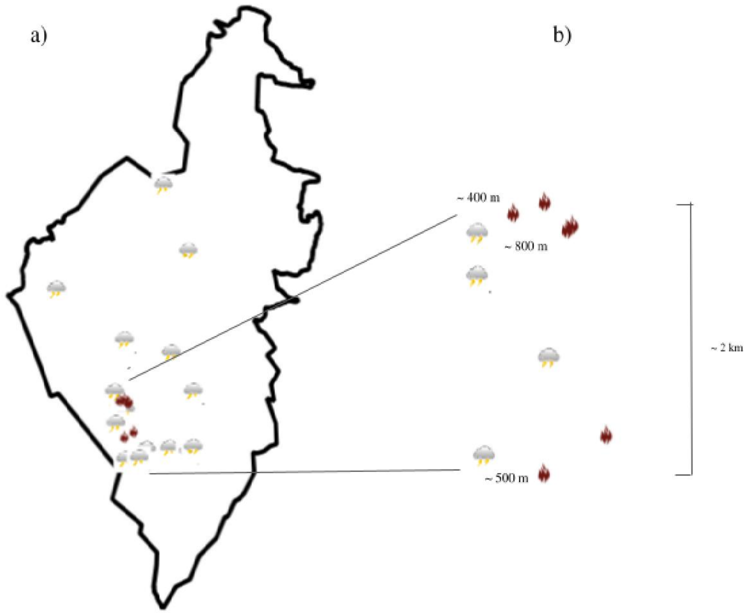

Figure 4. a) Spatial distribution of CG lightning and active fires within Serra do Cipó National Park on the day of natural fire. b) Distances (m) between closest lightning candidates and active fires detected by TERRA and S-NPP satellites.

The distance between the first active fire detected by TERRA and the closest CG lightning is around 800 m, and 400 m in relation to that detected by S-NPP. Further south of the first active fire detected (~2 km) the distance between the CG lightning and fire is 500 m (Figure 4b). Regarding the electrical characteristics of the lightning candidates, both present negative polarity, with the peak current of -7 and -11 kA. Negative peak currents below 20 kA are associated with the presence of long continuing currents (lasting more than 40 milliseconds) which presents greater potential to ignite a fire (Larjavaara et al., 2005; Saba et al., 2010).

Information on meteorological variables from a conventional station Conceição Do Mato Dentro-83589, MG (-19.02 S, -43.43 W), from the National Institute of Meteorology - INMET, located approximately 40 km south of the center of the National Park, records the daily average of air temperature of 26 ºC and relative humidity of 79% on the day of occurrence of the lightning candidates. There is no precipitation on the day of the case and no consecutive days without precipitation, ie, there is a record of precipitation in days preceding the case.

This case of natural fire has been confirmed by the Chico Mendes Institute for Biodiversity Conservation (ICMBio) as a source of lightning ignition. They reported an estimate of 192 ha of burned area, about 0.6% of the conservation area. Other wildfires by lightning events within the National Park were reported, but some cases were not detected by satellite sensors due to quickly suppressed fire while others were reported outside the study period.

To illustrate the burn scars related to the natural fire, we identify the burned area within the National Park, using the shortwave infrared, RGB (12.8A, 4) false-color composite from the Sentinel-2 viewer, of the Sentinel Hub Playground (https://apps.sentinel-hub.com/sentinel-playground). Figure 5 shows a comparison of the region before and after the wildfire event, highlighting the burn scar.

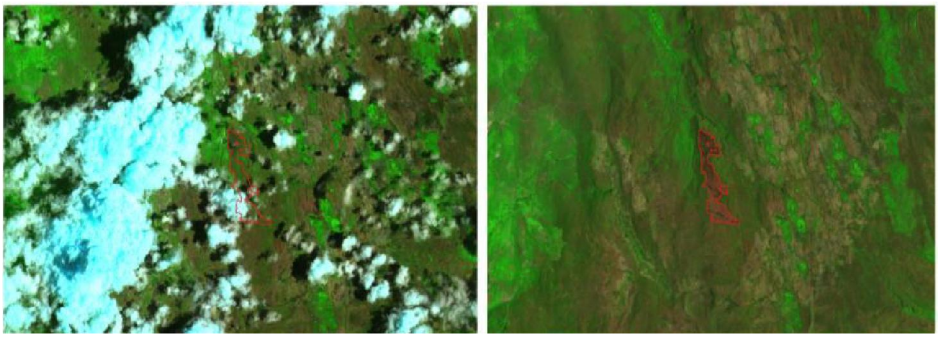

Figure 5. The contrast between pre and post changes images related to natural wildfire in Serra do Cipó National Park, from the Sentinel-2 viewer. Red polygon indicates fire scar.

Additionally, we quantify the fire severity within the extent of the fire-affected area in Serra do Cipó associated with natural wildfire. The approach method is still being elaborated by National Institute for Space Research (INPE; Marco XXX), it is based on the centroid value of each pixel inside the burned scar. Fire severity provides a description of how fire affects ecosystems, related to the loss or change in organic matter caused by fire (Gibson et al., 2020).

Figure 6 shows the spatial fire severity captured on February 2nd, from the burned scar. The average value of fire severity is 0.39, considered low severity. The highest value is 0.42, below 0.5 which is related to medium fire severity. Low severity may indicate that the fire-affected area was not recurrent from other fires, without a severe impact on vegetation. This approach provides guidance to managers about planning and implementing fire suppression in the conservation units.

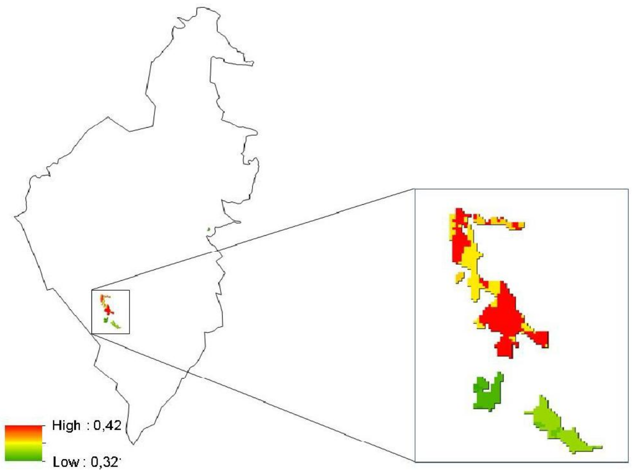

Figure 6. Fire severity with burn scar mapped on February 2, 2020 associated with fire natural event.

These findings imply that most wildfires within the Serra do Cipó landscape are not from natural sources and may be associated with fire propagation that occurs around the National Park, in the Morro da Pedreira Environmental Protection Area, where agricultural techniques with the use of fire still occur (e.g., Alvarado et al., 2017). However, lightning activity is expected to increase under projections of a warmer climate, and hence the potential for lightning-caused fires in the future (Price 2009; Li et al., 2020).

4. Conclusion

The aim of this study was to search for lightning candidates that ignite wildfires in Serra do Cipó National Park from 2015 to 2020, based on active fires detected through satellite remote sensing, according to the distance between fires and lightning in time and space.

It is found one event that could be associated with a lightning stroke, with negative polarity and peak current below 15 kA. The holdover time was less than 10 h between lightning occurrence and fire start detection and the spatial distance between lightning candidates and active fires were less than 1 km.

The results presented here can help local fire managers in making-decision to fire threats in protected areas. These results will also be useful for further investigation into the relationships between lightning and fire risk and severity.

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References

Alvarado, S. T., Fornazari, T., Cóstola, A., Morellato, L. P. C., Silva, T. S. F. (2017) "Drivers of fire occurrence in a mountainous Brazilian cerrado savanna: Tracking long-term fire regimes using remote sensing". *Ecological Indicators*, *78*, 270-281.

Barros, M. A., Macul, M. S. (2021). "Severidade de fogo como um indicador de impacto das queimadas em unidades de conservação. Estudo de Caso: PARNA Serra do Cipó/MG". São José dos Campos: INPE, versão 2011-11-03. Available at: http://mtc-m21d.sid.inpe.br/col/urlib.net/www/2021/06.04.03.40.25/doc/mirrorget.cgi?metadatarepository=sid.inpe.br/mtc-m21d/2021/11.03.16.33.43&languagebutton=pt-BR&choice=fullBibINPE. Acesses 08 November 2021.

Berlinck, C. N., Batista, E. K. (2020). "Good fire, bad fire: It depends on who burns". *Flora*, *268*, 151610.

Collins, L., Bennett, A. F., Leonard, S. W. J., Penman, T. D. (2019) "Wildfire refugia in forests: Severe fire weather and drought mute the influence of topography and fuel age". Glob. Chang. Biol. 25, 3829–3843. https://doi.org/10.1111/gcb.14735

Gibson, R., Danaher, T., Hehir, W., Collins, L. (2020). "A remote sensing approach to mapping fire severity in south-eastern Australia using sentinel 2 and random forest". *Remote Sensing of Environment*, *240*, 111702.

Giglio, L., Schroeder, W., Justice, C. O. (2016) "The collection 6 MODIS active fire detection algorithm and fire products". Remote Sens. Environ. 178, 31–41. https://doi.org/10.1016/j.rse.2016.02.054

Larjavaara, M., Pennanen, J., Tuomi, T. J. (2005) "Lightning that ignites forest fires in Finland". Agric. For. Meteorol. 132, 171–180. https://doi.org/10.1016/j.agrformet.2005.07.005

Ledru, M. P. (2002). "3. Late Quaternary History and Evolution of the Cerrados as Revealed by Palynological Records". In *The cerrados of Brazil* (pp. 33-50). Columbia University Press.

Li, Y., Mickley, L., Liu, P., Kaplan, J. (2020) "Trends and spatial shifts in lightning fires and smoke concentrations in response to 21st century climate over the forests of the Western United States". Atmos. Chem. Phys. 1–26. https://doi.org/10.5194/acp-2020-80

Libonati, R., DaCamara, C. C., Peres, L. F., de Carvalho, L. A. S., Garcia, L. C. (2020). "Rescue Brazil's burning Pantanal wetlands". *Nature* 588, 217–219. doi: 10.1038/d41586-020-03464-1

Moris, J. V., Conedera, M., Nisi, L., Bernardi, M., Cesti, G., Pezzatti, G. B. (2020) "Lightning-caused fires in the Alps: Identifying the igniting strokes". Agric. For. Meteorol. 290, 107990. https://doi.org/10.1016/j.agrformet.2020.107990

Myers, R.L. (2006). "Living with Fire: Sustaining Ecosystems & Livelihoods Through Integrated Fire Management". The Nature Conservancy, Global Fire Initiative.

Naccarato, K. P., Saraiva, A. C. V., Saba, M. M. F., Schumann, C., Pinto, Jr. O. (2012) "First performance analysis of BrasilDAT total lightning network in southeastern Brazil". In International Conference On Grounding And Earthing (GROUND'2012), Bonito, Brazil.

Pivello, V. R. (2011). "The use of fire in the Cerrado and Amazonian rainforests of Brazil: past and present". Fire ecology, *7*(1), 24-39.

Pivello, V. R., Vieira, I., Christianini, A. V., Ribeiro, D. B., da Silva Menezes, L., Berlinck, C. N., Overbeck, G. E. (2021). "Understanding Brazil's catastrophic fires: Causes, consequences and policy needed to prevent future tragedies". Perspectives in Ecology and Conservation.

Price, C. (2009) "Will a drier climate result in more lightning?" Atmos. Res. 91, 479–484. https://doi.org/10.1016/j.atmosres.2008.05.016

Saba, M. M., Schulz, W., Warner, T. A., Campos, L. Z., Schumann, C., Krider, E. P., Cummins, K. L., Orville, R. E. (2010) "High-speed video observations of positive lightning flashes to ground", J. Geophys. Res., 115, D24201, doi:10.1029/2010JD014330.

Santos Júnior, C. A., Bittencourt, O. O., Morelli, F., Santos, R. (2019). "Classificação de áreas queimadas por machine learning usando dados de sensoriamento remoto". In: SIMPÓSIO BRASILEIRO DE SENSORIAMENTO REMOTO, 19. (SBSR), Anais... São José dos Campos: INPE, 2019. p. 1784-1787. Available at: <http://urlib.net/rep/8JMKD3MGP6W34M/3TUPLEP>. Acesses 22 May 2021.

Schmidt, I. B., Eloy, L. (2020). "Fire regime in the Brazilian Savanna: Recent changes, policy and management". *Flora*, *268*, 151613.

Schmit, T. J., Griffith, P., Gunshor, M. M., Daniels, J. M., Goodman, S. J., and Lebair, W. J. (2017) "A closer look at the ABI on the GOES-R series". *Bulletin of the American Meteorological Society*, *98*(4), 681-698.

Schroeder, W., Oliva, P., Giglio, L., Csiszar, I. A. (2014) "The New VIIRS 375m active fire detection data product: Algorithm description and initial assessment". Remote Sens. Environ. 143, 85–96. https://doi.org/10.1016/j.rse.2013.12.008

Schultz, C. J., Nauslar, N. J., Wachter, J. B., Hain, C. R., Bell, J. R. (2019) "Spatial, Temporal and Electrical Characteristics of Lightning in Reported Lightning-Initiated Wildfire Events". Fire 2, 18. https://doi.org/10.3390/fire2020018

Setzer, A. W., Sismanoglu, R. A., Dos Santos, J. G. M. (2019). "Método Do Cálculo Do Risco De Fogo Do Programa Do Inpe-Versão 11", Junho/2019. CEP, v. 12, p. 010.