FIRE PATTERNS IN BRAZILIAN MUNICIPALITIES: RELATIONSHIP WITH THE FIRE PROBABILITY FORECAST

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ABSTRACT

Brazil contains some of the most fire-prone regions in the world, and this motivates the development of a fire probability forecast system. CEMADEN has collaborations with the states of Acre (AC), Goiás (GO), Maranhão (MA) and Mato Grosso do Sul (MS), which use the CEMADEN fire probability forecast data to guide prevention and mitigation actions. In this study, we aim to identify the fire pattern by municipality and the relation between the fire occurrence and fire probability forecast product for each state, using the 2022 January-September period as a case study. Our results demonstrate that AC state has the highest average burned area. GO and MA exhibit similar fire patterns and fire probability forecasts. MS municipalities reach the highest values in three of the fire patterns. We identified that some adjustments could be applied to the fire probability forecast data, aiming to improve its adherence to the spatial gradient.

Key words — *Fire pattern, Fire probability forecast, Climate, Anthropic use*.

1. INTRODUCTION

Fire patterns are determined by the presence of fuel and weather conditions and a source of ignition [1]. In Brazil, this process is complex and heterogeneous due to differences in the natural composition of the biomes and the distribution of climatic patterns across the spatial extent of the country [2]-[3]. In addition, Brazil is considered to contain some of the most fire-prone regions in the world, due to human actions, especially in the new agricultural frontiers in the central region, where the native savannas occur [4].

The use of risk forecasting systems in the context of fire occurrence can help to avoid loss of life and socio-environmental and economic losses [5]. There are platforms that provide fire risk forecasting for South America and Brazil [6]-[9]. Recently, Acre (AC), Goiás (GO), Maranhão (MA) and Mato Grosso do Sul (MS), started collaborations with CEMADEN, by using the seasonal fire probability forecast, produced using Anderson's methodology [6],[10]-[13] to guide prevention actions.

Considering the differences in vegetation types, human activities, meteorological conditions and latitudinal differences in those states, here we assess the forecast product at the municipal scale, aiming to answer two questions: 1. How are the fire patterns characterized in the municipalities by states? 2. How does the occurrence of fire by municipalities vary in relation to the fire probability forecast alerts? Thus, we hope to use this assessment to improve the fire forecast model and strengthen the collaboration with the local institutions by discussing these results.

2. MATERIAL AND METHODS

2.1. Study Area

This research was developed in the municipal scale for the states of AC, GO, MA and MS, where local stakeholders are already using the fire forecast system (Figure 1). The study sites cover areas with distinct latitudinal and anthropic activities, and four of the country's biomes: Amazon, Cerrado, Pantanal and Caatinga.

Figure 1. Location Map of the study areas.

2.2. Data collection and Methodological procedures

The state municipalities' fire patterns were obtained through analyses in NASA's burned area product from Jan-Sep/2022 [8]. The fire probability forecast integrated the fire period across the continent with natural conditions that influence the occurrence of fire [14], and was used in the second analysis, to identify their association with the burnt area dataset. We collect the monthly fire risk forecast dataset from January to July 2022, where each new data represents the forecast for the next three months (for example: the last round represents the forecast for July, August and September) [6]. Finally, we identified the fire type to which the higher warning categories ("high alert", "alert" and "attention") are associated and analyzed the spatial distribution of the municipalities with these categories.

3. RESULTS

The results were structured to answer two main questions: 3.1) what are the fire patterns by municipality for each state; and 3.2) what is the relationship between fire occurrence and the fire probability forecast, and how does this vary spatially.

3.1. Municipalities fire patterns

The AC state has the highest values of average burned area by the municipality and the largest number of municipalities with fire occurrence areas between 55 ha and 70 ha (Figure 2a). The burning duration had a mean of three days, with less than 20 hotspots on average recorded for each municipality (Figure 2b, 2c). In addition, the AC state exhibited the highest values of maximum flame intensity, 300 W, given by the fire radiative power (FRP) (Figure 2d).

We identified a similar general pattern in the distribution of values up to the third quartile between the GO and MA municipalities (Figure 2a; 2b; 2c). The difference is that MA has a higher concentration of municipalities with an average burned area of less than 50 ha, while the concentration in GO has an average burned area above 50 ha. In the case of fire intensity, MA has a higher mean of municipalities with higher values (Figure 2d), compared to GO. Both GO and MA contain municipalities where flame intensities greater than 250 W were observed

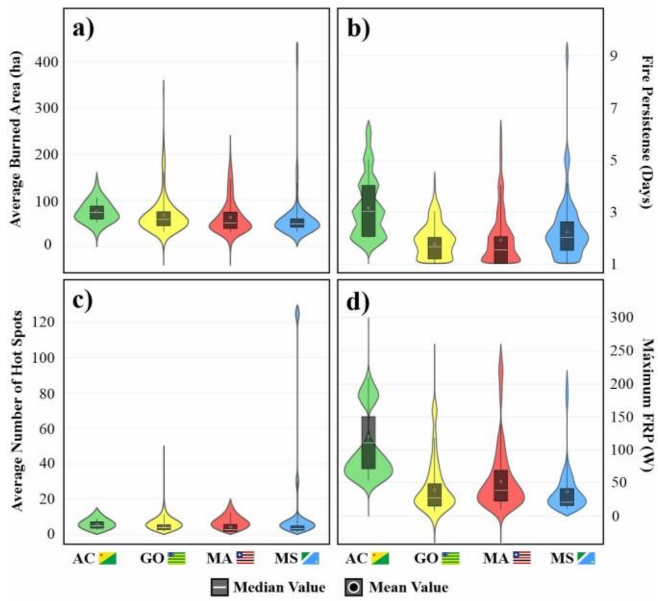

Figure 2. Fire patterns by municipalities for each State.

In MS, most municipalities have an average burned area of less than 50 ha, although for some municipalities this value can reach more than 400 ha (Figure 2a). MS is also the state containing municipalities with the highest fire persistence, with the same area burning for up to nine days, and municipalities with the highest mean number of hotspots. Despite it, MS shows lower variability in fire intensity (Figure 2b; 2c; 2d).

3.2. Forecast of fire risk in municipalities

The burned areas and hotspots in AC follow the pattern expected by the seasonal fire forecast, with the larger extent of burned area occurring during a period when the fire warning status was “alert” (Figure 3). The largest number of municipalities in AC were under the “observation” status during the period analyzed. However, in these municipalities, the burned area only reaches 20% of the value burned in the municipalities that were on “alert” status.

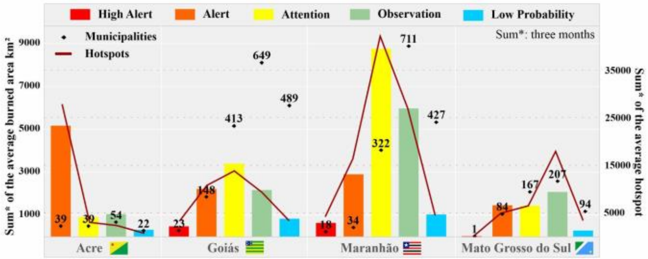

Figure 3. Relationships between forecast warning status and observed burned areas (left axis, bars) and hotspot counts (right axis, lines), for each State. The numbered points represent the three-month total number of municipalities under each forecast category.

For GO and MA we observed the same pattern in both burned area and number of hotspots, with the increase in the burned areas and the number of hotspots from the "high alert" to "attention" status, then decreasing until "low probability" status (Figure 3). In addition, there are large areas under "attention" and "observation" status, due to the high number of municipalities that were under levels of 1062 and 1033 respectively, in the states of GO and MA. For these two states, in all cases the values recorded for GO and MA for burned areas and hotspots in higher warning categories exceed the lower categories ("observation" and "low probability") by factors of about 2.

MS follows the expected pattern, with more burned area in municipalities with higher warning status, with 17.4km² on average by each municipality (Figure 3). The number of hotspots occurring in areas under the "alert" status is 72.5% lower than under the "observation" status.

The averages of burned area in municipalities that presented the higher warning categories in AC were mainly related to fires derived from deforestation (57%) and agriculture (27.9%) (Table 1). In GO, MA and MS the predominant fire type is associated with savanna and grassland, with 97.2%, 82.8% and 82.6%, respectively.

	Deforesta-tion Fires	Savanna / Grasslands	Clearing / Agriculture	Understory
AC	2358,8	533,69	1156,69	88,41
GO	52,27	3817,40	46,35	12,80
MA	600,66	6947,77	580,76	262,55
MS	124,01	1123,79	98,05	14,95

Table 1. Sum (km²) of the average area burned in the trimesters with the higher warning categories by fire type.

All municipalities had high warning status in AC at some point in the time series, with the same status recurs from two to six trimesters (Figure 4a). In GO and MA, the recurrence of the highest warning status was distributed in their border areas, and only those two states had a higher warning category during the seven trimesters, in two municipalities in each one (Figure 4b; 4c). In addition, 23 and 83 municipalities in the states of GO and MA, respectively, had no high warning status during the period. These areas were concentrated in the central-south of GO and central-north of MA. In MS, there is a distribution of the trimester recurrence of the highest alerts, between five and six, throughout the state's central portion, and the lowest recurrences in the surrounding areas (Figure 4d).

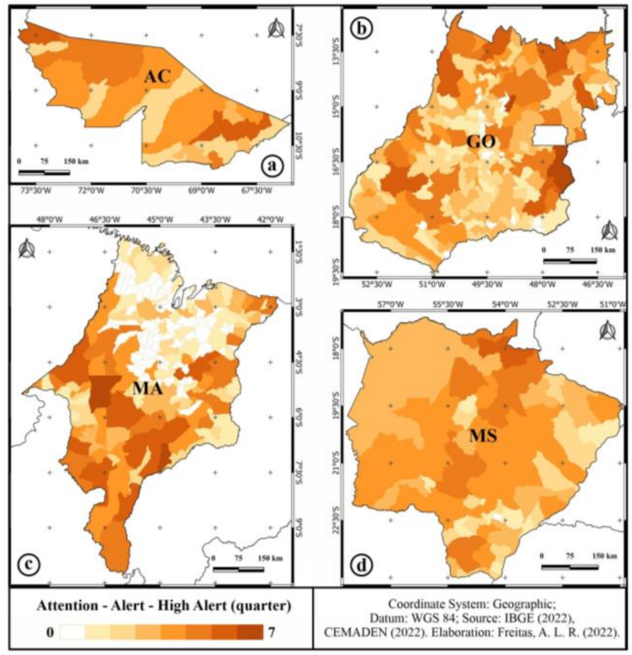

Figure 4. Number of forecasts of warning status of "attention" and above during the 7-month study period. The forecast was issued at monthly intervals, and each forecast was for the next 3 months.

4. DISCUSSION

Fire intensity is related to the amount of fuel available to burn [15]. This can explain the results found to AC, that had the highest FRP and the fire type related to deforestation and agriculture. In the other states, the maximum FRP is, on average, lower than that found for AC. The high values in these states may have burning related to deforestation, agriculture and understory.

The Amazonian anthropic activities and their environmental characteristics are different from other Brazilian biomes [1]-[3]. The dry season definition used in the fire probability forecast model considers a fixed value of water stress (100 mm/month) for the entire continent [14]. Therefore, it is important to consider a dry season threshold definition compatible with other ecosystems in the fire probability forecast to fit fire-related dry season patterns and the anthropic uses across states. Thus is particularly relevant for the GO and MA states, where there was a large amount of fire occurrence in municipalities with this warning category.

This pattern can fit in the Amazon portion of MA, but not in the rest of the state, which covers Caatinga and Cerrado. This may explain the absence of any higher warning status for municipalities in these states, once we identify in our results the occurrence of burned areas in municipalities with lower warning alerts (observation and low probability).

In MA, the occurrence of fires can be confused between natural and anthropic origin, even when the occurrence is concentrated in the agricultural frontier of MATOPIBA [4], [16]. More than 56,000 km² of forest were converted into agricultural areas in MA between 1985 and 2021 [17].

Despite lower values of burned area and a lower recurrence of higher warnings, in MS the transition from forest to agricultural areas was 53,000 km² [16]. One contributing factor is that during 2022 they registered the lowest hotspot occurrence in the last four years, with 51.9%, 11.7% and 10.5% of the average in the trimester Jul-Aug-Sep [18]. However, it is important to consider more information about anthropic activities, such as emerging agricultural frontiers, in addition to the variability already considered as part of the fire probability forecast.

5. CONCLUSIONS

A forecast system is a fundamental tool to avoid loss of life, to reduce socio-environmental damages and minimize economic losses. However, it demands a continuous configuration and adjustments to set it up for each region.

The current forecast system assessed for Acre, Maranhão, Mato-Grosso do Sul and Goiás show an adequate accuracy for two of them, AC and MS, for this case study. In AC, the results are consistently adherent to the biome characteristics.

The other two states registered many municipalities with the "attention" and "observation" categories in GO and MA. In these warning categories, we had a greater amount of burned area, which can be explained by the high number of municipalities. Since even with lower categories, if the number of municipalities is high, it is more likely that they will sum a large extent of burned areas, influencing the result, as identified in this research.

On the other hand, the results found for these two states, GO and MA, may indicate the need for adjustments, mainly considering anthropic activities. It is suggested a reassessment of alert level definitions.

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