QUANTIFYING THE FIRE THREAT AT THE SOUTHWESTERN AMAZONIAN TRANSNATIONAL FRONTIER

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ABSTRACT

Active fires in the landscape are an increasing threat to forest degradation in the Amazon. Although human ignited sources account for the most fire events in Amazon, climate changes may magnify its occurrence. We investigated the occurrence of fire and climatic anomalies in the southwestern Amazonia from 2003 to 2021. We gathered active fire and climate data to identify monthly anomalies in fire occurrence, total precipitation, consecutive dry days, and mean temperature. Additionally, we quantified the frequency of the anomalies along a 0.25ºx0.25º grid cell. Our results demonstrated that fire anomalies have been increasing in Acre and Madre de Dios in the last 10 years. Conversely, Pando have presented a decreased in the across grid anomalies during the time-series. Only total precipitation anomaly has increased over the last period. Overall, although climate impact extreme fire events, their increase may be related to aspects not addressed in this study.

Key words **—** Fire activity, climate change, drought, fire anomaly, MAP region.

1. INTRODUCTION

Active fires in the landscape are an increasing cause of forest degradation in the Amazon, representing great socioeconomic and environmental damage [1]. Land use and land cover changes such as deforestation for expansion of agricultural activities, and urban development are some of the fire drivers in tropical forests [2]. In addition, climate changes may magnify the fire occurrence and propagation by providing suitable conditions to it such as extended droughts [3].

Extreme weather events in Amazonia such as extended droughts are examples of how a negative climate can maximize the threat of active fires in the landscape. For example, in 2005, the transnational frontier among Brazil, Peru, and Bolivia was under the influence of an extended dry season which maximized the effect of human-ignited fire over 300,000 hectares of standing forests. The affected Brazilian portion (250,000 hectares of rain forests) represented over US$50 million of direct economic losses [4]. Afterwards, a considerably increase of 36% in number of fires has been reported during the prolonged droughts of 2015/2016 [5]. Lastly, during 2019 and 2020, an extensive fire crisis related to the increasing rates of deforestation and no extended dry season has been reported all over Amazonia [6], mainly in the Brazilian portion, which denotes the need for a more detailed investigation of fire conditioning factors in the region.

The increase in fires may undermine the ambitions of forest conservation and restoration programs planned in international agreements and policy initiatives for the coming years such as REDD+ (Reducing Emissions from Deforestation and forest Degradation). Tropical forests play an important role as carbon reservoirs. However, fire-affected forests may show a reduction of 24.8 ± 6.9% in carbon stocks due to increased mortality in the Amazon, resulting in a negative balance between carbon emission and carbon sequestration [7].

Understanding the risks and effects of climate change and land use on the dynamics of fires are fundamental for the socioeconomic and environmental fire risk planning of the Amazon region. Therefore, we investigated the occurrence of fire and climatic anomalies in the transnational frontier among Brazil, Peru, and Bolivia from 2003 to 2021.

2. MATERIAL AND METHODS

2.1. Study Area

The study area encompasses the transnational frontier cross-border Amazonian region between Madre de Dios (Peru), Acre (Brazil) and Pando (Bolivia), locally known as MAP region, and it is composed of approximately 91% of primary forests. The region is considered one of the most biodiverse ecosystems in the world [8], represented by tropical rainforest formations such dense and open tropical rain forests with flooded and non-flooded areas. Additionally, the region hosts at least 30 different ethnicities of indigenous people.

Because the area is a cross-border region among three countries, it is under the influence of different social economic contexts and political interests, which makes the MAP region strategic for studies on forest conservation and mitigation programs, and fire risk assessment. The non-aligned context of public policies, and political interests among the three countries may magnify the advancement of

deforestation in distinct patterns, impacting the fire dynamics since it shows to be positively associated with deforestation [9]. In 2020, the annual deforestation rates increased 137% compared to 2012 [10].

2.2. Data preparation

We used active fire and climate data to represent fire occurrence and climatic fire drivers, respectively. All input data are listed and described in Table 1.

Description	Spatial resolution	Source
Daily active fire data	1 km	MODIS/AQUA
Monthly mean temperature	0.25º	ERA/ECMWF
Monthly total precipitation	1 kmº	CHIRPS
Consecutive dry days	0.1º	CEMADEN

Table 1. Input data.

Satellite daily active fire product from 2003 to 2021 was used to represent the aggregate of fires detected in pastures, agricultural lands, degraded areas, and recently deforested areas in a minimum of one square kilometer during an afternoon overpass of the Aqua/MODIS satellite in the region. The active fire product was obtained from Fire Information for Resource Management System (FIRMS) platform (https://firms.modaps.eosdis.nasa.gov/). In addition, we removed from the final active fire dataset all active fires with a confidence level lower than 30%.

Climate data were used as a measure of water and temperature stress in forests. In this study, we included monthly total precipitation, consecutive dry days, and mean temperature from 2003 to 2021.

The monthly total precipitation is provided by Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) platform (https://www.chc.ucsb.edu/data/chirps), and it has been available since 1981 with a spatial resolution of approximately 1km. In addition, we used the number of consecutive days with precipitation less than 1 mm hereafter adopted as consecutive dry days (CDD). The data was provided by the National Center for Monitoring and Alerts for Natural Disasters (CEMADEN) [11], and it was also used as an indicative of water stress. This metric was derived from CHIRPS total daily precipitation from 2003 to 2021 with a spatial resolution of 0.1º.

The monthly temperature data is an atmospheric reanalysis product from the European Center for Medium-Range Weather Forecasts – Copernicus Climate Change Service (ECMWF) that combine climate model data with observations around the globe to estimate the surface temperature at 2 meters height. These products are available from 1979 to the present with a spatial resolution of 0.25º.

2.3. Time series evaluation and monthly anomalous events

In this study, we performed an evaluation of monthly anomalous events based on the monthly total precipitation, maximum consecutive dry days, and monthly mean temperature for each state/department of MAP region. Also, we employed a spatially approach to identify anomalous events in maximum monthly active fire count as well as its frequency. To carry out the assessment, we divided the time series into four periods so that the first three periods a major drought event was considered, and the last with no major drought event. The periods were 2003-2006, 2007-2011, 2012-2016, and 2017-2021.

Initially, we resampled all data to a 0.25º x 0.25º spatial resolution grid. For each grid cell, we calculated the total count of active fires, mean values of total precipitation and temperature, and maximum consecutive dry days.

Next, we calculated the anomaly for each variable according to [9]. The anomaly is expressed as the normalized standard deviation of the monthly accumulated value of the corresponding variable per cell (equation 1).

$$Anomaly = \frac{X_i - \mu_{2003-2021}}{\sigma_{2003-2021}} \qquad \text{Eq. (1)}$$

where i is the observed month (January to December), X is the value of each variable in a given month, μ is the historical mean of each variable, σ is the standard deviation of each variable for the entire time series (2003 to 2021).

In this study, a cell was considered anomalous in a given month if the value for the grid cell was at least |1.65| standard deviation, corresponding to the 90% confidence level of the distribution.

Finally, we calculated the frequency that each grid cell was taken as anomalous in each period. Also, we assessed the extension of the anomalous events by calculating the proportion of them in each state/department.

3. RESULTS

From 2003 to 2021, it has been detected approximately 254.000 active fires all over the MAP region. Acre alone concentrated 68% of all detected active fires, followed by Pando with 22.4% and Madre de Dios with 9.6%.

Historically, the MAP region presented the highest active fire count only during the major droughts of 2005, 2010, and 2015/2016. Conversely, the number of active fires has been increasing continuously over the last period (from 2017 to 2021). In fact, 2021 recorded the greatest number of active fires (16,043) in the region since 2010 (18,083), surpassing the fires detected during the 2015/2016 drought (14,539).

The occurrence of fires in the transnational frontier among Brazil, Bolivia and Peru mostly concentrated from August to October, with the peak of fires centering in September. On average, the three months period concentrates more than 90% of annual active fire records, and approximately 53% of them occurring only in September.

As shown in Figure 1, more than 60% of the studied area has been anomalous at least once from 2003 to 2021. The last period presented the greatest extent of area (72%) with fire anomalies in the MAP region. Additionally, 62% of the area have been anomalous less than six times on average for each studied period, and 5% more than six times.

At state/department level, the number of across grid cells with fire anomalies have been increasing in Acre and Madre de Dios, mainly in the last 10 years (Figure 1e). Conversely, Pando have presented a decreased in the across grid anomalies during the time-series.

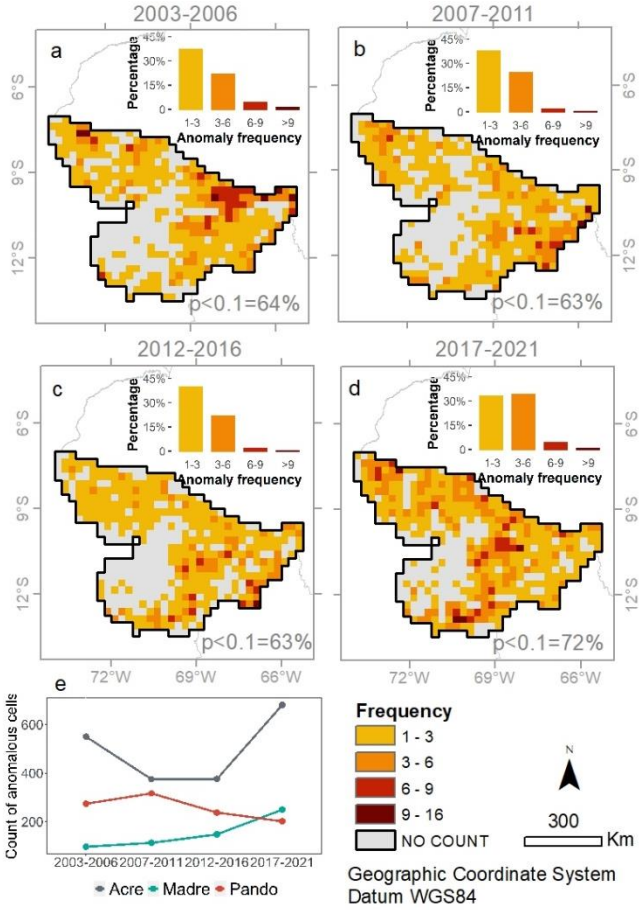


Figure 1. Recurrence of anomalies of active fires in MAP region from (a)2003 to 2006, (b) 2007 to 2011, (c) 2012 to 2016, and (d) 2017 to 2021.

Regarding the extent of the climatic anomalies, we noticed that only negative anomaly for total precipitation have increased from 76% to 89% of MAP region throughout the last two periods. In fact, the greatest extent for mean temperature and CDD anomalies occurred from 2012 to 2016 period, reaching 99% of the MAP region on average.

If only the cells with fire anomalies are considered, we noticed distinct patters in climate anomalies that could impact directly in the fire anomalies occurring in each state/department (Figure 2). For example, the count of grid cells with positive anomaly for mean temperature has decreased, and it increased for negative anomaly in total precipitation in Acre all over the studied time series. Although Pando and Madre de Dios have presented no change in the grid cell counting for negative anomaly in precipitation, we noticed a decrease in the positive anomaly for CDD and a slight increase in positive anomaly for mean temperature. Considering only the cells with fire anomalies, it should be mentioned that positive anomalies presented three times more grid cells compared to negative anomalies for all periods.

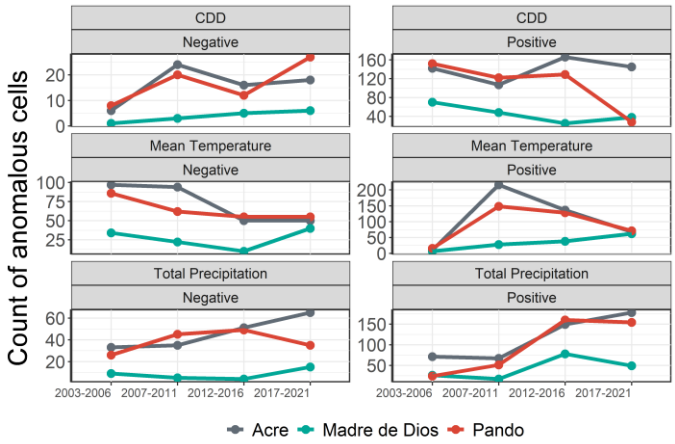


Figure 2. Number of across grid cells with anomaly in consecutive dry days (CDD), mean temperature, and total precipitation.

4. DISCUSSION

In this study we investigated active fire and climate anomalies in the MAP region from 2003 to 2021. Our results suggest that fire occurrence vary timely and spatially in the region. Most of the fire activity follows the end of the dry season, when the vegetation is more vulnerable due to the dry climate and high air temperature [2,12]. Therefore, human ignited fires, when not controlled, can trigger large forest fires.

In addition, our results revealed that last five years had the greatest extent of extreme fire events and increase in the recurrence of them even thought it was not a period with major droughts. The same pattern of fire increase has been reported by other studies in the Amazon [2, 6, 13]. Fires devastatingly affect non-adapted tropical ecosystems, especially recurrent fires by affecting the resilience of the ecosystem and creating positive feedback for new fires due to lower humidity on the accumulated fuel load [14].

Although the last period presented increase in the area affected by negative anomalies of precipitation compared to the previous period, extreme events of increased precipitation still outweigh the negative ones. This fact indicate that fire occurrence might be related to other drivers. For instance, most of the fire reports in Amazon

suggest that fire occurrence is largely related to human activities such as deforestation [6,13].

Undoubtedly, climate is an important factor for fire distribution in the Amazon, and it may explain up to one quarter of fire occurrence [15]. The Amazon Forest is sensitive to high temperatures and reduced precipitation levels, thereby recurrent extreme droughts events decrease the photosynthetic capacity, increasing tree mortality and reducing tree growth rates [2]. At this point, the exposure to extreme dry events is expected to aggravate considerably the risk of fire spread due to the amount of dry woody material.

However, the alarming rates of increasing deforestation in the southwestern Amazon in last few years may be the main reason for the increase of fire occurrences in MAP region. The strengthening of environmental policies to combat deforestation and firefighting is necessary so that the increased risk of fires evidenced in this study will be not aggravated in the future.

5. CONCLUSIONS

Our study provided important insights about fire and climate anomalies on a human modified landscape during drought and non-drought periods over last 19 years. For instance, our results have shown concerning increase in fire anomalies not only in climatic anomalous years. Furthermore, the areas with the highest frequency of anomalous fire events concentrate close to the anthropized regions, indicating human activity as potential drivers.

Thus, to improve fire risk assessments and reduce the modeling uncertainties we strongly suggest further studies to integrate socioeconomic and political aspects as part of their set of driving forces. Understanding climate and human as drivers for the dynamics of fires in the Amazon is essential for the fulfillment of international agreements to reduce CO2 emissions into the atmosphere.

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