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WEATHER PATTERNS ASSOCIATED WITH THE MOST HAZARDOUS HEAVY RAIN EVENTS IN SÃO PAULO AND NOVA FRIBURGO IN RECENT YEARS

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Abstract: This paper investigated the most hazardous heavy rainfall events that occurred in the cities of Sao Paulo and Nova Friburgo in recent years, aiming to identify the categories of weather patterns associated with these events. The investigation revealed that the propagation of cold fronts was the most frequent precursor of heavy rainfall events in both cities. Weather patterns related to the South Atlantic Convergence Zone, the Moisture Convergence Zone, and smaller scale troughs were also identified as relevant. The results of this study may be useful in future research that correlates the identified weather pattern categories with urban flash floods. Such studies may contribute to the improvement of flash flood warnings and the mitigation of their impacts.

Resumo: Este artigo investigou os eventos de chuvas intensas mais perigosos que ocorreram nas cidades de São Paulo e Nova Friburgo nos últimos anos, com o objetivo de identificar as categorias de padrões climáticos associados a esses eventos. A investigação revelou que a propagação de frentes frias foi o precursor mais frequente de eventos de chuvas intensas em ambas as cidades. Padrões climáticos relacionados à Zona de Convergência do Atlântico Sul, à Zona de Convergência de Umidade e a cavados de menor escala também foram identificados como relevantes. Os resultados deste estudo podem ser úteis em pesquisas futuras que correlacionem as categorias de padrões climáticos identificados com inundações repentinas urbanas. Tais estudos podem contribuir para o aprimoramento dos alertas de inundações repentinas e a mitigação de seus impactos.

Keywords: Disasters, Extreme Events, Weather and Climate Patterns

INTRODUCTION

Rain-triggered urban flash floods have a significant impact on urban mobility, leading to economic losses and reduced public welfare (Vale 2020, Haddad and Teixeira 2015). In the current context of climate change and local environmental policies that are, in many cases, misaligned with best preservation practices, the frequency of extreme meteorological events and urban flash floods is expected to increase (IPCC, 2023). One of the key non-structural measures to mitigate the impacts of such hazards is the maintenance of flash flood early warning systems. However, a critical point is that warnings tend to be more effective when issued with a satisfactory lead time–accuracy tradeoff. To that

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end, providing system operators with access to comprehensive and relevant information is essential to support their decision-making regarding the issuance of warnings.

The importance of identifying precursor weather patterns of flash floods has already been highlighted in previous studies (e.g., Doswell III et al. 1996), which argue that identifying the pattern makes it possible to estimate the potential intensity of the associated precipitation, and that this is essential for effective response and risk mitigation. This paper contributes to this effort by associating categories of weather patterns with the most hazardous heavy rainfall events recorded in the cities of Sao Paulo (Figura 1) and Nova Friburgo (Figura 2) in recent years. Both cities are monitored by the National Center for the Monitoring and Early Warning of Natural Disasters (Cemaden) and have a well-documented history of severe and recurrent flash floods. In São Paulo, six heavy rainfall events were investigated, while in Nova Friburgo, five such events were analyzed. In both cases, cold fronts (CF) emerged as the most frequent precursor weather patterns, although other patterns were also recognized as relevant.

The results of this study provide a foundation for broader future investigations involving a larger number of cities, in which occurrences of urban flash floods are associated with specific precursor weather patterns, allowing researchers to assess how frequently each identified pattern precedes such events. These studies can contribute to improving early warning systems aimed at mitigating the impacts of flash floods.

Figura 1 – First study area: São Paulo city, Brazil.

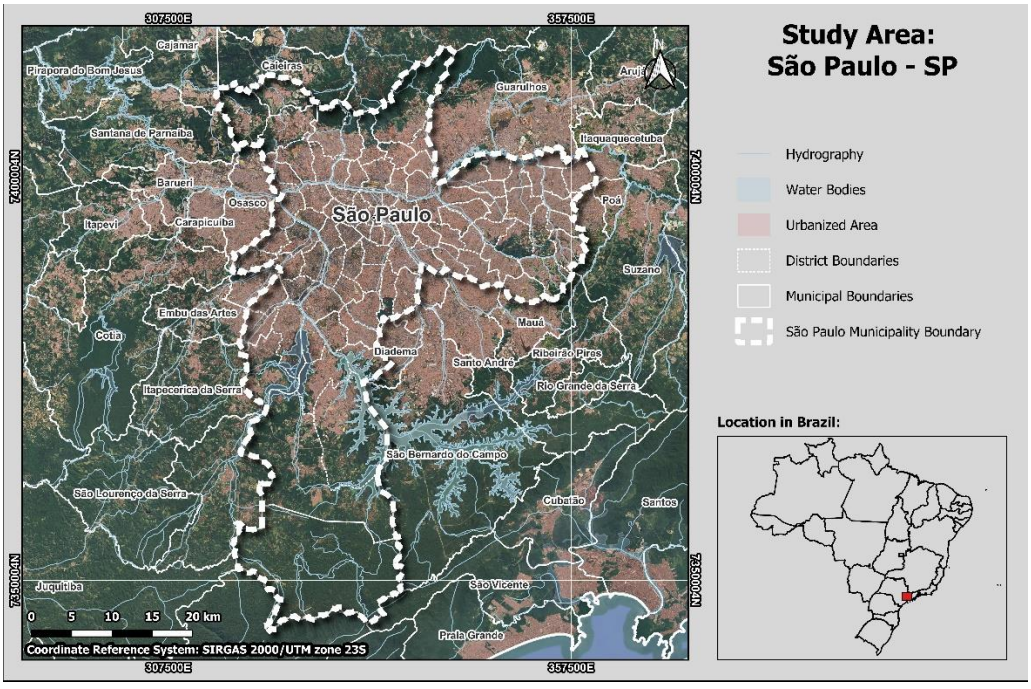
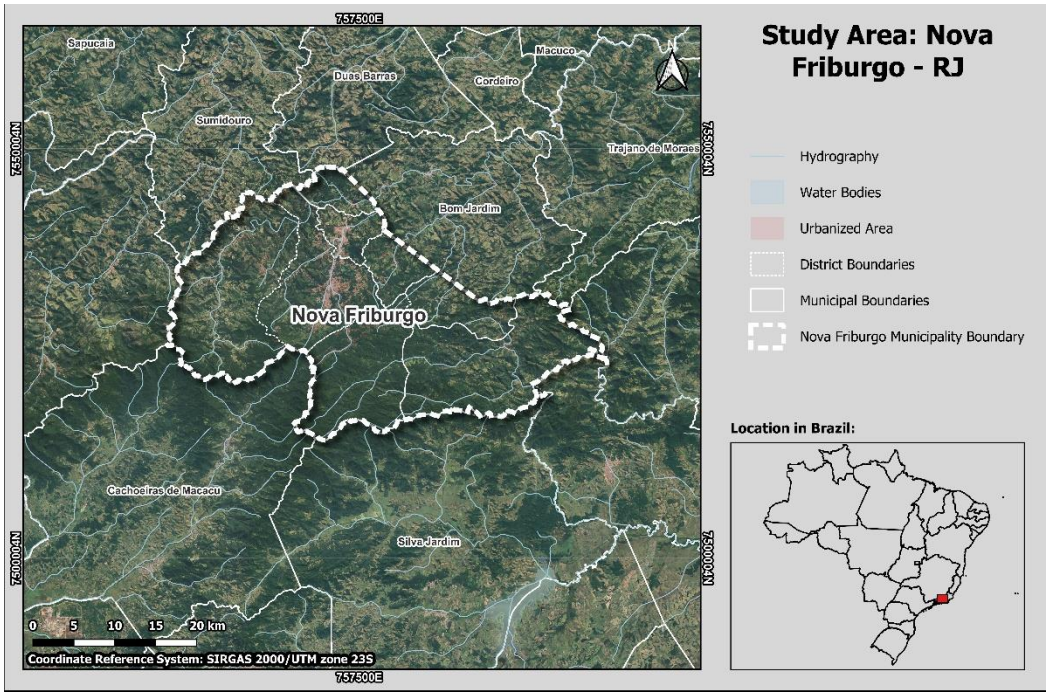


Figure 2 – Second study area: Nova Fribugo city, Brazil.



CLASSIFICATION METHOD

The meteorological classification was performed by analysing satellite images (CPTEC 2019a), synoptic charts (MARINHA 2019, CPTEC 2019b) and surface observations (REDEMET 2019). The following weather pattern categories were considered:

1. Cold Front (CF)
2. Atmospheric Med-Level Trough (TROU)
3. Local Convection (CON)
4. Moisture Convergence Zone (ZCOU)
5. South Atlantic Convergence Zone (SACZ)
6. None of the above (NONE)

The ZCOU category was introduced by the weather forecast team of the Brazilian Centre for Weather Forecast and Climate Studies (CPTEC) in last decade (SACRAMENTO NETO et al. 2010, PALLOTTA and Nakazato 2010). The NONE cat gory means that none of the other categories was identified.

Two main categories of flash flood events were considered based on their magnitude and associated impacts: Medium-Scale Events and Large-Scale Events.

Medium-Scale Events are characterized by significant occurrences of flooding, flash floods, and/or gradual flooding. Their impacts are typically localized, affecting specific neighborhoods or districts, and often lead to delays in emergency response and disruptions in traffic flow. In such cases, the municipality has officially declared or recognized a State of Emergency, with documented information available on damages and victims.

Large-scale events involve extensive damage with a severe impact on essential services across the

entire municipality. These events are often associated with a high number of displaced or homeless individuals and/or casualties. In response, the municipality has either declared or been recognized under a State of Emergency or a State of Public Calamity. There is confirmed information about significant damages and victims.

RESULTS

As a result of the classification method, several weather patterns were identified as precursors to the heavy rainfall/flash flood events analyzed. Among these, a predominance of *CF* category was observed.

São Paulo

CFs were associated with 66% of the significant flash flood cases identified in São Paulo.

- 04/02/2019: CF
- 10/03/2019: CF
- 23/12/2019: CF + ZCOU
- 10/02/2020: CF + SACZ
- 29/12/2020: TROU (Figura 3)
- 02/12/2022: TROU

Figura 3 - Morumbi, in the South Zone of São Paulo, on December 29, 2020.

Nova Friburgo

CFs were associated with 60% of the significant flash flood cases identified in Nova Friburgo.

• 22/02/2018: SACZ

• 08/12/2020 : SACZ (Figura 4)

• 23/01/2023: CF approaching and TROU

• 29/10/2023: CF approaching and TROU

• 22/03/2024: CF

Figura 4 - Conselheiro Paulino, in Nova Friburgo, on December 8, 2020.

In Sao Paulo, the weather pattern most frequently associated with flash floods was the CF, but three other patterns (ZCOU, SACZ, and TROU) also appeared in the results. In Nova Friburgo, CF was likewise the most recurrent pattern, and SACZ also proved to be relevant.

Medium and large-scale natural disaster events in the cities of São Paulo (SP) and Nova Friburgo (RJ) occur under meteorological conditions where the atmosphere is highly humid. Data analysis has shown that all recorded events occurred during the rainy season of the region. Furthermore, the influence of synoptic-scale meteorological systems, such as cold fronts and the South Atlantic Convergence Zone (SACZ), is prominent in most cases. The SACZ is a weather system that can persist in the same area for several days, leading to soil saturation, which facilitates the occurrence of natural disasters. However, cold fronts may be stationary, staying in the same location for several days and further exacerbating precipitation levels. When these systems interact with each other during the rainy season in these municipalities, the combined atmospheric conditions amplify the potential for higher

magnitude events.

In addition, another scenario identified in these events is the approach of a cold front to the municipality. These events are more difficult to predict because weather models often fail to accurately simulate these conditions. In many cases, this results in a large volume of rainfall in a short period of time due to diurnal heating and the influx of moisture carried by the approaching frontal system in the region.

This combination of factors underscores the complexity of forecasting such natural disasters and highlights the importance of understanding the role of synoptic weather systems in shaping the risk of disasters in these urban environments.

The cities of São Paulo and Nova Friburgo exhibit distinct territorial configurations and patterns of impact in the context of extreme hydrological events. In São Paulo, recurrent flooding affects densely urbanized lowland areas, particularly during the rainy season, exacerbated by high levels of soil impermeabilization, irregular settlements, and deficiencies in urban drainage infrastructure. In contrast, Nova Friburgo is characterized by rapid and intense flash floods, driven by steep slopes, marked geomorphological dissection, and slope-side occupation, which also favors the simultaneous occurrence of landslides. In both cities, the most exposed populations often reside in high-risk areas due to a chronic housing deficit and a lack of proper urban planning, facing limited access to essential services, social protection, and adequate infrastructure. The persistence of these vulnerabilities, combined with the recurrence of extreme events intensified by seasonal meteorological patterns, transforms hydrological events into recurrent and predictable phenomena, with disproportionate impacts on socially vulnerable groups.

CONCLUSION AND FUTURE WORKS

In this paper, occurrences of heavy rainfall recorded between 2018 and 2024 that triggered urban flash floods were analyzed in order to identify the precursor weather patterns. Six cases were considered in the city of São Paulo and five in the city of Nova Friburgo. Both cities have a history of severe and recurrent flash floods. The following categories of weather patterns were considered: CF, TROU, SACZ, CON, ZCOU and SACZ. To identify the pattern associated with each flash flood event, a method based on satellite imagery, synoptic charts, and surface observations was applied.

The analysis showed that CF was the weather pattern most frequently associated with flash flood occurrences in both cities (66% in Sao Paulo and 60% in Nova Friburgo), although other patterns (TROU, ZCOU, and SACZ) were also associated with some events.

The results presented in this paper may serve as a foundation for broader future research involving a larger number of cities, aimed at associating specific weather patterns with varying probabilities of causing certain types of hazards, such as urban flash floods. Identifying the precursor weather pattern is already highly valuable in itself, and research efforts can go further. As addressed by Doswell III et al. 1996, building on this information, it is possible to develop a more robust flash flood forecasting approach or model that not only predicts its occurrence but also provides insights into its severity. Therefore, such studies can enhance the effectiveness of early warning systems by increasing both their lead time and accuracy, thus contributing to impact mitigation.

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