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Weather Types Associated with Daily Intense Rainfall Events in The City of Recife - PE, Brazil

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Abstract
The present study aimed to characterize the weather types associated with intense rain events in the city of Recife, by identifying both the frequency of these events and their dynamic mechanisms that explained their genesis. For this, local surface data were related to regional synoptic patterns. Principal Component Analysis and Hierarchical Cluster Analysis were applied to identify groups of homogeneous days in terms of hourly surface atmospheric data. For each group, the monthly frequency of intense rain events was presented and, from synoptic charts and satellite images, atmospheric patterns referring to the typical days were analyzed. Three groups of weather types associated with the occurrence of heavy rains were identified. Group 1 expressed 79% of the intense events (with highest record in autumn), group 2 corresponded to 9% of cases (with highest incidence in winter), and group 3 was 12% of intense rainfall (concentrated in summer and autumn seasons). The most frequent weather types were related to the displacement of barometric troughs in the trade wind fields, due to the strengthening of the easterly flow from the South Atlantic Semifixed Anticyclone. It is noteworthy that the intensity of rain events was explained by the interaction between synoptic circulation systems in meso- and local- scale.

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INTRODUCTION

Precipitation is the atmospheric element that explains most of the climatic variability in tropical regions of the planet. Intense rainfall can cause several impacts on urban socioeconomic structures through processes such as flooding, inundation, or landslides (SZYNISZEWSKA; WAYLEN, 2012; SOUZA et al., 2012). For this reason, the understanding and characterization of these atmospheric phenomena, from a physical and statistical point of view, become important tools for planning and risk management in urban areas.

In this sense, the identification of weather types, which cause daily intense rainfall events, is important for understanding how atmospheric systems interact with the geographical factors of urban landscapes to generate impacts on these areas. Classical and recent approaches have been used to investigate the influence of atmospheric circulation on surface climate elements, classifying weather types that potentially relate to extreme events (BARRY, 1996; El KENAWY et al., 2014).

The concept of weather types has been approached by different schools of climatology. In Brazil, most of the geographical studies of climate are based on Monteiro's (1969, 1971) studies, which treats the climate as a succession of weather types through the idea of climatic rhythm. In synoptic climatology, two complementary approaches to the study of weather types stand out.

The first is the similarity analysis among daily surface meteorological data, and the second is related to the investigation of the synoptic situation or atmospheric circulation patterns. For the classification of weather types, the multivariate statistical techniques of Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) are widely used (SHERIDAN, 2002; PIOTROWICZ; CIARANEK, 2020).

The city of Recife, located in the east of the Northeast region of Brazil, presents susceptibility to intense precipitation events. Episodes of intense rainfall were found to present high annual recurrence for this locality (WANDERLEY, et al. 2018). The largest rainfall volumes are concentrated in the autumn and winter seasons and are related to the action of synoptic or mesoscale systems.

Among these systems, we highlight the Intertropical Convergence Zone (ITCZ), the Eastern Wave Disturbances (EWDs) and the action of coastal breezes (MOLION; BERNARDO, 2002; REBOITA et al., 2010; GOMES et al., 2019). Despite being well described in the literature, the atmospheric systems related to the high volumes of precipitation, in the east of the state of Pernambuco, have been little studied in association with the analysis of weather types.

Given this fact, the present study aimed to characterize the weather types and synoptic patterns related to intense precipitation events in the city of Recife, determining their frequencies of action and their physical characteristics.

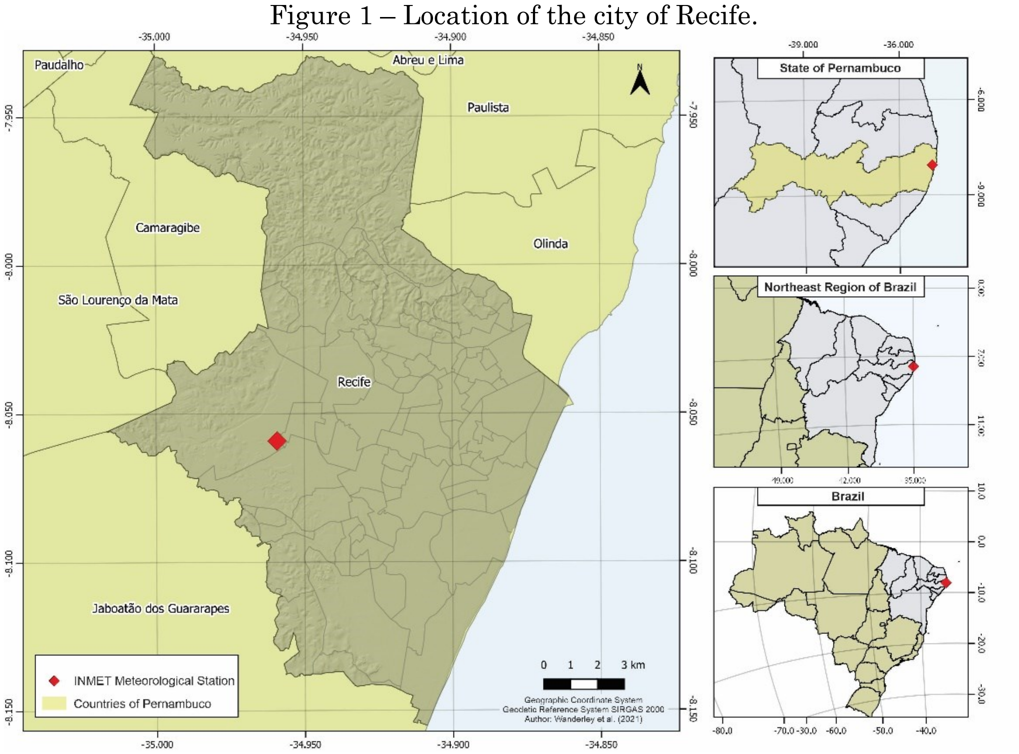
MATERIALS AND METHODS

The development of this work was guided by the following methodological flow: 1) collection of meteorological data; 2) identification of the thresholds of intense rainfall events; 3) application of multivariate statistical techniques for the identification of weather types; and 4) characterization of daily rainfall events and surface atmospheric variables related to the groups of weather types. Each of these steps will be detailed below.

Location of the study area

The weather station used in the study is located in the western portion of the city of Recife (Figure 1), on the coast of the state of Pernambuco in the Northeast region of Brazil.

Figure 1 – Location of the city of Recife.



Source: the authors (2021).

Collection of meteorological data

Hourly data were collected at 0h, 12h and 18h UTC (Coordinated Universal Time) of six meteorological variables from the conventional station (temperature, relative air humidity, atmospheric pressure, wind speed, wind direction and cloud cover) and daily precipitation data. The historical series were acquired from the Banco de Dados Meteorológico para Ensino e Pesquisa (BDMEP, which is a Brazilan meteorological database for teaching and research). The time frame of the study was between the years 1966 and 2019. Days with at least one variable without information were excluded from the analysis.

Identification of thresholds for intense rainfall events

Based on the daily rainfall data that presented a daily volume greater than or equal to 1.0 mm, the thresholds of intense rainfall events were identified. For this, the 95% quantile was used as the lower limit of the daily values of these events (XAVIER, 2002). In the present study, it was chosen to denominate the events as "intense" and not "extreme", since according to the literature (SOUSA et al. 2016; WANDERLEY et al., 2018), the city of Recife presents short return times for events equal or above 100 mm/day, which have almost annual recurrence. However, these are intense events, capable of negatively affecting urban infrastructure.

Application of multivariate statistical techniques for the identification of weather types

The days in which intense rainfall events occurred were associated with hourly meteorological variables. The hourly data set, referring to each day recorded with an intense event, was submitted to a Principal Component Analysis (PCA) with the objective of identifying the explanatory variables of maximum variance and rescaling the data (SHERIDAN, 2002; PIOTROWICZ; CIARANEK, 2020).

Subsequently, the Principal Components (PC) that represented the highest cumulative variance were submitted to Hierarchical Cluster Analysis (HCA). The Average Linkage method was selected by analyzing the cophenetic correlation coefficient. This clustering technique has been used previously in climate studies, showing consistent results (NAJAROV, 2017; LANA et al., 2020). Euclidean distance was used as a measure of dissimilarity among the groups. The PCA and HCA were run in InfoStat software (Di RIENZO, 2015).

Characterization of daily rainfall events and surface atmospheric variables related to groups of weather types

As a complementary method, the Boxplot chart was analyzed in order to characterize the daily rainfall events and the surface atmospheric variables related to the weather type groups. The wind speed and wind direction data for each weather type group were represented by the wind rose graphs, generated in the free WRplot View 7.0 software, to aid the interpretation and characterization of the weather types.

The groups resulting from the multivariate statistical procedures were related to the days with intense rainfall events. Synoptic maps and satellite images from the digital platform of the Centro de Previsão de Tempo e Estudos Climáticos (CPTEC/INPE, which is a Brazilian center for weather forecasting and climate studies) and surface meteorological data served to describe the groups, in order to identify patterns of atmospheric circulation and weather types' characteristic of each group.

As an alternative to select the days on which the analyses were performed, the typical days of the action of each type of weather on the surface were considered. This procedure was based on the identification of typical days (seed days) in the study by Sheridan (2002). Typical days were those where the atmospheric variables were within the mean + standard deviation of the data series.

The synoptic maps of the "typical days" were vectorized in Qgis 3.10 software for the presentation of the surface synoptic patterns related to the origin of the weather types.

RESULTS AND DISCUSSION

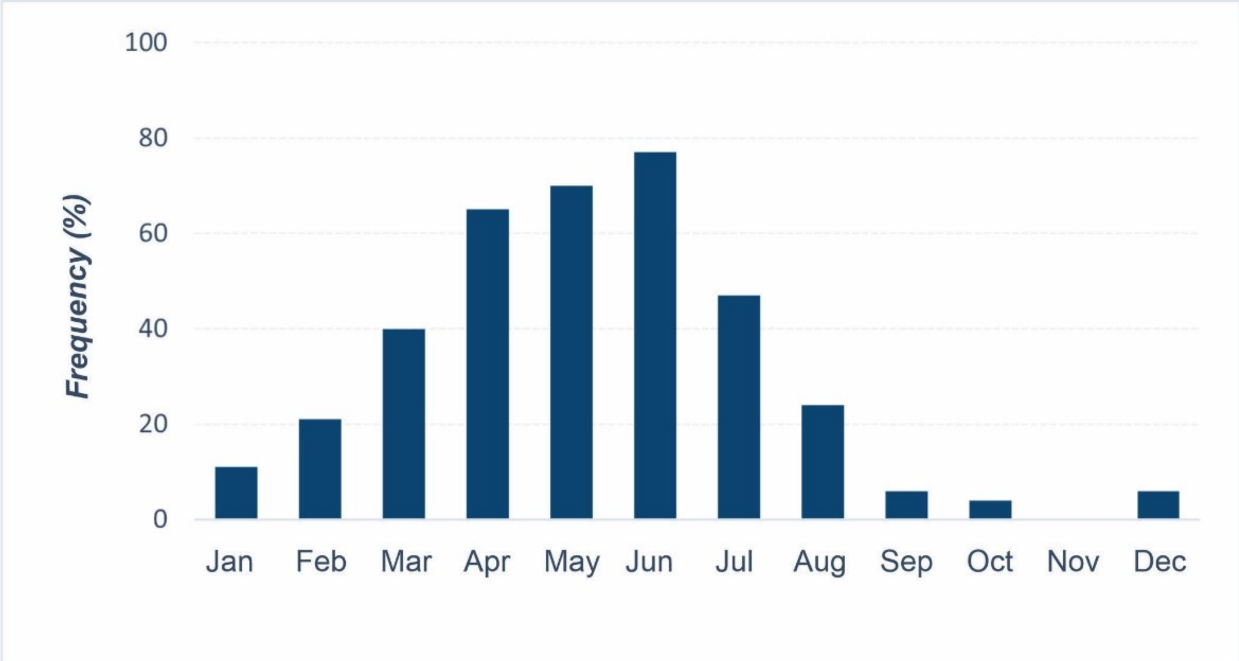
Intense rainfall events in the city of Recife

The intense rainfall events in the city of Recife were delimited by the 95% quantile in the rainfall series, with a lower threshold of 50.4 mm. The mean of the 374 intense events recorded between 1966 and 2019 was 75.9 mm and the median was 67.5 mm. The maximum daily precipitation value was 335.8 mm on 08/11/1970.

It is noteworthy that among the capital cities of the Northeast region of Brazil, Sousa et al. (2016) found that Recife presents the largest daily rainfall events for the return time of 50 years (203.8 mm) and 100 years (224.5 mm).

It was found that there was a concentration of events between March and August, with a peak between April and June (Figure 2). Over the time series, 65 events were recorded in April, 70 in May and 77 in June. The spring months are the least prone to the occurrence of intense rainfall, concentrating only 2.7% of the annual occurrences.

Figure 2 - Monthly frequency of daily intense rainfall (> 50 mm) between the years 1966 and 2019.



Data source: INMET (2020). Elaboration: the authors (2021).

Principal Component Analysis (PCA)

The first four PCs accounted for 69% of the cumulative variance in the data matrix (Table 1) and were retained for the proposed analysis. The first two components presented a cumulative proportion of 50%.

Factorial loadings referring to the variables that best synthesized the variance of the data were highlighted. It was observed that the weather types can be represented, with the greatest strength, by air temperature at 0h and 18h UTC, relative humidity at 0h UTC and wind speed at 0h, 12h and 18h UTC. Thus, the groupings of weather types presented internal similarities regarding these hourly atmospheric variables.

Table 1 - Eigenvectors of the principal components, referring to the meteorological variables on the surface at 0, 12, and 18h UTC.

Variables	PC1	PC2	PC3	PC4
T0	0.21	0.31	**-0.40**	-0.17
T12	0.34	-0.22	-0.003	-0.19
T18	**0.40**	-0.07	-0.07	-0.04
RH0	-0.11	-0.23	**0.61**	0.06
RH12	-0.26	0.33	0.08	0.09
RH18	-0.33	0.22	0.03	-0.07
P0	-0.30	-0.34	-0.17	-0.24
P12	-0.34	-0.28	-0.23	-0.22
P18	-0.35	-0.29	-0.20	-0.24
WS0	-0.09	-0.09	**-0.43**	**0.49**
WS12	-0.03	-0.26	-0.15	0.36
WS18	0.08	-0.26	-0.05	**0.56**
CC0	-0.12	-0.20	0.35	0.10
CC12	-0.23	0.34	0.01	0.20
CC18	-0.28	0.24	0.09	0.14
Variance (%)	28.0	22.0	10.0	8.0
Cumulative variance (%)	28.0	50.0	61.0	69.0

Legend: PC – Principal Components; T – air temperature; RH - relative humidity of the air; P - atmospheric pressure; WS – wind speed; CC – cloud cover. Values in bold are statistically significant ($p<0.05$). Source: the authors (2021).

PC1 was positively correlated with the air temperature at 18h UTC, indicating weather types associated with higher values of this variable at this time. Negative factorial loadings, although with less significance, indicated an inverse relationship with the values of atmospheric pressure for this PC, suggesting atmospheric conditions related to a possible weakening of the Semi-Fixed South Atlantic Anticyclone (SASA) over the eastern Northeast. PC2 did not show outstanding factorial loadings, with higher values for atmospheric pressure at 0h and cloud cover at 12h. PC2 showed a negative relationship for atmospheric pressure at 0h and a positive one for cloud cover at 12h.

The weather type referring to PC3 showed a positive correlation with humidity at 0h, and negative correlations with temperature and wind speed at 0h UTC. This pattern may be related to the strengthening of the land breeze mechanism over the coastline, favoring the development of instability.

Albuquerque et al. (2013), when investigating the hourly occurrences of rainfall over the city of Recife, associated the origin of precipitation with the mechanism of breezes. The convergence of the land breeze with the trade winds would be one of the most important mechanisms for the formation or intensification of atmospheric instability on the east coast of the Northeast region (KOUSKY, 1980;

MOLION; BERNARDO, 2002). Thus, a lower speed of the trade winds may be related to the action of land breezes, contributing to increased cloud cover and relative humidity of the air.

Wind speed at 0h and 18h UTC presented the highest loadings for PC4. The positive correlation with wind speed at these times indicates that this component was related to types of weather characterized by higher values of this atmospheric variable. However, in isolation, this pattern does little to explain the dynamic mechanisms related to the genesis of rainfall events. The main hypothesis is related to the strengthening of the trade winds and greater advection of moisture to the east coast of northeastern Brazil.

Cluster Analysis

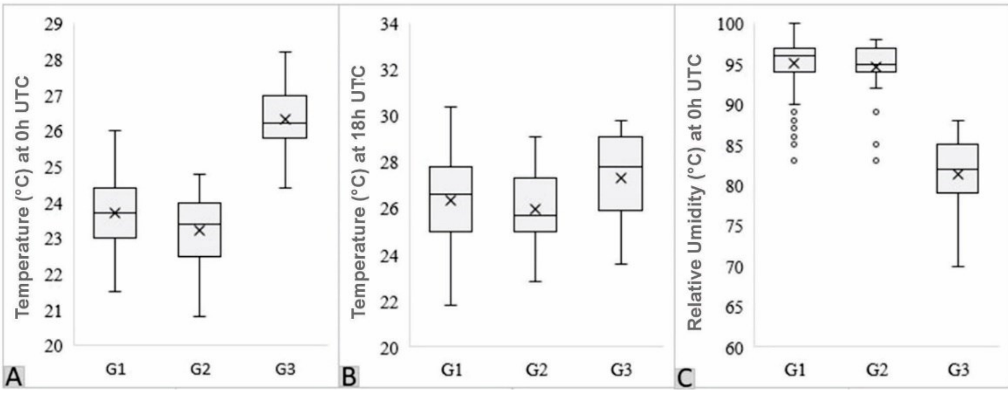
The cluster analysis of the days related to the occurrence of intense rainfall revealed the existence of three well-defined groups. These groups were determined by cutting the dendrogram, seeking the greatest amplitude of the junction distances. The cophenetic correlation index resulting from the grouping by the Average Linkage method was 0.75, indicating consistency in the determination of the groups.

These groups were distinguished by seasonal occurrence, surface physical characteristics, and the number of observed occurrences over the time series. Group 1 (G1) was the largest, representing 79% of the days analyzed, Group 2 (G2) represented 9% of the series, and Group 3 (G3) 12%. Groups G1 and G2 showed the greatest similarity, while G3 had the greatest distance.

Analyzing the hourly atmospheric variables that presented the highest loadings in the PCA for each group of days (Figure 3 A, B and C), except wind speed, which was analyzed separately, it can be seen that the hourly temperature at 0h and 18h presented higher typical values for G3 (Figures 3A and 3B).

For G1, significant variations were observed in the hourly temperature, especially at 18h, with a minimum value of 22°C and a maximum of 31°C. The relative humidity values at 0h (Figure 3C) were very high for G1 and G2, with typical variations close to 95%. For G3 these hourly variations were concentrated between 80% and 85%.

Figure 3 - Boxplot charts for temperatures at 0h (A) and 18h (B), and relative humidity at 0h (C) for the grouped daily weather types.



Legend: G1 – group 1, G2 – group 2, and G3 – group 3. Data sources: INMET (2020). Elaboration: the authors (2021).

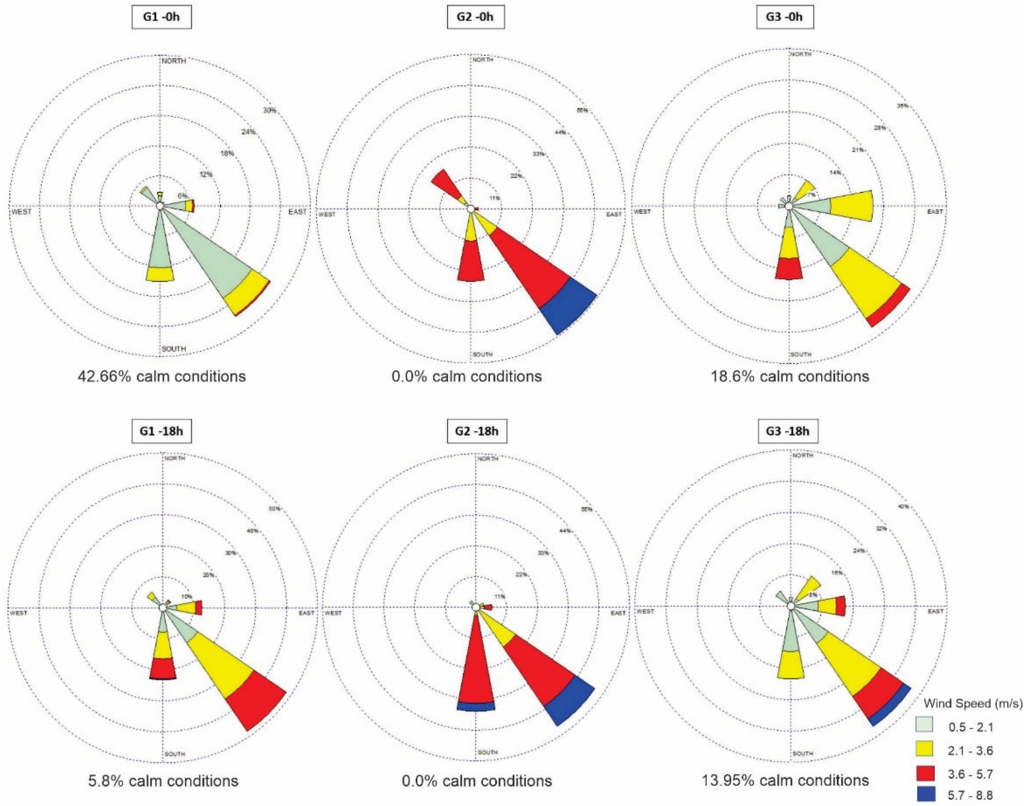
The analysis of the wind behavior for 0h and 18h UTC (Figure 4) shows a predominance of the southeasterly trade winds for all groups, with less frequent occurrences from the southerly, easterly, northeasterly, and northwesterly directions. With regard to wind speed, the distinctions among the groups are more pronounced.

For G1 at 0h, calm conditions represented 42.7% of the total frequency. Therefore, this type of weather was related to a weakening of the S and SE trade winds during the nighttime hours. At 18h, the frequency of calm conditions was 5.8% (Figure 4).

G2 presented the highest wind speed values at the times analyzed. The occurrence of calm conditions was not recorded at any time in this group. This wind pattern indicates a strengthening of the SE trade winds, with an advection of oceanic moisture to the east coast of the Northeast. The occurrence of northwesterly winds at 0h during 15% of the time may indicate some influence of land breezes during this time.

The behavior of the winds at 0h for G3 showed a percentage of 18.6% for the occurrence of calm conditions. At 18h calm conditions occurred in 13.9% of records. The predominant speed variation range was between 2.1 and 3.6 m/s. There was an intermediate behavior, with respect to wind speed, among those observed in the other groups.

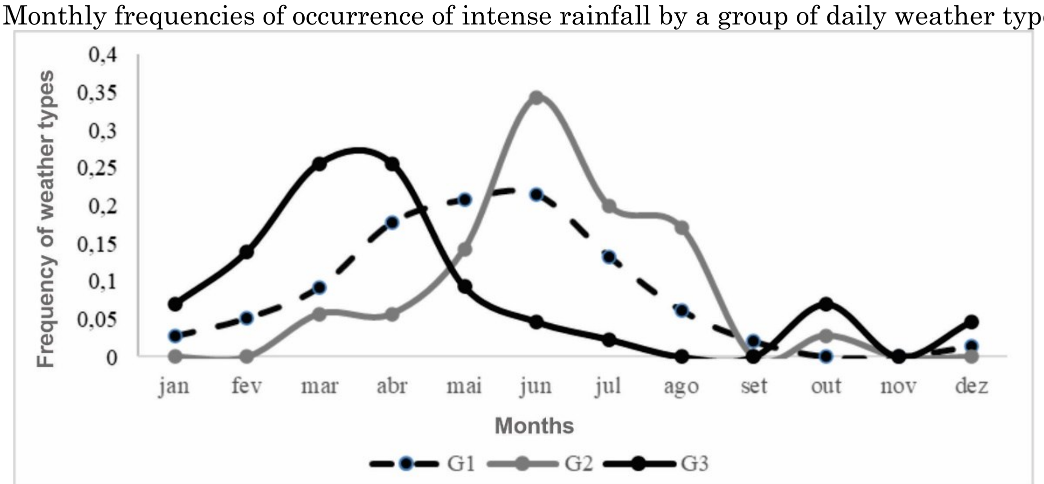
Figure 4 - Wind roses referring to the grouped weather types for the hours of 0h and 18h UTC.



Legend: G1 – group 1, G2 – group 2 and G3 – group 3. Data source: INMET (2020). Elaboration: the authors (2021).

When analyzing the monthly frequencies of occurrence of the groups of weather types, a distinct seasonal distribution was observed among the weather types related to intense rainfall events (Figure 5). G1 presented maximum frequencies in the autumn, between April and June. Those of G2 occurred predominantly between autumn and winter, with the highest frequency in June, followed by July and August. G3 had maximum occurrence between the summer and autumn months, specifically in March and April.

Figure 5 - Monthly frequencies of occurrence of intense rainfall by a group of daily weather types.



Legend: G1 – group 1, G2 – group 2 and G3 – group 3. Data source: INMET (2020). Elaboration: the authors (2021).

The seasonal distribution of the frequencies of the weather types suggests the influence of some synoptic, or mesoscale, atmospheric patterns related to the origin of intense rainfall. Gomes et al. (2019) studied the climatology of EWDs over the eastern Northeast and found that approximately 60% of the total rainfall is caused by these disturbances. Therefore, this mechanism may be the main modulator of rainfall events. According to these authors, EWDs can originate from the association with four distinct types of atmospheric systems: cold fronts, convective conglomerates from the west coast of Africa, ITCZ and High-Level Cyclonic Vortices (HLCVs).

Considering that the ITCZ and the HLCVs are typical summer and autumn atmospheric systems (SATYAMURTY; ROSA, 2020), it is suggested that the genesis of intense rainfall events in these seasons is related to the action of these mechanisms.

Analyzing the synoptic patterns in the Metropolitan Region of Recife in the years 2000 (considered rainy) and 2001 (considered dry), Girão et al. (2006) observed synoptic systems with seasonal occurrence similar to what was described above. These authors found a high frequency of ITCZ and HLCV in the configuration of rainfall during the summer and autumn, and highlighted the greater importance of troughs, formed along the Atlantic Tropical Mass (which is formed by hot and humid air originating from SASA), for the genesis of rainfall events in autumn and winter.

Therefore, the types of weather with greater occurrence in winter are, probably, correlated to instabilities originating in cold fronts. It is noteworthy that the direct action of fronts is rare on the east coast of the Northeast, with disturbances or troughs resulting from their advance over lower latitudes being more frequent (GIRÃO et al., 2006).

Comparing the monthly frequencies of weather types with the hourly wind data, one can establish some cause-and-effect relationships that help in the distinction among groups, especially between G1 and G2.

G1 had the lowest values of wind speed at the time of 0h, highlighting the possibility of influence of the land breezes. The daytime calm conditions, although less frequent, may indicate the action of synoptic-scale atmospheric systems capable of reducing the intensity of the trade winds, such as the influence of the ITCZ on eastward circulation during the autumn months.

In the case of G2, the higher occurrences in winter show the strengthening of the trade winds when, seasonally, there is the expansion of SASA. In this case, the more intense winds transport moisture from the ocean, contributing to the occurrence of precipitation in the eastern part of the Northeast.

The peak of intense events between March and April suggests greater influences of the ITCZ for G3. For this reason, lower wind speed values may be related to both the approaching convergence of the trade winds and the action of the breezes.

Analysis of synoptic patterns

The synoptic patterns corresponding to the typical days for each group were analyzed. We identified 49 typical days for G1, 5 days for G2 and 6 days for G3.

The G1 synoptic patterns were characterized by the strengthening of the easterly circulation over the east coast of the state of Pernambuco. At the geopotential height of 500 hPa, the establishment of anticyclonic circulation was often observed over the southeast or center of the country, with the northern edge of the anticyclone positioned over the eastern Northeast.

The SASA ridge extended over eastern Brazil, coupling the easterly circulation in the mid-troposphere with that observed at lower levels (at the geopotential height of 850 hPa or at the surface). In some situations, the positioning of the transient anticyclone, between the South region of the country and the Atlantic Ocean, also strengthened the easterly winds at the surface. Troughs in the low and especially in the middle atmosphere were associated with the easterly circulation, displacing disturbances in the trade winds field towards the east coast of the Northeast region.

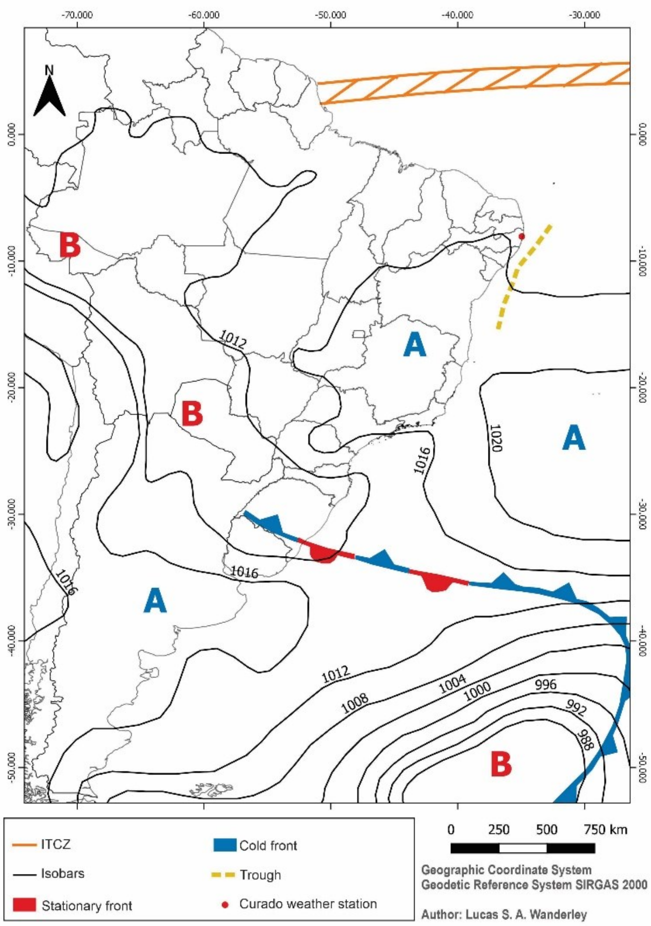
It was considered that for G1, the weather type was related to the occurrence of EWDs. This finding was based on previous studies that described this system as disturbances caused by troughs (much better configured in the middle troposphere levels) and cloud clusters that move from the ocean to the continent (COUTINHO; FISCH, 2007; SANTOS et al. 2012; NEVES et al. 2016). In a study conducted in the eastern Northeast, Gomes et al. (2019) found that 91% of EWD events occurring between April and August originate from disturbances caused by cold fronts.

The surface atmospheric conditions associated with these synoptic circulation patterns were marked, for G1, by calm conditions and high relative humidity at 0h UTC. This fact corroborates previous studies

(KOUSKY, 1980; MOLION; BERNARDO, 2002; ALBUQUERQUE et al., 2013), wherein the convergence of the land breeze with the trade winds (strengthened by the easterly circulation) is an important mechanism for the intensification of atmospheric instability along the east coast of the Northeast.

As a representative of G1, the typical day of June 17, 2010, was selected. For this day 116.4 mm of rain were recorded in 24h. This event comprised, along with days 18 and 19, one of the most intense rainfall episodes in the eastern Brazilian Northeast. In the surface synoptic chart, at 0h on that day, a trough was observed with a displacement in the northern circulation of the SASA towards the east coast of the Northeast region (Figure 6).

Figure 6 – Synoptic chart at 0h UTC on 06/17/2010 for part of South America and the Atlantic Ocean.

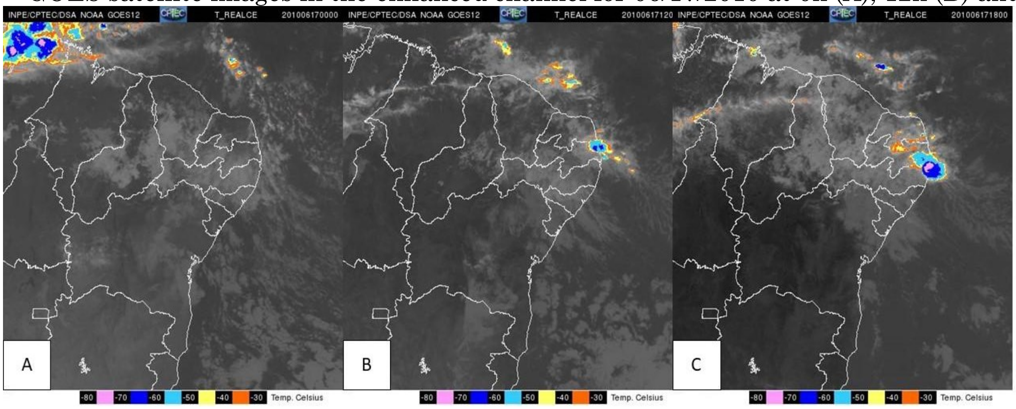


Legend: A – high-pressure center and B – low-pressure center. Data source: CPTEC/INPE (2021). Elaboration: the authors (2021).

The GOES-12 satellite images in the enhanced infrared channel for the hours of 0h, 12h and 18h showed the intensification of an EWD (Figure 7). At 0h a cluster of warm clouds approaching the east coast of the Northeast region of Brazil can be seen (Figure 7A). At 12h and 18h (Figures 7B and 7C), the development of convection can be visualized, with cloud tops reaching a temperature of -60°C.

It was found that as the trough approached the continent, there was an increase in instability to the east of this system. Machado et al. (2012) and Alves et al. (2013), when analyzing this intense rainfall event, found that the genesis of a mesoscale convective system on 06/17/2010 was modulated by an EWD in association with above-average temperatures of the waters of the South Atlantic Ocean.

Figure 7 - GOES satellite images in the enhanced channel for 06/17/2010 at 0h (A), 12h (B) and 18h (C).

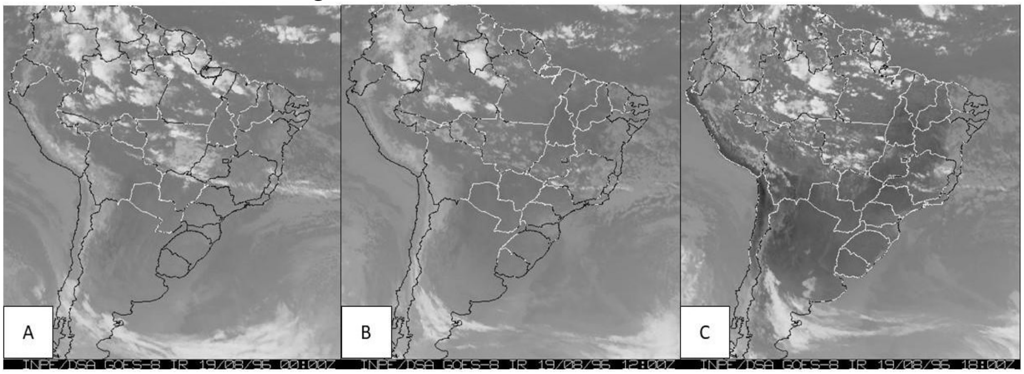


Source: CPTEC/INPE (2021).

For G2 the atmospheric circulation patterns were described only by satellite image analysis because no synoptic charts were available for the typical days.

The satellite image in the infrared channel for South America on 08/19/1996 represented a typical day for G2 (Figure 9). On this day there was a daily rainfall accumulation of 52.6 mm. Warm clouds were observed moving from the Atlantic Ocean to the east coast of the Northeast at the three analyzed times: 0h (Figure 8A), 12h (Figure 8B) and 18h (Figure 8C). The development of these clouds probably occurred in the field of the southeast trade winds (Figure 8C).

Figure 8 - GOES-8 satellite images of the infrared channel for 08/19/1996 at 0, 12 and 18h UTC.



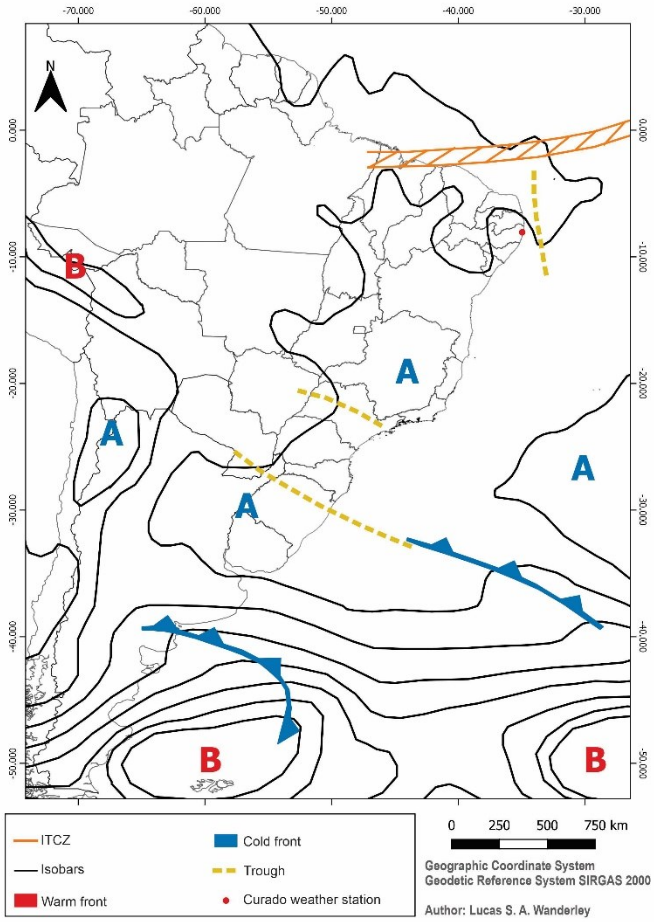
Source: CPTEC/INPE (2021).

The analysis of surface data suggests that for G2 the highest wind speeds, recorded at 0h and 18h UTC, may be related to the intensification of synoptic patterns observed for G1, with the strengthening of the trade winds from the establishment of coupled easterly flow between the middle and low tropospheric levels. Thus, the presence of troughs or disturbances at the northern edge of the anticyclonic circulation would favor the transport of moisture to the east coast of the Brazilian Northeast.

The pattern of atmospheric circulation observed for the days referring to the G3 weather type presented the development of convective instability, which was related to the positioning of the ITCZ near the north coast of the Northeast, and the positioning of HLCVs centered over the Atlantic Ocean or over the state of Bahia. These systems fed disturbances in the trade winds field, contributing to the genesis of the intense rainfall events.

The surface synoptic chart for 04/06/2009 represents G3 (Figure 9). On this date, a daily precipitation volume of 55.0 mm was recorded. The chart presented a synoptic situation in which ITCZ was acting over the north coast of the Northeast, generating convective instability. Over the eastern part of the Northeast, a trough located near the coast of the state of Pernambuco generated instability.

Figure 9 - Synoptic chart at 0h UTC on 04/06/2009 for part of South America and the Atlantic Ocean.

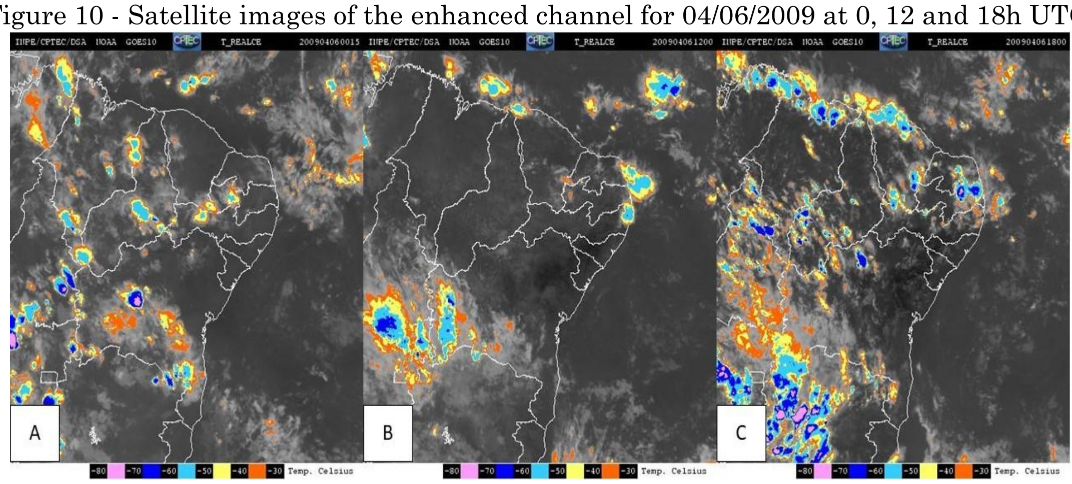


Data source: CPTE/INPE (2021). Elaboration: the authors (2021).

The satellite images of 04/06/2009 are presented for the hours of 0h (Figure 10A), 12h (Figure 10B) and 18h (Figure 10C). On this date, cloud cover moved from the Atlantic Ocean towards the coast of the Brazilian Northeast. At 0h, there was a predominance of warm clouds over the ocean near the states of Rio Grande do Norte and Paraíba, and development of convective instability over part of the interior of the region.

In the 12h image, the development of convective instability over the east coast of the Northeast region of Brazil was verified, with a cloud nucleus with a temperature at the top of -50°C over the coast of the state of Pernambuco. At 18h, the system that acted in the coastal strip advanced over the interior of the region, increasing the instability already observed at 0h.

Figure 10 - Satellite images of the enhanced channel for 04/06/2009 at 0, 12 and 18h UTC.



Source: CPTEC/INPE (2021).

Comparing the synoptic patterns referring to the groups of weather types related to intense rainfall events, a greater similarity was verified between G1 and G2. G3 presented greater distinctions in relation to the other groups, mainly due to the action of the ITCZ in southern latitudes, influencing the genesis of rainfall events.

From a point of view analogous to the studies of Kalkstein et al. (1998), Sheridan (2002), and Fontão et al. (2018), who chose to use the nomenclatures of air masses to refer to the types of surface weather, in the current proposal all groups of weather types would be characterized by the predominant action of the Atlantic Tropical air mass (mTa). This air mass is constituted by the easterly or southeasterly trade winds with origin in the SASA and, when associated with inverted troughs triggered by individual meteorological systems (ITCZ, HLVC or fronts), presents the potential for the genesis of intense rainfall events.

Table 2 presents a synthesis of the characterization of the weather types related to the genesis of intense rainfall in the city of Recife.

Table 2 - synthesis of the local and regional surface atmospheric characteristics, at synoptic scale, of the weather types explaining the genesis of intense rainfall in the city of Recife.

Group	**Period of maximum frequency**	**Local surface characteristics**	**Regional synoptic characteristics**
1	autumn and winter	Low wind speed at 0h UTC. Possibility of greater influence of land breezes at night High relative humidity values at 0h UTC. High temperature amplitude at 18h.	Influence of the SASA circulation. Trough formation in the easterly circulation related to the anticyclone.
2	winter	Higher wind speeds at 0h and 18h UTC. Humidity advection. Predominance of SE trade winds. High relative humidity at 0h. Shorter temperature variation intervals.	Expansion of the SASA and strengthening of the eastern circulation at low and medium levels. Formation of troughs in the easterly circulation related to the anticyclone.
3	autumn	Higher temperatures and lower humidity values at 0h UTC. Predominance of SE trade winds.	Trough formation in the easterly circulation. Increased influence of ITCZ and HLCV on the development of convective instability.

Source: the authors (2021).

FINAL CONSIDERATIONS

Intense rainfall events in the city of Recife were related to the occurrence of three groups referring to the daily events of intense precipitation. On the surface, these groups were differentiated by wind speed and air temperature. G1 represented the most frequent atmospheric characteristics related to the occurrence of 79% of the intense rainfall events, with maximum concentration in the autumn months. G2 was associated with 9% of the daily intense rainfall, occurring in the winter. G3 was most commonly recorded in late summer and autumn and corresponded to 12% of the analyzed events.

For all three groups, the weather types and synoptic patterns were related to the displacement of troughs formed in the SASA easterly circulation. EWD formation was found to be an important mechanism in modulating intense rainfall events. The synoptic patterns were also characterized by a greater influence of the ITCZ and EWDs during the summer and autumn.

The present study offered methodological contributions for the characterization and analysis of intense precipitation events. For future studies, we recommend the application of the proposed approach in other urban sites, or in case studies that aim to investigate the genesis or impacts of daily rainfall events.

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AUTHORS' CONTRIBUTION

Lucas Wanderley conceived the idea of the study, acquired the data, wrote the methodology, performed the multivariate statistical analysis and wrote the results and the result on the synoptic patterns related to the types of time. Ranyére Nóbrega contributed with the writing of the discussion of the results and with the validation of the methodology, applying his theoretical-conceptual experience in meteorology. Cristiana Duarte is responsible for supervising the text, evaluating the quality of data and results. Ayobami Moreira wrote the abstract, acted as second proofreader, contributed to the organization of the maps, with a presentation and discussion of the results. Rafael dos Anjos contributed with a graphic organization and presentation of the results referring to the characterization of the groups of days regarding the behavior of the surface atmospheric variables.