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IDENTIFICATION OF CLIMATIC PATTERNS AND ATMOSPHERIC DYNAMICS IN SÃO LUÍS, MARANHÃO

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Abstract: The article develops an understanding of how the climatic patterns of São Luís do Maranhão are organized in terms of classification, synoptic behavior, and climatic dynamics, promoting a review and update of its data and references base. In the identification of the climatic classification type that characterizes the municipality of São Luís, the main analytical-static climatic models as well as the most widely adopted genetic classification models in Brazil were used. Furthermore, the main geoecological factors determining its climatic dynamics were characterized, as well as the identification of atmospheric circulation systems at various levels of operation. It was concluded that the primary atmospheric system acting in the municipality of São Luís is the Intertropical Convergence Zone (ITCZ), with secondary influences from the Trade Winds (TW), High-Level Cyclonic Vortices (HLCVs), resulting in periods of atmospheric stability with drought, the South Atlantic Subtropical High (SASH), Eastward Wave Disturbances (EWDs), and Instability Lines (IL), which generate rainfall during dry periods, and on a local scale, the maritime breeze with daily winds and occasional rainfall due to convective systems. Its temperature remains high throughout the year with little daily, monthly, or annual variability.

Keywords: Climatic classification; Climatic dynamics; Synoptic analysis.

IDENTIFICAÇÃO DOS PADRÕES CLIMÁTICOS E DA DINÂMICA ATMOSFÉRICA EM SÃO LUÍS DO MARANHÃO

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Resumo: O artigo desenvolve a compreensão de como se organiza os padrões climáticos de São Luís do Maranhão em suas características de classificação, atuação sinótica e dinâmica climática, promovendo uma revisão e atualização da base de seus dados e referências. Na identificação da classificação do tipo climático que caracteriza o município de São Luís foram utilizados os principais modelos climáticos analítico-estáticos como também dos modelos genéticos de classificação mais adotados no Brasil. Além disso, foram caracterizados os principais fatores geoecológicos determinantes para a sua dinâmica climática, como também a identificação dos sistemas de circulação atmosférica em seus diversos níveis de escala de atuação. Concluiu-se que o principal sistema atmosférico atuante no município de São Luís é em destaque a Zona de Convergência Intertropical (ZCIT), e com atuações secundárias os Ventos Alísios (VA), os Vórtices Ciclônicos de Altos Níveis (VCANs) gerando períodos estabilidade atmosférica com estiagem, a Alta Subtropical do Atlântico Sul (ASAS), os Distúrbios Ondulatórios de Leste (DOL) e as Linhas de Instabilidade (LI) geradores de chuvas nos períodos de estiagem e em uma escala local de influência a brisa marítima com ventos diários e chuvas ocasionais por sistemas convectivos. A sua temperatura se mantém elevada por todo o ano com pequena variabilidade diária, mensal ou anual.

Palavras-chave: Classificação climática; Dinâmica climática; Analise sinótica

IDENTIFICACIÓN DE LOS PATRONES CLIMÁTICOS Y DE LA DINÁMICA ATMOSFÉRICA EN SÃO LUÍS DO MARANHÃO

Resumen: El artículo desarrolla la comprensión de cómo se organizan los patrones climáticos de São Luís do Maranhão en sus características de clasificación, actuación sinóptica y dinámica climática, promoviendo una revisión y actualización de la base de sus datos y referencias. En la identificación de la clasificación del tipo climático que caracteriza al municipio de São Luís, se utilizaron los principales modelos climáticos analítico-estáticos, así como los modelos genéticos de clasificación más adoptados en Brasil. Además, se caracterizaron los principales factores geoecológicos determinantes para su dinámica climática, así como la identificación de los sistemas de circulación atmosférica en sus diversos niveles de escala de actuación. Se concluyó que el principal sistema atmosférico actuante en el municipio de São Luís es la Zona de Convergencia Intertropical (ZCIT), y con actuaciones secundarias los Vientos Alisios (VA), los Vórtices Ciclónicos de Altos Niveles (VCANs) generando períodos de estabilidad

atmosférica con sequía, la Alta Subtropical del Atlántico Sur (ASAS), los Disturbios Ondulatorios de Este (DOL) y las Líneas de Inestabilidad (LI) generadoras de lluvias en los periodos de sequía y en una escala local de influencia la brisa marítima con vientos diarios y lluvias ocasionales por sistemas convectivos. Su temperatura se mantiene elevada durante todo el año con poca variabilidad diaria, mensual o anual.

Palabras clave: Clasificación climática; Dinámica climática; Análisis sinóptico

Introduction

Climate classification systems (CCS) are of great importance because they analyze and define the climates of different regions, taking into consideration various climatic elements simultaneously, facilitating the exchange of information and subsequent analyses for different purposes, as asserted by Ayoade (2003).

> The CCS indicate the climatic typologies of different places, defined based on the characteristics of atmospheric parameters, corresponding to important inputs for urban, rural, regional, and environmental planning, especially for activities directly related to the organization and production of space, such as agriculture, industry, and tourism. (p. 224)

For a proper organization of space and balanced development in harmony with its environment, up-to-date knowledge of climatic dynamics becomes essential for urban, agricultural, industrial, and economic planning. This helps determine the optimal location of infrastructure, such as roads, buildings, and irrigation systems, based on climatic conditions. According to Monteiro (2009) in agricultural activities, a thorough understanding of climatic patterns directly informs the choice of crop types, planting and harvesting times, as well as the use of appropriate agricultural practices. It also plays a crucial role in disaster prediction, as the study of climate aids in forecasting potential extreme weather events, such as storms, hurricanes, droughts, and floods. This enables authorities and the population to prepare adequately and minimize damage.

Identifying climatic patterns and atmospheric dynamics contributes to public health by identifying weather conditions that can affect people's health and the spread of various diseases transmitted by vectors linked to climatic conditions. The generation of energy, whether solar, wind, hydroelectric, or thermal, depends on climatic conditions. Knowledge of climate is essential for planning energy production and distribution efficiently and sustainably.

Additionally, in promoting tourism, as São Luís do Maranhão is a site of significant tourist activities with a substantial impact on the municipality's economy.

Studying the climatic characteristics of São Luís do Maranhão is fundamental for decision-making in many sectors of society and for addressing the challenges presented by global climate change. This helps promote sustainable development and adaptation to ever-evolving climatic conditions.

Therefore, due to the necessary and important update of information regarding its climatic patterns and atmospheric dynamics, with a more comprehensive classification that encompasses all existing models in a more significant and current investigation, the research presents an updated climatic typology of São Luís do Maranhão with all its characteristics of climatic patterns and atmospheric dynamics.

São Luís' Climate Classification by Analytical-Statistic models

In Brazil, the first regional climatic classifications were created by IBGE (Brazilian Institue of Geography and Statistics) by the model developed by NIMER (1979), this model was based on the perspective of classifying climate units of the natural Brazilian landscape primarily because the network of weather stations still didn't cover with quality the entirety of the national territory, along with not possessing the number of historical registers necessary to a climate classification the incorporated meteorological and natural landscape data.

Only at the start of the 21st century did the IBGE (2002) produce Brazil's climate classification which covered the analytical-statistic parameters along with the natural landscape. Thus, the IBGE determined that officially the climatic classification of the municipality of São Luís is in the zonal scale and its climate is similar to the Equatorial Tropical Zone with characteristics of 4 to 5 dry months, with a warm subtype of averages superior to 18ºC in all months of the year, bearing a semihumid hydric regime (subequatorial), showcasing maritime influence.

Utilizing a model that uses the climatic systematization of weather indices conjugated with the natural landscape, Köppen (1936) developed his model in which the climate is defined by the typology of its thermo-rainfall regime interpolated to the types of vegetation in the landscape. Therefore, São Luís' climate in Köppen's classification categorizes itself in the regional classification as **Typical Tropical Aw' - Tropical with summer and fall rains** type.

Although it's one of the world's first classification models, even today it's still greatly used, in addition to being of the climatic classifications most used in didactic books to determine the regional climate.

Another prominent climatic classification analytical-separative method is Thornthwaite e Mather's (1955) model which has as the lead variable the humidity index and the potential evapotranspiration represents an estimate of hydric demand concerning the effective temperature and the annual rainfall, regularly used in agriculture and ecology studies focused to the hydric resources. In Maranhão's adapted classification, through UEMA (2002), São Luís's climatic type is **B1WA' a' - Umid climate type B1.**

São Luís' Climate Classification by Genetic Models

Mendonça and Danni-Oliveira (2007) observe that with the Second World War meteorology and climatology bear a paradigmatic repercussion and in this period arose the conception of modern and dynamic, also named genetic, climatology. Influenced by this conception, it was devised new climatic classification models which take into account the new concepts derived from air masses and fronts. In geography's area of study, Maximilian Sorre's (1943) and Pierre Pédelaborde's (1970) contributions stand out in the development of geographic climatology from a dynamic perspective, in which, as Medonça and Danni-Oliveira (2007) assert, the atmospheric circulation and dynamic constitute the climate's genetic base since it has the origin of climatic phenomena as the fundament of classifying criteria.

Developed by Strahler (1984), emerges of the climate models most utilized and widespread in the genetic climate classification. It's considered uncomplicated and efficient and represents a proposal based on the climate controls that involve the air masses, the action centers, and their fronts, conjugating the precipitation characteristics that occur in locations.

To the region where the municipality of São Luís is located, utilizing the model developed by Strahler (1984), its climate classification showed results of **Tropical type alternately humid and dry exposed to the convergence of trade winds.** This classification states the strong influence of the ITCZ (Intertropical Convergence Zone) and the trade winds' impact assert on the municipality.

Furthermore, through the climate's genetic conception, Mendonça and Danni-Oliveira (2007) propose the Equatorial-tropical classification for São Luís:

> "At São Luís (MA), it's observed an expressive thermal regularity throughout the year, with the seafaring effect. Albeit, the rainfall presents two very distinct periods: rainy summer and fall (primarily March and April, with 450mm each month) and winter and spring less rainy or dry (mainly October and November, with 5mm each month)" p.159. (free translation)

Discerns yet that exist various other climate classification static models, genetic or conjugated, such as those produced by: De Martone (1926), Holdrige (1947), Flohn (1950), Budyko (1956), Bagnouls and Gaussen (1957), Troll and Paffen (1964), Rivas-Martinez (2001) and others. Whereas the initial objective is to allow the general comprehension of how São Luís' weather is classified, the main focus of the analysis is its climate dynamic.

São Luís' Climate Dynamic

With the aim of producing a more detailed analysis of the climatic dynamics of São Luís, in a conception where both the geographical factors of the landscape, also referred to as geoecological aspects by Monteiro (1990), and the atmospheric elements determining its atmospheric genesis are identified, we conducted studies on the overall performance of its main characteristics to determine its climatic configuration.

The city of São Luís, due to its geographical location at a low latitude - specifically at 2° 30' S, experiences direct maritime influence. It is situated on a coastal island at an altitude that reaches 70 meters at its highest point (SILVA, 2012), resulting in a climatic configuration that, combined with the regional performance of atmospheric systems and global atmospheric mechanisms, leads to low variability in thermal averages, both in daily variations and throughout the year (PINHEIRO, 2018). The perpendicularity of the sun's rays on the municipality's surface leads to minimal thermal variability and the absence of seasonal cycles of climatic seasons such as spring, summer, autumn, and winter. As Pinheiro (2018) asserts, this establishes a classification of the existence of only two seasons: a rainy season and a dry or drought season. The absence of a cold season (winter) means that the greatest temperature variations recorded in the municipality's climatological norm (1991-2020) are influenced by cloudiness and seasonal variation in solar radiation over the region, albeit small. Therefore, the lowest temperature values recorded by the Climatological Norm of São Luís (1991-2020) were obtained during the rainy season (higher cloudiness) (Figure 1).

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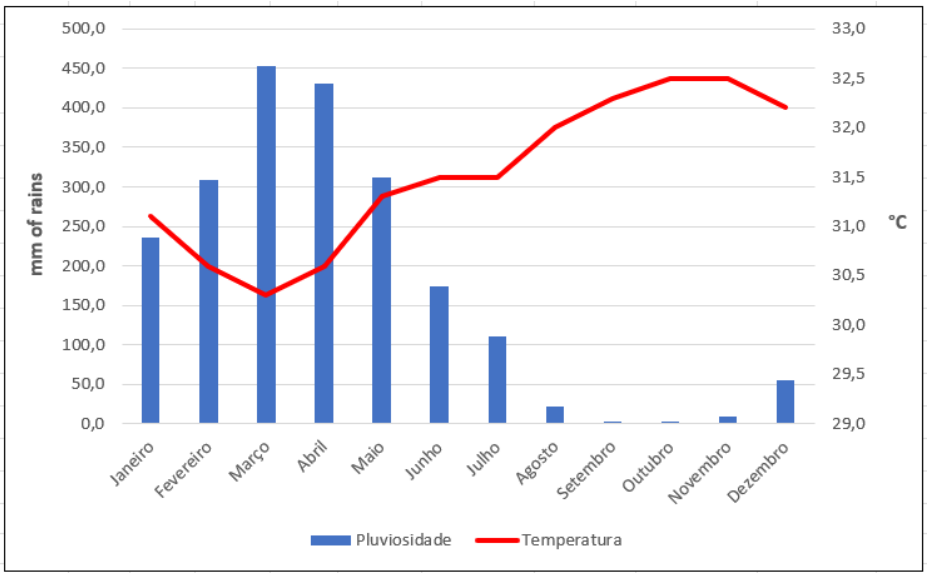
Revista Eletrônica do curso de Geografia
Graduação e Pós-Graduação
Jataí-GO | n 47 | Set-Dez/2023
ISSN 1679-9860

Figure 01 - Climatological Normal (1991-2020) for São Luís – MA



Source: INMET (2023)

It's also important the identification of the solar radiation incidence to the city's latitude throughout the year which enabled the creation of the graph (Figure 2) about the solar radiation incident generated through the Excel program the following equation:

$$\mathbf{Qo = 37{,}6\ (d/D)^2\ [\pi/180\ hn\ sen\ \phi\ sen\ \delta + cos\ \phi\ cos\ \delta\ sen\ hn]}$$

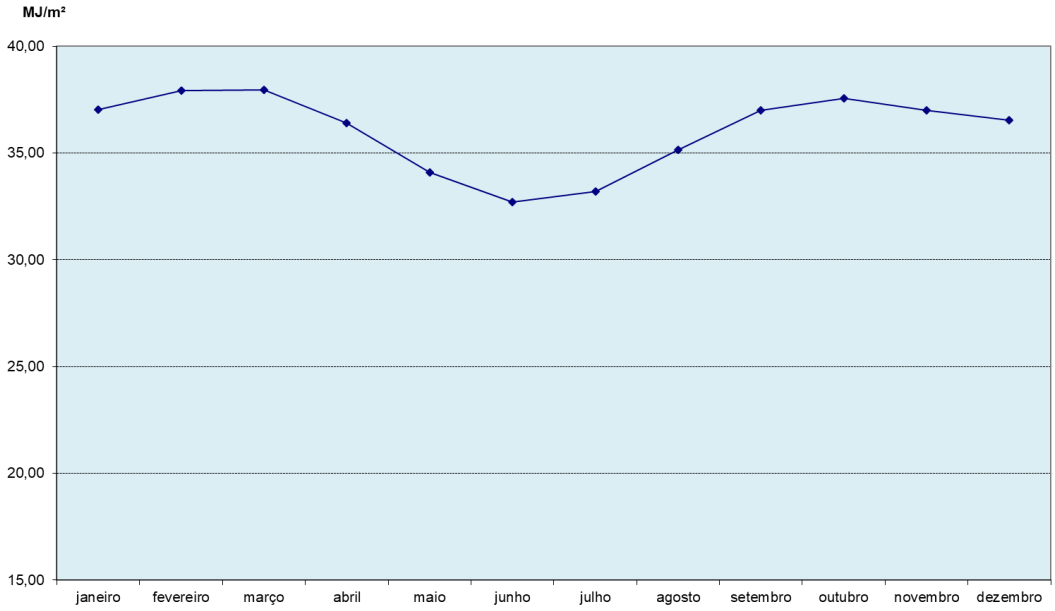
In which:

Qo = radiation at the top of the atmosphere
f = latitude (0 to ±90o)
send = solar declination (0 to ±23,45o)
cosd = 23,45 sen * [(360/365).(NDA – 80)]
h = hourly angle = [(local hour– 12).15]
hn = arccos [-tan f tan d]

Through the graphic, we can identify that occurs a lessening of solar radiation incidence in the months of June and July, which explains the decrease in temperature with the reduction of cloudiness in the region.

Universidade Federal de Jataí
Revista Eletrônica do curso de Geografia
Graduação e Pós-Graduação
Jataí-GO | n 47 | Set-Dez/2023
ISSN 1679-9860

Figure 2: Solar radiation incident at the top of the atmosphere to São Luís - MA's latitude.



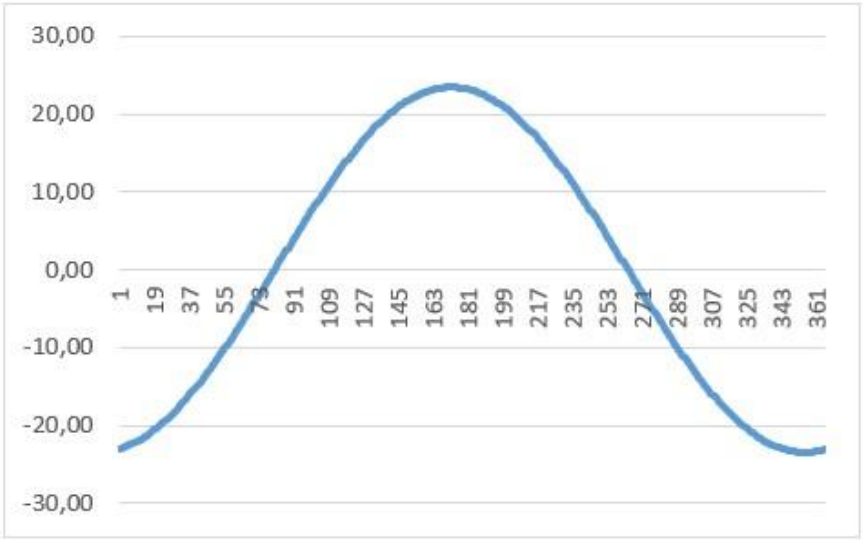
Source: Pinheiro (2018)

Important to register that the difference in annual's temperature variability to the municipality of São Luís - MA's is only 1,3ºC. That is, with the data supplied by the Climatology Normal the month with the highest temperature average is November at 26,9ºC and the month with the lowest temperature average is July at 25,6ºC. As well as jointly by the seasonal intensity of solar radiation at the top of the atmosphere and solar declination that occurs in the latitude where São Luís is located (Figure 3).

Its rainfall is well delimited by periods of intense frequency between the months of January to July and of almost total summer in the months of July to December (Figure 1). It's also been identified that part of the rainfall that occurs in the municipality of São Luís is induced by convective systems, that is, when the hot and humid air on the surface rises to a certain altitude, the effect of adiabatic expansion provokes the rapid cooling occasioned by the temperature differences in the vertical column in the troposphere. The rapid change of water's physical state with the steam's condensation, through the passage of sensible heat to lateral heat, provokes intense and isolated rains in the whole municipality of São Luís.

Universidade Federal de Jataí
Revista Eletrônica do curso de Geografia
Graduação e Pós-Graduação
Jataí-GO | n 47 | Set-Dez/2023
ISSN 1679-9860

Figure 3: Declination in solar incidence to the latitude of São Luís - MA.



Source: Pinheiro (2018)

Concerning its topography, it's characterized as smooth and through the entirety of Maranhão's island where São Luís is localized, demonstrating a leveled ground of low altitudes, always inferior to 70 meters (SILVA, 2012) (Figure 4).

The phytogeographic characteristics of Maranhão Island are the reflex of the transitional disposition between the semi-arid climate of the Northeast Region and the humid and sub-humid climates of the North Region with a high maritime influence. According to Bezerra (1997) Maranhão Island, where the municipality of São Luís is located, is characterized by the occurrence of the main vegetative units, the open ombrophile with low terrain, that possess the aspect of medium to tall height and its main species are: Babaçu, Imbaúba, Tabebuia, Tucum, and others. The vegetation with fluviomarine influence is also called the gallery or riparian forest and is constituted by hygrophilous and hydrophilic plants occupying isolated areas, bordering rivers and streams, and the third formation is vegetation with fluviomarine influence, which is characterized by the presence of mangroves, which according to Damázio (1980) are found on the island in three types: Rhizophora mangle, Lagungularia racemosa, and Avicennia nitida.

Another characteristic to comprehend São Luís' climate dynamic is its geographical location since it's a coastal island that bears direct maritime influence, which through the ocean-continent-atmosphere linkage, acts to determine the diurnal and nocturnal barometric

Universidade Federal de Jataí
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Jataí-GO | n 47 | Set-Dez/2023
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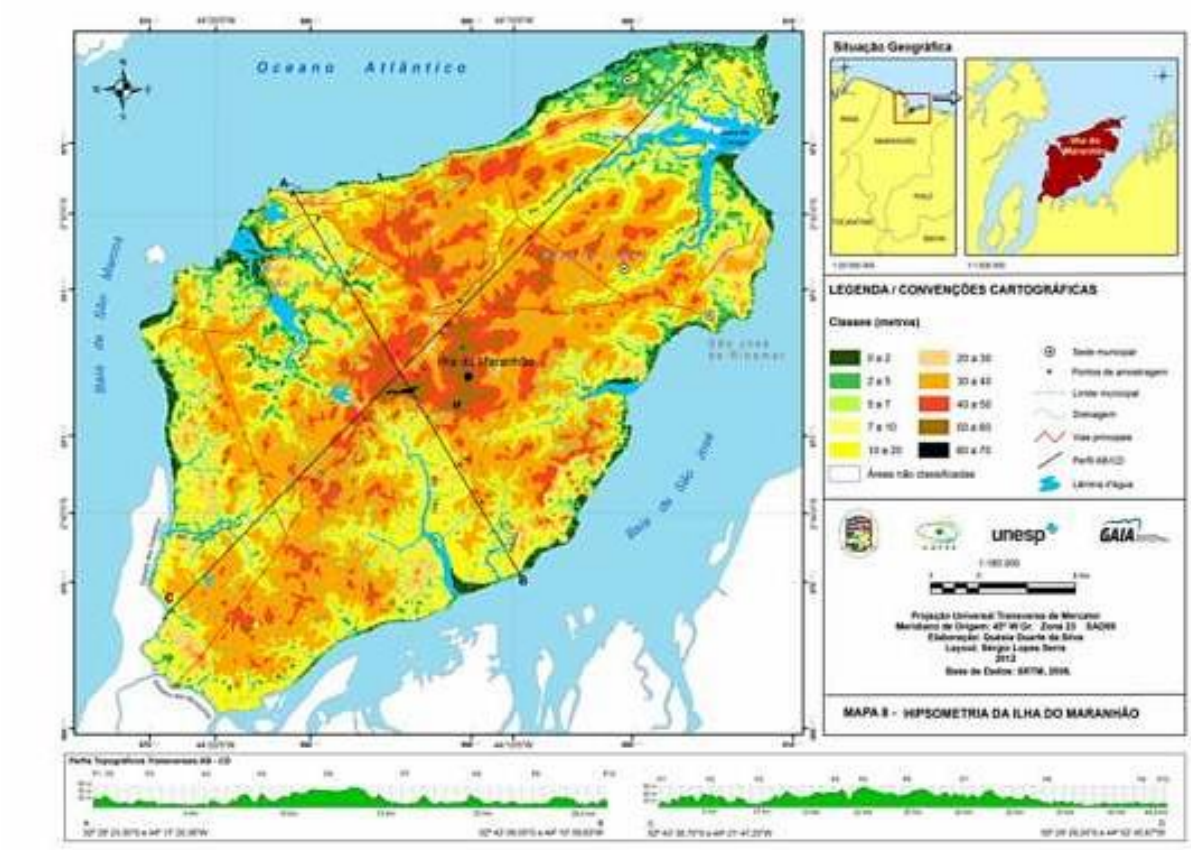
differences that drive the wind over the city, which serve to soften temperatures, and thus function to reduce daily thermal amplitudes and boost human thermal comfort, especially in more urbanized areas.

Figure 4: Hypsometry map of Maranhão Island



Source: Silva (2012)

From the perspective of a regional scale, observes Degola (2003) that the average profile from the wind associated with the South Atlantic Subtropical High (ASAS - Alta Subtropical do Atlântico Sul), has the predominance of SE (Southeast) in Brazil's oriental coast, although the proximities in the Northeast's north coast have predominance in the directions of NE/E (Northeast and East). São Luís' winds possess the predominance of going in the NE direction, with a variable intensity according to the months of the year, INMET/BDMEP (2017). (Figure 5).

In São Luís the highest wind intensity ratios are registered in the months of September, October, and November, which reach an average speed of 3,81m/s, and the trimester with the lowest speed average of 1,66m/s. November is the month in which it registered the most

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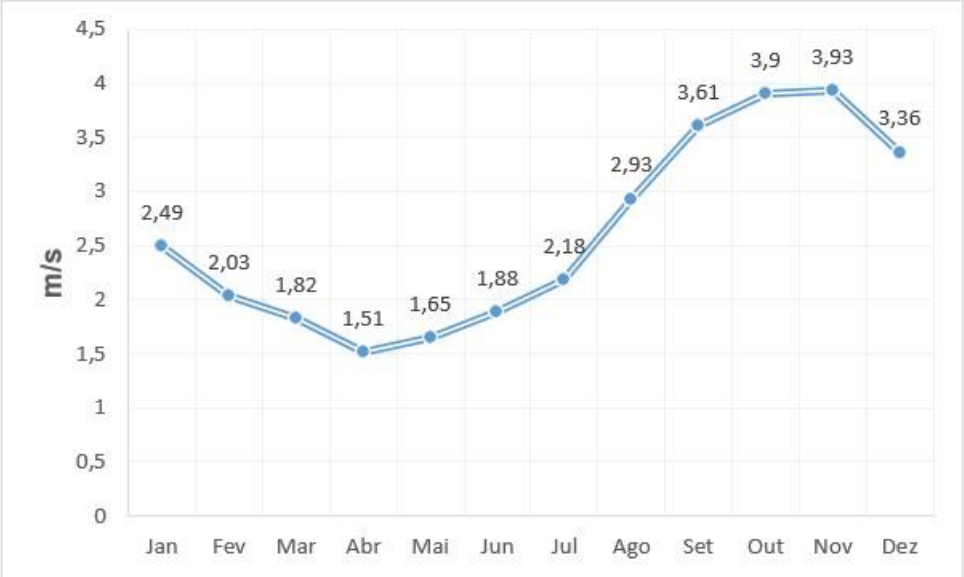
Revista Eletrônica do curso de Geografia
Graduação e Pós-Graduação
Jataí-GO | n 47 | Set-Dez/2023
ISSN 1679-9860

increased wind velocity and April, the lowest amount of speed. According to Mezenes (1995), the highest wind intensity values are registered in the second annual semester to São Luís, because it's an occasion in which the ITCZ is the closest to the north of the Atlantic, as such, farther to the Maranhão's shores, allowing space to the circulation associated to ASAS (South Atlantic Subtropical High - Alta Subtropical do Atlântico Sul), whose leaks to the surface are intensified closer to Brazil Northeast's shores.

Figure 5: Climatology Average (1960-1991) of São Luís's wind intensity.



Source: INMET/BDMEP - Org.: Authors

Atmospheric Circulation and Synoptic Systems

Among all the atmospheric systems that influence São Luís' climate, the most prominent is the action of the ITCZ (Intertropical Convergence Zone). Its seasonal migration to latitudes further north, up to 14° during the months of August/September, and to the south, down to 2° of latitude during the months of March/April, is crucial in generating precipitation or its absence.

Studies on the behavior of the ITCZ conducted by Uvo (1989) indicated that its prolonged stay in its northernmost or southernmost positions determines the amount of rainfall in the Northeast of Brazil. Furthermore, research by Nobre and Shukla (1996) on the behavior of the ITCZ confirmed that the wettest years in the northern Northeast Brazil (NEB) and the Eastern Amazon are characterized by the ITCZ remaining further south of its climatological

position until April/May, while in dry years, the ITCZ shifts northward starting as early as March. Thus, according to the authors, the movements of the ITCZ that determine rainfall variability are associated with the influence of the Sea Surface Temperature (SST) Dipole in the northern and southern Atlantic Tropical basins. Marengo and Hastenrath (1993) also observed a relationship between the positioning of the ITCZ in the Equatorial Atlantic and the occurrence of El Niño. They demonstrated that during years of significant warming of the Central Equatorial Pacific waters, the ITCZ anomalously positioned itself north of its climatological position over the Tropical Atlantic.

It is also worth noting studies that analyzed the behavior of the ITCZ in El Niño and La Niña years, as researched by Pezzi and Cavalcanti (2001). The authors state:

> It's inferred that ITZC positions itself north of the Equator in cases of "hot dipole" (hotter waters in the North Atlantic), in years of El Nino or La Nina, leaving NEB with precipitation under average. In the occurrence of a "cold dipole" (hotter water in the South Atlantic), the ITZC positions itself south of the Equator in the years of El Nino or La Nina, but, in the years of El Nino, this system affects only the extreme north of Brazil's Northeast, with precipitation above average, while the others areas present conditions of drought. In the years of La Nina, all the NEB area presents positive rain anomalies. (p.209)

Also the studies about ITCZ made by Melo, Calvalcanti, and Souza (2009), affirm that the ITCZ, when associated with other atmospheric systems like the Trade Winds Confluence Zone (ZCA) and the Sea Surface Temperatures (TSM) of the Atlantic and Pacific, can cause the strengthening or weakening of ITCZ'S role in determining the variability of Northeast's rainy season.

Another highlight presented in Uvo (1989)'s studies about ITCZ is the occurrence of the formation of fracturing of two ITCZ and the author states that when the phenomenon occurs, it promotes more rain in the Northeast of Brazil.

The ITCZ, in its most diverse forms of influence and activity, represents to the region and the municipality of São Luís the most important zone mechanism of impact and configuration of its climate. We also stress the scale level of influence, the presence of the Trade Winds over the region, and the municipality of São Lupis its presence is registered throughout all the year's months and retains a crucial role in diminishing the surface's temperature and promoting the clouds' movement and direction.

We underscore the importance of emphasizing the existence of other systems all in different scales of action relevant to the understanding of São Luís' climatic configuration.

Already in a regional scale of influence, we emphasize the High Levels Ciclonic Vortices (VCAN's) can be depicted as being meteorological systems characterized for showing very low-pressure centers that originate in the high troposphere (between 5 and 13 kilometers of altitude) making it so that the drought in these levels suffer subsidence and reach the surface. Its enactment, according to Ferreira et al. (2009) can take many days and is considered semi-stationary in its movement. Nonetheless, following the authors, this meteorological system represents a critical acting mechanism in the northeast region and part of the north of Brazil, provoking when in its event the absence of clouds in the center and rain in the surroundings of VCAN.

Another highlight in the acting of the atmospheric systems, this one also on a regional scale, is the influence of the Subtropical High in the South Atlantic – ASAS (South Atlantic Subtropical High) has over São Luís when manifested. This atmospheric mechanism stands out for repressing the occurrence of rain and increasing or decreasing the wind's speed in the Brazilian northeast. Degola (2013) conceptualizes ASAS as a system of high pressure in its anticyclone spin, and in average atmospheric levels, determines the air subsidence, that is, the air that lowers from the highest layers to the lowest ones, intercepting the formation of rain clouds and directly influencing the wind's speed. In his studies, Degola (2013) identified that when the ASAS is to the west of its climatologic position, it was observed an intensification of Trade Winds throughout Brazil's entire northeast region, especially in the months of spring and summer. As a counterpoint, when the ASAS is to the east of its climatologic position, it was observed the weakening of the Elysium winds in the northeast region. The author suggests that in the following years, the tendency will be that the ASAS will move towards the west, thus making Brazil's northeast region impacted by the intensification of the Alysium winds.

Another system that has influence over the region and in São Luís is the system called East Wavy Disturbances (DOL) or East Waves (OL) which is the meteorological phenomena formed in the influence area of the Trade Winds Confluence Zone (ZCA) close to the equatorial Line, its movements occur from east to west, from ocean to continent, provoking the increase in rainfall. Countinho and Fisch's (2007) research of the East Wavy Disturbances' actions in the region of the Rocket Launching Base, in Alcântra - MA, only 18km of distance from São Luís,

identified the presence of this meteorological system throughout the year, although its acting occurs only sporadically provoking occasional rains.

In more than a secondary meteorological system in the region's actions identified the Instability Lines (LI) that accordant to Cohen et al. (1996) are systems comprehended as a narrow scope of nebulosity that is formed in the tropical regions, in mesoscale, predominantly in the forms of lines, generating intense rainfall when manifested. Its actions in the area are studies produced by Barros and Oyama (2010) when they researched the rainfall in Alcântra's Rochet Launching Center and indicated that the Instability Lines are associated with the significant part of the ITCZ, and its occurrence manifests in the region solely between the months of February and June, and also that only in the month of April that the phenomenons act with its highest frequency.

Another secondary meteorological system that operates in the region is identified as Instability Lines (LI), which, according to Cohen et al. (1996), are systems understood as a narrow band of cloudiness that forms in tropical regions on a mesoscale, usually in the form of lines, generating intense rainfall when active. Their impact on the region, as indicated by studies conducted by Barros and Oyama (2010) when researching rainfall at the Alcântara Launch Center, shows that Instability Lines are largely associated with the ITCZ and that they occur in the region only between the months of February and June. Moreover, it is only in the month of April that the phenomenon is most frequently active (Figure 6).

Figure 6: Performance of Instability Lines (LI) in northeastern Brazil.

Source: FUNCEME

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Final Considerations

- In this study, it was possible to identify the classification of climatic types characterizing the municipality of São Luís through analytical-static climatic models as well as genetic classification models, thereby promoting a comprehensive understanding of its atmospheric configuration mechanisms.
- The main geographical factors determining its climatic dynamics and the synoptic systems at play were also identified. This allowed for the recognition that the key atmospheric systems present and active in the municipality of São Luís are, notably, the Intertropical Convergence Zone (ITCZ), responsible for the annual determination of the rainy and dry seasons; the influence of the Trade Winds, responsible for transporting moist air and causing rainfall; at a secondary level of influence, the High-Level Cyclonic Vortices (HLCVs), generating periods of atmospheric stability with drought; the South Atlantic Subtropical High (SASH); the Eastward Wave Disturbances (EWDs); and Instability Lines (LI), leading to short periods of rainfall in the region. On a local scale, there is the influence of the maritime breeze with daily winds and occasional rainfall from convective systems.
- The climatic type of São Luís is characterized by consistently high average temperatures throughout the year, with low daily, monthly, or annual variability. Its relative humidity remains high year-round, with an average of 80%. It is strongly influenced by the ITCZ, which dictates its annual rainfall conditions, resulting in a rainy season from July to December and a dry season from January to June. Its geographical characteristics determine that its climatic pattern is of the tropical equatorial type, with well-defined rainy seasons and high temperatures.
- The research does not definitively conclude the identification of the climatic patterns at play in São Luís, Maranhão. Global climate changes are causing alterations in various atmospheric dynamic mechanisms on various scales of operation; therefore, updates will always be necessary to monitor ongoing modifications.

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