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SEMIARIDITY AND RAINFALL VARIABILITY IN NORTHEASTERN BRAZIL

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ABSTRACT
The main objective of this research is to present some answers to questions related to the climate of the Northeast region of Brazil, specifically the semi-arid Northeast. This domain of nature in Brazil is subject to intense interannual rainfall variations and which generally presents high climatic susceptibility to desertification. But what are the causes for this semi-arid climatic condition in a country with a predominantly humid/tropical climate? The questions formulated for the development of this work were the following: why is the climate in the Northeast region predominantly hot? Why does a large part of the region have semiarid conditions? What are the geographical causes and atmospheric dynamics that are at the root of the semi-arid Northeast?
Keywords: Brazilian drylands, Northeast region of Brazil, atmospheric circulation patterns, semi-arid and subhumid climates.

RESUMO
O principal objetivo desta pesquisa é apresentar algumas respostas a questões relacionadas ao clima da região Nordeste do Brasil, especificamente do semiárido nordestino. Este domínio da natureza no Brasil está sujeito a intensas variações pluviométricas interanuais e geralmente apresenta alta suscetibilidade climática à desertificação. Mas quais são as causas desta condição climática semiárida em um país de clima predominantemente úmido/tropical? As questões formuladas para o desenvolvimento deste trabalho foram as seguintes: por que o clima da região Nordeste é predominantemente quente? Por que uma grande parte da região tem condições de semiaridez? Quais são as causas geográficas e da dinâmica atmosférica que estão na gênese da semiaridez nordestina?
Palavras-chave: Terras secas brasileiras, região Nordeste do Brasil, padrões de circulação atmosférica, climas semiáridos e subúmidos.

INTRODUCTION

The main objective of this research is to present some answers to questions related to the climate of the Northeast region of Brazil (NEB), specifically the semi-arid Northeast, which

was called by geographer Aziz Ab Saber to “Sertão”, “dry northeast” or “domain of the dry hinterlands” (Ab SABER 2003). This domain of nature in Brazil has been studied for a long time and deserves attention as it is a large area with semi-arid and subhumid climates, subject to intense interannual rainfall variations and which generally presents high climatic susceptibility to desertification (CONTI 2005, SILVA & LUCIO 2015, SALIMON & ANDERSON, 2018). But what are the causes for this semi-arid climatic condition in a country with a predominantly humid, tropical climate?

The questions formulated for the development of this work were the following: why is the climate in the Northeast region predominantly hot? Why does a large part of the region have semiarid conditions? What are the most relevant geographic factors in the genesis of this semiarid climate? What are the main hypotheses defended for the climatic causes of semiarid? To answer these questions, it became essential to analyze the geographic factors of climate (geographic location of the region, altitude, relief forms, distance from the coastal zone), as well as the analysis of atmospheric dynamics, understood from the circulation patterns of the atmosphere in the most varied scales and its complexities: Intertropical Convergence Zone – ITCZ; El Niño Southern Oscillation – ENSO; the acting air masses; the predominant precipitation-causing cloud types; and the performance of Upper Tropospheric Cyclonic Vortexes – UTCVs. Therefore, this short contribution (technical product) was divided into two parts: the first that tries to justify the predominance of high temperatures in the semi-arid region of the Northeast and the second that seeks to discuss the causes of semiaridity in the mentioned region.

The “semi-arid” polygon corresponds to 56.5% of the NEB, with high annual temperature and evaporation rates (SILVA 2004, ALVALÁ et al 2019), where rainfall levels are less than 800 mm and the aridity index is less than 0.50 (MMA 2007, CORREIA et al. 2011). Almost the entire interior of the region is semiarid, if we eliminate the great state of Maranhão, which has a humid equatorial climate, reducing the percentage of the semiarid area when considering the entire region. States such as Bahia, Ceará, Rio Grande do Norte, Paraíba and Pernambuco have more than 60% of their municipalities in the semiarid area, with emphasis on the states of Ceará and Rio Grande do Norte with more than 80% of their municipalities in the semiarid region (ARAÚJO-FILHO 2006, SUDENE 2015).

For a long time, researchers have been trying to explain the causes of the semiarid that covers a large part of the northeastern interior. Many of these studies have sought this understanding through geographic characteristics associated with atmospheric circulation patterns.

RESULTS AND DISCUSSION

Why is the climate in northeastern Brazil predominantly hot?

It is known that the angle of incidence of the sun's rays anywhere on the planet is determined by the latitudinal location of the place (AYOADE 2007). The Northeast region of Brazil, located between 1st and 18th of South Latitude and between 34th and 48th of West Longitude, is between the equator and the tropic of Capricorn and then annually subject to

two zenithal culminations of the Sun, once that of the “fixed” inclination of approximately 23º of the Earth's rotation axis with respect to the movement it performs around the Sun limits the maximum intensity of solar energy between the latitudes of 23.5º N and 23.5º S, with excess in the equator and deficit in the poles (TORRES & MACHADO 2011). Thus, “the greatest heating of the earth's surface occurs in this space, where the sun's rays fall directly throughout the year. The temperatures between these latitudes, therefore, remain high throughout the year” (FERREIRA 2006 p 50). The regions of planet Earth located in low latitudes or close to the tropical bands will generally present the highest temperatures on the globe arising from the interaction between solar energy and the earth's surface, and such values will only be modified by the influence of other geographic factors, of which the altitude deserves to be highlighted.

Altitude exerts influence on air temperature, as in the troposphere with increasing altitude there is a decrease in temperature (SANTOS et al. 2013, RAMASWAMY et al. 2017), this geographical factor being almost as important as latitude with regard to the thermal characteristics of a given place. According to Dias et al. (2007), the atmosphere is practically transparent to radiation from the Sun. It absorbs a small portion of this radiation while the surface stores a large amount of solar heat, working as a thermal absorber. It is the Earth's surface heated by solar energy that is primarily responsible for the greater supply of heat to the lower layers of the atmosphere (TORRES & MACHADO 2011). In the lower regions of the Planet, the concentration of air and the capacity to retain heat from terrestrial radiation will be greater and its temperature higher due to the proximity of heated surfaces, the higher the altitude of a place, the lower the air temperature and the local atmospheric pressure (STEINKE 2012). As the Northeast region of Brazil presents low altitudes, with the predominance of coastal plains, plateaus with an average altitude of 600 meters and "sertão" depressions, this is the main reason for the empire of high annual temperatures.

Why does the Brazilian Northeast show semiarid? - The geographical causes

Much more complex than the simple explanation for the origin of the high temperatures present in Northeastern Brazil is the answer to the region's semiarid condition. Among the main present geographic characteristics, there are the forms of relief in relation to the prevailing winds, the geographic location of the region in relation to the active air masses and the distance from the coastal zone. According to Ab Saber (1999) “the dry Northeast is not the empire of the highlands. In 85% of its total space, the Brazilian semiarid region, extends through plateau depressions, located between old massifs and occasional plateaus in the form of endless country hills” (p. 10). Thus, these depressions are hidden from the humid winds coming from the coast that reach the escarpments of the plateaus and plateaus directed towards them, underexposing the depressions to the humid masses coming from the Atlantic Ocean. Then a question arises: would the eastern escarpments of Diamantina and Borborema be capable of retaining all the moisture originating from the eastern Atlantic? For Reboita et al. (2016), this is not the main cause. Regarding this issue, Nimer (1979) stated that the air mass of the equatorial Atlantic, responsible for the high humidity in the northeastern east coast, is composed of two currents, a fresh and humid lower one and a hot and dry upper one. This mass produces continuous rains on the coast, mainly in winter, when the trades are

frequently cooled by its mixture with the maritime polar air, leaving the interior dry, with the exception only of the mountain ranges. Nimer's report tries to justify why the rains from the Atlantic instabilities, which present the East Coast with high levels of rainfall, are restricted to a narrow continental strip in the coastal zone and the forest zone.

A recent study (ARAÚJO 2015) on the shallow convection of clouds that form on the coast goes against this hypothesis raised by Nimer in 1979. Another hypothesis relates the origin of the NEB's semi-aridity to its geographic position in relation to the active air masses. Nimer (1979) through studies on atmospheric circulation, argued that the Brazilian Northeast would be the “end point” of several systems of disturbed atmospheric currents coming from the South (polar fronts), the North (ITZC), the East (Trade winds) and from the West (Tropical Instability Lines). In 2007, Mendonça & Danni-Oliveira (2007) talked about the Northeast, bringing the same argument that the Equatorial Continental, Equatorial Atlantic, Tropical Atlantic and Polar Atlantic air masses arrive in interior of the region with insufficient humidity.

Still under the explanation based on geographic climate factors, Molion & Bernardo (2002) bring Charney's hypothesis that semi-arid surfaces have high albedo and reflect more radiation than neighboring areas, presenting a relatively cooler tropospheric column, which consequently would inhibit the formation of convective clouds. However, a question arises: would the high albedo not be the result of the semiarid itself? - Since the semiarid surface is lighter than its surroundings due to the sparse Caatinga vegetation (rich in deciduous species) and frequent rocky outcrops.

Why does the Brazilian Northeast show semiarid? - The climatic causes

Related to the question of the origin of the semi-aridity of the dry hinterlands are the hypotheses about atmospheric circulation at the most diverse levels. Regarding geographic causes, the hypothesis that the Northeast region is the end point of several rain-producing systems has already been addressed. Here, we will focus on important synoptic systems at work and teleconnections, as well as sea breezes, starting the topic with the most studied system of atmospheric circulation related to rainfall when talking about the semi-arid Northeast, which is the Intertropical Convergence Zone (ITCZ). Numerous studies report the importance of ITCZ as the main mechanism responsible for the rains that occur in the north of the region between February and May (KAYANO & ANDREOLI 2009, Reboita et al. 2016). Thus, it is the longer stay of the ITCZ further north or south of the equator that determines the quality of the rainy season in the semiarid region (MELO et al. 2009). The variations in position and intensity of the ITCZ are directly related to changes in the positions and intensities of the subtropical anticyclones of the North Atlantic (Azores) and the South Atlantic (Santa Helena). These, in turn, are driven by pressure differences resulting from the receipt of solar energy and possible anomalies in the temperature of the sea surface, measured through the Tropical Southern Atlantic Index (TSA) and the Tropical Northern Atlantic Index (TNA) (REBOITA & SANTOS 2014). Positive temperature anomalies in the South Atlantic and negative in the North Atlantic are associated with rainy years and the opposite is associated with dry years (REBOITA & SANTOS 2014). Thus, in years when

the ITCZ is south of the equator and when it also presents a double band with strong cloudiness, it is certain that the rains will be intense in the semiarid region of the Northeast. On the other hand, with the ITCZ being more to the North, this position would bring subsidence to the South (Hadley's cell) over the Northeast, generating dry weather in the region during the winter and austral spring period (MELO et al 2009, REBOITA et al. 2016).

Molion & Bernardo (2002) suggested that the semi-aridity of the Northeast would be related to the adjacency to the Amazon region, where large and intense convective movements occur. According to these authors, “the ascending air over the Amazon acquires an anticyclonic movement at the high levels (*Bolivian* Anticyclonic Circulation) and diverges and part of it moves to the east, creating a descending branch and a strong thermic inversion” (p. 5).

Regarding teleconnections, Walker (1928) apud Kayano & Andreoli (2009) documented the coincidence between the anomalous warming of the waters of the eastern equatorial Pacific and the droughts in the Brazilian Northeast, when a strong ascending branch caused by the positive anomaly of the eastern equatorial Pacific generates a descending branch over the Atlantic Ocean and the one over the NEB, known as the Walker circulation. In positive anomaly condition (El Niño), there is drought in the Northeast, in negative anomaly condition (La Niña), there is rain in the Northeast (SILVA et al. 2017). However, Kayano & Andreoli (2009) agree that in recent years, the most accepted interpretation is that the variability of the sea surface temperature of the tropical Atlantic is, in fact, a determinant of precipitation anomalies in the Northeast, while ENSO, on certain occasions it could strengthen or weaken them.

Attention has also been paid to studies on the Upper Tropospheric Cyclonic Vortex (HCVV) that operate in the vicinity of the Northeast region of Brazil. According to Ferreira et al. (2009), "the UTCVs present a relatively cold center, mass convergence, subsiding vertical movements in its center and ascending in the periphery, and more intense nebulously, mainly in the direction of its displacement” (p.43). This vortex has been associated with cloudiness and rain and/or the presence of clear skies, as it brings rain at its periphery and clear skies at its center. This system is connected to both *Bolivian* Anticyclonic Circulation and the South Atlantic Convergence Zone (SACZ) and it operates mainly during the austral summer, the beginning of the rainy season in the semi-arid Northeast, and its position and intensity are also related to variation of the rainfall recorded at the beginning of the rainy season in the region.

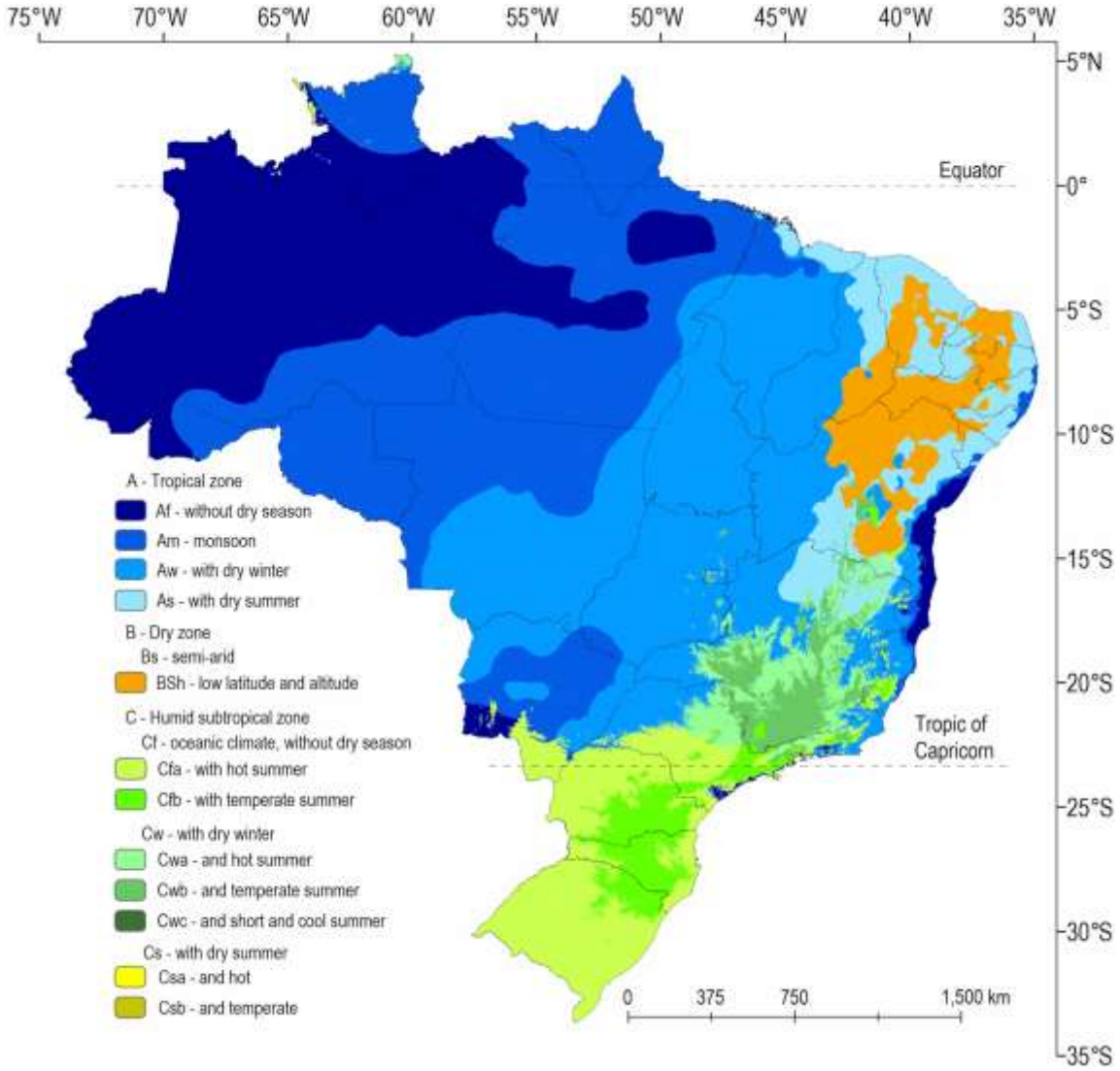
As for rainfall from different types of clouds, the study by Araujo & Vila (2017) showed that the dominant cloud type in the eastern coastal zone (wet region, where the trade winds blow inland) presents shallow convection and insufficient amount of water to promote rain also in the interior of the region. The strati form and deep convective precipitating clouds are more significant in the interior of the region (responsible for 60% of the precipitation that occurs in the semiarid), while the shallow convective clouds are relevant over the ocean and coastal areas. Also, according to the results of this research, the instability lines of medium to low intensity and the breeze circulation could explain this shallow convection annual march behavior in the east coast (rainy) of the Northeast region (ARAUJO 2015, ARAUJO & Vila 2017).

CONCLUSIONS

Through the research carried out, it was noticed that it is much simpler to understand the causes of the high temperatures present in a large part of the interior of Northeastern Brazil than the reasons for its semiaridity. It needs to be emphasized that the geographic climate factors and atmospheric systems discussed here continually act and interact, connecting sea and continental surfaces to global, regional and local atmospheric circulation patterns, which need to be carefully analyzed. The high radiation that responds to high temperatures throughout the year in the region, potentiate the loss of surface water, thus, the rainfall regime is of great importance as a determinant of semi-aridity in the region.

According to research carried out in the region, atmospheric rain-producing systems have a direct and indirect influence, and are potential rainmakers or inhibitors, when acting in conjunction with local geographic characteristics. The region's latitudinal location and modest altitudes explain the high temperatures recorded annually. The predominance of depressions located between massifs and plateaus, the geographic location in relation to the active air masses, the great ITCZ migrations, acting in conjunction or not with teleconnections, such as ENSO, the formation and location of UTCVs, in addition to the types of precipitating clouds, briefly exemplify the climatic complexity that is at the genesis of the semiarid domain of the dry hinterlands of northeastern Brazil.

Figure 1 – Semi-arid climate, with BSh semi-arid (low latitude and altitude).



Source: Alvares et al 2013

Figure 2 – Aspect of the semiarid depression in a dry season (Caicó/Brazil).

Source: Author, 2021.

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