MedCrave
Step into the World of Research
International Journal of Hydrology

Research Article
Open Access

Importance of thermodynamic conditions in extreme precipitation events in the city of Belem and metropolitan region

Abstract

The objective of this research was to verify the importance of thermodynamic factors in the occurrence of extreme precipitation events in Belém (PA) and metropolitan region, from August 2008 to December 2009. The study of the thermodynamics of the atmosphere was carried out in the light of theories of the Potential Available Energy for Convection (CAPE) and Convection Inhibition Energy (ISCED). In order to classify the extreme precipitation events, the decision method was used to associate them with the CAPE and the ISCED values. It was observed that the studied region has strong convective activity throughout the year, and that not always high CAPE and low ISCED produces precipitation. This situation determines deep convection, but to have precipitation there is a need for the dynamic forcing, even for the occurrence of extreme rainfall events in the rainy period, the dynamic forcing is ITCZ, and in the dry period what contributes is the Instability Line (LI). So when the precipitation process depended exclusively on the CAPE, it was necessary a high value to generate deep convection and consequently precipitation, whereas, in the process of precipitation with dynamic contribution, a significant value of CAPE was not necessary.

Keywords: CAPE, CINEMA, precipitation, extreme events

Volume 2 Issue 2 - 2018

Felipe Do Souto De Sá Gille, Maria Aurora Santos Da Mota

Postgraduate Program in Environmental Sciences, Federal University of Pará, Brasil

Correspondence: Felipe Do Souto De Sá Gille, Postgraduate Program in Environmental Sciences, Federal University of Pará, Brasil, Email felipesagille@hotmail.com

Received: March 03, 2018 | **Published:** April 17, 2018

Introduction

The release of latent heat is one of the main sources for the development of disturbances that occur in the tropical atmosphere, because the storage of potential energy is small because the temperature gradient is also small. The greater amount of latent heat released is associated with convective systems. Other sources of energy, besides the latent heat, which must be considered, are the surface heat flux and the infrared radiation. These parameters were studied by Neelin & Held[1] where they verified that the variation of these two parameters controls the atmospheric convergence and, of course, the precipitation through their joint effects in the supply of atmospheric static humid energy. In order to better understand the tropical atmosphere and improve forecasting models, Rennó & Williams[2] related the increase of Available Potential Energy for Convection (CAPE) and deep convection in the tropical atmosphere, with the decrease of the Inhibition Energy Convection (ISCED) and the mixing process, as they destroy positive buoyancy. The heat needed to generate this buoyancy is removed from the surface layer and a part of it is transported to free atmosphere from where it is irradiated into space.[3] The balance of this energy is transformed into mechanical work, which is used in the maintenance of the convective movements. The amount of work produced by this convective motion gives a measure of the amount of static equilibrium of the CAPE, which increases with increasing surface temperature. In addition to CAPE and CINE, parameters such as wind shear and relative humidity are also important for the development of deep convection.[4] The rainy season in the Tropical Amazon is initiated by the influence of Synoptic Systems conditioned by the increase of the amount of humidity in the Planetary Boundary Layer (CLP) and the decrease of the temperature at the top, reducing ISCED.[5] However, more than 80% of this precipitation comes from deep convection. Thus, understanding what controls changes in this deep convection become necessary to determine the seasonality of precipitation. The beginning of the rainy season will be determined not only by the energy source of the environment, which is indicated by the CAPE,[1] but also by dynamic conditions, such as the movement of the ascent of the plot and wind shear, which release the energy from the environment for the development of deep convection.[6,7] The growth of organized convective systems on a seasonal scale, such as the eastern waves[7,8] or intra-seasonal oscillations[9,10] depend on the released energy of these systems into the atmosphere and how the energy extraction is done. Surface temperature changes sometimes do not directly affect the onset of convection but are responsible for changes in circulation and thus affect the development of convection. Therefore, the thermodynamic conditions modulate the frequency and intensity of the plot's buoyancy.[11] The meso and large-scale systems intensify the local convective activity through wind shear generating CAPE, which favors the formation of storms, since the local thermodynamic conditions are related to the depth and longevity of the convection.[12] Betts et al.,[13] reported strong thunderstorms with the transition period from the dry season to the rainy season and the onset of the rainy season when CAPE is highest in almost all Amazonian sites. Therefore, they concluded that with a high CAPE the probability of a storm would be very high. However, not always large CAPE values are related to strong precipitation.[14] It is important to evaluate the ISCED values that could indicate the weakening conditions of the instability, thus not allowing the development of deep convection and consequently the formation of the storm. The city of Belém (PA) represents the largest urban agglomeration in the Amazon, in this region the highest occupancy rates were registered.[15] This is also one of the rainier regions with almost 3000mm.Ano-1. In order to study the parameters that contribute to the formation of storms, Tavares & Mota[16] carried out a study of the various thermodynamic indices. They verified that the CAPE and the ISCED are suitable for the city of Belém, for the rainy season, but it is necessary to make an adjustment for the dry period taking into account the ISCED. The formation of storms can be associated to several meteorological phenomena, such as the Intercropical Convergence Zone (ITCZ), which is one of the most influential meteorological phenomena in the Amazon region.[17] in the city of Belém. In addition to others that significantly influence weather conditions throughout the region. Therefore, the general objective of this work is to verify the importance of thermodynamic and dynamic factors for the occurrence of extreme precipitation events, in the city of Belém (PA) and metropolitan region, from August 2008 to December 2009.

Materials and methods

For the development of this research were used observational data of precipitation and radiosondes from August 1, 2008 to December 31, 2009. The daily precipitation was collected in ten points distributed by the city of Belém and in six points in cities of the metropolitan region, namely: in the meteorological stations of the Belém Air Space Detachment (DTCEA-BE), Instituto Nacional de Meteorologia INMET) and the Federal University of Pará (UFPA), at the pluviometric points of Jurunas, Maguari, Mangueirão, Marambaia, Montese (2 observation points) and Umarizal in the city of Belém, and Ananindeua, Carananduba, Icoaraci, Marituba, Outeiro and Santa Bárbara, in the metropolitan area, except Belém. The location of the data collection points is shown in Figure 1, Figure 2. Radiosonde data are from the Altitude Meteorological Station (EMA) located at Belém International Airport (PA), from August 1, 2008 to December 31, 2009, at 0000 and 1200 UTC times, available at http address: //www.weather.uwyo.edu/upperair/sounding.html. Also, satellite image and synoptic chart analyzes were used for the period considered to verify the weather conditions in the studied region, which were obtained through the addresses http: //www.redemet.aer.mil.br and htpp: //www.sat.dundee.ac.uk and information provided by the National Center for Aeronautical Meteorology (CNMA). We selected the data of extreme precipitation, from the accumulated precipitation data in 24 hours, from 01/08/2008 to 21/12/2009. From the precipitation data, from all the points collected, the maximum total precipitation was verified and the spatial average of the collection points was checked each day. In order to find and select extreme precipitation events, the decision method was adopted.[18] This method says that if a dataset is schematized in order of magnitude, the average value that divides the series into two equal parts is called the median. Physically, the first and ninth deciles present the rarest cases in the series, which, although they are very small, correspond to 10% of the total of the whole series, with values lower than the first decile are 10% smaller, as well as values higher than the ninth decile are 10% higher. The present study chose the ninth decile for daily total precipitation to be considered extreme daily rainfall. It was verified, then, that the values of precipitation between 47.9mm / day represents the ninth decile and daily rainfall equal to or greater than this value were considered extreme daily precipitations. Therefore, for the analyzed period, 42 extreme events of precipitation were found, being the most intense of all 96.3mm/day. After the selection of the events and the days that occurred, the thermodynamic and synoptic conditions were analyzed in order to verify their contributions to the occurrence of extreme precipitation. It was also analyzed the wind field, vorticity, divergence and humidity of the atmosphere at medium levels in order to verify the contributions of each parameter in the development of deep convection, since the main forcants that modulate the vertical currents inside convective cells are: the force due to the vertical pressure gradient and the buoyancy.[19] The analysis of the thermodynamic conditions was done evaluating the variation of the CAPE and the ISCED. Radiosonde data were used for CAPE and CINE calculations using the equations suggested by Emanuel et al.,[20] & Rennó et al.,[2] respectively. It was also verified the humidity at medium levels of the sounding through the analysis of the thermodynamic diagram SKEW T LOG P and then graphs were elaborated in order to verify the variation of the CAPE and CINE and the possible relation with the maximum and average precipitation accumulated for the city of Belém and metropolitan region. The CAPE calculation was done according to the equation, suggested by Emanuel et al.[20]

$$CAPE = \int_{NCE}^{NE} (\alpha_p - \alpha_a)\, dP$$

Where: a_p is the specific volume of the plot and α_a the specific volume of the environment. ISCED is the negative area of the thermodynamic diagram. It exists when the difference between the Particle Virtual Temperature ($Tv_{(par)}$) and the Virtual Environment Temperature ($Tv_{(amb)}$) is negative. This means that the pseudo-adiabatic displacement of the air parcel is colder than the environment. The CAPE limit values for the tropical region are shown in Table 1.

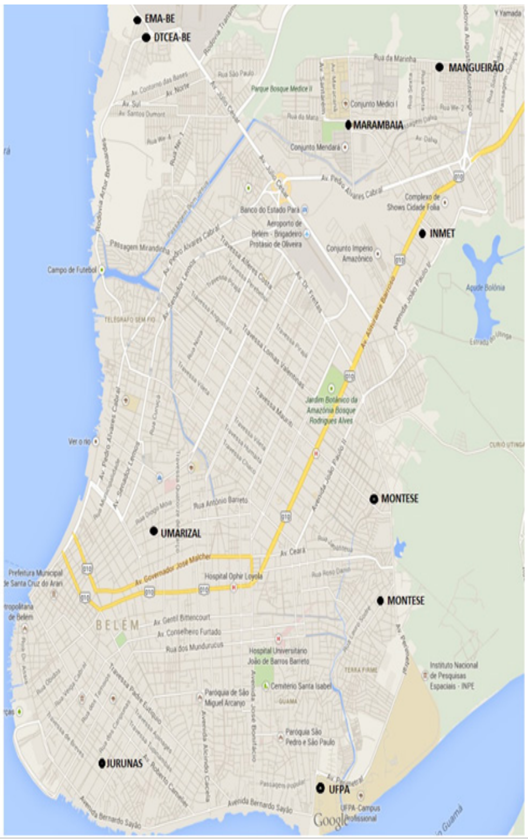

Figure 1 Location of Belém Altitude Meteorological Station (EMA-BE) and rainfall collection points in the districts of Belém (PA).

Table 1 The CAPE limit values for the tropical region

CAPE (J/kg)	Instability conditions
> 0 up until 1000	Limit for formation of deep convection
1000 up until 2500	Moderate Deep Convection
2500 up until 4000	Strong deep convection
> 4000	Severe Convection

Figure 2 Location of Belém Altitude Meteorological Station (EMA-BE) and precipitation collection points in the metropolitan region of Belém (PA).

Results and discussion

The analysis of precipitation variation, CAPE and ISCED in the period between August 1, 2008 and December 31, 2009 is made in this chapter. This analysis sought to determine the influence of thermodynamic conditions on the occurrence of extreme precipitation events in the city of Belém and the metropolitan region. The results show that, not always, high values of CAPE were related to the occurrence of precipitation, as shown in Figure 3. In these cases the absence of precipitation occurred due to the lack of a strong enough dynamic mechanism to raise the air parcel from the surface to the NCE causing the convection to be fired. It was observed that in order to generate rain, due exclusively to thermodynamic factors, it is necessary that the CAPE value be higher than 2000J/kg. The results are similar to the conclusions obtained by Mota & Nobre,[14] when they did the CAPE analysis for the State of Rondônia, and found that the CAPE should be above 4000J/kg so that deep convection and precipitation could occur in the absence of the dynamic forcing. In the studied period, extremes of precipitation occurred with low CAPE values, in this case, precipitation extremes occurred due to the dynamic breeze effect, which formed lines of instability along the coast of Belém generating strong precipitation in the region, as discussed by Gamache & Houze,[21] Garstang et al.,[8] Cohen et al.,[7] Alcantara et al.,[22] The presence of the Intercropical Convergence Zone (ITCZ) in the study region and cold fronts in southeastern Brazil also influenced the variability of the precipitation in Belém, as they contributed to the increase of convergence at low levels and to the increase of humidity in atmosphere. These results are similar to those found by Xavier et al.,[18] for the catchment area of Ceará and for Tavares & Mota,[16] for the city of Belém and the metropolitan region. The ZCIT, a large-scale dynamic forcing, intensifies convection and generates severe storms, which causes great material damage to society. It was also observed in this study that low values of ISCED do not determine precipitation occurrence, and that if the thermodynamic effects are associated with the dynamic effects, the amount of precipitation occurred in the studied region will be greater than that associated with these factors acting individually.

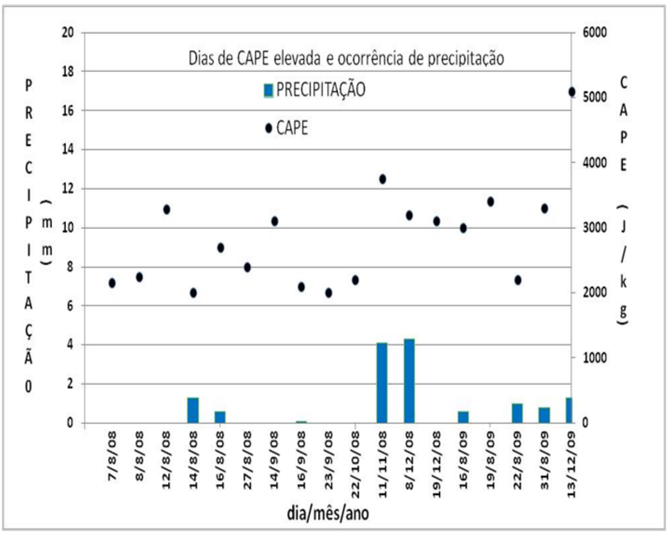

Figure 3

Precipitation variability

Figure 4 shows the total accumulated monthly rainfall (spatial mean of collection points) in the analyzed period, for the city of Belém and the metropolitan region. It is observed that a greater amount of precipitation occurred between the months of January and June of 2009, and the maximum occurred in March (354mm). This period with the greatest amount of monthly total precipitation (spatial mean of collection points) was called, in this research, "rainy season". The influence of the ITCZ in the region is due to the variation of the radiation received by each hemisphere, so that from September, the ITCZ is moving from the northern hemisphere to the southern hemisphere.[23] The period of least total monthly rainfall (mean of collection points), called the dry period in this work, occurred between July and December of the years of 2008 and 2009. Given that the lowest total monthly rainfall (spatial average of points of collection) occurred in November 2009 (49mm). In Figure 5, forty-two (42) extreme precipitation events (> 47.9mm for the sample analyzed) were observed, both in the rainy season and in the dry season.

The rainy season had a higher frequency of extreme events, twenty-eight events and also the highest accumulated precipitation in 24hours (96.3mm), observed on 01/04/2009, in the Montese Quarter. Considering that the total monthly precipitation (the spatial mean of the collection points) of the month of April 2009 was 297mm, on this single day it rained one third of the monthly total precipitation (spatial mean of the collection points) of this month. After selecting the ten largest extreme precipitation events from the whole series, it is verified that eight occurred in the rainy season, while in the dry season only two occurred. The same result found Tavares[24] when he associated the greater occurrence of extreme events to the rainy season. In addition, it was observed that in April, despite not being the month of greatest precipitation, five of the ten extreme rain events occurred, which had

Citation: Gille FDSDS, Mota MASD. Importance of thermodynamic conditions in extreme precipitation events in the city of Belem and metropolitan region. *Int J Hydro.* 2018;2(2):220‒225. DOI: 10.15406/ijh.2018.02.00072

the influence of the ITCZ, in its climatological march to the northern hemisphere. A large amount of Altostratus (AS) was found in the satellite analyzes, associated with cumuliform cloudiness of the ZCI. These AS were responsible for most of the continuous rainfall that occurred in the Tropical region.

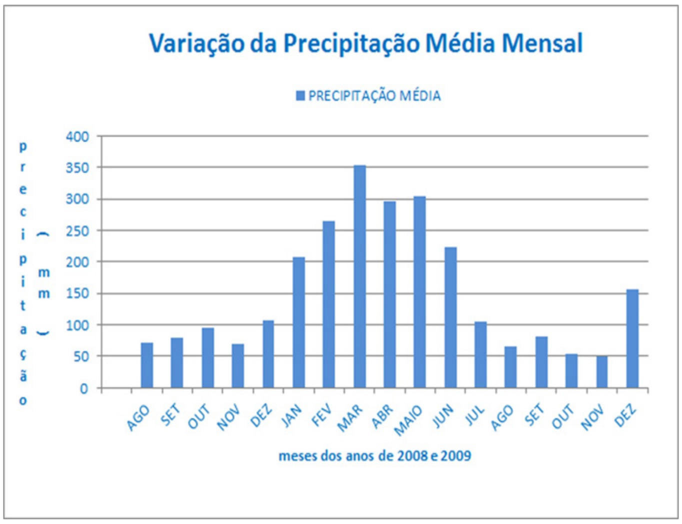

Figure 4

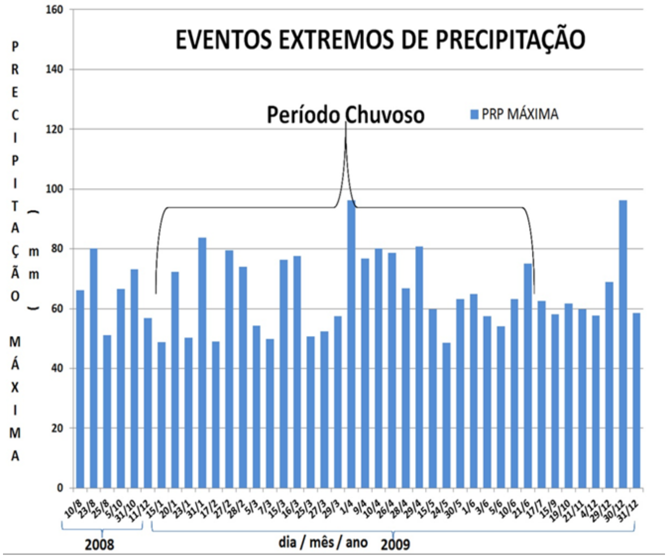

Figure 5

Variability of CAPE, CINEMA and precipitation

The average monthly variability of CAPE, ISCED and monthly total precipitation (monthly spatial average of collection points) is presented in Figure 6. It can be observed that CAPE behavior in the dry period (July to December) was similar to the rainy season (January to June), since in both periods there were lower values than the average of all studied period (continuous black line - 1,350J/kg). The monthly average CAPE values for the dry period were not always higher than the monthly average CAPE of the rainy season, as can be seen in November / 2008 (1,200 J / kg), July / 2009 (1,130 J / kg / kg / kg / kg / kg / kg / kg / kg / kg) and dry weight (kg / kg)), May / 2009 (1,500 J / kg) and June / 2009 (1,410 J / kg) of the rainy season. The results found in this paper differ from Tavares & Mota,[16] since the analysis presented here refers to the monthly average of CAPE and not to the absolute daily values of CAPE, which were related by the author when comparing the occurrence of one extreme event in the dry period with that of the rainy season. So, the monthly variation of CAPE was significant, independent of dry and rainy periods, with values between 900J/kg (minimum) and 1900J/kg (maximum). Characterizing the strong convective activity throughout the year, in the tropical region, mainly in the Amazon, because even with small CAPE, nevertheless, it represents convective activity.

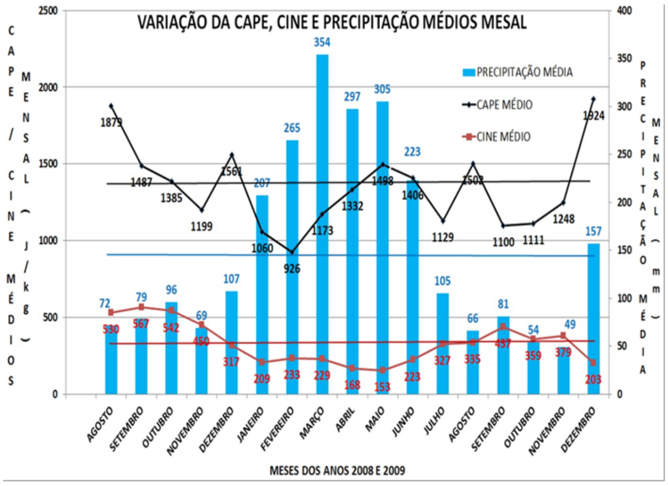

Figure 6

Therefore, for deep convection to occur and to generate precipitation, it is sufficient to perform the dynamic forcing to trigger the process. Regarding the monthly mean values, ISCED in the rainy season presented values lower than 300J/kg in all months, while in the dry period, their values were higher than 300J/kg also in all months. It is clear, then, that ISCED is higher in the dry period. In this way, the air parcel has a greater barrier to be broken, which hinders the development of clouds and, consequently, the occurrence of precipitation. Another important characteristic refers to the monthly average values of ISCED in the dry period. When its values were higher than 400J/kg, the total monthly precipitation (spatial mean of the collection points) of this period was not greater than 100 mm, as was observed in 2008 and 2009. Thus, it is evident that CINE is fundamental for the development of clouds and therefore for the occurrence of precipitation, but when it has a large value, it prevents the rise of the air parcel inhibiting convection and precipitation. That is, ISCED represents a significant barrier to the release of conditional instability in the tropical region.[2] Figure 7 shows the forty-two (42) extreme precipitation events, CAPE and CINE. It is possible to verify that the CAPE values, associated to extreme events in the dry period, are higher than the CAPE in the rainy season. CAPE values greater than 1500 J / kg were present when most extreme events occurred in the dry period, and less than 1500J/kg in most events during the rainy season. It is also verified that CAPE values below 700J/kg were only present in seven events, one occurred in the dry period and six in the rainy season. Of the ten largest extreme events CAPE was only less than 1000J/kg in one occurred on 09/04/2009, which characterizes the need to have a CAPE of at least 1000J/kg in the tropical region to support the convection convective circulations against mechanical dissipative losses (Rennó and Ingersoll, 1996). The ISCED was over 250J/kg in fifteen events, with six occurring in the rainy season and seven in the dry season. It can be verified, then, that the ISCED presented significant values in the days that occurred the extreme events. It is important to note that even though ISCED values are lower than CAPE, they are significant for convection, since ISCED represents a barrier to be overcome for the release of conditional instability in the tropics.[2]

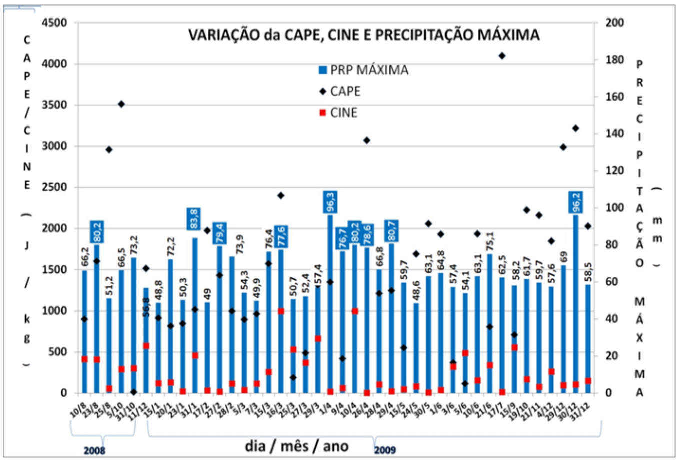

Figure 7

Thus, it was clear that thermodynamic conditions are essential for the release of convection, cloud formation and precipitation occurrence in the tropical region. Although CAPE is lower in the rainy season, this period is also marked by smaller ISCEDs, which favors convection. The smaller ISCED allied to the dynamic large-scale forcing, that is, the southernmost position of the ITCZ, favors the greater occurrence of extreme precipitation events. In the dry period, for an extreme event to occur, there is a need for CAPE to be higher, preferably greater than 1,500J/kg, and in some events this value is higher than 4,000J/kg, as observed in the day 07/17/2009. Of the fourteen extreme events analyzed, in the dry period, eleven occurred when CAPE was above 1,500J/kg. This statement corroborates with Tavares,[24] who also found, for the dry period, for the Belém region, the highest occurrence of extreme precipitation events when CAPE was higher than 1,000J/kg. The CINE, also, higher in this period, is not a factor that prevents precipitation. Values greater than 250J/kg, although inhibiting the rise of air, are important and necessary for the formation of storms, which can generate extreme precipitation events. This occurs because in highly unstable environments the convective activity is favored. In this way, that is, with the present inhibition, the instability is growing throughout the day due to surface heating. Thus some more isolated points, where the inhibitors weaken first, will be the preferred spots for the storm to shoot, so they can use more available energy, contributing to the cumuliform cloudiness. This greater vertical development of the cloudiness, in this period, could bring along with the vertical shear of the wind, more electrified clouds.

Another point, to be considered, is the occurrence of a layer of dry air at medium levels. This dry air helps to promote convective instability due to the production, by evaporation, of descending currents capable of generating new developments of the cloudiness and with that to sustain the storm. The dynamic event is also fundamental for the occurrence of extreme events. Although the ITCZ is shifted at this time of year to the northern hemisphere, the lines of instability, driven by the breeze, appear more frequently. These lines bring moisture from the ocean to the mainland and also contribute to increase the instability of the atmosphere, thus favoring the development of convective activity and thus increasing the possibility of an extreme event occurring.

Conclusion

It became clear that in the rainy season, extreme precipitation events are associated with the presence of the ZCIT, a large-scale forcing, and its climatological gait between the northern and southern hemispheres. At this station, in addition to short-lived rainfall, most of the precipitation occurs continuously, i.e lasting more than one hour. This precipitation is closely linked to the stratiform nebulosity of the ITCZ and occurs preferably during the early morning hours. The sum of rainfall, cumuliform clouds, and continuous precipitation, due to stratiform nebulosity, cause the extreme precipitation events of this period. In the dry period, most of the extreme events are associated with the breeze effect, which form LI, which invade the coast bringing more moisture to the continent and accelerate the vertical rise of the air parcel. The cold fronts in their displacement also influence the weather conditions in Belém, leading to greater convergence at low levels and also greater wind shear. The CAPE values, which are related to the occurrence of an extreme rainfall event in the rainy season, were lower than in the dry period, i.e, the CAPE measured before the occurrence of an extreme precipitation event in the rainy season is lower than the of the dry period. The high values of CAPE are related to the significant occurrence of precipitation. At these times the absence / small precipitation occurred due to the low amount of water vapor available in the atmosphere, and / or the lack of a forcing mechanism to raise the air parcel. It has become clear that ISCED is fundamental to cloud development, but it cannot be extremely large, if it is, the cloudiness will not have the vertical development necessary to provide significant precipitation. With the inhibition present, instability is increasing throughout the day due to surface heating. Thus some more isolated points, where the inhibitors weaken first, will be the preferred spots for the storm to shoot, so they can use more available energy, contributing to the cumuliform cloudiness.

Acknowledgments

The authors are grateful to the Financier of Studies and Projects (FINEP) for the financing of Project REMAM 1 and 2.

Conflict of interests

The authors declare no conflict of interest.

References

1. Neelin JD, Held IM. Modeling Tropical Convergence Based on the Moist Staticenergy Budget. *Monthly Weather Review.* 1987;115:3–12.
2. Williams E, Rennó NO. An Analysis of the Conditional Instability of the Tropical Atmosphere. *Monthly Weather Review.* 1993;121(1):21–36.
3. Rennó NO, Ingersoll AP. Natural convection as a heat engine: a theory for CAPE. *Journal of Atmospheric Sciences.* 1996;53:572–585.
4. James RP, Markowski PM. A numerical investigation of the effects of dry air aloft on quase-linear convective systems. *Monthly Weather Review*. 2010;138(1):140–161.
5. Greco S. Rainfall and surface kinematic conditions over central Amazonia during ABLE 2B. *Journal Geophysical. Research*. 1990;95:17001–17014.

6. Garstang M, Massie HL, Halverson J, et al. Amazon coastal squall lines. Part I: Structure and kinematics. *Monthly Weather Review.* 1994;122:608-622.
7. Cohen JCP, Silva DMAF, Nobre, et al. Environmental conditions associated with Amazonian squall lines: A case study. *Monthly Weather Review*. 1995;123:3163–3174.
8. Kayano MT. Um estudo climatológico e sinótico utilizando dados de radiossondagem de Manaus e Belém. INPE-1559-TDL/013, São Jose de Campos, Brasil. 1979. p. 82.
9. Knutson TR, Weickmann KM. 30–60 day atmospheric oscillations: Composite life cycles of convection and circulation anomalies. *Monthly Weather Review.* 1987;115:1407–1436.
10. Jones C, Weare B. A time series analysis of evaporation and wind speed over the Amazon Basin. Preprints, Fourth Symp. On Global Change Studies, Anaheim, CA. *Amerericam Meteorological Society*. 1993;423–426.
11. Fu R, Zhu B. Dicinson RE. How Do Atmosphere and Land Surface Influence Seasonal Changes of Convection in the Tropical Amazon. *Journal of Climate.* 1998;12:1306–1321.
12. LE Mone MA, Zipser EJ, Trier SB. The Role of Environmental Shear and Thermodynamic Conditions in determining the structure and evolution of MCS during TOGA-COARE. *Journal of Atmospheric Sciences*. 1998;55(12):3493–3518.
13. Betts AK, Silva DMAF. Progress in Understanding Land – Surface – Atmosphere coupling from LBA Research. *Journal of Advances in Modeling Earth Sistems*. 2009;2(2):20.
14. Mota MAS, Nobre CA. Relação da variabilidade da Energia Potencial Convectiva Disponível (CAPE) com a Precipitação e a Alta da Bolívia durante a campanha “Wet-AMC/LBA”. *Revista Brasileira de Meteorologia.* 2006;21(3b):344–355.
15. Castro E. *Geopolítica da Água e Novos Dilemas a Propósito da Amazônia e seus Recursos Naturais*. In: Luis E Aragon, editor. Miguel Clüsener-Godt (Orgs.). Problemática do Uso Local e Global da Água da Amazônia. Belém: NAEA; 2003. p. 334.
16. Tavares JPN, Mota MAS. Condições termodinâmicas de eventos de precipitação extrema em Belém-Pa durante a estação chuvosa. *Revista Brasileira de Meteorologia.* 2012;27(2):207–218.
17. Cavalcanti IFA, Ferreira NJ, Silva dias MAF, et al. *Tempo e Clima no Brasil*. Oficina de Textos. 2009.
18. Xavier TM, Xavier AFS, Alves JMB. Quantis e Eventos Extremos – Aplicações em Ciências da Terra e Ambientais. *RDS Editora Livrarias Livro Técnico.* 2007;278.
19. Nascimento EL. Previsão de Tempestades Severas utilizando-se Parâmetros Convectivos e Modelos de Mesoescala: uma Estratégia Operacional Adotável no Brasil?. *Revista Brasileira de Meteorologia.* 2004;20(1):121–140.
20. Emanuel KA, Neelin JD, Bretherton CS. On large-scale circulations in convecting atmospheres. *Quarterly Journal of the Royal Meteorological Society.* 1994;120(519):1111–1143.
21. Gamache JF, Houze RA. Water budget of a meso-scale convective system in the tropics. *Journal of Atmospheric Sciences*. 1983;40:1835–1850.
22. Alcantara CR, Silva DMAF, Souza EPE, et al. Verification of the role of the low level jets in Amazon squall lines. *Atmospheric Research.* 2011;100(1):36–44.
23. Tarakanov GG. Tropical Meteorology. *Mir Published Moscou*. 1982.
24. Tavares JPN. Tempestades Severas na Região Metropolitana de Belém: Avaliação das Condições Termodinâmicas e Impactos Sócio-econômicos. *Dissertação de Mestrado*. 2009.

Citation: Gille FDSDS, Mota MASD. Importance of thermodynamic conditions in extreme precipitation events in the city of Belem and metropolitan region. *Int J Hydro.* 2018;2(2):220–225. DOI: 10.15406/ijh.2018.02.00072