Rainfall extremes events climatology over the Amazon basin

Maria Valverde[1], José Marengo[1]

Abstract —The purpose of this study is to elaborate the climatology of extremes indices of rainfall in the Amazon basin. For this purpose, climatic indices (CDD, R95p, RX1day, Rnnmm) recommended by the joint World Meteorological Organization CCL/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI) were calculated. One of the most important aspects of this study is to characterize possible change in extreme of rainfall (e.g. floods, drought, etc) over Amazon basin, since these events have strongest impacts on society. Extremes indices were derived from daily precipitation at NOAA´s Climate Prediction Center (CPCp) with resolution 1°x1°, for period 1979-2005. The indices calculated in this study are R50mm and R80mm defined as the number of days per year with precipitation amount ≥ 50 mm and ≥ 80mm respectively. CDD defined as annual maximum number of consecutive dry days and R95p (very wet days exceeding the 95th percentile).These indices can be related to drought (CDD) and floods (R95p) events. The rainfall of Amazon basin exhibits high interannual and interdecadal variability associated with ENSO events and with the positive anomaly of SST in the North Atlantic. The annual variability of extreme precipitation indices, such as, maximum length of dry spells (CDD) and RR> 95p (R95p) were sensitive to identification periods of droughts. Also, it verified that extreme rains ≥ 50mm and ≥ 80 mm (R50mm and R80mm), occur with or without events El Niño. On the other hand, droughts are not necessarily associated with a diminution of extreme rainfall events (R50mm e R80mm). Individual locations in the west of the basin (Santarém, Cachimbo and Manaus stations) show negative trends of CDD. However, Rio Branco station (southeast of basin) showed statistically significant positive trends of CDD, and captured the drought of 2005 and 2010. The future scenarios of ETA_HadCM3 model for the period 2011-2040, show an increase (decrease) of the index CDD (R95p) for the average area of the Amazon basin, and it will be stronger in the 2071-2099 climatology. However, as this result is a projection of model there are still many uncertainties. The fact is that historically these extremes of rain are part of climate variability in the region, and they can happen again.

Keywords — Amazon basin, climatic extremes, heavy rainfall and regional model.

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1 INTRODUCTION

The Amazon basin is the largest tropical rain forest in the world, covering about 7.000.000 km^2. Of its total area, about 4.000.000 km^2 is located in Brazilian territory. It receives an average rainfall of 2500 mm/yr), and generates an annual discharge of over a trillion cubic meters of water into the Atlantic Ocean.

This basin constitutes one of the most important reservoirs of water that supplies and maintains the hydrologic resources over the Brazilian territory. The rainfall is the principal source, for this reason to understand its variability is important to evaluate the water availability over the basin. An increase in the number of wet days with 50mm and 80mm of rainfall can be associated with extremely heavy precipitations or floods events. In addition, the impact of tropical rainfall around urban areas is related with the intensity of the event. On the other hand, largest number of consecutive dry days are associated with extreme droughts as occurred in Amazon in 2005 and 2010 [4],[10],[3].

For this reason, it is necessary have a more comprehensive knowledge of the climate variability in the Amazon basin.

The objective of the present work is to elaborate climatology of extreme indices of rainfall over the Amazon basin. For this purpose, gridded daily rainfall observed, station network data and ETA_HadCM3 model data were used for 1979-2005 period. In addition, will be investigated the relationship between precipitations extremes and interannual variability of large-scale circulation (SOI and NATL).

Numerical model outputs are used to generate future climate change scenarios (2011-2099).

The behavior of the rainfall expressed through the extremes indices, can help to evaluate different change in the water availability over the Amazon basin that can affect mainly the urban areas and the areas of forest, generating flooding, floods or droughts.

On the other hand, indices on weather extremes are essential in long-term planning for the preparedness of meteorological disasters and risk reduction in a country.

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2 DATA AND METHODOLOGY

The Climatic Prediction Center gridded precipitation (CPCp) to period of 1979-2005 was used in this study. The sources of record of daily precipitation data for Brazil used are (a) Agência Nacional de Energia Eléctrica (ANEEL; National Agency for Electrical Energy; 1960–97), (b) Agência Nacional de Águas (ANA; National Water Agency; 1948–2004), (c) Fundação Cearense de Meteorologia e Recursos Hídricos (FUNCEME; Meteorology and Hydrologic Resources Foundation of Ceará; 1973–2004), (d) Superintendência do Desenvolvimento do Nordeste (SUDENE; Superintendence for Development of the Northeast; 1948–98), (e) Departamento de Águas e Energia Elétrica do Estado de São Paulo (DAEE; Department of Water and Electrical Energy for the State of São Paulo; 1948–97), in collaboration with the Centro de Previsão de Tempo e Estudos Climáticos (CPTEC; Brazilian Weather Forecast and Climate Studies Center), and (f) Technological Institute of Paraná (SIMEPAR, 1997–2004).

In addition, for this study we have utilized gridded monthly precipitation (0.25 x 0.25 km) obtained from the Group of Climatic Forecast (GPC) of the Division of Operations (DOP) of the CPTEC/INPE. Five rainfall gauge stations distributed throughout Amazon basin are used (Table I).

Moreover, the ETA_HadCM3 model has been used [2]. The seasonal climate version of the ETA_HadCM3 model was adapted to run decadal 6 time range integrations, with focus on the study of climate change scenarios related to different levels of atmospheric CO_2 concentration. For the present climate studies, the CO_2 concentration was set to a constant value of 330 ppm. It was used the period time of 1961-1990, and for future projections: 2011-2040, 2041-2070 and 2071-2099, of the scenario A1B [6].

In order to construct the climatology of extremes over the basin Amazon were calculated eight indices related with extremes of rain [1]. The formulation of the indices was established for the Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDMI). ETCCDMI is co-ordinated jointly by the World Meteorological Organization's (WMO) Commission on Climatology (CCL) and CLIVAR (see http://cccma.seos.uvic.ca/ETCCDMI/).

Climate extreme indices were calculated to related with extremes of rain [1], defined like number of day with precipitation ≥ 30mm, 50mm, 80mm and 100mm (Rnnmm), consecutive dry days when rain rate <1 mm (CDD), monthly maximum 1-day precipitation (RX1day) and 95th percentile of very wet day amounts (R95p). These indices evaluate the changes in the intensity, frequency and duration of extreme events of the precipitation.

The indices were calculated for the CPCp data, rainfall gauge stations and for the model output ETA_HadCM3.

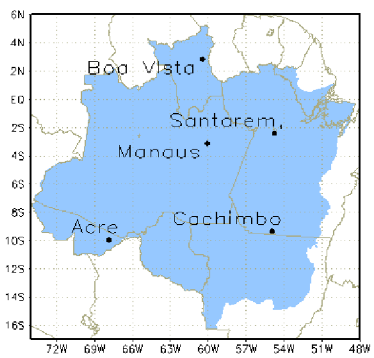
Statistical analyses included the used of the box and whisker diagram, or boxplot. The boxplot provides a graphical summary of a set of data based on the quartiles of that data set: quartiles are used to split the data into four groups, each containing 25% of the measurements. A box plot is a diagram that gives a visual representation to the distribution of the data, highlighting where most values lie and those values that greatly differ from the norm, called outliers.

Linear regression analysis was then used to calculate possible trends of the indices, with a Kendall-tau test used to estimate the statistical significance of these trends. Trend maps were constructed for each index and black color line illustrates trends that were found to be statistically significant at the 95% level.

In addition, we investigate the relationship between the occurrence of extremes events rainfall (floods and droughts) and Southern Oscillation Index (SOI), and the anomalies in the Northern Tropical Atlantic Ocean (NATL). These data are available in the following site http://www.cpc.ncep.noaa.gov/data/indices/.

Table I – Observational sites in the Amazon basin

Stations	Lat	Lon	Alt (m)	Period
Cachimbo	09 22 S	54 54 W	432	1961-1985
Boa Vista	02 50 N	60 24 W	140	1968-1997
Manaus	03 09 S	59 59 W	84	1959-1995
Santarém	02 26 S	54 43 W	72	1961-1997
Acre	09 57 14 S	67 51 44 W	185	1980-2010



2.2 Results

Figure 1a shows the error between annual rainfall from ETA_HadCM3 model and gridded precipitation observed (period 1961-1990). Negative errors (-2mm/dia) are observed in north and center areas of Pará, and north and southwestern Amazon. On the other hand, positive errors (2 mm/day) are observed in the east and center parts of MatoGrosso. Figure 1b shows the error of the ETA_HadCM3 model for the period of 1979-1990, and it was observed a pattern of errors similar with the period of 1961-1990. The gridded precipitation

from CPCp data used more rain-gauge datasets density since 1979 over the Amazonian region. This may have caused a small error between the CPCp data and observed data during the period 1979-1990 (Fig. 1c). This result suggests that extreme indices of rainfall from CPCp over the basin can represent what in the reality happens, and it can be used for validate the indices from ETA_HadCM3 model.
The extremes indices were not computed with the gridded precipitation observed data because the record was of monthly series.

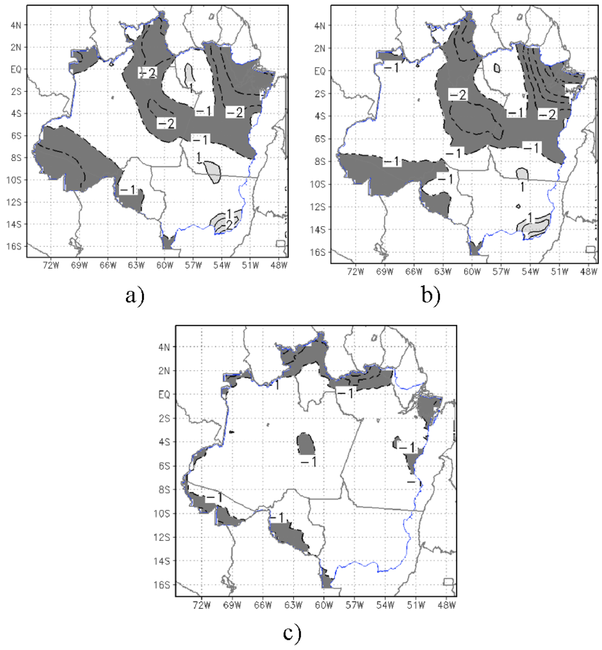


Fig. 1 – Annual error of the rainfall of the model ETA_HadCM3, for the period of 1961-990 (a), annual error of the rainfall of the model ETA_HadCM3 for the period 1979-1990 (b) and the annual error of the rainfall of the CPCp for the period of 1979-1990.

Figure 2 shows the mean annual cycle of the rainfall in average area of the basin for observed rainfall and the CPCp data. Moreover, the annual cycle for three stations: Boa Vista, Manaus and Acre are shows in the Figure 2.
The timing of the rainy and dry seasons from the CPCp data, for the average area of the basin, agrees reasonably well with observations, though the rainy season (Janeiro to April) is in general, underestimated (-0.55 mm). On the other hand, the annual cycle for each location shows large differences due to high spatial variability of the rainfall over the Amazonian basin. The Boa Vista station (BV), located in the North Hemisphere, shows an annual cycle opposite to the others stations (Manaus – MA and Acre - AC). On the other hand, MA stations show a regime of maximum rainfall between February to May, and the rainy season is strongly modulated by the seasonal displacement of the Intertropical Convergence Zone (ITCZ). In the epoch of maximum rainfall, it is observed the southward position of the ITCZ. The seasonal distribution of rainfall in the station of Santarém also is modulated by the ITCZ.
The rainy season in the AC station occur in the months from December to March. In this season the Bolivian High (BH) and occasionally the South Atlantic Convergence Zone (SACZ) acts more strongly over parts of basin, where AC is located. The station of Cachimbo also suffers the influences of the SACZ and BH during the rainy season.

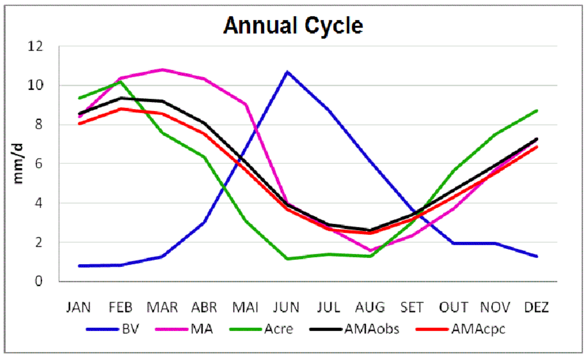


Fig. 2 – Annual cycle of the rainfall for the average area of the basin from the observed data (AMAobs), of the CPCp (AMAcpc), in the periodo of 1979-2005, and for the stations of Manaus (MA), Acre (AC) and Boa Vista (BV).

The Figure 3 shows the annual trend for four indices during 1979-2005, over the area of the basin. Trend of CDD (Fig. 3a) over the southeast part of basin (Matogrosso) is increasing at a rate 32 days/year. In addition, some areas of the southwest and northeast of the basin shows positive trend. This increase rate suggests the occurrence of droughts more prolonged. On the other hand, the trend of the very wet days (R95p) is decreasing over southwest and southeast part of basin. Specifically, it was observed a decreasing at a rate 400 mm/year over southwest of the basin. However, R95p is increasing at a rate about 600 mm/year over the northeast, north and northwest parts of basin (Fig. 3b).
Statistically significant trends of RX1day (Fig. 3c) and R20mm (Fig, 3d) over basin are very similar, with increasing over the northeast-north- northwest and south sectors, and decreasing in a little area of the central region of the basin. Specifically, over the southeast part of the basin RX1day is increasing at a rate of 30 mm/year, and R20mm is about 14 days.
Those results suggests, that although the period of droughts is increasing, and the years have become less humid (R95p), over the southeastern part of the basin, the short-term extreme rain events have increased. The positive trends of R20mm, RX1day and RX5day (figures not showed) confirm this idea.
On the other hand, slight negative trends of CDD over the north (Boa Vista) and northeastern part of the basin were observed, while heavy precipitation (R95p, R20mm and RX1day) is increasing.

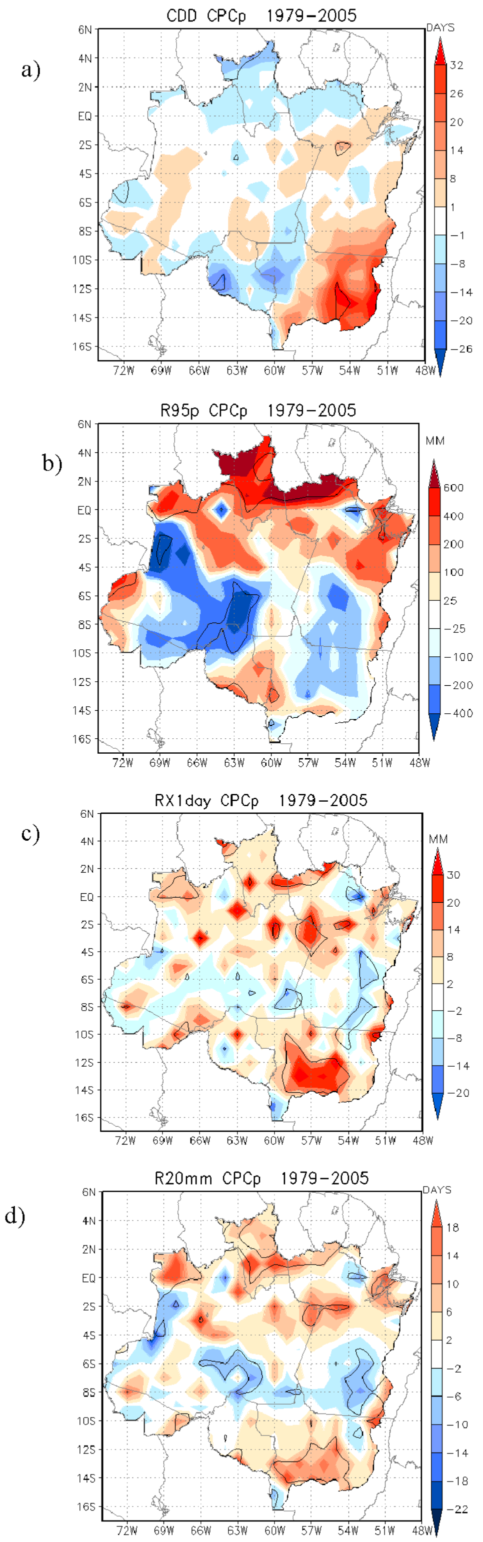


Fig. 3 – Annual trends over the Amazon basin for the period of 1979-2005.

The Figure 4a shows the interanual variability of the indices CDD, R20mm, and South Oscillation Index (IOS), for the average area of the basin.

The driest year was 1997, and it shows a greatest consecutive by day dry number (CDD), a smaller value of the R20mm, and the negative IOS. This year was an strong event the El Niño [8], that affected the average area of the Amazon basin, with prolonged periods of no rain. It was verified that in 1997 the fire in moist Amazonian forest achieved bigger proportions as compared with the El Niño 1983 [7]. It suggest that 1997 was a year of extreme drought over the Amazon basin. In addition, 1991 (strong event of El Niño) also recorded a high value of CDD.

On the other hand, in strong El Niño years (1982-1983 and 1987) didn't observe high values of CDD.

The year of 1988 (strong La Niña), also shows a high value of CDD. These results confirm the idea "drougth during episodes of El Niño do not always happen".

The CDD index didn't show a high value in 2005 (extreme drought) for the average area of the basin (Fig. 4a), it due to, the drought was particularly severe in the south and southwest parts of the basin [11],[4]. Moreover, in this year was observed a high value of R20mm.

The Figure 4b shows the CDD index for the station of Rio Branco (Acre) located in the southwest of the basin (Fig. 1). It was observed in 2005 (El Niño event) a higher value of CDD (about 64 consecutive days without rainfall), associated with the extreme drought occurred in this year. Also, the droughts ocurred in 1987 (El Niño) and 2010 (La Niña) were identified over Rio Braco, with high values of the CDD (but not so intense as to 2005). R50mm (Figure 4b) shows high values in 1997, 2005 and 2010. Those results confirm the idea what in droughts events may occurred short-term extreme rain. Specifically, in 1994 (El Niño) was observed a higher frequency of R50mm.

On the other hand, CDD showed a statistically significant positive trends, whereas trends of R50mm are weakly negative without statistically significant.

Figure 3c shows the relationship between the SOI and NATL, and it was verified that the drought in 2005, was not specifically related to El Niño, but to the anomalously warm tropical North Atlantic (NATL), as show the positive anomalies of the NATL (Fig. 3c). Studies related with the drought in 2005 confirm this results[11],[4].

On the other hand, the drought in 2010, that also affected the region of Rio Branco (Fig. 4b), presented highest value of NATL and it occurred in the end of El Niño and start of La Niña.

Studies related with the drought in 2010 [3] showed que it had three identifiable epicenters: in southwestern Amazonia, north-central Bolivia, and Brazil's Mato Grosso state. In 2005 only a single southwestern Amazonia epicenter was detectable.

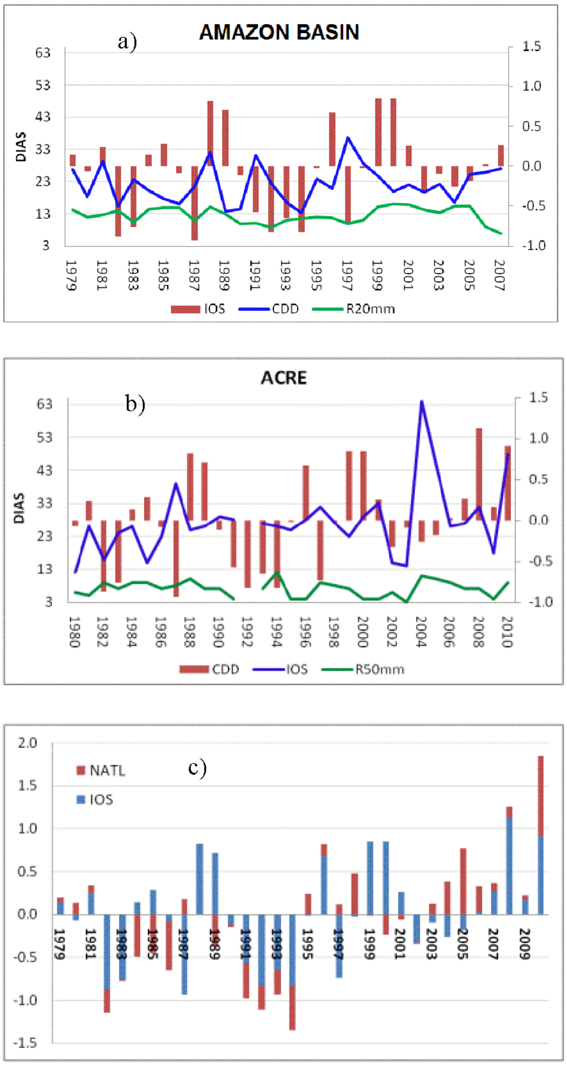


Fig. 4 – Interanual variability of consecutive dry days (CDD) and R20mm for the average area of the Amazon basin, for the periodo 1979-2005 (a), indices CDD and R50mm for the station of Rio Branco, for the period 1980-2010 (b), and the index IOS and NATL for the period of 1980-2010 (c).

Figure 5 shows the interanual variability of CDD and R50mm indices for the stations of Cachimbo Santarém and Manaus. The Cachimbo station, located in the southeastern part of the basin presented higher values of CDD when compared with other stations. It suggest that there were period prolonged droughts during the 60s. On the other hand, the station of Manaus showed lowest values of CDD. Cachimbo and Santarém coincided with maximum values of CDD in 1963 and 1976 (weak El Niño years) and it have been associated with the prolonged droughts that occurred in those periods. The drought in 1963 had large impact in the station of Cachimbo, moreover CDD showed the highest value (125 days) and the frequency of R50mm was lower (Fig. 5b).

The drought in 1963 was one of the most severe of the last four decades, and was only compared with the of 2005 and of 2010. Information of the Geological Service of Brazil regarding the decressing water-level of Rio Negro, the drought in 2010 occupies the first place, followed by the drought in 1963. The drought in 2005 occupies the eighth place.

The NATL index was more positive in the drought in 2010 and less positive in the drought in 1963, where the weak El Niño ocurred. This result suggests that the dynamic factors of the drought in 1963 were not directly related with the heating of the waters of the Atlantic North, as in case of 2005 and 2010 (Fig. 4c). Although, the rainfall dataset shows gaps, it is possible to observed the trend of the indices during the period 1979-2005. CDD presented slight negative trends without statistically significant, over Manaus and Santarém. On the other hand, R50mm showed statistically significant positive trends over the station of Santarém, suggesting that heavy rainfall event tends to increasing over Santarén.

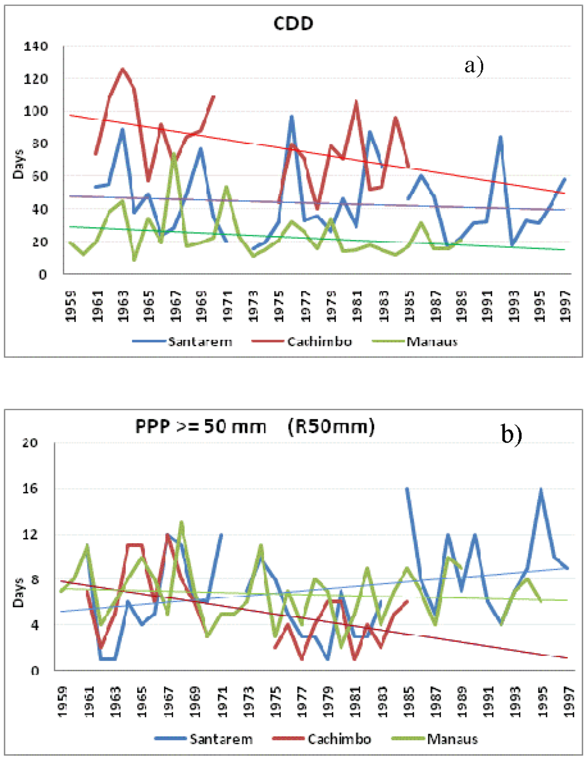


Fig. 5 – Lineal Trends of the indices CDD (a) and R50mm (b) for the stations of Santarém, Cahimbo and Manaus, located over the Amazon basin.

Figure 6 shows the decadal analysis of the indices R30mm, R50mm, R80mm and R100 mm. Boa Vista and Santarém showed a higher frequency of R30mm, R50mm and R80mm in the decade of 1990s. In this decade occurred strong and prolonged events of the El Niño (1990-94, 1997-98).

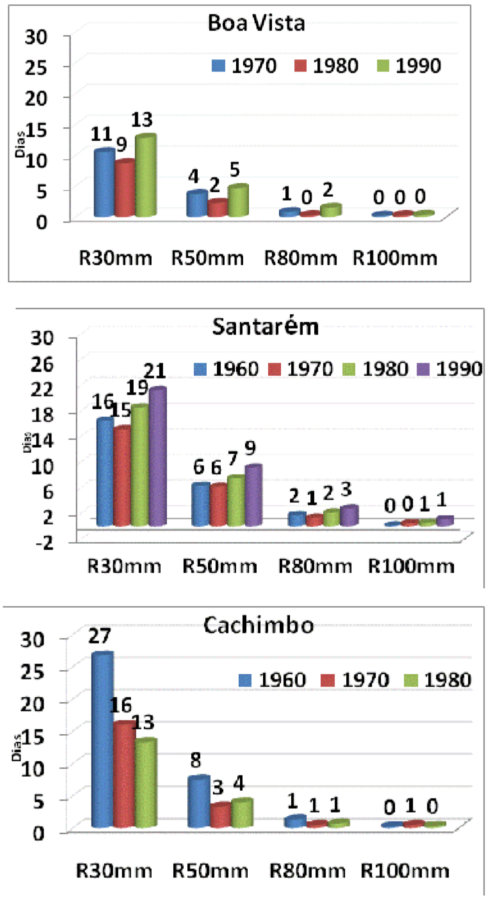
The stations of Cachimbo and Manaus were more sensitive with the occurrence of the El Niño years of the decade of 1980s, where a decreasing in the frequency of R30mm was observed. Decreasing may be associated with the occurrence of strong events El Niño (1982-1983 and 1986-1987). It is important to mention that since the decade of 1960 the station of Cachimbo shows decreasing of R30mm.

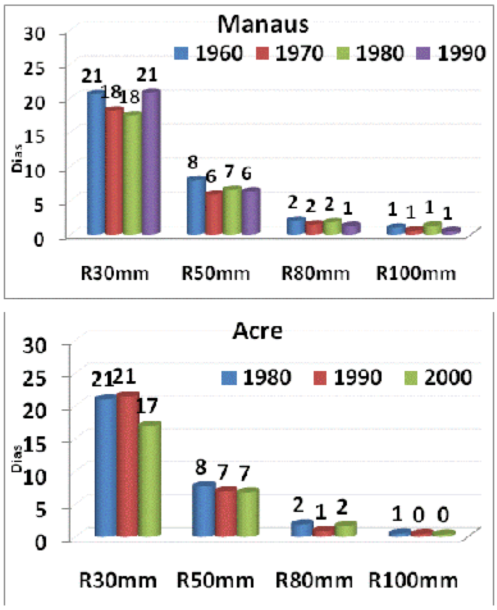
Trends of CDD and R30mm over the southeast of the basin (Fig. 3a) showed increasing and decreasing respectively, in agree with the decreasing of R30mm over Cachimbo.

Decreasing of R30mm, R50mm and R100mm was observed in Acre, in the decade of 2000s. This result is related with the droughts of 2005 and 2010 that affected also the southwest of the basin.

The 1990s decade shows three events (average value) de R80mm, and one event de R100mm in Santarém.

On the other hand, in Manaus all the decades showed one event (average value) of R100 mm.





Fig, 6 – Decadal analysis of R30mm, R50mm, R80mm and R100mm indices for the stations of Santarém, Cachimbo, Manaus, Boa Vista e Acre.

The Figure 7 shows the diagram of boxplot of the indices CDD, RX1day and R95p from daily rain of the ETA_HadCM3 model, for the average area of the Amazon basin. It was observed the evolution of the indices for the present climatology and for three future projections.

CDD (Fig. 7a) shows until 2071-2099 climatology an increasing of the consecutive dry day number. However, in the climatology 2041-2070 shows a decreasing in the median value when compared with 2011-2040 climatology, following an increasing in the 2071-2099 climatology. In the 2071-2099 is observed a maximum value (72 days) CDD.

On the other hand, RX1day (Fig. 7b) also shows the gradual increasing of the median value during 2011-2099 period. However, in the 2041-2070 climatology will be observed the lowest value of RX1day. Another one important characteristic is the highest range between quartiles and maximum and minimum value of the RX1day. This result suggests a high variability of RX1day for future climatology.

R95p (Fig. 7c) will have a decreasing in the value of the median until the 2071-2099 period. Moreover, there will be a high variability of R95p (2041-2070 climatology) when compared with climatology of 1961-1990.

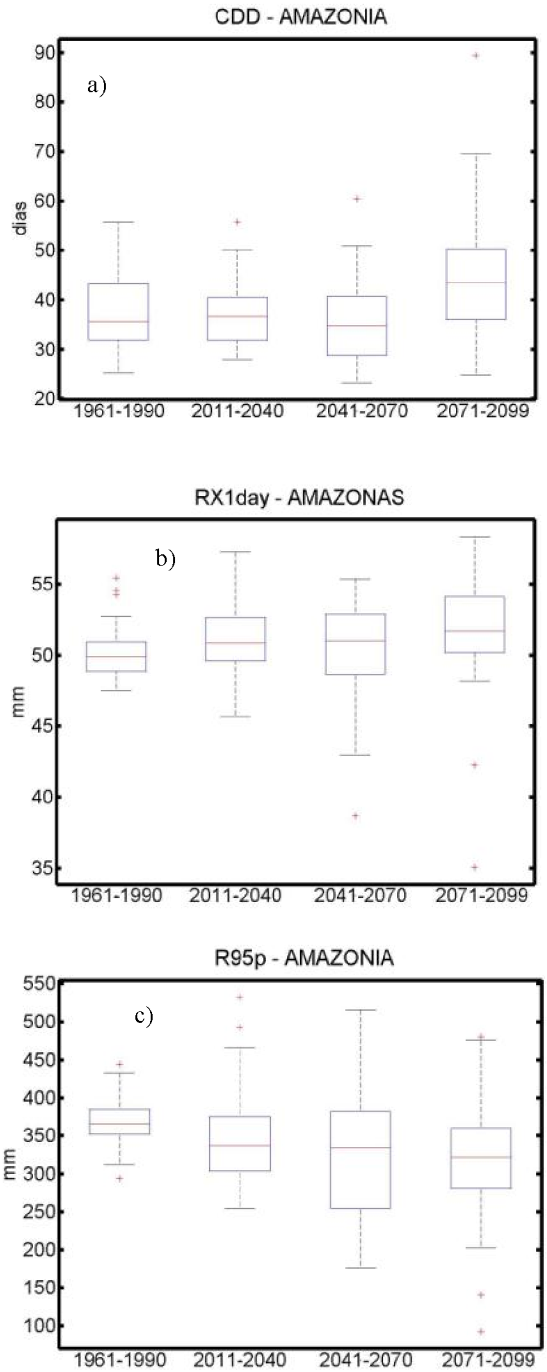


Fig. 7 – Diagrams of boxplot for CDD, RX1day and R95p, indices derived of the model ETA_HadCM3, for the average area of the Amazon basin, and for the present climate (1961-1990) and for the 2011-2040, 2041-2070 and 2071-2099 projections.

8 CONCLUSIONS

The analysis of indices of extremes precipitation in Amazon basin showed high variability interanual and decadal in the Amazon basin. CDD showed high sensibility to identify years of extreme droughts as in 1963, 2005 and 2010. On the other hand, events of extreme rainfall (R50mm and R80mm) occur with or without events of the El Niño. There isn't a clear relation between the occurrence of droughts and the El Niño or La Niña events. However, the NATL was positive in the extreme droughts occurred in the basin.

The southeast of the basin showed positive trend for the occurrences of prolonged droughts, and negative trends for R95p. Moreover, droughts (high values of CDD) necessarily were not associated with a diminution of R50mm and R80mm.

Individually each station (Santarém, Cachimbo and Manaus) showed a negative trend of CDD, suggesting a decreasing in the periods of drought. However, the stations of Acre showed positive trend of CDD.

Indices obtained from model such as CDD showed for future scenarios an increasing over the average area of the Amazon basin, where it will be more intense in the 2071-2099 climatology. These results suggesting events droughts more prolonged for future scenarios.

On the other hand, R95p tends decrease, where the extremely humid years will be less intense. However, this projection does not signify necessarily that events of short-term extreme rain (RX1day) will be less intense.

It is well known that model detected extreme weather events are not free from uncertainties, and without calibration, regional climate model may not catch the rainfall in daily-scale.

Future works about trend are being carried out with a bigger number of stations rain gauge over the Amazonia, moreover will be used others members of the ETA_HadCM3 model, in order to minimize the uncertainties.

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