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Trends in Precipitation Extremes over the Northern Part of Brazil from ERA40 Dataset

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A B S T R A C T

Trends in extreme climate indices were obtained with ERA40 gridded precipitation data over northern Brazil region that includes most of the Amazon Basin and interior of Northeast Brazil. The indices representing one-day highest precipitation in a month, number of rainy days, monthly maximum 5-day consecutive precipitation and number of heavy precipitation days showed increasing trends over most of the grid points of the study region. Although negative trends in wet days were obtained at some grid points, they are not statistically significant. The negative trends are mostly confined to Mato Grosso and southern Pará states, where the deforestation in the period of study was intense. Consistently, the index representing the number of dry days showed a negative trend at the points where the number of wet days, very wet days and annual precipitation amounts showed positive trends.

Keywords: Amazon, deforestation, sea surface temperature, reanalysis

Tendências nos Extremos de Precipitação sobre a Parte Norte do Brasil através dos Dados do ERA40

R E S U M O

Foram obtidas tendências em índices de extremos climáticos com dados de precipitação do ERA40 para a parte norte do Brasil que inclui grande parte da Bacia Amazônica e do Nordeste do Brasil. Os índices que representam os maiores valores de precipitação em um dia, número de dias chuvosos, precipitação máxima em 5 dias consecutivos e o número de dias anuais com precipitação intensa mostraram tendências crescentes para a maioria dos pontos de grade da região de estudo. Embora tenham sido encontradas tendências negativas para os dias úmidos em alguns pontos de grade, os mesmos não apresentaram significância estatística. As tendências negativas são principalmente limitadas para Mato Grosso e sul do Pará onde o desmatamento no período de estudo foi intenso. Constantemente, o índice que representa o número de dias secos mostrou uma tendência negativa para os pontos onde o número de dias úmidos, muito úmidos e a precipitação total anual mostraram tendências positivas.

Palavras - chave: Amazônia, desflorestamento, temperatura da superfície do mar, reanálises

1. Introduction

It is known that changes in extreme climate and weather events have significant impacts on the society. It is widely believed that some extremes will become more frequent, more intense and/or more widespread during the 21st century (IPCC, 2007). Thus, the demand for information services regarding weather and climate extremes is growing (Klein Tank et al., 2009), especially because the sustainability of economic development and living conditions depends on our ability to manage the risks associated with extreme events. Concerns over extreme climate events are greatly increasing because they are likely to cause

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more damage to society and ecosystems than simple shifts in the mean values. Moreover, understanding the spatial and temporal variability of hydrometeorological variables is crucial for sustainable water resources management (Jung et al., 2011). Knowledge of the behavior of extreme values is required mainly because we depend on food, water, energy, shelter and transportation which are sensitive to very high or very low values of meteorological variables.

Extreme climate events affect the society and ecosystems through multiple pathways, and the effects of climatic variables and their interactions are often complex, dynamic, and nonlinear (Zhang and Liu, 2005). For example, flood and soil erosion can be influenced differently by extreme precipitation events with changes in frequency or in intensity. Similarly, extreme temperature events can affect crop growth differently with changes in frequency, with an increase in continuous days of maximum and minimum temperature (Li et al., 2010). These authors affirm that even a short period of abnormally high or low temperatures can cause significant damage to crop growth and yield.

Changes of climate extremes should be considered as critical factors of climate change impact. Close examination of their characteristics is relatively limited so far. Im et al. (2011) suggested that one of the main reasons is related to a lack of reliable and homogeneous long-term daily time series of both observations and simulation data. The fourth assessment report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) affirms that subjects like climate variability and extreme weather have received increasing attention in the last few decades. The Panel pointed out that the low or high temperature days/nights over 70% of global land area are very likely to increase and heavy precipitation events in many mid-latitude regions are also likely to increase. It is already observed that the total area affected by drought has increased since the 1970s (IPCC, 2007).

In some regions both temperature and precipitation extremes have already shown amplified responses to changes in mean values (IPCC, 2001). Moberg and Jones (2005) indicated that extreme climatic events, such as heat waves, floods and droughts, can have strong impact on society and ecosystems and deserve our attention. It is widely conceived that with the increase of temperature, the water cycling process will speed up, which in turn will result in the increase of precipitation amount and its intensity. Wang et al. (2008) showed that many outputs from Global Climate Models (GCMs) indicate the possibility of substantial increases in the frequency and magnitude of extreme daily precipitation.

Understanding changes in climate variability and extreme events is not an easy task, given the interaction between the mean and its variability (Llano and Penalba, 2011).

There is growing evidence that the global changes in extremes of the climate variables that have been observed in recent decades can only be accounted for if anthropogenic, as well as natural factors, are considered, and under enhanced greenhouse gas forcing the frequency of some of these extreme events is likely to change (IPCC, 2007; Alexander et al., 2007). These results described the general trends in extreme climate events on a large spatial scale, but the studies on changes in particular regions were not conclusive and need further assessment (Li et al., 2010). Assessing changes in extreme climate events on a regional scale can identify indicators that cause environmental and other problems and provide information for rational countermeasures. Many studies investigated climate change and extremes on a very large scale (Easterling et al., 2000; Vincent et al., 2005; Haylock et al., 2006) or at national levels (Brunetti et al., 2006) but few of them made this on a local scale using a large number of weather stations (Brunetti et al., 2004; Santos et al., 2011). The IPCC in its reports (2001 and 2007) evidenced the need for more detailed information about regional patterns of climate change.

The Expert Team on climate change detection, monitoring and indices, sponsored by WMO (World Meteorological Organization) Commission for Climatology (CCI) and the Climate Variability and Predictability project (CLIVAR), an international research program started in 1995 in the framework of the World Climate Research Program, has developed a set of indices (Peterson et al., 2001) that represents a common guideline for regional analysis of climate.

The present study attempts to provide new information on trends, on regional scale, using long-term records of daily precipitation over Northern region of Brazil, through the analysis of different indices based on the reanalysis data from ERA40. This analysis is important for the region since any change in climate can have large impacts on the daily life of the population and environment. Dufek and Ambrizzi (2008) affirm that the factors identified though the analysis of recent climate variability can be important in understanding future changes.

2. Material e Methods

2.1 Study area and data

Daily precipitation dataset from 1961 to 2001, obtained from reanalysis of ERA40 project of ECMWF (European Centre for Medium-Range Weather Forecasts), has been used in this study. This period has been chosen because it characterizes a fairly long-term dataset and the dataset for the period is available in the website http://data-portal.ecmwf.int/data/d/era40_daily/. The reanalysis project ERA40 covered the entire globe in an imaginary grid of 2.5° of latitude x 2.5° of longitude and 19 vertical levels. More information and details about the ERA40 project can be obtained from website http://www.ecmwf.int/.

The total daily precipitation, which is the sum of observed precipitation at 6h00Z, 12h00Z, 18h00Z e 0h00Z, at the continental grid-points from 5°N to 17.5°S and from 35°W to 72.5°W is the variable considered. The study area covers totally the Northeast and North regions and partly the Middle West and Southeast regions of Brazil. However, this study focuses on the Northeast and North regions, covering more than 80% of the Brazilian territory (see Figure 1).

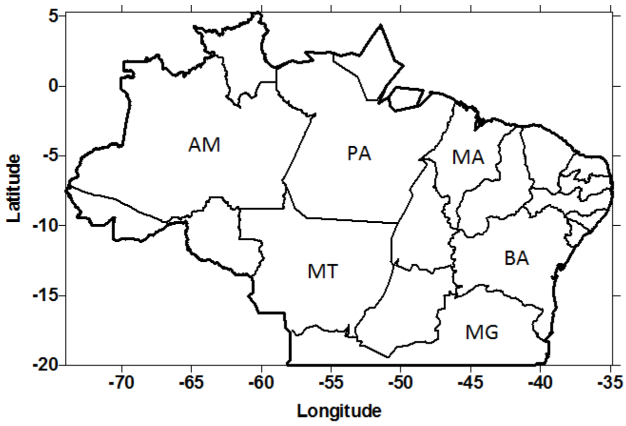

Figure 1: Study area covering Northeast and North regions and parts of Middle West and Southeast regions of Brazil. The Northeast Brazil region (NE) and names of some large states are indicated. AM: Amazonas, PA: Pará, MA: Maranhão, MT: Mato Grosso, BA: Bahia, MG: Minas Gerais.

The dataset was processed using the freely available software packages RClimDex, which performs data quality control and calculates indices, and RHtest, which performs homogeneity tests. These packages were downloaded from the ETCCDI website (http://cccma.seos.uvic.ca/ETCCDI/). An updated version of RClimDex that takes into account the precision of the input data (Zhang et al., 2009) has been used. The homogeneity test has been done using the RHtest software package, which can help to identify step changes in a time series by comparing the goodness of fit of a two-phase regression model with that of a linear trend for the entire series (Wang, 2008; Caesar et al., 2011). RHtest is used to help identify series break points for further investigation. Reeves et al. (2007) found that two-phase regression methods, as implemented in the RHtest software, had a level of performance comparable to methods such as the standard normal homogeneity test, with the optimal choice depending on the priorities of the user (e.g. accurately detecting the date of a change point or minimizing the number of false alarms). They also found that developments in the two-phase regression method since 1995, reflected in recent versions of RHtest, had substantially improved its performance (Caesar et al., 2011).

2.2 Methodology

RClimdex software developed by Xuebin Zhang and Feng Yang from Canadian Meteorological Service (Zhang and Yang,

2004) is used to obtain the climatic extreme indices following methodologies of Zhang et al. (2005) and Haylock et al. (2006) in this study. RClimdex provides 11 indices based on precipitation data (Table 1).

Table 1: Definition of extreme precipitation indices used in this study

Index	**Name**	**Definition**	**Units**
Rx1day	Max 1-day precipitation amount	Monthly maximum 1-day precipitation	mm
Rx5day	Max 5-day precipitation amount	Monthly maximum consecutive 5-day precipitation	mm
SDII	Simple daily intensity index	Annual mean precipitation when PRCP>=1.0mm	mm
R10mm	Number of heavy precipitation days	Annual count of days when PRCP>=10mm	Days
R20mm	Number of heavy precipitation days	Annual count of days when PRCP>=20mm	Days
R50mm	Number of heavy precipitation days	Annual count of days when PRCP>=50mm	Days
CDD	Consecutive dry days	Maximum number of consecutive days with RR<1mm	Days
CWD	Consecutive wet days	Maximum number of consecutive days with RR>=1mm	Days
R95p	Very wet days	Annual total PRCP when RR>95p	mm
R99p	Extremely wet days	Annual total PRCP when RR>99p	mm
PRCPTOT	Annual total wet-day precipitation	Annual total PRCP in wet days (RR>=1mm)	mm

Linear trend analyses were performed for all the precipitation indices obtained by RClimdex. The slopes of the linear trends are calculated by least squares fitting. Since a normal frequency distribution may not necessarily fit well the indices data, a non-parametric Mann-Kendall test (Sneyers, 1990) is used to identify whether or not trends are significant. The method is simple and robust, and it also has the advantage of being able to deal with missing values.

The null hypothesis (H_0) states that the deseasonalized data ($x_1, x_2, \ldots, x_n$) is a sample of n independent and identically distributed random variables. The null hypothesis that standard normal variable (Z_c) is not statistically significant or has no significant trend is accepted if $-Z_{1-p/2} \leq Z_c \leq Z_{1-p/2}$, where $Z_{1-p/2}$ is the standard normal deviate and p is the significance level for the test. Or, Z_c is statistically significant if $Z_c < -Z_{1-p/2}$ or if $Z_c > Z_{1-p/2}$ (Partal and Kahya, 2006). Kendall's statistic (S) is computed as follows:

$$S = \sum\sum \operatorname{sgn}(x_j - x_k)$$

The variance of S is given by

$$\mathrm{var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} e_i(e_i-1)(2e_i+5)}{18} \qquad (2)$$

where, x_j , x_k are sequential data values; n is the length of the dataset; m is the number of tied groups; and e_i is the size of the ith tied group. Z_c is obtained as follows:

$$Z_c = \frac{S-1}{\sqrt{\mathrm{var}(S)}} \quad (S > 0)$$

$$Z_c = 0 \quad (S = 0) \qquad (3)$$

$$Z_c = \frac{S+1}{\sqrt{\mathrm{var}(S)}} \quad (S < 0)$$

Positive values of Z_c indicate increasing trends while negative Z_c shows decreasing trends. When testing either increasing or decreasing monotonic trends at a significance level p, the null hypothesis was rejected for absolute value of Z_c greater than $Z_{1-p/2}$ (Partal and Kahya, 2006). In this study, significance level p of 0.05 is applied.

3. Results and Discussion

The trends of climatic indices evaluate the climatic alterations that have happened in the study area in the studied period of 41 years. The results presented here are for 104 continental grid-points in northern Brazil (Table 2). The spatial distributions of the trends that are statistically significant are highlighted.

Table 2. Annual trends of the extreme indices of precipitation for the Northern part of Brazil at 104 continental grid-points during 1961-2001. Lat and Lon are latitude and longitude, respectively, of the grid-points. The indices are explained in Table 1. (The bold and highlighted values represent significance at 5% level)

Lat	Lon	CDD (Days)	CWD (Days)	PRCPTOT (mm)	R10mm (Days)	R20mm (Days)	R50mm (Days)	R95p (mm)	R99p (mm)	Rx1day (mm)	Rx5day (mm)	SDII (mm)
5	-60	-0.034	-0.199	2.029	-0.006	0.006	0.29	0.498	0	0.048	-0.513	0.005
2.5	-50	**-0.21**	**1.319**	**33.073**	**1.523**	**0.58**	**16.881**	**-0.245**	0.112	0.599	1.339	**0.066**
2.5	-52.5	-0.208	0.02	**18.803**	**0.893**	0.205	9.853	5.967	0.051	0.325	0.578	**0.048**
2.5	-55	-0.019	0.237	9.777	0.305	**0.237**	**10.113**	6.309	**0.068**	**0.878**	**1.634**	0.033
2.5	-57.5	0.096	0.184	12.82	0.9	**0.45**	21.456	9.831	0.086	0.737	1.585	0.049
2.5	-60	-0.835	-0.376	**15.906**	**0.815**	**0.299**	14.763	**6.642**	**0.024**	**0.782**	1.218	**0.056**
2.5	-62.5	**-1.299**	0.286	**19.203**	**0.479**	**0.081**	6.573	**2.737**	**0.01**	**0.584**	**0.791**	**0.027**
2.5	-65	**-0.464**	**-1.035**	**18.295**	**0.517**	**0.444**	**18.156**	**6.946**	**0.113**	**1.79**	**2.258**	**0.058**
0	-50	**-0.505**	1.22	**37.75**	**1.646**	**0.544**	17.692	**4.326**	0.063	0.27	1.481	**0.081**
0	-52.5	**-0.697**	0.187	**21.862**	**0.969**	**0.253**	11.125	**3.437**	**0.026**	**0.657**	0.834	**0.045**
0	-55	**-0.529**	0.143	**25.348**	**0.938**	**0.367**	**17.937**	**9.585**	**0.087**	**1.585**	**3.525**	**0.063**
0	-57.5	**-0.223**	0.116	**38.19**	**1.638**	**0.61**	**29.127**	**14.272**	**0.42**	**1.397**	**3.336**	**0.096**
0	-60	**-0.465**	0.463	**35.151**	**1.414**	**0.403**	**22.369**	**10.329**	**0.058**	**1.225**	**2.27**	**0.082**
0	-62.5	**-0.895**	0.83	**27.514**	**0.898**	**0.193**	**11.199**	**5.565**	**0.031**	**0.762**	**1.43**	**0.043**
0	-65	**-0.338**	**-0.783**	12.504	0.398	**0.148**	**7.649**	**4.023**	**0.026**	0.433	0.864	0.021

continuação

0	-67.5	**-0.215**	**-1**	**18.653**	0.521	**0.361**	**18.521**	**9.427**	**0.089**	**1.467**	**2.502**	**0.046**
0	-70	-0.357	**-1.236**	**16.48**	**0.606**	**0.271**	**13.145**	**7.384**	**0.051**	**1.663**	**2.682**	**0.04**
-2.5	-45	**-0.684**	**1.341**	**60.226**	**1.841**	**0.884**	**37.305**	**17.377**	**0.293**	**2.036**	**5.479**	**0.152**
-2.5	-47.5	**-0.822**	0.129	**60.834**	**2.141**	**0.864**	**30.989**	**11.641**	**0.213**	**1.886**	**3.776**	**0.12**
-2.5	-50	**-0.384**	-0.192	25.432	1.043	0.197	2.362	0.097	0.001	0.412	0.452	0.031
-2.5	-52.5	**-0.373**	-0.278	7.538	0.308	0.062	1.814	-1.392	-0.027	0.38	0.816	0.002
-2.5	-55	**-0.668**	0.13	**12.886**	**0.462**	**0.155**	**8.618**	**4.227**	**0.028**	**0.678**	**1.086**	0.02
-2.5	-57.5	**-0.806**	**-0.58**	**11.13**	0.261	**0.159**	**7.411**	**5.614**	**0.027**	**0.769**	0.89	-0.002
-2.5	-60	**-0.51**	0.428	**27.34**	**1.069**	**0.295**	**17.452**	**9.372**	**0.035**	**1.239**	**2.082**	**0.058**
-2.5	-62.5	**-0.293**	-0.1	17.032	**0.595**	**0.132**	7.327	**3.359**	**0.017**	0.334	**0.851**	0.025
-2.5	-65	**-0.235**	**-1.39**	17.411	0.674	**0.181**	9.841	**4.361**	**0.029**	0.884	**1.281**	0.034
-2.5	-67.5	**-0.293**	-0.562	**36.064**	**1.467**	**0.394**	**21.12**	**8.464**	**0.098**	**1.901**	**3.051**	**0.079**
-2.5	-70	**-0.578**	-0.604	**23.775**	**0.782**	**0.234**	**12.009**	**5.852**	**0.051**	**1.265**	**1.851**	**0.048**
-5	-37.5	-0.726	0.03	-5.65	-0.135	-0.073	-4.741	-3.244	-0.029	-1.001	-1.245	-0.072
-5	-40	**-1.94**	-0.088	11.063	0.161	0.136	7.105	2.305	0.076	0.333	2.338	0.022
-5	-42.5	**-2.067**	0.238	**58.804**	**1.552**	**0.936**	**30.255**	**10.608**	**0.326**	**1.918**	**4.684**	**0.167**
-5	-45	**-1.583**	0.046	**79.616**	**1.919**	**1.186**	**50.087**	**19.016**	**0.476**	**3.321**	**6.335**	**0.195**
-5	-47.5	**-1.384**	**-0.693**	**63.789**	**1.62**	**1.093**	**40.264**	**15.529**	**0.376**	**2.924**	**5.173**	**0.159**
-5	-50	**-0.663**	-0.504	20.475	0.638	0.358	7.759	0.974	0.064	**1.876**	2.797	0.039
-5	-52.5	-0.23	**-1.459**	-8.436	-0.067	-0.035	-4.771	-4.397	-0.042	0.316	0.627	-0.025
-5	-55	-0.283	**-1.64**	-11.641	-0.192	-0.024	-1.058	-0.954	-0.014	0.637	0.32	-0.031
-5	-57.5	-0.691	**-1.036**	-3.084	-0.027	0.068	3.421	2.462	0.023	0.469	0.293	-0.011
-5	-60	-0.801	-0.078	**14.943**	0.437	0.111	5.875	3.215	0.021	0.09	0.693	0.03
-5	-62.5	**-0.256**	-0.152	14.258	0.358	0.091	4.651	2.822	0.011	0.162	0.466	0.023
-5	-65	**-0.291**	**-1.025**	13.764	0.358	0.203	11.923	6.051	0.05	0.968	1.36	0.031
-5	-67.5	**-0.483**	0.371	**37.96**	**0.953**	**0.218**	**14.671**	**8.923**	**0.09**	**1.68**	2.913	0.073
-5	-70	**-0.671**	0.132	**23.607**	**0.477**	**0.1**	6.41	**3.794**	**0.015**	**1.152**	1.596	0.039
-5	-72.5	-0.019	-0.637	2.71	0.031	0.013	1.132	1.069	**0.006**	0.393	0.328	0.004
-7.5	-35	**-0.656**	0.197	1.846	-0.054	-0.079	-3.207	-3.086	**-0.015**	**-0.906**	-1.33	-0.034
-7.5	-37.5	-1.095	-0.013	2.369	-0.03	0.005	0.137	0.418	0.005	-0.265	0.18	-0.035
-7.5	-40	**-3**	0.118	**19.282**	**0.466**	**0.343**	**10.466**	**3.583**	**0.095**	0.601	2.679	0.08
-7.5	-42.5	**-2.271**	-0.045	**48.124**	**1.044**	**1.01**	**25.826**	**8.276**	**0.326**	1.059	3.499	0.189
-7.5	-45	**-1.863**	-0.178	**41.478**	**1.092**	**0.737**	**24.334**	**9.433**	**0.267**	**1.621**	3.402	0.14
-7.5	-47.5	**-1.747**	-0.143	**30.538**	**0.866**	**0.606**	**18.976**	**5.479**	**0.189**	**1.868**	2.62	0.102
-7.5	-50	**-1.859**	**-0.477**	**17.794**	**0.829**	0.194	**6.271**	**1.719**	**0.066**	**1.502**	2.052	0.053
-7.5	-52.5	-0.884	**-1.182**	-2.584	0.378	-0.019	-7.121	-5.443	-0.081	0.632	0.463	-0.002
-7.5	-55	-0.796	**-0.83**	-12.516	-0.329	-0.054	-4.404	-2.503	-0.053	0.435	0.269	-0.03
-7.5	-57.5	-0.263	**-1.58**	-12.074	-0.306	0.003	-0.814	-0.778	-0.007	0.002	-0.256	-0.027
-7.5	-60	-0.766	-0.676	0.834	0.098	0.06	2.689	2.293	0.021	0.453	0.618	0.001

continuação

-7.5	-62.5	-0.446	**-1.071**	8.083	0.195	**0.074**	4.179	**1.928**	0.016	0.444	0.637	0.009
-7.5	-65	-0.398	-0.657	15.158	0.483	**0.086**	6.577	**2.707**	0.018	0.347	0.383	0.026
-7.5	-67.5	**-0.683**	0.205	**22.074**	**0.463**	**0.075**	5.812	**3.498**	**0.02**	**0.847**	1.565	0.032
-7.5	-70	**-0.92**	**0.634**	**25.179**	**0.424**	**0.049**	5.333	**1.885**	**0.005**	0.818	0.905	0.034
-7.5	-72.5	**-0.59**	**0.793**	**34.217**	**0.906**	**0.107**	**11.192**	**4.56**	**0.017**	**0.957**	1.285	0.058
-10	-37.5	**-0.928**	**0.254**	**11.207**	**0.326**	0.015	2.135	0.898	0.003	0.31	0.587	0.013
-10	-40	**-1.855**	0.065	**13.872**	0.288	**0.223**	**7.807**	**2.237**	0.055	0.629	0.882	0.021
-10	-42.5	**-1.297**	-0.016	**17.538**	0.386	**0.416**	**11.035**	**3.087**	0.137	0.655	0.881	0.112
-10	-45	**-1.96**	-0.228	16.55	0.436	**0.373**	10.113	**3.509**	0.084	**0.938**	1.721	0.072
-10	-47.5	**-1.314**	**-0.367**	5.781	0.096	0.171	5.575	1.599	0.038	0.683	0.728	0.011
-10	-50	-0.982	**-0.758**	4.21	0.213	0.163	4.902	0.396	-0.001	0.287	0.567	0.018
-10	-52.5	-0.817	**-0.847**	5.145	0.375	0.131	4.916	1.373	0.022	**0.95**	0.994	0.017
-10	-55	-0.495	**-1.3**	**-11.899**	-0.361	-0.013	-1.205	-1.133	-0.013	-0.008	-0.303	-0.03
-10	-57.5	-0.387	**-1.48**	**-14.814**	-0.313	-0.042	-2.671	-1.323	-0.014	0.03	-0.268	-0.026
-10	-60	-0.431	**-1.27**	-7.093	-0.169	-0.011	-1.289	-0.631	-0.004	0.007	0.114	-0.011
-10	-62.5	-0.8	-0.007	8.278	0.148	0.047	1.474	0.909	0.001	0.215	0.322	0.016
-10	-65	-0.576	-0.002	**15.286**	**0.509**	0.036	5.024	**1.569**	0.007	0.658	0.835	0.029
-10	-67.5	-0.666	0.274	**13.554**	**0.354**	**0.041**	4.317	**1.529**	**0.004**	0.548	0.683	0.017
-10	-70	**-1.047**	**0.779**	**25.866**	**0.608**	**0.066**	5.206	**1.905**	**-0.002**	0.303	0.502	0.041
-10	-72.5	**-0.865**	**0.607**	**34.124**	**0.91**	**0.097**	**10.918**	**3.81**	**0.012**	**0.985**	1.602	0.061
-12.5	-37.5	**-0.507**	0.211	**11.36**	**0.376**	0.068	2.47	1.604	0.004	**0.316**	0.264	0.015
-12.5	-40	**-0.721**	0.047	9.837	0.127	**0.138**	5.091	**2.926**	0.023	0.562	1.251	0.012
-12.5	-42.5	-1.059	-0.076	-0.511	-0.101	0.155	3.041	0.062	0.025	0.336	0.418	0.038
-12.5	-45	-1.054	-0.276	10.946	0.263	**0.353**	7.775	**2.954**	0.076	0.702	1.96	0.072
-12.5	-47.5	-1.188	-0.708	4.225	-0.08	0.236	6.504	1.836	0.042	0.186	0.36	0.015
-12.5	-50	-1.063	-0.585	3.795	0.141	0.175	7.038	2.416	0.031	0.482	0.794	0.014
-12.5	-52.5	-0.655	-0.799	7.525	0.343	**0.14**	6.473	**2.577**	0.017	0.784	0.837	0.017
-12.5	-55	-0.628	-0.26	-3.584	-0.21	-0.028	-1.961	-1.141	-0.007	-0.231	-0.603	-0.02
-12.5	-57.5	-0.663	-0.424	-2.126	-0.213	-0.036	-3.493	-1.708	-0.017	-0.392	-0.713	-0.017
-12.5	-60	-0.92	-0.248	-4.442	-0.249	-0.013	-1.333	-0.826	-0.01	-0.21	-0.287	-0.012
-12.5	-62.5	-0.584	0.186	7.272	0.149	0.03	0.831	0.854	-0.003	0.243	0.32	0.016
-12.5	-65	**-0.697**	0.028	**10.643**	**0.311**	0.035	**2.87**	0.977	-0.003	0.15	0.25	**0.011**
-15	-40	**-0.531**	0.074	3.508	-0.04	0.086	2.554	0.906	0.006	0.221	0.625	-0.003
-15	-42.5	-1.365	-0.108	1.222	-0.007	**0.168**	3.466	0.558	0.029	0.283	0.846	0.046
-15	-45	-1.11	-0.121	10.119	0.341	**0.316**	**8.065**	**1.98**	0.074	**0.855**	1.518	0.075
-15	-47.5	**-1.534**	**-0.296**	8.74	0.141	**0.325**	9.418	**3.071**	0.051	0.341	0.624	0.023
-15	-50	**-1.794**	-0.321	30.063	0.917	**0.551**	**20.614**	**7.318**	**0.148**	**1.532**	3.232	0.107
-15	-52.5	**-1.346**	-0.099	19.149	**0.644**	**0.277**	**11.529**	**4.678**	**0.067**	**0.948**	1.521	0.053
-15	-55	-1.253	**-0.706**	-3.95	-0.143	-0.023	-1.241	-0.504	-0.002	-0.198	-0.5	-0.02

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-15	-57.5	-1.275	-0.194	-2.758	-0.289	-0.044	-2.289	-1.58	-0.018	-0.408	-0.715	-0.026
-15	-60	-1.109	0.138	2.351	-0.1	0.032	0.98	1.015	0.008	0.308	0.588	-0.006
-17.5	-40	-0.333	0.055	4.568	0.07	0.053	2.06	0.93	0.013	0.071	0.561	0.003
-17.5	-42.5	**-0.606**	-0.003	5.717	0.087	**0.222**	6.076	**1.605**	0.025	0.445	0.49	0.014
-17.5	-45	**-1.605**	-0.202	**11.386**	0.359	**0.298**	**8.52**	**2.62**	**0.059**	**0.995**	1.403	0.057
-17.5	-47.5	**-1.595**	-0.222	**12.549**	0.276	**0.278**	**9.01**	**2.694**	0.035	0.345	0.45	0.022
-17.5	-50	**-1.928**	0.186	**32.556**	**1.009**	**0.538**	**19.067**	**7.448**	**0.128**	**1.064**	2.268	0.096
-17.5	-52.5	**-1.334**	-0.081	**17.025**	**0.628**	**0.254**	8.919	**2.385**	0.022	0.022	0.36	0.036
-17.5	-55	**-1.532**	-0.413	3.005	0.069	0.04	1.326	0.9	0.002	0.164	0.14	-0.004
-17.5	-57.5	-1.499	0.09	6.272	0.056	-0.007	-0.609	-0.486	-0.01	-0.183	-0.333	-0.006
-17.5	-60	-1.104	0.132	3.564	-0.057	-0.006	-0.894	-0.611	-0.005	-0.023	-0.483	-0.025

It can be seen from Figure 2a that in the whole study area there are only decreasing trends in the number of Consecutive Dry Days (CDD). Almost all the trends are statistically significant, thus indicating that the result is robust. These results are similar to those obtained by Haylock et al. (2006) who studied the extreme indices in South America using observational dataset for the period 1960 - 2000. In the central parts of Northeast Brazil region, strong decreasing trends of the order of 2 consecutive dry days per year are obtained.

Figure 2b shows the spatial distribution of the Consecutive Wet Days (CWD) index. Almost the whole study area presents a decreasing trend in the number of consecutive rainy days. Taking into account that the amount of consecutive dry days also decreased, it is possible to understand that alternations between dry and rainy days are increasing. If these trends continue, the rainfall in the interior Northeast Brazil would become more uniform, with reduced periods of consecutive dry days and consecutive wet days. An interesting conclusion is that the probability that a dry day happens after a wet day or vice versa has increased, however there is few coincident grid points in the maps with significant negative trend. These results differ from those obtained by Haylock et al. (2006).

Figure 2c shows that only in Mato Grosso State and at 3 grid-points in the extreme Northeast area presented decreasing trends in the maximum amount of precipitation in 1 day (Rx1day); however just at one grid point the trend is statistically significant. One of the possible causes of the decrease of the precipitation in Mato Grosso is the deforestation of the area, which produces an increase in the albedo and consequently a decrease in the available energy to maintain intense local convection. Moreover, recycling of water through evapotranspiration by the vegetation also reduces. However, even in places with negative trends, the observed values are about 1 mm year^{-1} only.

In the remaining area, the increasing trends of the Rx1day index are obtained, the largest value being 3 mm/year, at the grid-point 5°S 45°W (Maranhão State), and most of the neighboring points show increase greater 1mm/year. These increasing trends of the maximum precipitation in one day in northern part Northeast Brazil was also verified by Haylock et al. (2006), which is, probably, connected with the SST increase of the Tropical South Atlantic Ocean (Servain et al., 2000). Similar results are seen in Figure 2d, which represents the trends in the maximum 5-day precipitation amount (Rx5day) index.

The index SDII (Figure 2e) presents increasing trends in the annual mean precipitation. However, the positive trend presented at almost all the grid points is smaller than 1 mm year^{-1}. In Figure 2e (SDII) the area of negative trends extends into the state of Para, compared to Figure 2d (Rx5day). The negative-trend areas have been vigorously deforested in the period of study.

Considering that days with precipitation values higher than 10 mm (R10mm) are wet days, it is possible to identify in Figure 2f that the wet days are increasing in many parts of the study area, especially over the Amazon region. These days are not necessarily consecutive, but have presented increasing trend in their number, of about one wet day per year, and is statistically significant. Although the regions with decreasing trends of R10mm do not present statistical significance, they coincide with the grid-points which showed decreasing trends of SDII (Figure 2e). These results are in agreement with each other.

Number of days with precipitation higher than 20 mm (R20mm) considered very wet days presents a trend distribution (Figure 2g) that is almost a repetition of Figure 2f. Some grid-points in southern Bahia show positive trends, but those are not statistically significant. A comparison of Figures 2f and 2g indicates that the heavy rainfall events have been intensifying over the northern part of Brazil, especially over the Amazon area. The east coast of the Northeast presents statistically significant negative trend in R20mm. This has happened probably because in the second half of the studied period (1981-2001) the frequency of El Niño phenomenon was higher than in the first half (1961-1980).

Figure 2h shows the spatial distribution of the Extreme Wet Days index (R50mm). This index presents positive trends of the order of 0.5 day/year. The negative trends also were small and they did not present statistical significance. These results indicate that, in general, the daily extreme events of precipitation are occurring more frequently now than in the 1960s. Probably, this is a consequence of the increase in the SST of the Tropical South Atlantic which induces a higher evaporative rate and transport of the water vapor from the oceans to the continent (Servain et al., 2000).

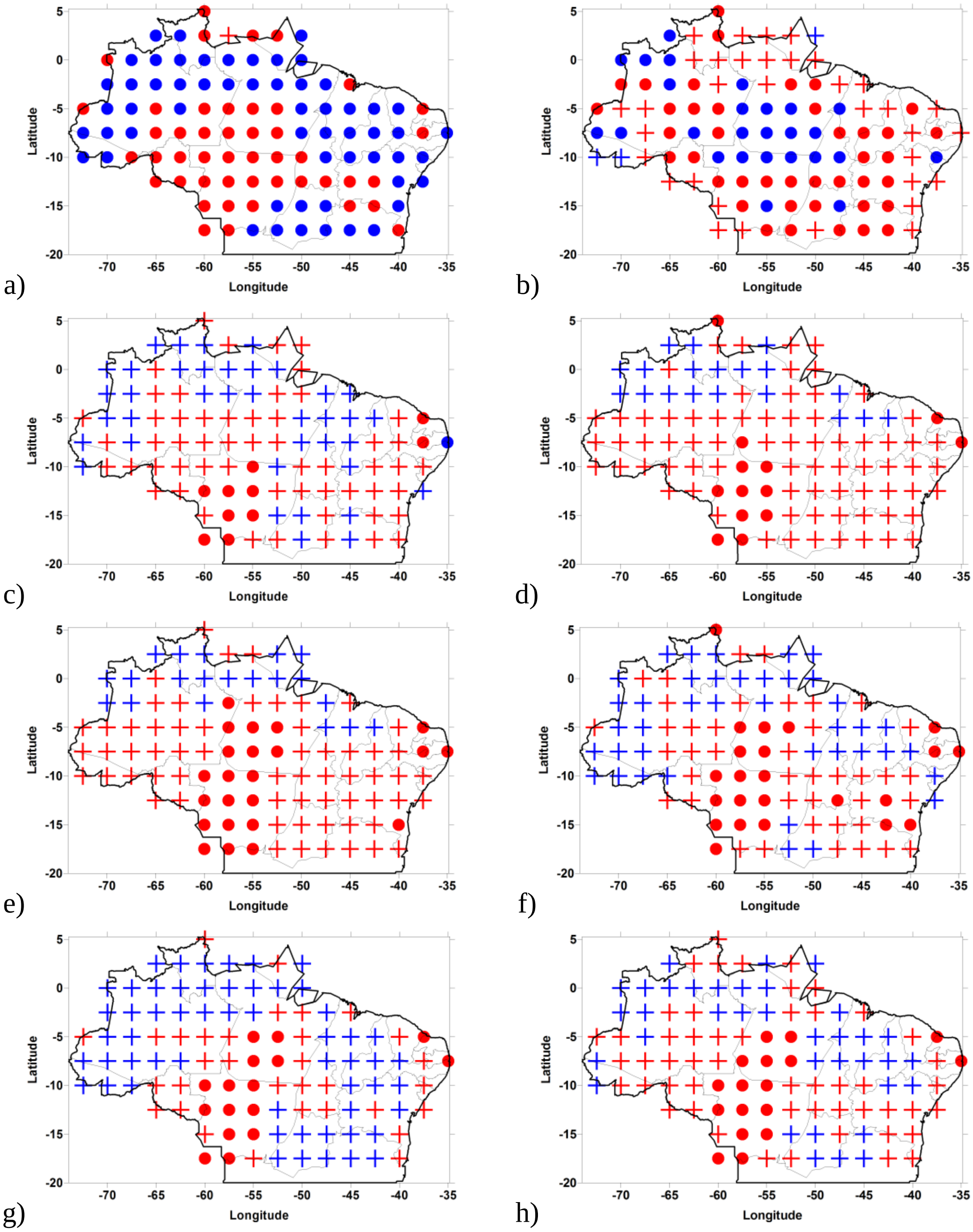

Figure 2. Spatial distribution of mean (a) CDD, (b) CWD, (c) Rx1day, (d) Rx5day, (e) SDII, (f) R10mm, (g) R20mm and (h) R50mm indices trends. (✚) and (●) are positive and negative trends, respectively, statistically significant at 5% level. (✚) and (●) are statistically not significant.

Figures 3a and 3b present the spatial distributions of extremely wet days, R95p and R99p. These indices show similar spatial distributions, however the R95p values are higher than R99p values as is expected. The maximum values of R95p index are seen at the grid-points 5°S 45°W (50.087 mm/year) and 5°S 47,5°W (40.264 mm/year), located over the Maranhão State. The maximum values of R99p are exactly over the same grid-points showed in the R95p index, but with maximum trends of about 19 mm/year. Possibly, in the same way as the R50mm index, the positive trend configurations for

R95p and R99p index are due to the increase in the SST of the Tropical South Atlantic Ocean.

The annual total precipitation index (PRCPTOT) behavior confirms the trends of increase in the precipitation over the study area (Figure 3c) observed in the indices previously discussed. Only in the central area and some grid-points over the Northeast showed negative trends, however, the trends are gradual increase of the precipitation over the study area, especially over the Amazonas, Acre and Roraima States in the North Region and Maranhão, Piauí and some part of Bahia States in the Northeast Region (Figure 3c). Most grid-points presented statistical significance for this index. In general, this predominant observed increase of the annual total precipitation is due to the increase in the SST of Tropical South Atlantic in the last 30 years from 1970 to 1999 (Servain et al., 2000). However, it is possible to verify that some places presented negative trends, showing the importance of local effects such as deforestation.

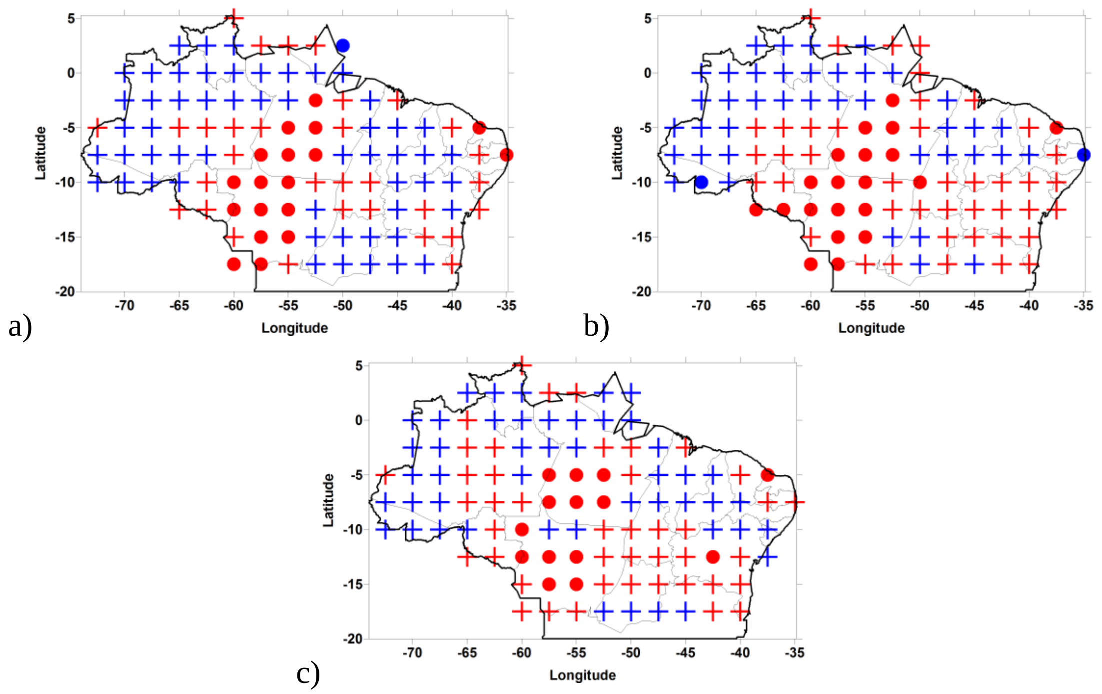

Figure 3.Spatial distribution of mean (a) R95p, (b) R99p and (c) PRCPTOT indices trends. (✚) and (●) are positive and negative trends, respectively, statistically significant at 5% level. (✚) and (●) are statistically not significant.

A summary of the trends of the indices at all the continental points is given in Table 3. The positive trends are predominant (except for the CDD). That is, in the 41-year period studied the total annual precipitation and related indices including the heavy precipitation events have increased in the northern and northeastern Brazil. The exceptions are the deforested regions in the states of Mato Grosso and Pará where some decreasing trends are noticed.

Table 3. Percentage of grid-points showing significant and non-significant trends at the 5% level for the precipitation indices for the Northern part of Brazil.

Index	Positive significant trend (%)	Positive non significant trend (%)	Negative significant trend (%)	Negative non significant trend (%)
CDD	0.0	1.0	41.3	57.7
CWD	6.7	31.7	23.1	38.5
Rx1day	36.5	52.9	1.0	9.6
Rx5day	19.2	68.3	0.0	12.5
SDII	21.2	56.7	0.0	22.1
R10mm	40.4	34.6	0.0	25.0
R20mm	54.8	29.8	0.0	15.4
R50mm	35.6	48.1	0.0	16.3
R95p	52.9	28.8	1.0	17.3
R99p	38.5	39.4	1.9	20.2
PRCPTOT	45.2	39.4	1.9	13.5

4. Conclusions

Based on these results the Mato Grosso state and some other parts deforested in the past few decades show characteristics that are different from the rest of the tropical Brazil. While the rainfall and the wet and the very wet days increased in the 41-years period studied in most parts of the tropical Brazil, the areas where the deforestation and vegetation fires were intense showed either insignificant increasing trends in some indices or showed decreasing trends. These results strongly suggest that deforestation and biomass burning on large scale can decrease the rainfall and the frequencies of wet and very wet days. These changes if continue over long periods may have unwanted consequences in terms of water supply. These results provide an argument for stopping or reducing the rate of deforestation in the region.

The data are the ERA 40 reanalysis, not the observed rainfall. However, the data is a mixture of direct and indirect observations and very short period model integrations. In the absence of a dense and reliable observational network with long periods of data in the region, the model analysis provides the best possible dataset. If the trends from the ERA 40 reanalysis are considered representative of the true atmospheric behavior, the results serve to indicate the changes observed in the 41 year period.

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