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Changes in precipitation extremes in Brazil (Paraná River Basin)

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Abstract. This research was aimed at addressing aspects related to variation in the amount of precipitation during the period from 1986 to 2011, in the Paraná River Hydrographical Basin, Brazil, for 32 meteorological stations using 11 climate indices created by the ETCCDI (Expert Team, ET, on Climate Change Detection and Indices, ETCCDI). The daily rainfall data were organized in spreadsheets, which were subjected to an intense quality control and an accurate historical research. For each pluviometric index, we have estimated the trends and the statistical significant of the slopes have been calculated. The results confirm that there is an increase in the number of wet days in most of the basin, since an increase in total precipitation in almost all analyzed stations was registered, and the precipitation considered extreme were the main contributors to such additions.
Successively, we have studied accurately the variations of rain of two municipalities (Curitiba, PR and Goiânia, GO - Brazil) located in different climatic regions of the study area. The aim was to evaluate the impact that rainfall may cause in these two large urban centers. In these two municipalities, it was found that the variation of rainfall amount can cause inconvenience to the population (floods and inundations) due to the increasing of extreme rainfall, such results may be of concern with the accelerated increase of these urban areas and their populations, suggesting, at least, the need of implementation of more effective urban planning for the future.

Keywords: precipitation, climate indices, climate change, Paraná River Basin, Brazil.

1. Introduction

According to Dufek (2008), over the past century, few studies have been published and are available, in international level, on extreme rainfall events and temperature alterations, whether in global, hemispheric and particularly regional scales (Acquaotta et al. 2014; Fratianni et al. 2014, 2009; Terzago et al. 2012). However, in recent decades, this situation has experienced strong changes, due to the intense concern of scientists with the possibility of an eventual global climate change (Groisman 1999; IPCC 2013, 2007, 2001, 1992, 1990; Marengo 2008) and the damage that this could result in different parts of the planet.

Among the many effects that a climate variability could be responsible for, a major concern is the imminence of a possible increase in the occurrence of extreme events around the globe, which could directly affect the human population and other living organisms. Several studies and investigations have been conducted in order to identify which elements of weather might be responsible for major natural and social impacts, besides understanding how these elements are causing such impacts and what are their intensities and frequencies of occurrences. As an example, we can cite the works of Easterling et al. (2000), Kalkstein (1993), Kunkel (1999), Meehl et al. (2000), Walther et al. (2002), among many others.

Currently, climate scientists have dedicated great attention to the extreme variations of values of two main climate elements, the temperature and the precipitation. And among several previous studies, many have proven, for several regions around the world, real alterations in the values of these elements, as verified in the researches of Acquaotta and Fratianni (2013), Aguilar et al. (2005), Alexander et al. (2009, 2006), Besselaar et al. (2012), Klein Tank et al. (2006, 2003, 2002), Moberg et al. (2006), Mueller and Seneviratne (2012), Sen Roy and Rouault (2013), Terzago et al. (2013, 2010), Vincent et al. (2005), Vincent and Mekis (2006), Wang et al. (2013).

Even with all these efforts, we must recognize that in some areas of the planet, few studies addressing changes in extremes of temperature and rainfall are available, especially when the scale of analysis is regional. Marengo et al. (2009) *e.g.*, commented that among the main difficulties for those willing to performed a more detailed analysis in this sense, in Brazil or in other countries of South America, the major difficulties are related to the absence of long-term stations and also to the poor quality of series of data (Acquaotta and Fratianni 2014). Problems of poor spatial distribution of stations for data collection, short historical series or low quality of climate data are quite common characteristics in emerging countries, which are still in development processes, like Brazil In the brazilian case, it is also necessary to consider that, due to its territorial dimension, the several urban lacks and the long existent distances between municipalities in some regions of the country, make more difficult the implementation, control and management of climate station of data collection.

Given all the problems exposed above, we consider that the production of research that is able to contribute to the understanding of possible changes that are occurring in the dynamic climate of Brazil, especially the precipitation, can be extremely positive in the sense of adding the results obtained in this region with those of many other regions that have been studied around the world. Furthermore, this kind of research supports the achievement of better planning for this country, in order to minimize adverse impacts and consequences that alteration in extreme values of precipitation can result to the society, *e.g.*, flood events, inundation, landslides slopes in urban areas and damage in agriculture, generating impacts on food production. All these problems are common in Brazil, a country where the climate is predominantly tropical, but with strong subtropical influences, contributing to very contrasted climate changes, even in normal conditions.

Thus, aiming at contributing to a better understanding of pluviometric alterations that have been recorded in Brazil, in the present research, efforts were concentrated on the interpretation of the rainfall in the catchment area of the Paraná River Hydrographical Basin, an extensive region of Brazil, which is considered the most important socio-economically region of the great brazilian hydrographic regions, since it presents the highest population density in this country (32% of the population), mainly concentrated in large and important municipalities (ANA 2013). The Paraná River Basin also presents the largest brazilian hydroelectric park (176 hydroelectric power plant) and the greater capacity for energy production in the country (59.3% of the total national). Due to the high rate of industrialization, the basin has the highest energy demand of the country, consuming nearly 75% of the national expenditure (ANEEL 2013). This basin is, obviously, extremely dependent on rainfall catchment, and any change in the dynamic of this climatic element can induce major impacts to the population, in several socioeconomic sectors.

Therefore, the main aim of this research is to present the changes that has being occurred in the pluviometric dynamics of the Paraná River Hydrographical Basin, in the brazilian portion, in order to contribute to a better socioeconomic planning of the area. This way, we expect to collaborate with results obtained in previous investigations, some of them covering the entire area of the basin (Boulanger et al. 2005; Camilloni and Barros 2003; Krepper and Zucarelli 2010; Panalba and Robledo 2010; Silva and Berbery 2006; Zandonadi 2009), some covering smaller areas within its territory (Boin 2000; Dufek and Ambrizzi 2008; Monteiro 1973, 2000a; Zavattini 1990), and even some studies covering neighboring or continuing areas of its territorial boundaries (Barros et al. 2008; Figueiró and Coelho Netto 2011; Grimm et al. 2000; Groisman et al. 2005; Haylock et al. 2006; Liebmann et al. 2004). This research also aims at supporting future researches by utilizing the rain as the main guiding element of its discussions, especially for tropical and equatorial climates, where rainfall influence is always very intense.

2. The Paraná River Hydrographic Basin

The Paraná River Hydrographic Basin is located in Brazil, between the geographical coordinates of 15º 25' 47" and 26º 50' 55" South latitude and 43º 34' 55" and 55º 55' 53" West longitude (Figure 1). It is the second largest brazilian river basin and its area (879,860 Km^2) occupies 10% of the national territory, distributed among the states of São Paulo, Paraná, Mato Grosso do Sul, Minas Gerais, Goiás, Santa Catarina and the Federal District. It borders five other major brazilian hydrographic regions: the North, with the Tocantins-Araguaia Basin; the Northwest, with the Paraguay Basin; the Northeast, with the São Francisco River Basin, the Southeast, with the Eastern Atlantic; and the South, with the Uruguay Basin (ANEEL 2013b e ANA 2013).

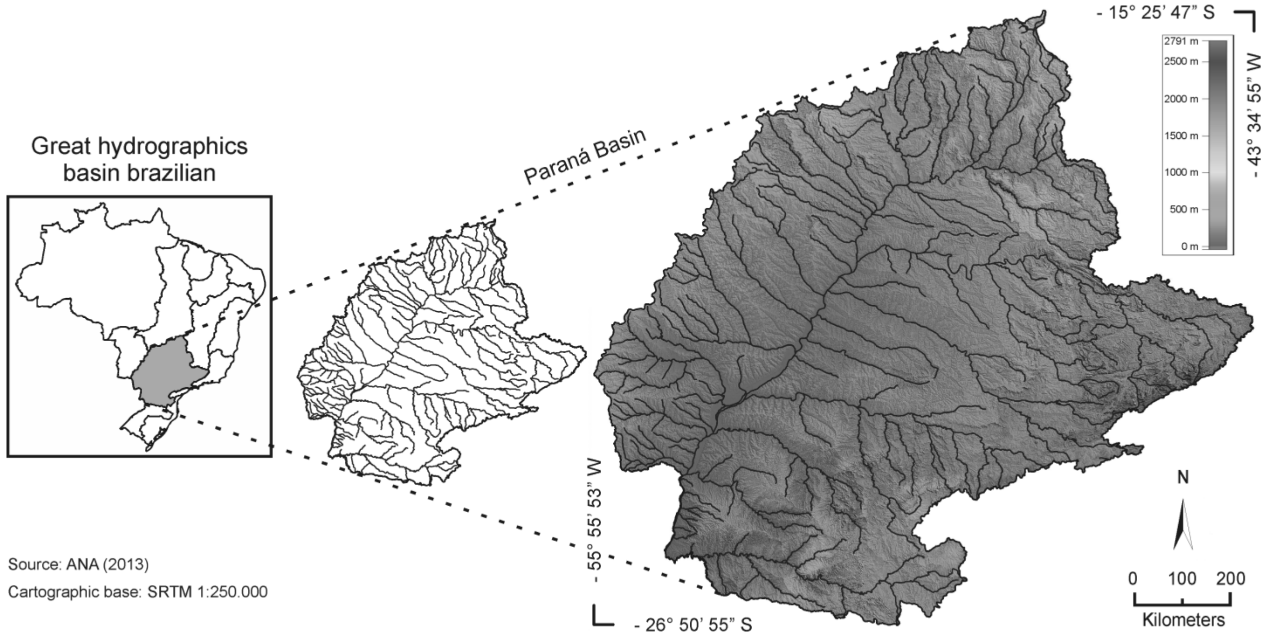


Figure 1. Division of the major hydrographical regions of Brazilian territory, highlighting the Paraná River Hydrographic Basin, its main drainage system and elevations of the landscape.

The Paraná River Hydrographic Basin landscape is very irregular in the East and Southeast region, due to the occurrence of crystalline rocks and higher altitudes. In the other areas dominate tabular wavy shapes, with gentle slope towards the Paraná River, locally interrupted by cliffs of "Cuestas" of Serra Geral. The Central Plateau of the basin is characterized by elongated or tabular hills with bulging tops, arranged on three levels with altitudes near to 1000 m, between 600 m and 700 m, and to 500 m. Since these levels are tilted, the altitudes decrease as approaching the main gutter. The highest level is referred as "Residual Plateaus Cuestiformes" and the others as "Reduced Plateaus" (Souza Filho and Stevaux 1997).

3. Data and quality control

Daily pluviometric data used in this research, for observation and analyzes, were obtained initially from 44 meteorological stations, belonging to the National Institute of Meteorology (INMET), a Brazilian government agency. The stations were distributed throughout the Paraná River Basin and covered the historical period from 1961 to 2011, 51 years.

The first process of analysis and quality control of the data was the verification of possible gaps in daily rainfall series from those initial 44 stations. To estimate the gap we calculated the monthly and annual series. We created the monthly values only if at least 80 % of the daily data was available, equal to a gap of 6 non-consecutive days (Klein Tank et al. 2002; Sneyers 1990) and for the annual values, at least the 96 % of the daily data, equal to a gap of 15 non-consecutive days (Klein Tank and Können 2003).

We observed that some of them contained a lot of missing data, in some cases, annual gaps, mainly during the years of 1979 to 1985, which made impossible, for this period, any kind of verification of the results. In attempt of solving this problem we have developed the historical research in the institute responsible for the data (INMET) who claimed to have been failures at the time of migration of data contained in a database of information given by an old computer system to another more modern. They affirmed that the problem is being solved. However, there is no definite date for the completion of the restoration project data.

This result preclude the use of the long series from 1961 to 2011. So we have selected a new time period, from 1986 to 2011. However, the choice of this new period preclude even more the use of the pluviometric stations from western sector of the basin, a region that already had shortage of data, especially for being more recent economically developed, with few urban areas, and consequently, lower population densities, which contribute to the lower density of stations of data collection, as well as for the existence of shorter historical series, often with lower quality than in other regions of the basin.

Therefore, in addition to force the use of a shorter historical series, the poor quality of the data also led to a decrease in the number of stations of data collection to be used in the analysis, from a total of 44 to only 32 stations, which have their information presented in detail in Table 1. The location of these stations throughout the basin can be verified in Figure 2, where is also possible to observe the absence of stations in the extreme east and the southern regions, since in these regions it was not possible to select stations with good quality of data who allow the application of the parameters and the verification of possible variations in pluviometric values during the select period.

To improve the dataset we also used data from several stations outside the limits of the basin by to the high quality of data and also to their vicinity to the basin, which ensure a better spatial coverage and higher quality of the investigated information.

Table 1. List of the 32 pluviometric stations used in the analysis.

Pluviometric Station		Code (WMO)	Latitude (S)	Longitude (W)	Elevation (m)
1	**Araxá**	83579	-19.60	-46.93	1023.6
2	**Avaré**	83773	-23.08	-48.92	813.0
3	**Brasília**	83377	-15.79	-47.92	1159.5
4	**Campo Mourão**	83783	-24.05	-52.36	616.4
5	**Campos do Jordão**	83714	-22.73	-45.58	1642.0
6	**Capinópolis**	83514	-18.68	-49.56	620.6
7	**Castro**	83813	-24.78	-50.00	1008.8
8	**Catalão**	83526	-18.17	-47.95	840.5
9	**Catanduva**	83676	-21.13	-48.96	570.0
10	**Curitiba**	83842	-25.30	-49.20	923.5
11	**Formosa**	83379	-15.55	-47.34	935.2
12	**Franca**	83630	-20.55	-47.43	1026.2
13	**Goiânia**	83423	-16.67	-49.26	741.5
14	**Guarulhos**	83075	-23.43	-46.46	735.0
15	**Ipamerí**	83522	-17.72	-48.17	773.0
16	**Iratí**	83836	-25.47	-50.63	837.0
17	**Ituiutaba**	83521	-18.97	-49.35	560.0
18	**Jataí**	83464	-17.93	-51.72	662.9
19	**Juiz de Fora**	83692	-21.77	-43.32	940.0
20	**Lavras**	83687	-21.23	-45.00	918.8
21	**Londrina**	83766	-23.32	-51.15	566.0
22	**Maringá**	83767	-23.42	-51.95	542.0
23	**Paracatú**	83479	-17.22	-46.87	712.0
24	**Pirenópolis**	83376	-15.85	-48.96	740.0
25	**Presidente Prudente**	83716	-22.12	-51.38	435.6
26	**São Carlos**	83726	-22.02	-47.90	856.0
27	**São Lourenço**	83736	-22.10	-45.02	953.2

28	**São Paulo (Mirante de Santana)**	83781	-23.50	-46.62	792.1
29	**São Simão**	83669	-21.48	-47.55	617.4
30	**Uberaba**	83577	-19.77	-47.93	737.0
31	**Unaí**	83428	-16.37	-46.88	460.0
32	**Votuporanga**	83623	-20.42	-49.98	502.5

* Source: INMET (2013) Datum: SAD-69

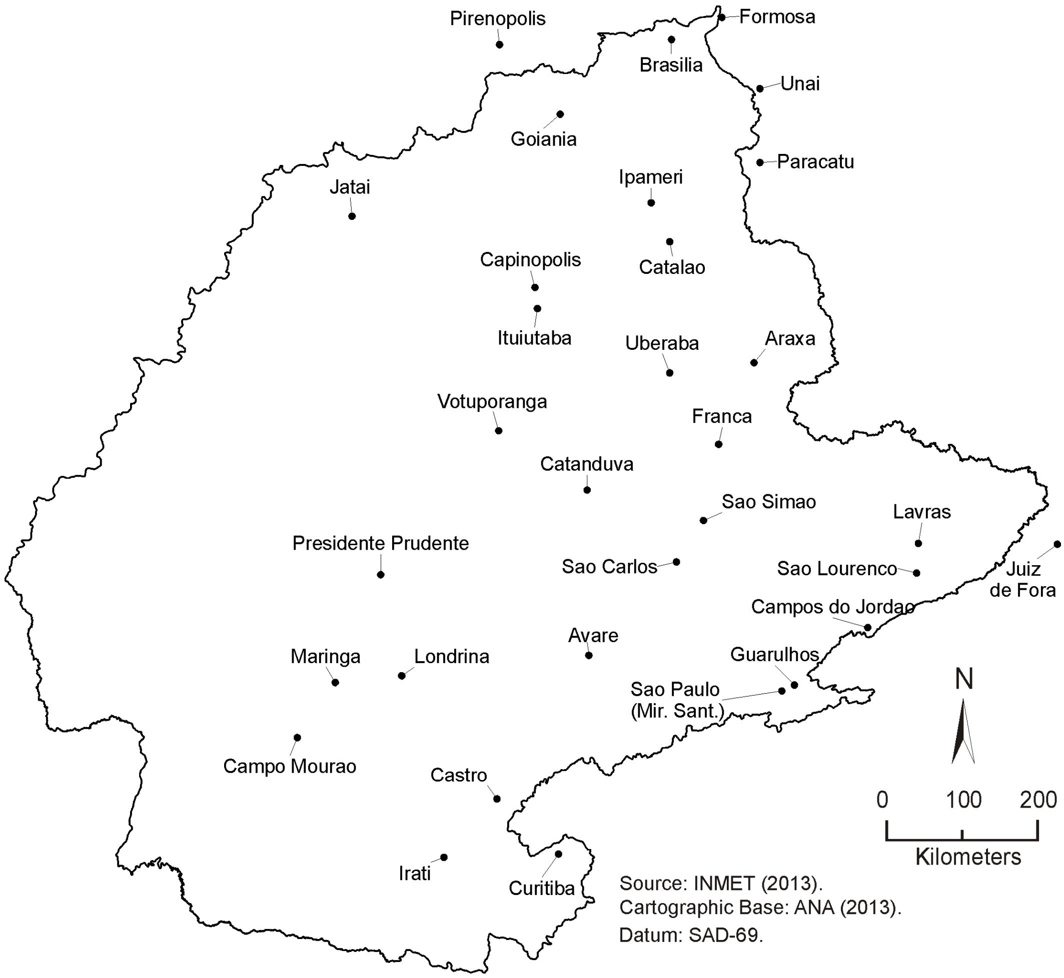


Figure 2. Location of the 32 pluviometric stations used in the analysis.

Completing the process of choice of stations and periods to be utilized, on daily data an accurate quality control was made by the software RClimdex (Zhang et al. 2004). The program highlights obviously wrong precipitation data, such as negative values, and creates plots that allow to visualize the behavior of the daily series (Figure 3). Also the program highlights the outliers. The outliers are daily values outside an threshold; in this study, the threshold is the 99th percentile calculated for each series on the available period. The identification of the outliers, maximum values of daily precipitation, is very important because it allow us to identify incorrect values due to erroneous transcription of the daily data. A typical example of a transcription error is a weekly accumulation that was transcribed as the value of one day. The incorrect values and outliers are transcribed and stored in tables by the software RClimdex, to be analyzed and corrected later, if necessary. Besides the program consider only the rainfall data equal or superior to 1 mm, being discarded the data lower than 1mm, considering that such amount of rain are inexpressive to the analyzes, not affecting consistently the rainfall in the basin.

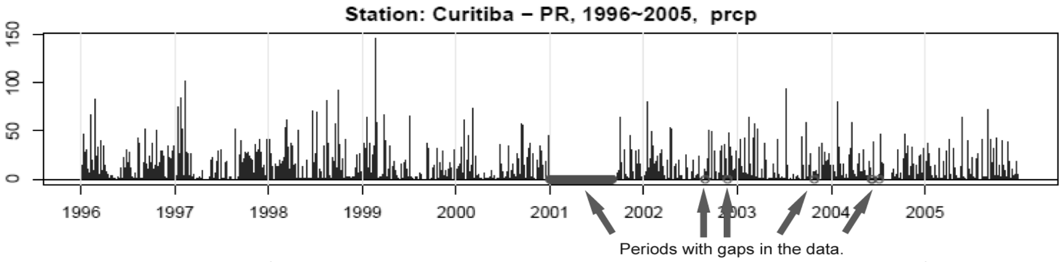


Figure 3. Example of plot showing the periods with gaps in the data generated by RClimdex software.

4. Climate indices

On the selected stations were calculated the climate indices in order to check the pluviometric behavior of the study area. In total, there are 11 indices created and organized by the ETCCDI to perform the calculations applied to the studies on rainfall data (Table 2).

The joint CCl/CLIVAR/JCOMM Expert Team (ET) on Climate Change Detection and Indices (ETCCDI) has addressed the need for the objective measurement and characterization of climate variability and change by providing international coordination and helping organizing collaboration on climate change detection and indices relevant to climate change revealing. The Expert Team (ET) and its predecessor, the CCl/CLIVAR Working Group (WG) on Climate Change Detection have been coordinating an international effort to develop, calculate, and analysis a suite of indices so that individuals, countries, and regions can calculate the indices in exactly the same way such that their analyses will fit seamlessly into the global picture (Karl et al. 1999; Peterson et al. 2001).

The 11 indices were calculated on annual scale. In the Table 2 are reported the definitions of the indices. For the monthly indices, RX1day and RX5day, the annual values were calculated as the maximum values of the monthly data.

Table 2. Identification and definitions of rainfall indices used in the research.

ID	Indicator Name	Definitions	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 total precipitation divided by the number of wet days (defined as precipitation > = 1.0mm) in the year	mm/day
R10mm	Number of heavy precipitation days	Annual count of days when precipitation > = 10mm	days
R20mm	Number of very heavy precipitation days	Annual count of days when precipitation > = 20mm	days
R1mm	Number of rainy days	Annual count of days when precipitation > = 1.0 mm	days
CDD	Consecutive dry days	Maximum number of consecutive days with daily rainfall < 1mm	days
CWD	Consecutive wet days	Maximum number of consecutive days with daily rainfall > = 1mm	days
R95p	Very wet days	Annual total precipitation when daily rainfall > 95th percentile	mm
R99p	Extremely wet days	Annual total precipitation when daily rainfall > 99th percentile	mm
PRCPTOT	Annual total wet-day precipitation	Annual total precipitation in wet days (daily rainfall > = 1mm)	mm

The percentile indices, R95p and R99p, use threshold closely linked with the peculiarity of the station. The percentile is calculated on the reference period that in the our case in the analyzed time period, from 1986-2011. The methodology uses bootstrapping for calculating the base period values so there is no discontinuity in the indices time series at the beginning or end of the base period (Zhang et al. 2005). In this way it is possible to calculate for each stations the heavy precipitation. The threshold of extreme events can change considerably in a large area as the analyzed zone. Instead some indices, R10mm and R20mm, use a determinate threshold to highlight as the same events change from station to station.

For each pluviometric index, the trends were also calculated, by linear least square with a statistical significance at 95% level.

All positive and negative values, respectively indicative of the increase or decrease of the trend, were organized in a spreadsheet and classified chromatically, in order to facilitate observation and analysis. The same criteria of chromatic classification was used for representation of the results through the maps, allowing to verify which areas had the most significant pluviometric alteration. However, in this case, all values of negative and positive trends for each of the 11 indices were divided in 7 ranges of classes. Thus, the first range is from 0 to 3, the second from 3 to 6, the third from 6 to 9, the fourth from 9 to 12, the fifth from 12 to 15, the sixth from 15 to 18, and the seventh from 18 to 21.

Finally we have chosen two large urban areas located within the basin, the municipalities of Curitiba and Goiânia, both representing two different climatic regions present in the study area. The aim of this step was to identify which amount of rainfall can eventually cause impacts in these two urban centers, such as floods and inundations. The study of the variations of precipitation by using climate indices allow us to understand if the risks of occurrences of new impacts will increase or not. Then we have selected these centers because it is possible to consult a great number of works regarding these issues.

5. Climatic aspects of Brazil and Paraná River Hydrographic Basin

Due to its continental dimensions, Brazil has a very broad climate diversification, influenced by its geographic location, its significant coastal extension, its importance and the different air masses that act on its territory. Among all these facts, the masses of air play an important role in the climate configuration, by having high mobility and dynamism, being generators of atmospheric currents that control all the acting general circulation in the Brazilian geographical space. Along the many paths that air masses ranging in the brazilian territory, there are always interactions with multiple geographic features, such as the landscape, which always end up causing temperature variations and very contrasting rain throughout the country. Added to all this complex interaction, we must also consider the influences caused by other systems and atmospheric phenomena, as in the case of the South Atlantic Convergence Zone (SACZ) and the El Niño and La Niña, the last two difficult to predict.

In this sense, in order to perform the investigation of the behavior and variations in any climate element in Brazil, it is first necessary to understand how atmospheric dynamics operating in this country. According to the climatic classification of Strahler (1951) two major climatic groups under the action and influence of air masses predominate in Brazil (Figure 4). The first group, or "Group A", is called "Climates controlled by Equatorial and Tropical Masses of Air" and "Group B" is called "Climates controlled by Tropical and Polar Masses of Air". These two major climatic groups are subdivided into five other climates, namely:

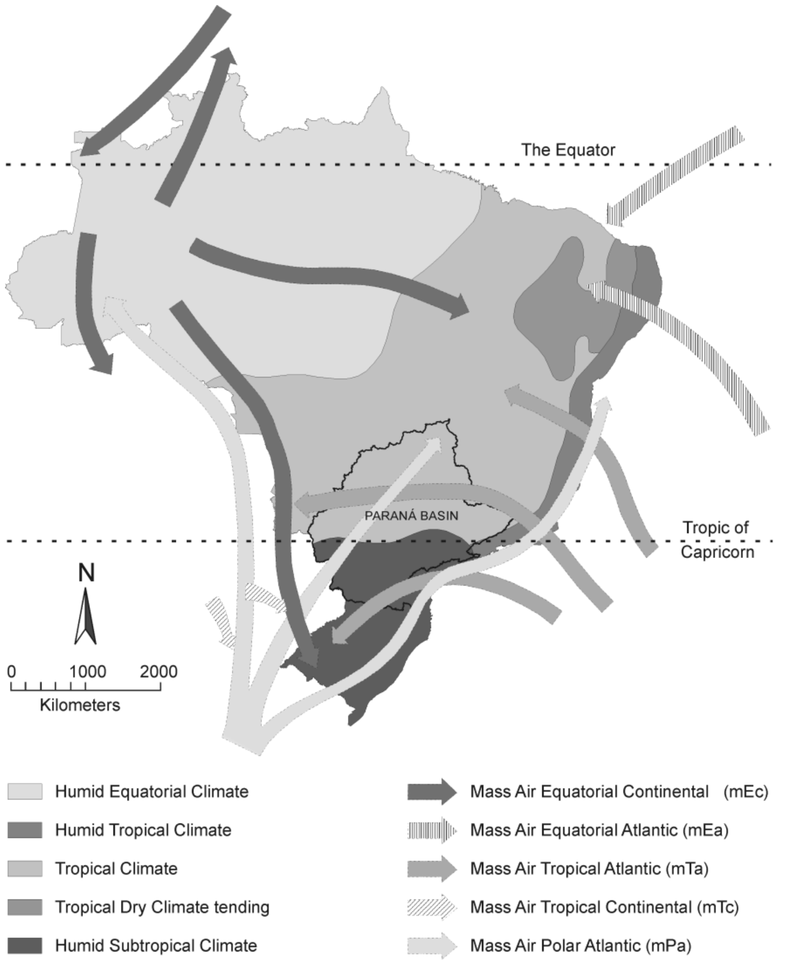
Climates controlled by Equatorial and Tropical Masses of Air

- Humid Equatorial Climate;
- Tropical Climate;
- Tropical Dry Climate tending;
- Humid Tropical Climate.

Climates controlled by Tropical and Polar Masses of Air

- Humid Subtropical Climate.

It was based on this climatic classification that Monteiro (1964, 1963b, 1963a, 1962) subsequently showed the main paths that the masses of air traverse along the brazilian territory (Figure 4), in order to demonstrate the influence of these atmospheric climate systems in the country. Continuing with his studies, Monteiro (2000, 1973) performed a clear demonstration of the action of these air masses, proposing a regional climate classification, based on the atmospheric dynamics acting in São Paulo State, in Brazil, using rain and landscape as guiding elements of his suggestion for classification of active weather in the region. In his proposal, Monteiro, besides confirming the existence of climate division demonstrated by Strahler to the region, also admitted that the division between those two major climatic groups occurs through a range of mobile transition. Such mobility is caused by the time of active masses of air in that region and spatial dynamics, and depends on the intensity of the centers of action that originate such masses, as well as, on how often they act in the region.



Adapted from: Strahler (1951) _ Monteiro (1962; 1963a; 1963b; 1964) and Mendonça & Danni-Oliveira (2007).
Organized by: Zandonadi, L. (2013).

Figure 4. Climate classification of Brazil according to the actions and influences of masses of air, highlighting the Paraná River Hydrographic Basin.

Still utilizing the element rain to perform a proposal for climate classification of genetic basis, at regional level, Zavatini (1990) and Zavattini (2009) also identified the continuation of this same line of transition between the two major climates, this time studying the Mato Grosso do Sul State.

The unification of these three climatic classification, which have the verification of the genesis of rain as the basis of their analyzes, by means of identification of atmospheric systems who originated them, was presented recently by Zavattini and Boin (2013), providing further clarification on climate setting existing within the Paraná River Hydrographical Basin. The presence of a climatic zone transition over the basin causes great pluviometric instability, which, when associated with a variation of landscape, generates greater volumes of rain in some areas and disabilities in others. This is one of the reasons because the whole central part of the basin is less watered by rainfall, since the area of higher atmospheric instability, caused by the climate transition line that separates the various active weather systems, is coincident with the area where the landscape is more flattened and present lower altitudes, generating lower interactions climate-landscape and, consequently, a decrease in orographic rainfall.

This pluviometric behavior had been verified by Zandonadi (2009) on research conducted to identify the distribution of rainfall in the Paraná River Hydrographical Basin. When using as a parameter of analysis the total annual rainfall for the period from 1976 to 2005 (Figure 5) the author concluded that the accumulated rainfall occurred exactly in the lower central region of the basin, especially near the Paraná riverbed, for both, years of habitual pattern (years that most recur throughout the analyzed series), and years considered extreme, in moments that the amount of rainfall was very high or far below what is considered normal. Another rainfall pattern observed in this study was that the highest volumes of annual rainfall is concentrated in the extreme south of the basin, due to higher influence of masses of air and polar fronts, arriving in this region more frequently than in other regions, causing a more homogeneous annual rainfall distribution. Also, when entering the basin, these masses of air and polar fronts interact with the higher altitudes of the southern landscape center, causing orographic rainfall, or, often holding the atmospheric systems for some more days, contributing to the increase in the volumes of precipitated rains.

The biggest influence of the landscape on the rainfall amount was noticed by Zandonadi (2009) at the extreme eastern, in the Serra da Mantiqueira, with the higher altitudes of the basin, approaching 3,000 m of altitude. Moreover, in this region, there must be a major action of the Atlantic Tropical Mass, which, despite being a stable air mass, once it is originates in the Atlantic Ocean, may concentrate more moisture at certain periods of the year, and can generate orographic rainfall when advance towards the continent and interact with the highest landscape.

In the same manner that occurs in the extreme east of the basin, the Atlantic Tropical Mass may also influence the highest annual precipitation, verified in the extreme north and northeast of the studied area, however, with less influence than in the extreme east, since in this region the landscape is not as sharp as in that one. In this region, the largest amounts are primarily associated with the equatorial and tropical systems, stemmed from the countryside, which act more intensely during summer and spring, when there are higher solar radiation, and consequently higher heating surface, causing major rates of air ascension, provoking large volumes of torrential rains, in a short period. On the other hand, although the masses of air and polar fronts reach this region with the lowest frequency and intensity, due to long distance and higher altitudes, they do not cease influencing the climate, and may cause frontal and even orographic rains, especially during autumn and winter, periods of greater action of these systems.

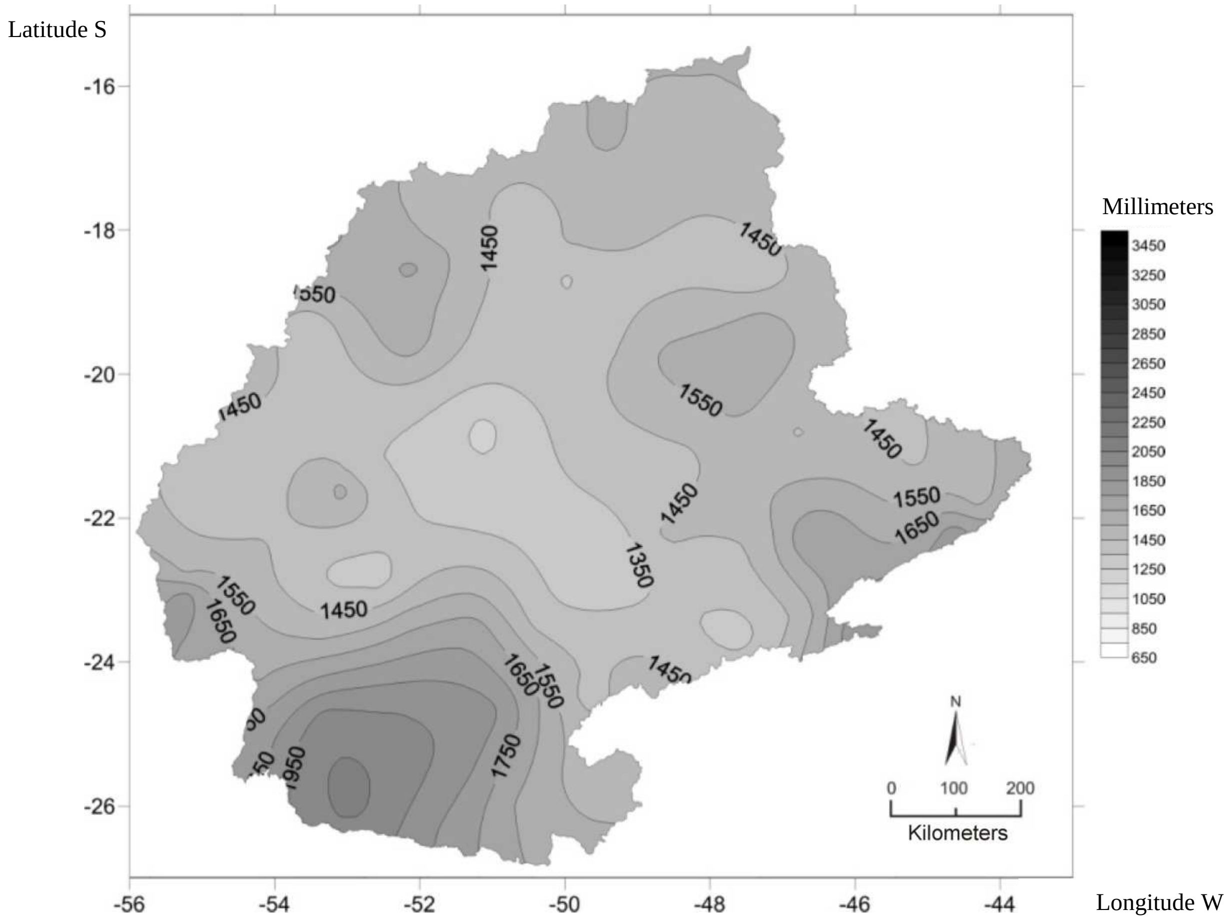


Figure 5. Mean annual rainfall distribution in the Paraná River Hydrographic Basin, in the period from 1976 to 2005.

Finally, the entire rainfall configuration shown above still has a very close proximity to the one shown by the INMET (2009), by means of the production of Brazilian Climatological Norms for the period from 1961 to 1990, demonstrating that the lowest annual rainfall average values occur exactly in the central part of the basin, increasing towards the higher areas, on their edges, and especially towards the south, where there are the highest annual average amounts.

6. Results

a) Climate indices

Observing the Table 3, it is possible to affirm that there is a consistent increase in the intensity of precipitation in most part of the Paraná River Hydrographic Basin. This increase is indicated by the SDII index (Simple Daily Intensity Index), who shows the intensity of occurrence of wet days during the analyzed period, and as we can see, only 5 of the 32 analyzed stations presented negative trends. The increase of SDII has been caused especially by increase of very wet days (R95p), extremely wet days (R99p) and moderate rains represented by R10mm and R20mm. The elevated number of pluviometric stations with positive trends for these indices clearly demonstrated this behavior. The index R1mm, number of rainy days, does not show a unique behavior. The number of stations with negative and positive trends is practically equivalent (18 negatives, 12 positives and 2 without signals of change), while for the indices R10mm, R20mm and R95p, the number of stations with positive trends increased significantly.

Table 3. Positive (light gray cells) and negative (dark gray cells) trends for each verified index in the 32 stations, from 1986 to 2011. White cells indicate the indices who did not present alterations and the highlight values (bold) represent 95% of significant level.

Pluviometric Stations	CDD	CWD	RX1day	RX5day	SDII	R1mm	R10mm	R20mm	R95p	R99p	PRCPTOT
Araxá	-0.61	0.08	0.21	0.06	0.09	0.00	0.12	0.18	8.52	2.20	8.86
Avaré	-0.09	-0.11	-0.14	-0.67	0.03	-0.32	0.00	0.01	-1.68	3.77	-1.97
Brasília	1.10	0.07	0.18	1.73	0.02	0.00	0.04	0.07	3.37	-0.70	1.59
Campo Mourão	-0.15	-0.06	-0.21	-0.29	0.05	-0.46	0.04	0.08	-0.75	-0.54	-1.98
Campos do Jordão	-0.02	0.04	0.14	1.17	**0.09**	0.57	**0.63**	**0.44**	**10.37**	0.64	**19.14**
Capinópolis	0.15	-0.02	-0.35	0.67	0.01	-0.05	0.18	0.05	0.74	1.04	1.02
Castro	-0.07	-0.07	1.06	0.23	0.05	0.29	0.29	0.28	1.61	0.81	10.28
Catalão	0.66	-0.08	-0.31	-0.66	0.06	0.07	0.26	**0.20**	2.75	1.29	6.78
Catanduva	0.13	-0.03	-1.03	-1.61	-0.04	-0.15	-0.32	-0.20	0.90	-3.02	-5.72
Curitiba	-0.22	-0.03	0.69	0.27	0.08	0.20	0.39	0.22	**7.32**	2.04	11.96
Formosa	0.86	-0.01	-0.18	-0.30	-0.03	-0.08	-0.26	-0.07	1.50	0.20	-3.51
Franca	-0.11	-0.05	-0.32	-0.40	0.03	0.39	0.18	**0.22**	2.18	-1.24	8.86
Goiânia	0.59	-0.02	0.91	0.55	**0.07**	-0.18	0.11	0.04	3.00	4.39	5.38
Guarulhos	0.23	0.04	-0.01	0.02	0.01	-0.15	-0.18	0.02	3.67	2.31	-1.24
Ipamerí	0.61	0.06	-0.07	0.02	0.02	-0.12	0.05	0.20	-1.47	0.14	1.09
Iratí	-0.19	0.01	-1.10	0.52	0.02	0.18	0.14	0.22	-0.27	-0.12	4.73
Ituiutaba	-1.10	0.10	-0.34	-1.01	-0.02	0.45	0.11	-0.02	4.22	-0.09	5.26
Jataí	0.03	-0.09	0.19	0.81	0.02	-0.20	-0.15	-0.11	4.03	1.60	-1.77
Juiz de Fora	0.12	0.17	0.71	0.56	0.11	0.57	**0.58**	0.43	**11.29**	**6.37**	**19.79**
Lavras	-0.88	0.12	-0.48	-0.09	0.04	-0.18	-0.13	0.10	0.75	-2.10	0.66
Londrina	-0.94	0.15	1.54	2.57	0.03	0.50	0.18	0.19	5.04	3.90	12.45
Maringá	-0.23	-0.05	0.31	0.06	0.04	-0.11	0.05	0.08	-2.82	2.79	1.85
Paracatú	1.41	0.05	-0.37	0.63	0.09	-0.11	0.06	0.21	5.16	-0.68	5.16
Pirenópolis	0.41	-0.08	-0.15	-0.45	0.05	-0.13	-0.04	0.09	1.88	-0.30	2.41
Presidente Prudente	0.30	-0.09	-0.33	1.62	0.03	0.03	0.04	0.08	3.48	-1.99	3.47
São Carlos	-0.22	-0.11	0.08	-1.47	-0.01	-0.04	-0.13	-0.12	2.76	-0.10	-1.30
São Lourenço	0.42	0.01	0.40	1.83	-0.01	0.04	-0.05	0.08	-0.35	-1.34	-0.76
São Paulo (Mirante de Santana)	0.40	0.02	0.17	-0.16	**0.09**	-0.46	-0.08	0.08	3.17	-0.16	2.84
São Simão	-0.05	0.01	0.18	1.18	0.03	-0.11	-0.27	0.11	**10.02**	2.70	1.94
Uberaba	0.07	-0.08	-0.47	0.13	0.10	-0.08	0.20	0.31	3.65	-0.75	9.19
Unaí	0.56	0.04	-0.08	-1.90	-0.05	-0.41	-0.11	-0.06	-8.60	-2.12	-11.25
Votuporanga	0.64	**0.15**	0.77	2.61	0.03	0.15	0.02	-0.05	**9.16**	3.42	5.63

From the index R99p, the number of stations with positive trends tends to reduce, however, still remains with higher number of stations with positive trends. The increase in wet days and more intense rainfall directly reflect in the increase of the total annual rainfall, as shown in the PRCPTOT index, where the majority of the stations (23 with positive trends) presented an increase in total annual pluviometric amount. In some cases, the increase in the PRCPTOT index was significant, as observed in the stations Campos do Jordão and Juiz de Fora, who presented positive trends of 19.1 mm/year and 19.8 mm/year, respectively. Besides the increase in the annual amount of rainfall, RX5day index also showed that there were more events of monthly rainfall recorded on consecutive days, especially up to 5 days. This increase in wet days is probably directly related to the increase in intense rainfall recorded.

The results described above confirmed the actual alterations in rainfall for various stations. However, these analyzes did not enable to know exactly what are the areas of the basin in which these changes are occurring, and, in order to support this understanding, maps representing the spatial distribution of trend values were prepared. These maps are shown in Figure 6.

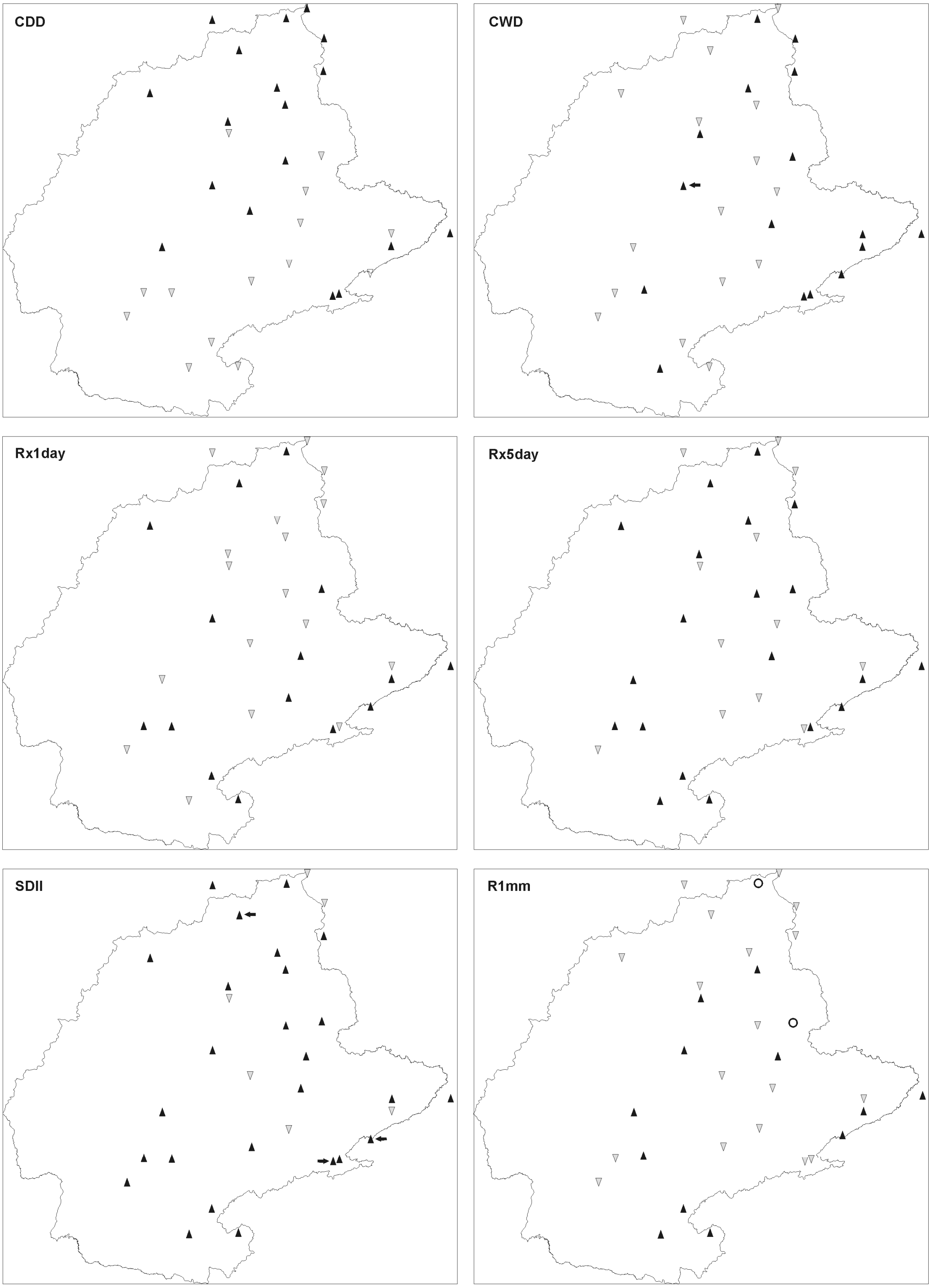
It is important to highlight that, even after the production of maps, it was difficult to establish a spatial pattern for each rainfall, given the heterogeneity shown by the values of trends over the study area. However, one more time it was possible to clearly recognize that there are alterations in the pluviometric behavior. On the map of the CDD index, for example, it is possible to see that the entire southern region of the basin showed declining trends of consecutive dry days, and this pattern is exactly the opposite of what occurs in the northern region of the basin, where trends indicate an increase in consecutive dry days. These patterns are somehow understandable, since the south of the basin is more influenced by the Pacific Polar mass and by Frontal Systems, which, when invade the region with more intensity throughout the year, can be responsible for rains that are distributed more homogeneously temporally, reducing the chances of occurring prolonged dry periods. On the other hand, in the northern region, more influenced by Topical and Equatorial masses, rainfalls tend to be more massive, but of short duration, since they are primarily generated by the intense convection of air caused by higher temperatures throughout the year.

For the CWD index, which represents the occurrence of consecutive wet days with rainfall higher than 1 mm, the only spatial pattern is noticed in the eastern region of the basin, exactly where are the most complex topography and highest landscapes of the study area. The interaction with the landscape can also be essential for the occurrences of wet days, once this is a region that is often influenced by the Atlantic Tropical Mass, of oceanic origin, carrying a lot of moisture. Evidence of trends of decreased in occurrence of consecutive dry days (CDD) presented for the southern region, as well as increasing trends of consecutive wet days (CWD) into the eastern region, can be done through the interpretation of the Rx5day index, of trend of occurrence of 5 consecutive days of rain, since it shows that the two regions had a decrease in the numbers of dry days and an increase of wet days. The SDII index that shows the intensity confirms this statement, which, incidentally, showed increases of the trends not only for the southern and eastern regions, but for almost the entire study area.

The calculated index used to show the values of trends for total annual precipitation (PRCPTOT) indicated that there was an increase in extreme rainfall for the eastern region. Comparing the trends shown by the PRCPTOT index with the R1mm, R10mm, R20mm, R95p and R99p, it is clear that the increases in rainfall in the eastern region were mainly caused by the increase in extreme rainfall events, especially those above 95th percentile (95p). The rainfall above R99p had also great impact, but with less participation than the 95p. Despite rainfall above 10 mm and 20 mm have increasing trends of less significant occurrence, they also contributed to the total annual rainfall to be higher in this region.

Contrary to what occurred in the eastern part of the basin, the significant increase in annual total wet-day precipitation (PRCPTOT) of most part of the southern region is not that significant when compared with the increases in extreme rainfall (R95p and R99p), but with less intense precipitation, mainly over 10 mm and 20 mm. Such behavior can be directly influenced by the greater temporal homogeneity of rainfall in this part of the basin, attributed to the actions of more constant Polar Mass and Frontal Systems.

The trends in significant increase in total annual rainfall in north-central sector of the basin are also related to higher rates of heavy rain, mainly above 95p, as well as to the highest event of rainfall above 10 mm. On the other hand, the northern extreme showed trends of rainfall declining, caused mainly by the reduction in the occurrences of less intense rainfall and, in some cases, in rainfall over 95p.


CDD
CWD
Rx1day
Rx5day
SDII
R1mm

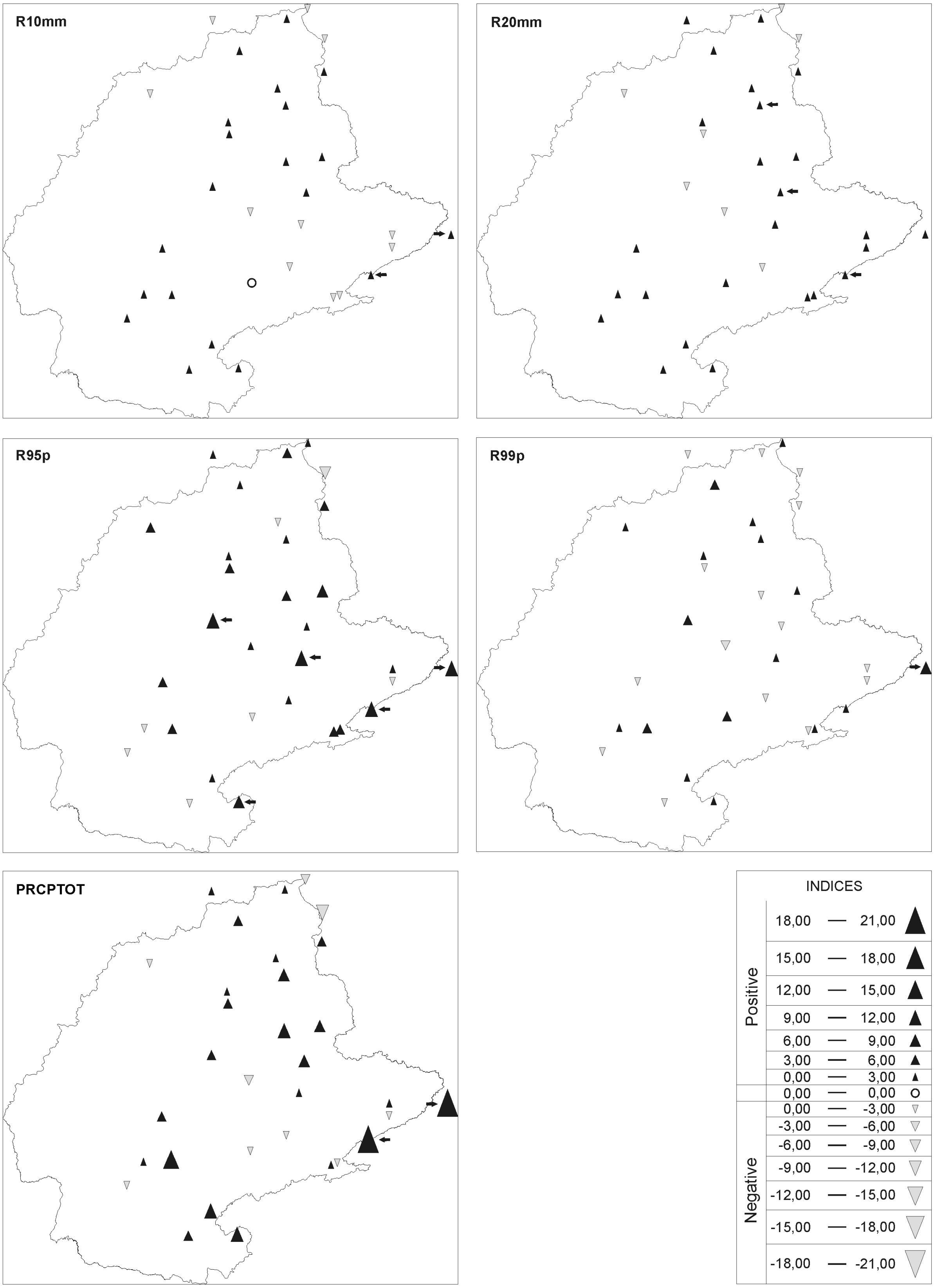


Figure 6. Spatial distribution of positive (light gray triangles) and negative (dark gray triangles) trends of 11 climate indices, calculated for the 32 pluviometric stations, in the period from 1986 to 2011. The size of the triangles indicate the intensities of variation of trends, both positive and negative. The white circles represent the indices that showed no significant differences in trends. The black arrows indicate the stations with more than 95% of significant level.

b) Heavy precipitation impact

One of the major problems of large brazilian towns are the damages caused by floods and inundations, which is directly related to the very intense rainfalls and can be responsible for diverse socioeconomic impacts. The prediction of when and with what amount these rains will happen is not easy, however, the knowledge of the pluviometric limits able to cause the greatest impacts may ensure that more effective actions and planning are implemented, minimizing the effects caused by extreme rainfall in the urban environment. To select these pluviometric thresholds from 1986 to 2011 we have classified by percentiles, the rains of two large Brazilian towns, the municipalities of Curitiba and Goiânia, both located in the Paraná River Hydrographic Basin, and each representing one distinct climatic region.

It was possible to study only these two locations because there are not many scientific literature on this analysis. Most of the analyzed series are unpublished. It is the first time that were studied. Curitiba and Goiânia are the only two big town with a good scientific research and situated in two different climate area where the flood and the inundations were studied in detail and were calculated the values of threshold that trigger these events.

The municipality of Curitiba is located in the southern of the basin, a region where the climate is mainly controlled by Tropical and Equatorial Air Masses. Therefore, once they are mainly associated with these systems, rainfalls are most often frontal, and depending on the atmospheric conditions and the interaction with the landscape, lasting several days. Furthermore, the increased presence of these systems lead to a better distribution of the rain throughout the year.

Unlike Curitiba, the municipality of Goiânia, is located in the northern part of the basin, a region where the climate is controlled by Equatorial and Tropical masses of air, and the distribution of rain is not as well spread throughout the year, since there is, in this region, a period when rainfall is more intense (spring and summer) and another that it is more scarce (autumn and winter). Moreover, in Goiânia, there are more torrential types of rainfall, which may present very expressive amounts of rain, in short periods of time. This is a very common type of rain in some areas of the basin, since the presence of higher temperatures, which causes the ascension of air and evaporation, is more intense, favoring the formation of large clouds heavily laden with moisture that are often associated to very intense storms.

According to research conducted by Cunico et al. (2002) and Zanella (2006), the most problematic cases related to floods and inundations in the municipality of Curitiba, occurred due to amounts of rainfall that exceeded 60 mm. However, both authors point out that there were already cases of impacts caused by lower volume of rainfall, especially when the sums of these smaller amounts occurred in daily sequences till reach 60 mm.

The threshold, 60 mm, for the municipality of Curitiba corresponds to 98th percentile of daily rainfall, calculated from 1986 to 2011. This value is classified as extreme rain highlighted by R99p and observing its trend, 2.04 days/year, it is evident as during the years the probability of floods increases. Furthermore, it was observed that the highest rainfall amount recorded in this town, for a single day, was 146.2 mm, *i.e.*, two times higher than the value recorded as responsible for impacts. According to Hack (2002), in most cases, volumes of rainfall equal to or above 100 mm, in 24 hours, assume a character of calamity in the municipality of Curitiba.

In the same period, the municipality of Goiânia presented a situation even more problematic that for Curitiba, since, according to Correntino (2007), disorders were record by floods whose amount of rainfall was only of 41 mm. This value corresponds to 94th percentile well represented by R95p index. Also for this location the trend of index is positive, 3 days/year. Observing the behavior of the indices more problems for the populations may be caused by R99p with a positive trend equal to 4.39 days/year. For the extreme rains were recorded values quite high, and the maximum amount of a single day was 136.6 mm, two times higher than the volume required to provoke inconvenience to the people.

Thus, associating the historic of flood events with the calculation of percentiles, for both municipalities, Curitiba and Goiania, it was possible to realize that the results are negative related to the possibilities of appearance of new cases of flooding in these towns. The problem becomes even more disturbing when the results of calculations of climate indices, presented previously, showed strong increasing trends in totals annual rainfall for these two municipalities. Considering Curitiba, this increase in annual rainfall is mainly conditioned to larger trends of rainfall events of greater intensity, above 95th percentile. For Goiânia, the recorded intensities of rainfall were even higher, with increasing trends in volumes, above 99th percentile and according to IBGE (2012), one should also consider that Curitiba (1,776,761,000 inhabitants) and Goiânia (1,333,767,000 inhabitants) are large municipalities, with very dense urban areas subject to a phenomenon known as “Heat Island” (Lombardo 1985), which causes increasing in temperatures and, consequently, enhancement in precipitation.

7. Conclusions

A set of 32 daily cumulated precipitation series from meteorological stations, homogeneously distributed over the Paraná River Hydrographic Basin, was analyzed. Data underwent a quality control procedure in order to filter the influence of non-climatic factors. Climatic indices demonstrated that in some regions the increasing trends in rainfall amounts were significant. While there is no spatial pattern in the distribution of these trends, it is clear that in large part of the basin there are significant increases in total annual rainfall, and this increase is correlated mainly to heavier rainfall.

The difference between the trends of increase and the reduction of rainfall is visible, since the values of each climate index clearly indicated the occurrence of larger amount of rain. Only at the extreme north of the basin decreasing trends of rainfall are more pronounced. In other areas, such as the center of the basin, there were weak trends of reduction in rainfall, however, it is difficult to affirm if there is a spatial distribution pattern, since not all indices corroborate this statement.

These results are relevant for climate change impacts and vulnerability assessment over Brazil. In fact, the correlation of percentiles calculations with historical surveys of flood, conducted to Curitiba and Goiânia, demonstrated that it was common to record precipitation amount well above those who already caused damage for the population of both municipalities. If we consider that the increasing trends of heavy rainfall observed for these two towns were strong, the problems can become even more alarming. Moreover, both municipalities have intense urban and population growth, which can aggravate the situation, if there is no correct planning for such expansion.

On the other hand, we understand that, despite the results have clearly pointed to an increase of rainfall in most part of the basin, this research needs to be improve, since the lack of pluviometric stations in some regions may influence the identification of a spatial pattern of trends presented by the analyzed climate indices. Moreover, the data utilized presented lacks that may influence the analyzes, and their improvement would be essential for next investigations, in order to confirm or not the obtained results. According to the INMET, which provided the data used in this research, most of the lacks in the data series for various stations was caused by problems in the database and not at the time of collecting the information for each climate variable. This problem is in correction processes, which shall remedy such deficiencies or at least improve parts of them. Thus, it is expected that soon such information is already available to society and that other researches can be carried out with longer data series and more quality, so the results presented here can be compared, ensuring greater reliability.

Anyway, this contribute is essential to improve the understanding of the brazilian climate and can bring considerable clarification related to its dynamics and alterations. The results of this research will be indispensable tools for the management and planning of Brazil, an economically emerging country that, due to its large size, has different climates and many problems caused by the strong climatic variability in its territory.

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