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An update on the rainfall characteristics of Brazil: seasonal variations and trends in 1979–2011

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ABSTRACT: We studied rainfall characteristics of Brazil for the period 1979–2011. This is an update for an earlier study with data from 1958 to 1978. We compared the three consecutive wet and dry months in the two data sets. In the northern most part rainy season earlier was in April to July and now it is occurring later. In a large part of the south central region the rainy season in austral summer and dry season in austral winter did not change. However, to the east of this region rainy season in the latter data occurs earlier. Calculation of linear tendencies showed, that over the northern Amazon region there is a significant increase of rainfall. This agreed with previous results. Over this region dry season is becoming drier and wet season wetter. In the west of Northeast Brazil (NEB) there is an increase of rainfall. In southeast Brazil there is a region of highly significant decrease of rainfall in both wet and dry seasons. This is confirmed in our analysis on river discharges in Sao Paulo and Minas Gerais states. The negative tendencies in rainfall have great impact on the hydroelectric generation not only in this region but also at the national level because the hydroelectric dams furnish energy on a national level. The increase in rainfall in Northern Amazon is probably associated with Atlantic warming that resulted in higher moisture transport from east. The decrease of rainfall in southeast Brazil seems to be associated with the plummet of rain producing systems from south due to increase of mean sea level pressure in the south.

KEY WORDS rainfall over Brazil; tendencies of rainfall over Brazil; river discharges in Brazil

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1. Introduction

Brazil has continental dimensions and so, has various rainfall regimes. More than two decades ago, Rao and Hada (1990) discussed rainfall characteristics of Brazil using 21 years (1958–1978) of data. On the basis of rainfall seasons, Brazil can be broadly divided in five regions: Amazon, Northeast Brazil (NEB), Central West Brazil, South East Brazil and South Brazil. Here we combine South East and Central West Brazil into one region now referred to as South Central Brazil. The period November to April constitutes the rainfall season of the Amazon region. Regarding the spatial distribution of precipitation, Amazon has four centres of maximum measure (Marengo and Nobre, 2009). One of them is located in the Northwest with precipitation greater than 3000 mm per year. This centre is associated with the westward moisture flux, as easterly trade winds from the Atlantic are forced to rise because of the Andes Mountain in the west. The second centre is located in the central parts of Amazon around 5°S with rainfall of around 2500 mm per year. The third centre is located in the southern parts of the Amazon, probably in part due to the South American Monsoon. Also there is a fourth centre near Belem (1.45°S, 48.47°W) with an annual precipitation of 4000 mm. The rainfall season of the northern parts of the basin occurs in the boreal summer of June-July-August, whereas for the southern parts it is in austral summer December-January-February (Rao and Hada, 1990). Reboita *et al.* (2010) suggested some of the mechanisms which cause rainfall in this region as Mesoscale Convective Complexes, local convection and upper level lows. Amazon region is the source of moisture for southern parts associated with transport of moisture by the Low Level Jet (Rao *et al.*, 1996; Marengo *et al.*, 2004) called South American Low Level Jet (SALLJ).

Regarding inter-annual variation, Amazon region exhibits large variability in rainfall causing impacts on social and economic aspects of the region. In general, inter-annual variations are associated with the occurrence of El Niño or La Niña. During the years of La Niña the rainfall tends to increase. However, it was observed that droughts during certain years were not associated with El Niño. In the Amazon basin, studies on the tendency of rainfall using the rainfall series and the river flow data as proxy to rainfall produced conflicting results (Gentry and Lopez-Parodi, 1980; Chu *et al.*, 1994; Depaiva and Clarke, 1995; Marengo *et al.*, 1998; Chen *et al.*, 2001; Marengo, 2004), probably because of the use of short and different period data. In a recent article, Satyamurty *et al.* (2013) studied the 2012 record flood in the Amazon basin. They used the annual range of River Negro water level (the difference between the peak and lowest level) for the

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period 1904–2012. From 1904 to late 1960 there was no significant trend, but since 1970 there is a strong positive trend. Because the river level range is a function of rainfall amount in the rainy season, we can expect a positive trend in rainfall in recent years (Espinoza *et al.*, 2013).

The NEB region spreads across the extreme northeast Brazil to the east of Amazon, approximately to the east of 47°W and to the north of 18°S. In this region rainfall is modest with an extensive semi-arid area (Rao and Hada, 1990). Strang (1972) and Rao and Hada (1990) showed that a large percentage of rainfall occurs for 3 months in this region and can be broadly divided into three parts: the central part with March, April and May, eastern part with June, July and August and the southern part with December, January and February as the rainfall seasons. Inter-annual variability in this region is basically related to the occurrence of El Niño or La Niña (Hastenrath and Heller, 1977; Polzin and Hastenrath, 2014) and the dipole in the Atlantic Ocean (Moura and Shukla, 1981). El Niño is generally associated with droughts and La Niña with heavy rainfall. Moura and Shukla (1981) showed that the simultaneous occurrence of warm (cold) waters in the North Atlantic and cold (warm) waters in south Atlantic provokes droughts (floods). However, Hastenrath and Greichar (1993) suggested that the inter-hemispheric gradient of sea surface temperature (SST) rather than the dipole is related to precipitation variability in the region. They suggested that this gradient of SST controls the position of Inter-Tropical Convergence Zone (ITCZ), which is the main cause of rainfall in this region (Reboita *et al.*, 2010). Andreoli and Kayano (2006) suggested the role of Walker circulation and extra-tropical teleconnections in inter-annual variations of rainfall. The rainfall in the eastern part of NEB is associated with the easterly waves in the South Atlantic Ocean coming from the East (Yamazaki and Rao, 1977; Rao *et al.*, 1993). Regarding the recent trends of total rainfall in NEB, some studies have found positive trends (Hastenrath and Greichar, 1993; Marengo *et al.*, 1998; Rao *et al.*, 2006; Oliveira *et al.*, 2014).

The central parts of Brazil (as mentioned earlier this region includes the customary South East and Central West Brazil) are characterized by 6 months of rain during the austral summer followed by 6 months of scanty rainfall in austral winter, the main characteristic of a monsoon region. For a long time this region was not considered to have a monsoon regime because there was no seasonal wind reversal (Ramage, 1971). However, recent analyses with better quality-data showed an annual reversal in the wind when the annual component was removed (Zhou and Lau, 1998). The characteristics of South American Monsoon System have been described in several recent studies (Marengo *et al.*, 2001; Gan *et al.*, 2004, 2006; Vera *et al.*, 2006; Bombardi and Carvalho, 2009; Reboita *et al.*, 2010 and Marengo *et al.*, 2013). Herdies *et al.* (2002) and Rao *et al.* (1996) showed that the moisture transport from the Amazon is the main source of rainfall in central parts of Brazil. Collini *et al.* (2008) and Grimm *et al.* (2007) discussed the role of soil moisture in these regions. Mechoso *et al.* (2005) concluded that the continental mass, topography and SST control the characteristics of Monsoon Regime. In a recent study, Rao *et al.* (2014) using the wind data to define the beginning and end of the rainfall in central part of Brazil (Gan *et al.*, 2004), showed that the duration of South American summer monsoon is extending. Extreme rainfall events in this region occur when the South Atlantic Convergence Zone (SACZ) is strong (Carvalho *et al.*, 2002). Carvalho *et al.* (2002) also found that more extreme events are seen during El Niño than La Niña.

South Brazil is characterized by well distributed rainfall throughout the year (Liebman and Mechoso, 2011), although in the North, rainfall tends to reach a maximum in austral summer. Rao and Hada (1990) found that rainfall in this region has strong connection with the occurrence of El Niño or La Niña with high (low) rainfall in El Niño (La Niña). This is consistent with what was found in other studies such as Grimm *et al.* (1998, 2000) and Pscheidt and Grimm (2009) who noted that the extreme rainfall events occur in El Niño years. For Southern Brazil, Reboita *et al.*, 2010 attributed the weakly distributed precipitation to transients systems such as cold fronts, extra tropical cyclones, cut-off lows, upper tropospheric trough, mesoscale convective systems, inverted comma clouds and atmospheric blockings.

In a recent study, Haylock *et al.* (2006) discussed the trends in total and extreme rainfall events in South America during the period 1960–2000. They found a shift towards wetter conditions in South Brazil. They related this shift to dominating El Niño conditions with a general lowering of Southern Oscillation Index (SOI). This trend of lower SOI also contributed to a more northward location of ITCZ causing lower rainfall in NEB, the Amazon basin and a South Eastward shift in the SACZ. However, in this study the authors used smaller number of stations in Brazil (their Figure 7), and a large part of Central Brazil was omitted. Although they used a large number of stations (354) in eastern Brazil, majority are located in São Paulo State only. With this set of stations they found a shift to wetter conditions in southeast and drier conditions in northeast, this change again they attributed to the change in SOI.

In this study we used a very high density network of rainfall series for Brazil for the period of 32 years (1979–2011). Thus this study uses more than a decade of recent data compared to Haylock *et al.* (2006). In the previous study of Rao and Hada (1990) the authors used rainfall data for a period of 21 years (1958–1978). Thus in this analysis we propose to see what changes have taken place since 1978. An analysis of the impact of rainfall trend on river discharges and hydroelectric generation is also performed.

2. Data and methodology

We make use of Climate Research Center (CPC) gauge based analysis of global daily precipitation (ftp://ftp.cpc.ncep.noaa.gov/precip/CPC_UNI_PRCP/GAUGE_GLB/V1.0/) for a period of 26 years from 1979 to

2005 and (ftp://ftp.cpc.ncep.noaa.gov/precip/CPC_UNI_PRCP/GAUGE_GLB/RT/) from 2006 to 2011 with 0.5° lat. 0.5° lon. horizontal resolution. In CPC a suite of unified precipitation products are created with consistent quality, quality improvement being done by combining all sources of information available at CPC, by taking advantage of the optimal interpolation and objective analysis techniques. Time tendencies were calculated from the yearly totals and the significance was calculated by using Student's *t*-test.

Precipitation data was also obtained from stations in Brazil from Instituto Nacional de Meteorologia (INMET) for the period 1979–2011 (available in http://www.inmet.gov.br).

In the study of Rao and Hada (1990) there were some sparse data regions, therefore caution should be exercised during the comparison (see their Figure 1). There was a data sparse region around equator between 60° and 55°W and another around 15°S between 60° and 50°W. In general, Eastern Brazil is represented with a dense network of stations. In this study the CPC data with 0.5° lat. 0.5° lon. horizontal resolution cover all the areas of the country.

For the sea level pressure we used the NCEP/NCAR reanalysis obtained from the site: http://iridl.ldeo.columbia.edu/SOURCES/.NOOA/.NCEP-NCAR/) with 1.9047°lat. × 1.875°lon. horizontal resolution. We also utilized monthly SST from the site: http://iridl.ldeo.columbia.edu/SOURCES/.NOOA/.NCDC/.ERSST/.version3b/.sst/ with 2°lat. × 2°lon. horizontal resolution.

Data of river discharges were obtained from Operador Nacional do Sistema (http://www.ons.org.br/operador/vazoes_naturais.aspx).

3. Results

This study and that of Rao and Hada (1990) use different data sets. Thus, statistical comparison between these data is important to give us confidence of the results. Rao and Hada (1990) used observed data from INMET for the period 1958–1978. Unfortunately we do not have access to this data set. For comparison of data of CPC with that of observed data, we use available data from INMET (1979–2011). Figure 1(a) shows scatter diagram of the mean, first and third quartiles (left, middle and right column) of the annual and trimestral INMET and CPC precipitation (mm) values for the five geographic Brazilian regions. The monthly data series are for the period of 1979–2011. Figure 1(b) shows the histogram of mean, standard deviation, first and third quartiles of the annual and trimestral INMET and CPC precipitation (mm) values grouped into the five geographic Brazilian regions. In Figure 1(a) the Correlation Coefficient (C.C) and R^2 are also given. The high correlation coefficients more than 0.9 show that rainfall variability between two data sets in all the five regions is in good agreement. The scatter is a little wider in the Austral summer, December, January and February.

In Figure 1(b), the histograms also show good agreement between the two data sets. In the first quartile generally high values are seen for the North region except for June-August and September-November. As is well known the annual and seasonal means of precipitation in North East Brazil are low. Also the standard deviation is high in this region in the principal rainy season (March, April and May) showing higher variability. Thus, there is a good agreement between CPC and INMET data in the main regions of Brazil for the mean annual, quartiles and the trimesters. This gives confidence that the rainy and dry seasons determined later are actually changing but not just a result of using different data sets, i.e. CPC and observed data.

We determined 6 months of rainy periods and 6 months of dry periods for Brazil to show that the precipitation pattern of the six wettest months over large part of Brazil is similar to the climatology, although in some regions the rainy season has a shorter period, such as for NEB. Figure 2(a) and (b) show the rainy and the dry months, respectively. In Figure 2(a) it can be seen that a large part in Central Brazil is characterized by 6 months of rainy season from October to March. This result agrees with Gan *et al.* (2004) who found that 90% of the precipitation over the Central West Brazil occurs from October to April. As one moves northwards the onset of rainy season is delayed, now observed in January and lasting till June. A small portion in the west of this region has rainy season in February to July. North of the equator the rainy season occurs in the boreal summer months (from March to September), but in the eastern part of NEB rainy season occurs a few months earlier (June, July and August). In the central part of NEB, the rainy season is from December to May, towards the east the wet period is from March to July. In the southeastern sector of southern Brazil the wet period is from May to October and in western and northern sectors through September to February. Figure 2(b) shows that for a large region in Central Brazil the dry season is in austral winter during the months of April to September. The dry season occurs later as we move North ward. In South Brazil although there is no clear dry season, the dry 6 months are from March to August over northern and western sectors and from November to April over southeastern sector. Although many of these aspects are already known from the earlier studies, here we discussed them for the sake of completeness and also to see if there are any changes in recent years.

Figures 3(a)–(c) show the annual rainfall, the consecutive six rainiest and six dry months, respectively. These six rainy and dry months are the same as in Figure 2(a) and (b). In the annual rainfall distribution, rainfall (Figure 3(a)) is in maximum measure in northwest Brazil and then rainfall decreases towards the east. The isohyets have a clear northwest to southeast inclination showing the importance of SACZ in the rainfall distribution. In South Brazil there is high rainfall and in NEB with a central region of about 600 mm. The distribution of six rainy months is similar except that the rainfall is high. In the six dry months there is a large region with rainfall less than 150 mm in NEB

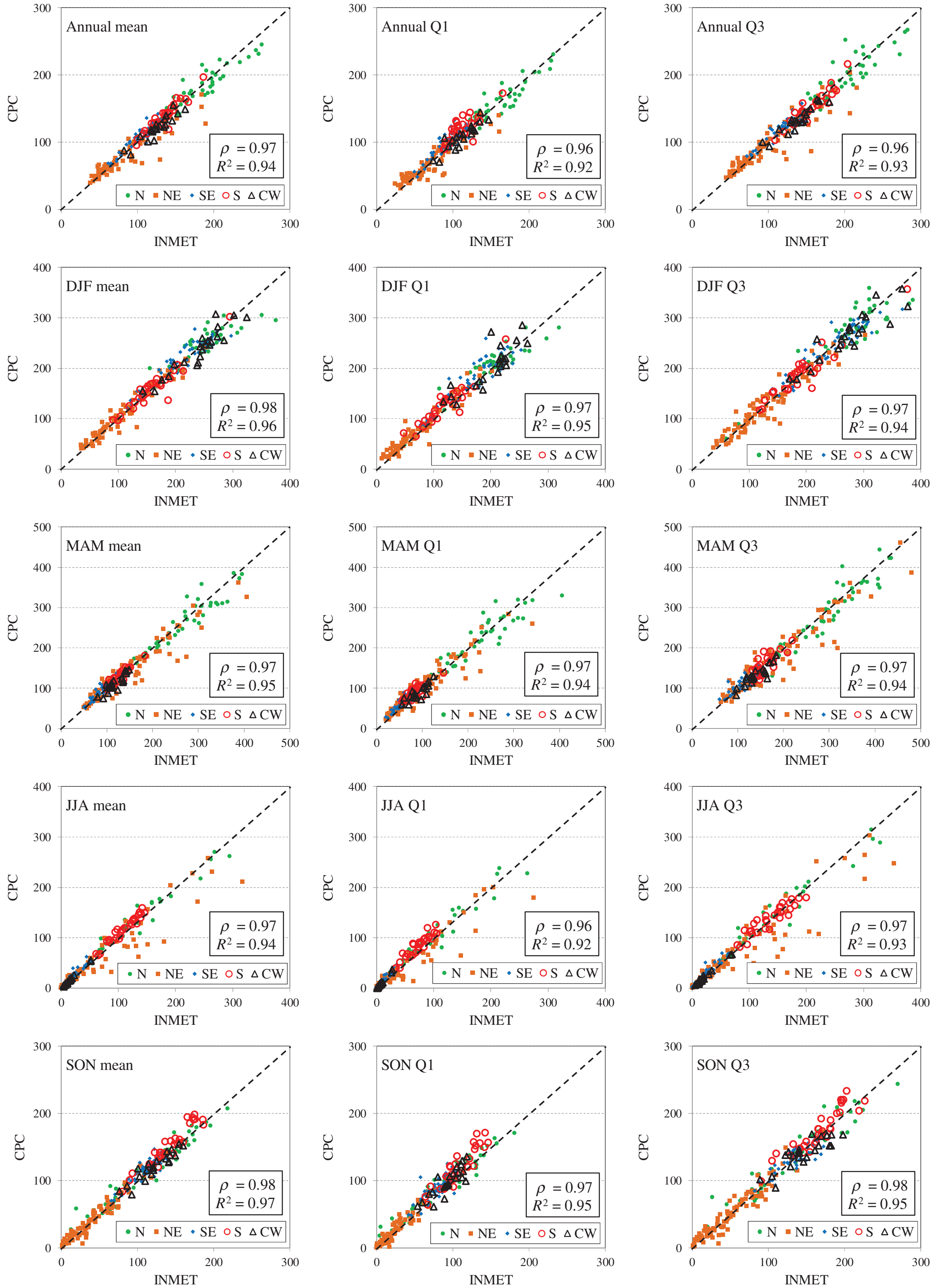

Figure 1. (a) Mean, first and third quartiles (left, middle and right column) of the annual and trimestral INMET and CPC precipitation (mm) values for the five geographic Brazilian geographic Brazilian regions. (b) Mean, standard deviation, first and third quartiles of the annual and trimestral INMET and CPC precipitation (mm) values grouped into the five geographic Brazilian regions. The INMET and CPC monthly data series are from the period 1979 to 2011.

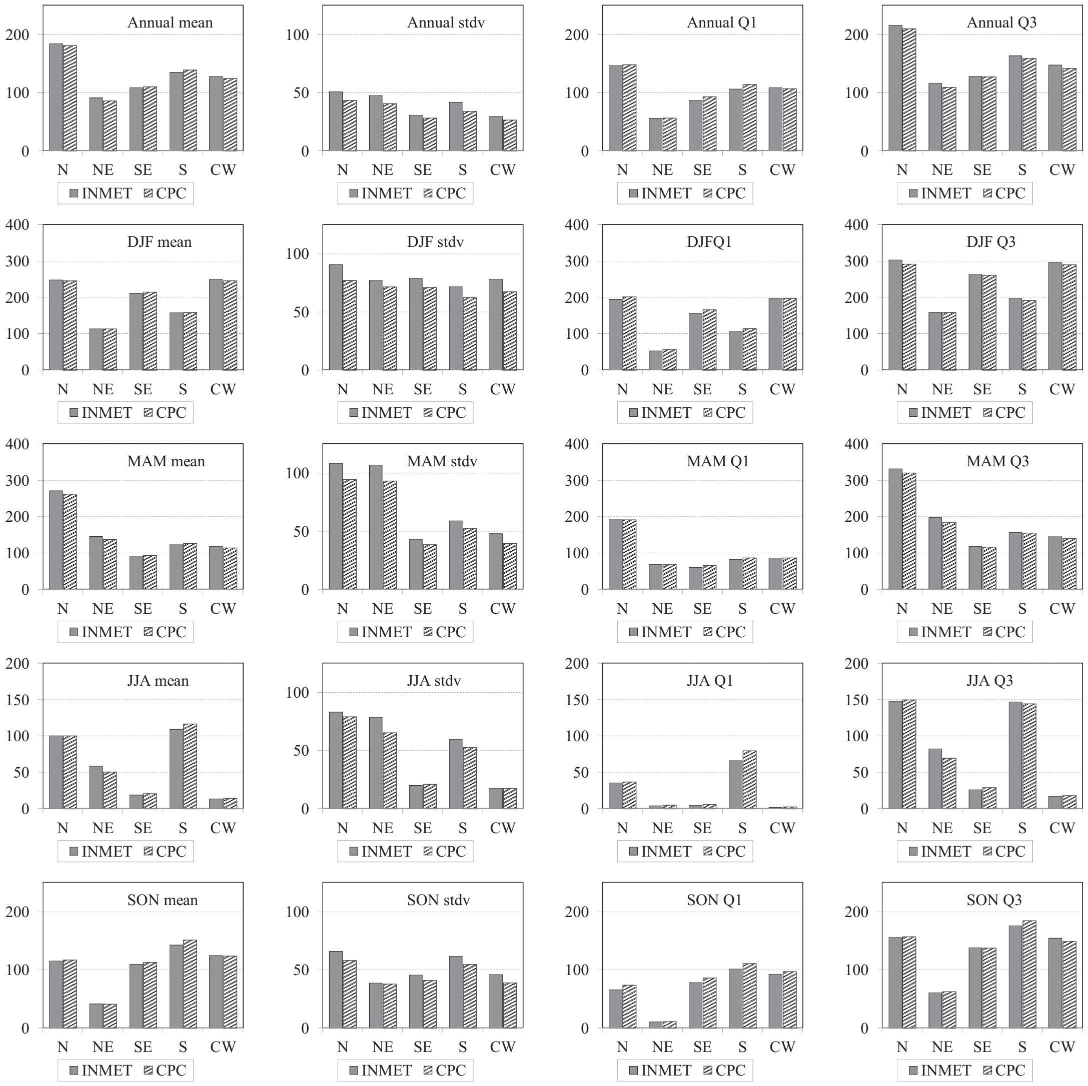

Figure 1. Continued

extending further south. Rainfall is highest in the Northwest varying between 900 and 1200 mm, decreasing again in the northwest to southeast direction. South Brazil has rainfall varying between 600 and 900 mm in rainy season, as showed by Liebman and Mechoso (2011).

In an earlier study, Rao and Hada (1990) determined three consecutive rainy and dry months. Here we compare these with the present data to find out what changes have occurred since 1979. Figure 4(a) gives the three rainiest months in the earlier (white lines) and this study (coloured). In the northern most part, earlier the rainy season was through April to June but now, it has been delayed to May-June-July (yellow sector). In most of the regions of the Southeast, rainy season occurred in February-March-April in the earlier data but now seen in January-February-March in its western sector. Further south the rainy season occurs earlier (January-February-March) in both data sets. South of 10°S in a large region of the west in both data sets, the rainy season occurs in December-January-February. To the east of this region the rainy season in the recent data occurs earlier (November-December-January). Further south, some small regions have varying rainfall seasons. In South Brazil there is a large variability in the three wet months. Over the western sector the wet season is through September to November in both data sets. In earlier data, in the Southeastern sector, the rainy season was during July-August-September but now it preceded that to April-May-June. Wet season in the central region earlier was through January to March but now shifted to June-July-August in eastern sector and February-March-April in western sector of the central region. This discrepancy occurs because the annual cycle of the precipitation does not show a definite rainy or dry season. As there is inter-annual variability in precipitation depending on the period studied, the three rainy months can change.

Regarding the three dry months, in a large region the dry season remained the same (June-July-August) in both the data sets, indicating no change. To the South, in the earlier data the dry season was in July-August-September, further south it was March-April-May. Now in South Brazil the

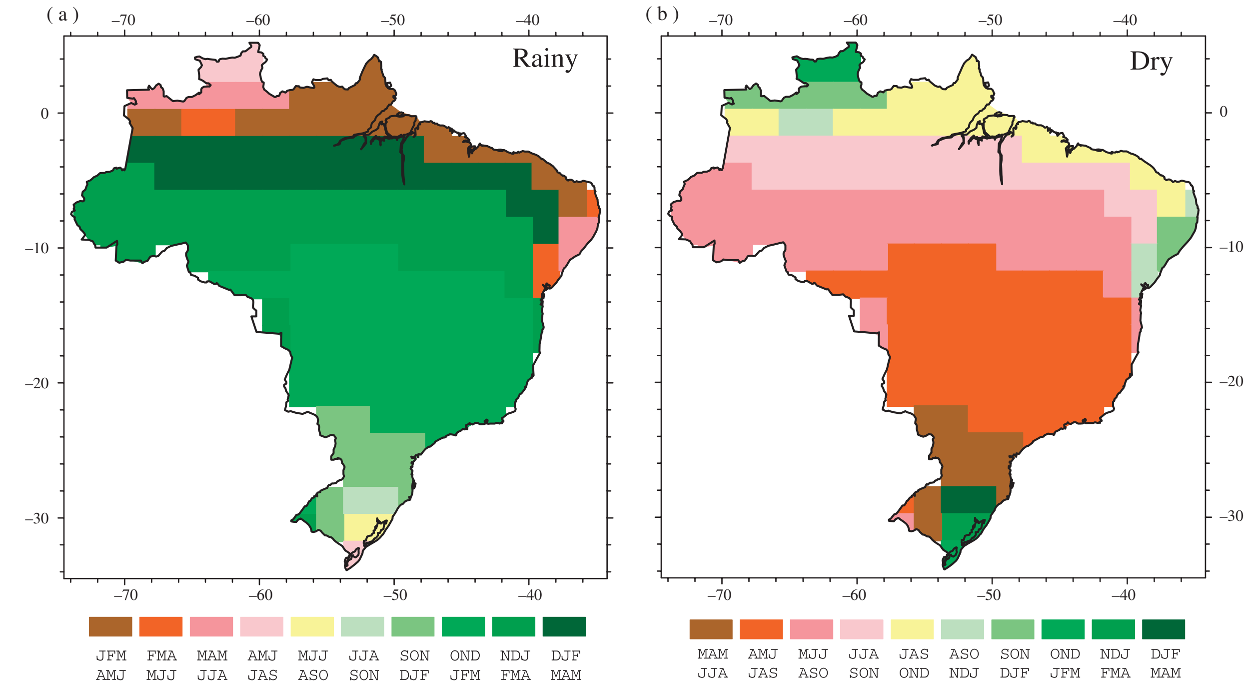

Figure 2. The six (a) rainiest and (b) driest consecutive months in Brazil. The monthly data are from CPC for the period from 1979 to 2011.

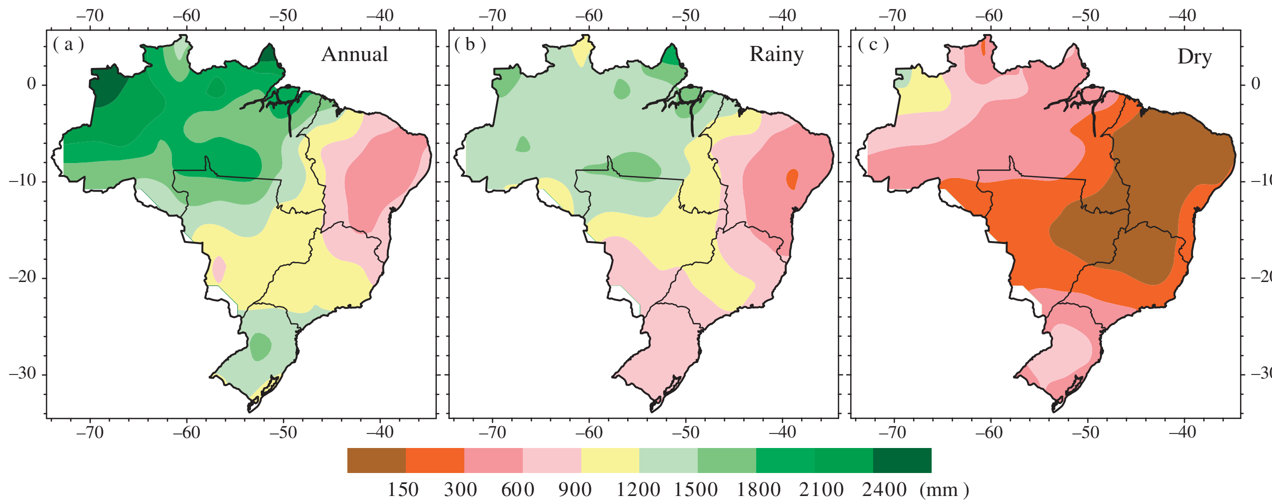

Figure 3. Climatology of precipitation (mm) over Brazil: annual (a), during the six most rainy consecutive months (b), and during the six most dry consecutive months (c). The monthly precipitation series are from CPC for the period from 1979 to 2011.

dry season occurs for the western, northeast and southeastern regions in June-July-August, April-May-June and in November-December-January respectively. To the north and northeast of Brazil there are small regions with varying dry seasons.

Figure 5 shows the linear tendency (mm year^{-1}) of precipitation for the rainy and dry seasons and also for the annual rainfall for the period 1979–2011. The cross hatched areas in figure, represent a *t*-test confidence level of over 95%. Over north Amazon region there is a significant increase of rainfall in the rainy season in an order of 10 mm per year or more. This is consistent with what Satyamurty *et al.* (2013) found recently. They found that the annual range of the River Negro level has been increasing since 1970. River Negro level can be taken as a proxy to the rainfall of River Amazon basin. The Rio Negro Basin presents areas where the precipitation values during 1979–2011 show increasing (positive) and decreasing (negative) tendencies (Table 1) with significance level greater than 95%. To the north of this region there are isolated pockets of decreasing tendencies, but they are not statistically significant. During the dry season there is decreasing tendency, thus over this region dry season is becoming drier and wet season is becoming wetter, increasing the annual cycle of rainfall. According to Hooper *et al.* (2005) changes in the regional climate can be associated with anthropogenic factors such as deforestation and misuse of ecosystem. To the south of this

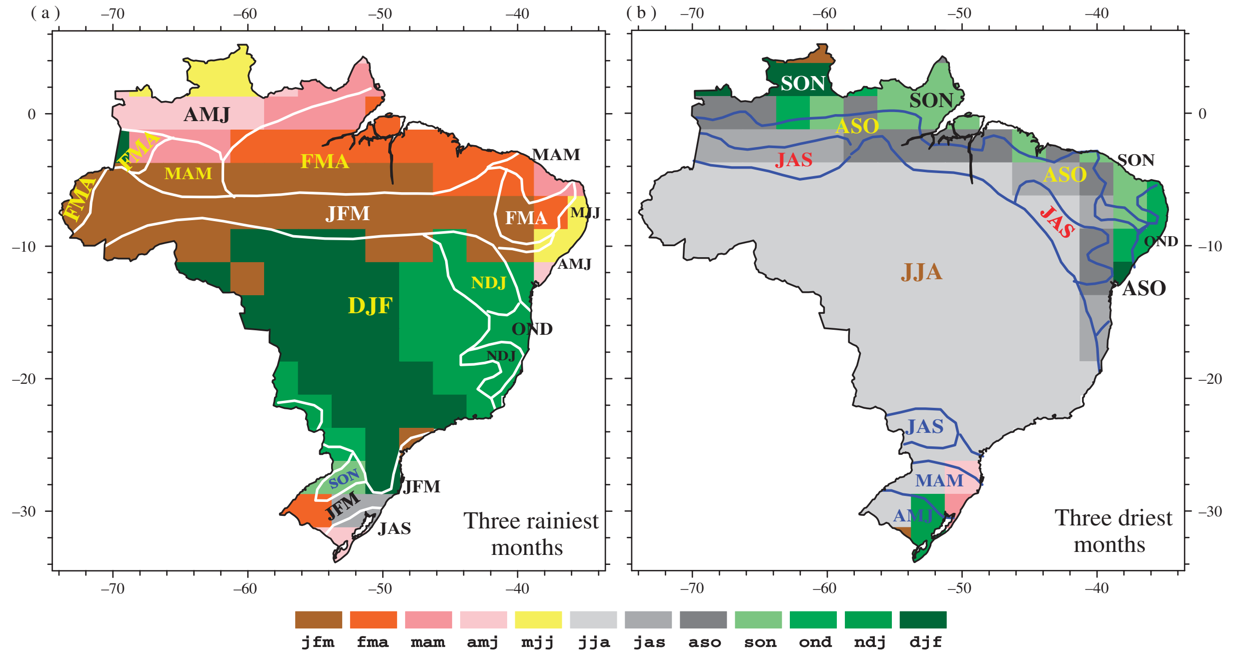

Figure 4. The three rainiest (a) and driest (b) consecutive months over Brazil. Comparison between recent (1979–2011) results (coloured scale) with the 1958–1979 results (white and blue lines). The trimester labels shown in (a) and (b) refer to the older results. The more recent data series are from the CPC.

region both rainy and dry seasons are becoming drier. In northeast Amazon and West NEB there is increasing tendency of rainfall in both wet and dry seasons. These results agree with Santos *et al.* (2009) who found an increase in the Ceará state precipitation during the period from 1935 to 2006. To the east of this region there is not much change. These features have already been commented in earlier studies (Marengo, 2004, 2009; Gloor *et al.*, 2013). In southeast Brazil there has been a highly significant decrease of rainfall both in rainy and dry seasons such that the rate of decrease in the annual rainfall is almost 10–20 mm year^{-1}. In an earlier study, Blain (2009) found no significant increase of rainfall in São Paulo state (south of this region). On the other hand, Bombardi and Carvalho (2009) found a decrease of the precipitation over central eastern Brazil in 6 of 10 IPCC models when they compared the future scenarios with the present. This decrease found here will have serious impacts on the social and economic life because many of the hydroelectric generation stations of power function in this region. To the west of this region there is an increasing tendency of the wet season duration and decreasing tendency of the dry season. Thus, there is increase of annual cycle just as in the north Amazon. In south Brazil eastern parts are becoming wetter in both dry and wet seasons, whereas the western parts are becoming drier in both wet and dry seasons. This result agrees with Pinheiro *et al.* (2013) who found an increasing trend in 16 meteorological stations and a decreasing trend in 2 stations, one over northwest and other central-northern sectors and this in part agrees with Haylock *et al.* (2006) who found increase of rainfall in this region. This result also agrees with Liebmann *et al.* (2004) who found a positive trend to south of 20°S during the January-March season.

3.1. Possible causes of the tendencies in rainfall

Several studies have shown that the rainfall trend in Amazon is associated with the El Niño Southern Oscillation (ENSO). During the warm phase of ENSO, associated with El Nino, there is often a deficit of precipitation in northern and central Amazonia (Rao *et al.*, 1996; Marengo *et al.*, 1998; Uvo *et al.*, 1998), and when the Atlantic is cold, a delay in onset and an early cessation of precipitation occurs (Marengo *et al.*, 2001). Other studies have suggested the role of enhanced northeast trades and the increase of moisture flux for the positive trend of rainfall (Marengo, 1992; Rao *et al*, 1996). Strong Atlantic trades bringing more moisture into the Amazon are associated with a southward displaced ITCZ, which in turn is related to an anomalous distribution of Atlantic SST anomalies. (Hastenrath and Heller 1977, Moura and Shukla 1981, Nobre and Shukla 1996).

In order to associate the trend of rainfall during the period with the distribution of SST, we computed the tendency of mean annual SST for the period 1979–2011 (Figure 6). Earlier we found that over north Amazon there is an increasing trend of rainfall. As shown in Figure 6, over a large region of north Atlantic including the adjoining sea of the NEB coast a positive tendency of SST can be seen. This increase of SST favours higher evaporation and higher moisture flux to the interior of the continent because of easterly winds. Many studies have shown that the moisture convergence is important for the rainfall of the Amazon region (Curtis and Hastenrath, 1999; Marengo *et al.*, 2004; Satyamurty *et al.*, 2012, 2013). In a similar way in the western parts of NEB, moisture flux and convergence favoured higher rainfall noted earlier. Over eastern Tropical Pacific there is negative tendency of SST. This

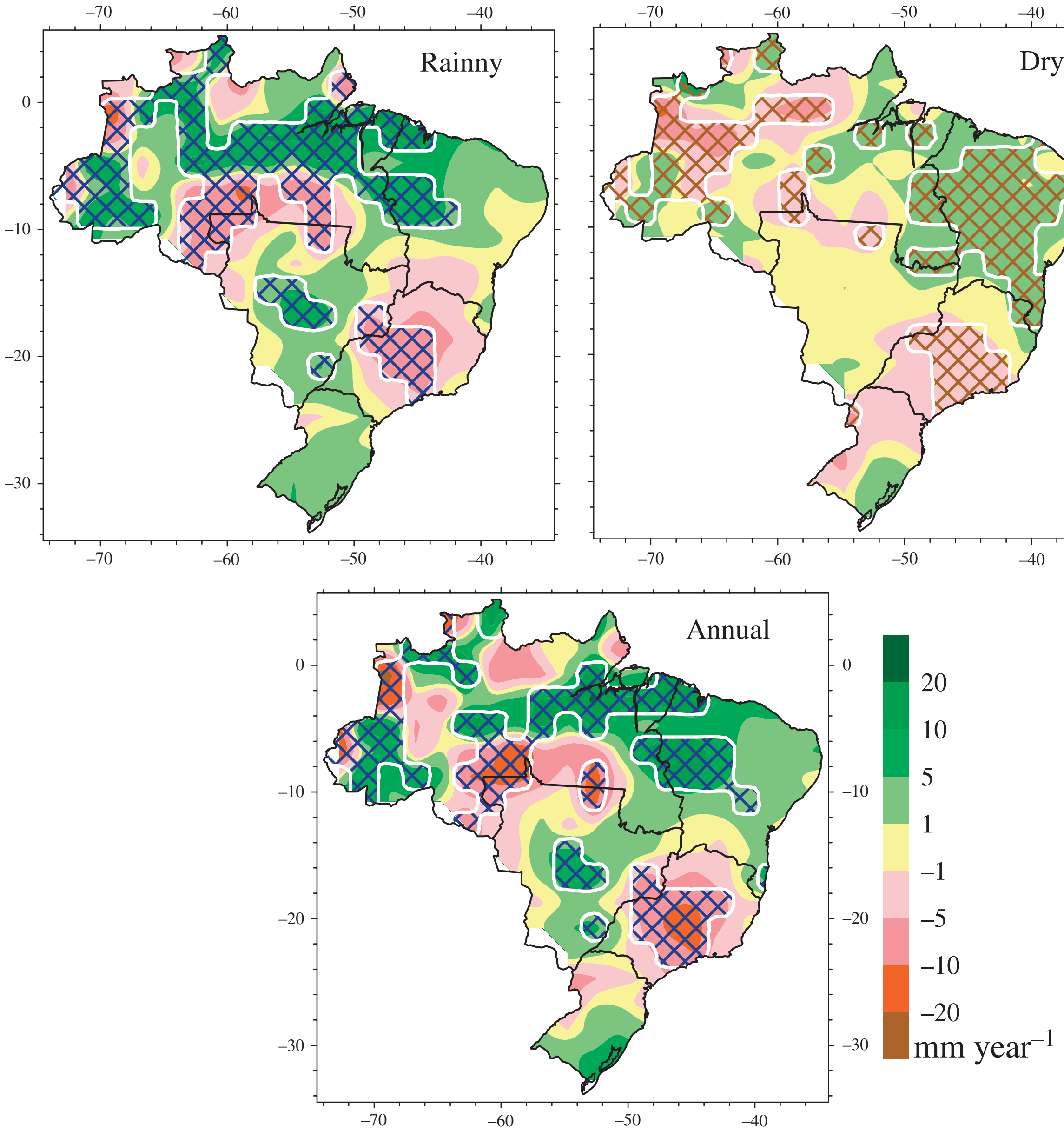

Figure 5. Tendency (mm year^{-1}) of precipitation increasing during the annual, rainy and dry semesters. Cross hatched areas represent *t*-test confidence level over 95%. Positive values represent increasing and negative values decreasing tendencies. Monthly data are from CPC for the period from 1979 to 2011.

Table 1. Tendency of the mean precipitation values during the annual, rainy and drier semesters over the Rio Negro (AM) Basin. Monthly data series are from CPC for the period from 1979 to 2011. The significance level is based on the Student's *t*-test table.

			Annual	Rainy semester	Drier semester
Significance > 95%	Positive correlation	Area (%)	17	18	7
	Negative correlation	Area (%)	20	12	17

situation contributes to the increase of precipitation over NEB (Uvo *et al.*, 1998)

Figure 7 shows the tendency of mean sea level pressure for the period 1979–2011. Over south of South America a positive tendency is seen. This positive tendency restricts the rain bearing systems to the south and the northern parts suffer lack of rain. Pezza and Ambrizzi (2003) have shown that the total number of Southern Hemisphere cyclones has decreased. Thus, the lack of rain causing cyclonic systems and fronts caused this decrease of rainfall.

3.2. River discharges

To see whether the decreasing trend of rainfall in south-east Brazil is reflected in river discharges, we examined the trends in the river discharges of the São Paulo and Minas Geris States. Figure 8 shows the 17 points of dam sites

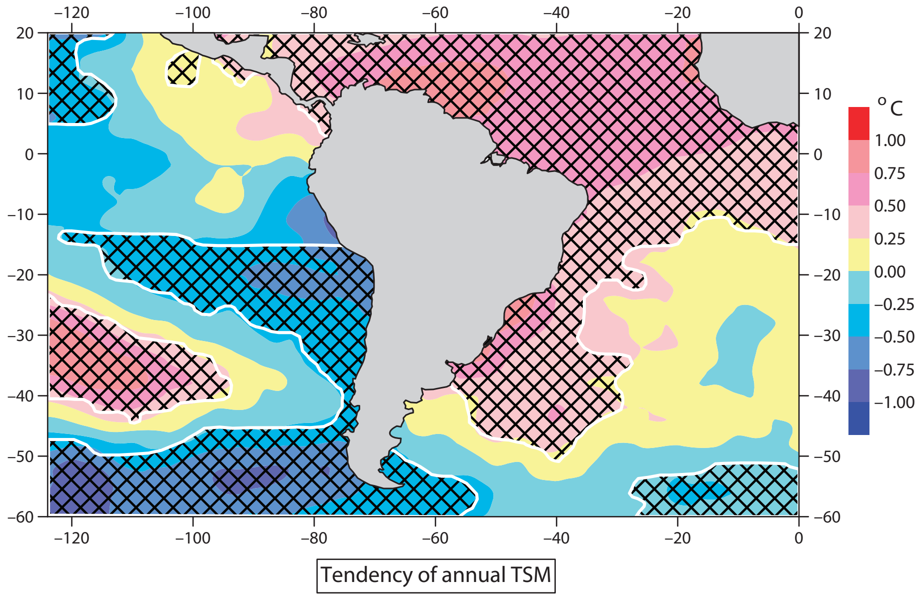

Figure 6. Tendency (°C) of the mean annual SST for the period from 1979 to 2011. The cross hatched area represents confidence level over 95% for the tendency values.

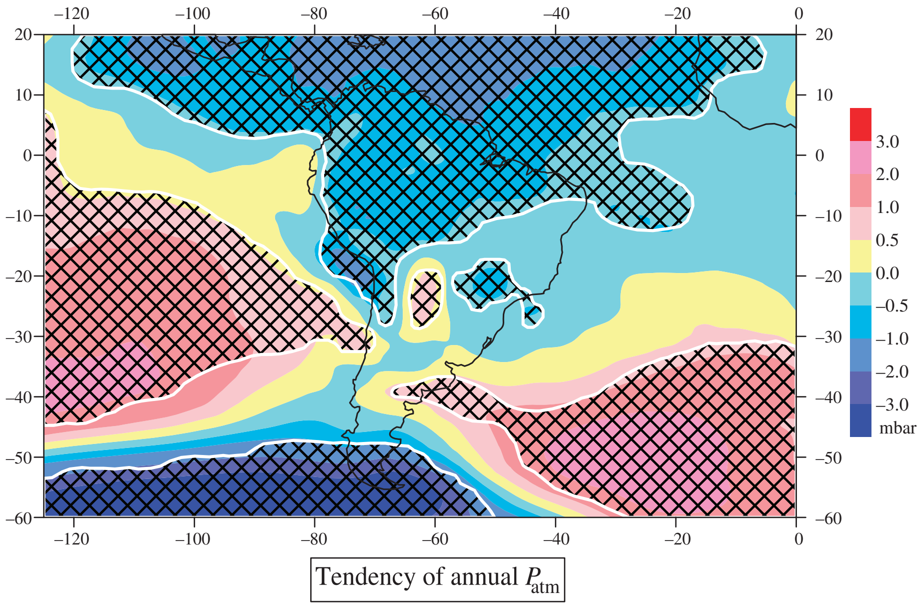

Figure 7. Tendency (mbar) of the mean annual atmospheric pressure at surface for the period from 1979 to 2011. The cross hatched area represents confidence level over 95% for the tendency values.

and Table 2 gives the names of these sites. The daily data of river discharges for the period 1979–2011 are used to calculate the tendencies. Table 3 gives the trends in annual flux at these 17 points. The values of the relative trend are the fractions of the annual flux. It can be seen that at 12 points the trends are negative and some of them are significant at 95% level. Also shown are the trends in the maximum and minimum flux for 6 months. In the minimum flux at 15 points the trends are negative and some of them are significant at 99% level. These results confirm the negative tendencies of rainfall in southeast Brazil. The diminishing trends of rivers of southeast Brazil may eventually be associated with an increase of water collection for human need, such as agriculture practices. Nevertheless rainfall seems to have had a relevant contribution during the last 30 years. Comparing Figures 5 and 8 it is seen that the Southeast reservoir areas present a negative tendency of the precipitation around -5 mm year^{-1} (or -165 mm during the period) for both the annual and rainy periods with 95% of confidence level. A slight negative tendency is also seen during the dry period.

The negative tendencies in rainfall have great impact on the hydroelectric generation and also on agricultural output and have severe impact on the life not only in this region but also on a national level because the hydroelectric dams furnish energy to other regions of the country. Also the

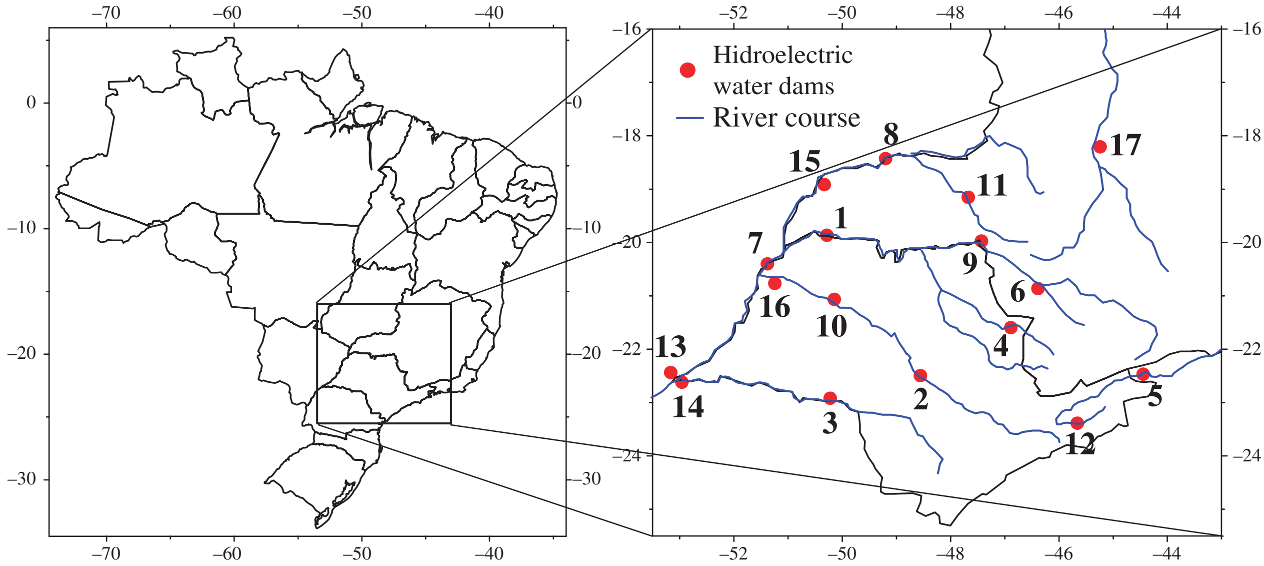

Figure 8. Location of the hydroelectric dams listed on Table 2.

Table 2. Hydrologic basin and river locations of some SE Brazilian hydroelectric dams.

N	Station	Basin	River
1	Agua Vermelha	Grande	Grande
2	BARRA BONITA	Tietê	Tietê
3	canoas 2	Paranapanema	Paranapanema
4	Euc. Da Cunha	Grande	Pardo
5	Funil	Paraíba do Sul	Paraíba do Sul
6	Furnas	Grande	Grande
7	Ilha Solteira	Paraná	Paraná
8	Itumbiara	Paranaíba	Paranaíba
9	Jaguara	Grande	Grande
10	N. Avanhandava	Tietê	Tietê
11	Nova Ponte	Paranaíba	Araguari
12	Paraibuna	Paraíba do Sul	Paraibuna-Paraitinga
13	Porto Primavera	Paraná	Paraná
14	Rosana	Paranapanema	Paranapanema
15	São Simao	Paranaíba	Paranaíba
16	Tres Irmaos	Tietê	Tietê
17	Tres Marias	São Francisco	São Francisco

agricultural products of these two states are necessary for National Consumption.

4. Summary

In an earlier paper Rao and Hada (1990) studied the rainfall characteristics of Brazil for the period 1958–1978. In this study we updated these results with the data from 1979 to 2011.

First we determined 6 months of rainy and 6 months of dry periods for Brazil. A large part in Central Brazil is characterized by 6 months of rainy season from September to February. The dry season is in austral winter months. Thus this region has typical monsoonal characteristics. In NEB the central parts have rainy season from December to May and towards the east in March to July. In South Brazil there are no clear dry and wet seasons. These results confirm the rainfall characteristics of Brazil in earlier studies.

We compared the three consecutive wet and dry months determined in the earlier study for the period 1958–1978 with this study for the period 1979–2011, to see what changes have taken place. In the northern most part, rainy season, in earlier period was during April-May-June but now the rainy season occurs later. To the southeast of this region the rainy season remained the same, i.e. in February-March-April. South of 10°S in a large region, in both the present and previous data sets the rainy season occurs in austral summer, December-January-February and dry season in austral winter June-July-August. Thus the monsoonal characteristics did not change. To the east of this region the rainy season in the latter data occurred earlier. To the south of the large monsoonal region, dry season extended now occurring in July-August-September.

Next, we calculated the linear tendencies of rainfall over Brazil during the period 1979–2011 and also their significance. Over north Amazon region there is a significant increase of rainfall. This is consistent with the recent study of Satyamurty *et al.* (2013), who found that the annual range of River Negro is increasing. Over this region the dry season is becoming drier and wet season wetter, thus the annual variation of rainfall is increasing. We also noted an increase of rainfall over the west of NEB.

In southeast Brazil there is a region of highly significant decrease of rainfall in both wet and dry seasons. To see whether this decrease reflects in river discharges, we calculated the tendencies of river discharges of São Paulo and Minas Gerais states, which confirmed the negative tendencies. These negative tendencies in rainfall have great impact on the hydroelectric generation and also on agricultural output at a national level. Also the agricultural output of these two states is necessary for the national distribution.

Table 3. Location of some hydroelectric water dams at São Paulo and Minas Gerais States. Tendency, significance and relative tendency of the annual, maximum and minimum semestral water flow measured at those locations. The significance level of the tendency was calculated by the Student's t-test. The bold values correspond to a t-test significance level higher or equal than 90%. The data series of daily water flow for the period 1979 to 2011 are from the ONS (National Electric System Operator): http://www.ons.org.br/operacao/vazoes_naturais.asp.

N	Water dam	Tendency ($m^3 s^{-1}$)	Significance (%)	Relative tend (%)	Tendency ($m^3 s^{-1}$)	Significance (%)	Relative tend (%)	Tendency ($m^3 s^{-1}$)	Significance (%)	Relative tend (%)
1	Agua Vermelha	**−408.3**	**95**	**−18.4**	**−546.8**	**90**	**−17.3**	**−269.9**	**95**	**−21.2**
2	Barra Bonita	20.3	<90	4.3	61.1	<90	9.5	−20.5	<90	−6.9
3	Canoas 2	69.7	<90	13.4	**131.7**	**90**	**19.8**	7.7	<90	2.1
4	Euc. Da Cunha	**−15.2**	**90**	**−17.7**	**−21.3**	**90**	**−17.6**	**−9.0**	**90**	**−18.0**
5	Funil	−11.4	<90	−5.1	−7.3	<90	−2.3	−15.6	<90	−11.7
6	Furnas	**−229.7**	**95**	**−24.7**	**−290.0**	**95**	**−21.4**	**−169.3**	**99**	**−33.8**
7	Ilha Solteira	**−848.6**	**90**	**−14.6**	−1167.5	<90	−14.1	**−529.7**	**95**	**−16.0**
8	Itumbiara	**−396.8**	**90**	**−25.7**	**−582.1**	**90**	**−25.3**	**−211.6**	**95**	**−26.9**
9	Jaguara	**−216.3**	**95**	**−20.4**	**−273.3**	**90**	**−17.6**	**−159.3**	**99**	**−28.2**
10	Nova Avanhandava	42.0	<90	5.2	111.5	<90	10.3	−27.5	<90	−5.1
11	Nova Ponte	**−85.3**	**95**	**−29.5**	**−112.1**	**90**	**−26.4**	**−58.6**	**99**	**−37.8**
12	Paraibuna	−7.9	<90	−11.5	−6.5	<90	−7.1	**−9.4**	**95**	**−19.6**
13	Porto Primavera	−721.7	<90	−8.9	−814.8	<90	−7.3	**−628.7**	**95**	**−12.3**
14	Rosana	99.5	<90	7.2	172.8	<90	10.2	26.2	<90	2.5
15	São Simao	**−551.0**	**90**	**−20.6**	**−734.7**	**90**	**−19.0**	**−367.3**	**95**	**−24.8**
16	Tres Irmaos	43.6	<90	5.0	111.8	<90	9.7	−24.5	<90	−4.2
17	Tres Marias	**−210.7**	**90**	**−29.5**	**−306.6**	**90**	**−26.8**	**−114.9**	**95**	**−40.2**

We examined the possible causes for the rainfall tendencies in Brazil. We found that over the north Atlantic and northern parts of south Atlantic the SST is increasing. This seems to favour higher moisture transport to the interior causing increase of rainfall over north Amazon and west NEB. We also found that there is a belt of positive mean sea level pressure over the southern South America preventing northward movement of rain bearing systems such as fronts and cyclones. This may be at least one of the reasons why rainfall is decreasing over southeast of Brazil.

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