

Rainfall patterns in the Southern Amazon: a chronological perspective (1971–2010)

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Received: 6 February 2014 / Accepted: 26 April 2015 / Published online: 5 May 2015
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Abstract The aim of this study is to characterize rainfall patterns in a vast transition zone between the Amazon and the Cerrado Biomes. The analysis is focused on annual and seasonal tendencies, mainly about the onset and offset of the rainy season, its length and shifts. More than 200 Rain Gauges (RGs) were analyzed in the study area using Pettitt's and Mann-Kendall's non-parametric tests allied to a Linear Regression Analysis over the period 1971–2010. The onset and offset dates of the rainy season and its duration are also identified for 89 RGs. Pettitt's test indicates ruptures in 16 % of the rainfall time series while Mann-Kendall's monthly test indicates that 45 % of the RGs had negative trends, mainly in the transition seasons (spring and austral autumn). Linear Regression Analysis indicates negative trends in 63 % of the time series concomitant to the rainy season onset and offset analysis, which confirms a delay for the onset of the rainy season in 76 % of the RGs and a premature demise for 84 % of the RGs. Identification of the tendencies for rainy season duration indicates that the rainy season has become shorter at 88 % of the RGs. There were recurring patterns in the results displaying drier conditions in RGs localized in deforested areas opposed to forested locations.

1 Introduction

The Brazilian Southern Amazon and Northern Cerrado region covers a vast transition zone between the Amazon and the Cerrado biomes (TZAC). The area has constituted an expansion

Electronic supplementary material The online version of this article (doi:10.1007/s10584-015-1415-1) contains supplementary material, which is available to authorized users.

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frontier for grain production and ranching driven by the international commodities market in the last three decades (Verburg et al. 2014a, b). This rapid development of the agricultural frontier had increased the vulnerability to climatic change in the region, especially to drought events as seen in 2005 and 2010 (Lean et al. 1996; Marengo et al. 2001; Liebmann and Mechoso 2011; Marengo et al. 2011; Davidson et al. 2012).

The climatological features of the Amazon Basin have been extensively detailed by, e.g., Marengo (2004), Davidson et al. (2012), Nobre et al. (2013) and many others. The transition between the dry and wet season is primarily dictated by the onset of the South American Summer Monsoon (SASM) system. SASM, in turn, is controlled by large-scale thermodynamic processes involving the equatorial sea surface temperature (SST) (Gan et al. 2004; Carvalho et al. 2011; Nobre et al. 2013). The onset of the rainy season is established after the period of maximum seasonal temperature. During this phase, the atmosphere is very stable, thus it is required a large increase in temperature and humidity at the earth's surface to reach enough energy to create convection and instability (Gan et al. 2004). The increase in temperature acts to destabilize the atmosphere and cause a reversal in the horizontal temperature gradients and vertical wind shear (Gan et al. 2004). While the onset of the rainy season takes place typically in a span of one month, the demise can take much longer (Nobre et al. 2013).

The SASM system is composed of several circulation patterns. The three main patterns are: a) the “Bolivian High”, an upper tropospheric anticyclone centered over the Bolivian Plateau (Virji 1981); b) the “Northeast Trough”, a semi-stationary upper-level trough near the northeast coast of Brazil (Kousky and Gan 1981); and c) the South Atlantic Convergence Zone (SACZ), which is a relatively narrow frontal-like system with a northwest-southeast orientation from the Amazon to the subtropics, reaching the Brazilian South Atlantic (Kodama 1992). Precipitation amounts and variability in the whole of the Amazon Basin, including its southern part, are to a large extent explained by the Intertropical Convergence Zone (ITCZ) and the SACZ; sea surface temperature (SST) in both Atlantic and Pacific Oceans (Andreoli et al. 2011; Marengo et al. 2011); convective activity associated with penetration of frontal systems from southern Brazil (Siqueira and Machado 2004); and the South American Low-Level Jet East of the Andes, a moisture corridor carrying humidity from the Amazon Basin (especially during the austral summer) to southern Brazil, northern Argentina and the La Plata Basin (Marengo et al. 2004).

Because the Amazon biome comprises a large territory encompassing several degrees in latitude and longitude, the rainfall regimes in the northern and southern parts present distinct characteristics. In TZAC, SACZ convective activity combined with local air mass circulation, topography, and atmospheric phenomena associated with large-scale circulation greatly impacts rainfall distribution (Negri et al. 2000; Siqueira and Machado 2004). The TZAC rainfall regime presents a strong seasonality: more than 70 % of the rain in TZAC occurs between the months of November–March, with the rainiest period between January–March. During the austral summer rainfall averages between 45 and 55 % of the annual total in contrast to the dry winter months (Durieux 2003). The dry period in TZAC usually lasting from June–September is common to almost all the TZAC regions (e.g. Funatsu et al. 2012), in contrast to the Equatorial Northern part of the Amazon basin, which has a shorter dry season (Marengo 2006).

After 1976 negative rainfall trends (Coelho et al. 2013) have been observed in the whole Amazon basin due to a climatic shift when the Pacific Decadal Oscillation (PDO; Zhang et al. 1997) in the Southern Hemisphere changed from its negative to positive phase (unfavourable for precipitation in tropical South America). This feature combined with El Niño-like

conditions in the Pacific Ocean and the increase of SST in the Tropical North Atlantic Ocean reinforced subsidence conditions over the Amazon (Marengo 2004; Satyamurty et al. 2010). The increase of SST in the Tropical North Atlantic Ocean, which is negatively correlated to precipitation in Amazonia, was linked to the drought episodes occurred in 2005 and 2010 (Molinier et al. 2009; Yoon and Zeng 2010).

Interactions between land surface and the atmosphere, and particularly, between soil moisture and evapotranspiration, work as dynamic mechanisms driving the remaining variance of hydrological processes on annual and inter-annual time scales in the Amazon (Sheil and Murdiyarso 2009; Debortoli et al. 2013; Fu et al. 2013). Changes in land surface (forest to pasture, agriculture and urban areas) impose strong physical modifications influencing the amount of potential energy used in convective process. These modifications are provided by latent heat and albedo alteration, following surface changes, thus engendering variations in the rainy season extent (Fu et al. 1999; Dubreuil et al. 2012). Some agricultural practices, in particular those used in intensive farming by soybean producers which involve clearing land with fire, can have consequences for cloud formation and thus precipitation (Fu et al. 2013). Observational studies have shown that the increase of aerosol loading due to burnings can have impact on precipitation (e.g. Rosenfeld 1999; Malhi et al. 2008; Koren et al. 2008) but with conflicting results. While some studies detected intensification in rainfall associated with increased aerosol loading from biomass burning, others found evidence of suppressed precipitation and reduced ice particle radii associated with polluted clouds particularly in the dry season. Specific experiments indicated that continentality influences more often the TZAC region than the northern part of the Amazonian biome, thus deforestation might play a major role in cloud convection and subsidence over forest and deforested areas respectively (Costa 2004; Costa et al. 2007 and Costa and Pires 2010).

Even under the complex set of elements interweaving natural and anthropogenic factors, we bring up the question of which precipitation patterns may be evolved in TZAC. Thus, in order to assess the precipitation regime during the last four decades of continuous deforestation in the region (1971–2010), we focused our analysis in characterizing annual and seasonal climatic tendencies and ruptures at a regional scale, and also, climatic shifts in the onset and offset of the rainy season and its length. The area analyzed comprises the states of Rondônia and Mato Grosso including the adjacent areas and frontier states of Amazonas, Pará, Tocantins and Goiás (see map at Online Resource 1). This region was chosen due to its location at the southern edge of the Amazon Deforestation Arch, known for its strong climatic continentality and seasonality (Liebmann and Marengo 2001). According to INPE-PRODES (2012) most of the deforestation in Rondônia and Mato Grosso occurred between 1993–1995 and 2003–2004.

To accomplish this objective we have assessed Rain Gauges (RGs) data in both deforested and forested areas. Two statistical parametric tests (Pettitt and Mann-Kendall) and a linear regression analysis were used. In addition, we have identified the onset and offset of the rainy season, including its shifts and length based on Liebmann et al. (2007, hereafter LB07). Furthermore, we have used an ordinary exponential kriging interpolation analysis to map both linear regression and season onset and offset shifts. The region's natural climatic variability is discussed in light of these results.

The paper is structured as follows: Section 2 describes the data and methods: Rain gauges selection, statistical tests, the consistency methodology applied to the RGs data, and the rainy season identification method. In Section 3 results are discussed considering the natural large-

scale climatic influences in the region, as well as the different outcomes most likely due to deforestation impacts and its interactions within TZAC precipitation regime. Finally, Section 4 presents the conclusions of the present work.

2 Data and methods

2.1 Data

Two sets of data were used in this work: first, a set of 207 RGs data to identify the level of homogeneity in the series, and later, a subset of 89 RGs (from the previous 207) to identify onset, offset and length of the rainy season.

The historical precipitation data set was collected from ANA Hidroweb (2012) (Brazilian National Water Agency) online application. Initially 634 RGs were collected (4,907,645 days of rain) then validated. A consistency check based on Fetter et al. (2012) method was then applied. The outcome from this step was a total of 207 RGs corresponding to 2,497,297 days of rain measured, with only 270,755 days having hiatus, which represents 10 % of the total RGs data.

Our downscaled Fetter's adapted method considered the TZAC region's precipitation patterns, and it was derived from a national consistency RG analysis, developed for the Brazilian Climate Change Sub-Network in Regional Development, of the National Institute for Spatial Research (INPE). The downscaled consistency method considered the regional following parameters for TZAC data:

- (a) In the TZAC, RGs daily precipitation values exceeding 350mm were scarce, as opposed to the northern regions of the Amazon biome (Online Resources 1). Therefore, to avoid biases in the analysis due to these rare extreme events (Fetter et al. 2012) data inferior or equal to 100mm was considered "consistent", and precipitation greater than 350mm considered "inconsistent". Subsequently RGs values between 100 and 350mm were submitted to the following criteria: for each "X" gauge if the rainfall average of the 10 neighboring RG nearest to "X" is superior to 10 % of the precipitation value of gauge "X", than the data is considered "consistent"; if not, it is considered inconsistent and eliminated (Vila et al. 2009).
- (b) The ensemble of monthly data and monthly totals were analyzed for each RG to eliminate suspected values, e.g., precipitation extremely higher or lower when compared to the monthly average values, and data with many fails (hiatus). For instance, whenever a hiatus existed at monthly level the following criteria was applied to the data: if during a specific "X" year only 2 months presented hiatus, this absence could be substituted by the respective historical average. If the hiatus was longer than 2 months during the specific "X" year, then this year was not included in the analysis;
- (c) All RGs series considered contained rainfall data between 1971 and 2010. This rule initially expected to eliminate all the RGs with less than 30–40 years as recommended by the World Meteorological Organization (WMO). However, due to the historical context of colonization within less than 40 years we decided to include RGs with 20 years or more. Nevertheless, only RGs with no more than 5 consecutive years of hiatus were selected.

To develop and calculate the rainy season annual length and its seasonal onset and offset climatic shifts, we decided to select 89 RGs from the previous 207. This RGs selection had the objective to fulfill the 30-year minimum data as recommended by the WMO. Yet, much of these RGs (50 of them) were located in the southern and eastern parts of the analyzed area. These regions have experienced colonization prior to the 1970s in opposition to the northern ones; therefore, to obtain a coherent spatial distribution covering approximately the same period within the analyzed RGs subset, we decided to include RGs with a minimum of 27 years increasing RGs numbers in the northern-forested sites (see map at online resources 2-B).

2.2 Methods

2.2.1 Pettitt test

The Pettitt test identifies whether the historical precipitation series are homogenous. It is a non-parametric test that does not require a hypothesis in data distribution. Pettitt test is adapted from Mann–Whitney test based in a range that identifies the moment of a transition (rupture) in the series (Pettitt 1979). The test consists in cutting the main series of N elements into two sets at each time t between 1 and $N-1$. The main series has a break at time t if the two sub-series have different distributions. The parameters we have used in the 207 RGs test were the following: alternative hypothesis $\neq 0$; level of satisfaction 5 %; number of simulations 10,000; t (time) maximum in simulation 180 (s). Period of hiatus in data were ignored as explained in Section 2.1. The test was run for all RGs with more than 20-years in the series.

2.2.2 Mann-Kendall test

The Mann-Kendall (MK) test is normally used in parallel to a non-parametric test to determine if trends can be identified in a temporal series including a seasonal component. This non-parametric trends test is the result of an improved test initially studied by Mann and followed by Kendall, being finally optimized by Hirsh, which held in consideration the seasonal component (Libiseller and Grimvall 2002).

The test is based in the null hypothesis H_0 meaning that there are no trends in the series. The test has 3 alternative hypotheses in the series evolution: negative, null and positive. The Mann-Kendall test is based in the calculus of the measure of Kendall and the rate of association between two fundamental data sets based in a range (Mann 1945). The test was applied for the 207 RGs in two different analyses: I - considering the total accumulated precipitation for the annual rainfall series, and II - monthly-seasonal resolution for all RGs. The analysis discriminated the RGs in: (1) those presenting positive and negative trends in the Mann-Kendall annual test, (2) those presenting positive and negative trends in the Mann-Kendall monthly test (3) those presenting no tendency, and finally, (4) those presenting negative or positive Mann-Kendall trends concomitant to Pettitt test ruptures.

2.2.3 Linear regression analysis

A Linear Regression (LR) analysis allowed assessing the historical rainfall series during the period of 1971–2010. In fact this approach was necessary because Mann-Kendall and Pettitt tests do not identify subtle trends even though we know that they become important when

numerous. This method was also added in order to compare with and support Pettitt and Mann-Kendall findings. An ordinary exponential kriging interpolation analysis was used to map the linear regression results (see Online Resources 5-A for the methodology).

2.2.4 Rainy season's onset-offset identification, tendencies and length

A diverse set of statistical methods has already been developed to identify the onset and offset of the rainy season in tropical regions (Marengo et al. 2001; Odekunle 2003; Liebmann et al. 2007; Liebmann and Mechoso 2011). Overall these methods incorporate daily rainfall data and in some cases aggregate variables such as temperature and relative humidity.

Based in the above methodologies, we have decided to implement a slightly modified version of LB07 method. In the original method, a quantity called “anomalous accumulation” (AA) was computed, so that AA would represent the accumulated difference between the daily and climatological precipitation values. The calculation is started 10 days prior to the beginning of the driest month and is summed for a year. However, unlike in LB07 original method, here we chose the beginning of the rainy season as the day when AA is the minimum (and not a minimum before a certain number of consecutive positive values); conversely, the demise of the rainy season is defined as the day when AA reaches a maximum. We found this slight modification to be more appropriated to detected the onset and offset in the TZAC seasonal climate.

Based on a chronological perspective (1971–2010) using LB07 modified method we identified the spatial distribution (Fig. 1) of the onset and offset of the rainy season. The analysis carried from daily data identified trends in historical series during the period and also the onset and offset dates and their spatial distribution among biomes. The accumulation of points derived from the method allowed to identify the month, day dates and the annual chronological periods of rainfall, based in the maximum and minimum total accumulated average points of precipitation, as illustrated in Online Resources 2-A.

We applied the modified LB07 method to the 89 RGs data starting at the first day of August, a time of the year where there are no influences of the rainy period and precipitation occurs exclusively with the passage of cold fronts (Li and Fu 2006). To calculate the difference between the maximum and minimum accumulated points among the averages we used the following equation:

$$V_j = \sum_{01/08}^j (P_j - \bar{P}_m)$$

Equation. $\sum_{01/08}^j$ = The first day of August, where j represents the difference between the averages of the minimum accumulated and the onset of the respective year; and P_j is the day before, representing the difference between the averages of the maximum accumulated; and \bar{P}_m , the daily precipitation average during the 1971–2010 period.

The onset and offset dates were detected calculating the average difference of minimum accumulated points of the precipitation curve that starts at the first day of August for the onset analysis. The offset was calculated by the average difference of the maximum accumulated precipitation points of the curve during the year until the 31st of July. We decided to reject those years with more than 2 months of missing daily data (62 days).

Finally these findings were then submitted to Mann Kendall test to check for homogeneity for both onset and offset of the rainy season.

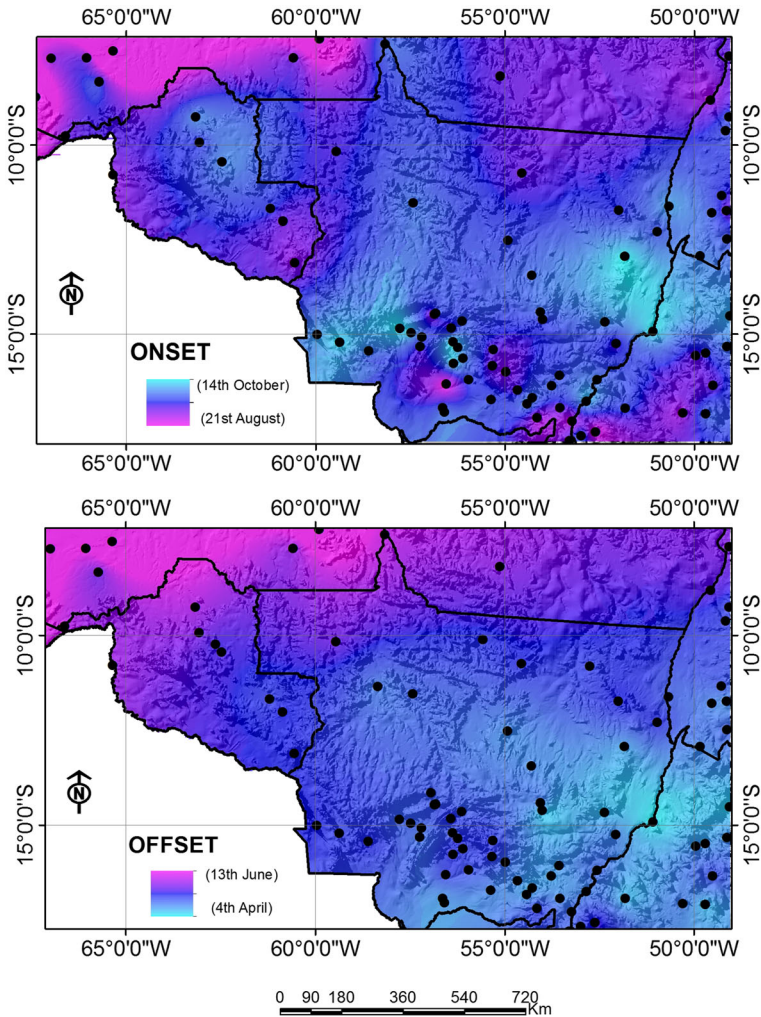


Fig. 1 Ordinary Exponential Kriging interpolation for the rainy season (a) onset and (b) offset date for the TZAC between 1971 and 2010. Limits of onset and offset (Offset 4th April and 13th of June and Onset 21st of August and 14th of October depending on location)

3 Results

3.1 Pettitt test

Within the 207 RGs used in Pettitt test 39 RGs (16 %) indicated significant ruptures in the series (Online Resource Map 3-B). Among those, 33 RGs showed negative ruptures (i.e. reduction in precipitation after the rupture), and 6 RGs showed positive ruptures (i.e. increase in precipitation after the rupture). In Online Resource graphic 3-A we observed an increase in RGs ruptures from the beginning of the 1980s extending until the late 1990s.

Rainfall ruptures in RGs may be linked to natural phenomena or differences in measuring due to changes in RGs technologies and data acquisition (Edwards 2010). ENSO events during

1970–2010 (1982/83, 1991/92, 1994/95, 1997/98, 2004/2005, 2010) combined with anomalous heating in the Atlantic Ocean caused reduced rainfall in the Amazon Basin (Cavalcanti et al. 2013). When we look for ruptures in ENSO years we found that the RGs analyzed showed negative ruptures in 1983, more expressively in 1994/1995 and also 1997/1998. These years were characterized by a weak SACZ, a displacement of the ITCZ to the north, positive anomalies in the SST in Central Equatorial Pacific Ocean and negative anomalies in the SST in Southern Tropical Atlantic Ocean (Cavalcanti et al. 2013). However, the rupture observed in 1994 can be partly explained by the systematic data hiatus in ANA's historical series in 1992 and 1993.

An interesting pattern arose presenting data ruptures associated to periods of intense deforestation and advance of the pioneer frontier in Southern Amazonia. In fact, in 1994 Amazonian deforestation reached its highest levels in history, with more than 29.000 km^2 deforested (PRODES 2012). The results found in these ruptures (associated with years of intense deforestation) are in accordance with the time series techniques, tests and results of Espinoza-Villar (2009) and Lean et al. (1996) for the year of 1994.

3.2 Mann-Kendall test

In Online Resources 4 Table 1 Mann-Kendall annual test indicated that 35 RGs (17 %) of the 207 RGs presented negative trends and 10 RGs (5 %) presented positive ones. However, 162 RGs (78 %) did not indicate any tendency in the annual test. Notwithstanding 19 RGs (9 %) presented negatives trends and ruptures concomitantly with Pettitt test and 4 RGs (2 %) positive ones.

At monthly level Mann-Kendall trends were more significant. In April-May, seasonal trends were more numerous in the southeast region with 43 (35 %) of RGs presenting negative trends. In September-October, negative trends were more significant in the northwest for 29 RGs (24 %). Furthermore July analysis showed that 11 % of the RGs presented negative trends. A relevant number of RGs also suggested an increase in precipitation during the rainy season especially in December and March (Online Resource graph 4-A and map 4-B).

The above pattern might indicate a weaker rain recycling mechanism during the dry season and during season's transitions. Therefore an extension of the dry season and a reduction in the rainy season is possible as found in Fu et al. (2013). However, seasonal (monthly) changes were not followed by relevant changes in the annual analysis as seen in the MK annual test.

At monthly level we verified that Li et al. (2008) had identically identified a stronger seasonality component due to a longer dry season. Accordingly, climate-modeling studies developed by Nobre et al. (1991) and Davidson et al. (2012) depicted scenarios of strong precipitation reduction if deforestation patterns linger for the center-west and the southern-oriental parts of Brazilian Amazon.

MK seasonal test therefore indicated a concentrated and shorter rainy period and a longer and drier winter season, not followed by a change in annual total precipitation. These reductions were closely linked to late onsets and premature offsets denoting a longer dry season.

3.3 Linear regression analysis

The Linear Regression analysis results revealed that 136 of the RGs (63 %) had significant negative trends and 76 RGs (37 %) positive ones (annual values). The tendencies map (Online

Resources 5-B) indicated that the southern and southwest of Mato Grosso state and the southern part of Amazonas had the majority of positive trends. On the other hand, negative trends were observed coincidentally in regions strongly affected by deforestation (Spracklen et al. 2012; Rosolem 2005) in the northwest region of Rondônia, and in the north and southeast of Mato Grosso, and also in the north of Tocantins and Goiás.

3.4 Rainy season's onset and offset

The 89 RGs analyses results based on LB07 modified method indicated that the onset of the rainy season in TZAC was less uniform and had a heterogeneous spatial distribution when compared to the offset, which revealed a latitudinal north–south and longitudinal east–west gradient (Fig. 1). This is in agreement with the results of Arvor et al. (2014) who used satellite data products to investigate rainfall patterns and the onset and offset in Mato Grosso state. Our findings also identified a strong contrast of the latitudinal-longitudinal gradient between the Cerrado and the Amazon biomes, indicating that the onset of the rainy season was linked to the shift from north to south of the ITCZ, and to the development of SACZ from the beginning of September to end of November. These gradients are congruent with the development of the SASM system (of which both ITCZ and SACZ are part of), when low-level winds turn from east to west and from north to south between 0 and 20°S (Gan et al. 2004).

In Fig. 1 the interpolated ordinary exponential kriging map for the rainy season's onset and offset indicated the averages for the season. The onset as indicated in the top map occurred in the first half-month of August for the northern regions, and at the last half-month of September in the Cerrado and southwest of TZAC. In the daily analysis for the onset, the average indicated a maximum date of 234 (~21st of August) representing the season's onset in the Amazonian region and 288 (~14th of October) in the Cerrado.

For the offset (bottom map Fig. 1) the data indicated a latitudinal and longitudinal well-defined gradient suggesting a smooth climate transition from an equatorial to a more tropical climate. This offset gradient also depicts the retreat of the ITCZ and the SACZ. According to Gan et al. (2004), this latitudinal gradient can be explained by the shift from East-Southeast to West-Northwest of the South Atlantic Tropical anticyclone, which brings stable conditions in TZAC from June to September. The offset occurs in the first half-month of June in the northern regions (Amazon) and at the end of the first half-month of March in the Cerrado. As for the offset days, day 165 (~13th of June) is representative of the northern Amazonian region rain season offset, and day 95 (~4th of April) for the Cerrado.

The northwestern part of Mato Grosso and the northeastern part of Rondônia depicted strong differences in the onset of the rainy season even though they share the same latitude. Rondônia's northeast is nowadays largely deforested as opposed to the northeast Xingu's region of Mato Grosso state.

To understand the divisions between the rainy season onset and offset over distinct areas, characterized by distinct biomes, we separated the 89 RGs in latitude and territorial limits according to i's classification. In Online Resource 6-A Table 2 we depicted the RGs in the biomes latitudinal position, and also the onset and offset dates of the rainy season.

The cross-comparison among the RGs, biomes and latitudes showed that there were no significant differences in the average monthly or daily dates for the same biome or latitude. However, as identified in Fig. 1 there was a strong contrast in precipitation values when we distinguished between RGs located in the Amazon and in the Cerrado (considering the monthly and daily onset–offset values). If we compare these findings to the typical climatology

values for the region (Liebmann and Mechoso 2011; Marengo 2006; Foley and Costa 1999) we conclude that the method had performed well and had captured the daily, monthly and annual values for both rainy season onset and offset.

3.5 Rainy season climatic shifts and length

Considering the climatic shifts in the chronological series, MK test and LR analysis indicated a significant reduction in the rainy season's length between 1971 and 2010 (Online Resource 7 A-B). The major impacts are observed in the offset with 75 % (LR) and 76 % (MK) of the RGs with an earlier demise. The "S" value in MK indicated 6 % of strong negative trends for the offset. In opposition, 24 and 25 % RGs respectively had a later offset. For the onset analysis it has been detected that 61 % (LR) and 84 % (MK) of the RGs had a later onset, and 39 and 16 % showed, respectively, an earlier onset for LR and MK. From MK results, the "S" value in the onset indicated 7 % of positive and 7 % of strong negative trends.

Online Resource Maps 7-A and B indicate that later onset phases were observed throughout the whole area, with strongest values in southern areas. The earlier offsets were mainly (and strongly) observed over southern areas (Mato Grosso and Rondônia states). Conversely, early onsets and late offsets were mostly observed in forested regions. It seems that the season length decrease can be associated both to regional climate changes and local evapotranspiration and soil moisture depletion.

To check and clarify the results for the onset and offset using MK test and LR analysis, we calculated the number of days of the rainy season for each year and for each station during the period. Hence we confirmed that rainy season's length (based on the number of rainy days) has decreased in both analyses Fig. 2.

In MK test 88 % of the 89 RGs indicated a shorter rainy season. From those, 19 % had strong negative trends and 12 % positive ones. In the LR analysis 79 % RGs indicated a shorter rainy season and 21 % a larger one. If considered the biomes distribution for the LR analysis we notice a decrease in the rainy season for 34 % of the RGs in Amazonia and 44 % in the

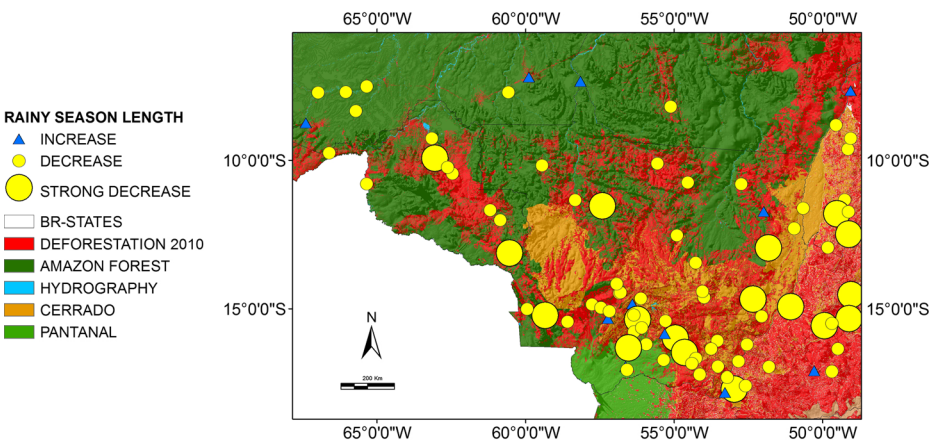


Fig. 2 Tendency of the Rainy seasons length during 1971–2010. *Small yellow circles* represent the RGs with negative trends for the rainy season's length; *larger yellow circles* represent a strong decrease in the rainy season's length; *blue triangles* indicate positive trend within the rainy season's length. There were no RGs depicting a strong increase in the rainy seasons length

Cerrado, and an increase in the rainy season for 9 % of the RGs in Amazonia and 13 % in the Cerrado. For MK test results we noticed a decrease in the rainy season for 36 % of the RGs in Amazonia and 51 % in the Cerrado, and an increase in the rainy season for 8 % of the RGs in Amazonia and 5 % in the Cerrado.

Lean et al. (1996) and Rosolem (2005) also identified a reduction in precipitation during the transition months in the deforested areas of the Arch of Deforestation in Amazonia. For these authors about 70 % of Mato Grosso's and Rondônia's rains are concentrated between November and March, thus a rainfall reduction in this transition seasons (between summer and austral winter) could emphatically diminish the annual hydric balance.

4 Conclusion

The 207 analyzed RGs depicted at least 2/3 of reduction in annual average precipitation depending on the analysis method. The tendency is significant for 94 RGs (45 %) during spring and autumn months according to Mann-Kendall monthly test, however, not significantly noticeable in the annual totals. The precipitation reduction in the rainy season is condensed in the onset and offset, affecting only modestly rainfall totals concomitant to Fu et al. (2013) findings.

RGs in deforested areas (more numerous in TZAC) indicated more negative than positive precipitation trends during the transition months. The onset-offset analysis suggested a reduction in rainy season's length for more than 88 % of the RGs in the 1971–2010 period, with a later onset and an earlier offset. The onset of the rainy season also revealed a heterogeneous pattern (late in the northwest of Rondônia and early in the MT Xingu's Indigenous reservoir central-northeast areas).

ENSO events and regional climatic variability related to large-scale atmospheric circulation help to explain ruptures and the tendencies during the transition seasons. However, at local and regional level the postponed onset and the premature offset (demise) of the rainy season are not fully explained by large-scale and climatic intra-seasonal variability. There were recurring patterns in the statistical tests displaying drier conditions in RGs localized in deforested areas opposed to forested locations. It might be that during the dry season, regions covered with forest are more capable to keep the energy in form of latent heat in the atmosphere-biosphere than typical Cerrado savannas or where deforestation has occurred (Machado et al. 2004; Costa and Pires 2010; Costa et al. 2007).

According to Fu and Li (2004) latent heat fluxes over the land surface are important sources of atmospheric humidity during the initial stages of the transition seasons and the dry period. Considering that the transition from dry to wet season in TZAC is initiated by fluxes of latent heat above the soil surface, and local vegetation variations in evapotranspiration, land surfaces could affect the amount of energy in the planetary boundary layer. These characteristics can corroborate to the convective energy available to precipitation processes in the atmosphere column with feedback in precipitation (Betts et al. 2008). Therefore, the increase in local precipitation derived by forest evapotranspiration can easily force the onset of the rainy season, which in turn, influences large-scale circulation processes affected by land and sea temperatures (Spracklen et al. 2012).

Normally in TZAC local and regional high humidity above forest canopy support latent heat fluxes which propitiate convection. Poorer conditions of latent heat flux due to forest cover loss or deforestation creates a more drier than usual troposphere thus prorogating the dry

season's onset (Schubert et al. 2004). In a context of a drier TZAC, the persistency of anomalies in soil moisture could lead to prolonged variations in the intensity of the regional water cycle causing droughts or floods (Schubert et al. 2004).

Deforestation however cannot be directly associated to climatic shifts in the rainy season's length; even though the role of evapotranspiration of forests is known to have an impact on the precipitation (Debartoli et al. 2012; 2013; Costa 2004; Makarieva et al. 2013). Contrasts observed in forest cover or deforested areas during the onset-offset of the rainy season analysis are yet to be submitted to further examination. Hypothesis considering deforestation impacts on rainfall should contemplate additional tests encompassing forest cover and deforestation areas through remote sensing methods allied to rainfall data.

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