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Extreme Drought Events over the Amazon Basin: The Perspective from the Reconstruction of South American Hydroclimate

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Abstract: The Amazon basin has experienced severe drought events for centuries, mainly associated with climate variability connected to tropical North Atlantic and Pacific sea surface temperature anomalous warming. Recently, these events are becoming more frequent, more intense and widespread. Because of the Amazon droughts environmental and socioeconomic impacts, there is an increased demand for understanding the characteristics of such extreme events in the region. In that regard, regional models instead of the general circulation models provide a promising strategy to generate more detailed climate information of extreme events, seeking better representation of physical processes. Due to uneven spatial distribution and gaps found in station data in tropical South America, and the need of more refined climate assessment in those regions, satellite-enhanced regional downscaling for applied studies (SRDAS) is used in the reconstruction of South American hydroclimate, with hourly to monthly outputs from January 1998. Accordingly, this research focuses on the analyses of recent extreme drought events in the years of 2005 and 2010 in the Amazon Basin, using the SRDAS monthly means of near-surface temperature and relative humidity, precipitation and vertically integrated soil moisture fields. Results from this analysis corroborate spatial and temporal patterns found in previous studies on extreme drought events in the region, displaying the distinctive features of the 2005 and 2010 drought events.

Keywords: extreme droughts; Amazon; downscaling; precipitation assimilation; hydroclimatology

1. Introduction

Drought is a widespread phenomenon and affects most ecosystems, even those considered as humid biomes with high precipitation rates such as Amazonia [1,2]. Several studies have shown that anthropogenic activities associated with the conversion of natural vegetation into pasture and agriculture, fire practices, and climate variability may interact and enhance the occurrence of hydroclimate extremes such as droughts in the Amazon Basin (henceforward AB) [3–6]. Recent studies reveal that the Amazon rainforest is more vulnerable to future droughts than other tropical forests [7]. Accordingly, there is an increasing concern about loss of forest and ecosystem services together with climate impacts due to extreme droughts due to the large geographic extent of the AB, together with its influence in global biogeochemical cycles and the presence of high levels of biodiversity in the region.

Several studies indicate that the region has been suffering severe drought since the end of the last century, as in 1997/1998, 2005, 2010 and 2015 [8–11]. The intensity and frequency of these extreme drought episodes in the AB during the last years, approximately one episode every five years with a significant increase in the coverage area, is remarkable [8]. However, each of these extreme episodes was dominated by different circulation regimes, and consequently, varied markedly in terms of

temporal intensity and spatial patterns [11–14]. Drought events in the Amazon basin are associated with teleconnections due to El-Niño Southern Oscillation and/or tropical North Atlantic sea surface temperature (SST) anomalous warming [15–17]. 1998's drought was related to both teleconnections but especially to the strong El Niño of 1997–1998 and affected northern and eastern areas of AB [18]. Meanwhile, 2005's drought was related to the elevated warming in the tropical North Atlantic SST, and its epicenter was in the west of the basin; 2010's event was related to both teleconnections and occurred in a larger area of the basin having three different epicenters: west, northwest, and southeast areas [19,20]. 2015's drought was related to the El-Niño Southern Oscillation and had precipitation deficit through the whole basin but particularly in the eastern area [8,10].

Traditional methods of drought assessment and monitoring depend heavily on rainfall data as recorded in meteorological and hydrological networks. However, the availability of reliable modeling datasets covering wide regions over long periods of time has progressively strengthened the role of climate models outputs in environmental studies, in particular in those related to drought episodes [21]. Both general circulation and regional models have improved in recent years in terms of depiction of processes and phenomena to address impacts of global climate change [22]. Part of this breakthrough comes from increased spatial resolution and part comes from the inclusion of climate controls from new system components and their interaction. The use of regional downscaling of general circulation models provides a technique to generate more refined climatic information on extreme events through better representation of physical processes [23,24].

In such context, the Satellite-Enhanced Regional Downscaling for Applied Studies (henceforth SRDAS) product has been used in the analysis of South American hydroclimate, with hourly to monthly outputs from January 1998 to the near present, with continuous assimilation of satellite-based precipitation estimates [25]. In the current study, SRDAS is used in the analyses of the drought episodes of 2005 and 2010 in the Amazon basin and corresponds to a 16-year numerical integration of a regional modeling system driven by the six hourly outputs a global reanalysis. Most of the features of larger synoptic to planetary waves from the global reanalysis are maintained in SRDAS through scale-selective bias correction, which is comparable to the spectral nudging technique from [26].

Accordingly, recent drought events (i.e., 2005 and 2010) provide a unique opportunity for assessing how SRDAS is able to reproduce the shifts in the amount and distribution of Amazonian rainfall and other drought-related variables, in turn quantifying the sensitivity of this regional reconstruction in replicate changes in oceanic modes such as ENSO and the Atlantic Multidecadal Oscillation (AMO) under the current trend of climate warming.

2. Materials and Methods

2.1. Data and Products

2.1.1. Station Data

Observational monthly precipitation and temperature fields for this study are from National Institute of Meteorology (*Instituto Nacional de Meteorologia*—INMET) and Airspace Control Institute (*Instituto de Controle do Espaço Aéreo*—ICEA), both in Brazil. Table 1 describes the meteorological stations used in the analysis, located near the epicenters of each one of the droughts in three different states in Brazil, namely Coari in Amazonas (AM), used in the characterization of the 2005 drought, and Cruzeiro do Sul, in Acre (AC), located in the western epicenter of the 2010 drought, within the time interval of 1981–2010. Both INMET's stations, the ICEA station, Vilhena, in Rondônia (RO), was selected for the analysis of the southeastern epicenter of the 2010 drought. These meteorological station datasets have different available periods, for instance Coari and Cruzeiro do Sul are available from 1961 to the beginning of 2016, and Vilhena only from 1971 to October of 2015. In order to allow a comparison between them, we have selected the period from 1981 to 2010, which is defined by the World Meteorological Organization as the base period of the current climate. The precipitation and temperature records were analyzed and the percentage of missing values was computed along the

entire time series. The obtained percentage of missing values was up to 7.30% for all stations, not hindering the climatological anomaly analysis.

Table 1. Station description and representativeness.

SID ¹	Name (State Code)	Altitude (m)	Longitude	Latitude	Drought Epicenter
81770	Coari (Amazonas)	34	63.15° W	4.10° S	2005
81881	Cruzeiro do Sul (Acre)	220	72.68° W	7.61° S	2010
83208	Vilhena (Rondonia)	605	60.06° W	12.42° S	2010

¹ Station Identification Code (SID).

2.1.2. Regional Modeling System and Satellite-Based Products

SRDAS is available over South American domain (93.6° W–25.8° W and 20.4° S–42.6° S), with atmospheric and surface initial conditions on 1 January 1998 at 0000 UTC, hourly outputs from 1000-hPa to 10-hPa levels and with horizontal resolution of approximately 25 km. The regional spectral model (RSM) [27] is the atmospheric model used in SRDAS, with the new version of scale-selective bias correction (NSSBC) already implemented in RSM [28], and driven by the six hourly outputs from the National Centers for Environmental Prediction–Department Of Energy (NCEP–DOE) R2 global reanalysis [29], except for the SST fields, which are updated daily from the product Optimum Interpolation SST at $\frac{1}{4}$ -degree resolution, version 2, based on satellite SST from only the advanced, very high-resolution radiometer (AVHRR) [30].

Most of the features of larger synoptic to planetary waves from NCEP–DOE R2 are maintained in SRDAS through NSSBC, which is mainly applied to the rotational part of the wind field. The continuous assimilation of the three-hourly satellite-based precipitation estimates, obtained from the Climate Prediction Center Morphing technique (CMORPH) [31], is also included in RSM [25] to primary correct the representation of the deep convection in SRDAS, however atmosphere–land surface interactions are also expected to be enhanced.

Ultimately, both NSSBC and the precipitation assimilation scheme (henceforward PA) are employed to improve the RSM long-term integrations. In SRDAS, the RSM version is that coupled to the four-layer Noah Land Surface Model (Noah LSM) [32]; and NCEP–R2 provides the atmospheric and land surface initial conditions to RSM and Noah LSM, respectively.

2.2. Methodology

The study region corresponds to the Amazon Basin (Figure 1) which has an area of about 6.3 million km²—approximately 5 million km² in the Brazilian territory and the remainder divided among other South American countries, such as Peru (17%), Bolivia (11%), Colombia (5.8%), Ecuador (2.2%), Venezuela (0.7%), and Guyana (0.2%).

In this study, monthly means of precipitation, 2-m above the ground air temperature and relative humidity, and 4-layer integrated soil moisture from January 1998 to December 2013 are computed over the region of 80° W–51° W and 6° N–21° S, using the SRDAS hourly outputs. The SRDAS monthly means are averaged over three distinctive regions located north (1), west (2) and southeast (3) in the Amazon basin, as displayed in the study area (Figure 1), which also exhibits the elevation in meters of the entire study domain, as well as the station sites. The choice of each subregion from Figure 1 was made based on each drought epicenters as described in previous studies [8,19,33]. Monthly values were used to calculate the long-term means and standard deviations, which were then used to obtain standardized anomalies for each month. To smooth short-term fluctuations out, the five-month running mean is applied in the time series of standardized anomalies calculated over each of the three regions. Comparisons with selected station data located in each of the three regions are performed to establish SRDAS reliability to depict the drought-patterns along, taking into special attention the droughts of 2005 and 2010, with the spatial distribution of the anomalies computed from the monthly means over the Amazon basin. We only analyze the months with the lowest anomalies in precipitation, soil

moisture, and relative humidity, and with the highest temperature anomalies, considering the lag between the responses of the atmosphere and the surface conditions.

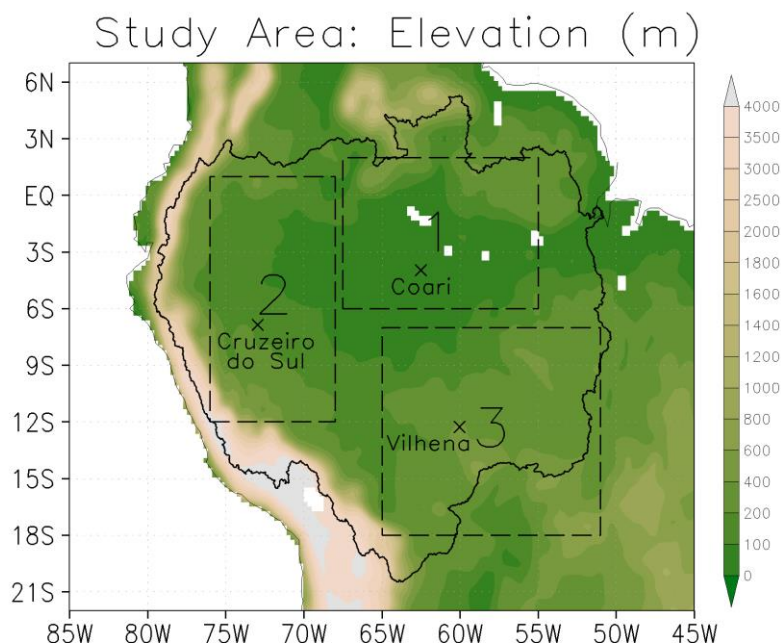


Figure 1. Study area elevation (m) from the Satellite-Enhanced Regional Downscaling for Applied Studies (henceforth SRDAS). Delimited with boxes (dashed lines) are regions north (1), west (2) and southeast (3) in the Amazon basin. Station sites are marked with “X”, namely: Coari (AM), Cruzeiro do Sul (AC), and Vilhena (RO).

3. Results

Here, the 2005 and 2010 droughts in the Amazon basin are characterized using the interannual and intra-annual variability of precipitation and near-surface temperature from the three available meteorological stations, namely, Coari, Cruzeiro do Sul, and Vilhena; and the SRDAS outputs for the regions 1, 2, and 3, including relative humidity and soil moisture. The three stations are inside the drought epicenters of the 2005 (Coari) and 2010 (Cruzeiro do Sul and Vilhena), as reported in previous studies [19,20,33,34].

Results from in situ measurements pointed to the existence of negative precipitation and positive temperature standardized anomalies from early 2005 and 2010, intensified during the winter (Figure 2). Coari (green curve) had positive near-surface temperature anomaly throughout the year of 2005, reaching its maximum in June whereas its minimum in precipitation anomaly was in July. Precipitation (temperature) anomalies greatly oscillated during the year 2010 in Cruzeiro do Sul (blue curve), mostly with negative (positive) values, with June (September) being the most extreme month associated with drought conditions. The lowest oscillation in the precipitation anomaly was registered during the drought season in Vilhena (red curve), and September was the month showing the highest air temperature anomaly value, as reported by [20] when analyzing the 2010 drought epicenters using remote-sensed land surface temperatures. Although the two methods to determine the temperature fields are different, there is still strong relationship between them [35]. The SRDAS product from the 1999–2013 base period shows the same precipitation and temperature interannual variability for each drought epicenter (Figure 3).

In situ measurements of relative humidity and soil moisture are not available for none of the three ground stations considered here. Nevertheless, as expected, SRDAS shows negative relative humidity and soil moisture anomalies during the two extreme drought events. Dryness of the soil is usually a result of an extended period of severe rainfall deficit and prolonged low levels of relative humidity, and high incoming solar radiation [36,37]. Strong radiative anomalies due to clear sky conditions were

observed in the region during the 2005 and 2010 drought events [8], leading to extremely dry soil conditions such as the ones observed in SRDAS during the 2005 and 2010 droughts (Figure 3).

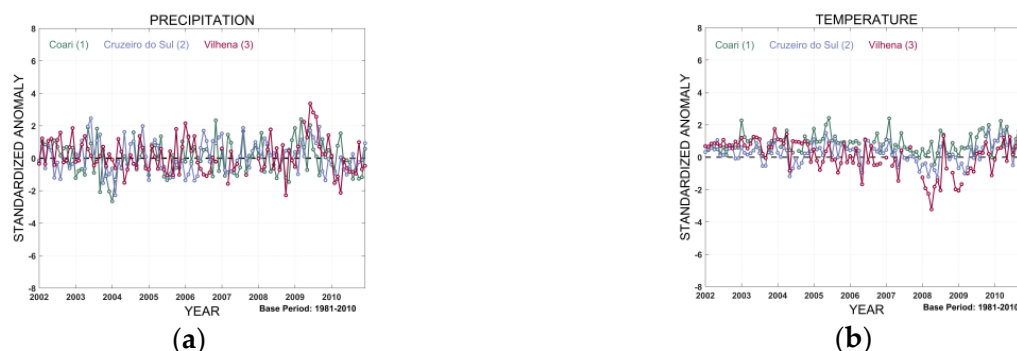


Figure 2. Standardized anomaly of observed: (a) precipitation and (b) temperature at the following station sites: Coari in Amazonas (AM) (green curve, for 2005), Cruzeiro do Sul in Acre (AC) (blue curve, for 2010) and Vilhena in Rondônia (RO) (red curve, for 2010). Monthly mean and standard deviation calculated over the base period 1981–2010.

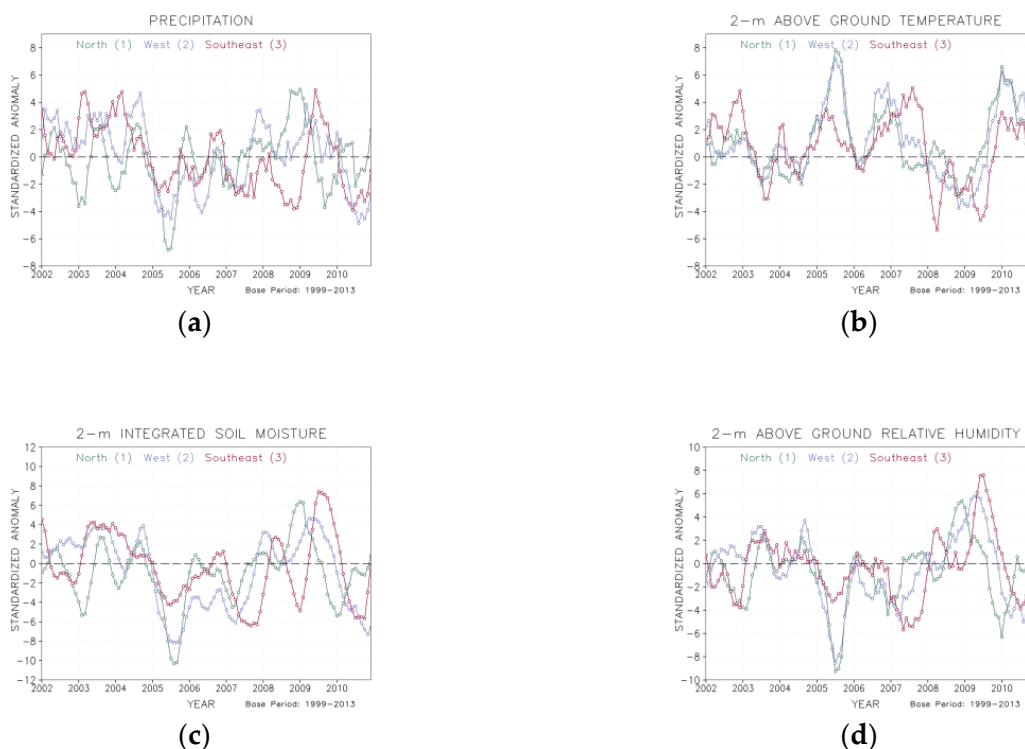


Figure 3. The standardized anomaly of: (a) precipitation; (b) temperature at 2-m above ground; (c) vertically integrated soil moisture; (d) relative humidity at 2-m above the ground as modeled by SRDAS. Monthly means are averaged over the following regions: north (area 1, green curve), west (area 2, blue curve), and southeast (area 3, red curve) in the Amazon basin, as delimited in Figure 1. Monthly mean and standard deviation calculated over the base period 1999–2013.

We analyzed the intra-annual variability of precipitation and temperature based on the historical distribution in each one of the three epicenters, considering the 1981–2010 period for the meteorological station datasets (Figures 4–6) and the 1999–2013 period for the SRDAS dataset (Figures 7–9). For the meteorological station datasets (Figures 4–6) each monthly boxplot represents the historical distribution for the 1981–2010 period. For the SRDAS (Figures 7–9) each monthly boxplot represents the historical distribution for the 1999–2013 period. Thus, each boxplot represents the minimum value (the whisker below the box), the 1st quartile (the base of the box), the median or 2nd quartile (the line inside the

box), the 3rd quartile (the cover of the box), the maximum (the whisker above the box), and the outliers (the values below or above the difference between the 3rd quartile and the 1st quartile multiplied by 1.5) of each historical distribution. The seasonal variability for the year of 2005, based on the 1981–2010 period of observed data, indicated monthly precipitation values above the median for almost half year. In particular, from February to May, monthly precipitation values were below the 1st quartile for almost the entire drought season from June to September when most of the events happen, reaching the inferior limit in July (0.57 mm/d) (Figure 4a). Contrarily, the temperature was above the third quartile for the whole year and, even though it decreased in July when compared to June, it reached its maximum (28.56 °C) in August (Figure 4b).

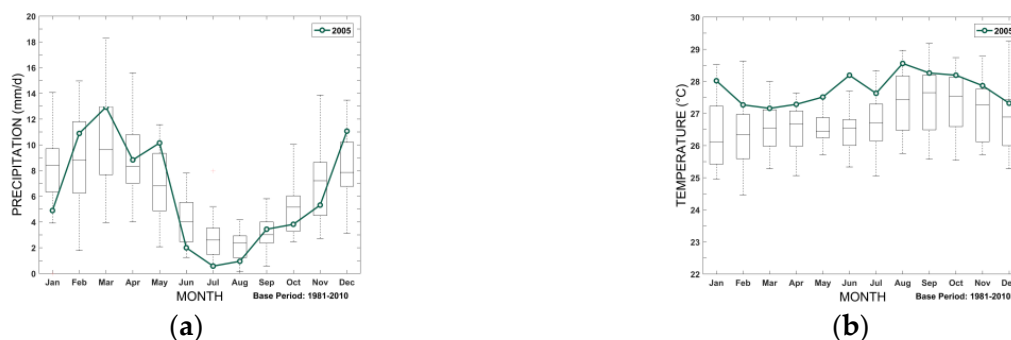


Figure 4. Intra-annual variability of observed: (a) precipitation (mm/d) and (b) temperature (°C, right panel) monthly values at the Coari station in Amazonas (AM). Each monthly boxplot represents the historical distribution for the 1981–2010. The green curve depicts the above variables for the year of 2005.

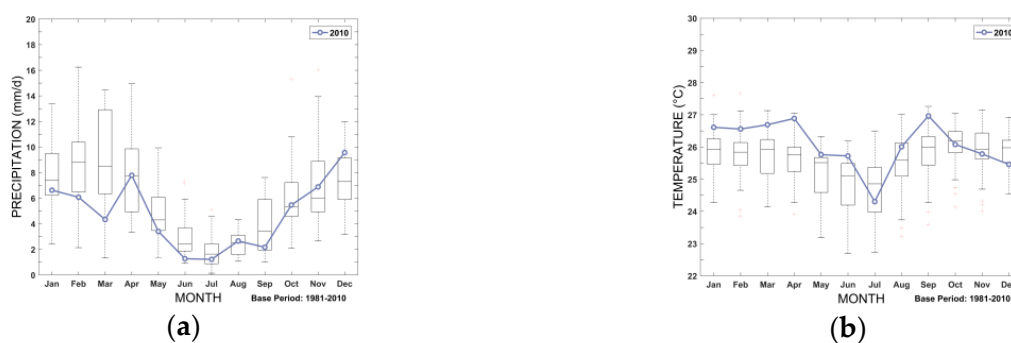


Figure 5. The same as Figure 4 but for Cruzeiro do Sul station in Acre (AC) and for 2010 (blue curve).

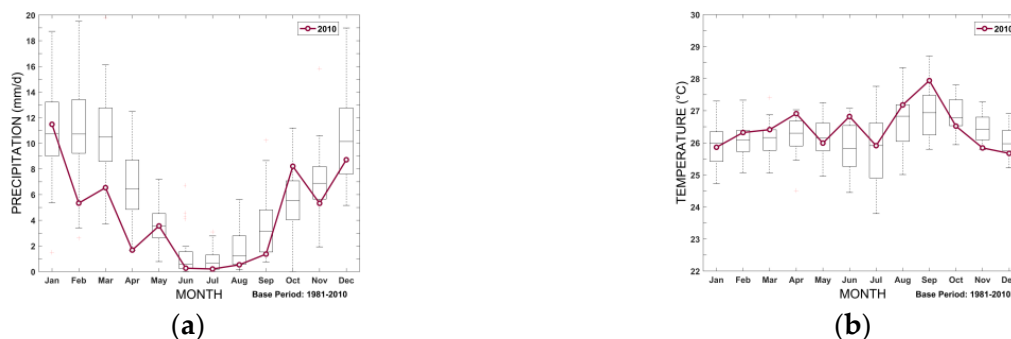


Figure 6. The same as Figure 4 but for Vilhena station in Rondônia (RO) and for 2010 (red curve).

The SRDAS product shows similar configuration for precipitation and temperature from observed data, but with lower (higher) precipitation (temperature) variability during the whole year of 2005. In agreement with Coari station, SRDAS had the lowest precipitation value in July (Figure 5a). For the 2-m temperature, the month with the highest value was September followed by August in SRDAS,

whereas at the station site, the maximum in temperature occurred in August (Figure 4b; and Figure 7b). The 2-m soil moisture showed a lag from both variables, reaching its minimum in October (Figure 7c). In 2005, from May to November, 2-m soil moisture values were below the minimum limit of the month (Figure 7c). The relative humidity reached the lowest value in September (Figure 7d) in agreement with the highest temperature value in the same month.

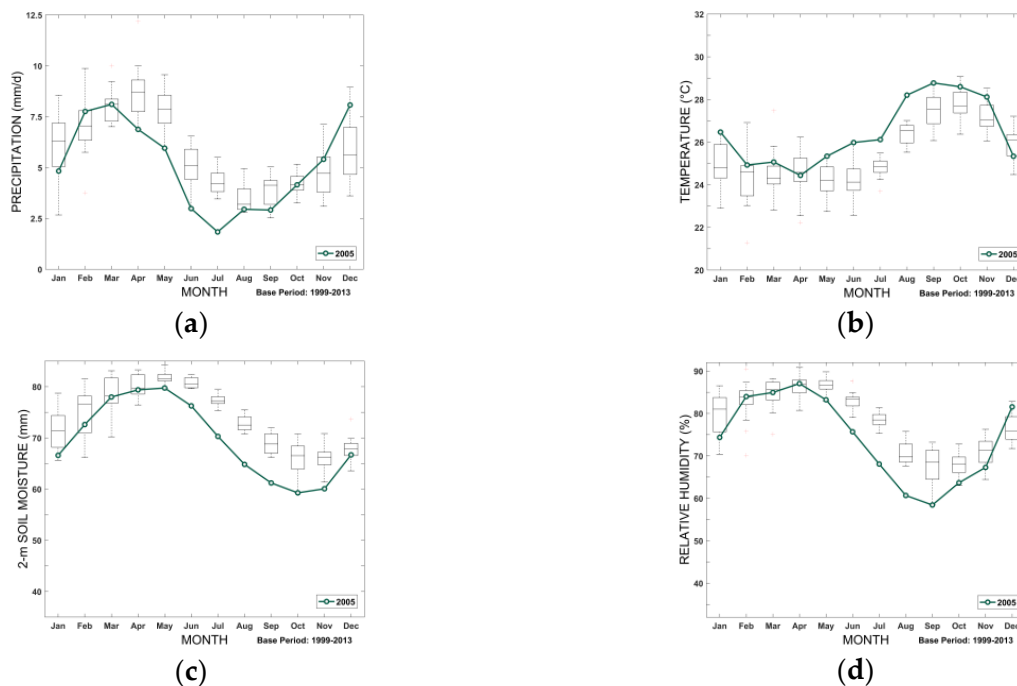


Figure 7. Intra-annual variability of SRDAS variables over the northern region (area 1 from Figure 1): (a) precipitation (mm/d); (b) temperature at 2-m above ground (°C); (c) 2-m integrated soil moisture (mm); and (d) relative humidity at 2-m above de ground (%). Each monthly boxplot represents the historical distribution for the 1999–2013. The green curve depicts the above variables for the year of 2005.

In the 2010s, in the western epicenter, precipitation was below the first quartile for almost the entire drought season, except for August. Although the lowest values happened in June and July, September exhibited precipitation near the first quartile and was the month with the highest temperature value (Figure 5). Differently from the observed data, SRDAS showed decrease in precipitation from March to August, the latter being the month with the lowest value in 2010. Although September had slightly increased precipitation in comparison with August, its value was still below the inferior limit (Figure 8a). SRDAS displayed similar temperature variability in comparison to the station, with the highest temperature value in September (Figure 8b), and above the third quartile from February to October. The 2-m vertically integrated soil moisture had the lowest value in October, showing two-month lag from the lowest value in precipitation and a month lag from the highest temperature value (Figure 8c). The 2-m relative humidity lowest value occurred in September as the highest value in temperature (Figure 8d), however their intra-annual variability showed better agreement in the northern area.

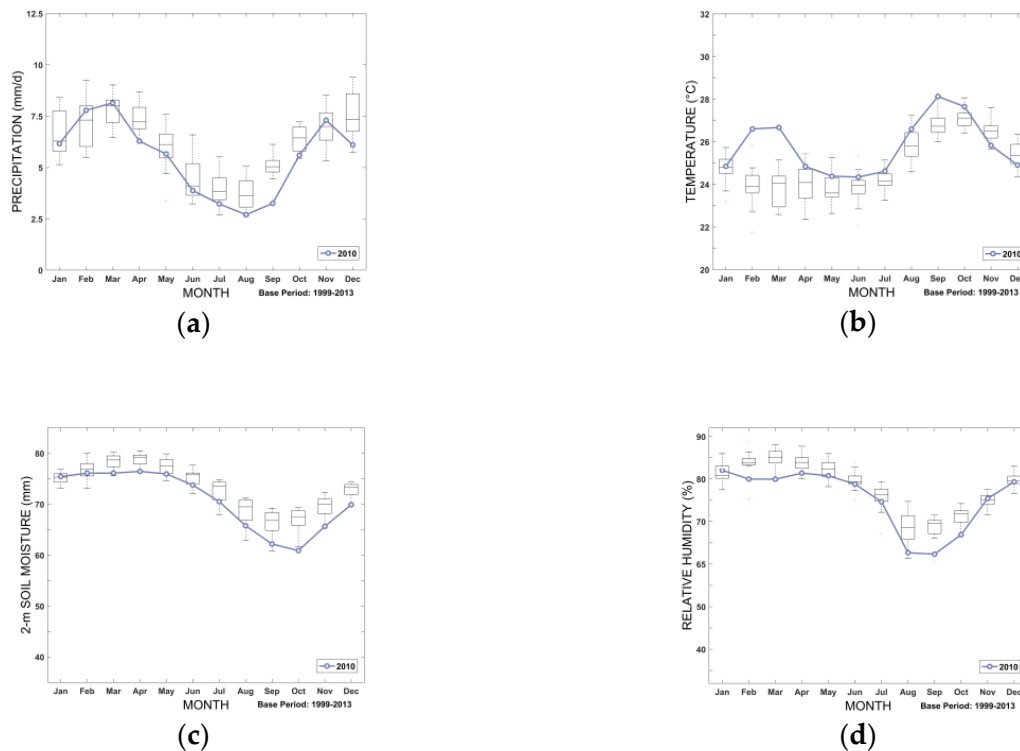


Figure 8. The same as Figure 5 but for the western region (area 2 in Figure 1) and for 2010 (blue curve).

In the southeast area, precipitation exhibited large variability throughout the year 2010, however was close to zero during the drought season in both station and SRDAS datasets (Figure 6a; and Figure 9a). In contrast to the other two areas, the intra-annual variability of the SRDAS temperature showed less agreement with the observed data, but reached its peak in September as in the observation, surpassing the maximum limit and the third quartile, respectively (Figure 6b; and Figure 9b). For the 2-m soil moisture, a three-month lag from the precipitation minimum was seen in this area, with the lowest value occurring in September (Figure 9c), which was also the month with the highest temperature value. Similarly, the 2-m relative humidity also had the lowest value in September (Figure 9d).

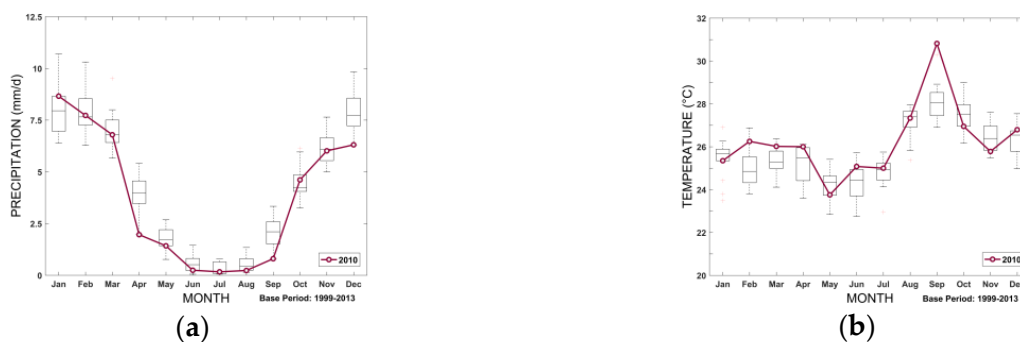


Figure 9. Cont.

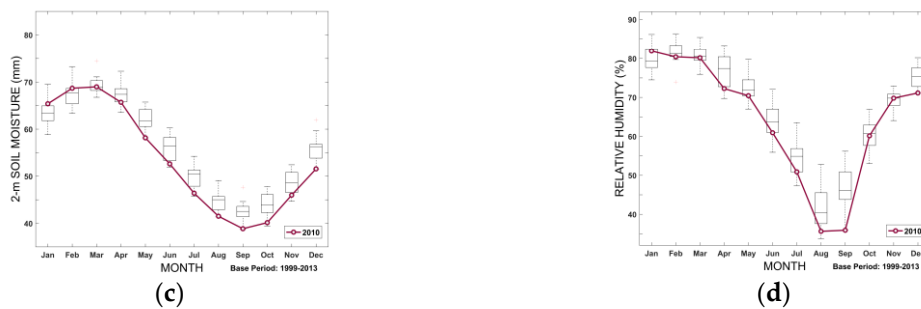


Figure 9. The same as Figure 7 but for the southeastern region (area 3 in Figure 1) and for 2010 (red curve).

The SRDAS precipitation (2-m temperature above ground) values are averaged over an entire region what might explain the lower (higher) values of precipitation (2-m temperature above ground) in comparison with the observed values at station sites.

The following analysis of spatial distribution of the SRDAS anomalies was performed only for the months exhibiting the most extreme drought conditions for each station (Figures 4–6) and SRDAS (Figures 7–9). The 2005's drought had its driest month in July for precipitation, and the lowest relative humidity and the highest temperature anomaly values in September, as previously discussed in this section; and soil moisture showing a month lag from temperature and three-month lag from precipitation, with the lowest anomaly value in October (Figure 10). The area 1 (seen in Figure 1) showed the anomaly lowest/highest values for the four analyzed variables along with part of area 2. In contrast to the 2005's drought, the 2010's drought occurred in a larger area of the AB, starting in the north and ending in the southeast, but the deficits in precipitation and soil moisture happened in the west (Figure 11a,c) whereas higher temperature values and the relative humidity deficit were observed in the basin's southeast region (Figure 11b,d).

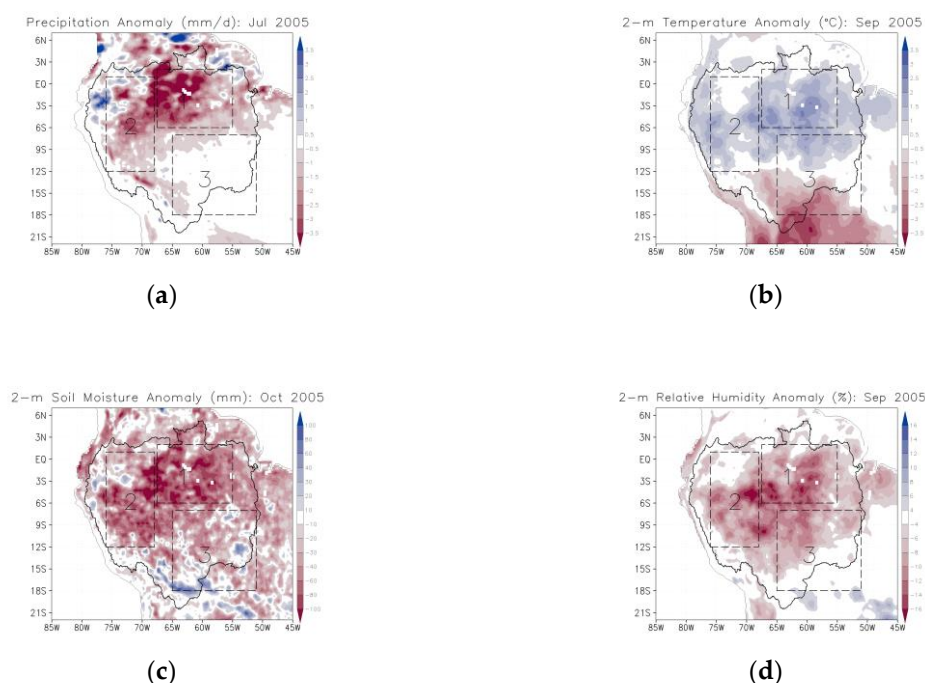


Figure 10. The 2005 drought anomaly fields of: (a) precipitation in July (mm/d); (b) temperature at 2-m above ground in September (°C); (c) 2-m integrated soil moisture in October (mm); (d) relative humidity at 2-m above ground in September (%). Boxes (dashed lines) delimit areas: north (1), west (2), and southeast (3). Solid black contour encompasses the Amazon basin.

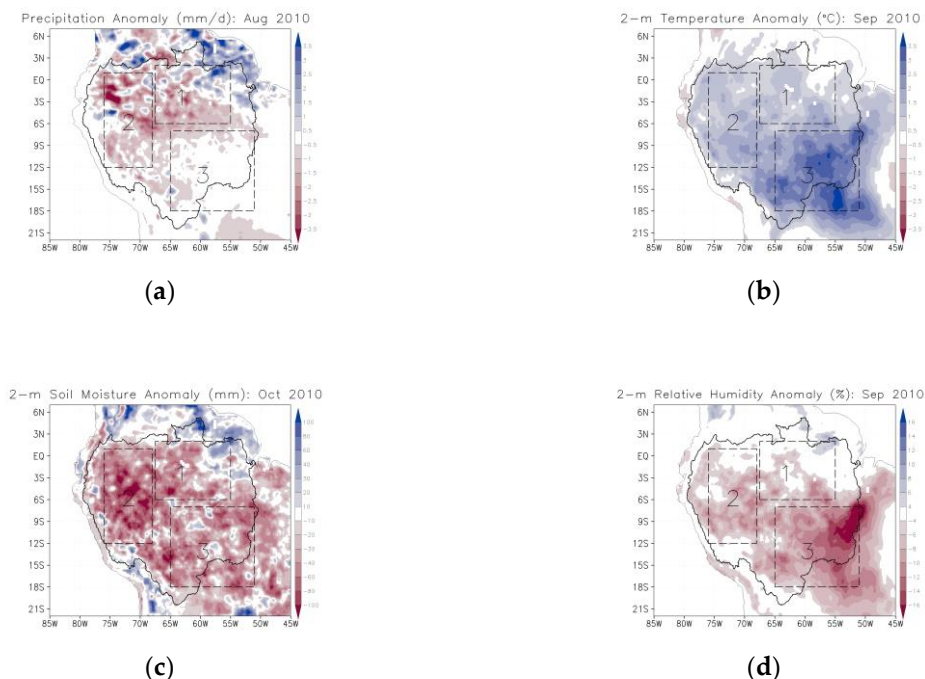


Figure 11. The 2010 drought anomaly fields of: (a) precipitation in August (mm/d); (b) temperature at 2-m above ground in September ($^{\circ}\text{C}$); (c) 2-m integrated soil moisture in October (mm); (d) relative humidity at 2-m above ground in September (%). Boxes (dashed lines) delimit areas north (1), west (2), and southeast (3). Solid black contour encompasses the Amazon basin.

4. Discussion

Climate projections point out to an intensification of El Niño–Southern Oscillation- and AMO-related anomalies impacting the Amazon, including an increased frequency of extreme droughts due to the global warming [38,39]. The tropical forests sustain the hydrological cycle through evapotranspiration, contributing to physical, chemical and biological processes and feedbacks, which non-linearity may buffer or amplify climate changes [40]. Furthermore, recent studies have shown that the Amazon Basin in the beginning of the 21-century have had an unprecedented number of extreme drought events [8,11,16,19] and undergone a large-scale conversion of forests into pasture and cropland over the last decades [41–43], thus altering the land–atmosphere interface and contributing to changes in the regional and local hydrological cycle [44–46]. Deforestation and land use process over the region are associated with fire practices, increasing atmospheric aerosol concentrations, which in turn promote feedback mechanisms between clouds and precipitation [47,48], thus contributing to changes in the water cycle. The interaction between temperature trends, deforestation and extreme events in the last centuries reveals an intensification of the Amazon hydrological cycle since 1990 [49], beyond the natural variability [50]. Evidence of external ocean forcing in the Amazon’s hydroclimate shows that both equatorial Pacific and tropical Atlantic SST anomalies are correlated with many variables that influence the Amazon basin [51,52]. As stated by Panisset et al. [8], different physical climate mechanisms were responsible for the contrasting spatial patterns of the 2005 and 2010 droughts. Because the 2005 drought has been associated with the tropical North Atlantic SST anomalous warming, its core of the precipitation, humidity, and soil moisture deficit was mainly over the western part of the AB whereas the eastern sector was less impacted exhibiting normal conditions and positive anomalies. The warming of the North Atlantic Ocean induces changes in the north-south divergent circulation, the weakening of the northeast trade winds and the moisture fluxes due to the northward shift of the Intertropical Convergence Zone (ITCZ) [11]. Consequently, resulting in less precipitation over the western AB as shown in previous studies [8,14,19,53] as the most severe of the last 100 years, the 2005 drought occurred in the western and southern area of AB, but also in the northern area as

corroborated by the SRDAS product. Previous studies detected the highest precipitation deficit in the southwestern area of the basin [19], SRDAS also indicates drought occurrence in this region, albeit the minimum in precipitation during the dry season appears mainly in the northern area of AB, decrease in precipitation can be seen in the western area as well. Even though the detected drought core by SRDAS differs slightly from previous studies, the product indicated that the winter season was abnormally hot and dry with rainfall reaching the climatological first quartile. Departures from the month presenting the extremes in precipitation and temperature from the SRDAS results when compared to in situ data are due to the spatial differences because the observed data are from stations located in the delimited drought area, and the SRDAS product corresponds to an average over the whole regions 1, 2, and 3 (Figure 1).

The drought event of 2010 was more spatially extensive than the former, presenting another epicenter in the southeastern region besides the northwestern/western epicenter [15,20,33,54]. The northwestern/western epicenter of the drought of 2010 are attributed to AMO, whereas the southeastern one is related to a moderate to strong warming of the Pacific SST during a positive ENSO event [20]. This warming of Pacific SST induces changes in the west–east Walker circulation, reflecting dry conditions over Eastern Amazonia due to the subsidence that inhibits rainfall over the region [10,55]. According to our results, the 2010 drought was associated with reduced precipitation, humidity, and soil moisture and extreme temperatures over the west and southwest AB but also over the southeast sector. SRDAS showed that the precipitation deficit occurred mainly in the western region where a larger area of negative anomaly of soil moisture was found, with maximum detected in almost the whole area 3.

Changes in soil moisture rely on modification not only of relative humidity (shown in Figures 10 and 11) in which the maximum deficit occurred in the same area, especially in the 2005 drought, with 1-month lag, but as well as precipitation anomalies, which precede the soil moisture deficits [4–6,33,56–59]. SRDAS shows that precipitation returns back to normal or above normal conditions on the same or following month of the soil moisture minimum, and temperature shows a distinct positive anomaly at the drought peak. SRDAS also detects the relation between higher temperature values and lower relative humidity in both drought events that favors the occurrence and propagation of fire [60,61]. Although SRDAS and the Gravity Recovery and Climate Experiment (GRACE) observe different parameters (SRDAS uses only the soil moisture, and GRACE uses the integral of surface water, soil moisture, and groundwater), it is interesting to compare both results. When compared SRDAS integrated soil moisture with GRACE terrestrial water storage shown in [53], for the 2005 drought, GRACE shows its minimum in August/September and the month that represents it in SRDAS is October but, in 2010, both of them show a minimum in October, during the drought peak in different regions though [62]. The SRDAS precipitation showed consistency to previous studies [11] that exhibited daily minimum rainfall (GPCP) values during the dry season to both of the droughts. The 2005 drought had the minimal influence of temperature differently from the 2010 drought, which experienced extreme temperature anomalies in the western area of the basin, and it was also proved by SRDAS, but in area 3 [8].

5. Conclusions

Traditional methods of drought assessment and monitoring depend heavily on rainfall data as recorded in meteorological and hydrological networks. However the availability of reliable satellite imagery covering wide regions over long periods of time has progressively strengthen the role of remote sensing in environmental studies, in particular in those related to drought episodes [8,63]. Accordingly, the aim of SRDAS is to provide long-term downscaled fields from global reanalyses over South America taking advantage of the spatial and temporal coverage of the remote sensing products. Here we show that the newly released reconstruction of South American hydroclimate, corroborates previous studies on the intensity and location of the 2005 and 2010 droughts in the Amazon Basin [8,11,16], therefore contributing to the analysis of environmental disasters and risk

assessment in areas with sparse gauge data. Indeed, the SRDAS temperature and precipitation anomalies showed consistency with in situ observations along each drought epicenter. The results show that the product can identify similar and divergent spatiotemporal patterns of the two different extremes from 2005 and 2010 [8]. The SRDAS product makes use of the data assimilation improvements brought from the coarse-resolution R2, through the use of a new scale-selective bias correction, mainly applied to the rotational component of the horizontal wind [25]. Thus, the SRDAS concept of combining regional models and the assimilation of remote sensing products shows to be useful to the analyses of extreme climate events, such as drought in Amazon region.

Moreover, the product showed the capacity of recognizing the N-SE propagating pattern of the 2010 drought. NSSBC maintains synoptic to planetary waves from the NCEP-R2 boundary conditions nearly unchanged in the inner domain of SRDAS. Therefore, planetary modes, such as ENSO and AMO, are expected to influence the SRDAS hydrometeorological variables. Thus, our results highlight the ability of this product to reproduce the effects of the two main teleconnections mechanisms responsible for drought occurrence over the region, namely the ENSO and AMO.

Albeit in situ measurements of soil moisture are unavailable for the ground station analyzed here, the one-month lag in soil moisture anomalies detected by SRDAS over the drought episodes is in accordance to the literature. Precipitation assimilation of satellite-based products is an essential feature of SRDAS that provides more accurate high-resolution gridded variables to better reproduce the Amazon extreme droughts, especially the soil moisture, which isn't represented well in global hydrology and land surface models [64].

There is an increasing concern about loss of forest and ecosystem services due to extreme drought occurrence in the Amazon basin. Deforestation, fire and climate change have been reported as primary agents altering hydrological cycle in the region [44,45,65,66]. Such interactions among anthropogenic pressures, climate changes, and forest responses present potential positive feedbacks that may increase forest degradation and loss [67]. Despite this, drought should be recognized as having an important impact—patterns of drought incidence need to be further studied to allow for resources for innovative ideas for drought monitoring and environmental policies. Such concerns support the need to provide reliable drought information. Here we show that the newly released reconstruction of South American hydroclimate provides baseline and refined information for most of actors involved in the drought management process, such as precipitation, temperature, soil moisture, and relative humidity. This is a preliminary analysis that requires further research aiming to evaluate the differences between the SRDAS product and global reanalysis datasets, as well to include other in situ and remote sensing-based indicators (e.g. soil moisture, cloud cover) and to better understand the advantages and caveats of the newly released hydroclimate reconstruction in reproducing Amazon drought patterns. Finally, in 2015, a new record-breaking drought related to a strong El-Niño event also took place in the Amazon Basin and thus further requires more research in the context of the SRDAS response to these extreme events.

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