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Local rainfall trends and their perceptions by Amazonian communities

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Abstract Climate change in the Amazon region is the subject of many studies not only due to its stance as an emblematic ecosystem but also as a region where changes have been dramatic for over 30 years, mainly due to deforestation. We investigate how people settled in the Amazon perceive environmental changes by comparing these perceptions with satellite rainfall data for 12 sites representing the community diversity in the region. Perceptions are varied and agreement with physical, measured data is not always good. However,

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the arc of deforestation, where the downward trend of rainfall is more strongly observed, also appears as the region where the populations have the highest perception of rainfall change.

1 Introduction

The Amazon region is one where climate change is closely monitored due to its role in the major global cycles of water and carbon (e.g., Gash et al. 1996; Betts et al. 2004). In this region lives an heterogeneous population consisting of ancient Amerindian and traditional communities, exploiting forest and river resources, as well as migrants from the pioneer front that transform rural areas and develop new urban centers (Dubreuil 2002; Fearnside 2005; Arvor et al. 2012).

An initial phase of intensive and predatory modes of development in the period of 1970–1990 was followed by a phase where sustainable development experiments proliferated (Le Tourneau and Droulers 2010). However, living conditions remain precarious especially in rural areas despite rapid economical development, and environmental impacts continue to increase; thus the overall sustainability of the Amazon remains questionable. The magnitude of changes in Amazonia—deforestation, agricultural colonization, soil erosion, and biodiversity loss—has highlighted issues related to the region's sustainable development strategies. According to different models, nearly 40% of forest areas could disappear by 2040 if government policies remain as they were until the early 2000 (Laurance et al. 2001; Nepstad et al. 2014). The impact of these changes on the environment are already emerging with local and regional climate change (e.g., Cook et al. 2012; Nobre et al. 2016, and references therein) and with the disappearance of species (Ochoa-Quintero et al. 2015; Barlow et al. 2016). The stakes are both global and local as people try to balance their lifestyles and territorial development with the changes—observed or perceived—in their environment. In general, a perception of change is a first, necessary step to adaptation (Hansen et al. 2012), thus developing adaptation strategies to climate change implies to understand how populations perceive and use their environment. In the Amazonian context, many communities depend on the rivers for their livelihood at several levels, and are thus more vulnerable to pronounced variations in precipitation and water levels. Indeed, environmental perceptions have an intrinsic value that reveal the culture and local wisdom, and is crucial for public policy, environmental management, and for the definition of adaptation strategies related to climate change (Curi et al. 2016), as recognized in the Paris Agreement (COP-21 Article 7.5).

In this context, the Duramaz project (2005–2010; Le Tourneau et al. 2013a), initiated an original program to qualify and quantify sustainable development for selected sites in the Amazon using indexes to measure the degree of socio-economical development and environmental commitment. Thirteen locations that reflect the diversity of social, ecological, and economic situations across the Brazilian Amazon were chosen as study sites. In each

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location, in-depth studies were conducted, including the collection of a vast array of socio-economic data at site, household, and individual levels. The geographical location of 12 of the research locations are shown in Fig. 1; one of the sites did not have a significant amount of sampling to perform an analysis of perceptions of climate change and was not included here.

In the present study, we combine quantitative and qualitative data to examine observed rainfall patterns and the perception of their changes by populations in these communities. We seek to identify key indicators of the perception of climate dynamics and its evolution by the population, through the surveys conducted with local populations. By comparing the observed, physical data with the perceptions by the local communities, we aim at a better understanding of how these populations perceive their environment, and by what preeminent climate indicators they evaluate their habitat and support social and economical decisions.

2 Data and methods

2.1 Rainfall data: the PERSIANN-CDR product

The rain gauge network over the Amazon region is notoriously sparse, irregular, and in many places, of dubious quality (e.g., Ronchail et al. 2002; Debortoli et al. 2015; Delahaye et al. 2015). Satellite-based rainfall estimates are thus essential to obtain both a global view of precipitation patterns over this region, as well as to get precipitation estimates at
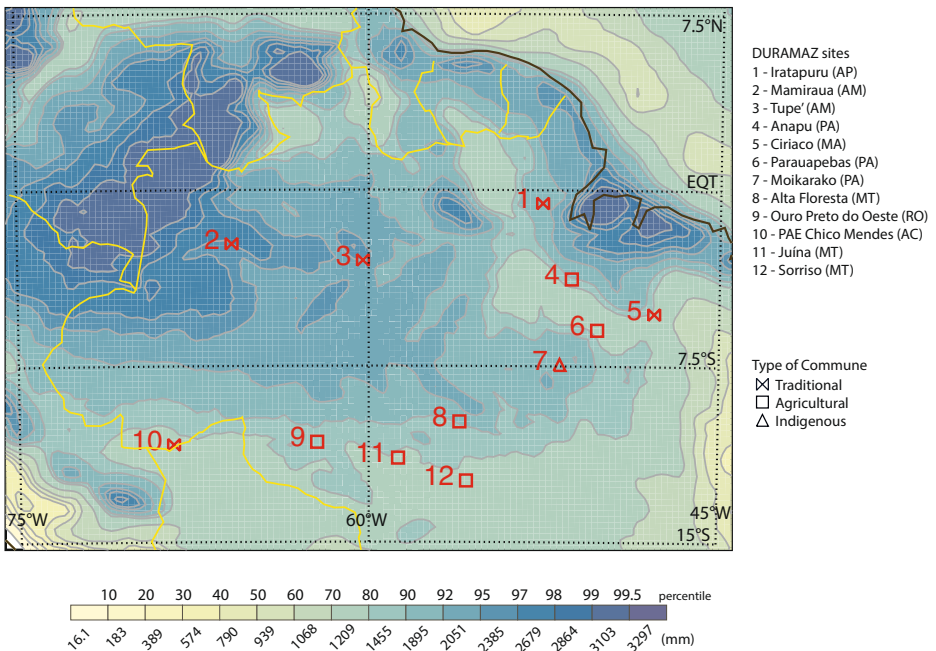

Fig. 1 25-year (1983–2008) mean annual precipitation issued from PERSIANN-CDR; the year 1992 was not used as February data is not available. Notice that the color scale is based on percentiles given the large spatial variability of precipitation totals across the Amazon basin. *Red symbols* show the position of study sites of the program DURAMAZ (Le Tourneau et al. 2013a)

locations where conventional ground-based measurements are not available, which is the case of several study sites of DURAMAZ where the nearest ground-based station are at times hundreds of kilometers afar.

In this work, we use the daily rainfall estimates from the "Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks—Climate Data Record" (PERSIANN-CDR; Sorooshian et al. 2014; Ashouri et al. 2015) to derive trend estimates for gridpoints nearest to the study site. The PERSIANN-CDR product is based on the PER-SIANN system (Hsu et al. 1997, 1999), and uses both geostationary infrared and daytime visible imagery to generate rainfall in near-global scale (60° S to 60° N) with a spatial resolution of 0.25° latitude × 0.25° longitude. Data is available for the period of 1983-(delayed) present. We use data for the period of 1983–2008 covering 26 years, choosing the end year as that in which the DURAMAZ questionnaires took place. The long time series available and the rather good spatial resolution to represent the "community scale" made this dataset attractive for the purposes of this study.

Although comparisons of PERSIANN and rain gauges in the Amazon (Delahaye et al. 2015) and validation of PERSIANN-CDR at global scale (Ashouri et al. 2015) are available, an inter-comparison between ground-based rainfall measurements and PERSIANN-CDR product specifically for the Amazon is not available in the literature. In order to estimate the quality of PERSIANN-CDR for the present study, we performed basic checks to evaluate the ability of this data set to realistically capture spatial and seasonal precipitation features and differences across the basin. Figure 1 shows the 25-years mean annual distribution of precipitation over the Amazon region. The main precipitation features are well captured: A maximum over 3000 mm/year is observed in the northwestern edge over Colombia and Venezuela, with another maximum (also above 3000 mm/year) along the equatorial coastline at the French Guyana, extending to the south of the Amazon delta. In between these maxima, a "dry corridor" of less of 1500 mm yearly rainfall runs with a northwest-southeast axis parallel to the coast. In the central part of the Amazon from ∼12°S to the Equator line, a northward gradient of precipitation is observed. The monthly mean rainfall for the same period, depicted in Fig. 2, shows the seasonal "migration" of precipitation across the basin. While the northern part of the region has year-round rainfall occurrence, the southern half shows a clear seasonality with rainfall totals that ebbs and flows with the onset and demise of the so-called South-American Monsoon System (SAMS; e.g., Vera et al. 2006; Marengo et al. 2012).

We also performed a simple comparison between the available ground-based precipitation data from meteorological stations near the study sites (less than 50 km distance) with PERSIANN-CDR values at the nearest gridpoint to the ground station. Only ground stations with at least 25 years of measurements and less than 5 years of missing data were retained. The correlations between ground-based and PERSIANN-CDR annual cycle (that is, the 25-year monthly means) are high, around 0.9 for all stations, but the correlation between annual totals for the 25 years ranged between 0.3 (Ouro Preto do Oeste) and 0.9 (Anapu), with a median correlation value of 0.7. Bias of monthly mean values vary among the stations without apparent spatial preference. The absence of systematic biases indicate that differences are probably not related to the PERSIANN-CDR precipitation estimation method (Ashouri et al. 2015). The root mean square (RMS) relative to the long-term mean annual totals also vary among the stations, without a clear pattern. All stations present the same order of magnitude of RMS, although differences in their values can attain 50%. A summary of the values of statistical parameters above is presented in the Supplementary Material Table SP1.
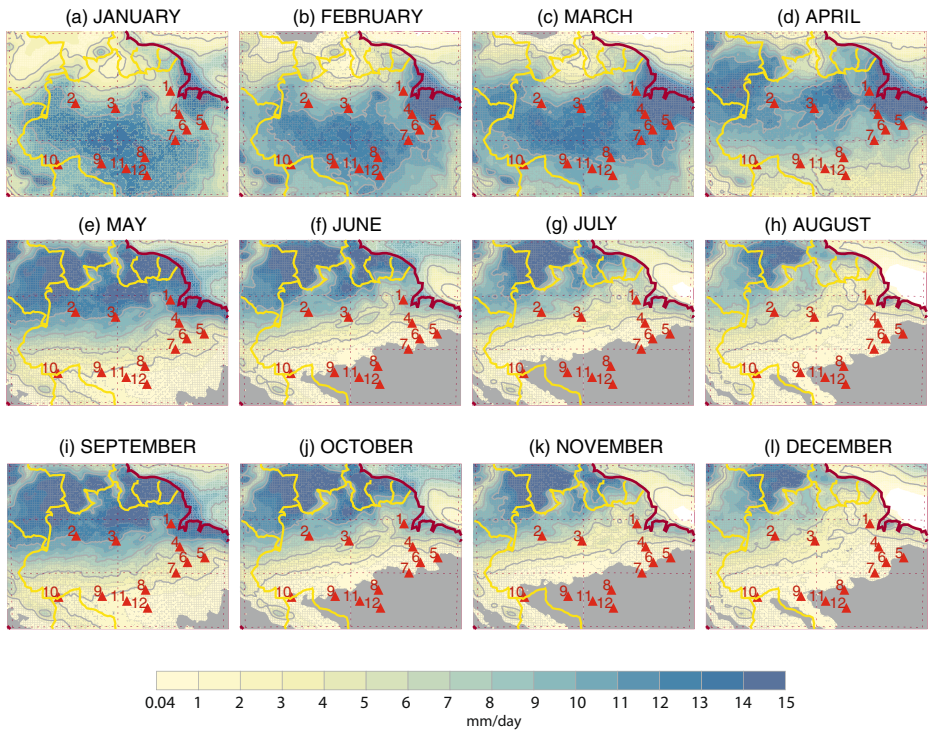
Fig. 2 25-year (1983–2008) daily mean precipitation per month issued from PERSIANN-CDR; February 1992 is not available. *Red symbols* show the position of study sites of the program DURAMAZ as in Fig. 1

2.2 Precipitation patterns analysis

Onset and Demise dates of the rainy season in the Amazon were estimated based on a slightly modified version of Liebmann et al. (2007) method. First, a quantity called "anomalous accumulation" was computed:

$$A(day) = \sum_{n=1}^{day} [R(n) - \bar{R}] \tag{1}$$

where $R(n)$ is the daily precipitation and $\bar{R}$ is the climatological annual daily average. The calculation is started 10 days prior to the beginning of the driest month and is summed for a year. From the annual series of A, the beginning (end) of the rainy season is defined as the day when A is the minimum (maximum). This simplified version was found to work better for sites where the rainy season may have a false start (Debortoli et al. 2015).

Simple linear trends of the total annuals, onset, and demise dates were also estimated. The 1-sigma confidence interval (equivalent to one standard-deviation) is presented along with trend values. Thus, if a trend is smaller than its confidence interval, it is not significant, as the trend could be due to the natural variability of the system.

2.3 Questionnaires DURAMAZ

The DURAMAZ research project conducted extensive fieldwork in each of the selected sample sites. The details of the DURAMAZ project are extensively laid out in Le Tourneau and Droulers (2010), and Le Tourneau et al. (2013a, b); here, we only present a summary of the method and methodology. Of the 12 sites used in this study (Fig. 1), 6 correspond to family-scale agriculture (Anapu, Parauapebas, Alta Floresta, Ouro Preto do Oeste, Juína) or "agrobusiness" (Sorriso) sites, 5 are traditional communities located within protected areas (Iratapuru, Mamiraua, Tupé, Ciriaco, PAE Chico Mendes), and 1 is an amerindian village within a protected area (Moikarako). A massive amount of socio-economic quantitative data have been collected through three questionnaires which were each applied at a given scale. Nearly 900 households were interviewed between May 2007 and August 2008 representing about 1250 accumulated days of fieldwork across all sites. At the site level, the most relevant stakeholders were surveyed on the issue of governance and institutional aspects. At the household level, socio-economical data were collected on household composition and income, agricultural production, schooling, transport, consumption, etc., with a total of 110 variables. It also included a number of questions about the perception that local population had about the environment and the ongoing changes they were witnessing (or not). Finally, at the individual level, life-history questionnaires gave a wealth of data about the trajectories of the people who compose the contemporary local communities. For each site, interviews were conducted under a sampling scheme. When the site had less than 75 families, every household was surveyed. Otherwise, a random sampling was realized to conduct 75 interviews, with the verification by the survey team that all parts of the studied area were represented in the sample. In each household, the chief of family was interviewed.

An indicator system was then derived from those data to obtain a view about sustainability and governance issues. It was composed of four main modules (living conditions; environmental conditions; needs of the present and future prospects; governance) and built on 44 sub-indicators derived from the questionnaires. The present study exploits the results of question 70–71 of the household questionnaire in which the family head was asked about his/her perception of climate change over recent years. The questionnaire allowed the following responses for question 70: "changes in the dates of the harvests," "changes in rainfall cycle," "increase of the dry season's length," "the climate is warmer," "the climate is colder," "the winds changed," "no change," "other." The respondents could choose between one or more answers. Question 71 was used in order to detail the answer in case it was "other," and any comment in relation with climate change perception.

3 Results

3.1 Satellite-based precipitation trends

Many studies have shown a tendency to decreased rainfall totals in the Amazon (e.g., Espinoza Villar et al. 2009). Depending on the region, the trend is more or less marked depending on the season but several authors agree on a negative trend (that is, a reduction) in the length of the rainy season, often linked to a late start and lower intensity of the beginning of the rainy season particularly in the southern part (Dubreuil et al. 2012; Debortoli et al. 2015; Almeida et al. 2016). Here, we do not attempt to produce a new comprehensive analysis of rainfall trends in the whole of the Amazon, but to focus on trend estimates at the 12 sites for which we have data on perceptions of climate change by local communities.

Table 1 Name and geographical coordinates of the Duramaz study sites shown in Fig. 4, rainfall trends (based on PERSIANN-CDR for the period 1983–2008; in mm/year), difference of the number of days in the rainy season (ΔRSD) averaged over the first and last 5 years in the series (rounded to the closest integer; in days/decade), and perceptions of climate changes by Amazonian communities at the study sites

Duramaz site	Location				Perceptions				
	Longitude (°E)	Latitude (°N)	Trend±1-σ (mm/year)	ΔRSD (day/dec)	No changes	Rainfall cycle changes	Increase in DSL	Hotter climate	Colder climate
Iratapuru (PA)	−52.58	−0.57	−7.2 ± 9.6	−9	32.4	26.5	0	44.1	8.8
Mamiraua (AM)	−65.85	−2.29	13.2 ± 5.4	19	2.3	6.8	0	95.5	2.3
Tupé (AM)	−60.25	−3.00	4.0 ± 7.0	−16	40.0	4.4	0	51.1	6.7
Anapu (PA)	−51.33	−3.79	0.3 ± 10.0	−3	0.0	54.1	37.7	82.0	0
Ciriaco (MA)	−47.79	−5.27	−0.1 ± 8.7	−11	32.4	5.6	7.0	54.9	7.0
Parauapebas (PA)	−50.22	−5.97	3.3 ± 6.9	−12	8.1	45.9	27.0	43.2	0
Moikarako (PA)	−51.82	−7.44	4.2 ± 4.7	−6	57.6	18.2	18.2	12.1	3.0
Alta Floresta (MT)	−56.10	−9.87	−2.7 ± 5.3	−5	2.5	55.6	14.8	92.6	1.2
Ouro Preto do Oeste (RO)	−62.22	−10.74	0.3 ±3.7	−14	1.9	66.7	22.2	79.6	0
PAE Chico Mendes (AC)	−68.38	−10.84	−8.1 ± 4.2	−14	51.9	10.4	10.4	26.0	0
Juína (MT)	−58.74	−11.42	−2.7 ± 4.4	−10	10.9	78.2	4.2	64.7	7.6
Sorriso (MT)	−55.81	−12.39	3.8 ± 4.6	−7	0	50.0	10.0	48.3	0

For the latter, columns show the percentage of answers to the question 70. DSL is the abbreviation for "Dry Season Length"

Simple linear trends based on annual precipitation totals were calculated for each of the 12 sites (Table 1). Most sites in the northern part of the domain show a near-neutral or positive rainfall tendency, while for the southern sites the tendency is typically negative. However, the uncertainties are large for the entire domain, due to the large interannual variability. Figure 3 shows for each station, the onset and demise dates for each year between the period concerned, as well as the linear trends for each. The stations of Tupé (Fig. 3c), Anapu (Fig. 3d), Ciriaco (Fig. 3e), and Parauapebas (Fig. 3f) show a delay in the onset of the rainy season, while the sites of Iratapuru (Fig. 3a) and the southern stations of Alta Floresta, Ouro Preto, Chico Mendes, Juína, and Sorriso (Fig. 3h–l) show earlier demise trends; in both cases that translate to a shortening of the rainy season (Table 1). The site of Mamiraua (Fig. 3b) shows a very ill-defined, small amplitude annual rain cycle (not shown), translating to a large spread of onset dates and thus to large uncertainties on precipitation pattern trends and determination of the length of rainy season. This is also true for the site of Tupé, which shows large onset dates variability, and large range in the number of days in the rainy season.

3.2 Response to questionnaires

The most frequent response (58% of respondents) pointed to a perception of a warming climate, against 3% of responses indicating a colder climate and 20% "no change." These
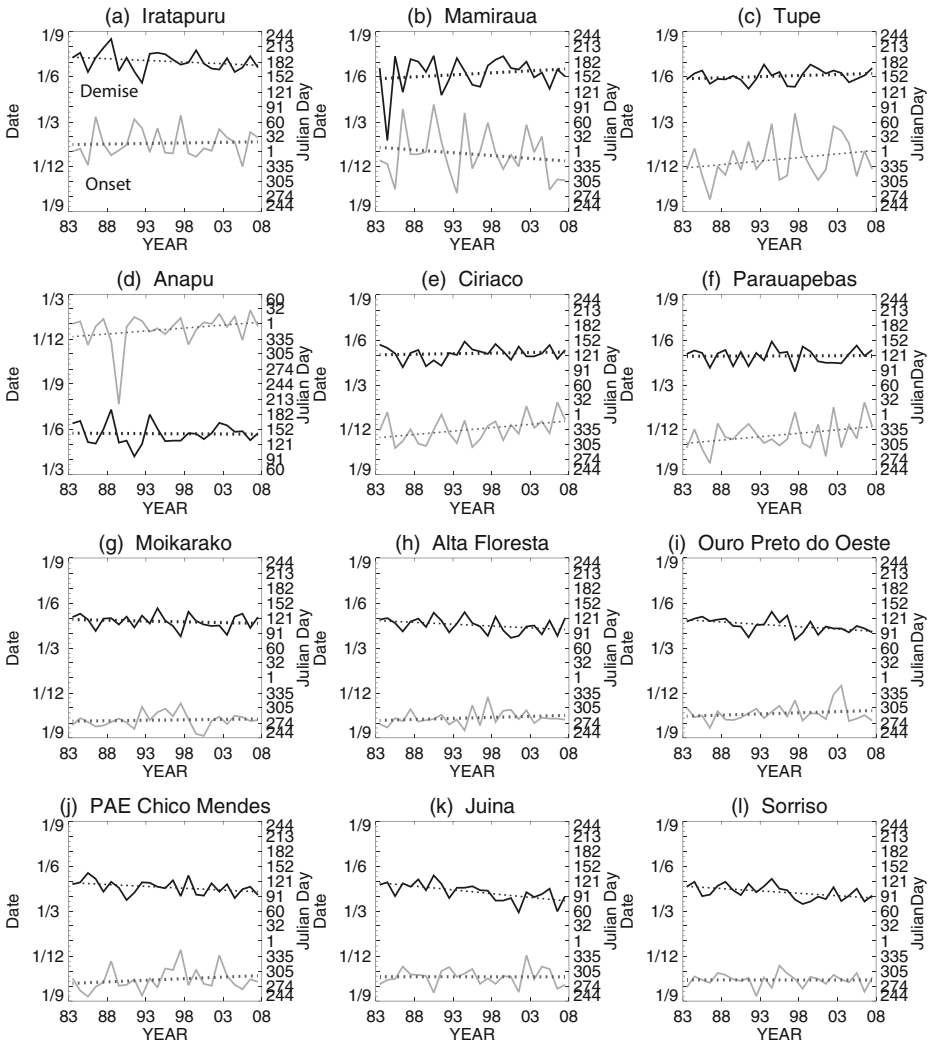
Fig. 3 Onset (*gray*) and demise (*black*) dates of rainy season for each DURAMAZ site. *Thin dotted lines* correspond to the linear trends for the period 1983–2008 for these two variables. Notice that the *y*-axis in **d** (Anapu) starts on March 1 for clarity in the interpretation of results

variations can be attributed to the observation of effectively warmer conditions, but since the spatial distribution of responses shows no obvious pattern, it could be that the responses were either induced by the question itself or partly conveys the influence of the media coverage on climate change. Indeed, interviews conducted by another Brazilian research team show that such perception is shared by the majority of smallholders in all biomes of the country (Litre et al. 2014). Unfortunately, it was not possible to have a long-term in-situ temperature measurements on all of our study sites, and no such data is available from satellite measurements, therefore we show results from the analysis based on trends in rainfall.

Comparing physical quantities (often considered as "objective") with social data on perceptions constitutes a challenge (Morton 2007; Brondizio and Moran 2008; Neethling et al.

2016). Several bias must be taken into account: Differences in the nature and date of establishment of the communities as well as generational effects were all considered within the protocol developed in the project DURAMAZ. Thus, the statistical analysis provides the proper representation of the collected answers, as laid out in Section 2.3. Table 1 summarizes for each site the percentage of answers for each of the possible answers of the questionnaire, while Fig. 4 shows a synopsis of perceptions of rainfall changes for studied sites.

We are mostly interested in the perceptions related to precipitation, which appear as significant for about ∼35.2% of the interviewees. Nearly all answers related to changes in rainfall indicate perception of decrease in rainfall volume, stronger intensity, and most frequently lengthening of the dry season (12.6%). These results are in general agreement with the overall trends observed in the Amazon: precipitation pattern changes are less clearly perceived than those of temperature, and that is linked to (i) the greater spatial and temporal variability of rainfall and a less clear signal of its trends across the basin, and (ii) lesser imprint of any debate on climatic change regarding rainfall.

Narrowing the analysis into detail, the perceptions of changes by the communities are varied and the agreement with the satellite observations are not always good. Three aspects are apparent when comparing Table 1 and Figs. 3 and 4:

1. The results at the site of Mamiraua do not match, with lack of perception of any changes (less than 7%) while the satellite-estimated rainfall tendency is positive. This community situated upstream from Manaus is probably more sensitive to the variations of the
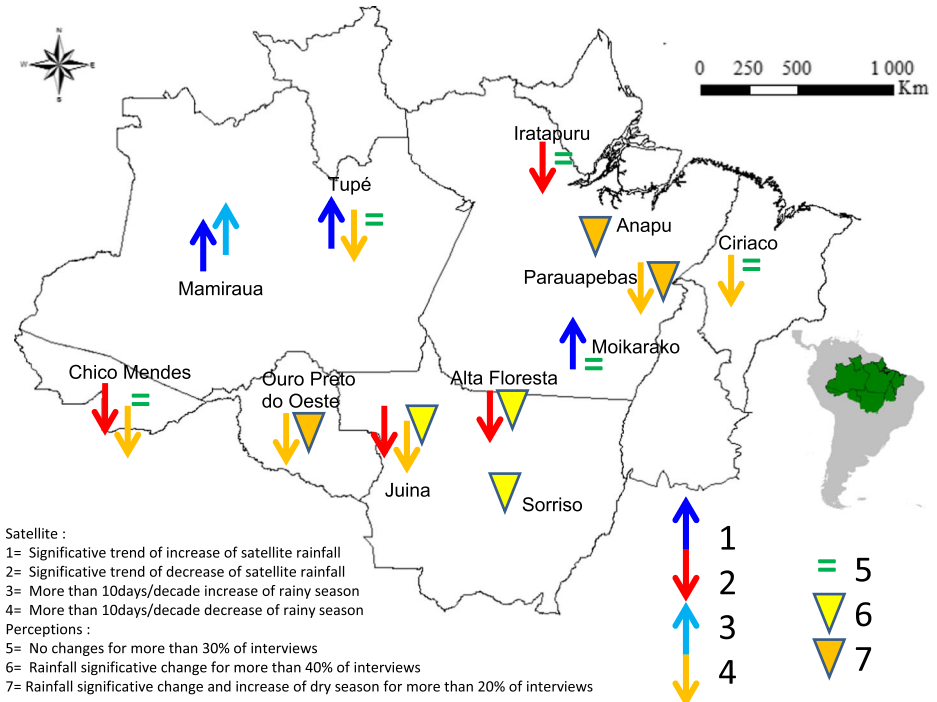

Fig. 4 Synopsis of perceptions of rainfall changes for the studied sites

Amazon river levels than to the local precipitation (Drapeau et al. 2011). Similarly, the sites of Tupé, Moikarako, Chico Mendes, and Iratapuru indicated that the perception of no changes (more than 30% of positive responses) is disparate with that shown by observations: shortening of rainy season, and changes in rainfall amounts (increase in Tupé and Moikarako, decrease in Iratapuru and Chico Mendes).

2. For the site of Anapu, nearly 38% of the interviewees reported a perception of increase in dry season length and 54% in changes in rainfall cycles. These are hardly observed by satellite-based analysis. This mismatch could have been induced by other factors that lead to water stress and influenced the performance of their agricultural activities, such as evapotranspiration or dry spells. This perception could also be influenced by the debate around the Belo Monte Dam project, which was underway at the time the questionnaires were handed.

3. The perception of changes in precipitation (more than 40% of interviewees) and a drier climate were observed for the sites of Sorriso, Juína, Alta Floresta, Parauapebas, and Ouro Preto do Oeste. All these sites are within the deforestation arc, where drying trends are well documented, and appears as well as the region where the population have the strongest perception of rainfall changes. These sites are agricultural communities and the attention paid to rainfall is crucial since it directly impacts their main economical activity, as pointed by Arvor et al. (2014). In Sorriso (large agro-business farms), there may be more sharing of "climate conditions" knowledge between workers and agro-technicians, which could impact the perceptions.

4 Summary and conclusions

In the present study, we compared results of climate change perceptions by Amazonian communities with analysis of rainfall trends based on satellite data. Our results indicate that even if the perceptions are varied, and not always aligned with measured data, the arc of deforestation in southern Brazilian Amazon clearly shows an agreement of lower rainfall and higher perception of rainfall change by communities. Many times, however, the most striking element in "open answers" was the increase of the irregularity (or unpredictability) of rainfall. Both agricultural-based and traditional communities (that count on fishing, extractivism or family-scale agriculture) seem primarily sensitive to the interannual variability of rainfall.

This study confirms the importance of understanding how populations perceive their environment, and especially climate conditions. The metrics of the natural sciences are fundamental to define, calculate, and predict climate change but are not sufficient to establish strategies on how to address the problems, especially at local scale. From a public policy point of view, perceptions are important to explain why some public measures can be successful or fail. The next step of this work will include a deepening of these preliminary studies detailing the questionnaires to the Amazonian communities, drawing on Brazilian Research Network work on global climate change (Redeclima) (Lindoso et al. 2014). This will detail the link between agricultural practices and rain season patterns, and examine the impact of particular years (wetter or drier) on the perception of the climate by the local communities.

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