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### ► To cite this version:

Beatriz M. Funatsu, Pedro Mutti, Vincent Dubreuil, Damien Arvor, Pablo Sarricolea, et al.. Monitoring hydroclimatic extremes and changes (1981-2021) in the San Francisco river basin (Brazil). 36ème Colloque de l'Association Internationale de Climatologie, Département de Météorologie – Hydrologie / Faculté de Géographie / Université de Bucarest, Jul 2023, Bucarest (Roumanie), Roumanie. hal-04234808

**HAL Id: hal-04234808**

**<https://hal.science/hal-04234808v1>**

Submitted on 10 Oct 2023

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## MONITORING HYDROCLIMATIC EXTREMES AND CHANGES (1981-2021) IN THE SAN FRANCISCO RIVER BASIN (BRAZIL)

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**Résumé :** Dans cette étude, une analyse spatiale à fine échelle de la climatologie des extrêmes hydroclimatiques dans le bassin versant du fleuve San Francisco (SFW, région nord-est du Brésil) pour la période 1981-2021 a été effectuée. Nous avons aussi estimé des tendances et cherché des liens avec la végétation dans une perspective de bilan hydrologique. Les résultats montrent que 52% du bassin ont présenté une augmentation de plus de 15 jours secs consécutifs, et pour 68%, une diminution de 5% des précipitations annuelles totales moyennes. L'intensité des précipitations a augmenté/diminué de 10% (indiquant plus/moins de pluie en un temps plus court) dans ~28%/14% du bassin. L'augmentation des conditions de sécheresse se traduit également par une augmentation du déficit de pression de vapeur dans une grande partie du SFW, et suggèrent que la végétation a été confrontée à un stress hydrique accru au cours de ces 4 dernières décennies.

**Mots clés :** Extrêmes des précipitations, bassin versant du fleuve San Francisco, tendances climatiques, bilan hydrique.

**Abstract:** *Monitoring hydroclimatic extremes and changes (1981-2021) in the San Francisco River basin (Brazil).* The San Francisco Watershed (SFW), located in the Brazilian northeast region, has been subject to increases in temperature and precipitation extremes. Here, we present a fine-scale spatial analysis of climatology and trends of hydroclimatic extremes for the period 1981-2021, and links with vegetation through a hydrological balance perspective. Our analysis shows that 52% of the basin presented an increase of more than 15 consecutive dry days, and 68%, a decrease in 5% of the mean total annual precipitation. The intensity of the rainfall has increased/decreased by 10% (indicating more/less rain in a shorter time) in ~28%/14% of the basin. The increased dry conditions are also reflected in increased vapor pressure deficit in most of the SFW. These trends imply that vegetation (native or crops) have faced increased hydric stress in the last 4 decades.

**Keywords:** Hydroclimatic extremes, San Francisco watershed, long-term trends, hydrological balance.

### Introduction

Partially located in the Brazilian Semiarid region in northeast Brazil, the São Francisco watershed (SFW) is a strategic hydrological system for power generation, agricultural development and the integration of the national territory. Droughts are recurrent in the Brazilian Semiarid (e.g., Mutti et al. 2022, Freitas et al. 2022) and climate change projected scenarios indicate their intensification in this region (Seneviratne et al., 2021) which will further strain water availability. Observational data have shown increase in the frequency of temperature and precipitation extremes over NE Brazil in the recent decades (Regoto et al. 2021), highlighting the need for hydroclimatic monitoring, and in particular, of dry and wet extremes conditions, for adapted water management. This study aims at providing a climatology and trends of the frequency and intensity of hydroclimatic extremes at fine spatial scale specifically for the SFW, and reflect on the implications of observed trends on vegetation through the perspective of the hydrological balance. Specifically, we aimed at examining (i) the spatial distribution and climatological frequency of hydroclimatic extremes, (ii) long-term (40 years) linear trends, and (iii) links with vegetation responses through analysis of atmospheric water balance components at monthly scale for the whole of the SF basin.

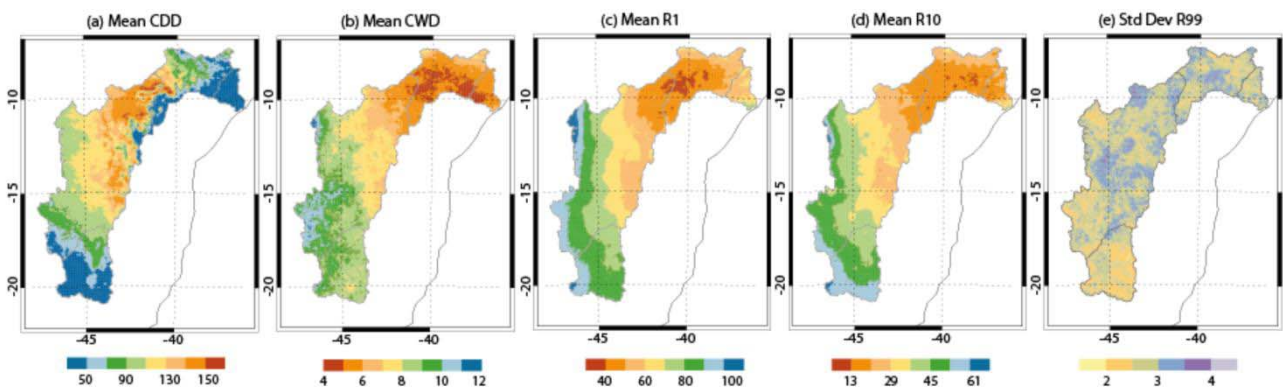
### 1. Data and Methods

Two datasets were used: (1) Chirps v2 (<https://chc.ucsb.edu/data/chirps>) daily precipitation, at horizontal resolution of 0.05x0.05°, and (2) Terra Climate (Abatzoglou et al. 2018) monthly mean actual evapotranspiration (AET), potential evapotranspiration (PET), vapor pressure deficit (VPD), and downward surface shortwave radiation (SRad), with resolution of ~4 km. The study period is 1981-2021. In the Terra Climate dataset, the monthly reference evapotranspiration was calculated using the Penman Montith approach, and its estimation assumes a reference grass surface across space.

Precipitation extreme frequency was estimated at annual scale, using indices defined by the Expert Team on Climate Change Detection and Indices (ETCCDI; [http://etccdi.pacificclimate.org/list\\_27\\_indices.shtml](http://etccdi.pacificclimate.org/list_27_indices.shtml)), as in Funatsu *et al.* (2021). All indices were computed at each grid point in the domain. Here we present results for consecutive dry (CDD) and wet days (CWD), extremely wet days (R99: precipitation PR above the 99<sup>th</sup> percentile; percentiles defined using the 1981-2020 baseline period), number of wet days (R1: PR  $\geq$  1 mm), heavy precipitation days (R10: PR  $\geq$  10 mm), and maximum 1 day precipitation (Rx1). Trends of the frequency of extremes for the 41 studied years were estimated by simple linear regression, with a 95% confidence interval uncertainty estimate.

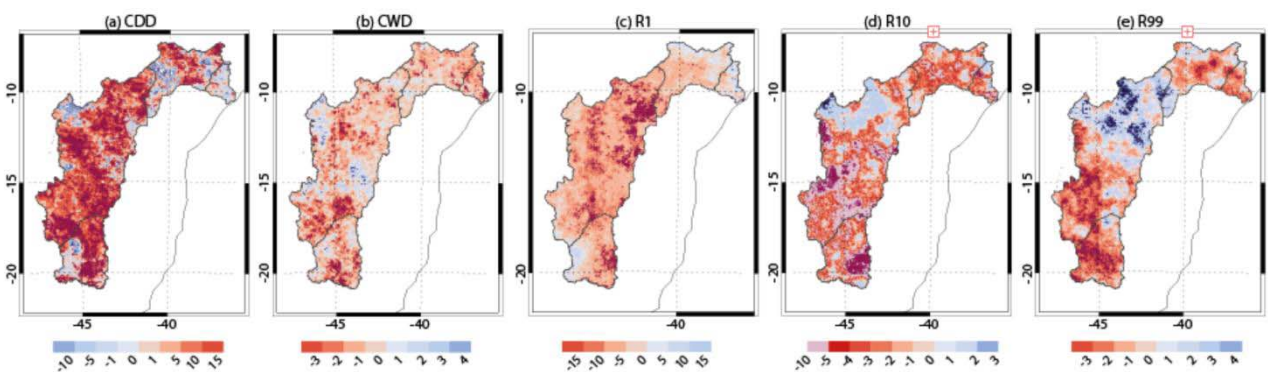
## 2. Results and Discussion

A 41-year climatological representation of the frequency of dry and wet extremes is shown in Figure 1. The spatial distributions of R1 (Figure 1c) and R10 (Figure 1d) follow the mean annual precipitation pattern. Higher R1 and R10 values are measured in the southern sub-basin (Upper San Francisco, USF, which corresponds to the SF river source and is under the influence of a humid tropical and subtropical climate). These values then progressively decrease north and eastward in the semi-arid Mid SF (MSF) and Mid-Low SF (MLSF) and finally increase again towards the coastal area (Low SF, LSF). Standard deviation is shown for R99 (Figure 1e) as, by definition, the average R99 falls between 3 to 4 days a year; this map shows that typically the actual R99 occurrences range between 1-7 days a year. The longest sequence of dry days (CDD; Figure 1a) is found in the semi-arid regions in the northern half of the MSF and in part of the MLSF, reaching roughly 5-6 months, and is shorter at both edges of the basin, with up to 50 CDD. Consecutive wet days (CWD) are longer in the western portion of the basin and shorter in the eastern half (Figure 1b).



**Figure 1.** Spatial distribution of the mean values of (a) CDD, (b) CWD, (c) R1, and (d) R10, and of the standard deviation for (e) R99, over the period 1981-2021, for the San Francisco Watershed, and sub-basins.

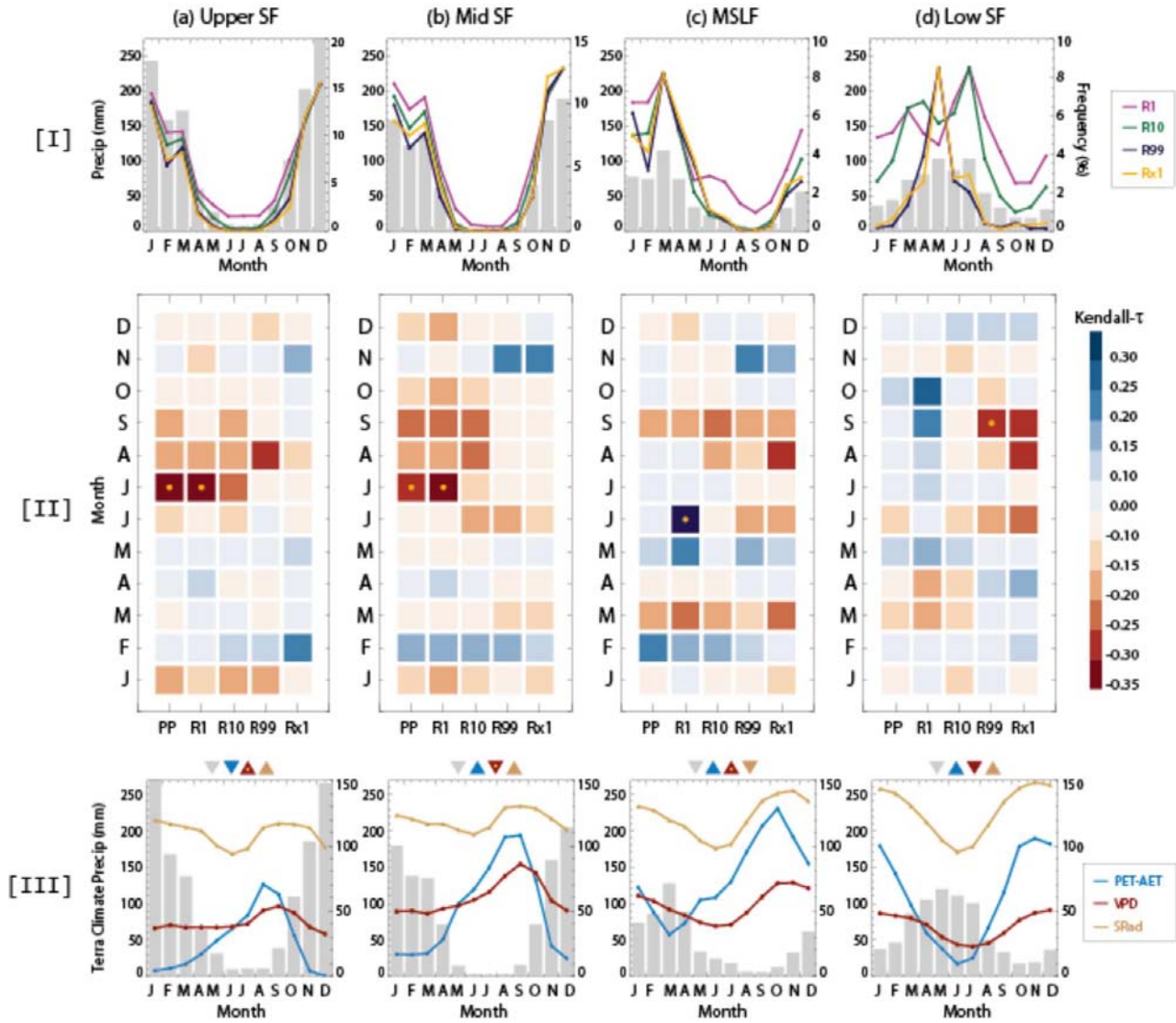
Respective linear trends for these variables for the same period are shown in Figure 2. The most striking feature in all panels is the increase of dry conditions (Figure 2a, b, c), and decrease of strong precipitation and wet conditions (Figure 2d, e), even though the trends are not statistically significant for most of the basin. A notable exception regards a statistically significant increase in R99 in the lower portion of the MSF (Figure 2e).



**Figure 2.** Spatial distribution of linear trends (1981-2021) of (a) CDD, (b) CWD, (c) R1, (d) R10, and (e) R99, over the period 1981-2021. Dark red and dark blue (out of color scale tones) represent positive and negative significant (95% confidence interval) trends. Trend values are of days per 41 years.

It is worth mentioning that the Northeast Brazil region experienced its most severe drought from 2012 through 2016, with implications that lasted until at least 2018, and possibly contributed to the negative trends observed there (Dubreuil et al., 2019, Mutti et al., 2022).

Because the SFW spans a large latitudinal stretch, the sub-basins have a temporal lag in the seasonality of the dry and wet conditions during the year, notably an “inversed” rainy-dry season between LSF and USF (Figure 3.I a, d). This is explored in Figure 3.I, which shows, for each sub-basin, the mean monthly proportion of different precipitation extreme indices, and the long-term trends by month. The different frequency indices present noticeable correlations in the USF, MSF and to some extent, the MLSF (Figure 3.I a-c). The LSF shows a slightly more spread precipitation distribution along the year, with stronger rainfall from May to July (Figure 3.I d).



**Figure 3.** [I] Monthly distribution of Chirps-based mean precipitation (mm), and the relative monthly frequency (with respect to the yearly total) R1, R10, R99 and Rx1, [II] monthly trends given as Kendall- $\tau$  coefficient for the same variables with significant trends marked with a yellow dot, and [III] Terra Climate-based monthly distribution of precipitation, DET (= PET-AET, mm), VPD (\*50 hPa) and downward solar radiation (\*0.6 W m<sup>-2</sup>). [III] also shows the 41-year trend signal, with upward/downward-facing triangle denoting a positive/negative trend (yellow dots indicate statistically significant trends).

Monthly mean trends (Figure 3.II) show that in the USF and MSF, dry months (Jun-Jul-Aug) have become drier, as well as in the beginning of the wet season (Sep-Oct) (Figure 3.II a,b). The MLSF shows mixed trends (Figure 3.II c), but drier conditions at the height of the wet season (Mar), a wetter end of wet season (May-Jun), and less extreme rainfall during the dry season (JJAS). In the LSF (Figure 3.II d), the number of rainy days (R1) tend to increase from May to October (rainy season) without increase in the total

precipitation; in addition, extreme rainfall (R99 and Rx1d) tend to decrease, suggesting that the rainfall intensity decreased in the LSF sub-basin.

Concerning links with vegetation, we examined the impact of these changes by analyzing parameters linked to the hydrological balance. The monthly mean evolution of DET (that is, the difference between PET and AET) and VPD highlights the typical behavior of seasonally dry tropical forests and savannas which natively cover part of the study region. VPD increases as a result of rising temperatures and potential evapotranspiration. DET, on the other hand, does not promptly increase with VPD, since semiarid plant species close their stomata with the increase of VPD to avoid water loss. DET begins to increase 1-2 months earlier relative to VPD, with the onset of the wet season and the increase in water availability, which leads to stomata opening. The only variable that presents significant trends at the annual scale is VPD, which is positive in the USF and MLSF, and negative in the MSF and LSF. Since VPD is one of the critical variables in determining plant photosynthesis via stomata opening controls, an increase in VPD has the potential to decrease vegetation greening. This implies that the observed increase upwards of 15 days in CDD in > 50%, and a decrease of 5% of the total mean annual precipitation in more than 68% of the SFW, combined with an overall increase in VPD can have accrued detrimental consequences on vegetation health. It is worth noting that VPD trends in the MSF are significant but only very slightly negative.

## Conclusion

The San Francisco Watershed region has been subject to increased dry conditions in the globality of the basin, particularly in the dry season, even though increased frequency of extremely wet days and associated increase in rainfall intensity have been observed as well in parts of the MLSF. These dry conditions are also reflected in an increase in DET (via decrease in AET) in most of the basin, except in the upper sub-basin, suggesting that vegetation greenness is affected by these precipitation changes. Increase in dry conditions are also reflected in an increase of VPD, which further stresses vegetation growth. Further analysis taking into account land cover type will help the assessment of the impacts of these changes for specific vegetation types (shrubs, crops).

**Acknowledgments:** The authors acknowledge support by the Climat AmSud program through the project PRELASA (PREcipitation Extremes and Landscape Analysis in South America ; ref : 21-CLIMAT-12).

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