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The Association between climate indexes and tropical cyclones in decadal rainfall in San Ramón, Costa Rica

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Abstract

The decadal variability of precipitation over San Ramón, Costa Rica (SR-CR) and its relationship with the ONI, CLLJ, AMO indexes, and the frequency of tropical cyclones is investigated. Correlation tests are applied between the different indices with eight decades of precipitation in San Ramon. De-cadal precipitation shows that the driest were 1960-69 and 1980-89, and the wettest were 1970-79 and 1990-99. Every twenty years there is a climate change from wet to dry or dry to wet. During El Niño (ONI) events, the Pacific increases sea surface temperature (SST) and precipitation decreases in SR-CR and during La Niña, SST decreases and tends to rain more in SR-CR. Low values of the CLLJ tend to increase the incidence of precipitation in the area. Cyclonic activity has an appreciable influence on rainfall in SR-CR, the first two decades there were one and two cyclones. However, the rest of the decades showed more cyclones per decade, as is the case with 2010-19 with 8 cyclones. The relation-ship between the AMO index and precipitation in San Ramon has a 3-month lag.

Keywords: *Precipitation, multidecadal variation, ONI, CLLJ, AMO, tropical cyclones, San Ramón, Costa Rica.*

Resumen

Se investiga la variabilidad decadal de la precipitación sobre San Ramón, Costa Rica (SR-CR) y su relación con los índices ONI y CLLJ, el AMO y la frecuencia de ciclones tropicales. Se aplican prue-bas de correlación entre los distintos índices con las ocho décadas de precipitación en San Ramón, La precipitación decadal muestra que las más secas fueron 1960-69 y 1980-89, y las más húmedas 1970-79 y 1990-99. Cada veinte años se produce un cambio climático de húmedo a seco o de seco a húme-do. Durante los eventos de El Niño (ONI) el Pacífico aumenta la temperatura de la superficie del mar (TSM) y disminuye las precipitaciones en SR-CR y durante La Niña, la TSM disminuye y tiende a llover más en SR-CR. Los valores bajos del CLLJ tienden a aumentar la incidencia de precipitaciones en la zona. La actividad ciclónica tiene una influencia apreciable en las precipitaciones en SR-CR, las dos primeras décadas hubo uno y dos ciclones. Sin embargo, el resto de las décadas mostraron más ciclones por década, como es el caso de 2010-19 con 8 ciclones. La relación entre el índice AMO y la precipitación en San Ramón tiene un desfase de 3 meses.

Palabras claves: *Precipitación, variación multidecadal, ONI, CLLJ, AMO, ciclones tropicales, San Ramón, Costa Rica.*

1 Introduction

Precipitation has an enormous impact on agricultural and industrial, irrigation, power generation, water management. It is also important for hydraulic structures in rivers and bridges, culverts, land use plan-ning. Precipitation results from a complex natural processes and act at a global, regional, and local scales and depends on natural patron like air masses, altitude, latitude, exposure and is subject to tem-poral fluctuations at each scale. Its interdecadal to multidecadal variability leads to periods of drought or flood across Costa Rica. Hence, great efforts have been made to explore the variability on interdeca-dal to multidecadal timescales (Zhou et al., 2009; Huang et al., 2012; Hoyos et al, 2018; Chen et al., 2019). However, previous studies focus on annual or interannual research but a few decades-long transitions owing to the limitation of the short instrumental data. Several areas in Costa Rica, especially rural areas have short series of precipitation data. These short series affect the robustness of the conclusions on the mechanism controlling decadal variability in certain regions of Costa Rica. Nevertheless, the excellent data records that San Ramon meteorological station (Subestación San Ramón y Sede Occidente) has is extremely valuable for a climatological study at the decadal level, being one of the longest records of a rural area of Costa Rica. So far in rural areas there have been no studies on a decadal scale, precisely because of the difficulty of collecting extensive historical records of precipitation.

However, the complexity of precipitation regimes is of undeniable climatological importance, but an understanding of their characteristic features also has economic and agricultural relevance. The main purpose of this research is to analyze the interdecadal variability of precipitation and its possible rela-tionship with precipitation variability, which is an important subject in climate variability. It is known that Costa Rica is influenced by changes in sea surface temperatures (SST) in the North Atlantic Oceans and the South Equatorial Pacific (Enfield and Alfaro, 1999; Magaña et al, 1999; Quesada and Waylen, 2008; Quesada y Waylen, 2013). Some of this research uses SST and atmospher-ic pressure field (SOI). This is how some scientists such as Enfield and Alfaro, 1999; Giannini, et al, 2000; Quesada and Waylen, 2008). They consider that changes in sea surface temperatures are due to low or high atmospheric pressures in both oceans. These can occur in different ways, whether one ocean has high atmospheric pressure and the other low or both have low atmospheric pressures, the latter case is currently happening (IMN, 2023). These changes in atmospheric pressures can lead to the ENSO, El Niño (warm phase) or the La Niña (Cold Phase) in the equatorial Pacific Ocean. The North Atlantic Ocean is characterized by cold temperatures in the waters during the winter and part of the spring in the Northern Hemisphere and the rest of the seasons part of its waters (intertropical zone 20 North Latitude) remain warm during the rest of the seasons. Cold waters are those that come from the north pole or high latitudes near Siberia and warm temperatures are those that come from the Gulf of Mexico. However, during certain years the conditions change or could even pass from a few months to a few years under the same condition, only cold or warm (Hastenrath, 1988).

Meanwhile, the surface waters of the Pacific Ocean during certain periods or even years can also be cold or warm (Waylen, 2000). It seems that there is an isostatic effect between both oceans when one stays cold the other tends to stay warm. However, this condition is changing, precisely in this year (2023) both oceans show warm conditions and is under the presence of an El Niño event. Under the warm phase, the Pacific slope of Costa Rica presents a deficit in precipitation levels, especially in the Central region and the Northeast region of the country. San Ramón, where the El Estero micro basin is located, is precisely located on the Pacific range of Costa Rica, although it presents a geographical exception of great relevance and is that through an in-termontane depression that exists in Tapezco, Zarcero, air masses loaded with humidity enter in some periods in certain years and decades change atmospheric conditions and induce the influence of both oceans or one more than the other during certain decades. The Warm phase of ENSO (El Niño) influence on Costa Rica precipitation, when it works, can be un-derstood in terms of tropical SST and heating anomalies forcing the Pacific–South America (PSA) tele-connection pattern (Mo and Higgins 1998; Kidson 1999; Grimm 2003). The atmospheric response to tropical Pacific decadal variability (PDV) works in a similar way to the response to ENSO and partly explains wetter conditions in Costa Rica in some decades like the 1970-79. In other cases, present warm shift in tropical Pacific SSTs like the one from 1980-89 (Figure 3). Further, it has been argued that the ENSO impact on precipitation is influenced by the phase of Pacific decadal variability (Andre-oli and Kayano 2005; Barreiro 2010).

Troup (1965) argues that the variation of atmospheric pressure is an indicator of the state of the system as expressed through the Southern Oscillation Index, which weights the difference in atmospheric pressure between Tahiti (South America) and Darwin (Australia), the SOI is a comparative measure of how atmospheric pressure changes in two large regions, western and central-eastern, of the Tropical Pacific Ocean. One of the best-known indices is the NINO34 which is presented as anomalies of the average SST (sea surface temperature) which has been recommended for studies of the ENSO events by agreement of NOAA (National Oceanic & Atmospheric Administration of U.S.A) (NOAA, 2016). Méndez et al. (2009) investigated on the spatial and temporal teleconnections of the MEI to the precipitation anomalies and maximum and minimum temperatures in Mexico and Central America, showing important teleconnections during the month of December, January, and February in arid and semi-arid regions of northeastern Mexico, concluding that the MEI has a marked influence on the country's climate at regional and consistent scales. Kerr (2005) relates the Atlantic Multidecadal Oscillation Index (AMO) to tropical storm frequency; high values indicate a warmer ocean and more tropical storms, and low values indicate a cooler ocean and less tropical storm activity. For the Central America countries, two low-level circulations play a very important role on precipitation. The CLLJ is directly linked to precipitation distribution and variability over Central America (Wang, 2007; Amador, 2008; Hidalgo et al., 2015; Durán-Quesada and Alfaro, 2016; Durán-Quesada et al., 2017). In addition, each year tropical cyclones impact the region, sometimes with devastating effects, like during the passage of hurricanes Harvey, Irma, and Maria in 2017 (IOM, 2017; Blake and Zelinsky, 2018).

2 Methodology

The area of the basin is in the topographic sheet Naranjo, 1: 50 000. This area ranges from the upper part of the micro-basin, where the town of Valverde is located, downstream, three kilometers away is the town of Alfaro until reaching the city of San Ramón that covers a high percentage of the El Estero hydrographic micro-basin. (Fig. 1). It is located between the geographical coordinates 10°06´00” (North) with 84°27´30” and 10°15´00” with 84°29´30” of the Projection System (CRTM05). The El Estero micro basin was drawn from the Naranjo leaf, scale 1: 50,000 of the National Geographic Institute (IGN). In addition, a Geographic Information System (GIS) was used. Its waters drain into the Rio Grande, which in turn flows into the river. Grande of San Ramón, which together with the sub-basin of the Virilla River becomes part of the hydrographic basin of the Grande de Tárcoles River.

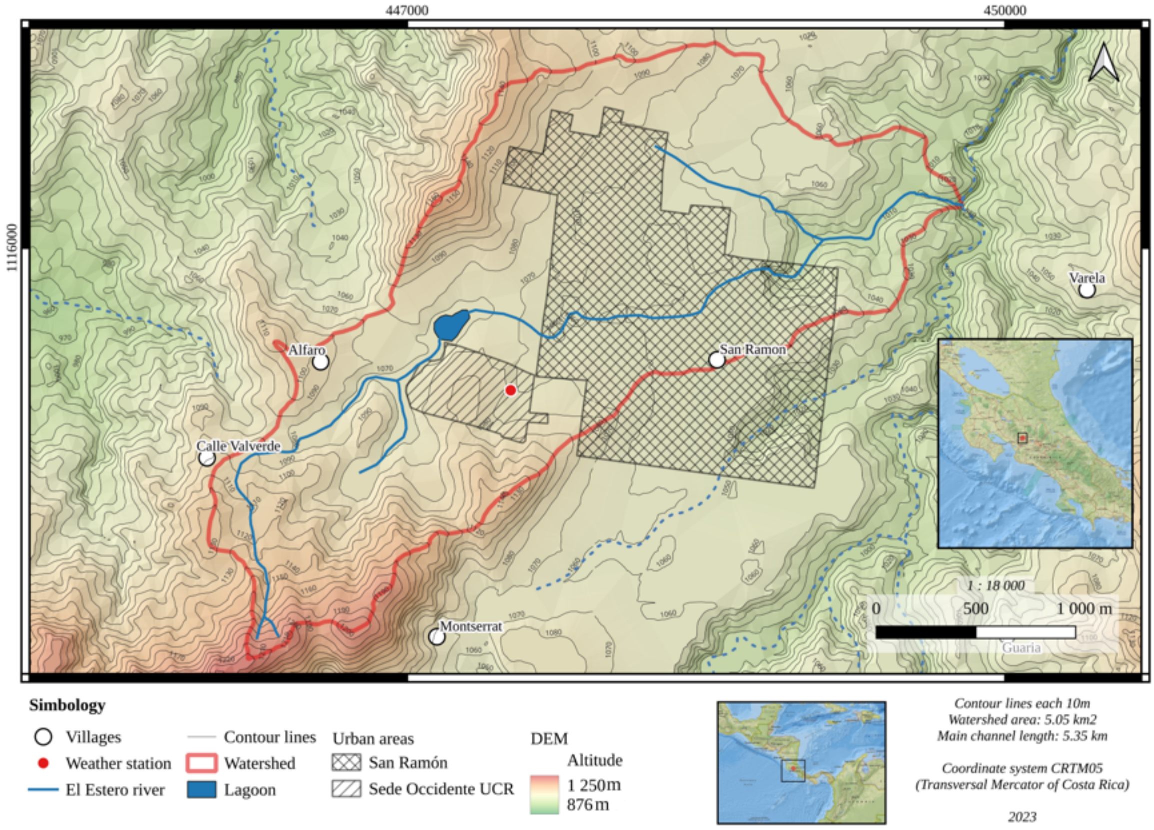

Figure 1: Location of the study area.

Station data of monthly and annual total precipitation employed in this analysis were taken from the Costa Rican Electricity Institute and completed from a new station located in the Sede Occidente, UCR, meteorological station (to simplify it will be called San Ramon meteorological Station). This data has an extension of eighty years. It starts in 1940 until 2019.

In addition, different databases have been used, such as ONI, CLLJ and AMO indexes and tropical cyclones that allow finding the causes of the regularity or variation in climatic precipitation in the micro basin under study databases were taken from NOAA. The methodology is based on analysis of the main components such as the mobile correlations between the main components and the Niño 3.4 in-dex have allowed to evaluate the temporal evolution of the EMedR-Nino relationship3.4. which have allowed to see the relationship between the period under study and the oceanic index.

This research analyzes the variability of the decadal rainfall and the variability of the Sea Surface Temperature (SST) of the Pacific and Atlantic oceans, as well as the global indices, which were obtained from the CDC/NCEP2. To analyze the relationship between rainfall and global and regional indices, Pearson's linear correlation was used. The base period for the calculation of the relation between precipitation and indexes was 1940-2019. Likewise, the precipitation index of the Caribbean Low-Level Jet was used to obtain a monthly bivari-ate analysis from January 1950 to December 2019, using the free software Geogebra. The "x" axis corresponds to the CLLJ value, "y" axis corresponds to the monthly rainfall. Red line indicates the best-fit line.

Decadal behavior of precipitation in San Ramón

It can be said that precipitation in the Costa Rican Pacific range and the temperature in the waters of the Pacific Ocean have an inverse relationship. The warmer the water on the sea surface tends to rain less, the colder the water tends to rain excessively. If the figure of interannual rainfall for San Ramón (Figure 3) is compared with the ENSO events, the most direct and evident case of relationship occurred in cold phase of 1973-1976 that was very intense. But to get a better idea you can analyze the table 2 that illustrates the most notorious relationships between rainfall and ENSO phases for San Ramón. The most intense warm phase, under this ONI index, correspond to the periods 2014-2016, followed closely by the period 1997-1998 and 1982-1983. The most intense cold phases have been those of 1954-1956, 1973-1976, 1988-1989, and that of 1998-2001. For its duration El Niño of the period 1957-1959 has been one of the most extensive, while the most durable La Niña has been that of the period 1998-2001.

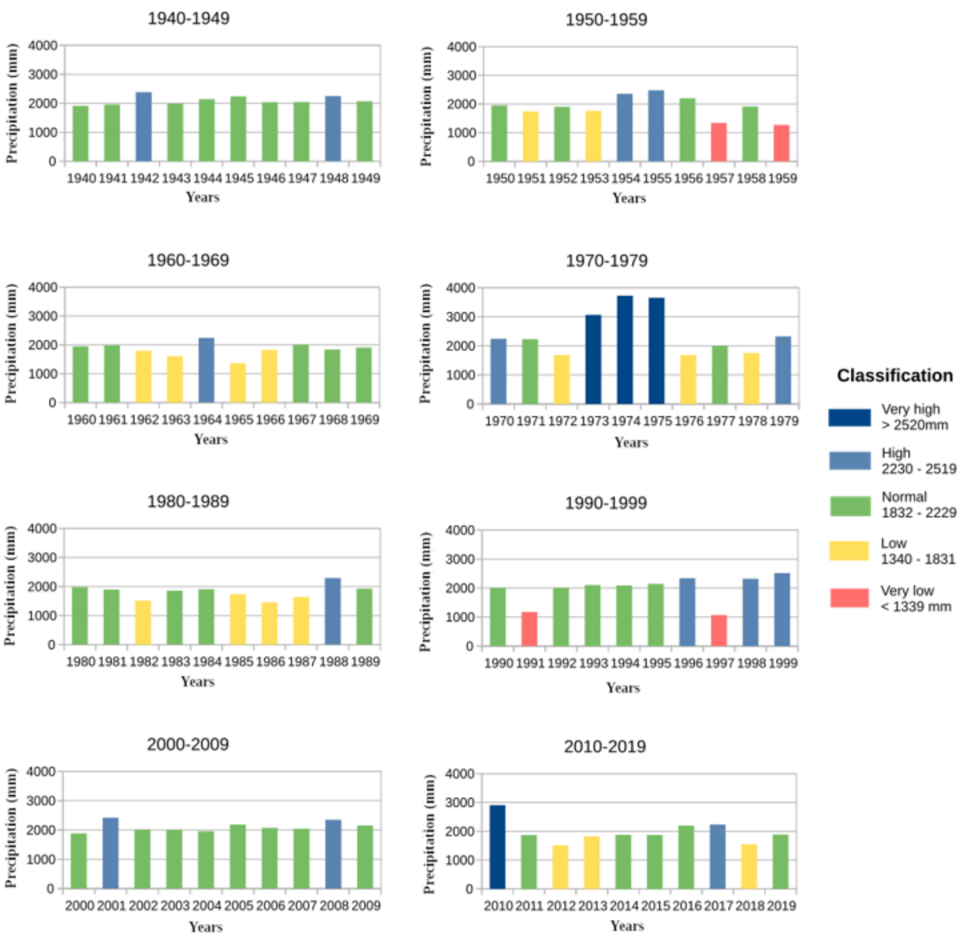

Figure 2: Very dry, dry, normal, rainy, and very rainy years for decades.

As can observe similarities between some decades with others. For example, the 1940s shares a lot of similarity with the 2000s, the 1950s shares similarities with the de 1990s, in both periods followed warm phase of the ENSO that significantly reduced rainfall, the 1960s with the 1980s and finally between the 1970s and the 2010s, where the strongest cold phases in recent history occurred, driving a significant excess of precipitation in the El Estero Micro basin. There is a consistent cyclical oscillation, as reflected by the values of precipitation accumulated over the years of registration of the Meteorological Station.

To define the classification of the previous figure, the relationship years with precipitation in millimeters for inter-annual precipitation was used, separating precipitation levels from very high to very low. The values in deep blue and red are therefore extremes of precipitation. At first glance you can notice a decadal pattern in the variation of these extremes. In turn, this variation is explained mainly by the ENSO cycles, as analyzed in the decadal behavior of precipitation.

The following table 1 shows a classification of the time periods where MEI v2 values indicating an ENSO event prevailed for at least 4 months. Under this classification El Niño of the period 1982-1983 turns out to be the most intense with the highest value recorded for the MEI v2, followed closely by a warm phase of the period 1997-1998; while La Niña of the period 2010-2012 is the most intense, followed by the current one of the periods 2020-2022. The longest-lived El Niño has been that of the period 1991-1993, while the last La Niña of the period 2020-2022 has been the one that has lasted the longest. Some phases of short duration are noticed before or after a phase of longer duration and how in a matter of a month the conditions can change from a warm phase to a cold one and vice versa, separated by only one month that is considered neutral according to the MEI v2 index. A detailed analysis of precipitation shows a clear influence of ENSO cycles in their incidence on San Ramón, the maximum peaks have occurred during cold phases of ENSO, while the minimum values have occurred in periods of warm phase of ENSO.

Table 1: Classification of ENSO phases by intensity and duration according to MEI v2 values.

Period	Phase	Extreme value	Duration (months)	Intensity**
Mar 1980 - Jun 1980	Warm	0,6	4	Medium-low
May 1982 - Jun 1983	Warm	2,9	14	Very strong
Jan 1985 - May 1985	Cold	-1,2	5	Medium-low
Jun 1986 - Dec 1988	Warm	1,9	19	Strong
May 1988 - sep 1989	Cold	-1,8	17	Strong
May 1991 - oct 1993	Warm	2	30	Very strong
Jun 1994 - ene 1995	Warm	1,5	8	Strong
Jul 1995 - Jul 1996	Cold	-0,9	13	Medium-low
Apr 1997 - Apr 1998	Warm	2,5	13	Very strong
Jun 1998 - Jun 2000	Cold	-1,7	25	Strong
Sep 2000 - May 2001	Cold	-0,9	9	Medium-low
Jul 2002 - Feb 2003	Warm	1	8	Medium-low
Sep 2005 - Mar 2006	Cold	-0,8	7	Medium-low
Jul 2006 to Dec 2006	Warm	0,9	6	Medium-low
May 2007 - Apr 2009	Cold	-1,5	25	Strong
Sep 2009 - Mar 2010	Warm	1,3	7	Medium-low
May 2010 - Feb 2012	Cold	-2,4	22	Very strong
Apr 2013 - Jul 2013	Cold	-1,2	4	Medium-low
Apr 2015 - Apr 2016	Warm	2,2	13	Very strong
Jul 2017 - may 2018	Cold	-1,3	12	Strong
May 2020 - jul 2022	Cold	-2,2	27*	Very strong

Decadal behavior of San Ramon precipitation in the relationship with the ONI, the CLLJ and the passage of some tropical cyclones near Costa Rica, 1950-2019

The ONI has been shown as the index that has the greatest correlation with precipitation in San Ramón, since it shows exactly the periods of decrease such as those of excess rainfall. The CLLJ index is a very good indicator for wind patterns over the mountain ranges of Costa Rica, so its influence is also reflected in precipitation from Northeast to Southwest. The following figures show the behavior of monthly precipitation during the last 80 years in San Ramón, divided into decades. It shows the behavior of the ONI as an indicator of ENSO conditions, sea surface temperature (SST) and the behavior of the Caribbean Low Level Jet Index (CLLJ), (for its acronym in English, for both) calculated by NOAA from 1950 to 2019. It was necessary to elaborate two figures for a better visualization. The following figures (3, 4) show the behavior of monthly precipitation during the last 80 years in San Ramón, divided into decades. It shows the behavior of the ONI as an indicator of the conditions of the ENSO (ocean surface temperature) and the behavior of the CLLJI (Caribbean Low Level Jet Index) calculated by NOAA from 1950 to 2019.

These two figures show how precipitation varies during ENSO cycles. During El Niño events it decreases with respect to normal or neutral conditions and during La Niña it tends to rain more of the ENSO cycle. This is especially true for those periods where warm or cold ENSO conditions occur during the rainy season (May to

October). San Ramon tends to have a climatological behavior of the Pacific slope, so an increase in the Trade wind means a reduction in rainfall, which occurs both by the presence of a warm phase of ENSO, and by an increase in the value of the Caribbean low-level jet (CLLJ). The CLLJ shows a cyclical variation during the year that coincides with the conditions of the Trade flow and its generating point in the high pressure of the Azores. High values of the CLLJ tend to strengthen the winds and move rainfall away from San Ramón; while the low values of the CLLJ tend to increase the incidence of rainfall in the area, being a more noticeable pattern during the rainy season. This behavior is quite noticeable at times when the CLLJ increases during the months of July-August, which together with the brief strengthening of the high pressure of the Azores cause the decrease in precipitation known as "veranillo" of San Juan, canículas. These figures show how precipitation varies during ENSO cycles. During the warm phase this decreases with respect to the normal or neutral conditions of the ENSO cycle. Also, during the cold phase, it tends to rain excessively.

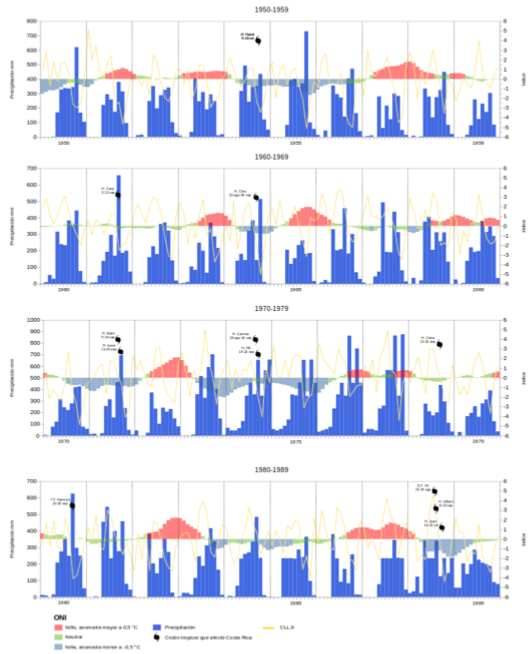

Figure 3: Decadal behavior of precipitation in San Ramón, the ONI, the CLLJI and the passage of some tropical cyclones near Costa Rica, 1950-1989.

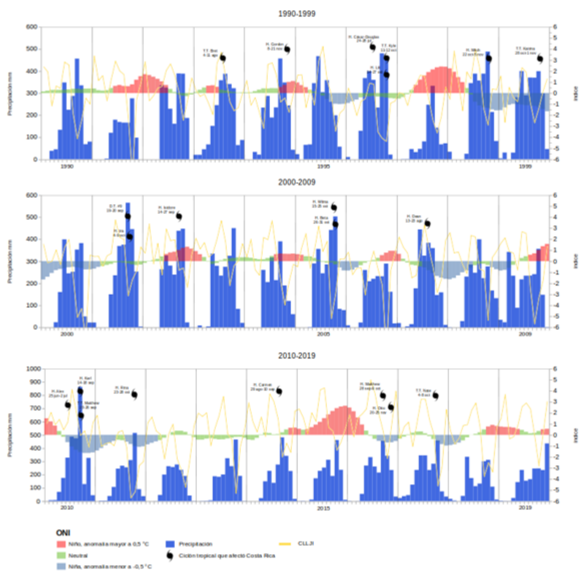

Figure 4: Decadal behavior of San Ramón precipitation with the ONI, the CLLJI and the passage of some tropical cyclones near Costa Rica, 1990-2019.

The following table 2 shows the main tropical cyclones that have most affected Costa Rica from 1950 to 2019, considering their trajectory and intensity. The possible relationship with the increase in precipitation for the San Ramón station is shown. Note that some values are repeated, this because two hurricanes affected in the same month. Some of these hurricanes are also shown in figures 5 and 6.

Table 2: Major tropical cyclones that have affected Costa Rica, 1950-2020.

Period	Cyclone name	category	Type of impact on CR	Precipitation in San San Ramón	Ration to average*	Difference %
12 - 23 Agu 1951	Charlie	Huracán 4	Indirect	173,3	-108,79	-38,56
20 - 27 Oct 1952	Fox	Huracán 4	Indirecto	341,3	5,51	1,64
23 - 27 Sep 1953	Florence	Huracán 3	Indirect	293,3	-72,91	-19,91
24 - 30 Sep 1954	Gilda	Tormenta T	Indirect	351,4	-14,81	-4,04
5 - 18 oct 1954	Hazel	Huracán 4	Indirect	434,8	99,01	29,48
12 - 20 sep 1955	Hilda	Huracán 3	Indirect	369,8	3,59	0,98
21 - 30 sep 1955	Janet	Huracán 5	Indirect	369,8	3,59	0,98
30 ago 6 sep 1958	Ella	Huracán 2	Indirect	324,2	-42,01	-11,47
9 - 17 jul 1960	Abby	Huracán 1	Indirect	178	-71,34	-28,61
17 - 24 jul 1961	Anna	Huracán 2	Indirect	295,7	46,35	18,59
3 - 13 sep 1961	Carla	Huracán 4	Indirect	656,3	290,09	79,21
27 oct -1 nov 1961	Hattie	Huracán 5	Indirect	187,5	-148,28	-100,62
28 sep - 11 oct 1963	Flora	Huracán 4	Indirect	286,9	-48,89	-14,56
20 ago - 5 sep 1964	Cleo	Huracán 4	Indirect	513	177,21	48,39
5 al 10 - nov 1964	T.T. 30	Tormenta T	Indirect	11,3	-136,07	-92,33
21 sep - 11 oct 1966	Inés	Huracán 5	Indirect	301,5	-34,28	-10,21
5 - 22 sep 1967	Beulah	Huracán 5	Indirect	336,1	-30,10	-8,22
29 ago - 4 sep 1969	Francelia	Huracán 2	Indirect	336,1	-30,10	-8,22
21 al 25 - nov 1969	Martha	Huracán 1	Direct	89,8	-57,57	-39,06
17 al 26 - may 1970	Alma	Huracán 1	Indirect	316,2	87,41	38,20
18 al 25 - agosto 1971	Chloe	Tormenta T	Indirect	461	178,90	63,42
5 al 18 - sep 1971	Edith	Huracán 5	Indirect	693	326,79	89,23
11 al 20 sep 1971	Irene	Huracán 1	Direct	693	326,79	89,23
29 ago - 10 sep 1974	Carmen	Huracán 4	Indirect	654	287,79	78,58
14 al 22 - sep 1974	Fifí	Huracán 2	Indirect	654	287,79	78,58
13 al 20 - sep 1978	Greta	Huracán 4	Indirect	438	71,79	19,60
25 ago - 6 sep 1979	David	Huracán 5	Indirect	387,9	21,69	5,92
29 ago - 14 sep 1979	Frederic	Huracán 4	Indirect	387,9	21,69	5,92
1 al 11 - ago 1980	Allen	Huracán 5	Indirect	249	-33,09	-11,73
20 - 26 sep 1980	Hermine	Tormenta	Indirect	425	58,79	16,05
7 - 9 dic 1985	T. T. 13	Tormenta	Indirect	10	-51,33	-83,69
6 - 8 sep 1987	D. T. 8	Depresión	Indirect	345	-21,20	-5,79
9 - 13 oct 1987	Floyd	Huracán 1	Indirect	237	-98,78	-29,41
20 - 24 ago 1988	D. T. 6	Depresión	Indirect	340	57,90	17,03
8 - 19 sep 1988	Gilbert	Huracán 5	Indirect	325,6	-40,60	-11,08
10 - 23 oct 1988	Joan	Huracán 4	Directo	235	-100,78	-30,01
17 - 24 1988	Keith	Tormenta	Indirect	145	-2,37	-1,61
24 - 26 may 1990	D. T. 1	Depresión	Indirect	133,4	-95,38	-41,69
4 - 11 ago 1993	Bret	Tormenta	Direct	387,4	105,30	37,33
14 - 21 sep 1993	Gert	Huracán 2	Indirect	341	-25,20	-6,88
8 - 21 nov 1994	Gordon	Huracán 1	IIndirect	243,8	96,42	65,42
7 - 21 oct 1995	Roxane	Huracán 3	Indirect	199	-136,78	-40,73
24 - 28 jul 1996	César-Douglas	Huracán 1	Indirecto	359,9	110,55	44,33
11- 12 oct 1996	Kyle	Tormenta T	Indirecto	456,9	121,11	36,06
14 - 27 oct 1996	Lili	Huracán 3	Indirecto	456,9	121,11	36,06
16 - 26 nov 1996	Marco	Huracán 1	Indirecto	21	-126,37	-85,75
15 sep al 1 oct 1998	Georges	Huracán 4	Indirecto	388	21,79	5,95
22 oct - 5 nov 1998	Mitch	Huracán 5	Indirecto	488	152,21	45,32
28 oct - 1 nov 1999	Katrina	Tormenta	Indirecto	398,9	63,11	18,79
19 - 20 sep 2001	D. T. 9	Depresión	Indirecto	564,9	198,69	54,25
4 - 9 oct 2001	Iris	Huracán 4	Indirecto	445,3	109,51	32,61
29 oct - 5 nov 2001	Michelle	Huracán 4	Indirecto	253	-82,78	-56,17
14 - 27 sep 2002	Isidore	Huracán 3	Indirecto	437,8	71,59	19,54
8 - 17 julio 2003	Claudette	Huracán 1	Indirecto	234,7	-14,64	-5,87
9 - 14 ago 2004	Charley	Huracán 4	Indirecto	213,9	-68,19	-24,17
2 - 24 sep 2004	Iván	Huracán 5	Indirecto	389,7	23,49	6,41
3 al 7 jul 2005	Dennis	Huracán 4	Indirecto	244,8	-4,54	-1,82
11 - 21 julio 2005	Emily	Huracán 5	Indirecto	244,8	-4,54	-1,82
15 - 25 oct 2005	Wilma	Huracán 5	Indirecto	502,8	167,01	49,73
26 - 31 oct 2005	Beta	Huracán 3	Indirecto	502,8	167,01	49,73
14 - 21 nov 2005	Gamma	Tormenta	Indirecto	83,6	-63,77	-43,27
13 - 23 ago 2007	Dean	Huracán 5	Indirecto	383,4	101,30	35,91
31 - ago - 5 sep 2007	Félix	Huracán 5	Indirecto	359,3	-6,90	-1,88
25 ago - 4 sep 2008	Gustav	Huracán 4	Indirecto	223,1	-58,99	-16,10
1 - 4 sep 2008	Ike	Huracán 4	Indirecto	223,1	-143,10	-39,07
5 - 10 nov 2008	Paloma	Huracán 4	Indirecto	167	19,62	13,31
4 - 10 nov 2009	Ida	Huracán 2	Indirecto	147,8	0,42	0,28
25-jun-2 jul 2010	Alex	Huracán 2	Indirecto	327,8	52,20	18,94
14 - 18 sep 2010	Karl	Huracán 1	Indirecto	862,9	496,69	135,63
23 - 26 sep 2010	Matthew	Tormenta	Indirecto	862,9	496,69	135,63
11 - 15 oct 2010	Paula	Huracán 2	Indirecto	127,9	-207,88	-61,91
20 - 25 oct 2010	Richard	Huracán 2	Indirecto	127,9	-207,88	-61,91
19 - 22 ago 2011	Harvey	Tormenta	Indirecto	254,7	-27,39	-9,71
23 - 28 oct 2011	Rina	Huracán 3	Indirecto	514,5	178,71	53,22
1 - 10 ago 2012	Ernesto	Huracán 2	Indirecto	276	-6,09	-2,15
9 - 18 ago 2012	Helene	Tormenta	Indirecto	276	-6,09	-2,15
22 - 29 oct 2012	Sandy	Huracán 3	Indirecto	189,1	-146,68	-43,68
22 - 28 oct 2014	Hanna	Tormenta	Indirecto	341,4	5,61	1,67
2 - 6 ago 2016	Earl	Huracán 1	Indirecto	215,5	-66,59	-23,60
28 sep - 9 oct 2016	Matthew	Huracán 5	Indirecto	454	87,79	23,97
20 - 25 nov 2016	Otto	Huracán 3	Directo	234	86,62	58,77
17 ago - 1 sep 2017	Harvey	Huracán 4	Indirecto	234	-48,09	-17,04
4 al 8 oct 2017	Nate	Huracán 1	Indirecto	457,18	121,39	36,15
21 - 25 ago 2020	Marco	Huracán 1	Indirecto	215,5	-66,59	-23,60
1 - 3 sep 2020	Nana	Huracán 1	Indirecto	454	87,79	23,97
4 - 10 oct 2020	Delta	Huracán 4	Indirecto	342	6,21	1,84
31 oct 13 nov 2020	Eta	Huracán 4	Indirecto	234	86,62	58,77
13 - 18 nov 2020	Iota	Huracán 4	Indirecto	234	86,62	58,77

Considering the table 2, it can be said that hurricanes do have an appreciable influence on the behavior of precipitation, the first two decades there were one and two cyclones. However, the rest of the decades showed more cyclones per decade. For example, in the 1970-79 (5) [1], 1980-89 (4), 1990-99 (7), 2000-09 (6), and 2020-29 (8). It behaviors shows that cyclones are increasing with the time, since 1970 to 2019 there are more cyclones, especially in the Atlantic Ocean, it means more rainfall over the Pacific range of Costa Rica where SR is located. The probability of more floods is increasing over the study area. There have been some cyclones that have affected the SR-CR with big floods like Fifi in 1974, Mitch in 1998, Otto in 2016, among others. Even though, most of the cyclones have indirect track over Costa Rica, those have affected with a lot of rainfall over the SR-CR area.

In the months of September and October 1988 there were four cyclones and two of them have reached their maximum category near the country: Gilbert (category 5), Joan (category 4), Mitch (category 5) the last two almost had a direct impact. According to the data of the station, in that year it rained excessively during the months of August and December. Figure 2 shows the track and satellite images of these two hurricanes.

Decadal precipitation and the AMO Index

The AMO is the Atlantic Multidecadal Oscillation Index, which seeks to measure an oscillatory pattern, with a periodicity of more than a decade, in the surface temperature of the North Atlantic Ocean, as defined by UCAR (September 17, 2023) on its website. It should not be confused with the NAO (North Atlantic Oscillation Index) which measures a year-on-year variation.

If the behavior of this index is compared with the monthly rainfall values in San Ramón, the following linear correlation graphs are obtained. A very low correlation is observed, which makes sense given the distance at which the North Atlantic oscillation occurs with respect to the local climatology of Costa Rica.

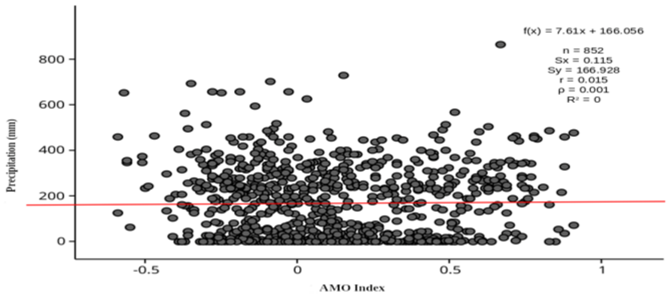

Figure 5: Correlation between AMO values and precipitation in San Ramón.

An upward trend can be noted in the data, so that high values of the AMO index correspond to higher rainfall. If one considers that this index basically measures marine surface temperature anomalies, this behavior makes sense given the expected increase in the number of tropical storms and cyclones, the possibility of greater atmospheric humidity in the Caribbean. Humidity that is transferred to Costa Rica by the action of the Trade winds. Possibly the influence of the AMO in a tropical country like Costa Rica is more noticeable on the Caribbean side.

However, it is known that the North Atlantic multidecadal oscillation does have a significant influence on rainfall in North America and Europe, geographically closer areas, as well as on the behavior of tropical cyclones in the North Atlantic, generating excess moisture in warm phases or dryness in cold phases (NOAA, January 15, 2023). There may be a delay or time lag in the behavior of the data. The following figure seeks to show a possible trend in the precipitation data, delaying the AMO value by one, two, three, four and five months from the corresponding date.

The figure 5 shows the behavior of the correlation between the AMO index and precipitation in San Ramón. Figure 6 shows the variation of the correlation coefficient and the offset of the ONI index over the period 1950-2020. The highest degree of association between these variables occurs for a three-month lag. This means that a variation in sea surface temperature in the Niño 3.4 region is reflected in rainfall three months after the event occurred in that region. Although the correlation is statistically significant, it is relatively weak ($r < 0.25$). That behavior is consistent with the fact that few El Niño episodes lead to appreciable changes in the affected area). It can be noted that the highest value of r corresponds to a 3-month deface ($r = -0.583$; $R2 = 0.0034$), which somehow is indicative of a higher correlation in the data, even though it is not high, at least shows a relationship between the San Ramon rainfall and the AMO. However, it is noticing the change in the slope of the line, from positive to negative, accordingly, there is now a decreasing trend: high and positive values of AMO index are associated with less rainfall.

This is still an exploratory analysis, but the better correlation adjustment in the data is remarkable as the temporal gap in the AMO index increases with respect to precipitation in San Ramón, improving considerably with respect to the direct association between the index and the data from the San Ramon meteorological station. It can be hypothesized that the decreasing trend when applying a temporary face is revealing a climatological component of the Caribbean regime in San Ramón that can be appreciated through this index.

For the months of May-June you have an R^2 increases, but it is still very low. This shows that CLLJ have a mild influence. This is because it is a bimonthly period where the Intertropical Convergence Zone (ITCZ) has greater influence on the El Estero micro-basin. The months of July-August indicates a very low linear correlation, but it seems that positive values of the CLLJ cause a slight increase in precipitation. Negative values coincide with lower precipitation records. It seems plausible to state that when the CLLJ value is higher, precipitation tends to increase. For this period this behavior is more clearly noticeable. It is precisely in these two months where a better correlation between both variables is shown. On the other hand, in the months of September-October, although there is a positive correlation, the relationship between one variable and another is less influential. That is, the value of the CLLJ influences less in the months of September-October. Very similar to the first bimonthly period (M-J) there is a greater presence of ITCZ.

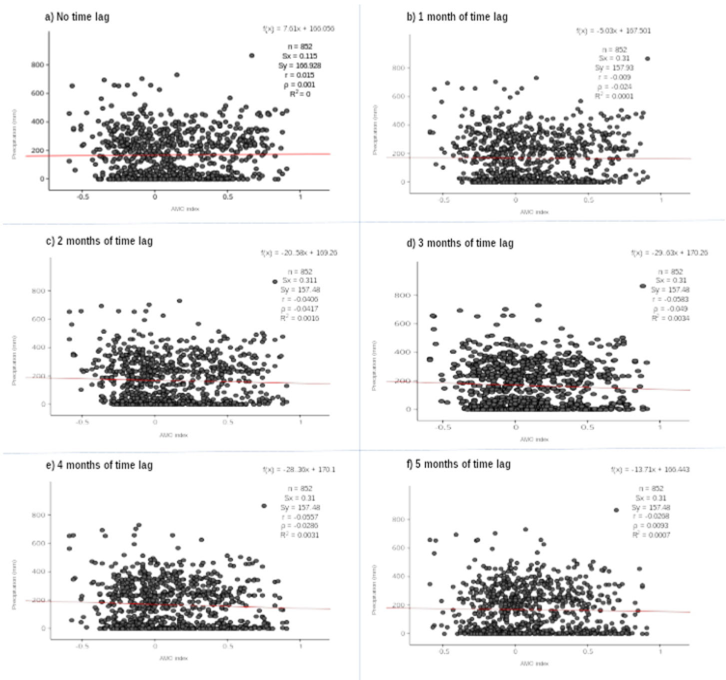

Figure 6: Correlation of the AMO index with rainfall in San Ramón considering temporary faces.

3 Results and discussion

The results confirm decadal variations in the eight decades investigated, showing that the decades 1970/1979 and 1990-99 showed higher levels of precipitation. While the decades of 1960-69 and 1980-89 were drier. This indicates that every two decades there exist a climate change in precipita-tion. In addition, the decadal variations show a relationship between the first index of precipitation variability in EMed, and El Nino being modulated by patterns of decadal variability, TSM in the At-lantic and Pacific basins. Specifically, the results indicate how EMedR-Nino3.4 teleconnections show greater influence on decadal precipitation. While the relationship with the AMO (Atlantic Multide-cadal Oscillation) has a correlation even though it is low, especially in the period of July / August. Several hypotheses are raised and discussed to explain these results, which represent a step forward in improving knowledge of the role played by ocean variability in the modulation of teleconnection mechanisms at decadal scales.

Some additional events for the analysis of the creek that cross the city of San Ramon in periods of heavy rainfall, according to figures 2, 3, 4, 5, 6, 7, 8 indicate very accurately that it is very likely that, under a storm and tropical cyclone, among others, could lead to a flood when the El Estero creek overflows. The "potential to cause flooding" is because with only two-thirds of the depth of the channel or with a measure or 0.6 m. in some places of the creek would produce an unprecedented flood.

4 Conclusions

During the decades of 1970-1979 there was Hurricane Fifi that flooded the city of San Ramon and in the decade of 1990-1999, there was another hurricane El Mich that also caused a great flood in the city and surroundings. This also indicates that during the Cold phase and when the CCLJ show greater intensity there is a greater probability that precipitation levels will increase in the El Estero micro basin and therefore the possibility of flooding in the creek and flooding much of the city of San Ramon and surroundings increases. It also can be noted that the highest value of r corresponds to a 3-month deface ($r = -0.583$; $R2 = 0.0034$), which somehow is indicative of a higher correlation in the data, even though it is not high, at least shows a relationship between the San Ramon rainfall and the AMO. However, it is noticing the change in the slope of the line, from positive to negative, accordingly, there is now a decreasing trend: high and positive values of AMO index are associated with less rainfall.

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