Research Article

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Spatial distribution of daily and monthly precipitation in the Central Caribbean side of Costa Rica

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Abstract

The spatial variations of trends of relevant monthly and daily precipitation, as the probability of wet or dry conditions is taken into consideration to see the amount of precipitation per station. The research examined six rainfall stations in the Caribbean slope of Costa Rica in a period between 1989 to 2019. The research uses the rain data provided for a National Meteorological Institute (IMN) and the figures were made using ArcGIS. This study aims to consider the amount of precipitation, the mean daily, monthly, total rainfall, probability of wetness, monthly maximum daily precipitation, and deviations in monthly total precipitation from average. It was shown how on the Caribbean side some months have an opposite answer depending on the ENSO phase. Each station has different answer depending on their location and the month. For instance, certain months like March, April and October present some dryness. The research reflects that in the Caribbean slope of Costa Rica the warm phase behaves in different way in the same region, even though this is somehow flat. Although, Costa Rica is a small country (51.179km²) is far from being uniform, and the results presented in this research reveal differences in the daily and monthly rain. In the Caribbean slope the ENSO phases increase impact in monthly and daily circulations over the Atlantic through the Jet streams (CLLJ).

Keywords: Caribbean slope, Costa Rica, daily and monthly precipitation, cold phase, warm phase, jet streams

Introduction

The Caribbean side of Costa Rica is a region where it is imperative to understand precipitation patterns, variability, and extremes. The low-lying coastal region of the Caribbean is exacerbated by the amount of precipitation during most part of the year. The development of this region is characterized by being one of the poorest ones in Costa Rica. So, to achieve planning, policy actions and conservation, it is extremely necessary to have knowledge of the precipitation in the region. These social and economic reasons provide considerable motivation for increasing and expanding current knowledge of precipitation in the Caribbean area of Costa Rica.

The monthly rainfall exhibits a large amount of variation throughout the year, with an initial minimum in March and October, and a maximum in July and December. The climatology of the Caribbean precipitation is well known for having a distribution of the mean rainfall primarily dominated by the location of the land. The synoptic influence for Caribbean precipitation is the North Atlantic subtropical high (NAH), whose latitudinal position and strength affect the velocity of the trade winds, sea surface temperature, and coastal upwelling, which all act to modify precipitation amounts in the region.[1]

The Caribbean low-level jet (CLLJ) is an easterly jet located over the Caribbean Sea, between the northern coast of South America (Venezuela and Columbia) and the Greater Antilles (Cuba, Haiti, Dominican Republic, and Puerto Rico). It is present throughout the year and transports large amounts of moisture from the tropical Atlantic into the Caribbean Sea, into the Gulf of Mexico, across Central America, and into the Pacific basin.

In this paper, it is important to understand the dynamics of the climatological CLLJ, including how the jet's variations are controlled on monthly and diurnal time scales. In addition, the relationship between the CLLJ and rainfall is examined, with special attention to any connections between the jet and ENSO.[2] High-speed wind streams are often called "jets". Some of these jets are regarded as large-scale low-level jets, while others are known as "gap jets", as these are strong winds developed after passing topographic gaps.

A strong easterly wind current in the Caribbean develops during the boreal summer and reaches its maximum magnitude at 925 Mb in July. This current, known as the Caribbean Low-Level Jet (CLLJ), was first studied by Amador[3] who used data from the NCEP/NCAR Reanalysis project[4] for the boreal summers of 1982 to 1994.

The CLLJ contributes to easterly wave activities and affects the vertical wind shear and moisture over the Caribbean.[5] These local environments control tropical cyclone (TC) formation (e.g., Gray, 1968); therefore, CLLJ is closely linked to TC formation and is a key phenomenon in the Caribbean. The first climate projection for the Caribbean was made at the end of the 20th century. However, according to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,[6] projections for the Caribbean are limited. Amador[3] found an interesting climatic characteristic in the tropical region of the American continent: an intense wind current at low levels of the tropical atmosphere, especially at 925, 850, and 700mm, with mean winds of 15*m s-1*.[7]

This wind current has been known since then as the Caribbean Low-Level Jet (CLLJ), but in recent studies, it has received another name, the Intra-Americas Low-Level Jet (IALLJ). The CLLJ is barotropic unstable and centered between 13.0° and 15.0° N and between 70.0° to 80.0° W.[3,8,9] In the present century, changing climate may noticeably affect the CLLJ[10] and have larger hydroclimatic consequences; however, because of the region's position to the strong winds and the difficulty of its low topography, it normally gets floods easily.

During the boreal summer, when the jet is active, the humidity from the Caribbean is pushed westward and converges at the Caribbean coast between Nicaragua and Costa Rica, producing strong precipitation over the east coasts of these countries and no precipitation at all over the Caribbean Sea.

The influence of this jet extends into the north Pacific, east of 120.0° W, producing mesoscale eddies that affect the circulation in the area.[11] As the NASH extends westward and retreats eastward during the year, the CLLJ has a semiannual variability: two maxima in the summer and winter, and a small recession in the spring and fall, directly associated with the NASH displacement. A research done by Wang and Lee[5] shows that the CLLJ forms when the North Atlantic Subtropical High (NASH) is strong and displaced Tropical Low-Level Jets to the west, creating a pressure gradient that accelerates the easterly winds in the Caribbean.

The Caribbean region of Costa Rica has precipitation variability on distinct temporal periods. For an instant, ENSO (El Niño-La Niña- Southern Oscillation) has variability in different time periods. However, not only ENSO influences amount of rainfall during certain periods of a particular year, but also the North Atlantic Oscillation (NAO) affects the precipitation in such a region of Central America.[12]

ENSO impacts the Caribbean through changes in convergence patterns and sea surface temperatures (SSTs) in the Caribbean that cause changes in rainfall.[10,12] The phase of the NAO modulates the behavior of warm ENSO events.[13] The region is also affected on shorter time scales (days to weeks) by the propagation of easterly waves, which can later become tropical storms and hurricanes that represent a primary rainfall source in the Caribbean, contributing to the second rainfall peak in the annual cycle.

This research investigates the monthly and daily changes in precipitation due to the CLLJ and ENSO from the spatial point of view in the Caribbean region of Costa Rica.

Study area and methodology

The Central Caribbean region of Costa Rica is in Eastern region as you can see in Figure 1. In this case, six stations were taken into consideration to carry out this research. From these stations, five are close to the coast and just one (Guayabo) is about forty kilometers from the coast. However, it is important to consider it to see how much rain extends inside the Caribbean territory.

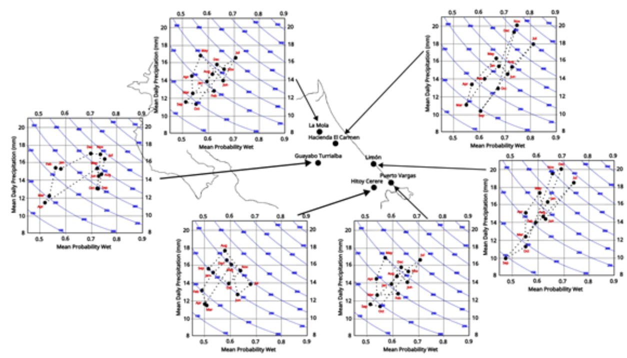

Figure 1 Location of the study area and station considered in the analysis.

Monthly precipitation total

$$\sum_{i=1}^{n} P_i$$

Where n = number of days in the month

P_i = daily rainfall total

Mean daily precipitation.

$$\frac{1}{m}\sum_{i=1}^{n} P_i$$

Where m = number of days in month with measurable precipitation

Probability of wet day

$$\frac{m}{n}$$

Probability of daily total greater than 10mm

$$\frac{m_{10}}{n}$$

Where m_{10} = number of days in month with measurable precipitation greater than 10mm

Probability of daily total greater than 20mm

$$\frac{m_{20}}{n}$$

Where m_{20} = number of days in month with measurable precipitation greater than 20mm

Probability of daily total greater than 30mm

$$\frac{m_{30}}{n}$$

Where m_{30} = number of days in month with measurable precipitation greater than 30mm

Monthly maximum daily precipitation (P_i)

It also used the Geographic Information System (ArcGIS) to draw the map and the figures were made by an Excel combined with some ArcGIS.

Results

The amount of precipitation in six sectors of the Caribbean region of Costa Rica is analyzed in order to see their behavior. To figurate the differences among sectors, it was taken into consideration the following aspects: Mean probability of wet, mean monthly precipitation (mm), probability of daily precipitation, mean daily precipitation (mm), monthly total precipitation by ENSO Phase, Monthly Total Precipitation by ENSO Phase, Deviations in Monthly Total Precipitation from Average, Difference in Mean Monthly Totals (Cold minus Warm) as Percentage of Overall Mean, Difference in Mean Daily Totals (Cold minus Warm) as Percentage of Overall Mean, Difference in Probability of wet (Cold minus Warm) as Percentage of Overall Mean (Figure 2).

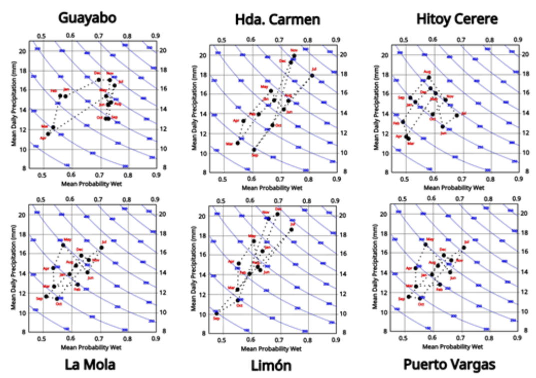

Figure 2 Stations under study.

The sectors that have stations show some differences among them. For instance. Guayabo, Hitoy Cerere, La Mola y Puerto Vargas present some similarities: The probability of precipitation goes from 12 to 20mm. Meanwhile, the mean probability of wet conditions goes from 0.5 to 0.7. Contrary, Limon and Hda. El Carmen has a probability of precipitation between 10 and 20mm. However, the mean probability of wet conditions of wet goes from 0.5 to 08mm.

Mean monthly precipitation.

In this case, the analysis shows that March and September and the stations of Limon and Puerto Vargas for March, September have the lowest amount of mean monthly precipitation (mm). April has somewhat of a similar situation, except for Limon which has a higher mean monthly precipitation. May and June have medium values. However, July, December, and January show the highest values of mean monthly precipitation (mm) (Figure 3).

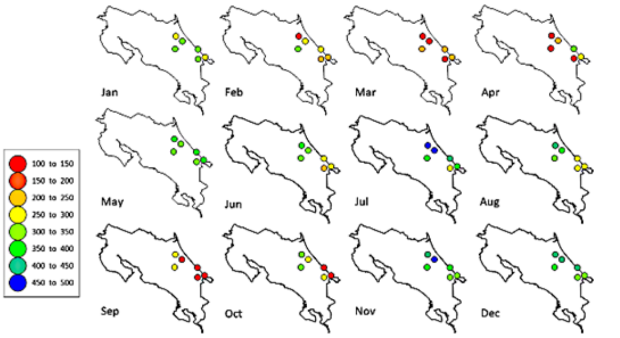

Figure 3 Mean monthly precipitation (mm).

The following figure shows the mean daily precipitation (mm), finding that February, March, September, and October have the lowest mean. Conversely, July, December, and January have the highest values (Figure 4).

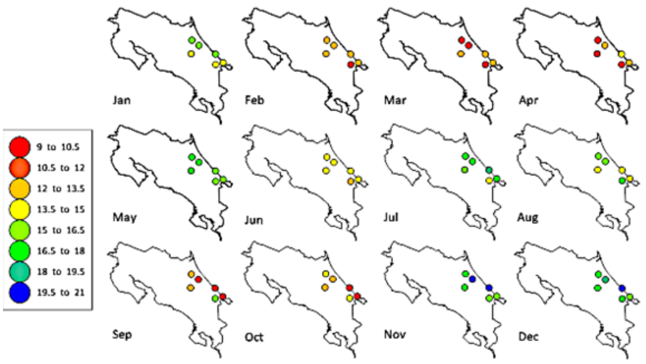

Figure 4 Mean daily precipitation (mm).

According to Figure 5 the months of February, March, and April and the stations of Limon, Hitoe Cerere and Puerto Vargas show a low probability of having daily precipitation. Otherwise, November, December, and especially July has the probability to have higher means.

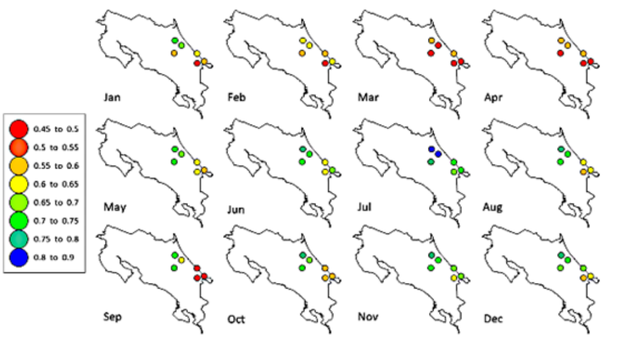

Figure 5 Probability of daily precipitation (mm).

The monthly total precipitation during the ENSO phase shows values between 250 to 350mm for January, however, during the cold phase the values increase between 300 to 400mm. This means that during January the cold phase rains a little bit more. In February, during the warm phase, it goes from 0 to 250mm. During the cold phase it increases until from 250mm and only La Mola station shows values from 0 to 150mm (Figure 6).

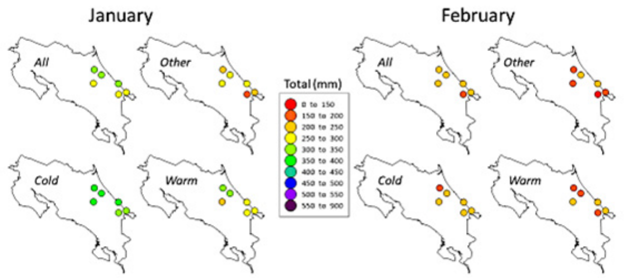

Figure 6 Monthly total precipitation by ENSO Phase for January and February.

The monthly total precipitation during the ENSO phase shows values between 250 to 350mm for January, however, during the cold phase the values increase between 300 to 400mm. This means that during January the cold phase rains a little bit more. In February, during the warm phase, it goes from 0 to 250mm. During the cold phase it increases from 250mm, and just in La Mola station it shows values from 0 to 150mm (Figure 6).

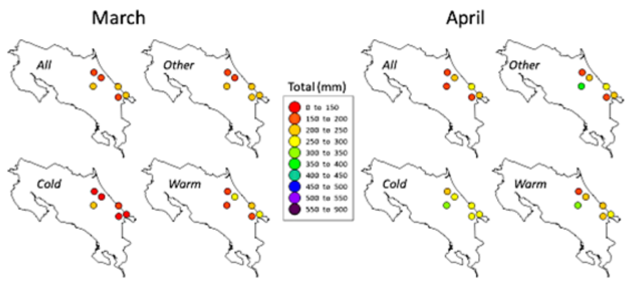

Figure 7 Monthly total precipitation by ENSO Phase for March and April.

During March the cold phase there are small values that go from 0 to 250mm and during the warm phase go from 150 to 300mm. Meanwhile the values are a little bit bigger, it goes from 0 to 300mm. In April during the cold phase, it goes from 250 to 300mm, the cold phase shows higher values than the warm phase (Figure 7).

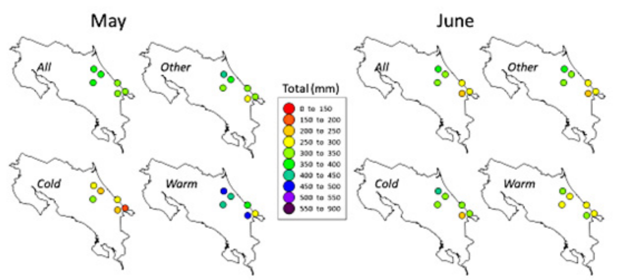

Figure 8 Monthly total precipitation by ENSO Phase for May and June.

During May the cold phase shows inferior monthly total precipitation than the warm phase. However, in June both phases show similar monthly precipitation (Figure 8).

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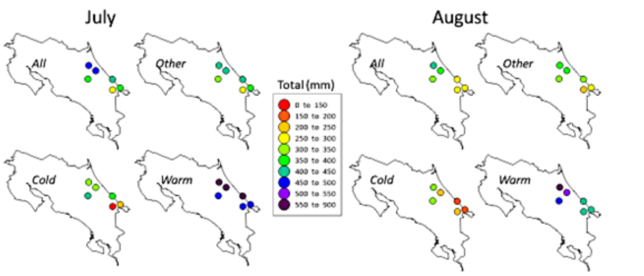

Figure 9 Monthly total precipitation by ENSO phase during July and August.

During the cold phase, the monthly total precipitation is inferior to the warm phase which shows the highest values of the whole year. At the same time, during August the values are higher during the warm phase, especially in the station's La Mola, Hda. El Carmen and Guayabo (Figure 9).

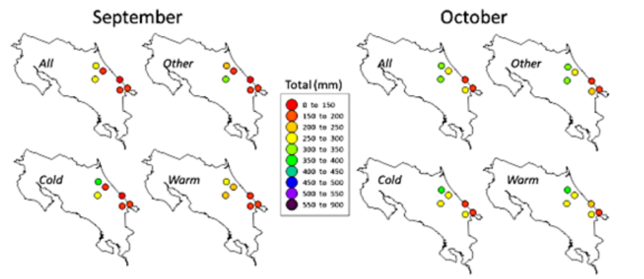

Figure 10 Monthly total precipitation by ENSO phase during September and October.

In September the monthly total precipitation during both phases is very similar, except for La Mola which shows a higher monthly total precipitation. In October monthly total rainfall increases especially during the warm phase (Figure 10).

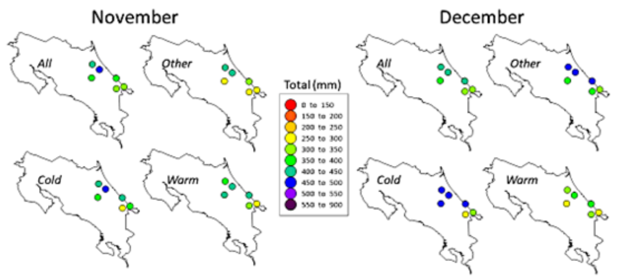

Figure 11 Monthly total precipitation by ENSO phase during November and December.

During the cold phase the Hda. El Carmen is the only exception that has monthly total values between 450 to 500 mm. Otherwise, in December, the cold phase has four stations with values between 450 to 500mm. The warm phase just shows monthly total precipitation between 250 to 400mm (Figure 11).

During the cold phase, the deviations in monthly total precipitation from average is higher during the cold phase during January. In February the cold phase also has a higher deviation in monthly total precipitation from the average (Figure 12).

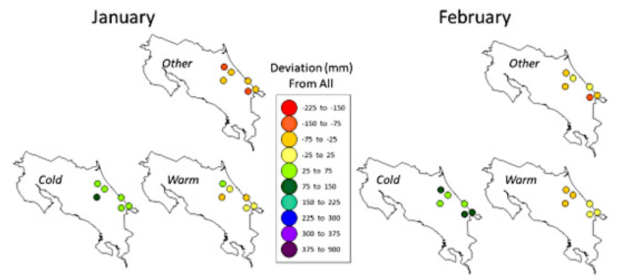

Figure 12 Deviations in monthly total precipitation from average in January and February.

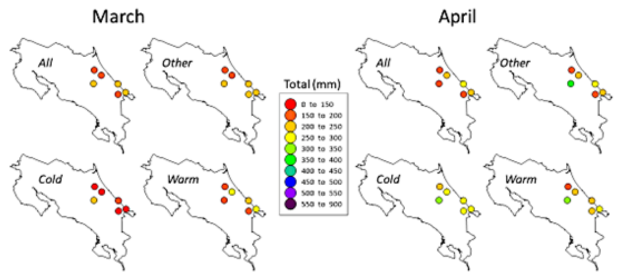

Figure 13 Deviations in monthly total precipitation from average for March and April.

The monthly precipitation totals from the average are very similar for March and April in both phases (Figure 13).

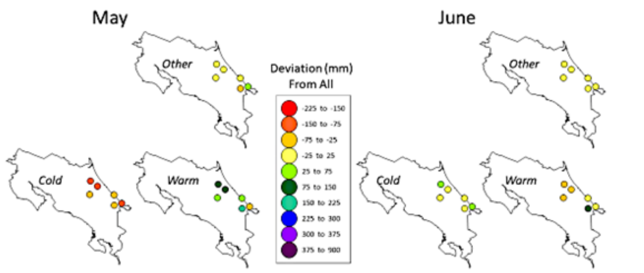

Figure 14 Deviations in monthly total precipitation from average in May and June.

During the cold phase the monthly total precipitation is -225 to -25mm. During the warm phase, the monthly precipitation goes from -75 to 150mm. The stations of La Mola and Hda. El Carmen shows higher values of monthly precipitation total from the average (Figure 14).

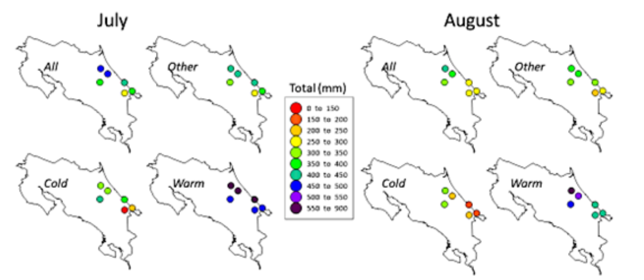

Figure 15 Deviations in monthly total precipitation from average in July and August.

The deviation in monthly total precipitation from the averages is higher in July and August during the warm phase (Figure 15).

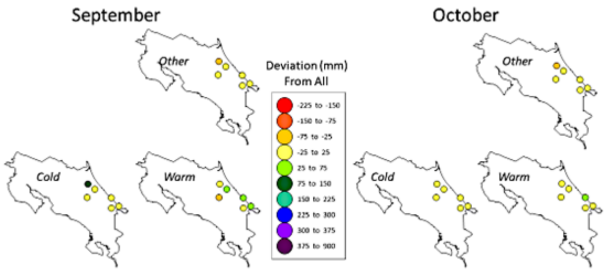

Figure 16 Deviations in monthly total precipitation from average in September and October.

The deviation in monthly total precipitation from the average shows higher values that go from 25 to 75. However, the station La Mola during the Cold phase shows deviation in precipitation between 75 and 150. In October both phases present very similar deviation in monthly precipitation from the average (Figure 16).

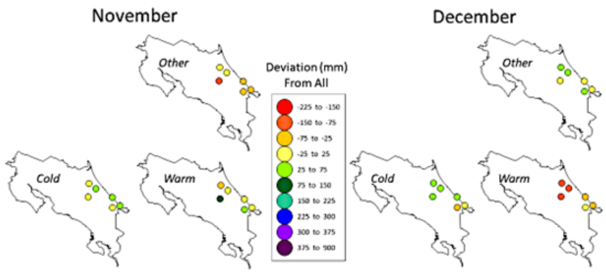

Figure 17 Deviations in monthly total precipitation from average in November and December.

In November the cold phase shows higher monthly precipitation from an average between 75 and 150 mm. In December such an average of monthly precipitation is higher during the cold phase of ENSO (Figure 17).

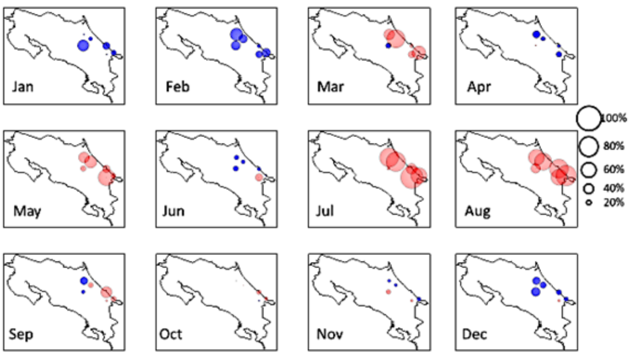

Figure 18 Difference in mean monthly totals (Cold minus Warm) as a percentage of the average of overall Mean.

During the warm phase it is possible to see that March, May, Jul and August show higher percentages in the probability of the average of overall mean the rest of the months behave as a cold phase, but with less percentage of the average in a stronger way (Figure 18).

The difference in mean daily totals as a percentage of overall mean increase in February during La Niña. However, during March, May, July, and August is higher during El Niño (Figure 19).

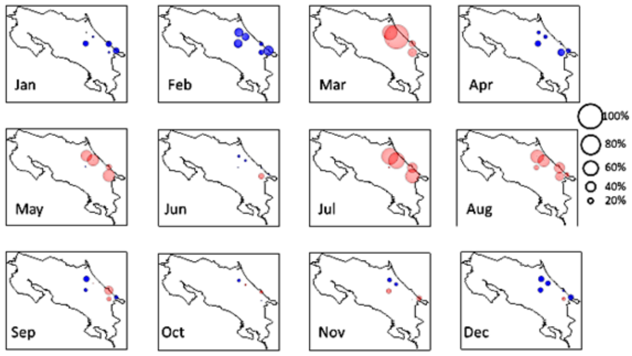

Figure 19 Difference in mean daily totals (Cold minus Warm) as a percentage of overall mean.

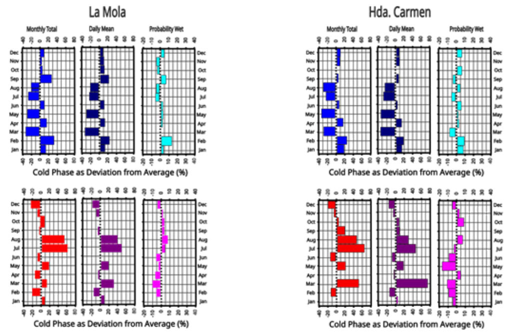

Figure 20 Difference in the probability of wet (Cold minus Warm) as a percentage of the overall mean.

The monthly total and daily mean in La Mola present more negative values during the cold phase. However, the probability of wet presents two positive wet values. On the other hand, Hda. El Carmen also presents more negative than positive values during the cold phase for both monthly and daily precipitation. Meanwhile, the probability of wetness has not a clear answer (Figure 20).

During the warm phase of ENSO, la Mola presents positive monthly total and daily mean as a percentage of overall men and the probability of wet condition is very irregular. Hda. El Carmen also presents positive monthly total and daily mean values, and the probability of wetness is irregular (Figure 20).

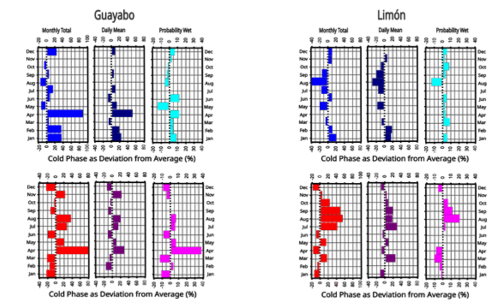

Figure 21 Difference in the probability of wet (Cold minus Warm) as a percentage of the overall mean.

The Guayabo station shows a monthly total, daily mean, and probability of wet as a percentage of the overall wet with positive values for both cold and warm phases. Limon station for monthly totals has a positive monthly total of precipitation and the daily mean shows negative precipitation and the probability of wet is somehow positive. During the warm phase, the three samples are positive (Figure 21).

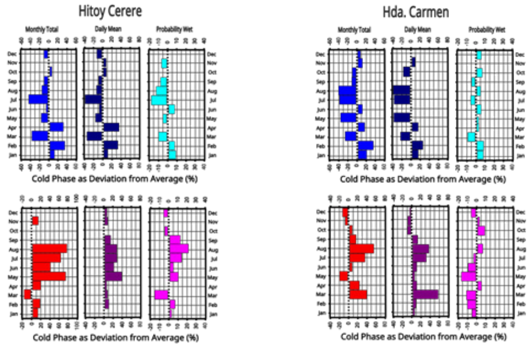

Figure 22 Difference in the probability of wet (Cold minus Warm) as a percentage of the overall mean.

During the cold phase, Hitoy Cerere for monthly totals and daily mean as an overall percentage of overall mean show both negative and positive data and the probability of wet is irregular. However, the warm phase shows data very positive. In the case of Hda El Carmen the cold phase presents negative monthly totals, daily mean, and probability of wet with negative values. However, during the warm phase for the three samples, the data is positive. That means that during the warm phase it tends to rains more (Figure 22).

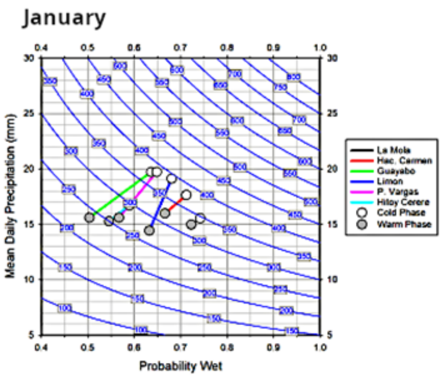

Figure 23 Probability of mean daily precipitation wet (mm).

All the stations in the study show that during the cold phase there are more chances of wetting conditions, especially in the Guayabo station, the wettest one during January (Figure 23).

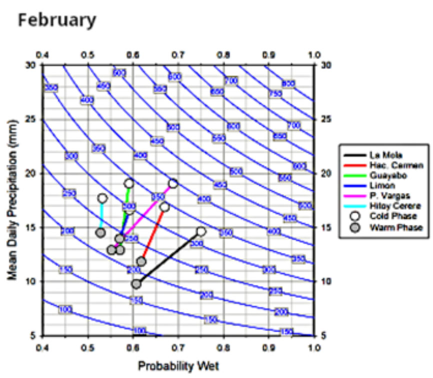

Figure 24 Probability of mean daily precipitation wet (mm).

The probability of mean daily precipitation wet during February also presents the cold phase to be wettest. The station of Puerto Vargas has the warmest month (Figure 24).

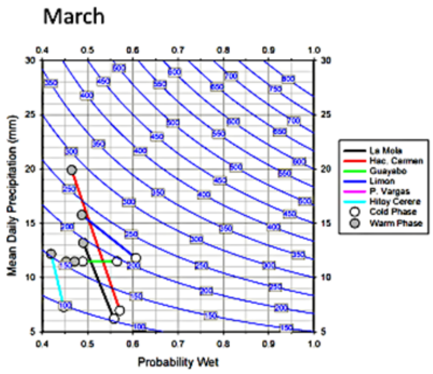

Figure 25 Probability of mean daily precipitation wet (mm).

During March all the stations show a probability of mean daily precipitation to be higher during the warm phase. However, the precipitation is low (Figure 25).

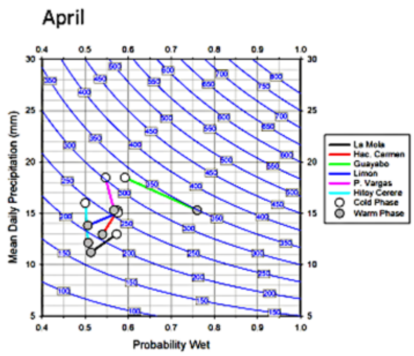

Figure 26 Probability of mean daily precipitation wet (mm).

During the month of April, all the stations show higher wetness during the cold phase (Figure 26).

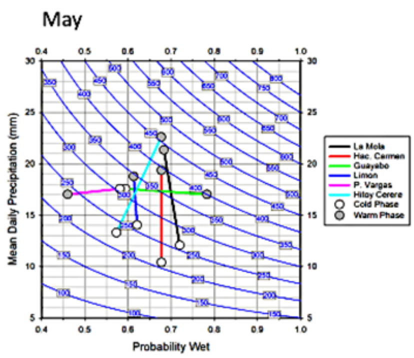

Figure 27 Probability of mean daily precipitation wet (mm).

In May the situation changed, most of the months presented a higher probability of wetness during the warm phase, being the Hitoy Cerere the one to have the higher values (Figure 27).

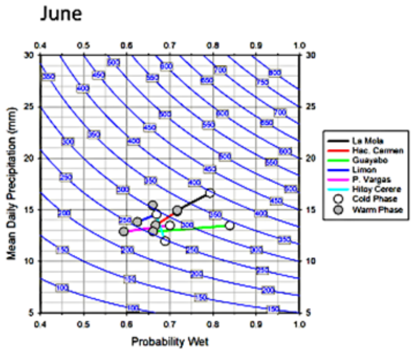

Figure 28 Probability of mean daily precipitation wet (mm).

In June most of the data for all stations look very similar, with the exception that some warm phases dominate, such as the case of La Mola station (Figure 28).

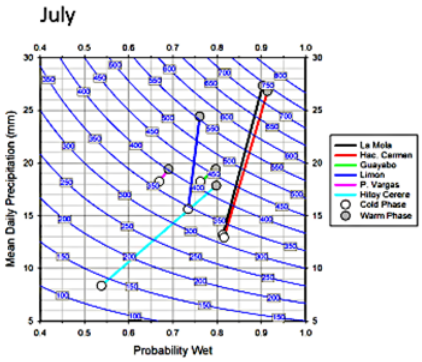

Figure 29 Probability of mean daily precipitation wet (mm).

July has a strong particularity of being the probability of being wet all the station during the warm phase. For instance, stations like La Mola and Hda. El Carmen shows a higher probability of being very wet (Figure 29).

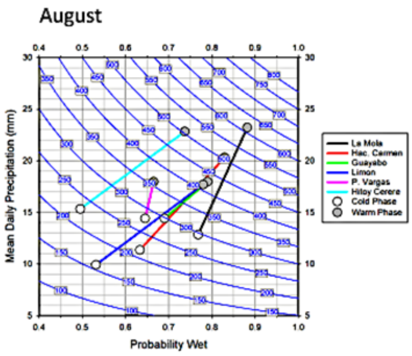

Figure 30 Probability of mean daily precipitation wet (mm).

During August most of the region have more probability of being wet during the warm phase. In particular, the La Mola station (Figure 30).

The month of September has some stations with a higher probability of being wet, but other ones do not show this particularity (Figure 31).

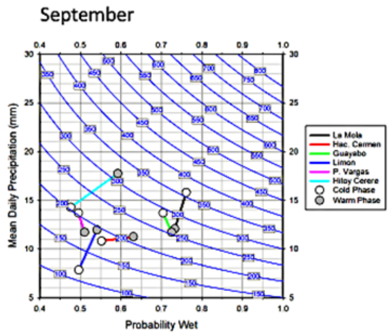

Figure 31 Probability of mean daily precipitation wet (mm).

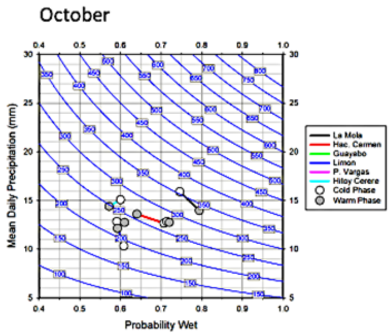

Figure 32 Probability of mean daily precipitation wet (mm).

During October a similar situation happened in a few stations with a high probability of wet conditions (Figure 32).

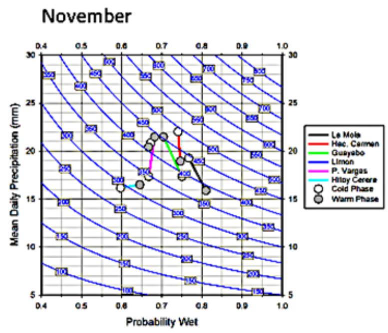

Figure 33 Probability of mean daily precipitation wet (mm).

During November the probability of being wet is mixed, however, most stations have some probability of being wet (Figure 33).

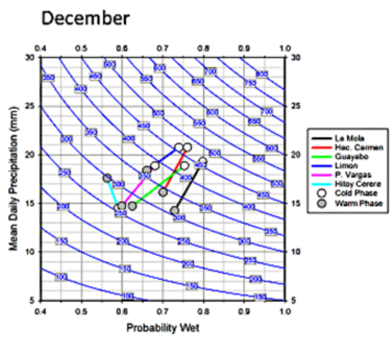

Figure 34 Probability of mean daily precipitation wet (mm).

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December has a probability of having most of the region with more rainfall during the cold phase.

Discussion and conclusion

The growing wet season has increased during the warm phase. It is something different that happens in the Pacific side where the cold phase dominates in certain periods and the warm in another one. This also results in a significant declining trend in the cold phase throughout the region, while in the regionally averaged warm phase, the trends are to increase. This happens especially in months like July, December, and January.

There is a consistent pattern of trends in daily precipitation over the studied area that is related to increasing precipitation. The monthly precipitation sometimes is not so clear, but some months increase their rainfall in July and December. The results make us able to find out changes in the Caribbean slope if we compare it with the Pacific slope. While the Pacific is dry the Caribbean is rainy.

The findings put emphasis on great enhancement in intensity in monthly totals, daily mean, and wet conditions of rainfall along the Caribbean range with a higher amount in some stations during the warm phase. This includes the intensity and the probability of being wet during the warm phase. This includes the intensity and the probability of being wet during the warm phase. There exists a large difference occurring between range locations considering the several years of study. The fluctuations of each station fluctuate according to the intensity of the precipitation.

The CLLJ itself is also shown to be subject to intraseasonal associated with rainfall. It is observed in all stations that show a significant coherence with intraseasonal variability in the precipitation. The boreal summer strengthening of the Caribbean LLJ is associated with subsidence over the subtropical North Atlantic from the May-to-July shift of the ITCZ and the evolution of the Central American winds.

Additionally, the midsummer minimum of Caribbean precipitation is related to the Caribbean LLJ through greater moisture flux divergence. From May to September the moisture carried by the Caribbean LLJ into the Gulf of Mexico is strongest. The summer interannual variability of the Caribbean CLLJ is due to the variability of the meridional pressure gradient across the Caribbean basin, influenced by tropical Pacific.[14,15]

In conclusion the daily and monthly variability of precipitation in the Caribbean side of Costa Rica has been linked to both phases of ENSO. The location of each station does not have any relationship with the amount of precipitation during a particular phase, being July and December the ones that have more precipitation during each year. During the La Niña period the South and Central Caribbean side show more precipitation during the month of December because the Los Nortes seem to be strongers. Large positive and negative precipitation anomalies (up to 50% of the annual mean) were observed in both phases of ENSO based on the index of ONI.

The largest changes and most coherent patterns were observed in the warm phase of ENSO, when Caribbean precipitation is generally above average. For instance, during December Limon, Hda El Carmen and La Mola have higher mean daily precipitation during the cold phase. The rest of the stations show more precipitation during the warm phase. Meanwhile, July the same three stations Limon, Hda El Carmen y La Mola have a large amount of precipitation during the warm phase. Otherwise, it means that the position of the Caribbean side of Costa Rica daily and monthly precipitation seem to be higher during the warm phase. However, there are some months like December that precipitation increases during the cold phase in most of the Caribbean region.

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Conflicts of interest

The author declared that there is no conflict of interest.

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