Food and Agriculture Organization of the United Nations

New canicula index

to study its impact on Agriculture in the Central American Dry Corridor and its connection with El Niño

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Content

Foreword

The canicula is a meteorological phenomenon that causes a reduction in rainfall during the rainy season, generally in July and August. It is during this period when agriculture can be affected in the Central American region, particularly in the Dry Corridor area, leading to significant losses in the most vulnerable people, whose livelihoods depend on water resources.

To better understand this phenomenon, the Food and Agriculture Organization of the United Nations (FAO), in collaboration with the Regional Committee on Hydraulic Resources (CRRH), has analysed the impact of the canicula on agriculture, the frequency of occurrence and its intensity, by using geospatial information. Geospatial information has a ten days (dekad) frequency of analysis on vegetation, at a one-kilometre spatial resolution. This sensor has allowed the study of the canicula phenomenon experienced from 1984 to date in areas of annual crops and pastures, to be able to anticipate possible future effects.

This new index will make it possible to study drought in the region, along with another aspect that affects it: The El Niño phenomenon. This phenomenon is an atmospheric and oceanic event that influences global climate, with a particular effect on the intensity and extension of the canicula. However, some years have suitable precipitation for most of the crop cycle, favouring the healthy development of crops.

As a result of the intensification of the canicula, the crop yields are severely affected, which compromises the efforts of smallholder farmers and put their families at risk of food insecurity, given their dependence on crops for food.

This study was carried out with the firm purpose of contributing to a broader knowledge of these phenomena in the countries of Central America, and to strengthen their capacities to trigger early actions for disaster reduction and other mitigation measures.

We trust that this study provides knowledge on the interaction of agriculture and the canicula, as well as on the El Niño phenomenon in the subregion, and generates a productive dialogue that manages to improve preventive action against natural hazards.

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Executive summary

- This study shows the versatility of the Agricultural Drought Monitoring and Early Warning System (ASIS) to adapt and create new indices for the evaluation of climate impacts on agriculture.

- A new index is introduced in this study for the analysis of the rainfall reduction period in July/August, during the rainy season from May to November, locally known as canicula, or *"Veranillo de San Juan"* in Central American countries. The canicula has a substantial impact on the Central American Dry Corridor.

- The index is based on satellite information that FAO receives globally at a one-kilometre resolution every ten days (dekad).[1]

- The methodology used for the creation of the canicula index is described in detail so that it serves to inspire the development of other indices of a specific nature, such as studies on the flowering and the number of floats in coffee beans;[2] sucrose content accumulation in sugar cane; or the incidence of the pine weevil.

- The Nicaraguan Dry Corridor has been recognised as the epicentre of the canicula affectation in the agricultural sector of Central America, with a 25 percent probability (one year every four years) of more than 20 percent loss resulting from drought in agricultural areas.

- The connection between the canicula and the oceanic and atmospheric indices was studied. The presence of the El Niño phenomenon and the sea surface temperature anomalies of the Atlantic Ocean, turn out to be the variables that explain with higher statistical significance the intensity and duration of the canicula in the region.

- Ultimately the rising of sea surface temperatures due to climate change causes the intensification of the El Niño events. The abovementioned fact could generate conditions that favour more accentuated canicula events in Central America.

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1 *Dekad:* A convention between FAO and WMO agreed to call the ten-day period "*dekad*", with a k, to distinguish it from its associated meaning of decade 10-year period.

2 Floats coffee beans: Cherry coffee separated by virtue of it being positively buoyant in water applied to selectively picked coffee the vast majority of which is ripe or immature.

1

Introduction

1 Introduction

The Food and Agriculture Organization of the United Nations (FAO) has developed the canicula index given the importance of this climatic event in the development of crops in Central America. The canicula index will be part of the ASIS[3] (Agricultural Drought Monitoring and Early Warning System) indices platform. The ASIS platform for Central America is hosted on the server of the Regional Committee on Hydraulic Resources (CRRH), a technical institution of the Central American Integration System (SICA), specialized in meteorology, climatology, hydrology, as well as hydraulic resources of the Central American region.

The objective of the index is to evaluate the reduction of rainfall during the rainy season which, in years of extreme canicula, causes considerable losses in annual crops. These extreme canicula events, accentuated or extended, put at risk of food insecurity about two million families who depend on subsistence agriculture in the Central American Dry Corridor. The canicula index evaluates the impact of the decrease in rainfall through the reduction of biomass production of the vegetation

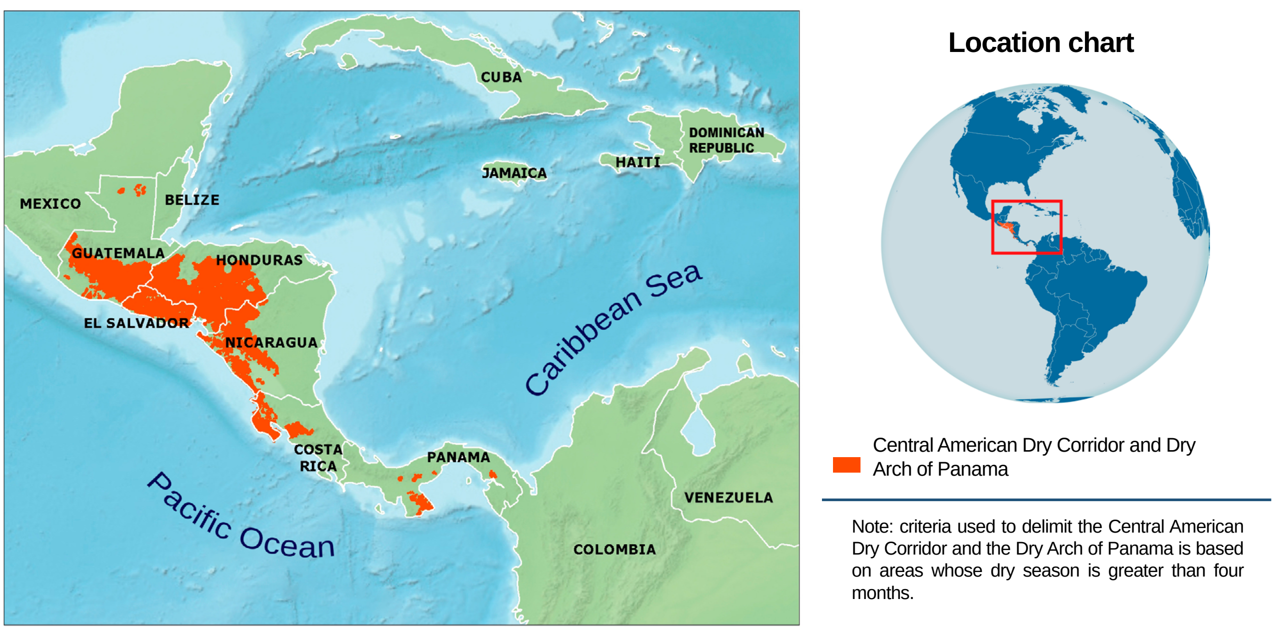


Figure 1

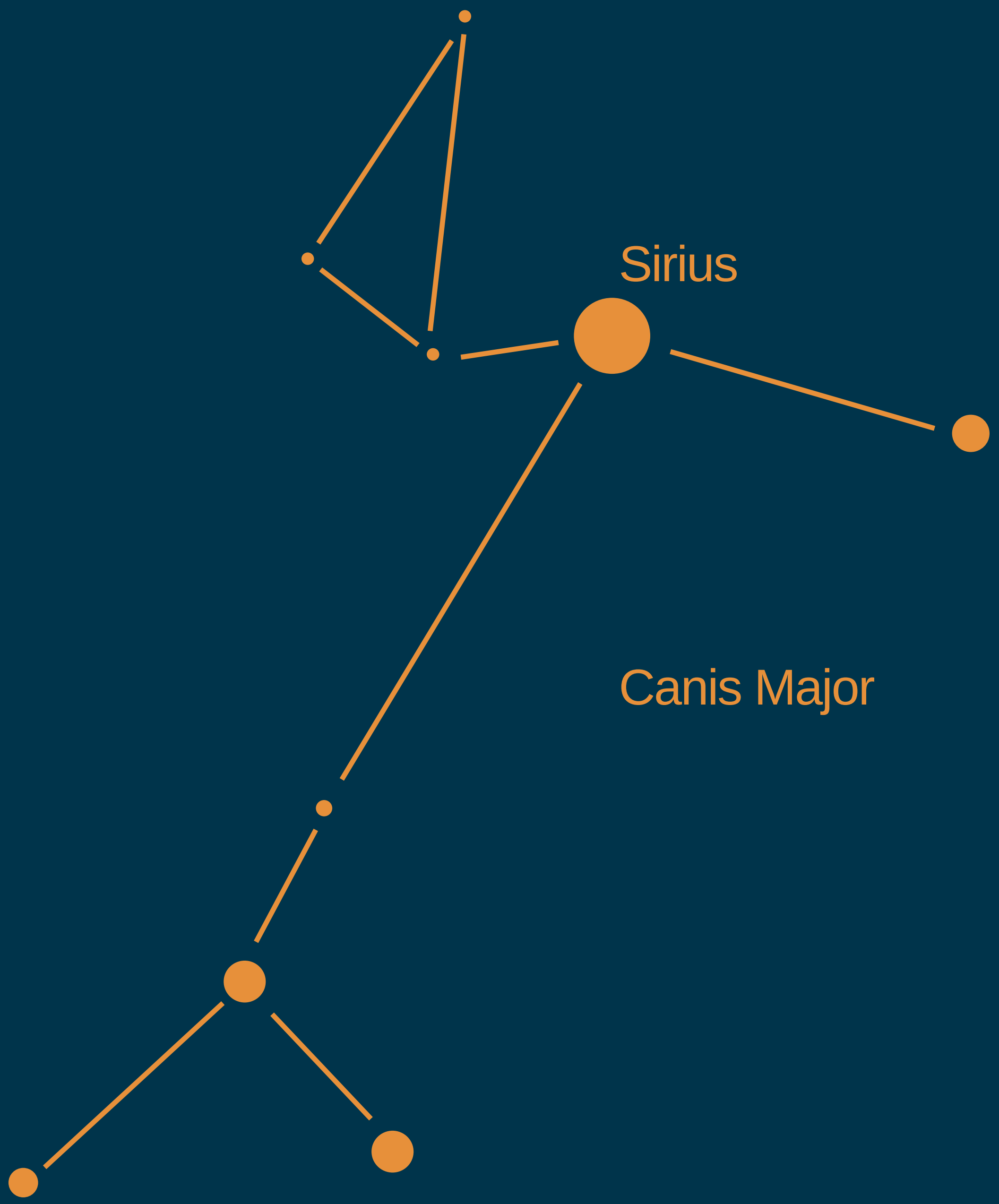
Central American Dry Corridor based on the Central American Atlas for the sustainable management of the territory. Source: Central American Commission for Environment and Development, 2011. Conforms to United Nations world map, 2020.

[3] Explanatory video on the ASIS platform. Available at: https://youtu.be/QlW6qowJlU8

using satellite images at one-kilometre resolution. This natural weather event occurs in July and August, and affects from the South of Mexico to the Central American Dry Corridor, ending in the Dry Arc of Panama (Figure 1). Farmers in Mesoamerica know this event well, because there are years in which the decrease in rainfall causes severe losses in the maize, beans, and rice crops planted in *Primera*[4] season (May-July); and also causes delays in planting the *Postrera* season (August-December). This decrease in rainfall between July and August is called "canicula" or *"Veranillo de San Juan"*. Such a reduction in rainfall in the middle of the rainy season allows farmers to have two planting seasons, hence creating a bimodal[5] distribution of rainfall in Mesoamerica.

[4] Crop Seasons in Spanish: First crop season (Primera), Second crop season (Postrera), and Third crop season (Apante).

[5] In statistics, a bimodal distribution is a continuous probability distribution with two different modes. These appear as distinct peaks in the probability density function.



2

Origin of the “canicula” name

2 Origen of the “canícula” name

The canicula (canicular period or canicula days) is the season of the year in which heat is perceived with the highest intensity, both in the southern and northern hemispheres (lagged six months apart). The duration ranges from four to seven weeks, depending on the place.

The canicula begins a few weeks after the summer solstice (which occurs on June 21 in the northern hemisphere and December 21 in the southern hemisphere) and is the time when the midday sun is at the maximum possible height above the horizon. An approximate date for the northern hemisphere would be July 14.

The term canicula is derived from *"canis"* (dog) and refers to the phenomenon of abrasive or intense heat. There is an astronomical foundation for this atmospheric event, which alludes to the constellation Can Major and its star Sirius, also known as "The scorching one" (Figure 2). Sirius, by its Latin name, is the proper name of the star Alfa Canis Maioris (α CMa, also Alfa Canis Majoris). It is the brightest star in the sky seen at night from Earth, located in the constellation of the southern celestial hemisphere Canis Maior. This star is actually a binary[6] star, well known since ancient times. For example, in Ancient Egypt, the heliacal[7] rising of Sirius marked the flooding of the Nile, and has been present in civilizations as disparate as the Greek, Mayan, and Polynesian. Sometimes, colloquially, Sirius is called the "Dog Star" due to the constellation to which it belongs.

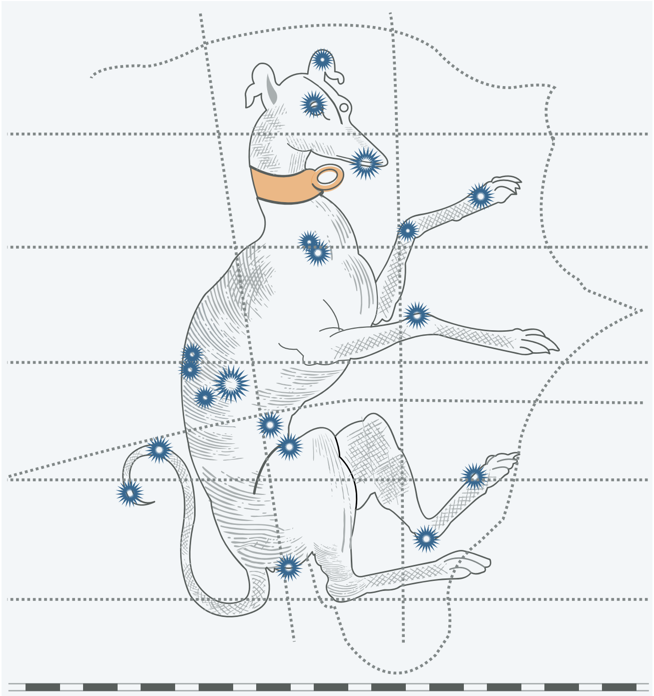


Figure 2

The canicula takes its name from the constellation Canis Maior. Source: Atlas of the Stars, original figure by Alexander Jamieson, 1822.

Conversely, rural people from Central American countries, especially the older ones who grew accustomed to start planting their crops by looking at the stars, noted that around July 15 a dry climate prevailed; therefore, it was not convenient to sow. This dry time ended around August 15, on which date planting was resumed. This time seemed to coincide with the position of the Can Minor constellation at zenith by midnight, approximately between 15 degrees and -15 degrees zenith. This period was called Canicula (small dog), because of its reference to the Can Minor.

[6] A binary star is a star system made up of two stars that orbit each other around a common centre of mass. Recent studies suggest that a high percentage of stars are part of systems with at least two stars.

[7] The heliacal rising of a star is its first appearance on the eastern horizon after its period of invisibility.

The canicula coincided in 2018 with the so-called by experts "global heatwave", whose effects spread across many countries in the northern hemisphere (BBC, 2018). The explanation is complicated, as it is the result of a combination of factors. Among them is the weakening of the "Jet Stream Winds", which are the winds that flow from west to east and play a fundamental role in determining the weather in North America and Europe. This core of strong winds extends seven to ten kilometres above the Earth's surface and, when intensified, create storms and rains. On the other hand, when weakened, generate hot and dry climate (Figure 3).

According to the United States National Aeronautics and Space Administration (NASA, 2016), the northernmost position of the "Jet Stream" can be influenced by temperatures in the northern Atlantic Ocean, which have been relatively warmer in the sub-tropics and colder in southern Greenland in recent times. This phenomenon is called the Atlantic Multidecadal Oscillation (AMO). AMO is responsible for the ocean temperatures to vary over 70 years, during which a maximum and a minimum temperature appears in the ocean. On the other hand, climate change increases the chances of heat waves occurring more frequently on Earth.

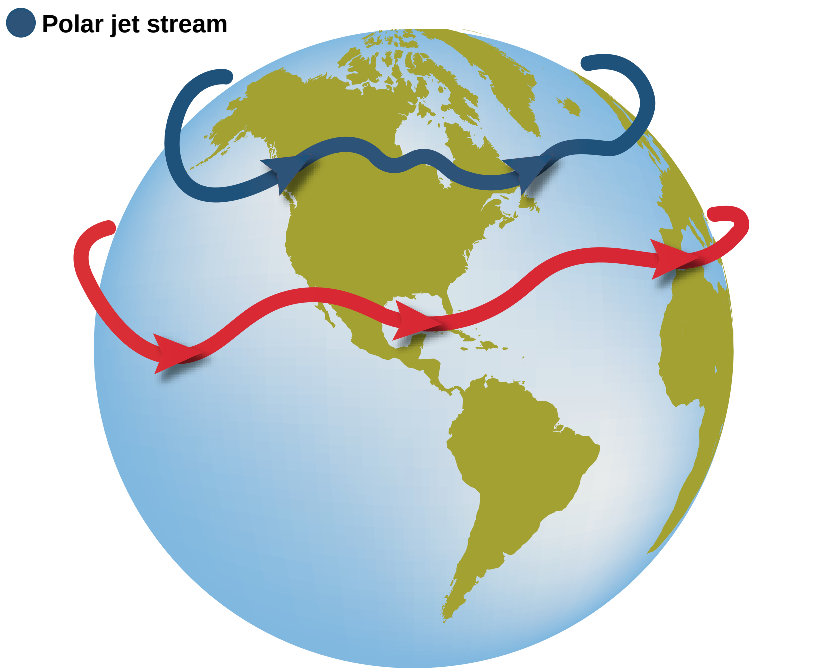
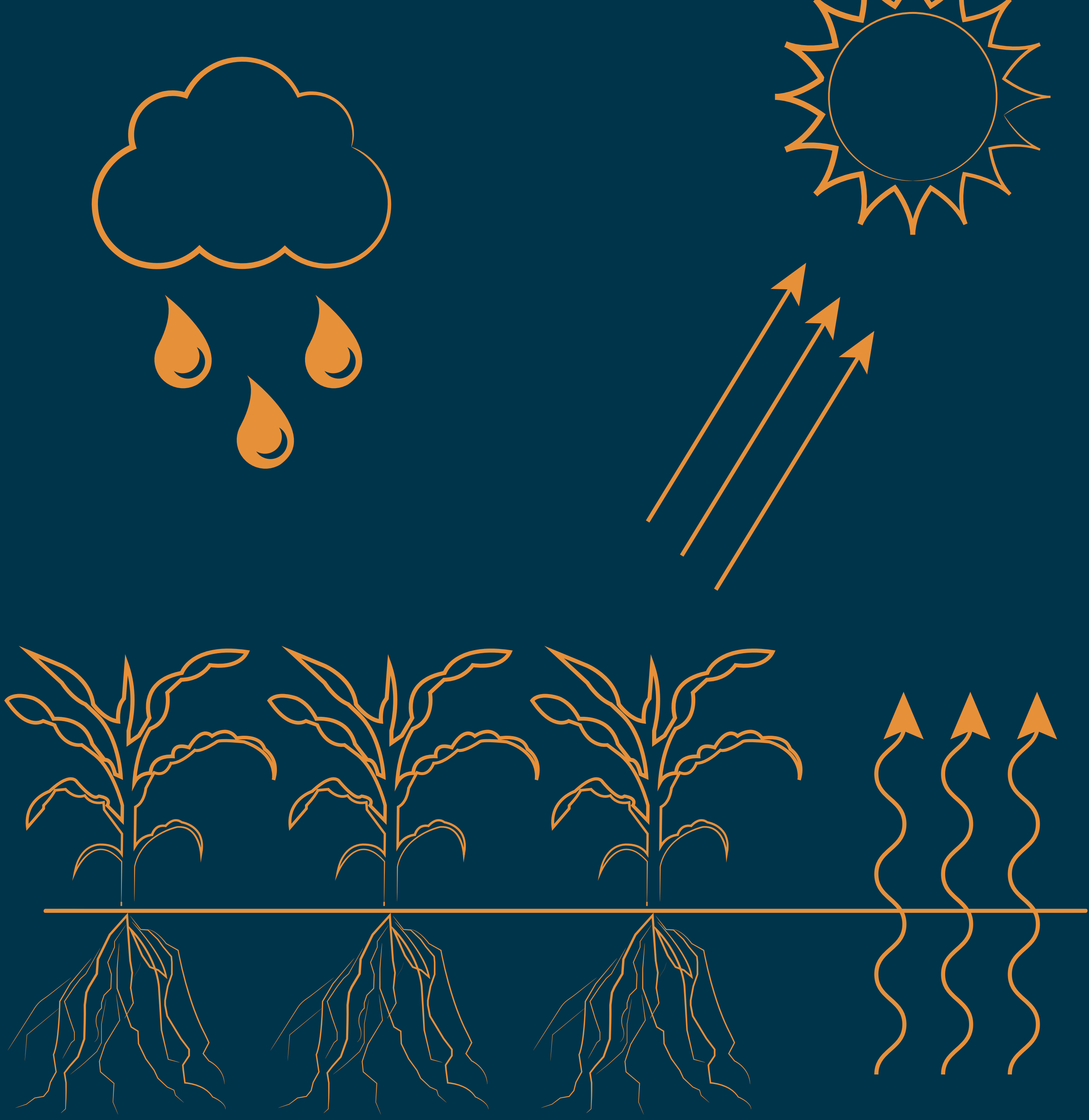


Figure 3

General configuration of polar and subtropical jet streams. Source: Own elaboration. Conforms to United Nations world map, 2020.



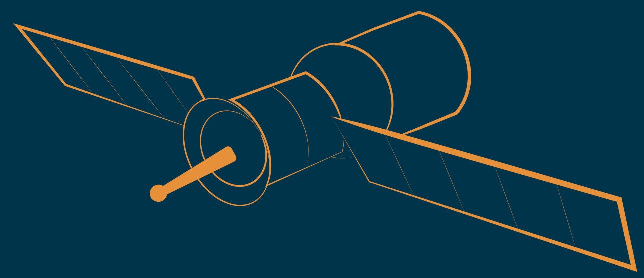
3

Benefits of the canicula at the agricultural level

3 Benefits of the canicula at the agricultural level

Although it is true the canicula is associated with adverse situations in agriculture (especially drought), in years of moderate canicula there are several benefits for agriculture, such as:

- Lower incidence of fungal and bacterial diseases.
- Greater evapotranspiration during the period of heat, which allows for better development of the crop.
- Fruits with better weight and size for less amount of water in the plant.
- Better drainage in soils.
- Greater root aeration.
- Lower relative humidity in crop fields.
- More days with high luminosity.



4

Methodology for calculating the canicula index

4 Methodology for calculating the canicula index

The following land use classifications were selected to analyse further the canicula: annual crops, perennial crops and pastures within the Central American Dry Corridor, thereupon a single agricultural use classification[8] was formed. Vegetation health index (VHI) images are analysed using this classification during July and August. The VHI anomalies are averaged over time, and the percentage of the affected area is calculated within the classification of agricultural use. The methodology designed to calculate the agricultural stress index (ASI) is applied (Rojas et al., 2011; Roel *et al.*, 2016), within the canicular period of July and August (Figure 4).

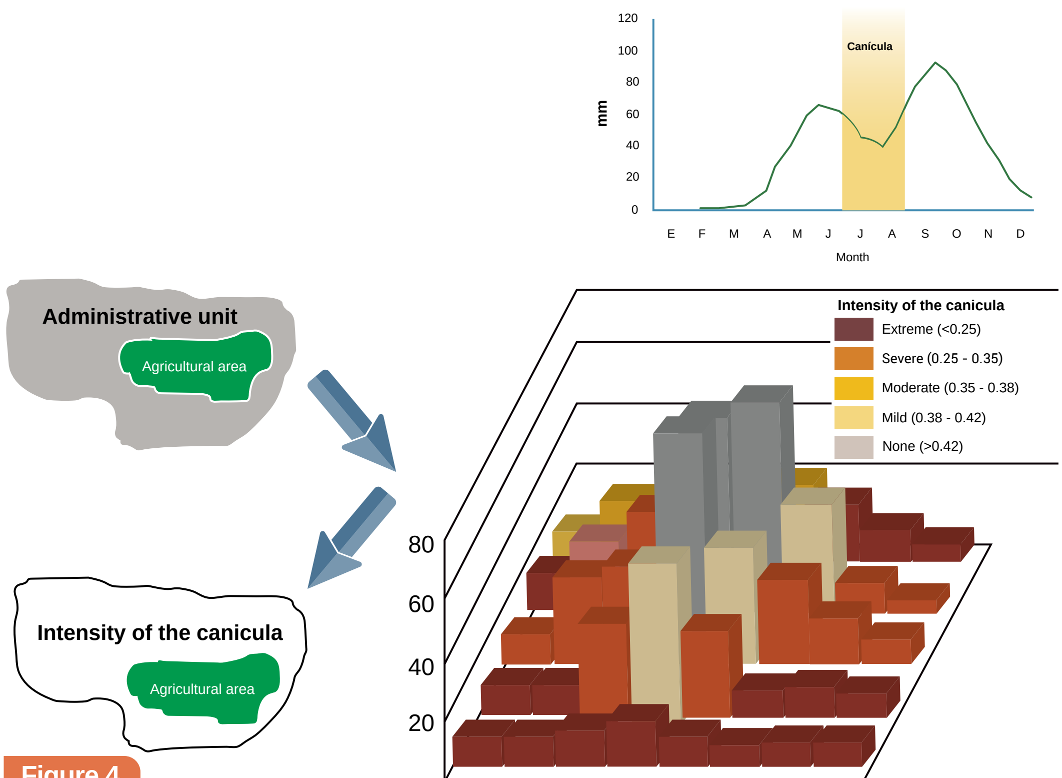


Figure 4

The first step to estimate the canicula index is to calculate the temporal average of the vegetation health index (VHI) in July and August, evaluating the intensity of the canicula. The second step is to calculate the percentage of the agricultural area affected by drought at the administrative unit level. According to the degree of decrease in vegetation due to the reduction in precipitation, the canicula is classified as extreme (VHI <0.25), severe (VHI [0.25, 0.35]), moderate (VHI) 0.35, 0.38 [) or mild (VHI [0.38, 0.42]).

[8] The Vegetation Health Index (VHI) is a standardization of two indices: one related to biomass production (VCI) and the other related to temperature (TCI). The methodology for its calculation by Kogan (1995).

To understand the canicula event, Figure 5 shows the average distribution of rainfall recorded by the Villa 15 de Julio weather station in the Chinandega department of Nicaragua. Figure 5 shows the decrease in rainfall in July and August. Figure 6 represents the theoretical distribution that the canicula can take year by year, according to its intensity. Situation "A" represents an equidistant canicula centred on July and August, while situation "B" represents a not very pronounced canicula, also equidistant but one that could occur in wet years. Situation "C", symbolizes a canicula where the decrease in precipitation occurs mainly in July. This scenario has severe consequences for the *Primera* crop season (May-July) given that the decrease in rainfall coincides with the crop flowering and grain-filling, which can lead to significant yield losses in basic grains. Situation "D" represents a canicula where the decrease in rainfall occurs with higher intensity in August. This scenario may lead to a delay in the *Postrera* season (August-December). Ultimately, all possible combinations of these four scenarios can occur.

Figure 7 presents as an example, the analysis of the canicula occurred in 2018. The map of the canicula index (upper map of Figure 7) shows the cumulative effect of the canicula impact during July and August. To analyse the scenarios described above (Figure 6), we study the evolution of the vegetation health index (VHI) every ten days (dekad).

The canicula of 2018 characterises several of the scenarios described above. The scenario of most significant concern to smallholder farmers is scenario “C” where crop flowering and grain filling are affected. This effect happens in areas with VHI values less than 0.35, which can be seen in Figure 6, since these areas uphold values below 0.35 throughout July. Subsistence farmers reported losses of around 80 percent and in some cases, even total losses of maize crops in these areas. On the other hand, scenario “D”, for example, is observed in areas of the department of Choluteca in Honduras. The values of VHI, during July and the beginning of August, were higher than 0.35 and only had values lower than 0.35 in the last two dekad of August.

The 2018 canicula practically did not affect crops in Costa Rica or Panama due to the presence of a low pressure that caused the moisture-laden masses to converge in these two countries, causing rainy storms (Figure 8).

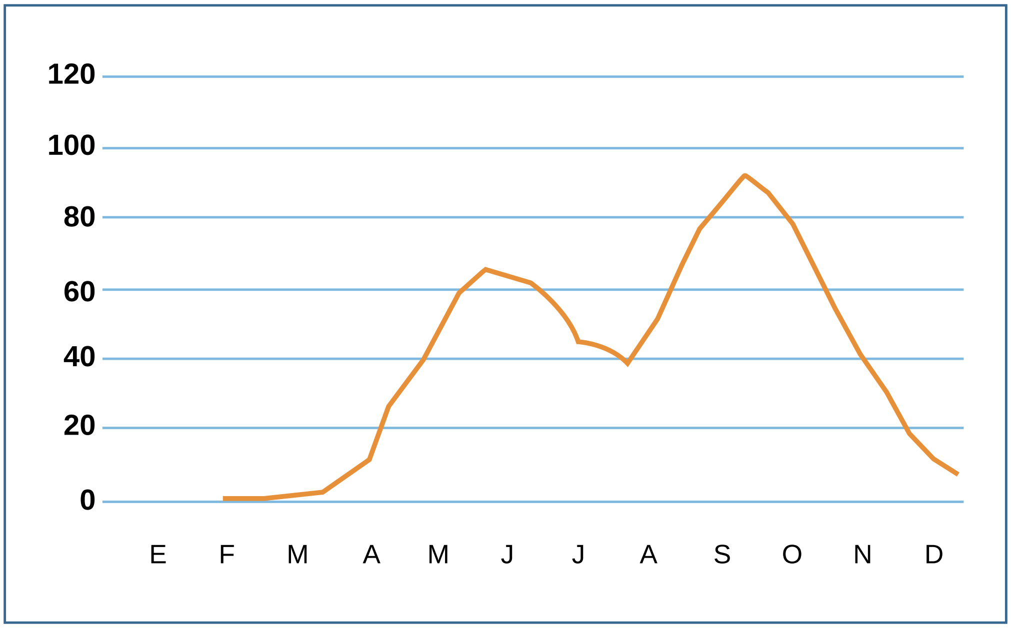


Figure 5

Bimodal distribution of precipitation at the Villa 15 de Julio meteorological station in the department of Chinandega, Nicaragua. The decrease in rainfall in July and August is due to the canicula.

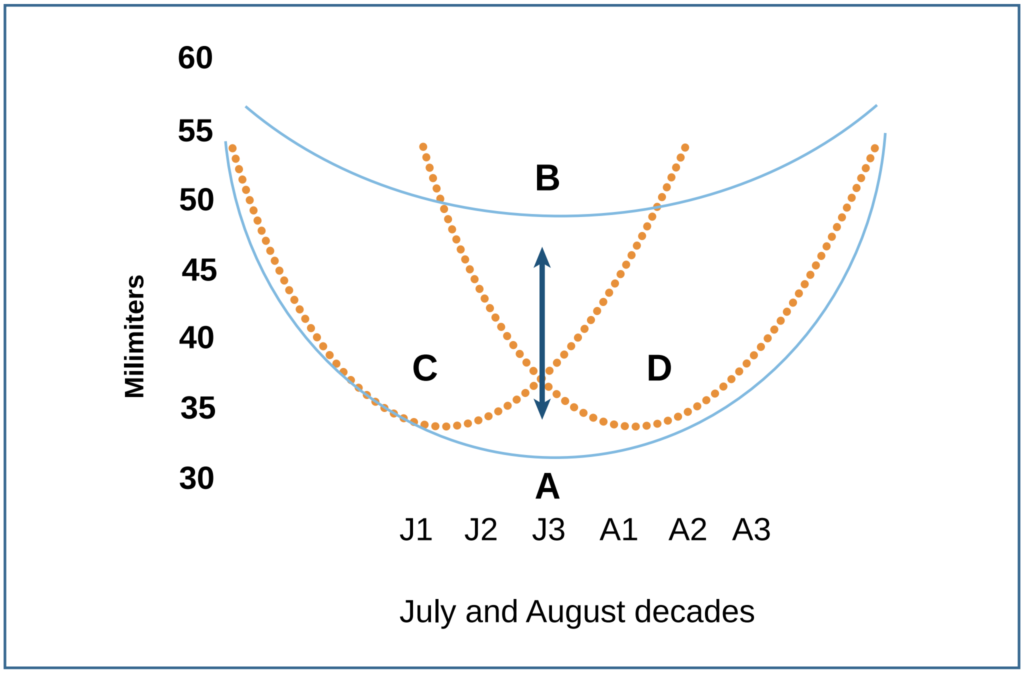


Figure 6

Theoretical scenarios that can take the behaviour of rainfall reduction during canicula of July and August. "A" extreme equidistant canicula, "B" mild canicula, "C" accentuated canicula in July; “D” accentuated canicula in August. The arrow indicates variation in the decrease/increase of precipitation or intensity.

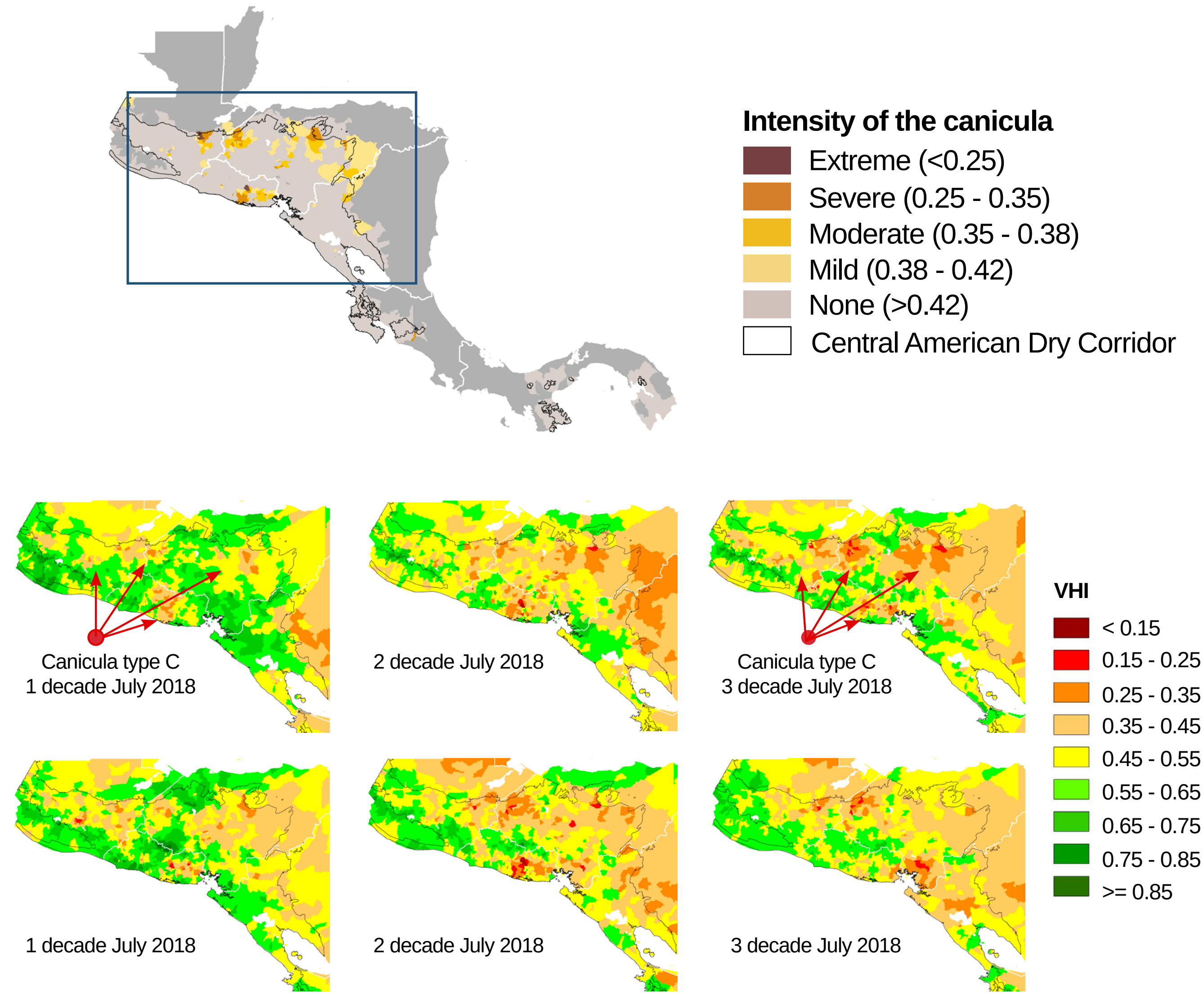


Figure 7

The canicula index estimates the areas of agricultural use that were affected by the canicula during July and August 2018 (Map above). The effect is expressed as a percentage of the area affected by drought. In the sequential maps (1 dekad of July to 3 dekad of August 2018), the image shows the vegetation health index (VHI), the biomass reduction occurring in the central part of El Salvador during July, two nuclei in the northwestern and northeastern part of Honduras and the central part of the Dry Corridor of Guatemala (canicula type "C"). This reduction in biomass coincides with the crop flowering and grain filling of the maize, leading to losses in the final crop yield—source: Agricultural Drought Surveillance System, FAO-CRRH, 2018. Conforms to United Nations world map, 2020.

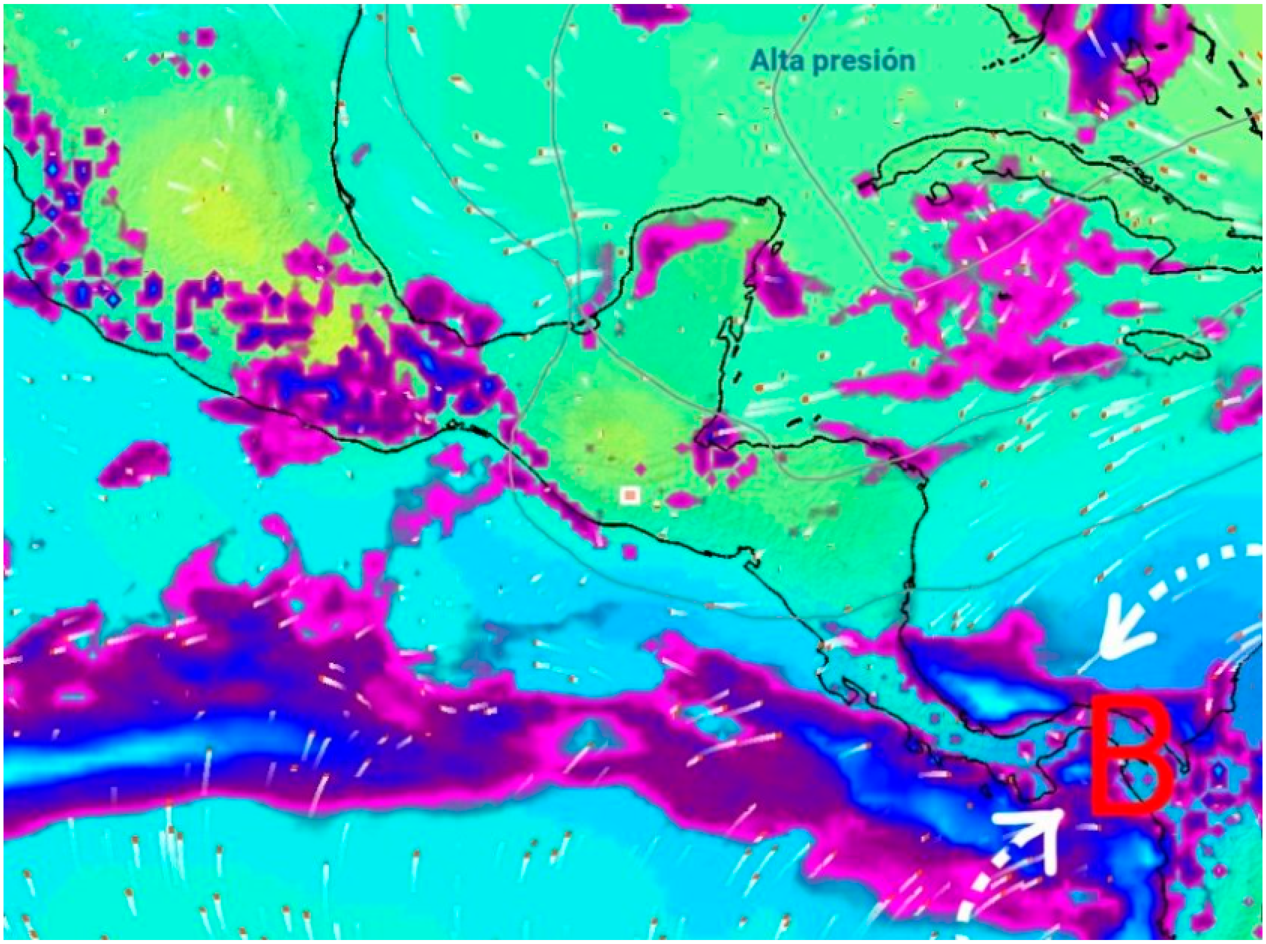
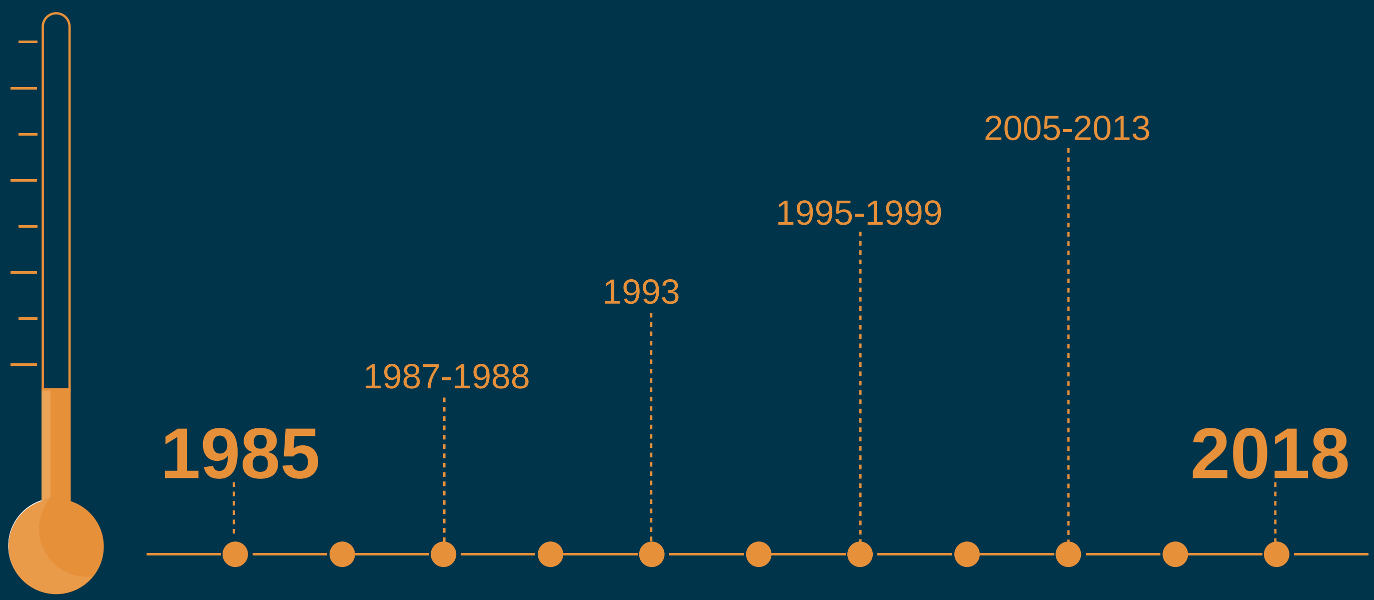


Figure 8

In July and August 2018, Guatemala, Honduras, and Nicaragua experienced drought conditions during the canicula days; meanwhile, in Costa Rica and Panama, there was humidity entering from both coasts that caused storms with rains. The white arrows point the path of the moisture-laden clouds toward the low-pressure centre (B, red). Source: ClimaYa.com http://climaya.com/imagenes-satelite/



Studies on canicula historical events (1985-2018)

5 Studies on canicula historical events (1985-2018)

Figure 9 (a, b, and c) shows the drought index for the last 34 years (1985-2018). In 1991, the most widespread canicula had occurred in the Dry Corridor of Central America. There are 17 years of the total of the series which showed practically imperceptible caniculas (1987, 1988, 1993, 1995, 1996, 1997, 1998, 1999, 2005, 2006, 2007, 2008, 2009, 2010, 20011, 20012 and 2013). For the remaining 16 years, caniculas were within the scope from mild to severe. It was observed during most of these events, that the canicula is more intense and widespread in the Dry Corridor of Nicaragua.

Figure 10 shows the percentage of the agricultural area affected by the canicula. During the hottest years, vegetation biomass production is reduced in July and August due to the decrease in rainfall. The impact on crops will depend on the sowing date, usually the maize that is sown in May and is harvested in July/August (90-100 days of cycle) could be severely affected. In contrast, local long-cycle duration maize varieties (150-250 cycle days) will suffer less impact from the canicula (for example, long-cycle maize varieties, which are grown in the Guatemalan highlands northwest of the Dry Corridor).

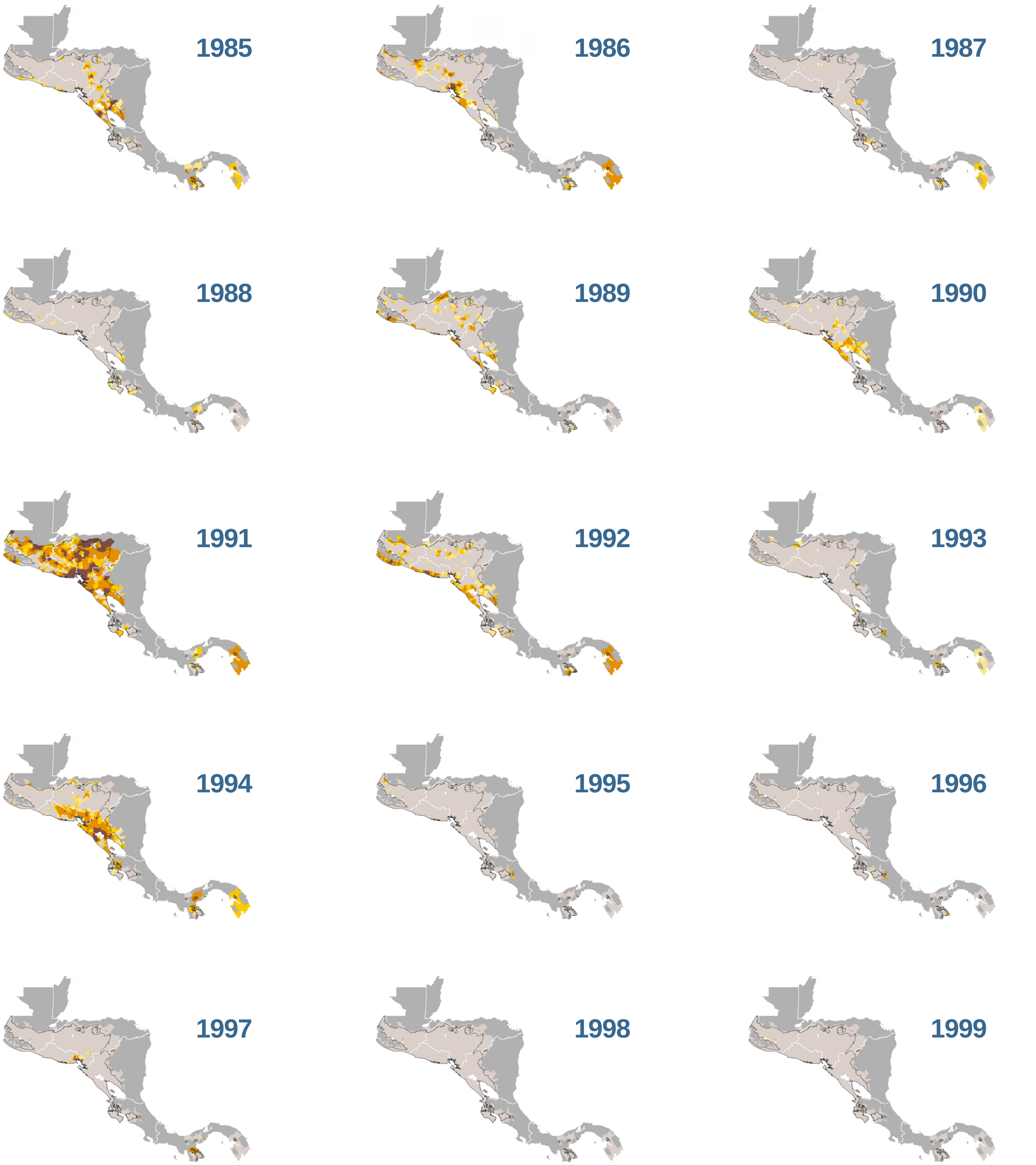
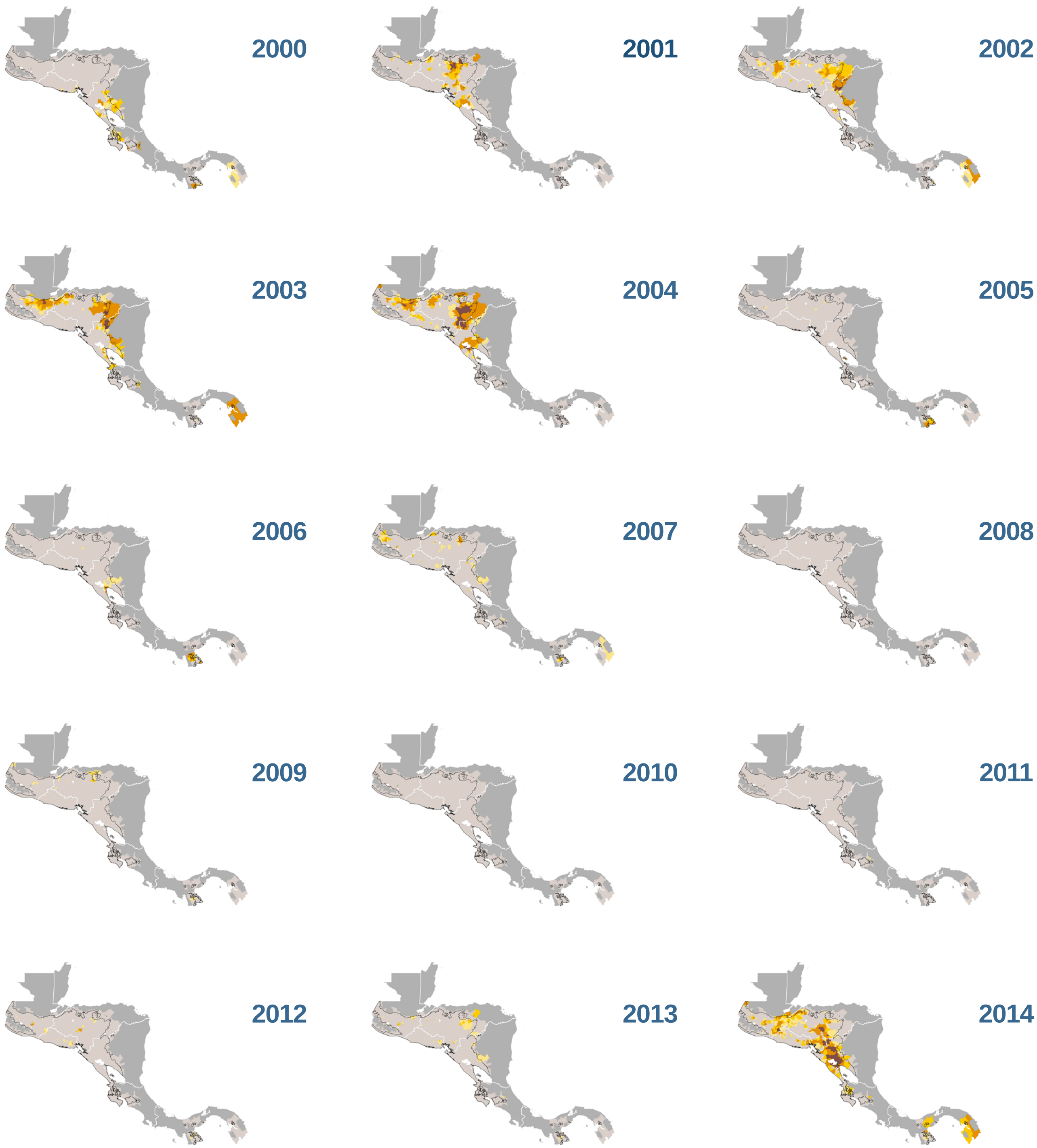


Figure 9-a

Canicula index from 1985-1999 for the Central American Dry Corridor. Conforms to United Nations world map, 2020.



Intensity of the canícula

- Extreme (< 0.25)
- Severe (0.25 - 0.35)
- Moderate (0.35 - 0.38)
- Mild (0.38 - 0.42)
- None (> 0.42)

- Central Amiercan Dry Corridor

Figure 9-b

Canicula index from 2000-2014 for the Central American Dry Corridor.
Conforms to United Nations world map, 2020.

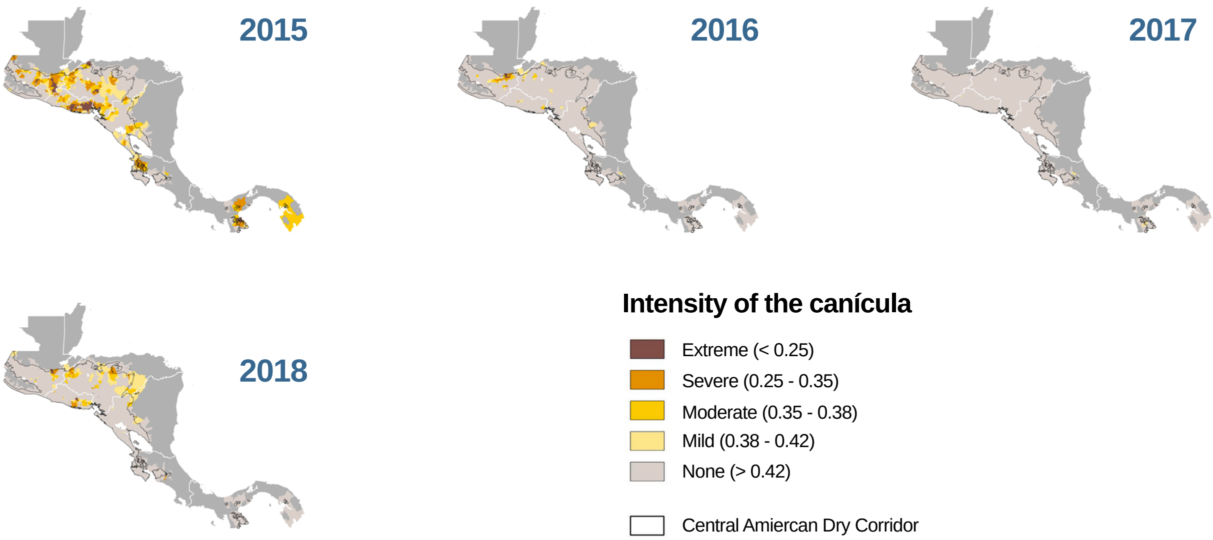
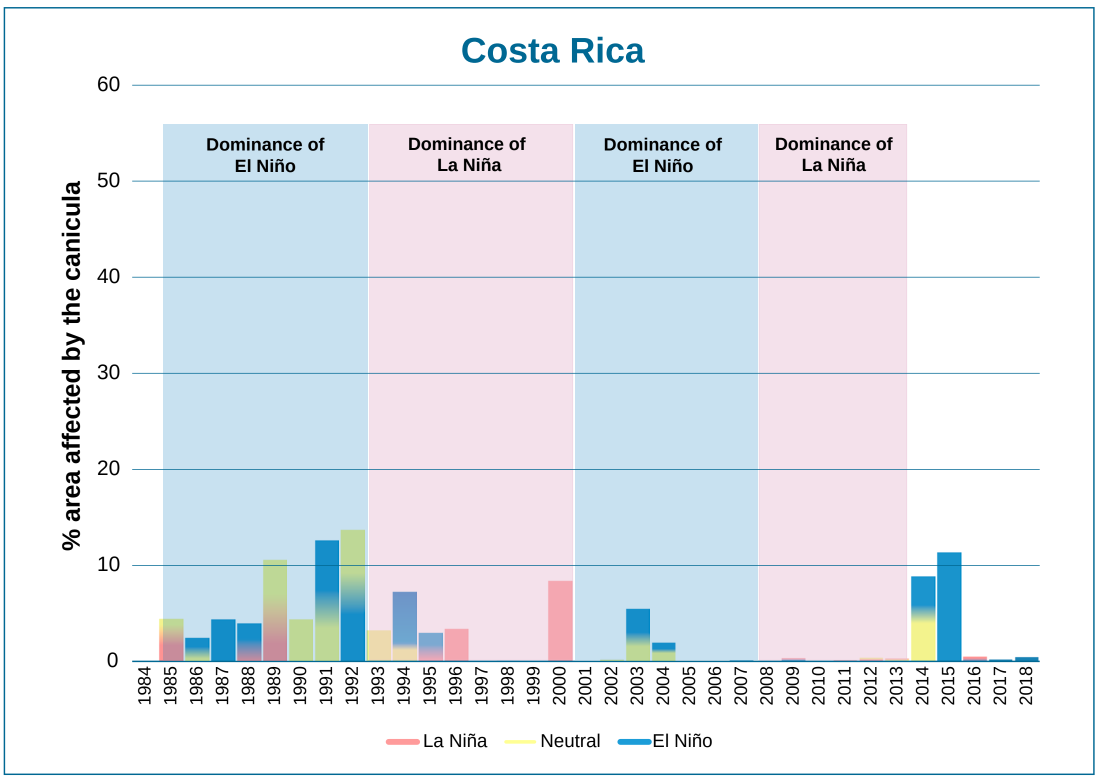
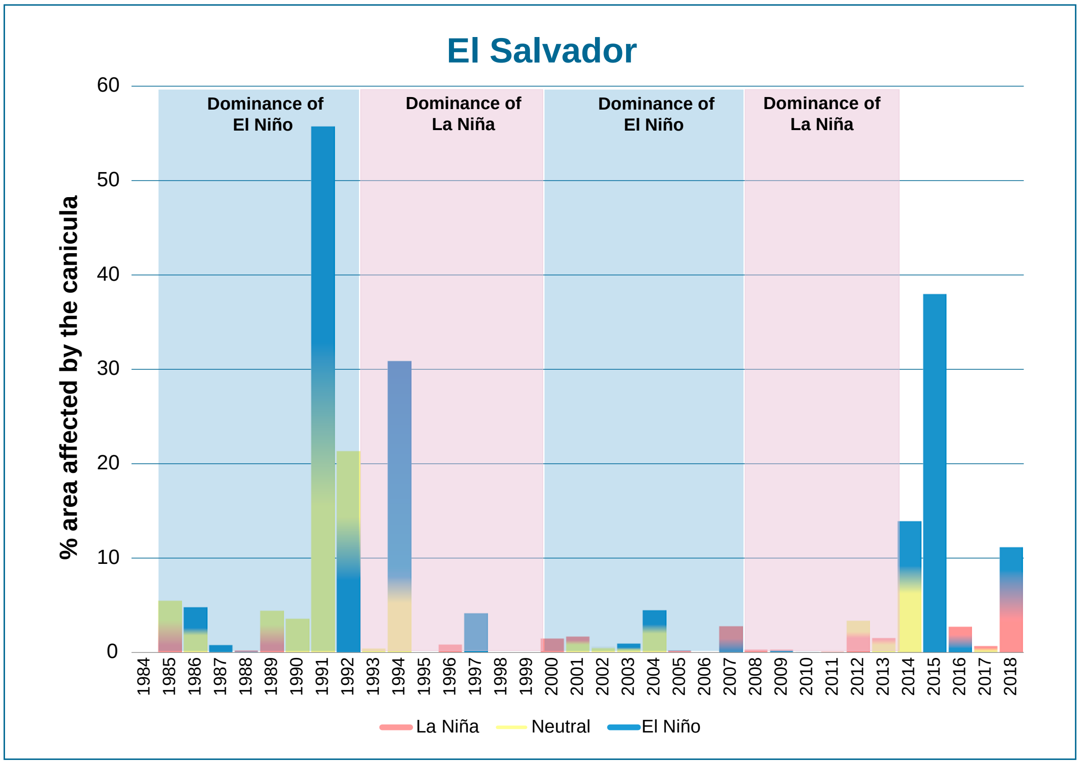


Figure 9-c

Canicula index from 2015-2018 for the Central American Dry Corridor. Conforms to United Nations world map, 2020.




El Salvador
% area affected by the canicula
60
50
40
30
20
10
0
Dominance of El Niño
Dominance of La Niña
Dominance of El Niño
Dominance of La Niña
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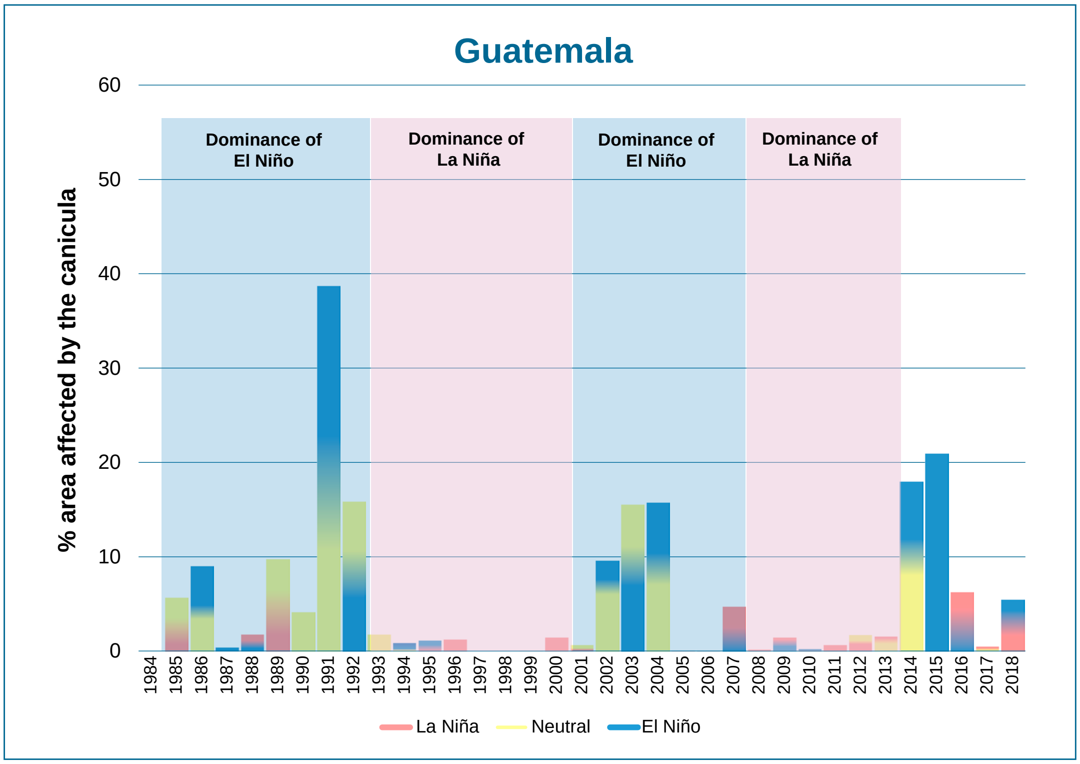
Neutral
El Niño


Guatemala
% area affected by the canicula
60
50
40
30
20
10
0
Dominance of El Niño
Dominance of La Niña
Dominance of El Niño
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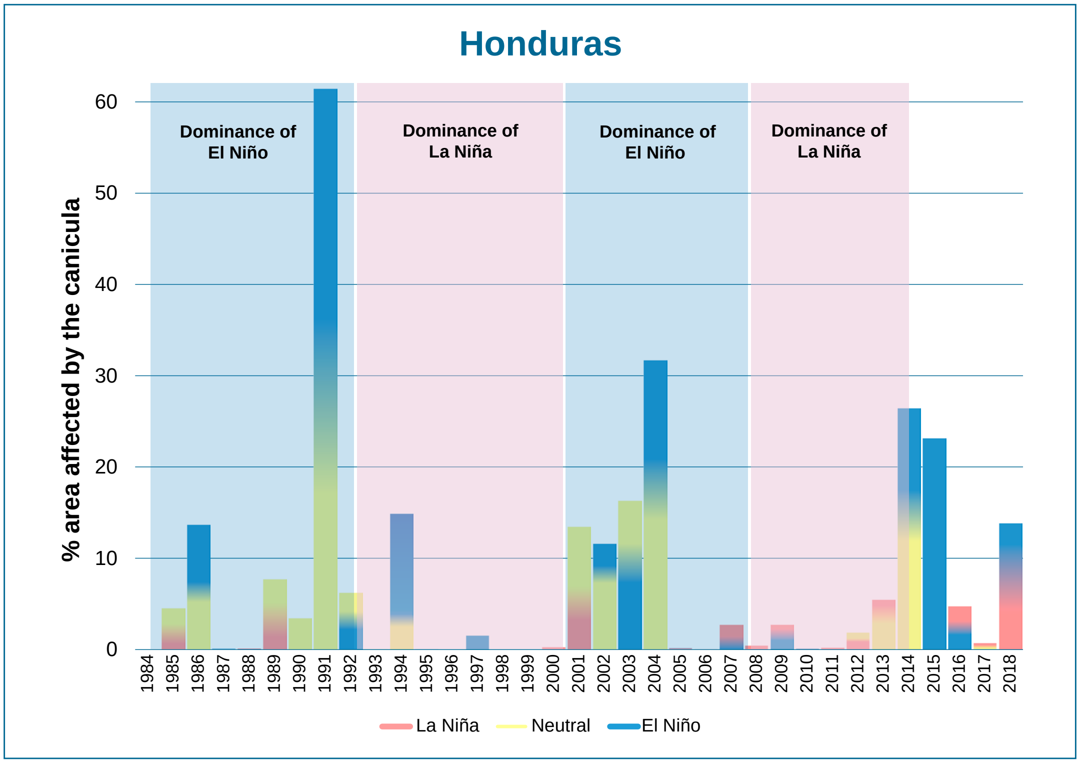
El Niño


Honduras
Dominance of El Niño
Dominance of La Niña
Dominance of El Niño
Dominance of La Niña
% area affected by the canicula
0
10
20
30
40
50
60
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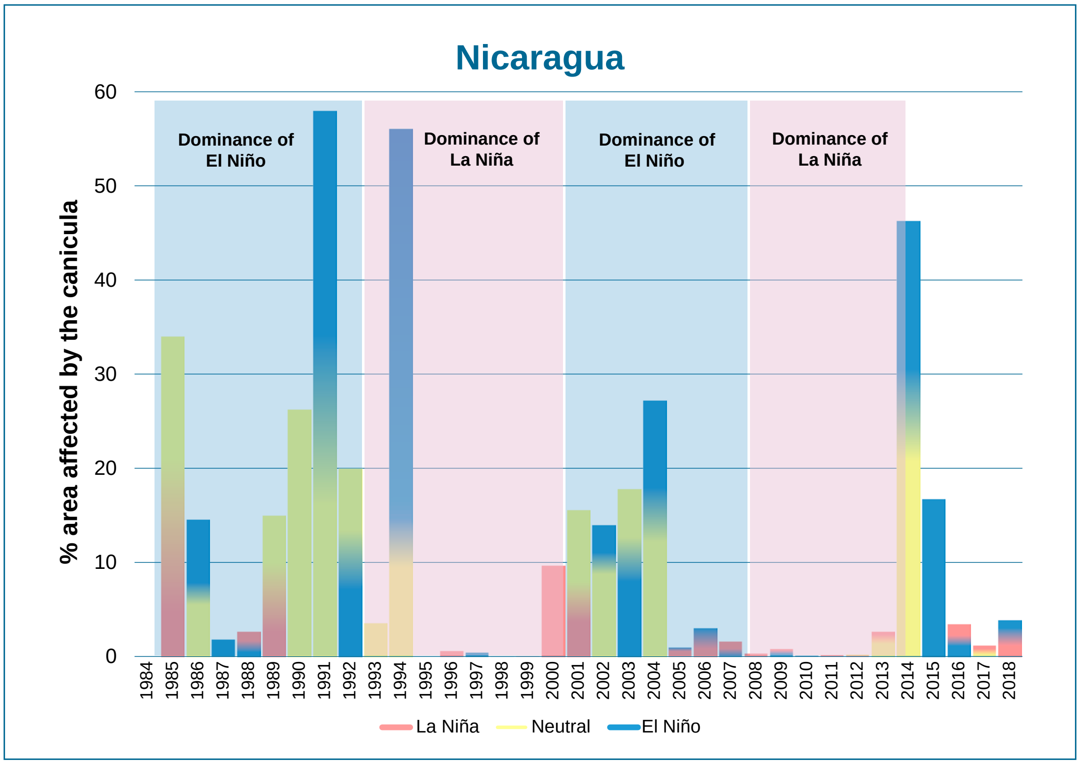
Nicaragua
Dominance of El Niño
Dominance of La Niña
Dominance of El Niño
Dominance of La Niña
% area affected by the canicula
0
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1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
La Niña
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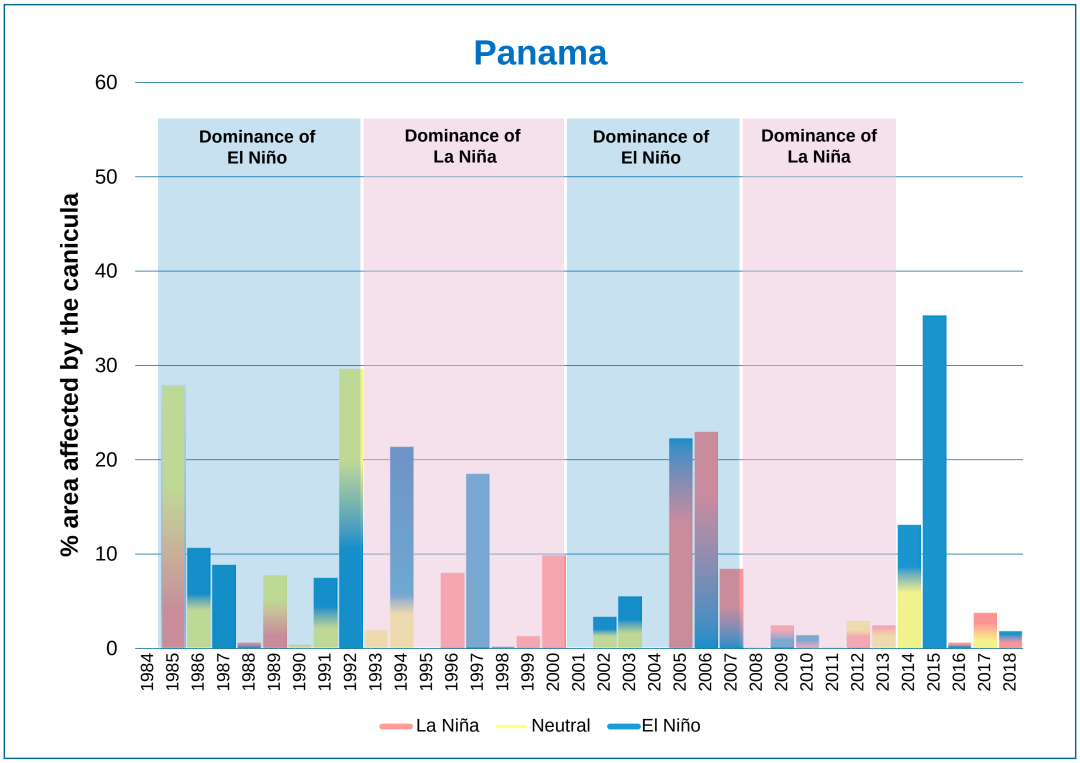


Figure 10

Dry Corridor of Central America (1985-2018). Agricultural area affected by the canicula. The height of the bar indicates the percentage of affectation by country, the colours of the bar indicate the El Niño, Neutral or La Niña phases. The division into groups of years according to periods of dominance of El Niño (light blue) or La Niña (pink). In general, a higher intensity of the canicula is observed during the dominance of El Niño.

6

Probability of occurrence of the canicula

6 Probability of occurrence of the canicula

From the historical series of 34 years (1985-2018), a calculation was made of the empirical probability of occurrence that the affected agricultural area exceeded 20, 30, and 50 percent within the analysed administrative unit. Figure 11 presents the results by country, by province or department and by district, municipality, or county, according to the political division in each of the Central American countries.

The aggregated results indicate that countries with the highest probability (15-20 percent) of suffering an extreme canicula event are Nicaragua and Panama; nonetheless, the impact on agricultural production is very different. In Nicaragua, the Primera season represents the most important crop in the country; while in Panama, the Primera season only represent 20 percent of the production of basic grains. Costa Rica is the country less likely to be affected (<5 percent) by the canicula, which harms 20 percent of the reference area within the selected administrative unit. Conversely, Nicaragua shows the highest probability of affectation, with more than 50 percent of the agricultural area in the Dry Corridor affected by the canicula and with a probability of occurrence between 5-10 percent.

The results at the province or department level show several prominent hubs where the intensity of the canicula affects the agricultural area of the Dry Corridor. The central Pacific part of Nicaragua, the department of Izabal in Guatemala, the administrative units around the Gulf of Fonseca and the provinces of Herrera, Los Santos, and Darien in Panama stand out. Maps at the district, municipality, or departmental level show in more detail where the canicula impacts most frequently, causing levels of affectation of more than 20, 30 or 50 percent in the agricultural area.

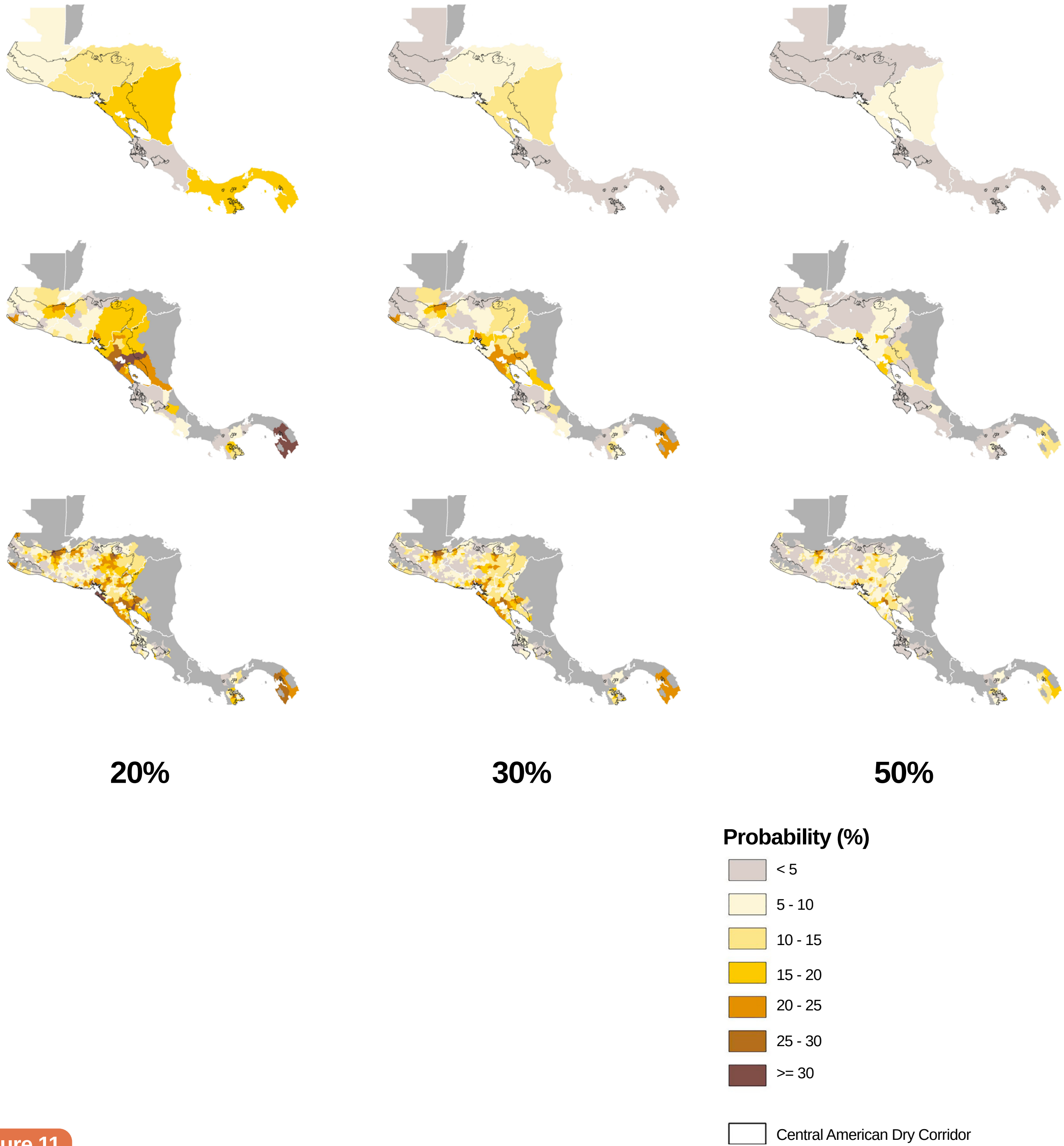


Figure 11

Probability higher than 20, 30, and 50 percent that an affectation due to drought will occur in the agricultural area during the canicula in the Dry Corridor of Central America. Maps at the top: probabilities of 20, 30 and 50 percent of the agricultural area affected at the country level. Intermediate maps: probabilities of 20, 30, and 50 percent of the affected agricultural area at the department or province level. Maps at the bottom: probabilities of 20, 30 and 50 percent of the agricultural area affected at district/department/municipality level. Conforms to United Nations world map, 2020.

7

Correlation of the canicula with the El Niño indices and temperature anomalies in the Atlantic

7 Correlation of the canicula with the El Niño indices and temperature anomalies in the Atlantic

Among the different indices available in the scientific literature related to the El Niño phenomenon, some have been selected as potential explanatory variables for the variation of the canicula in Central America. In addition, sea surface temperature anomalies in the Atlantic Ocean are included in the analysis as a variable that can mitigate or exacerbate the impacts of El Niño.

The selected indices are:

- Southern Oscillation Index (IOS) (atmospheric index)
- El Niño 1 + 2
- El Niño 3
- El Niño 3.4
- El Niño 4
- NCT (Ren and Jin, 2011)
- NWP (Ren and Jin, 2011)
- Global Tropic Index (10 ° South-10° North, 0-360) (TROP)
- Tropical North Atlantic Index (5-20° North, 60-30 ° West) (NALT)
- Tropical South Atlantic Index (0-20° South, 30° West-10° East) (SALT)

Annex 1 describes in more detail the used variables mentioned above in the correlation analysis. Spearman's correlation coefficient was used as a measure of association between the variables: El Niño indices (atmospheric and oceanic), sea surface temperature anomaly of the Atlantic Ocean, and the agricultural area affected by the canicula by country.

The Spearman correlation coefficient is a measure of the association or interdependence between two random variables and does not imply causality. Like the Pearson coefficient, it is a measure that ranges between -1 and 1, indicating a strong negative or positive association, respectively, where the value 0 (zero) means no correlation.

This coefficient is a nonparametric measure, which implies that there are no assumptions about the distribution of the data. It is an especially useful correlation measure when a normal distribution of data is questionable. It also allows association when measurements are estimated on an ordinal scale; however, it may be insensitive to the presence of extreme data.

The sign of the correlation coefficient will indicate the direction in which the variables are related. A negative sign indicates that the variables are inversely related, while a positive sign means that both are proportionally direct. If the agricultural area of country A, and a determined El Niño index maintain a positive correlation, it implies that as the index increases, so will the affected agricultural area by the canicula. A negative coefficient indicates that if the El Niño index increases, the agricultural area affected by the canicula will decrease.

Figure 12 shows the Spearman correlation coefficients for the selected variables (variables with weak correlation are not presented). In most countries, the coefficients are statistically significant at 1 percent. Some variables, such

as the sea surface temperature anomalies of the Atlantic Ocean for July (NATL_7) and the Southern Oscillation Index for March (ISO_3), were relevant for all the countries analysed and are inversely correlated.

According to the results of research carried out in Costa Rica by Waylen and Quesada (2001), drought during the canicula is less severe when the Atlantic Ocean is warmer, and the reduction of the rains is more generalised in Costa Rica. Cooler temperatures in the tropical Atlantic signify a strengthening of the North Atlantic anticyclone and trade winds. When combined with warmer temperatures (lower atmospheric pressure) in the eastern equatorial Pacific, the pressure gradient across the isthmus increases, intensifying the orographic effect of the range. When the Atlantic is warmer, the consequent reduction in the strength of the trade winds reduces precipitation in most of the Mesoamerican region. According to the Spearman coefficients (Figure 12), there is an inverse correlation that confirms previous research for Central American countries, meaning that the warmer the Atlantic is in July, the greater the reduction in rainfall during the canicula in the Central American Pacific zone. This correlation is stronger in Nicaragua (rho = -0.67) and decreases in Panama (rho = -0.44). For all Central American countries, the variable NAT_7 is significant at 1 percent (p-value <0.01).

The Southern Oscillation Index (ISO) indicates the development and intensity of the El Niño or La Niña episodes in the Pacific Ocean. ISO is calculated using the differences in atmospheric pressure between Tahiti and Darwin. There are different methods to calculate the ISO. This study uses data from the Australian Bureau of Meteorology.[9]

Continuous negative ISO values below -8 often indicate El Niño events. These negative values are accompanied by continued warming of the central and eastern tropical Pacific Ocean and a decrease in the strength of the Pacific trade winds. Continuous positive ISO values above 8 are typical in a La Niña episode. Figure 12 shows inverse Spearman correlation values, which are interpreted as an accentuation of the canicula during the presence of negative atmospheric pressure values between Tahiti and Darwin that favour the formation of the El Niño phenomenon. Of these correlations, only the coefficient for Costa Rica is statistically significant at the 0.05 level; However, the other countries also show this inverse relationship, which is considered to play an important role in explaining the intensification of the canicula.

The third variable showing a statistically significant correlation at 0.01 is one of the indices proposed by Jin and Ren (2011). These authors propose two indices, transformation of the sea surface temperature anomalies of the Pacific Ocean in the zones of El Niño 3 and El Niño 4. This transformation aims to capture better the two types of El Niño: El Niño Canonical and El Niño Modoki[10] (in this case, the temperature anomaly occurs more in the centre of the Pacific Ocean) (Ashok *et al*., 2007; Weng *et al*., 2009). From

[9] Available information at: http://www.bom.gov.au/climate/glossary/soi.shtml.
[10] The distinction of the two types of El Niño is still under discussion.

the correlation analysis, the variable Nwp_8 (anomaly during August, which describes El Niño Modoki) is also significantly and correlated. All correlation coefficients are statistically significant at 1% (p-value <0.01), except for Costa Rica and Panama. The Spearman correlation coefficient (rho) varies from 0.64 in Nicaragua to 0.15 in Panama.

Once the set of initial variables has been reduced, and the relevant correlations identified, linear regression models are proposed by country, in order to assess the participation of the independent variables in explaining the variability of the agricultural area affected by the canicula. Table 1 shows the proposed models and their statistical evaluation.

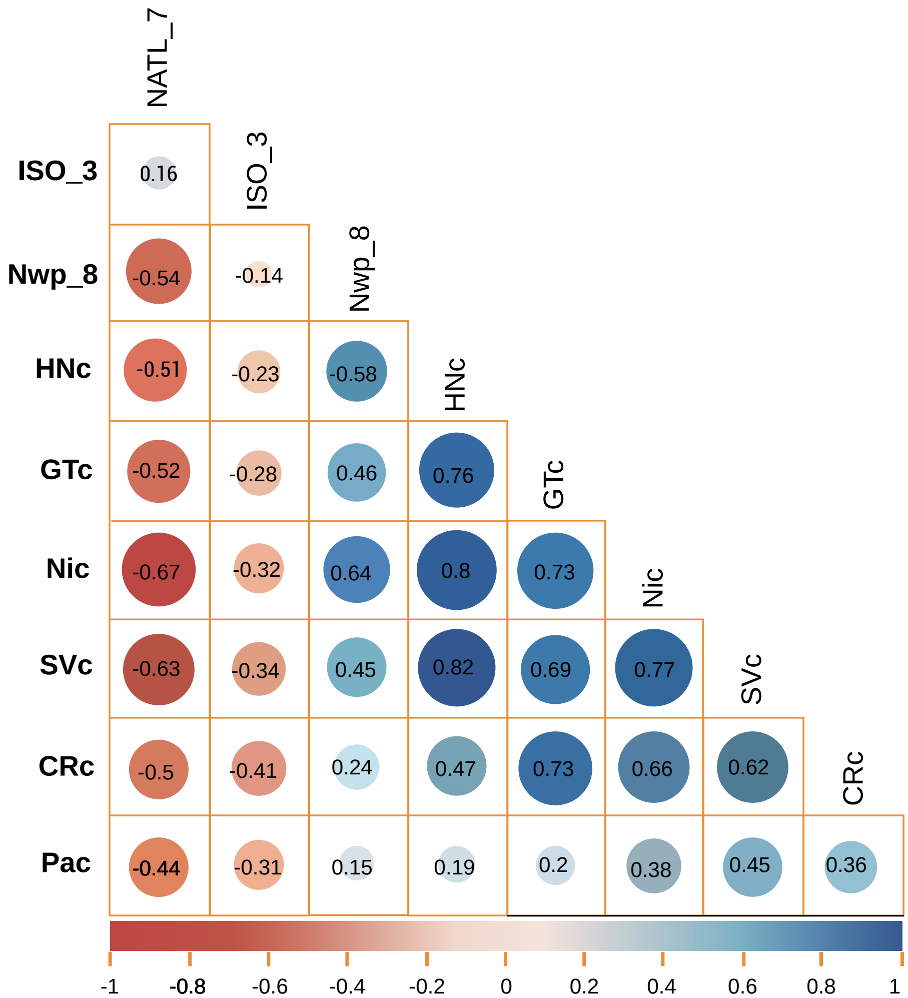


Figure 12

Spearman correlation coefficients (rho) between the variables: the Atlantic Ocean surface temperature anomaly for July (NATL_7), the Southern Oscillation Index for March (ISO_3), the transformation of the anomaly of the El Niño 3 and El Niño 4 in August (Nwp_8) and the agricultural area affected by the canicula for Honduras (HNc), Guatemala (GTc), Nicaragua (NIc), El Salvador (SVc), Costa Rica (CRc) and Panama (PAc).

Country	Proposed regression model		R^2 adjusted	Variance Inflation Factor (VIF)	Durbin- Watson (DW)
Nicaragua	NIc = 12.12 – 0.57 **NALT_7*** – 0.31 **ISO_3****		0.41	1.005	1.9
	(±5.4) (±0.2)				
Honduras	HNc = 7.93 – 0.48 **NATL _7*** + 0.20 **ISO _3**		0.24	1.005	1.9
	(±4.8) (±0.2)				
Guatemala	GTc = 5.81 – 0.45 **NATL _7*** – 0.32 **ISO _3****		0.28	1.005	1.4
	(±3.1) (±0.1)				
El Salvador	SVc = 6.6 – 0.53 **NATL _7*** – 0.33 **ISO _3****		0.37	1.005	2.0
	(±4.3) (±0.2)				
Costa Rica	CRc = 3.34 – 0.49 **NAT_7*** – 0.37 **ISO _3****		0.37	1.005	1.7
	(±1.5) (±0.1)				
Panama	PAc = 8.25 – 0.29 **NAT_7***** – 0.27 **ISO _3**		0.12	1.005	2.0
	(±4.1) (±0.2)				
	***Significant at 1%** ****Significant at 5%** *****Significant at 10%**	c = agricultural area affected by drought due to the canicula			

Table 1

Multiple regression models between the agricultural area affected by drought due to the canicula in the Dry Corridor of Central America explained by its variation, by the sea surface temperature anomaly of the Atlantic Ocean for July (NATL_7) and the Southern Oscillation index of March (ISO_3).

The adjusted R-square is used[11] to evaluate the percentage of the variability in the agricultural area affected by the canicula, associated with the independent variables included in the model. The adjusted R-square, in relation to the R-square, has the advantage of penalizing the inclusion of variables that provide little information to the model.

Standardized regression coefficients[12] for the countries show that the variable NATL_7 is significant in all the proposed regressions, with a negative sign (inverse relationship with the dependent variable) and its most pronounced effect occurs in Nicaragua. In Nicaragua, for each unit of increase in the NATL_7 variable, the dependent variable (agricultural area affected by the canicula) is reduced by 0.57 units, regardless of the level of the ISO_3 variable. In this country, these two variables explain 41 percent of the variation of the canicula, which is a useful approximation, considering the complexity involved in the relationship between climate and agriculture.

[11] The adjusted R^2 gives us information on the percentage of variability in the response (agricultural area affected by the canicula) associated with the independent variables included in the model, this is a modification of the R squared or coefficient of determination, and refers to the percentage of variability in the response (agricultural area affected by the canicula) due to the relevant variables included in the model for explanation, making it neutral with respect to the additional variables.

[12] Standardized coefficients are used since they are expressed in typical scores, therefore the effect of the units in which the variables were originally analysed has been eliminated.

The negative effect on the agricultural area affected by the canicula is slightly lower for Honduras, for each unit of increase in NATL_7, the agricultural area affected by the canicula is reduced by 0.48 units, regardless of the level of the ISO_3 variable. The model explains 24 percent of the variation of the area affected by the canicula ($R^2 = 0.24$), it is required to identify other variables that can explain this phenomenon with greater precision.

In El Salvador and Costa Rica, the variables NATL_7 and ISO_3 explain 37 percent of the variability of the agricultural area affected by the canicula. It is also necessary in these cases to identify other variables that can contribute to the model with an improvement in the explanation of the variability of the agricultural area affected by the canicula.

For Guatemala, by a unit of increase of NATL_7, the agricultural area affected by the canicula is reduced by 0.45 units, regardless of the level of the ISO_3 variable. The model with the two variables explains 28 percent of the variation in the agricultural area affected by the canicula.

In Panama, the variables NATL_7 and ISO_3, contribute to explain the variations in the agricultural area due to the canicula, but the adjustment measure of the model indicates the need for additional analysis to reinforce the documentary evidence on the effects of the canicula. In Panama, the variability in the agricultural area affected by the canicula is explained only at 12 percent. The above responds to the agricultural situation of this country, where the canicula has little impact because most of the basic grains are planted in the second half of the year, while in the rest of Central America, basic grains are cultivated at the beginning of the rains (approximately May), so the canicula in this case represents a hazard to crop flowering and grain filling.

All the regression models built, considering the ISO_3 variable, are significant at 0.05 (p-value <0.05) with a negative sign. In Honduras and Panama, this variable is not statistically significant, but it provides important information to explain the variability of the agricultural area affected by the canicula.

8

Conclusions

8 Conclusions

- The canicula is the reduction of rainfall during the rainy season, in July and August, which can mainly affect basic grains during the crop flowering and grain filling phases. This natural climatic event manifests from the south of Mexico to the Central American Dry Corridor and ends in the Dry Arc of Panama.

- Extreme accentuated or extended canicula events put at risk of food insecurity around two million families that depend on subsistence agriculture in the Dry Corridor of Central America.

- As a result of the canicula, a decrease in rainfall during July has severe consequences for farmers who plant their crops in the *Primera* season (May-July), since the decrease in rainfall coincides with the crop flowering and grain filling phases. This scenario implies significant yield losses in basic grains (type "C" canicula). When the decrease of rainfall occurs with higher intensity in August, it causes a delay in the *Postrera* season (August-December) type "D" canicula. This delay may shorten the harvesting period in some years, reducing the yield of the crops planted in *Postrera.*

- The FAO-ASIS tool has demonstrated sufficient flexibility to generate indices different from those programmed (VCI, TCI, VHI, ASI, drought categories) that are adapted to analyse specific problems such as the canicula. Similarly, other specific indices could be generated to analyse, for instance, the flowering of the coffee tree or the development of floats coffee beans. In regards to sugar cane, generating an Index to study the accumulation of sucrose in the plant could be a thought.

- The short cycle maize varieties (90-100 days) planted at the beginning of the May rains in the Dry Corridor, are more susceptible to being affected by the canicula. Long-cycle varieties (150-250 days) planted in the upper areas of the Dry Corridor, are less vulnerable to the hazards of the canicula.

- The canicula affects the Pacific zone of Nicaragua with higher frequency and intensity, followed by areas in Honduras, Panama (provinces of Los Santos and Herrera, and some areas of the Darien province) and part of the Dry Corridor of Guatemala (Chiquimula and Zacapa).

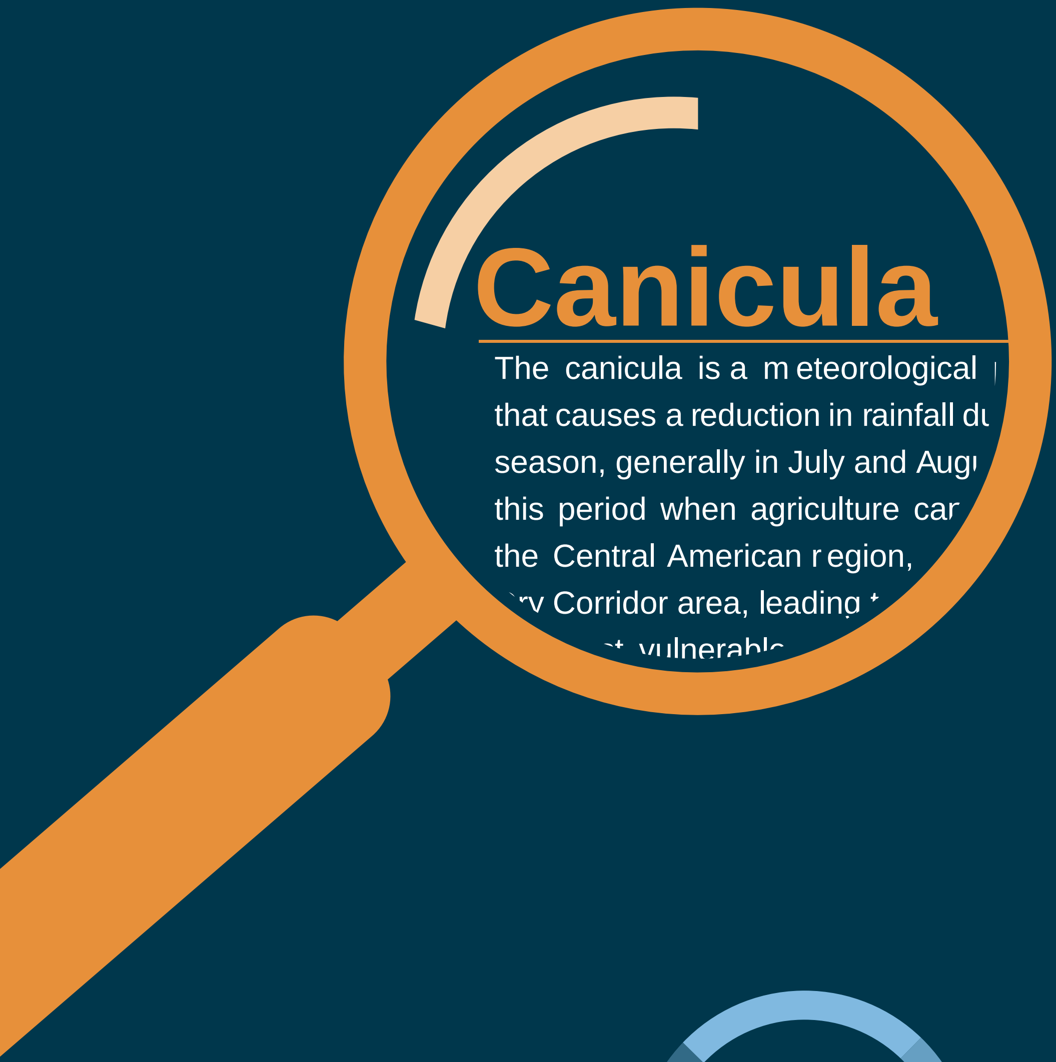
- The intensity and accentuation of the canicula in Central America is more correlated with the version of Modoki El Niño than with the version of Canonical El Niño. The Modoki El Niño version has increased its frequency of occurrence in the last decades, presenting favourable conditions for an increase in the frequency of occurrence of extended caniculas in the region.

- Variables of the sea surface temperature anomalies of the Atlantic Ocean for July (NATL_7) and the Southern Oscillation Index for March (ISO_3), are inversely correlated with the intensity of the canicula. On the other

hand, the sea surface temperature anomaly of the Pacific Ocean in August (Nwp_8) has a direct relationship with the incidence of the canicula. This means that the presence of El Niño, with a warm Atlantic Ocean, favours the expansion and intensification of the canicula in Central America.

- Results of the multiple regression analysis point out the sea surface temperature anomalies of the Atlantic Ocean (NATL_7) and the Southern Oscillation Index for March (ISO_3) as the most explanatory variables of the variation of the canicula in Central America. Both explain 41 percent of the canicula behaviour in the Pacific zone of Nicaragua. This level of explanation may be considered top, given the complexity of climatic phenomena and their relationship with agriculture. The explanatory level of the independent variables decreases to 12 percent in Panama, where the presence of the canicula has little effect because of the late sowing of the crops (Postrera). For the rest of Central American countries, these variables explain more than 24 percent of the variation of the canicula.

- Finally, it should be noted that the warming of the oceans due to climate change is causing increasing anomalies that are leading to more extreme El Niño events. This, in the end, could result in conditions conducive to intense and accentuated canicula events in the region.



9

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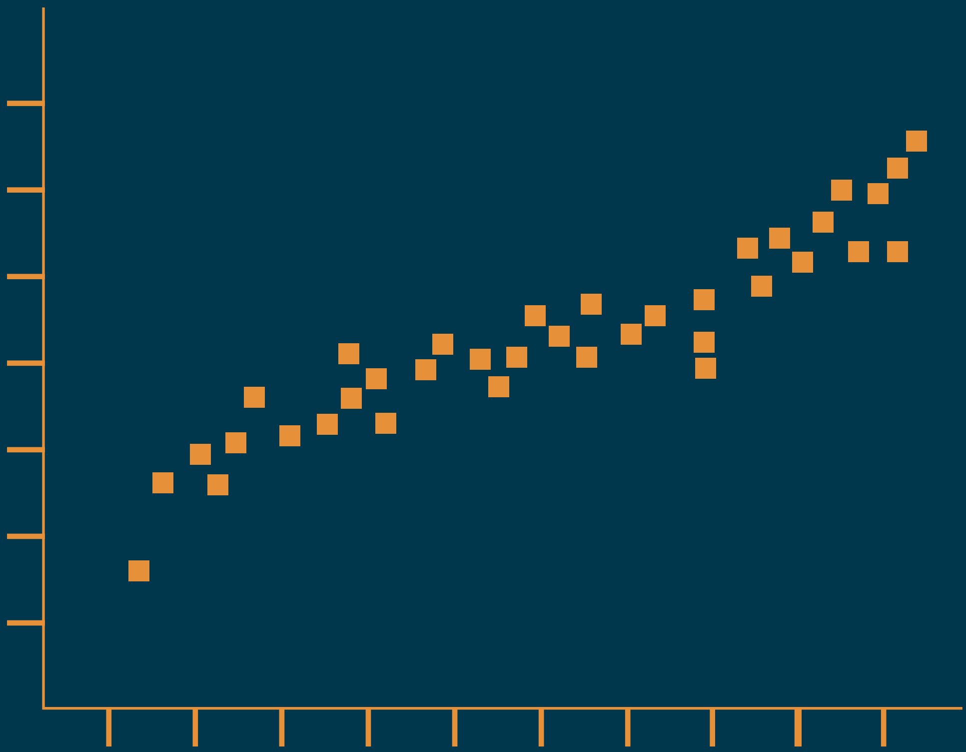

A

Annexes

1 Indices used in the correlation analysis

Southern Oscillation Index (SOI)

The Southern Oscillation Index (SOI) indicates the development and intensity of El Niño or La Niña episodes in the Pacific Ocean. SOI is arithmetically calculated from monthly fluctuations in air pressure values between the island of Tahiti (French Polynesia) and the city of Darwin (Australia) (Figure A1).

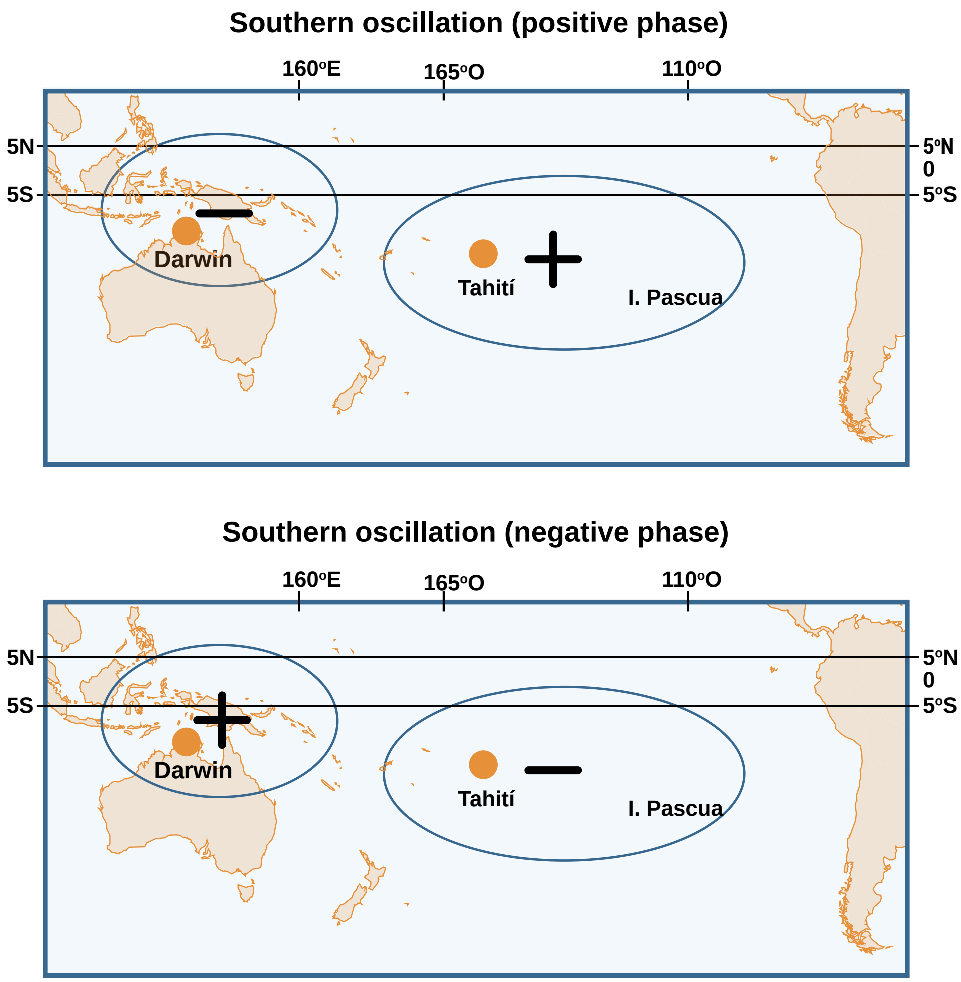

Figure A1

The Southern Oscillation Index (SOI) measures the difference in atmospheric pressure between Tahiti and Darwin. The existence of sustained negative SOI values frequently indicates episodes of the El Niño phenomenon. Conforms to United Nations world map, 2020.

El Niño 1+2 (0-10S, 90W-80W)

El Niño 1 + 2 region is the smallest and located further east of the El Niño regions where sea surface temperatures are measured, near the coast of South America. This index tends to have the greatest variance of the El Niño indices (Figure A2).

El Niño 3 (5N-5S, 150W-90W)

This region was the first to be monitored to predict the occurrence of El Niño, but the researchers later learned that the key region for the coupling of the atmosphere and the ocean was further west. For this reason, the El Niño 3.4 region became the classic region to define El Niño and La Niña events (Figure A2).

El Niño 3.4 (5N-5S, 170W-120W)

El Niño 3.4 is represented by sea surface temperature anomalies in the Pacific, near the date change line for the coasts of South America. El Niño index 3.4 is used to define the ONI (Oceanic Niño Index) and is used operationally by NOAA (National Oceanic and Atmospheric Administration) to define El Niño or La Niña events (Figure A2).

El Niño 4 (5N-5S, 160E-150W)

El Niño 4 index captures the sea surface temperature anomalies of the central equatorial zone of the Pacific. This region tends to have a lower variance than other El Niño regions (Figure A2).

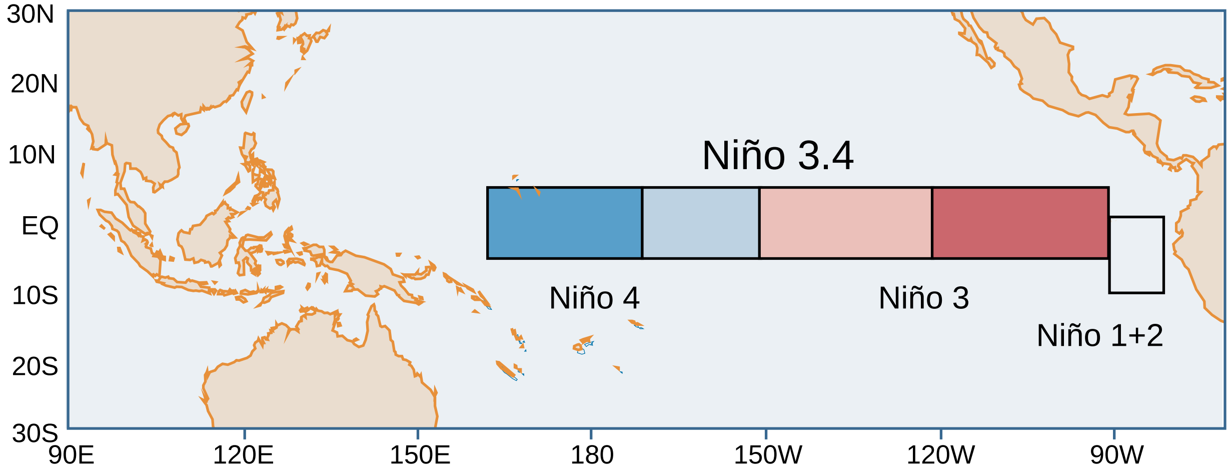

Figure A2

Regions in the Pacific Ocean that define the El Niño phenomenon indices. Source: NOAA, https://www.climate.gov/
Conforms to United Nations world map, 2020.

NCT and NWP

Ren and Jin, (2011) propose two indices: a transformation of the sea surface temperature anomalies of the Pacific Ocean in El Niño 3 and El Niño 4 zones. The intention of this transformation is to better capture the two types of El Niño: The Canonical El Niño and The Modoki El Niño.

In addition to the indices of the Pacific Ocean that represent the area of formation of the El Niño phenomenon, the sea surface temperature anomalies of the following areas were analysed (Figure A3):

- Global Tropic Index (10°South-10°North, 0-360) (TROP)

- Tropical Northern Atlantic Index (5-20° North, 60-30° West) (NALT).
- Tropical Southern Atlantic Index (0-20° South, 30° West-10° East) (SALT).

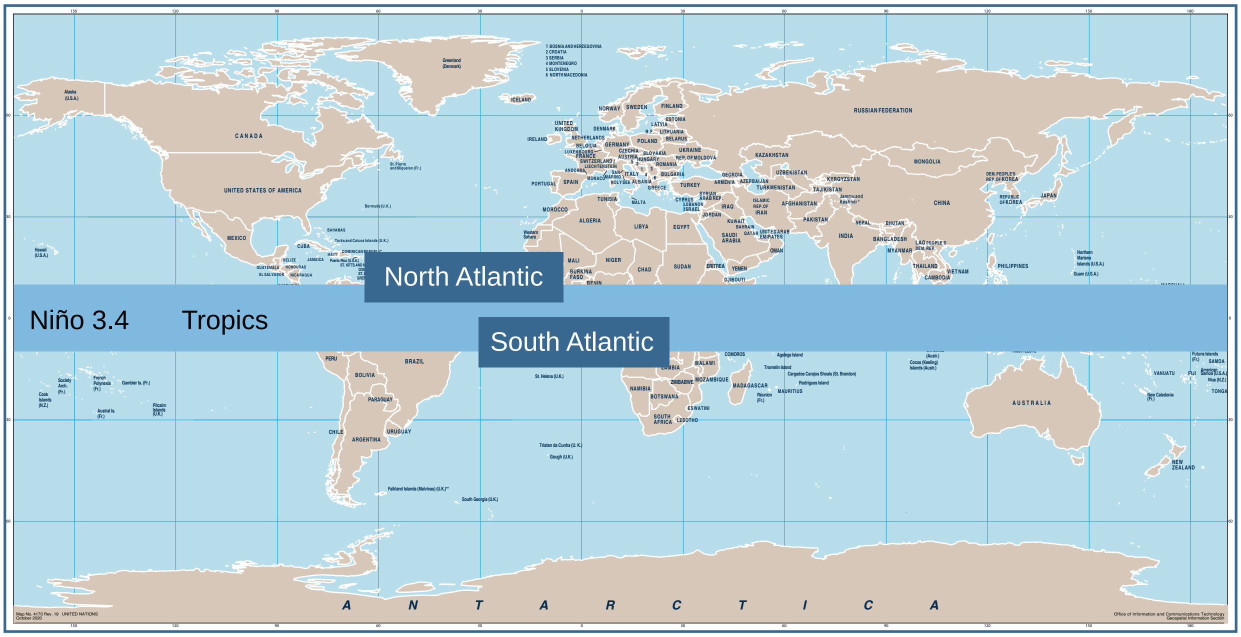

Figure A3

Regions in the Atlantic Ocean from which the following indices are derived: Global Tropic Index, Tropical Northern Atlantic Index and Tropical Southern Atlantic Index. Conforms to United Nations world map, 2020.

2 Statistical tests

The following statistical tests were performed on the proposed models:

1. The linearity assumption was verified through a scatter plot (Figure A4).
2. The residual independence assumption was tested for the linear regression models using the Durbin-Watson statistic. All regression equations satisfactorily follow through with this assumption.
3. The correlation analysis shows a high correlation (rho = 0.54) statistically significant at the 0.01 level between the NATL_7 and Nwp_8 indices. This could suggest a multicollinearity problem[13]; however, both variables are included in the multiple regression analysis and it is verified there is no multicollinearity. The variable Nwp_8 loses significance in the multiple regression in relation to the variable ISO_3, so it is not included in the equations as an explanatory variable of the variation of the canicula intensity.
4. The non-existence of multicollinearity between the variables of each proposed regression is tested using the variance inflation factor (VIF), resulting in no violation of this assumption in any of the proposed regressions.

[13] Multicollinearity is the strong linear dependency relationship between more than two explanatory variables in a multiple regression that fails the Gauss-Markov assumption when it is exact. In other words, multicollinearity is the high correlation between more than two explanatory variables.

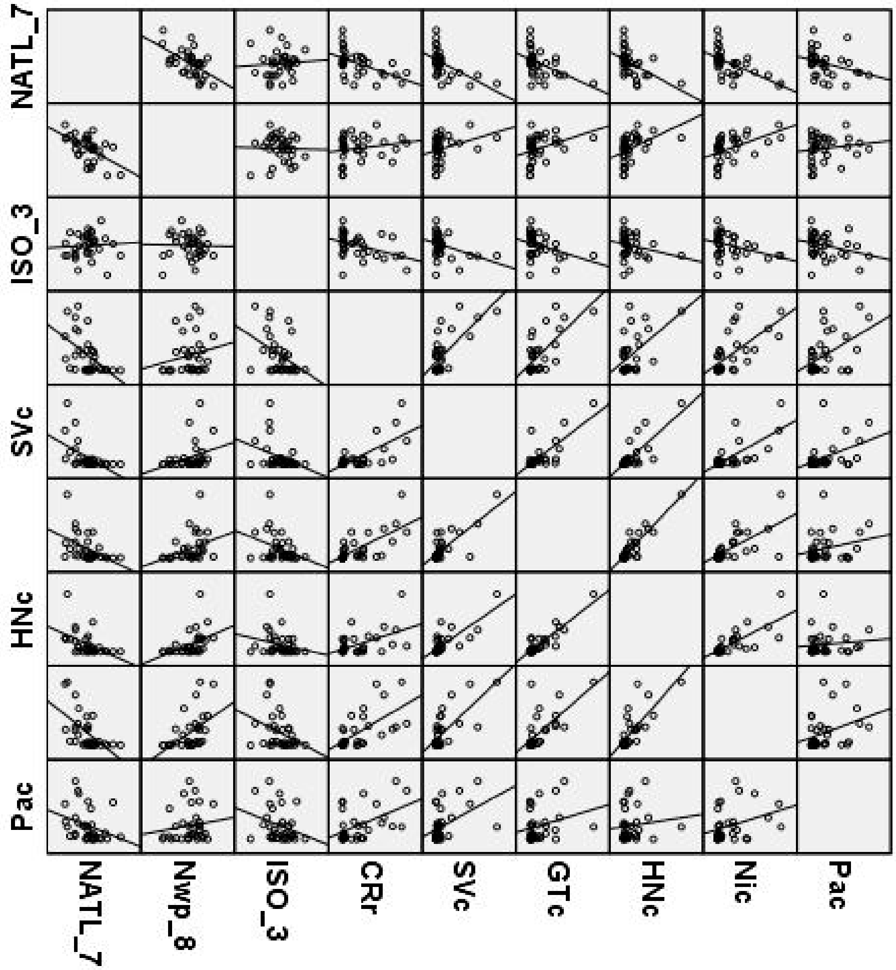

Figure A4

Dispersion diagram between the sea surface temperature anomaly variables of the Atlantic Ocean for the month of July (NATL_7), Southern Oscillation Index for the month of March (ISO_3), transformation of the El Niño 3 and El Niño 4 anomaly of the month of August (Nwp_8) and the area affected by the canicula (Pac, Nic, HNc, GTc, SVc, CRc).

The canicula is the reduction of rainfall during the rainy season, in July and August, which can mainly affect basic grains during the crop flowering and grain filling phases. This natural climatic event manifests from the south of Mexico to the Central American Dry Corridor and ends in the Dry Arc of Panama.

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