

Effects of Atlantic and Pacific Ocean Teleconnections on Corn Yield East of Puebla, Mexico: Case Studies

Ma De Los Ángeles Velasco-Hernández^{1*}, Tomás Morales-Acoltzi², Miguel Ángel García-Castro¹, Rogelio Bernal-morales³, Joaquín Zagoya-Martínez⁴, José Pedro Juárez-Sánchez⁵ and Benito Ramírez-Valverde⁵

¹Faculty of Chemical Engineering, BUAP, University City, Puebla, Mexico.

²Mathematical Modeling of Atmospheric Processes, Center for Atmospheric Sciences, UNAM, Mexico City, Mexico.

³Climate Change Research Center, Faculty of Agrobiological Sciences, UATX, Tlaxcala, Mexico.

⁴BUAP Institute of Sciences, Zeolite Research Department, Puebla, Mexico.

⁵Postgraduate College, Campus Puebla, Puebla, Mexico.

Authors' contributions

This work was carried out in collaboration among all authors. Author MDLAVH and Author TMA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MAGC, RBM and JZM managed the analyses of the study. Author JPJS and Author BRV managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Ocean-atmospheric interactions have effects at different scales; forming microclimates, which can explain variations with climatic or natural anomalies, between meteorological processes. This research analyzes and identifies the relationship of the teleconnection hydrometeorological effects, which determine the distribution of precipitation in corn yield. The data were used from a semi-structured interview directed to corn producers, where seven years of case studies were identified for the eastern region of the state of Puebla, Mexico. The Graphics were made with "pentad scale

distribution". The results show the importance of geographical location for agricultural activities in relation to a valley with altitudinal gradient. In addition, the corn growth cycle is associated with tropical disturbances from east Puebla region as well as Hurricane activity. It was identified that the relationship of teleconnections and the distribution of rainfall are main factors that influence in the development good or bad of corn, showed in the yields, where the different phases of ENSO (EL NIÑO Southern Oscillation) have a differentiated impact on the availability of precipitation in this case studies of the present investigation.

Keywords: ENSO; maize; phenology; precipitation; teleconnection.

1. INTRODUCTION

Teleconnection is defined as the ocean-atmosphere interaction that occurs at a distant terrestrial point and causes persistent and recurrent modes of low-frequency climatic variability [1]. When defining it, highlight that the behavior patterns between two different sites, due to the climatic variability caused by some measurement (temperature, pressure, etc.) [2]. That is, a teleconnection index is defined as the difference in temperatures between two different places (action centers). In reference to distant hydrometeorological events, there are processes that relate climatic variability through physical teleconnection mechanisms to connect anomalies of sea surface temperature with climatic variability in the region [3]. The teleconnection relationships that managed to explain the anomalies related to the variability of rainfall in Europe in relation to trends in the variability of the equatorial and tropical Atlantic [4].

In recent decades, the irregularity of rainfall has caused several problems worldwide, such as the devastating 2003 European summer heat wave raise the evidence that basin-scale changes in the Atlantic Ocean, probably be related to the thermohaline circulation. Which shows intra-seasonal and interannual variability [5]. All teleconnection patterns occur naturally in our incomprehensible atmospheric system and can occur in the internal dynamics of the atmosphere [6]. Seasonal weather anomalies are influenced by the variability in longer time scales, also called teleconnections, these are some of the most relevant internal causes of climate system variation [7]. It is considered pertinent to design conservation strategies in a natural national park considering that, in climatic times of extreme drought, this slope receives significant moisture subsidies because of the generation of local convective phenomena. Teleconnections have been identified in extreme drought events recorded during the period 1978-2010 in the

North of Colombia and large-scale circulation, characterized by the Niño 3.4 index and the Atlantic Tropical North Index (ATN), which are related with modulation from atmospheric circulation phenomena in the Atlantic and Pacific Oceans [8].

The coastal entities of the national territory, on some occasions, get to be affected by tropical cyclones that impact continuously from one season to another and a lesser extent to the interiors [9]. In recent years, studies have been conducted on the influence that teleconnections have in Mexico, the results have shown that the Pacific Decadal Oscillation has a statistically significant impact on the climate of the north and northwest of the national territory [10]. Anomalous anticyclonic trend is influencing Central Himalaya. These trends have contributed to variations in cloudiness, temperature, radiation, and circulation across High Mountain Asia (HMA), that are relevant to the regional hydrological cycle [11]. More studies in the fields of atmospheric dynamics, and about its impacts in Mexico, all this, to have better short and long-term forecasting systems, such as an example of this, is the relationship between EL NIÑO (interannual scale) and tropical cyclones in the Atlantic Ocean (meteorological time scale) [12]. Although the mechanisms that condition and control the climate have already been identified, it has not yet been possible to establish a direct connection between the weather and weather scales. Concerning crop phenology, some studies show frost damage with changes in temperature during winter and before spring (average temperature increase), which are important because they regulate the latency period (inactivity) and the development of the plant [13].

In other countries the association of EL NIÑO with extreme precipitation events was also observed [14,15,16], as in Saudi Arabia, showing Extreme Precipitation Events (EPEs) are also associated with El Niño Southern Oscillation

(ENSO), which shows that during the positive (negative) ENSO phase the frequency of EPEs increases (decreases) over the country. Moreover, the El Niño, with positive circumglobally wave train (CGT) enhances the EPEs frequency over Saudi Arabia while vice-versa happens for La Niña (with negative CGT) phase [17]. With the increase in temperature, changes can be expected during the crop cycle, from this increase, the harvest dates can be anticipated, modifying the phenology [18]. This impact depends on the species since they must accumulate a certain number of degree days for fruiting or flowering [19]. Studies related to corn show that an increase in temperature will negatively modify its phenological stages, affecting the flowering stage, while water scarcity or abundance and the development of pests and diseases adversely affect production [20]. Other study mentioned, with the climate variability on the forecast for Michoacán, Mexico is: less precipitation in less time, and higher temperature. For sites currently planted, in March, with long-cycle maize (220 days), this will mean the future change to June sowings with cycle materials short (140 days), drought tolerant, character negatively associated with floral asynchrony, and the altitudinal movement of cultivars [21].

A recent investigation found that in native corn populations there was a possibility of a 20-day reduction for female flowering because of climate change, changing the planting date from April to June and decreasing the area of foliage (29%) and the yield (46%) [22]. Research studies at different scales are interesting as in the macro or global scale [23], at a national level [24], at a local level [25] and in mountains areas [26]. The importance of understanding the influence of regional climate and the significant and underestimated the effect of remote variability or remote control of tropical cyclones [27]. Therefore, the objective of the research is to analyze and identify the relationship of the hydrometeorological effects of teleconnection, which determine the distribution of precipitation in corn yield in a region with an altitudinal gradient in the East of the state of Puebla, Mexico.

2. MATERIALS AND METHODS

Two municipalities were selected that correspond to Region III known as Serdán Valley, east of the state of Puebla. Of the 31 municipalities that make up this valley, the municipalities of

Chalchicomula de Sesma (Ciudad Serdán), with an average altitude of 2649 masl and coordinates 18°59'00"N 97°27'00"W and Tlachichuca with an average altitude of 2593 masl. and coordinates 19°06'00"N 97°25'00"W stand out. In both spaces the altitudinal gradient is the main characteristic of the study site that includes: ituir1) Plain road.

This is the central part of the Valley (also known as the Serdán region), from north to south and is the area with the highest agricultural productivity 2) Hills. This type of terrain is in the foothills of the mountains, mainly in the eastern and western part, with the most notable areas comprising the slopes of the Citlaltepec volcano. 3) The mountains. Where the volcano Citlaltepec, of 5,545 masl, is also the Sierra Negra, from 3,000 to 4,000 masl and includes the Sierra de Soltepec, from 2,200 to 3,000 masl (Fig. 1). Country (blue), state (green), study region (yellow).

A study of agricultural regionalization of corn for the state of Puebla taking variables of precipitation, temperature, soil types and climate and mentioned that the municipality of Chalchicomula de Sesma belongs to the best region to produce corn in the State, which he called Optimal Region [28]. A small-scale agriculture is practiced, they had an average of 5.9 ha under temporary conditions, distributed in several farms with an average yield of 2.328 ton ha⁻¹ in the study period (1996-2004), these were calculated directly in the field Based on the method called Average Weight Mazorca [29], the Serdán region contributed 25% of the total corn production at the state level [30].

Although there is a tendency to change economic activities, maize production continues to be the predominant activity. Predominating the ejido (85.7%), the crops are sown under temporary conditions, highlighting corn, and to lesser extent beans and beans. What makes agriculture completely climate dependent [31]. As historical data of the region, [32] using linear regression mentions that from 1975 to 1995 corn yields were increased by 100 kg ha⁻¹ annually and 1996 to 2004, the Average yields for "Chalchicomula de Sesma" were 2,328 kg ha⁻¹.

To know the relationship of empirical knowledge with meteorological events and yields of corn crops, semi-structured interviews were applied to 70 farmers, 28 in Chalchicomula de Sesma and 42 in Tlachichuca-, specifically in the production

of corn, considering their average age (58.5 years) and their experience working in the field (41 years), especially growing corn; in the municipalities of study. The seventy interviews carried out allowed the identification of six growth stages for corn cultivation in both municipalities of the study site. The native corn of the region reaches physiological maturity in an average of 180 days. This period may vary depending on the circumstances and the orographic slope. The bars of different colors shown in Figs. 3-9 show the six phenological stages of corn where: stage 1. Germination (15 days), stage 2. Seed growth (30 days), stage 3. Development of the plant (85 days), stage 4. Flowering and pollination (120

days), stage 4. Grain formation (160 days), stage 5. Physiological maturity (180 days), heading. Besides, with data from the National Meteorological System of México were identified the tropical depressions of the studies cases.

The database (DB) consists of daily time series (TS) of precipitation (PCP) and maximum (MaxT) and minimum temperatures (MinT) for two weather stations (National Meteorological Service of Mexico), representative of the region Table 1, due to the surrounding east winds the mountainous area associated with the Citlaltépetl volcano, which covers different observation periods.

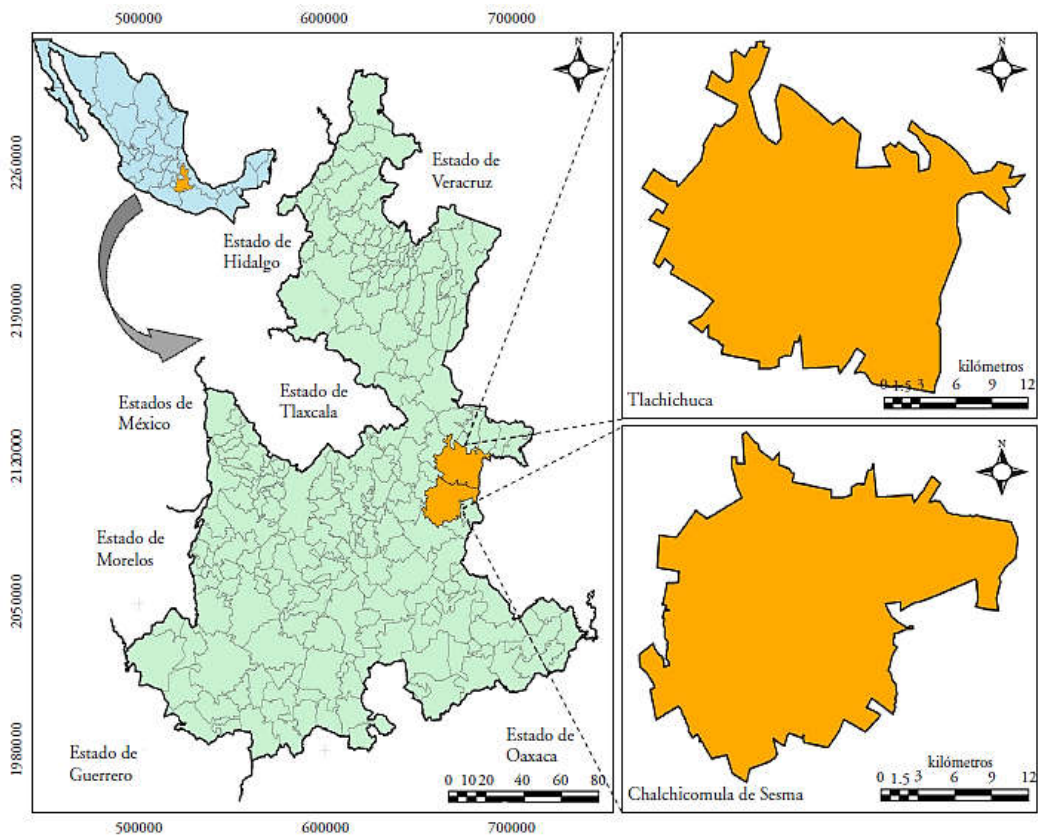


Fig. 1. Location of the study region: “Chalchicomula de Sesma” and Tlachichuca

Note: Own elaboration using the Arcview Ver. 3.2 program

Table 1. Selected data from the study site: Chalchicomula de Sesma y Tlachichuca

Year case studies	Weather station	Municipality where the station is located
1980	21056 “La Trinidad”	Chilchotla
1983	21056 “La Trinidad”	Chilchotla
1987	21056 “La Trinidad”	Chilchotla
1992	21026 “Serdan”	Chalchicomula de Sesma
2011	21026 “Serdan”	Chalchicomula de Sesma
2013	21026 “Serdan”	Chalchicomula de Sesma
2018	21026 “Serdan”	Chalchicomula de Sesma

For the elaboration of the graphs, the time scale shown in the graphs corresponds to the accumulated rainfall in pentads (five days), because the rain is intermittent, and the distribution is shown in greater detail. To describe the relations of the teleconnections of the case studies and the development of the grain and the ENSO, the data were correlated with the statistical test to find associations between hurricanes, tropical storm, and the type of event (EL NIÑO, LA NIÑA and NEUTRAL) with Cramer's V with a confidence interval of 95% and an error of 0.05.3.

3. RESULTS AND DISCUSSION

Table 2 shows the results based on the interviews, where six years of studies were identified, and the producers reported yields that varies from 1.5 to 4.5 t ha⁻¹. And the information of 2018 was from Data of the Agrifood and Fisheries Information Service, for corn grain. Finally, with data from the National Meteorological System, the precipitation data were placed showing a wide variation in precipitation from 425 mm to 1,474 mm and the average maximum and minimum temperature. Table 2.

The average maximum and minimum temperatures maintain little absolute variation. One of the strategies used by farmers to schedule the sowing date of the next agricultural cycle is based on the amount of water available from November to February. With respect to the case studies, in 1980, they accumulated 39 mm from November 1979 to February 1980, with a maximum in January of 27 mm, in EL NIÑO conditions, which generated precipitation and, therefore, available moisture associated to the altitudinal gradient, since they are sown at heights from 3,500 meters above sea level, a different sowing date. In Fig. 2, an excellent distribution of rainfall with an average of 894 mm was identified. Higher temperature variability was observed with a maximum of 24°C. With respect to the beginning of the agricultural cycle, farmers benefited from residual soil moisture, associated with the accumulated rainfall in January and February. The low temperatures very close to the base temperature for corn (with the appearance of agronomic frosts). In 1980, the minimum temperature that exceeded the base temperature for corn, however, had a maximum of 30°C and was greater in mid-year. However, in the season, the lack of rain was evident during periods of one to two weeks, which were not decisive for the

stages of corn growth, due to the adequate distribution of rainfall. Considering the EL NIÑO event, whose associated warming potential was established at the end of 1979; This was a year with neutral phase, as was the whole year of 1980, considered a "good" year of 4-4.5 t ha⁻¹ and the following year 1981, which also had neutral conditions.

According to the Atlas of Tropical Cyclones in Mexico, considering the PCP pentads (five-day periods) associated with tropical disturbances, the pentad from August 3 to 7 corresponds to Hurricane ALLEN in the Atlantic, which lasted from August 1 to 11. In particular, the maximum PCP refers to the same Pentad, which appears to be related to the same system. The hurricane season in the Atlantic in 1980 identified the accumulated pentad from September 22 to 26, due to tropical storm HERMINE, with a Pentad from September 20 to 26 and entering Mexico on September 24. It is likely that the coincidence with the date of the tropical storm DANIELLE, in the Atlantic, which occurred from September 4 to 7, which allowed the physiological maturity stage to benefit, in the pentad from September 2 to 6. With respect to the activity in the Pacific, the date of the THREE tropical depression, from June 17 to 19, coincided with the pentad of maximum rainfall corresponding to the stages of flowering and pollination. Although there may be a remote teleconnection, this tropical system also affected the teleconnection mode on the southern coast of Veracruz, Mexico. These conditions, associated with a good distribution of rainfall, can be considered ideal for achieving the best yields.

In Fig. 3, the case of 1983 is shown. During the months of January and February, it rained, so farmers began to cultivate. The minimum temperatures showed an approximate average of 5°C, compared to the base temperature for corn, which is 7°C, this temperature represents a risk for the crop, and the maximum temperatures were observed in the middle of the year and decreased after July. In addition, the lack of rainfall during the months of March, April and May could have affected the cultivation of corn in the growth stage, although, in June, July and early August it rained, this was insufficient, since It may be related to the stage of flowering and grain formation reflected in a low yield between 2-2.5 t ha⁻¹. In relation to EL NIÑO, it was presented throughout the year with a poor distribution of rainfall. With respect to a teleconnection in relation to the PCP, the 1983 Atlantic hurricane season was the less active

Table 2. Identified data of the case studies

Year case studies	Performance reported by the producer (t ha ⁻¹)	Precipitation (mm)	Average maximum temperature (°C)	Average minimum temperature (°C)	Average rainfall of the study site (mm)
1980	4,0 – 4,5	894	21,9	6,8	735.5
1983	2,0 - 2,5	739	18,7	6,6	735.5
1987	2,0 - 30	425	18,6	5,2	735.5
1992	4,0 – 4,5	1,474	17,4	5,5	735.5
2011	1,5	459	23,4	6,3	735.5
2013	3,5	483	22,4	7,1	735.5
2018*	2.43	592	22,8	6,3	735.5

*Data of the Agrifood and Fisheries Information Service, for corn grain

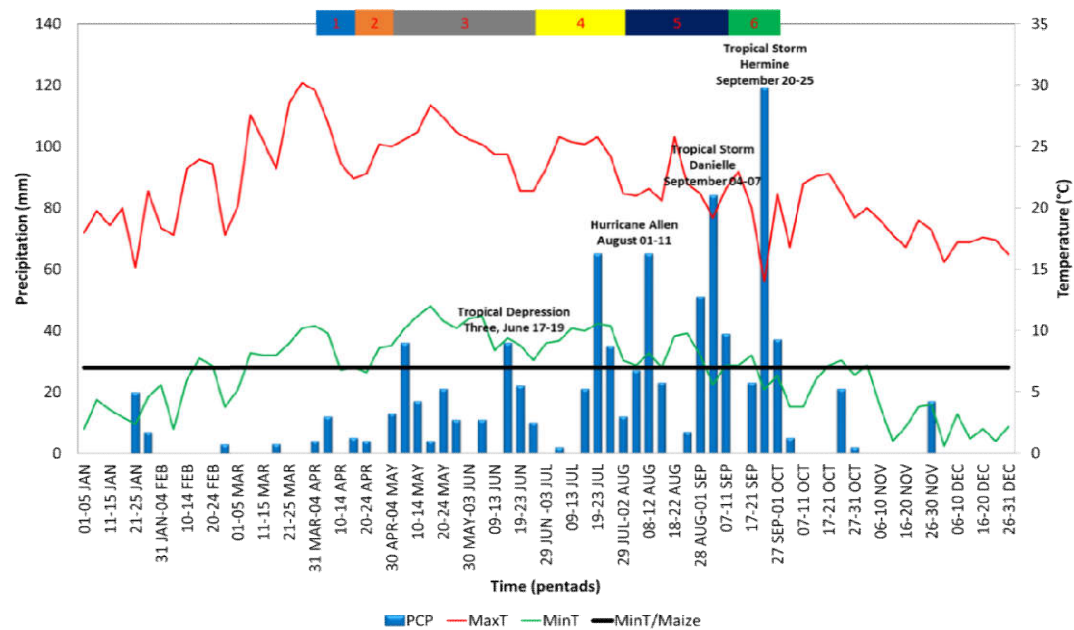


Fig. 2. Variability of rainfall in pentads and temperature in relation to the teleconnection of meteorological events, case 1980

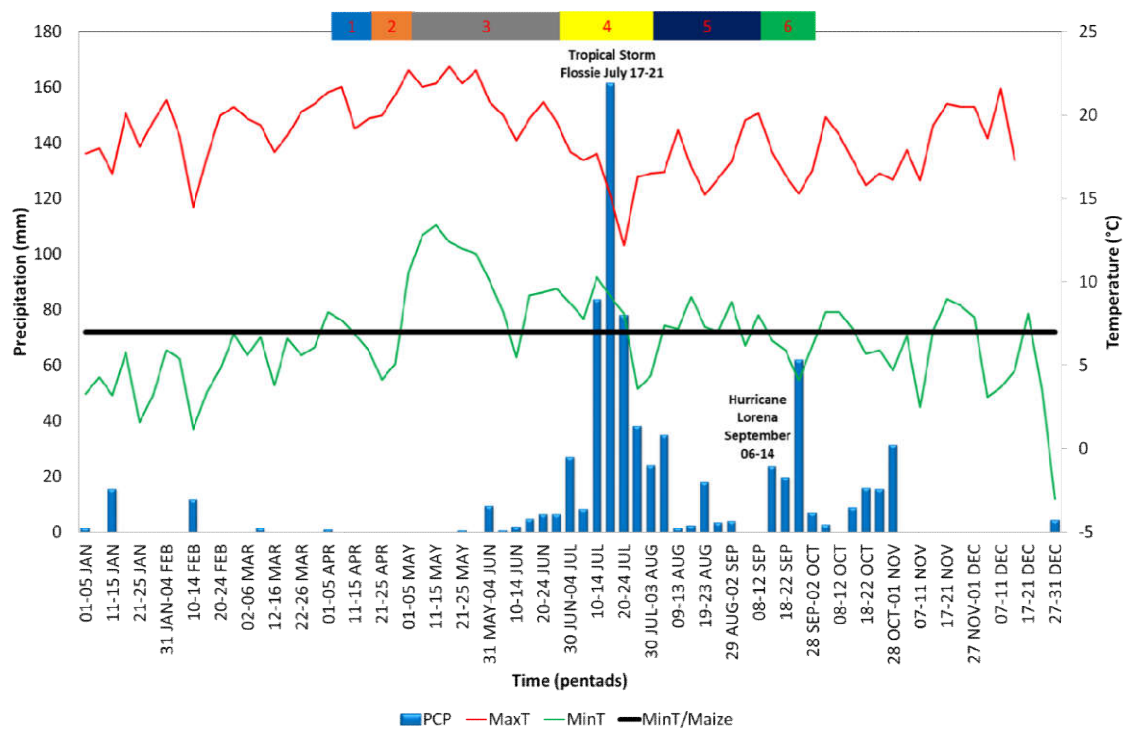


Fig. 3. Variability of rainfall in pentads and temperature in relation to the teleconnection of meteorological events. Case: 1983

hurricane season in 53 years. The EL NIÑO event probably contributed to this level of activity. It also influenced a quiet area of the Atlantic hurricane season. On the other hand, the tropical storm FLOSSIE showed with a duration from July 17 to 21 formed in the Pacific, which coincided with the maximum of PCP, and Hurricane LORENA, with a duration from September 6 to 14, which contributed little to the pentad from September 13 to 17.

In Fig. 4, the case of 1987 is shown. During the months of April to June, it rained 12 mm on average. The minimum temperature was at the same level as the base temperature of 7°C, for the cultivation of corn, which represents an important variable because the cultivation of corn is in the growth stage. However, meteorological, and agronomic frosts were evident. The maximum temperature showed an average of 22°C, with great variability in the middle of the year and decreased during the month of August. This year considered "regular", with a yield of 2-3 t ha⁻¹, is related to the EL NIÑO event, which began in 1986 and continued throughout 1987, until early 1988. The hurricane season in the Atlantic of 1987 was lower than the average limited by the EL NIÑO event. On the other hand, the unnamed tropical storm from August 9 to 17

formed in the northwest of the Gulf of Mexico, however, no relationship was found with the pentads analyzed. Particularly in the Pacific, hurricane EUGENE, from July 22 to 26, was relevant because there was a relationship with the maximum of PCP and it is likely that it might have contributed to the phenological phase of flowering and pollination. The distribution of rainfall was regular, although it seemed to be affected by another hydrometeorological event called "canícula" (midsummer drought).

In Fig. 5, the case of 1992 is shown, during the month of January, the rainfall was sufficient for farmers to have the confidence to start the planting season even in the mountainous areas that they usually sow during February and early March. In mid-March and April, rainfall reached an average of 220 mm of rainfall, benefiting the growth and flowering stages of the plants. The maximum temperature was maintained on average 18°C during the year, except for June. Hurricanes in the Pacific showed no coincidence with PCP values in the months of March and April. With respect to the ENSO event, six months EL NIÑO and six months of NEUTRAL phase are shown. During these months the corn crop was not affected, achieving a good yield of 4-4.5 t ha⁻¹. Another variable that can be

observed is the importance of the microclimate of the locality, where the existence of orographic factors allowed good conditions for the benefit of the agricultural sector, despite the presence of EL NIÑO.

According to the Atlas of Tropical Cyclones in Mexico, in the Atlantic Ocean, hurricane ANDREW appeared from August 16 to 28 in 1992, coinciding with the rainfall values, in which the category 5 hurricane occurred, which represented a good storm for a "good" performance, and according to the corn phenology, they were in the stage of grain formation. With respect to the hurricane season in the Pacific in 1992, it was the most active in history, in relation to Fig. 3, the pentads that had coincidences like tropical storm AGATHA, from June 1 to 5 and hurricane DARBY, of July 2 to 10. On the other hand, Hurricane LESTER, from August 20 to 24, was important for the PCP and Hurricane VIRGIL (category four) from October 1 to 5, had a slight coincidence with precipitation at the stage of physiological maturity.

In Fig. 6, the case of 2011 is shown. At the beginning of the year, it did not rain until mid-March, affecting the farmers who sow in February. Low rainfall occurred in May, June,

and October. The minimum temperature was lower than the base temperature of 7°C, for the cultivation of corn, which implies a partial and total loss at the beginning of planting. The figure shows agronomic frosts at the beginning of the year for three months and at the end of the year during the last four months and weather frosts during October. The maximum temperature showed an average of 22°C, with great variability in the middle of the year and decreasing during the month of August. Obviously, all stages of corn growth were affected by the poor distribution of PCP, also, the drought in mid-summer. This year, considered with low yields of 1.5 t ha⁻¹, is related to LA NIÑA event, during the first 4 months of the beginning of the year and 4 months at the end of the year. There is a significant relationship with EL NIÑO and the hurricane losses in the years of LA NIÑA that shows more damage [33]. According to the Atlas of Tropical Cyclones in Mexico, in 2011, the Atlantic hurricane season was moderate, although Hurricane ARLENE passed through Mexico from June 28 to July 1 and dissipated in the mountains of the Sierra Madre, which stayed from June 29 in the state of Veracruz, Mexico, from June 28 to July 1, coinciding with a maximum of PCP. In relation to the activity of the hurricanes of the Pacific, it was a season below

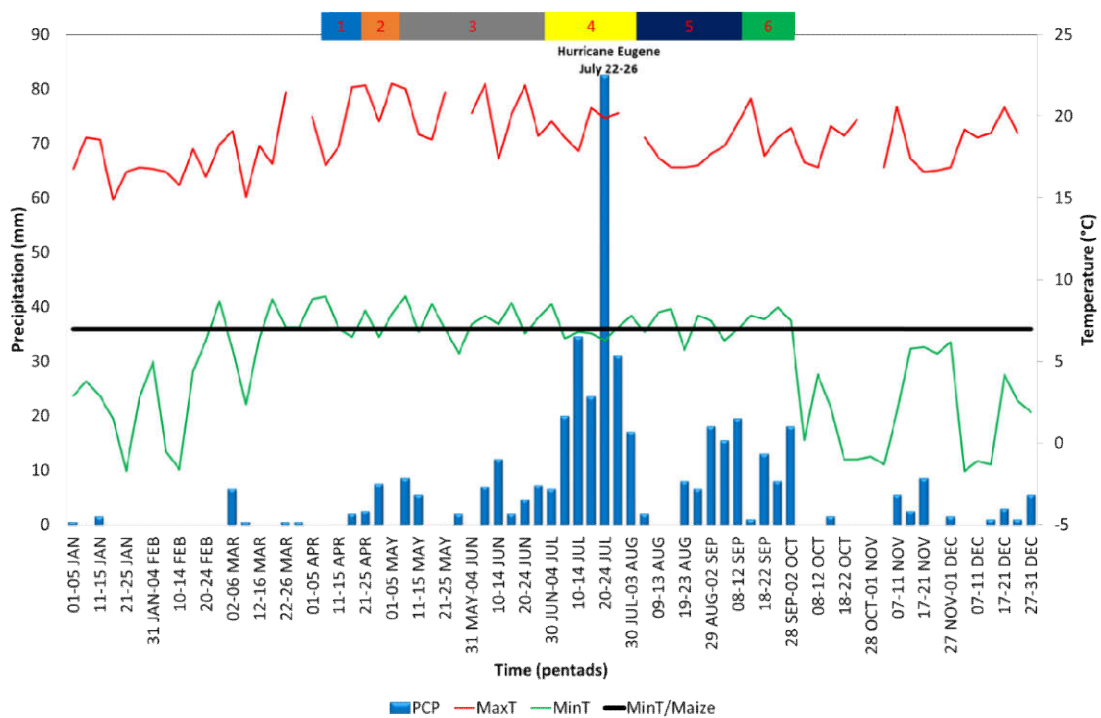


Fig. 4. Variability of rainfall in pentads and temperature in relation to the teleconnection of meteorological events, case: 1987

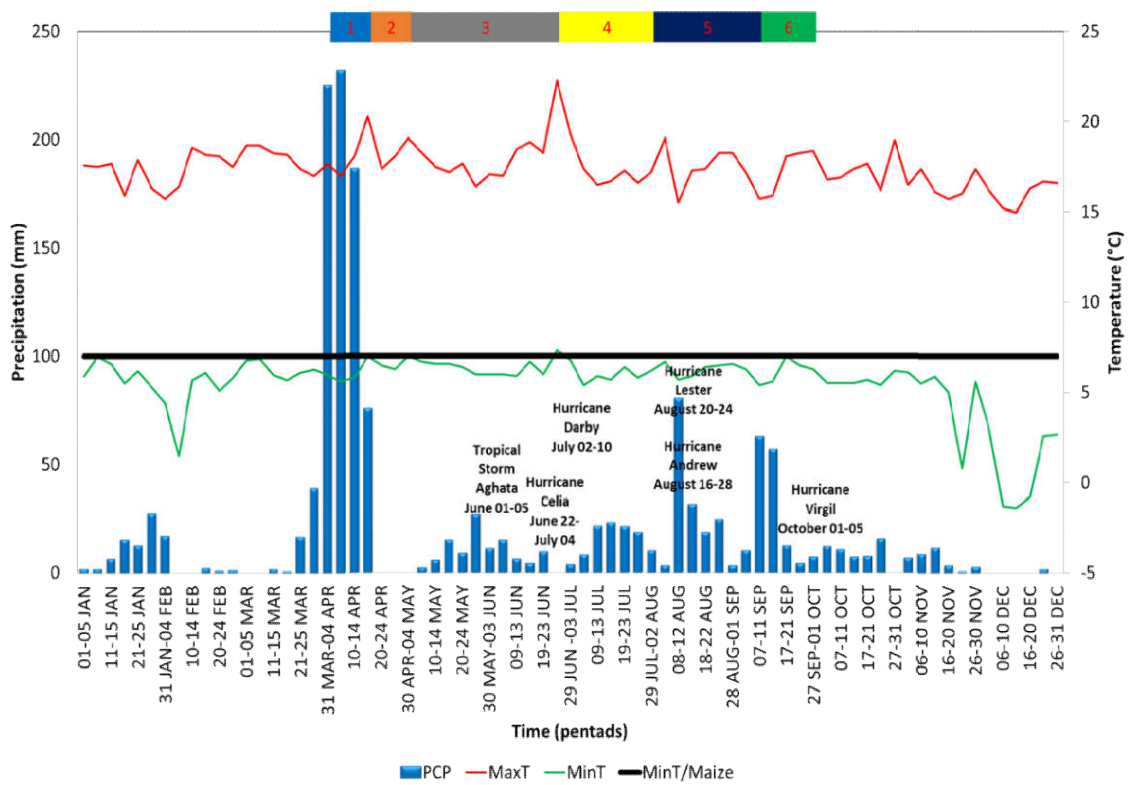


Fig. 5. Variability of rainfall in pentads and temperature in relation to the teleconnection of meteorological events: case 1992

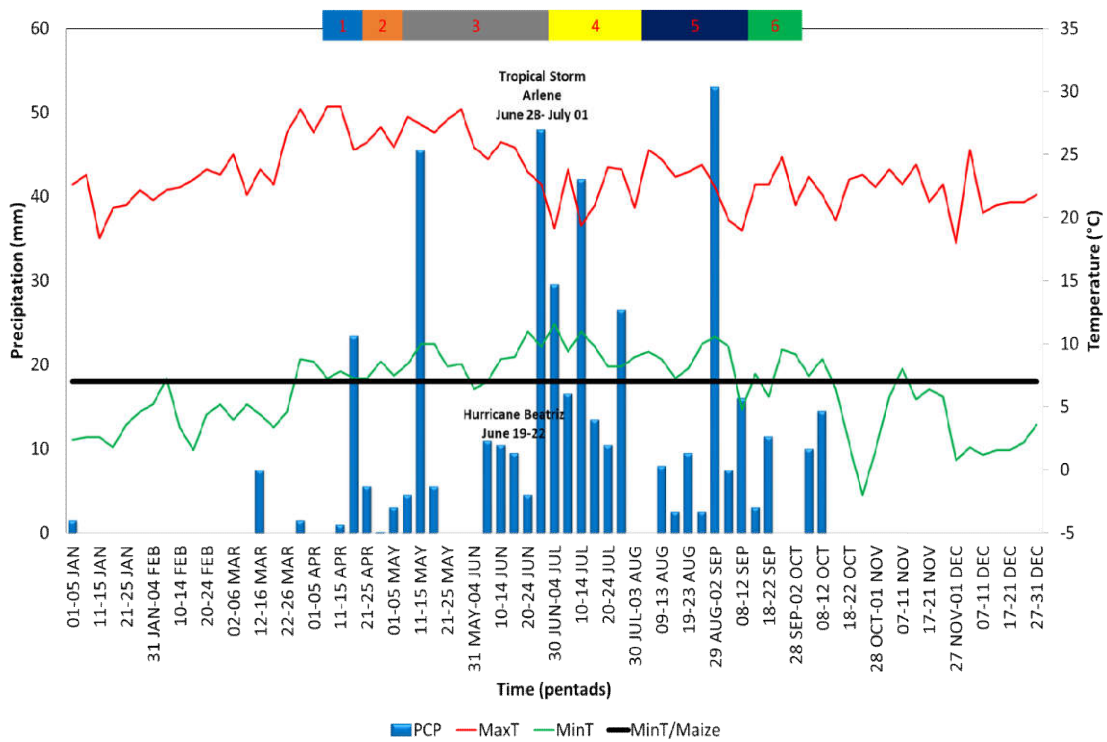


Fig. 6. Variability of rainfall in pentads and temperature in relation to the teleconnection of meteorological events, case: 2011

the annual cycle of tropical cyclone formation. On the other hand, the presence of hurricane BEATRIZ, from June 19 to 22, coincided with little PCP, which was not enough to obtain a good yield, since it was in the phenological stage of plant development. In this year, the problem was not the distribution of the rain, it was the "frost" in September since the first frost is expected at the end of the month or beginning of October, "San Francisco Cordonazo".

In Fig. 7, the case of 2013 is shown. Although it is evident that there is a minimum amount of precipitation during the first three months, the optimal distribution occurs in subsequent months. Meteorological and agronomic frosts are shown in the first three months at the beginning of the year and the last three months at the end of the year. The minimum temperature was at the same level as the base temperature of 7°C, for six months, which was vital to obtain a yield of 3.5 t ha⁻¹. Although the event of the "canícula" (midsummer drought), a period that diminishes - not necessarily- the rain" occurred, the corn crop was not affected. The maximum temperature showed an average of 25°C, reaching maximum temperatures of 28°C, in April and May, at the beginning of October, an energy balance was observed between the maximum and minimum temperatures. The conditions for a good distribution of the rain were remarkable this year, and it is related to EL NIÑO event in a NEUTRAL phase. Atlantic hurricane season in 2013, started with tropical storm BARRY, with a duration from June 17 to 20, which coincided with the PCP pentad, it is likely that it might have contributed to the development of the plant, along with tropical storm FERNAND, from August 25 to 26, which is likely to have favored the phenological stage of corn, it also coincided with the PCP from August 24 to 28, as well as the tropical depression EIGHT from September 6 to September 7. In turn, the hurricane n INGRID, from 12 to 19 September, favored physiological maturity stage. Other events were: Hurricane BARBARA, from May 28 to 30, which did not contribute to the PCP in the analyzed pentads, although it passed through the northeast of the state of Veracruz, Mexico. Hurricane ERICK, from July 4 to 9, coincided with one of the pentads from July 5 to 9.

In Fig. 8, the case of 2018 is shown, where, at the beginning of the year there is no precipitation and at the same time, a minimum amount is presented which is not significant. In mid-March, the precipitation improves, however, at the end of

May and July there is a shortage of rains, so it would be affecting the metabolism of the plant in its growth and development where the main crops of the region stand out: corn and beans. It is important to mention that if the lack of rain continues, drought will affect several hectares. The forty days of the phenomenon known as "canícula" (midsummer drought) are representing a real concern for farmers; high temperatures and lack of rain are not benefiting plants, presenting an annual average of 592 mm of PCP. Weather frosts are shown in January and December, with an average of 6.3°C and the maximum temperature was 22.8°C, both variables do not represent negative impacts for the crop. However, the yield was 2.43 t ha⁻¹, which is considered a regular value, compared to the other case studies in the present investigation. In relation to EL NIÑO event, the phases were: three months of LA NIÑA, six months in a NEUTRAL phase and three months of EL NIÑO. The 2018 Atlantic hurricane season was the third in a consecutive series above average and harmful, with fifteen named storms, eight hurricanes and two major hurricanes (category 3 or greater on the Saffir-Simpson Hurricane Scale). However, none touched Mexico. The 2018 Pacific hurricane season produced the highest value of Cumulative Cyclonic Energy (ACE) in the East Pacific basin registry. The season marked as extremely active above normal since they have reliable records since 1971, it broke a record of Accumulated Cyclonic Energy with 317 units exceeding 26 years ago, also considered the most intense since the 2015 season and was linked with the 1985 season for registering five storms named in the month of June, with a high record. For this case, the tropical storm CARLOTTA in southwest Mexico (Guerrero) was showed up from June 14 to 19, where it coincides with the Pentad of June 10-14 and hurricane JHON category 2, which was presented from 5 to August 10, which is likely to have coincided with the pentad from August 9 to 13.

Fig. 9a shows the frequency of hurricanes, storms, and tropical depressions with respect to the phases of EL NIÑO, NIÑA and NEUTRAL. The statistical test to find associations between hurricanes, tropical storm, and the type of phenomenon (EL NIÑO and LA NIÑA) was Cramer's V with a confidence interval of 95% and an error of 0.05. No statistical association ($p = 0.924$) was found between the events; however, a greater numerical distribution is observed when the NEUTRAL phase predominates in the year

(Fig. 9a). In Fig. 9b. The frequency of hurricanes, storms and tropical depressions is shown considering the case studies. No significant

association was found ($p = 0.902$). However, a greater numerical distribution is observed in 1992 with the NEUTRAL phase predominating.

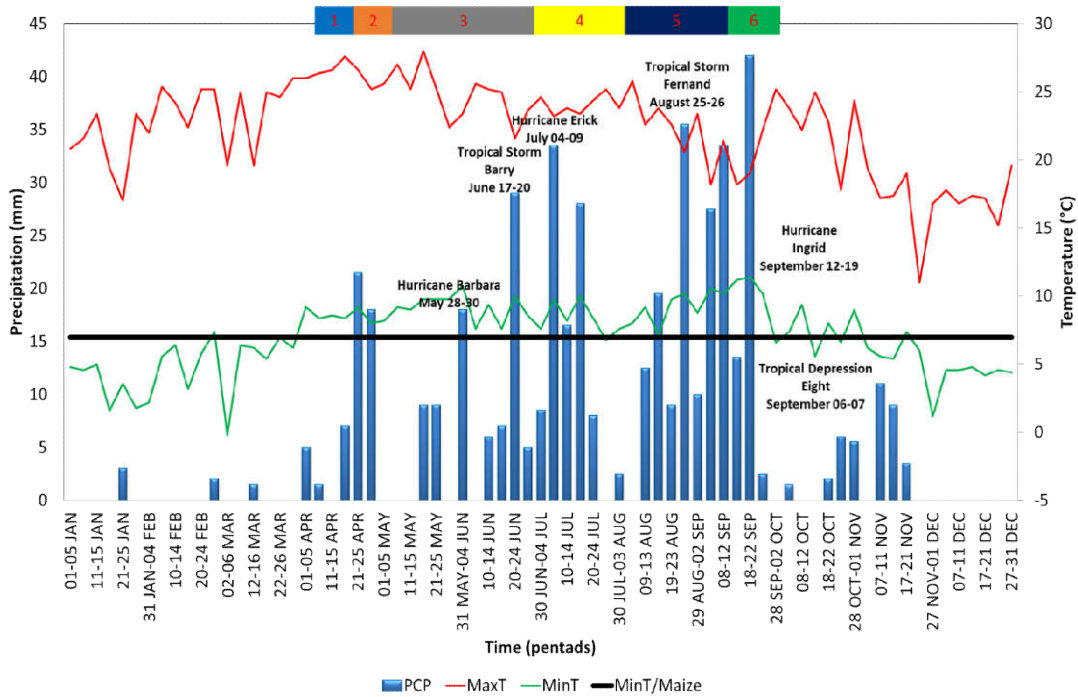


Fig. 7. Variability of rainfall in pentads and temperature in relation to the teleconnection of meteorological events, case: 2013

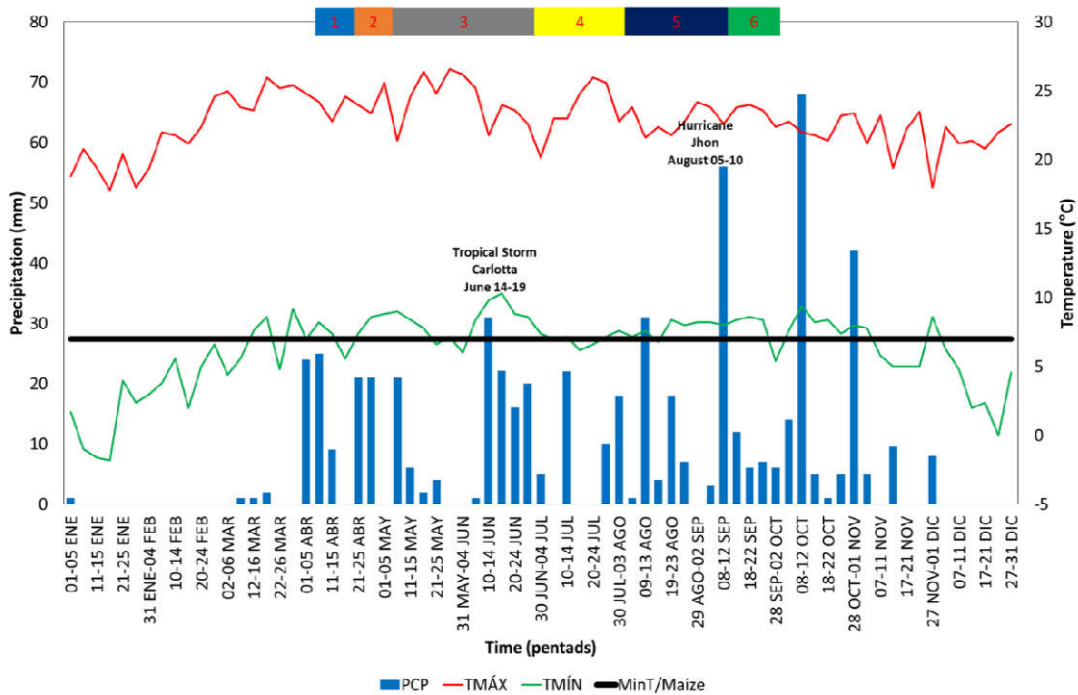


Fig. 8. Variability of rainfall in pentads and temperature in relation to the teleconnection of meteorological events, case: 2018

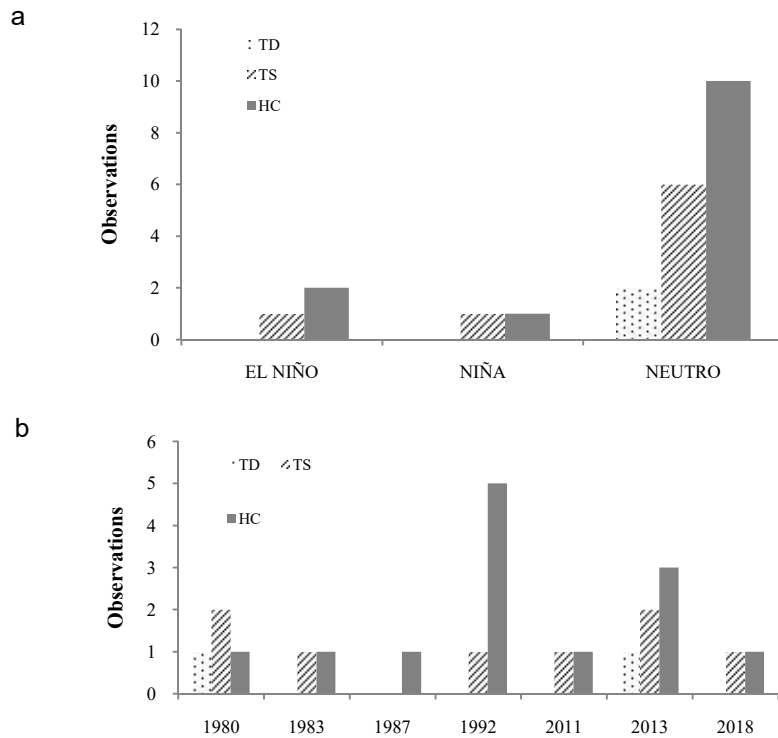


Fig. 9. a and b. Frequencies of hurricanes, storms and tropical depressions regarding the EL NIÑO, LA NIÑA and NEUTRAL phases. Frequency of hurricanes, storms and tropical depressions with respect to the case studies

Note. TD: depresión tropical; TS: tormenta tropical; HC: huracán

4. CONCLUSION

The results show that there is an effect of the teleconnection of meteorological variables, associated with systems, in a region with an altitude gradient, such as the growth cycle of corn, in which it is obviously related to eastern waves and other tropical disturbances. In this sense, it is considered that teleconnections and rain distribution are the main factors in the development of corn. The different phases of ENSO (EL NIÑO Southern Oscillation) have a notorious impact on the distribution and quantity of rainwater, as found in the present investigation. Likewise, other effects were identified, in which the distribution of the minimum temperature threshold throughout the phenology of corn is particularly important to determine the sowing dates with reference to the altitudinal gradient. Despite having an inherent limitation in the number of years of observations, it is necessary to take advantage of the yield-ENSO relationship to estimate a monthly precipitation forecast for the next agricultural cycle, using a method such as that observed and discussed with farmers. This will provide

feedback on scientific and empirical knowledge, in favor of a climate-appropriate agriculture and linked to the country's agricultural policies.

CONSENT

As per international standard or university standard, respondents' written consent has been collected and preserved by the author(s).

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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