

# **Climatic Threat Spaces as a Tool to Assess Current and Future Climate Risks: Case Studies in Mexico and Argentina**

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AIACC Working Paper No. 30  
June 2006

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An electronic publication of the AIACC project available at [www.aiaccproject.org](http://www.aiaccproject.org).

## ***AIACC Working Papers***

Distributed by:  
The AIACC Project Office  
International START Secretariat  
2000 Florida Avenue, NW  
Washington, DC 20009 USA  
[www.aiaccproject.org](http://www.aiaccproject.org)

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The AIACC project is funded by the Global Environment Facility, the Canadian International Development Agency, the U.S. Agency for International Development, and the U.S. Environmental Protection Agency. The project is co-executed on behalf of the United Nations Environment Programme by the global change SysTem for Analysis Research and Training (START) and The Academy of Sciences for the Developing World (TWAS).

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# **Climatic Threat Spaces as a Tool to Assess Current and Future**

## **Climate Risks: Case Studies in Mexico and Argentina<sup>1</sup>**

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### 1. Introduction

Extreme climatic events associated with climate variability have exposed the vulnerability of the human systems to those events (Le Roy, 1991; Jáuregui, 1995; Florescano and Swan, 1995; Stern and Easterling, 1999). In response, these systems have generated different adaptation strategies and measures according to different socioeconomic conditions to cope with climatic events. The economic globalization processes have, on the one hand, extended, in principle, the access to knowledge and technology that can support a wide range of coping capabilities. However, in the developing countries there are also accelerated losses of resources in many social groups and a deterioration of the social organizations that have applied and supported those capabilities. As O'Brian and Leichencko (2000) have stated, climate change and economic globalization are two “external” processes that affect agricultural systems in the developing world.

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<sup>1</sup> The research reported in this paper was supported by grant number LA29 from Assessments of Impacts and Adaptations to Climate Change (AIACC), a project that is funded by the Global Environment Facility, the Canadian International Development Agency, the U.S. Agency for International Development, and the U.S. Environmental Protection Agency and co-executed on behalf of the United Nations Environment Programme and by the Global Change SysTem for Analysis, Research and Training and The Academy of Sciences for the Developing World. Correspondence regarding this paper should be directed to Dr. Cecilia Conde, [conde@servidor.unam.mx](mailto:conde@servidor.unam.mx).

Mexico and Argentina are examples of developing countries that are under the pressure of economic globalization. Current social conditions are such that a relatively small change in normal climatic conditions might trigger important impacts in agricultural activities.

Even though economic global conditions affect both countries, different impacts of similar climatic extreme conditions can be expected in their agricultural sectors. Comparing the different responses and discussing them with farmers, we examine how these differences might enrich our understanding and their own perspectives of the problem.

The present analysis will focus on the vulnerability of the agricultural sector exposed to extreme climatic events in two regions in Argentina and Mexico (Gay et al., 2002<sup>1</sup>): the central region of Veracruz (Mexico) and Roque Sáenz Peña Department (county) (Córdoba Province, Argentina). Farmers in both countries aim to export most of their agricultural production and are, therefore, highly exposed to climatic and market variations. By means of “climatic threat spaces” we will describe cases in which climatic variables have played a major role in agricultural losses (coffee, maize), as well as cases in which other stressors could have been responsible for losses.

The detection of other stressors—different from climate—that affect agricultural production is particularly important. Changes in agricultural policies or prices, for example, have affected crop production even when climate conditions have been favorable. Historic records of crop production, prices, changes in agricultural policies, expert judgment, and newspaper information, can be used to explain the important decreases in crop production in a particular year.

These threat spaces can help to describe the climatic variability in the regions under study, including the detection of extreme climatic events. The study of climate variability and the analysis of extreme events are important issues in the new generation of climate change studies (see, e.g., Ebi et al., 2005; Downing and Patwardhan, 2005; Conde, 2003), such as those conducted to support the development of the National Communications <sup>2</sup>. In these efforts, the assessment of current vulnerability and adaptation strategies to climatic events are fundamental for the analysis of future conditions. The results presented here can be used as an analysis tool to identify threats and potential opportunities resulting from scenarios of climate change.

## **2. Methods**

Climatic threat spaces (Conde, 2003) are constructed by means of seasonal or monthly scatterplots of precipitation and temperature, similar to those constructed for climate change scenarios (i.e., Hulme and Brown, 1998; Parry, 2002), but for climatic threat spaces, we focus first on current climate anomalies and we use one standard deviation or the interquartile range of the two variables to decide which years could be classified as normal years and which could be considered critical. The one standard deviation criterion is currently used (Gay et al., 2004<sup>b3</sup>) by the Mexican Ministry of Agriculture to give economic support to farmers affected by extreme climatic events (*contingencias climatológicas*). For the case of Mexico, the analysis based on one standard deviation implies for producers the possible economic support from the government given a drought (minus one standard deviation from normal conditions) or flood event (plus one standard deviation from normal conditions). During the cited project (Gay et al., 2004<sup>b3</sup>), the subsecretary that conducted the program acknowledged

the limitations of these criteria and asked for our assistance to change it. However, it is still the criteria used to provide economic assistance. When extreme events occur, the amount given to producers depends on the specific product they are cultivating, that is, the lowest support is given to the rain-fed maize producers and the higher to the fruit producers.

On the other hand, the use of the interquartile range is a more robust method than using the standard deviation, “since this range is generally not sensitive to particular assumptions about the overall nature of the data.” Also, the interquartile range “is a resistant method that is not unduly influenced by a small number of outliers” (22; Wilks, 1995). We can then use this method without considering the shape of the data’s distribution and also be sure that the extreme climatic events (outliers) will not influence the limits of the initial coping range for the analysis of climatic events. Using the quartile range leaves out the 50% of the distribution (25% in each tail) in which extreme values occur. To get a more precise description about the tails of the data, a crossed schematic plot can be used. This type of plot helps classify extreme values with respect to their degree of unusualness. According to Wilks (1995), the unusualness of an extreme value depends on the intrinsic variability of the data in the central part of the sample. If the quartile range is large, then a given extreme value is less unusual; on the other hand, if the quartile range is smaller, it is considered more unusual. Schematic plots classify unusual observations as “inside,” “outside,” and “far out,” through the construction of inner and outer “fences”. Crossed schematic plots provide an objective, robust, and resistant classification for extreme values of paired climatic observations.

Climatic data included in the plots cover a period of more than 30 years, with 1961–1990 as the reference period. Years of extreme conditions in temperature and/or precipitation are selected as potential conditions in which possible extreme events might have affected crop production. Particularly, El Niño or La Niña years are specified in the plot, to visualize the possible effect of strong El Niño/Southern Oscillation (ENSO) years, which have been documented in previous studies (Podesta et al., 2000; Magaña, 1999; Seiler and Vinocur, 2004) in the regions of study. For the purposes of this study, El Niño and La Niña years in the threat spaces are considered when the bimonthly values of the multivariate ENSO index (MEI; <http://www.cdc.noaa.gov/~kew/MEI/>) are above (or below) 1 (or –1). Particular attention is given to the strongest ENSO events since 1950.

The quartile range for the climatic variables is considered as a first approximation for the limits of the coping range for agricultural activities. The hypothesis is that normal climatic conditions (with respect to 1961–1990) should be within the optimal or near-optimal conditions for crop production in the regions under study and that small variations around that average can be tolerable for the system. Most of the crop models used to analyze the crops' sensitivity to climate are based on this hypothesis (i.e., Baier, 1977; Jones and Kiniry, 1986).

Optimal conditions for a specific crop can be described in the threat space to help determine whether the region provides optimal or near-optimal conditions or whether the climatic circumstances represent an important threat for that particular production. The coping range's boundaries, which were defined initially in terms of statistical measures, could then be redefined in terms of the climatic requirements for the specific crop.

A series of crop production years are analyzed, and years showing relevant decreases or increases are searched within the threat space for a potentially responsible climatic factor. Years with extreme climatic conditions are expected to have an impact on agricultural yields and production. The climatic anomalies during these years can be identified as one of the possible stressors when negative changes in the expected production are found. These results can illustrate the relative weight of climate in the current vulnerability of producers in the regions under study.

Even if the decreases in production were important for a given critical year, other stressors besides climate could have contributed to this, so the “story” must be traced from different sources: historic records of prices and of changes in agricultural policies, rural studies (Eakin, 2002), in-depth interviews and focus group discussions with producers in the region (Gay, et al, 2002 <sup>1</sup>; Maurutto et al., 2004 <sup>4</sup>), newspaper articles (i.e. Martínez, 2002 <sup>5</sup>; La Red, 2004) and other secondary sources of information. Special care should be taken regarding some environmental factors such as soils and pests, which are complexly related to climatic variations. In any case, all of these factors should be part of the “story” that must be documented to decide the weight of climatological factors on agricultural production. The threat spaces do not address such issues, since they are just a tool to construct the relevant initial questions in a study of vulnerability to climate variability and change.

When climatic conditions were favorable but important losses occurred, other stressors could be considered as potential causes. The different sources of information stated above are decisive in understanding which factors could be considered as the main

determinants in farmers' reduced adaptive capacity, that is, the increase in farmers' vulnerability.

In summary, threat spaces seen under the scope of the specific crop requirements, can be used as a tool to assess the current vulnerability of agricultural production to extreme climatic extreme events (drought, floods, frosts, heat waves) in a particular region.

In light of these results, the climatic threat associated with climate change scenarios can be evaluated. Climate change scenarios were constructed using the Model for the Assessment of Greenhouse Gas-Induced Climate Change and a Scenario Generator (Magicc/Scengen Model; version 4.1) (Wigley, 2003; Hulme et al., 2000). The outputs of three general circulation models (GCMs) obtained from Magicc/Scengen were used: EH4TR98, GFDLTR90, and HAD3TR00, considering the two emission scenarios A2 and B2 (Nakicenovic et al., 2000; Intergovernmental Panel for Climate Change (IPCC), Working Group III, 2001), and for the years 2020 and 2050. Simple interpolation methods have been applied to obtain the possible changes in the mean temperature and precipitation values for specific locations (Sánchez et al., 2004<sup>6</sup>; Palma, 2004).

Changes in temperature and precipitation obtained from the outputs of each model are introduced into the threat spaces that were constructed to assess current vulnerability, in order to visualize possible future climatic threat conditions and to analyze future vulnerability to climate change. When the anomalies for both variables are outside the limits of the coping range defined above, the climate scenario is considered to increase importantly the climatic threat and therefore is relevant in terms of assessing

vulnerability and for developing adaptation strategies for the agricultural activities in the region.

The above does not imply that the other climate change scenarios with values within the coping range should be discarded in the future threat analysis. The changes obtained from the climate change scenarios only relate to changes in the means of the variables, and consideration should be given to the distribution (variability) of the mean. A simple approach to visualize the possible changes in variability is to suppose that the other parameters of the distribution of the data will not change and the distribution will be transposed to the new mean without altering its shape. The changes in the frequency of extreme events can be used to describe the possible increase in climatic threat.

Another approach to include variability in climate change threat spaces is to draw schematic plots constructed with observed data around the future mean value, providing a plot of future minimum, lower quartile, median, upper quartile, and maximum.

Therefore, the probability of having climatic events outside the coping range of a given crop (or activity) can be estimated. Although these methods are based on the assumption that current and future variability are the same, they can provide a rough scenario of future variability that can be helpful for stakeholders and decision makers to visualize that, although the new mean can still be inside the coping range, a large part of the distribution can turn out to be outside. Further analysis should be made to consider the possible changes in climatic variability associated with the change in the climatic means and changes in extreme events. This is important when climate change scenarios are communicated to producers and to decision and policy makers. The method described in this work could be applied to initiate participatory techniques of coping strategies (i.e.,

Jones, 2000a, b; Jones and Boer, 2005; Jones and Mearns, 2005; Conde and Lonsdale, 2005).

### **3. Study Cases**

#### **3.1 Case Study: Coffee Production in Veracruz, Mexico**

Agriculture is an important economic activity in the state of Veracruz, generating 7.9% of the state's gross domestic product (GDP) and providing jobs to 31.7% of the state's labor force (Gay et al., 2004). In 2000, coffee production was developed in 153,000 hectares and involved 67,000 producers; also, 95% of the coffee produced was exported, with a production value of 151.1 million dollars (Gay et al, 2004a).

Veracruz is the second largest coffee producer in the country. Coffee plantations in the state are relatively recent, becoming an important agricultural activity in the 1940s and 1950s, particularly because of the good prices after World War II (Bartra, 1999). Until the 1980s, governmental policies led to an increase of nearly 75% of the production and a duplication of the number of coffee producers in the country, most of them with plantations of less than 10 Ha. Currently, most of these coffee producers are suffering the consequences of the 1989–1994 “megacrisis” (Bartra, 1999) of coffee prices, a situation that prevails until today. Since that period, international prices of coffee have been decreasing; the coffee market is saturated with production (caused by overproduction and high level of coffee stocks in consumer countries). Another factor that makes it more difficult for coffee producers in Mexico is that Vietnamese coffee is now being imported, and this has affected the producer's competitiveness within the national coffee markets. Even if the quality of that coffee is very low compared to the Mexican product, it is

preferred by some processing industries. These conditions have exacerbated poverty in the state: in the year 2000, about half of the municipalities were classified as under very high and high poverty levels<sup>7</sup>.

Veracruz (Figure 1) is one of the largest states, located in the Gulf of Mexico, between Tamaulipas and Tabasco. The region under study is situated in the central region of the state of Veracruz, between latitudes 18° 30' and 20° 15' north, and longitudes 95° 30' and 97° 30' west. It occupies an area of about 183,600 km<sup>2</sup> (Palma, 2004), with high altitudes where coffee production can be developed in almost optimal conditions, and it contributes about 90% of the total production of coffee in the state (Araujo and Martínez, 2001<sup>8</sup>).

The analysis of climatic data has led to the conclusion that the central region of Veracruz can be analyzed as a single region, considering that the precipitation and temperature regimes (depending on altitude) are similar in some of the counties or *municipios* (Douglas, 1993<sup>9</sup>; Palma, 2004). This fact simplified the climatic studies and was also useful for the development of climate change scenarios.

Coffee producers have been very concerned about the low international prices and the lack of governmental support since the 1990s (Bartra, 1999). Also, the historic records of great losses and results from a recent study (Gay et al., 2004) show that changes in temperature and precipitation have severely affected coffee production. In terms of current vulnerability, the lack of awareness of climatic threats could increase vulnerability, and the reduction in technical support can reduce the response capacity of the producers to adverse climatic events.

For coffee production the optimum average annual temperature range<sup>10</sup> is from 17 to 24 °C, and the optimal yearly precipitation is between 1500 and 2500 mm (Nolasco, 1985). These climatic conditions are observed in Teocelo, Veracruz, located at latitude 19°38' N, longitude 96°97' W, at a height of about 1218 m above sea level. It has a mean annual temperature of 19.5°C and an annual precipitation of 2046.9 mm, which are within the optimal ranges for coffee production (Nolasco, 1985). However, seasonal analyses must be developed and related to the specific requirements at the different stages of the plant development. Because coffee is being produced at near-optimal conditions, it is reasonable to expect that the boundaries of the coping climatic range are nearly equal to those delimited by the quartile range, determined with the climatological conditions of Teocelo, Veracruz (Figure 2).

Regarding specific requirements for crop development, coffee requires dry weather just before flowering. Particularly, during spring (March, April, May: MAM), a small decrease in precipitation or “relative drought” during one or two months (Nolasco, 1985; Castillo et al., 1997) is considered optimal for coffee flowering. Figure 2 shows this condition for the month of April in Teocelo. One expert in the region<sup>11</sup> informed us that without this small decrease, “the flower becomes leaves” meaning that the excess of rain could damage the flowering process.

During winter and spring, frost could reduce coffee production, so minimum temperature is the variable that must be analyzed for those two seasons, combined with the possible changes in precipitation. For summer, maximum temperature and precipitation are the two variables that must be considered for the analysis of possible heat waves, drought, or floods that could affect the development and maturity of the

coffee cherry. During autumn, the coffee fruits undergo development and maturing, so climatic extreme events and pests are the two factors that can damage them.

The analysis of the importance of the selection of these seasonal variables will be described below, but in a previous research (Gay et al., 2004), a statistical analysis showed that the relevant variables to include in a regression equation to model coffee production were summer and winter temperature and spring precipitation.

Environmental conditions in the coffee plantations are complex, as they are developed using the shade of diverse trees. For example, excess humidity usually increases the danger of pests in the plantations (Castillo et al., 1997). When relative humidity and temperatures are high, pest like “Roya”, (*Hemidileia vastatrix*) and “minador de la hoja” (*Leucoptera coffeella*) can damage coffee plantations. Other pests, such as “escamas” (*Saisrta spp*, *Coccus spp*), which clearly damage the coffee in the region, thrive during drought conditions. Governmental support to cope with these pests or other environmental factors has been reduced critically, as surveys have shown, particularly after the “megacrisis” ( Castellanos et al, 2003 <sup>12</sup>, Eakin et al., 2005).

Harvesting occurs during the end of autumn, winter, and the beginning of spring. Climatic conditions could affect those labor activities; particularly, during strong El Niño events, colder and wetter conditions in winter could prevent producers from reaching the coffee plants that are located far into the forests or at higher altitudes.

The effects of climatic events on coffee agrosystems in Mexico are difficult to detect, because this system is classified as rustic, immersed in a complex forest ecosystem that makes coffee plants quite resilient to climatic variations (Nolasco, 1985). For that reason, the anomalies reported for the extreme climatic events that have severely

affected coffee production in the past will be taken as the thresholds to determine current and future climatic threats, and for which the system is more vulnerable (Figure 2).

The decrease in April rains must not be associated with a drought period during spring. Several spring droughts, especially during strong El Niño events, have severely affected coffee production in the region (Martínez, 2002<sup>4</sup>, La Red, 2004<sup>13</sup>), particularly during May 1970, May 1983, and May 1998. In Figure 3A, spring anomalies for minimum temperature and precipitation are shown for Atzalan, Veracruz (19° 80'N, -97° 22' W, 1842 m above sea level), also located in the same region, but with more reliable and complete data series (Bravo et al., 2005).

The effects of drought conditions in spring during El Niño years are well documented in Mexico (Magaña, 1999; Conde et al., 1999), since it is one of the climatic events that producers are more concerned with (Castellanos, 2003<sup>12</sup>). The average reduction in expected precipitation in 1970, 1983, and 1998 was below 60% in the region under study. Important losses of 25% and 17% in coffee production occurred in Veracruz in 1970 and 1998, respectively (Figure 4). Several plantations in the study area were severely affected, so the lower limit of a possible coping range in regard to spring precipitation will be fixed at that level (-60%).

The temperature anomaly for spring of 1970 was a “mixed” signal, since during April, temperature rose to more than 40°C, but during May, after the intense heat wave, one of the worst frosts affected the region. Thus, the combination of high temperatures and very low precipitation during April, and then the very intense frost with still a drought condition during May, caused great damages in coffee production, (see data for 1970, in Figures 3A and 4). That frost damaged the quantity and quality of coffee that

was expected to be exported (La Red, 2004<sup>14</sup>). One interesting feature that can be seen in the spring threat space (and also in the winter threat space, not presented in this work), is that in the 1960s and 1970s, frost events were more frequent than in the 1980s and 1990s. However, an extremely damaging frost occurred by the end of 1989, so even less frequent, the decrease in the intensity of those events cannot be confidently established. The frost event described above occurred on several days, so the seasonal averages used in the threat spaces might obscure such climatic events (i.e., frost, heavy rains). This is a limitation of the seasonal threat spaces that cannot substitute for the analysis of daily data to study the behavior of those extreme climatic events. However, on the basis of the other sources of information (interviews in depth with regional experts, or the newspaper articles), a specific search for those events can be developed.

Considering the requirements for coffee with respect to precipitation and minimum temperature, the threat space for spring (M, March, A, April, M, May) should include those cases in which minimum temperature could be below 10°C, when the coffee plant can be damaged (Castillo et al., 1997). This means that anomalies of  $\leq -2^{\circ}\text{C}$  during spring lie in the threat space for coffee in Veracruz (Figure 3B). No limitation is depicted for an increase in minimum temperature, because even  $+3^{\circ}\text{C}$  is within the range of optimal requirements.

Previous drought conditions in 1983 and 1998 damaged coffee plants; thus the lower boundary should be established in  $-50\%$  of the normal conditions (300 mm). Precipitation should not exceed  $+50\%$ , as in that case the relative drought that the coffee requires could be diminished or not be present. Also, excess rain could affect the plant and soil conditions by favoring the spread of pests.

A threat space that considers the anomalies for *maximum temperature* and precipitation (not shown) shows possible combinations of climatic threats that could occur when anomalies for maximum temperature are greater than +1.5°C, combined with a 20% reduction in precipitation, a situation that occurred in 1975 (when almost half the coffee production was lost in the central region of Veracruz (Figure 4). The greater losses in other years were caused by other stressors, different from climatic extreme events, such as changes in the political or economical conditions (Figure 4).

Adverse climatic conditions during spring could increase the sensitivity of the coffee plants and its environment, so in the subsequent seasons changes in climatic conditions (even inside the coping range) could cause damages. This issue is not discussed here, but it is certainly one important element in the ecological study of this agrosystem.

Summer (June, July, August: JJA) precipitation is quite high in the central region of Veracruz (more than 900 mm in Teocelo and Atzalan, for example). Nevertheless, exceeding the optimal limit for coffee can cause important damages through flooding or severe storms (Figure 5). Such floods were recorded in 1970, 1973, 1996, 1997, and 1981 (La Red, 2004<sup>15</sup>; Martínez, 2002<sup>16</sup>).

Strong ENSO years, might be associated with important drought periods, like the episodes that occurred in 1982, 1989, and 1997. This is also associated with an increase in maximum temperature, such as the ones that occurred in 1982 and 1991 (see Figure 5). Significant losses in production could be attributed to these events, such as the 30% loss in production in 1982 and the 36% loss recorded in 1989. However, 1989 was a critical

year for coffee production, since the climatic events during summer and winter coincided with the economic “megacrisis” that occurred for the coffee production in Mexico.

To produce a good coffee crop, it is necessary that no more than 30% of excess of rain should fall during summer (1,150 mm), since the upper optimal annual limit (2,000 mm) could be easily surpassed, considering the amount of rain in the other seasons. Similar arguments can be stated for decreases in precipitation, and the lower limit could be –40% of the normal conditions, like the ones that occurred during 1982 and 1989.

Another interesting issue that can be seen in the climatic threat spaces is that there were years when climatic conditions inside the box characterized normal conditions (e.g. 1992, 1993, Figure 4) and yet resulted in important losses in coffee production in Veracruz, as well as throughout Mexico. For these cases, precise studies should be developed to analyze in greater detail monthly and daily data distributions, identifying possible extreme events that were lost in the seasonal average. If no important climatic signal is detected, then it is highly probable that other stressors impacted the coffee system. This is an important use of the threat spaces, because they could be used as a tool to assess the importance of climate in production losses. Similar analyses as the one described above could be developed for autumn and winter seasons.

The extreme climatic events described above can be an important element in explaining the anomalies in coffee production in the State of Veracruz and in Mexico (Figure 4). In 1989, the governmental institute (Instituto Mexicano del Café; INMECAFE) that regulated the coffee prices and market was abolished. This event and the severe frost that affected Veracruz central region during 1989 are two important stressors that have contributed to the reduction in coffee production in the region. Before

1989, coffee producers began to substitute coffee plantations for sugar plantations, “tired of promises of good coffee prices”. Trees that gave shade to the coffee plant (like *chinines*, *chalahutes*, *abines*<sup>17</sup>), were cleared, causing severe ecological damage (La Red, 2004<sup>18</sup>). In 1989, the coffee prices were very low and adversely affected coffee production regionally and nationally (Figure 4). The tendency to switch from coffee to sugar cane has persisted and has intensified in Veracruz, even when the total production of coffee has increased in the region. In ecological terms, this tendency can be seen as an irreversible process. Also, the abandonment of the agro-ecosystem caused by the low coffee prices and the occurrences of extreme climatic events described above, could be responsible for the spread of pests (like “broca”, *Hypothenemus hampei*), which is an important environmental stressor in plantations in the lower altitudes. In 1971, 1982, and 1998, there were significant losses in coffee production in Veracruz, while the national production increased (see Figure 4). These conditions can be related to the extreme climatic events discussed earlier. It can be stated that for those years, climatic events played a major role in these losses.

Such climatic events exemplify the possible climatic threats that coffee producers will face in the future. Earlier surveys that have examined coffee producers’ perceptions of climate show that the most worrisome climatic events are associated with drought, heat waves, strong winds, and frosts, and they attributed most of their losses to these events (Gay et al., 2004a; Eakin and Martinez, 2003<sup>19</sup>; Castellanos et al., 2003<sup>12</sup>). A low perception of climatic threats might increase the vulnerability of producers to extreme climatic events. It is important to consider that coffee farmers did not find climate as a relevant variable in their activity as much as the economical factors. However, care

should be taken when interpreting the results of perceptions of climatic threat obtained from a survey, as the respondents could be biased by recent climatic events.

Nevertheless, these data are a very important source of information to base decisions about which events must be documented and defined with the stakeholders (i.e., what does “heat” mean? Is it associated with drought? Has the intensity of the frost events decreased in the last decade?).

As has been noted earlier, coffee development is highly correlated with climate variability, with spring precipitation and summer and winter temperatures being the most relevant climatic variables (Gay et al., 2004). This conclusion is also supported by newspaper sources. While the construction of threat spaces and the search for climatic events in newspaper articles were performed simultaneously, regression analysis and fieldwork were performed separately, but the conclusions were quite similar.

### **3.2 Case Study: Maize Production in Roque Sáenz Peña County, Argentina**

Argentina is an agro-exporter country with most of the agricultural production based on “the pampas,” one of the worlds’ major agricultural regions. The Córdoba province is situated in the center of the country and ranked fifth in size among all the Argentine provinces. Eighty three percent of its surface is dedicated to different agricultural activities developed under variable edapho-climatic conditions from soils that have no limitations, compared to other soil types, which can only be used for livestock production.

Córdoba contributes approximately 14% of the national agricultural GDP, 14% of the national livestock, 17% of the cereal, and 25% of the national oilseed production. The

agri-food and agroindustrial systems are the most dynamic and most important economic sectors in the economy, representing 25% of the state gross geographical product<sup>20</sup> (Instituto Nacional de Tecnología Agropecuaria (INTA), 2002). This province is the second largest maize producer in the country, contributing about 32% of the total national production ( Secretaría de Agricultura, Ganadería, Pesca y Alimentos de la República de Argentina, SAGPyA, 2004).

The research area was the southern half of the province of Córdoba, including eight departments (political divisions, counties). For this case study, the city of Laboulaye (34° 08'S, 63° 14'W), situated in the Presidente Roque Saénz Peña County, was selected for the analysis (Figure 6). The area is flood prone and is typical of the poorly drained plains in the south of Córdoba Province, characterized as a semiarid-subhumid temperate area (INTA, 1987).

Annual mean precipitation is 845 mm (1961–1990). Most of the precipitation is concentrated during the warm period (October to March). Seasonal distribution shows that 28.5% of the rain occurs in the fall season, 38.4 % in the summer, 26.4% in spring, and only 6.7 % in winter. Mean annual temperature is 16.3°C, with the month of July being the coldest (8.8°C) and January the warmest (23.7°C). Mean annual precipitation and maximum and minimum temperatures are shown in Figure 7.

Climate and its variability are major factors driving the dynamics of the agricultural production in the area. Inter-annual and inter- seasonal climatic fluctuations result in high variability in crop production affecting negatively the local and regional economy. Floods and droughts with different frequencies, intensity, and extent alternate in occurrence in the area. Floods are caused mainly by excess rainfall in the flood-prone

basin and by the overflowing of rivers and streams. Additional factors (some of them human-induced) such as soil saturation, volume of runoff, physical characteristics of the area (soil type, size of the flood zone, topographic relief), control structures, and management characteristics, also play a significant role in the occurrence of the phenomenon (Seiler et al., 2002).

Besides the climatic and soil characteristics, ethnographic research (surveys, in-depth interviews, focus groups meetings, etc.), involving key regional and local actors, with the active participation of farmers, government officials, cooperative managers, and others, informs us of the perception of climate threats and the importance of climate in particular aspects of agricultural decision making. Farmers are always aware of the effect of climate on their activities, but they have a “naturalized” perception of climate, as it is a part of their daily life, which relates to their living reality and to their historical past (Maurutto et al., 2003; Maurutto, M. C., unpublished data). Farmers identified droughts, floods, and hailstorms as the most important events affecting their activities, flood being the threat that causes the most damages (Rivarola et al., 2002; Vinocur et al., 2004).

Maize requires air temperatures between 10°C and 34°C during the growing period, with different thresholds depending of the stage of the crop in the growing cycle (Andrade et al., 1996, Andrade and Sadras, 2002). High temperatures during plant germination to flowering could shorten the period of development, as the thermal time required by the crop for flowering is completed earlier. This will result in a shorter time for the interception of solar radiation, which could result in yield reduction (Andrade, 1992). Water requirements for maize are around 450–550 mm during the crop cycle. Water shortage is very critical during the period from 15 days before flowering to 21

days after flowering. During this period, the number of grains per square meter, which is the principal component of the yield in this crop, is determined (Uhart et al., 1996). The magnitude of the yield losses depends on the time of occurrence and the intensity and the duration of the water stress. Because the probability of water stress is higher in January, the time of planting becomes important to cause the flowering of the crop to happen before December 15th of the previous year.

Precipitation and maximum temperatures anomalies for summer (D, December; J, January; and F, February) for the area under study are shown in Figure 8. We selected the summer season to explain maize yield because the principal components of the crop's yield are determined during this season. Temperature and precipitation values during the summer are also determinant factors as explained above. The box in Figure 8 represents values of the interquartile range for maximum temperature and rainfall for the 1961–1990 period. The anomalies of rainfall and maximum temperature can be related to maize yield deviations from the linear trend (Figure 9) to identify events that might cause yield reduction or surplus.

Yields above the trend of the crop yield series 1961–1990 (linear regression,  $R^2 = 0.68$ ,  $P < 0.00001$ ) were found for different crop seasons (e.g., 1961–1967, 1973–1974, 1992–1995, etc.). If a coping range of one standard deviation from the trend is established ( $SD = \pm 26.2\%$ ), maize yields exceeded this threshold in 1962, 1963, 1964, 1978, 1982, and 1998 crop seasons (Figure 9, 1962 = 1961–1962 crop season). Three of these seasons (1998, 1982, and 1978) were identified in the risk space (see 77, 81, and 97 in Figure 8) as a result of high rainfall anomalies during the summer, although yields were also above the trend, indicating that exceeding this threshold does not imply yield

losses. Crop yield during the crop seasons of 1969, 1972, 1976, 1980, 1990, and 1997 was below the one standard deviation threshold (Figure 9). Some of these seasons can be identified in the risk space due to low rainfall and high maximum temperatures (Figure 9, e.g., 71, 89). Although a discussion about the effects of La Niña/El Niño events is outside the scope of this paper, it is interesting to point out that some of the years characterized by high/low rainfall anomalies during summer and high/low yields coincide with El Niño/La Niña events (e.g., 1971–1972, 1988–1989, 1997–1998). In this region, precipitation tends to be low from October to December in cold events (La Niña) and high from November to January during warm events (El Niño) (see Magrin et al., 1998) coinciding with the critical period of the maize crop when the grain number is determined.

Extreme events like floods and droughts were documented in the area (*Diario (newspaper) La Comuna, Laboulaye, Diario (newspaper) Puntal, Río Cuarto, Holguín de Roza, 1986*). Severe droughts were recorded in February 1967, June 1988, and during 1989<sup>21</sup> (La Niña events) causing decreases in maize yield (Figure 9). Flood events were documented in 1979 (from January to August) in 1986–1987 (from May 1986 to June 1987) and in 1998–1999 (from March 1998 to May of 1999)<sup>22</sup> (see Holguín de Roza, 1986). The 1986–1987 flood event (also an El Niño event) resulted in significant maize yield reductions among other adverse effects in the region (Figure 9). Heat waves or unusual frost events were not documented for the area during this period of analysis.

Representing the anomalies for summer precipitation and maximum temperatures, we identified events that exceed normal values, depicting a risk space for maize for Laboulaye. When rainfall anomalies are below 30% and maximum temperature

anomalies are above 1.5°C, important yield decreases are found (e.g. 1971–1972, 1967–1968, 1988–1989 crop seasons (Figures 8 and 9). In contrast, when the summer precipitation anomaly is above the quartile threshold and the maximum temperature is below that threshold, events are located in the upper left portion of Figure 8. These conditions do not affect maize yield, indicating that scenarios tending toward these conditions, at least for the summer, will be harmless for maize. Finally, there are few examples of years with conditions of those of the upper right corner of Figure 8 (summer precipitation and temperatures above the quartile threshold), so we are not able to assess their effects on maize yield and production.

#### **4. Climate Change Scenarios for México**

As stated in the introduction, climate change scenarios were constructed for 2020 and 2050 using MAGICC/SCENGEN model version 4.1 (Wigley, 2003; Hulme et al., 2000). The outputs of the EH4TR98, GFDLTR90, and HAD3TR00 models were used under A2 and B2 emission scenarios (Nakicenovic et al., 2000). Simple interpolation methods (Sánchez et al., 2004) and a downscaling technique (Palma, 2004) have been applied to obtain the possible changes for specific locations. The results obtained were also compared with those shown in the IPCC Data Distribution Center (<http://ipcc-ddc.cru.uea.ac.uk/>) and with the ones in the Canadian Institute for Climate Studies (<http://www.cics.uvic.ca/scenarios/data/select.cgi>).

The EH4TR98 model (German Climate Research Center /Hamburg Model) model and the HAD3TR00 model from the Hadley Center provided the best approximations to the observed climate for Mexico (Morales and Magaña, 2003<sup>23</sup>; Conde, 2003). The GFDL (U.S. Geophysical Fluid Dynamics Laboratory) model is also

used to generate climate change scenarios, since it has been also used in previous research (Gay, 2000) in Mexico.

Discussion of the specific techniques (Conde, 2003) applied and the considerations made to construct the base and the climate change scenarios are outside the scope of this paper. However, the results from that work will be used to illustrate the usefulness of the climatic threat spaces discussed above (Conde, 2003, Conde et al., 2004).

Using the month of July to illustrate climate changes for summer, Figures 10A and 10B show the possible changes in temperature and precipitation for the central region of Veracruz. Considering all the GCMs outputs, the projected changes range from 0.9°C in 2020 to 2.7 °C in 2050. The projected changes in precipitation range from a decrease of 29% to an increase of 42%, depending on the year and model used.

These ranges open the question of what combinations of temperature and precipitation could represent a climatic threat in the future. Also, it is important that the key stakeholders in the region decide which combinations of temperature and precipitation have represented threats in the past for their specific region and their specific activity.

The changes in temperature and precipitation for each scenario could be introduced in threat spaces described in the previous sections. When the anomalies for both variables are outside the limits of the coping range (Figure 11), the climate scenario is considered to increase climate threat importantly in the future, and therefore special attention should be paid to it in terms of assessing potential future impacts to agricultural activities in the regions.

In July, the limits of the threat space (not shown in the previous discussion, but similar to those for summer) for coffee production are related to precipitation and to maximum temperature. In this case, the proposed coping range must not exceed an increase of 30% or a decrease of 40% for precipitation and must not exceed a change in maximum temperature of 1.5°C (Figure 11).

Considering the previous analysis, the projected changes from the ECHAM4 (A2 and B2) and GFDL (B2) models are within the coping range. The projected changes for the Hadley model, in the emission scenario A2 (H\_A2, Figure 11) are in the threat space, implying possible important decreases in production, considering the historic impacts and the current climatic threat spaces.

However, if climate variability is considered to follow the distribution of the observed data, then even the scenarios that are within the coping range could represent a climatic threat. As an example, if the ECHAM4 (E\_A2 and E\_B2) scenarios are considered, which are in the coping range (Figure 11), instead of having two years (5%) with temperatures over or equal to 30°C as the observed data show, there could be 4 years (11%) that could exceed that upper limit (Figure 12). This shows that areas not threatened now could be threatened in the future, so these scenarios should be taken into account for future vulnerability studies.

According to the models' projections for the climatic mean values, a relocation of the observed minimum, lower quartile, median, upper quartile, and maximum values can be performed, providing a scenario of possible changes in climate variability. Each marker in Figure 13 represents different means and variability in temperature (horizontal lines) and precipitation (vertical lines). The dotted line shows current mean and

variability (TO and PO), and all of the other markers are future scenarios, for the emission scenario A2. The box represents the coping range for July (Figure 11), and it is used to illustrate how, once a variability scenario is provided, relatively small and moderate changes in mean can imply important changes in the probability of adverse conditions for a specific crop. These changes in probability could be interpreted as changes in the viability of a certain crop (or activity) given climate change conditions. It also reveals the possible increase in future vulnerability of the coffee producers to climatic hazards.

The results obtained with regression equations constructed in previous work (Gay et al., 2004), which relate climate and economic variables with coffee production, show the most important decreases might occur when the projected changes in spring, summer, and winter precipitation are considered. The regression parameters derived are presented in equation 1.

$$P_{coffee} = -35965262 + 2296270(T_{summ}) - 46298.67(T_{summ})^2 + 658.01618(P_{spr}) + 813976.3(T_{win}) - 20318.27(T_{win})^2 - 3549.71(MINWAGE) \quad (1)$$

where

$P_{coffee}$  = projected changes in coffee production,

$T_{summ}$  = mean summer temperature,

$T_{win}$  = mean winter temperature,

$P_{spr}$  = mean spring precipitation, and

MINWAGE = the real minimum wage.

Considering that optimal temperatures for coffee in the summer and winter are 24.8°C and 20.0°C, respectively, and that the mean precipitation for spring is ~81 mm,

the expected production of coffee in the central region of Veracruz is 549,158.4 tons. Considering that the changes in those variables could be represented by the scenarios for April, July, and January, a decrease of 9% to 13% in coffee production could be expected in the year 2020.

### **5. Climate Change Scenarios for Argentina.**

The same models and methodology were applied to develop climate change scenarios for Argentina. The results show minor increases in temperature, compared to the Mexican study case. The likely changes in temperature and precipitation for Laboulaye in January are shown in Figures 14*A* and 14*B*. The projected changes in precipitation range from decreases of  $-0.7\%$  to  $-4\%$ , while the projected changes in temperature range from  $0.2^{\circ}\text{C}$  to  $1.5^{\circ}\text{C}$ , depending on the model used.

Those changes are consistent with the ones found by other authors (Ruosteenoja et al., 2003) for the southern South America (2010–2039), ranging from  $-3\%$  to  $+5\%$  in precipitation during summer (December, January, February, or DJF) and an increase of about  $1^{\circ}\text{C}$  in temperature for the same season.

Even if the increase in temperature is minimal ( $+0.33^{\circ}\text{C}$  as projected by the ECHAM4 scenario for 2020 for January), the changes in extreme events should be considered. If the distribution of values of maximum temperature is considered to prevail under climate change conditions, the frequency of extreme values for that variable might increase. The situation in Laboulaye is depicted in Figure 15 with two events with maximum temperature above  $34.0^{\circ}\text{C}$  ( $4.3\%$ ) in the base year that could increase to 4 ( $10.3\%$ ) in 2020.

Comparing the threat space constructed for the region (see Figure 8), it could be stated that the climate change scenarios that might represent future threats are the ones that project increases in temperature and decreases in precipitation, similar to the climatic conditions during strong La Niña years. However, all the models project a decrease in precipitation for 2020 and 2050 for January (Figure 14B), indicating risky conditions for maize. When summer season (DJF) is considered (data not shown), all the climate change scenarios projected increases in temperature and in rainfall with different amounts based on the particular scenario. This latter situation, similar to the conditions in 1975, could lead to decreases in maize yields, but there are few previous events that could illustrate the farmer's responses to these conditions. Therefore, it is difficult to determine the ultimate effects of these climatic changes on crop yield. Sensitivity analyses using crop models, which also include changes in the variability besides changes in the mean values of rainfall and temperature, will help to assess the conditions that could affect crop yield (Vinocur et al., 2000).

## **6. Conclusions**

Analyses of regional climatic variability help in defining the current climatic threat. In this sense, climatic threat spaces can be a useful tool for defining “threat” with stakeholders and for communicating risk. The dispersion diagrams for temperature and precipitation illustrate climatic threat to a specific agricultural production and the damages that they could cause to specific crops. The magnitudes of the hazard and of the losses can be used to characterize the vulnerability of agricultural producers. Regional climate change scenarios can be introduced to the climatic threat spaces, and future threats or opportunities can be discussed with key stakeholders in the region.

Even if the changes in the mean values proposed by the outputs of several GCMs appear to be within the coping range, caution should be taken with the behavior of the extreme events in the future. Considering that under climate change conditions, the climate variability will be similar to the observed in current values (as a first approximation), the frequency of extreme climatic events might increase, increasing then the future vulnerability of the system under study.

A limitation of these threat spaces is that they are not for the analysis of extreme events in daily frequency (frosts, heavy rain, for example), since threat spaces are constructed using seasonal means, which can hide the effect of a daily extreme value. However, using other sources, as newspaper articles, interviews, and surveys, along with specific daily climatic studies, this limitation can be overcome.

### **Acknowledgment**

The research reported in this paper was supported by grant number AL29 from Assessments of Impacts and Adaptations to Climate Change (AIACC), a project that was funded by the Global Environment Facility, the US Agency for International Development, the Canadian International Development Agency, and the U.S. Environmental Protection Agency and that was implemented by the United Nations Environment Programme and executed by the Global Change System for Analysis, Research and Training (START) and the Third World Academy of Sciences (TWAS). We acknowledge specially the students that participated in the fieldwork or did their thesis during this project: Jenaro Martínez, Beatriz Palma, Raquel Araujo, Gerardo Utrera, Andrea del Valle Rivarola, Cecilia Maurutto, Dana Lucero. We also recognize

the assistance of Rosa Ma. Ferrer in two of the fieldwork activities (Huatusco and Coatepec), and of Oscar Sánchez, who helped in the development of the climate change scenarios.

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<sup>7</sup> Consejo Estatal de Población, Xalapa, Veracruz (<http://coespo.ver.gob.mx/boletin11dejulio.htm>).

<sup>8</sup> Araujo, R., and J. Martínez. 2001. AIACC workshop presentation. Vulnerabilidad Social de la Producción de Café en el Estado de Veracruz, México.

<sup>9</sup> Arthur Douglas (1993) criteria for establishing regions in Mexico are: “(1) similarity in slope aspect and station elevations, (2) minimum data recovery of 95% for the period 1947–1988, and (3) climatological rainfall totals (annual) within 20% of the area-wide mean”. These criteria applied by Palma (2004) and Bravo (2005) to study climatic regions in Veracruz in more detail, also validated the series of data in each station.

<sup>10</sup> International Coffee Organization (<http://www.ico.org/>), the National Federation of Coffee Producers of Colombia (<http://www.cafedecolombia.com/>), the Coffee Research Institute (<http://www.coffeeresearch.com>).

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<sup>15</sup> El Universal 02/06/1970:3; El Universal 1973/07/28:1, El Universal 1973/08/31:1 El Universal, 8/1996.

<sup>16</sup> El Diario de Xalapa, 5/1997.

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<sup>19</sup> Eakin, H., and J. Martínez. 2003. Presentation to coffee farmers and experts in Coatepec, Veracruz. December 6 – 8, 2003.

<sup>20</sup> The gross geographic product (GGP) of a particular area amounts to the total income or payment received by the production factors (land, labor, capital, and entrepreneurship) for their participation in the production within that area. It is a regional GDP.

<sup>21</sup> Diario Puntal, 04/06/1988.

<sup>22</sup> La Comuna, 17/05/1979; 07/06/1979;19/07/1979; Diario Puntal, 29/03/1987; Revista La Semana, 17/03/1998; Revista La voz del Sur, 12/1997, 05/1998.

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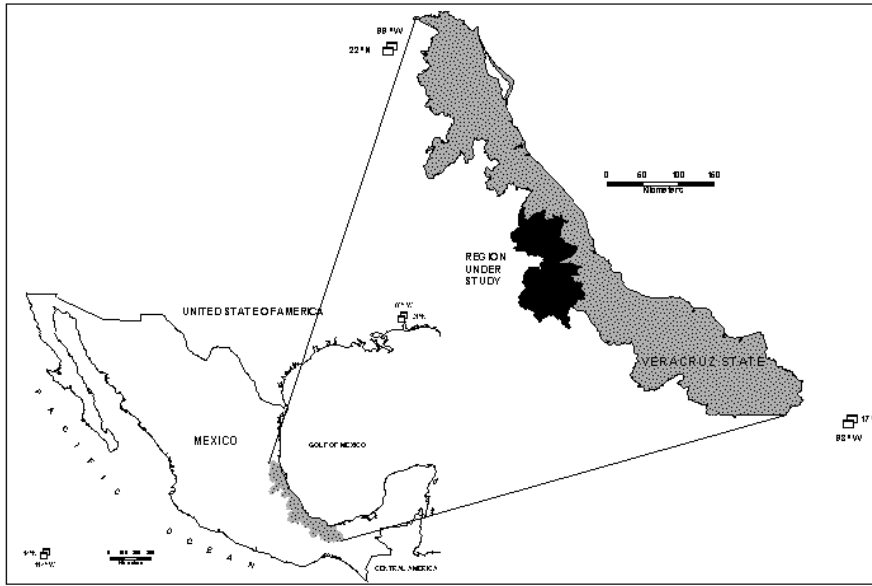
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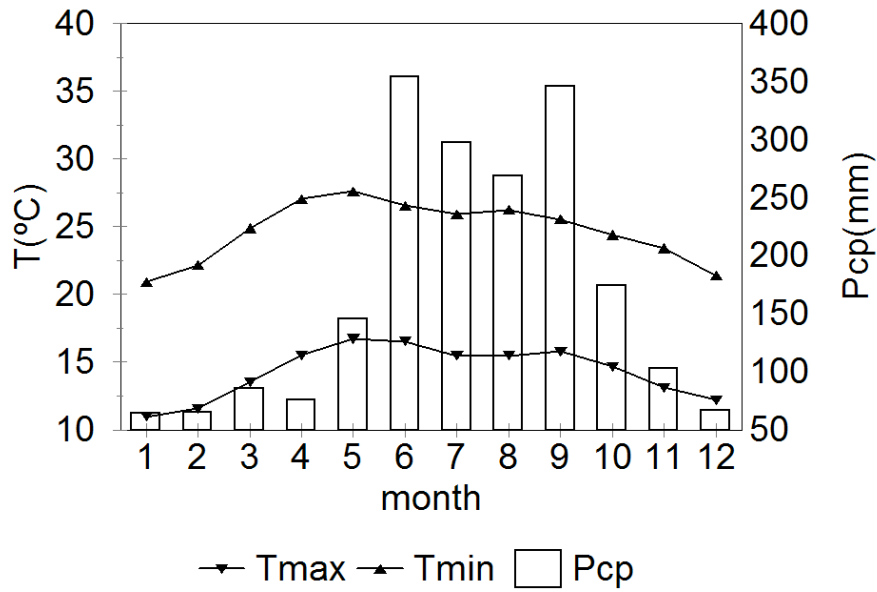
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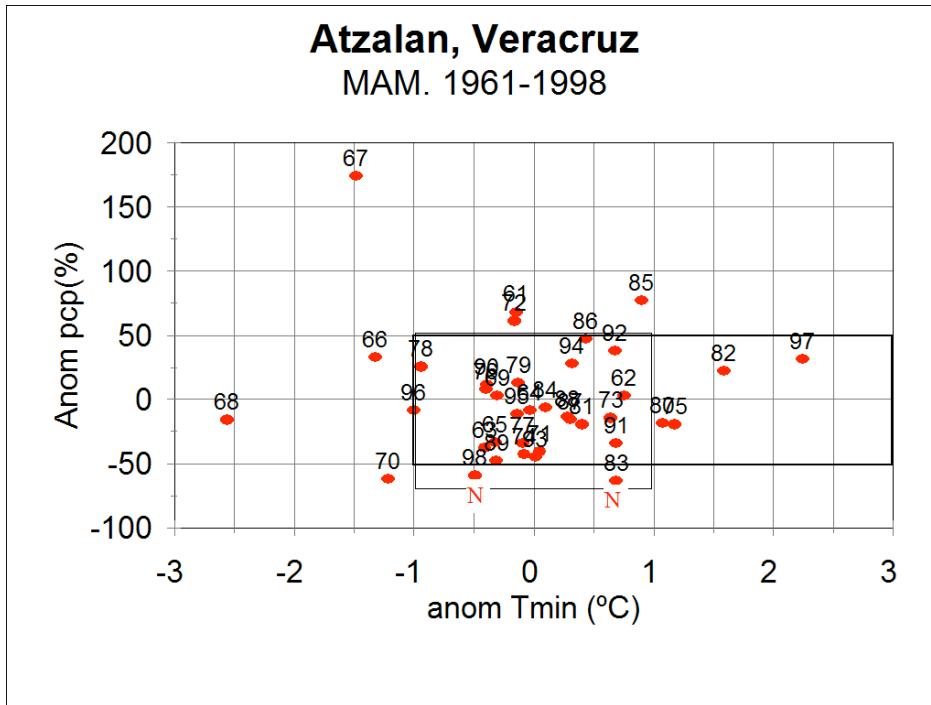


**Figure 1.** The state of Veracruz and the region under study. Locations described here are situated at about 1000 and 1500 m above sea level.

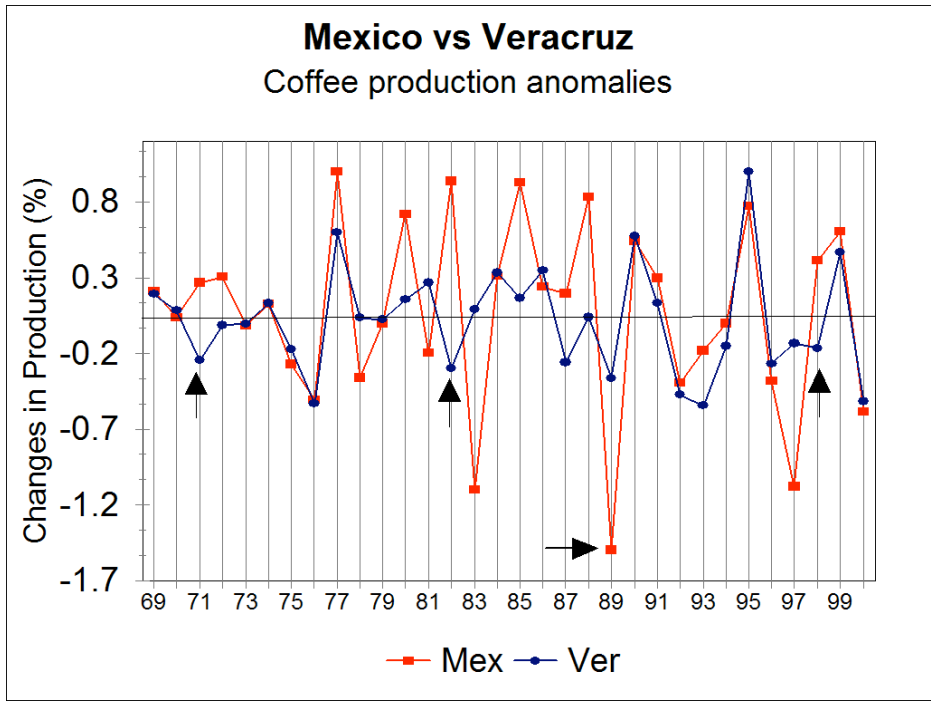
### Climatology 1961-1990 Teocelo, Ver.



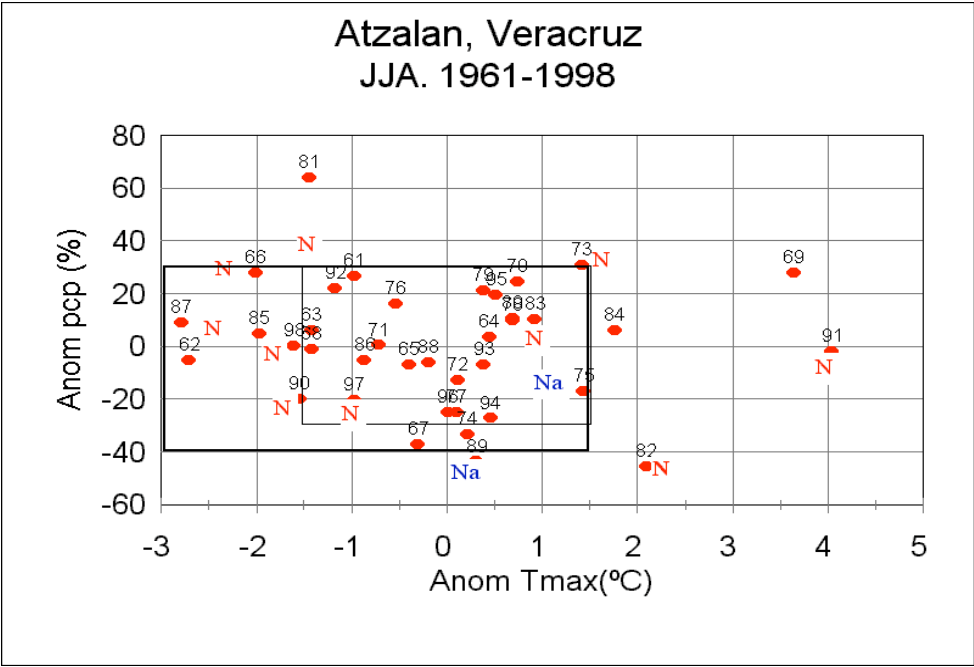




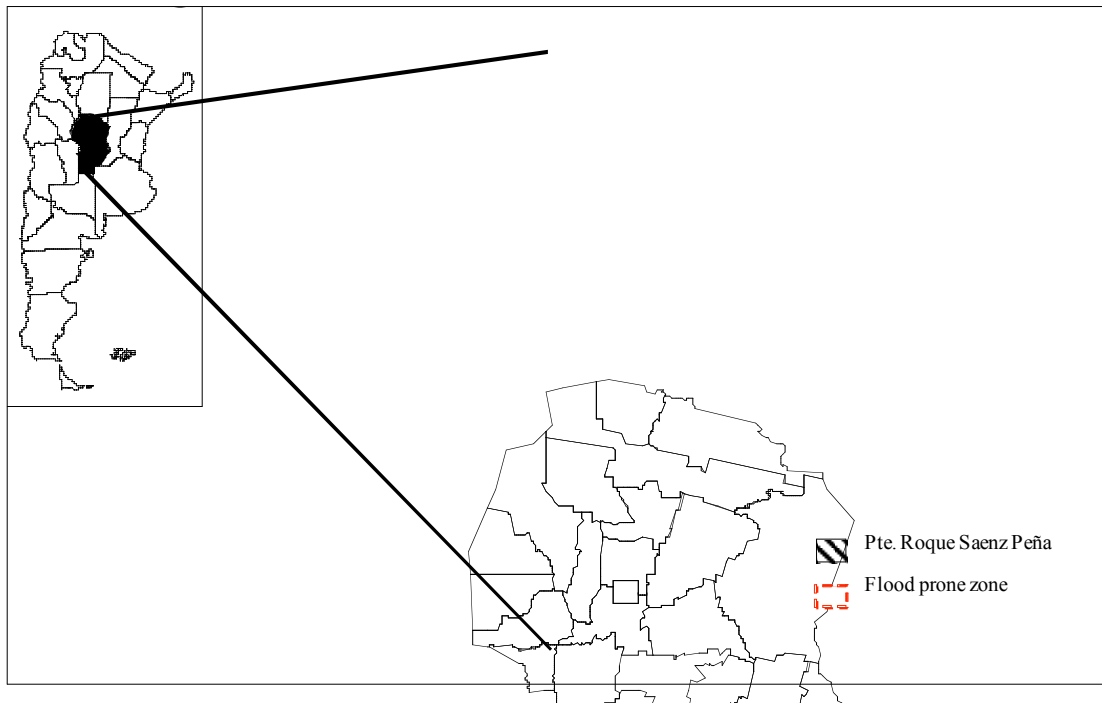
**Figure 3B.** Climatic threat space for coffee during spring (MAM), considering the minimum temperature and precipitation requirements of the coffee plant. The square box represents the initial coping range proposed. Climatic anomalies outside the rectangle are considered to be risky for coffee.



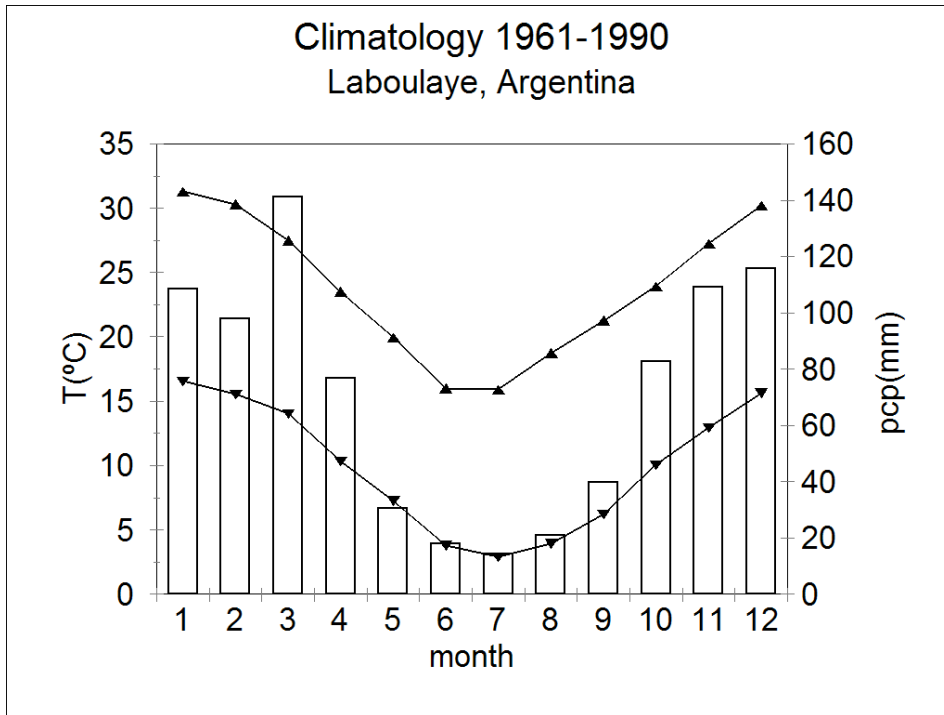
**Figure 4.** Coffee production anomalies for Mexico and for the state of Veracruz. Arrows show critical years in coffee production, either for the country and the state (1989), or for only the state (1971, 1982, 1998).



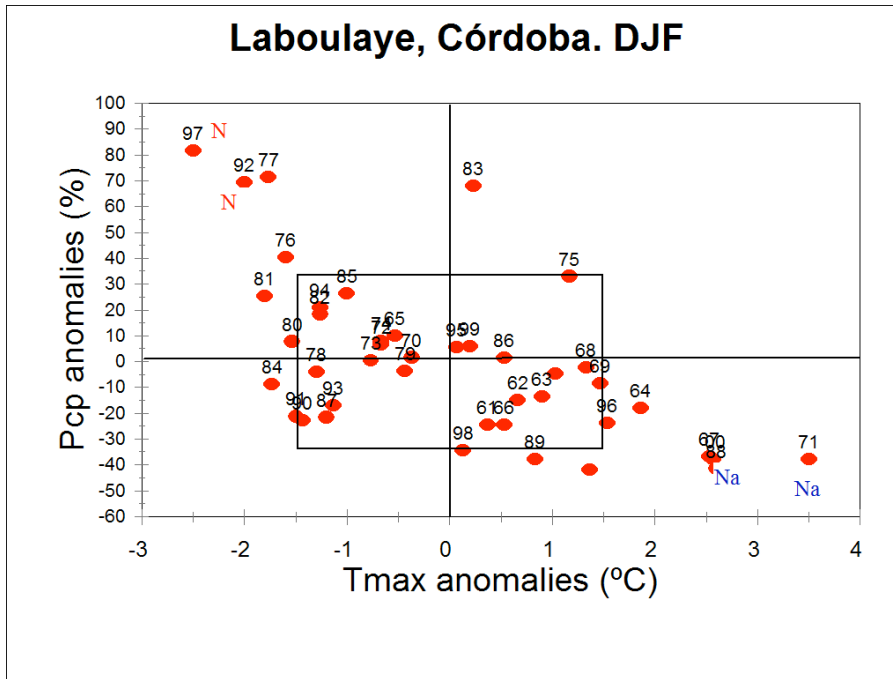
**Figure 5.** Threat space for Atzalan, Veracruz in summer (JJA). Anomalies for maximum temperature ( $T_{max}$  °C) and for precipitation (%). The rectangle represents the limits of the proposed coping range. The square box represents the quartile range calculated considering 1961–1990 period. **N**: El Niño year. **Na**: La Niña year. The scale is adjusted to the minimum and maximum values in the series. For visual purposes, it is not the same as in Figures 3A and 3B



**Figure 6:** Region of study, location of the city, and flooding-prone area (box).

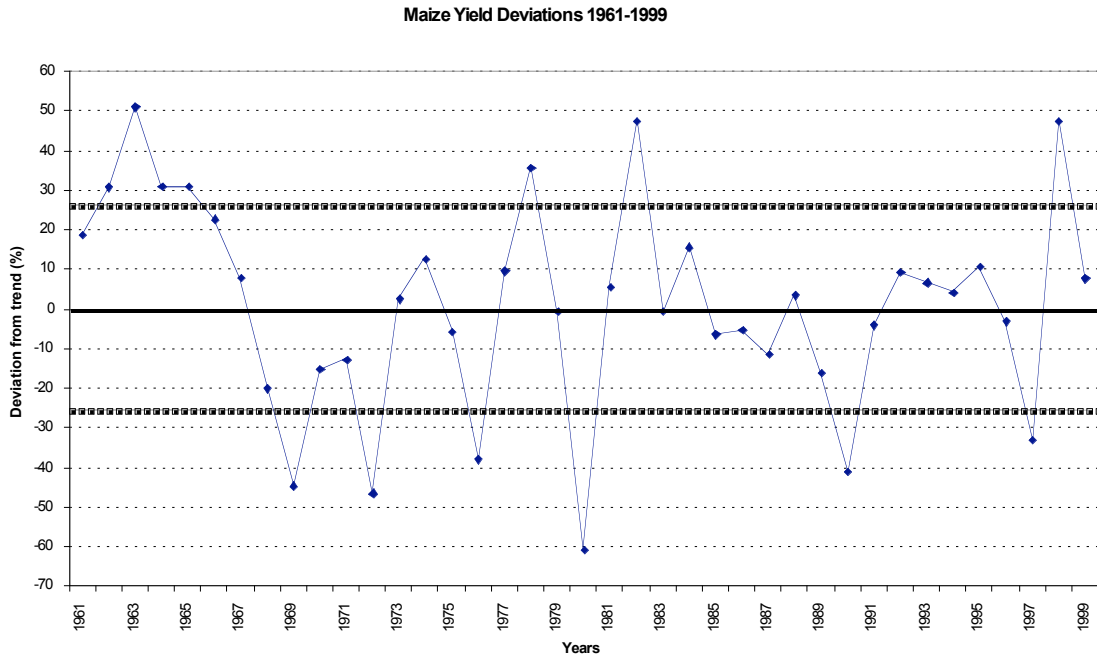


**Figure 7:** Normal climatic conditions for Laboulaye (Argentina) considering maximum (Tmax), minimum temperatures (Tmin), and precipitation (Pcp).

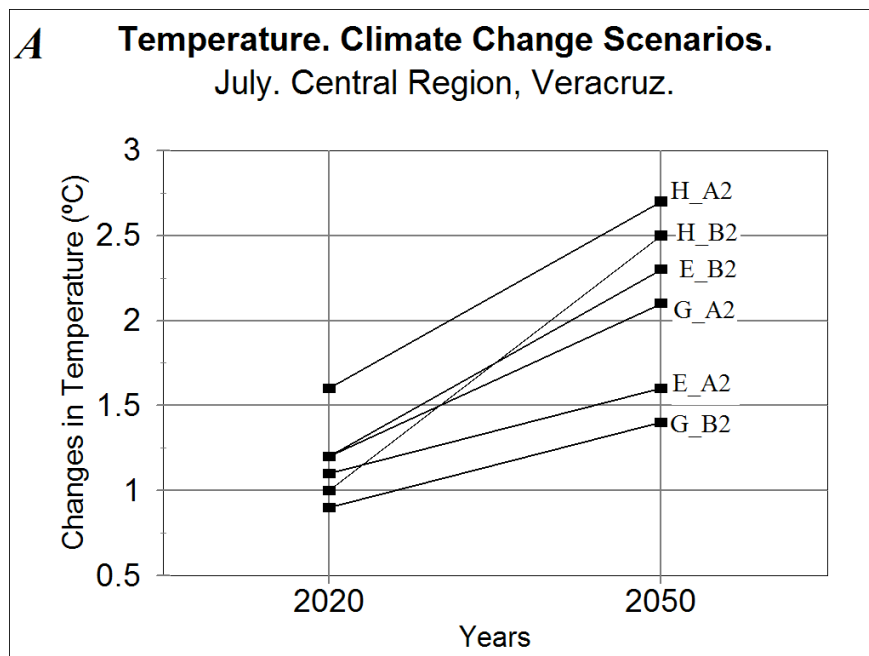


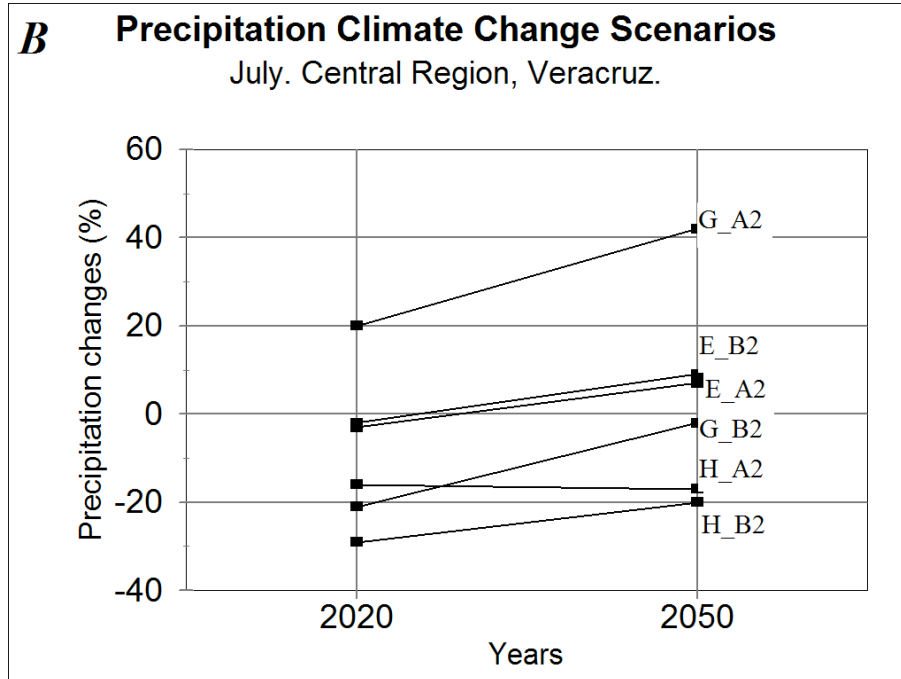
**Figure 8.** Climatic threat space for Laboulaye, Córdoba, for summer season (DJF).

Quartile ranges for the anomalies of the climatic variables are shown as a box. Years are represented by the last two digits (i.e., 97 equals 1997). **N** and **Na** represent an El Niño and La Niña year, respectively.

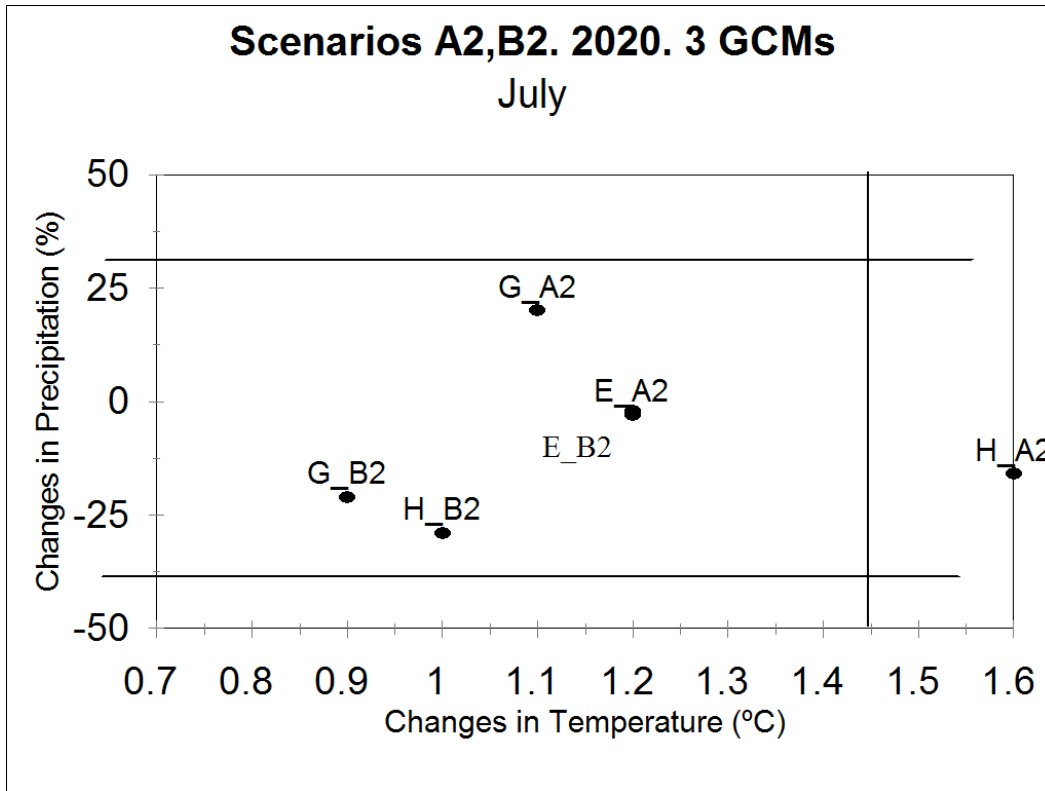


**Figure 9.** Maize yields deviations from linear trend of the series 1961–1999 for the Department of Roque Saenz Peña (Córdoba, Argentina). 1961 = 1960–1961 cropping season. The dotted lines above and below zero represents plus and minus one standard deviation.

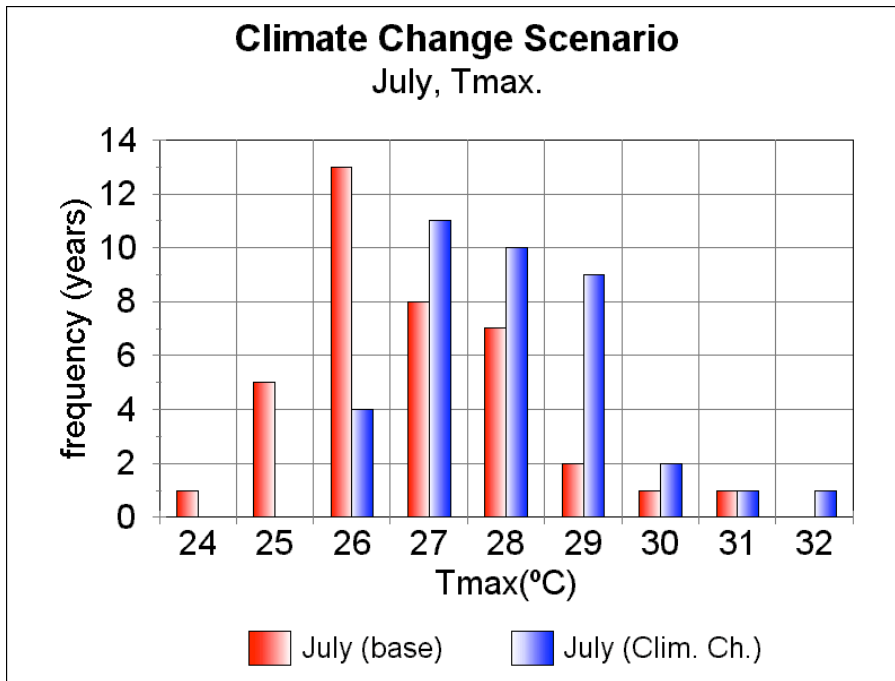




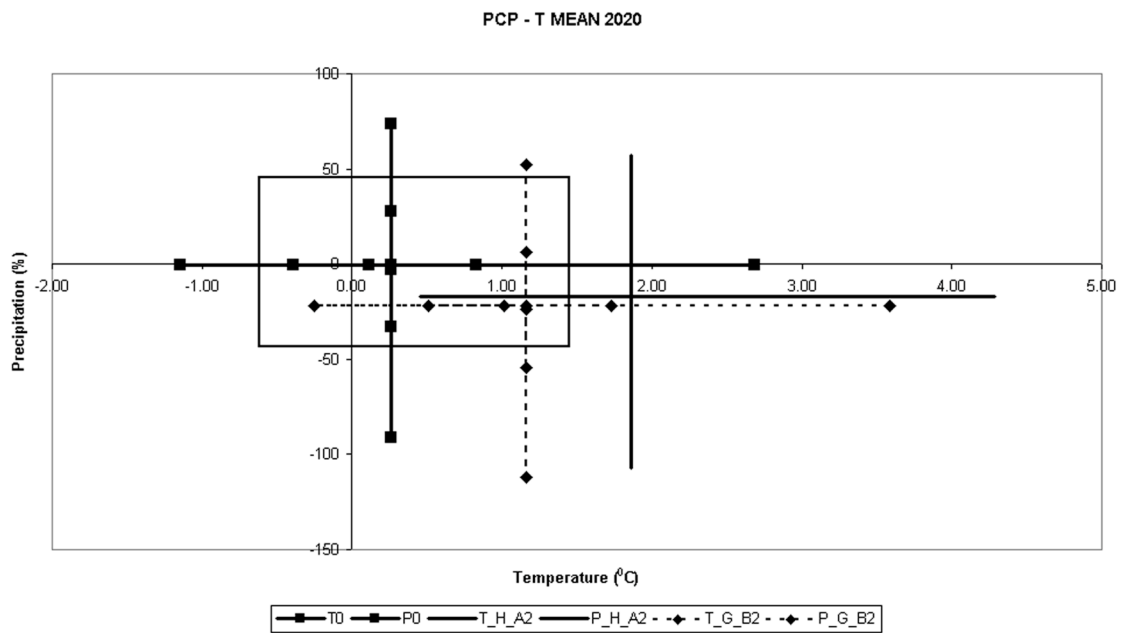
**Figure 10. A:** Projected changes in temperature for the central region of Veracruz (2020 and 2050), using 3 GCM (G: GFDL; H: Hadley; E: ECHAM) outputs and two SRES scenarios (A2 and B2). **Figure 10. B:** Projected changes in precipitation for the central region of Veracruz (2020 and 2050), using 3 GCM (G: GFDL; H: Hadley; E: ECHAM) outputs and two SRES scenarios (A2 and B2)



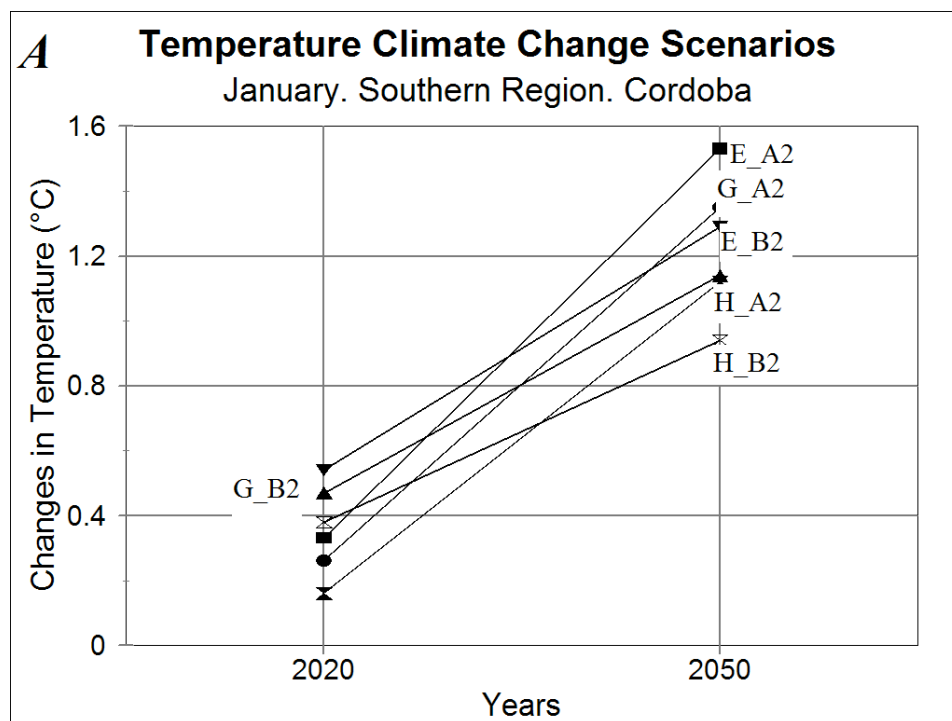
**Figure 11.** Climatic threat space (outside the rectangle) for coffee production in the central region of Veracruz, considering climate change scenarios. The projected changes are based on the models ECHAM4 (E\_A2 and E\_B2), GFDL (G\_A2 and G\_B2), and for the Hadley model (H\_A2 and H\_B2).

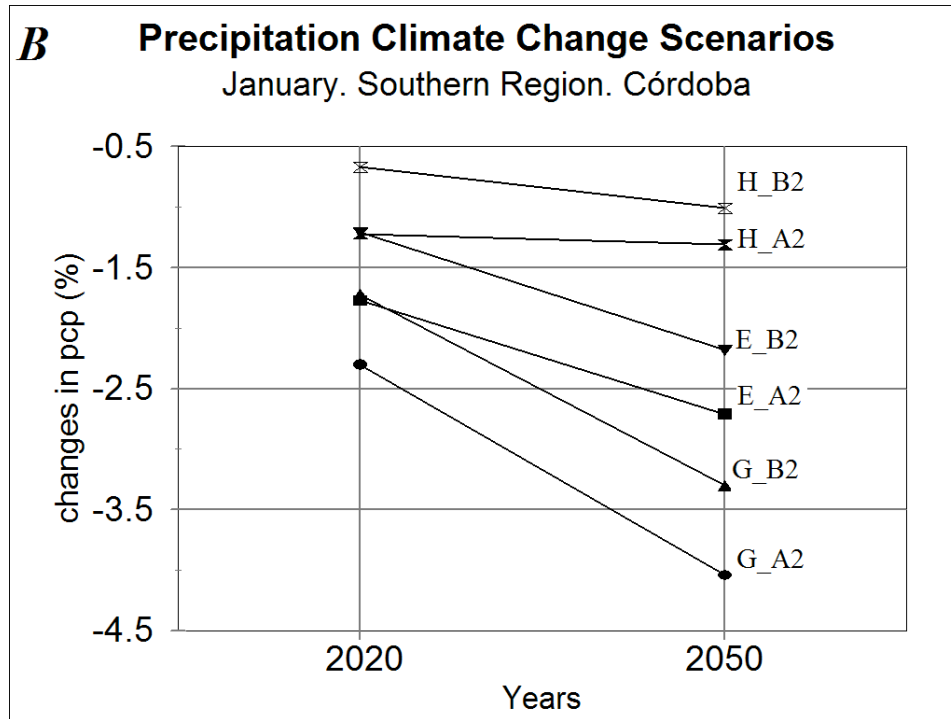


**Figure 12.** Frequency maximum temperatures (Teocelo, Veracruz, 1961–1998) considering the observed data (July–base) and with the increase in temperature as proposed by ECHAM4 (A2) model (July, .Clim. Ch.) for the year 2020.

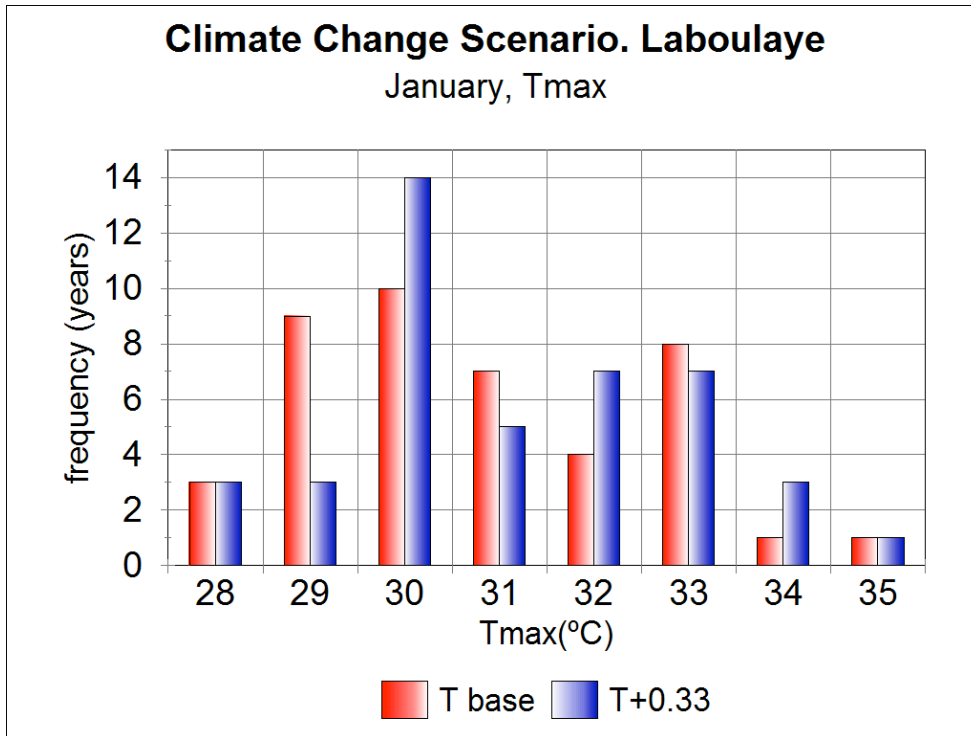


**Figure 13.** Current mean and variability conditions and climate change scenarios for 2020. The crosses show a mean value and variability for current and for each future scenario of temperature and precipitation. T0 and P0 are current temperature and precipitation conditions and the black box represents the coping range (Figure 12). The scenarios were constructed using mean temperature (T) and precipitation (Pcp) for the HadCM3 (A2 scenario), and the GFDL (B2 scenario), which project the highest and lowest changes in temperature, respectively (figure 11).





**Figure 14.** *A*: Projected changes in January temperature for the southern region of Córdoba, Argentina (2020 and 2050), using 3 GCM (G: GFDL; H: Hadley; E: ECHAM) outputs and two SRES scenarios (A2 and B2). *B*: Projected changes in January precipitation for the southern region of Córdoba, Argentina (2020 and 2050), using 3 GCM (G: GFDL; H: Hadley; E: ECHAM) outputs and two SRES scenarios (A2 and B2).



**Figure 15.** Observed (1960–2002) and projected DJF maximum temperature (2020) based on ECHAM4 under the A2 emissions scenarios for Laboulaye, Argentina.