

Chapter 3

The Climate of Cuatro Ciénegas Basin: Drivers and Temporal Patterns



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Abstract The Cuatro Ciénegas Basin (CCB) is considered an important biodiversity hot spot despite its arid climate conditions. The valley is located in the southern part of the Chihuahuan desert at 26° 50' 41" N and is strongly affected by a divergent wind zone with high pressure at 30° N. The average annual solar radiation is 5.28 kWh m⁻² day⁻¹, exhibiting a seasonal pattern with the highest values occurring in the summer months. The annual mean temperature is 21.9 °C. The average temperatures of the coldest month (January) is 12.9 °C while the hottest month (July) is 28.8 °C, resulting in a seasonal monthly pattern similar to that of solar radiation. The temperatures show a variation over the years with an apparent increase in the frequency of extreme cold events during the winter and extreme hot events during the summer. These results suggest that the winters are becoming colder while the summer months are becoming warmer. This annual variability is associated with the North Atlantic Oscillation (NAO). The annual averages of potential evapotranspiration and annual precipitation are 2602 mm year⁻¹ and 211 mm year⁻¹, respectively, suggesting that the average annual rainfall only represents only 8% of the annual water for evapotranspiration demand. The annual precipitation also shows high variability over the years as a consequence of El Niño, NAO, and tropical cyclones. The models under global climate change predict that the climate of CCB has a trend of becoming drier and warmer with a high frequency of extreme climatic events, resulting in a more extreme climate.

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Introduction

The deserts are the most distributed ecosystems in the world, because they cover about 40% of the Earth's surface (UNEP 1997). The water availability in these ecosystems is the most limiting factor for plant productivity (Williams 2014), because the annual precipitation represents only 65% of the evapotranspiration demand (FAO 2007).

Desert ecosystems comprise nearly 50% of Mexico (Rzedowski 2006). One of the most important deserts in North America is the Chihuahuan Desert, because it covers 36% of the North American dry lands and represents an important hot spot of biodiversity (Archer and Predick 2008). Within this desert, the Cuatro Ciénegas Basin (CCB) is considered the most important wetland of Mexico (Souza et al. 2011).

This chapter describes the factors that determine the CCB climate, the temporal variability of climate parameters, and the climate scenarios under global climate change. To meet these objectives, we used a temperature and precipitation dataset covering a period of 76 years (1941–2017) taken from the weather station within CCB (<http://smn.cna.gob.mx/>). The resulting data were processed with Clic-MD software (Bautista et al. 2016). The daily solar radiation data covering a period of 30 years were taken from dataset surface meteorology and solar energy (NASA 2018).

Temporal Pattern of Solar Radiation and Temperature in CCB

The average annual solar radiation within CCB is $5.28 \text{ kWh m}^{-2} \text{ day}^{-1}$. Figure 3.1a shows monthly solar radiation reflecting its seasonal pattern, with the lowest values in December and January, while the highest values are between April and July. These data are a result of global net solar radiation variation (Bonan 2015).

The annual mean temperature (T_{mean}) is $21.9 \text{ }^\circ\text{C}$. The average temperatures of the coldest month (January) is $12.9 \text{ }^\circ\text{C}$ and of the hottest month (July) is $28.8 \text{ }^\circ\text{C}$, resulting in a seasonal monthly pattern similar to that of solar radiation (Fig. 3.2). However, the differences between the annual average maximum temperature (T_{max}) and minimum temperature (T_{min}) is $14.6 \text{ }^\circ\text{C}$. The winter months have a T_{max} above $20 \text{ }^\circ\text{C}$ (December and January), while the hottest months in the summer are above $34.7 \text{ }^\circ\text{C}$ (June to August; Fig. 3.2). Similarly, the T_{min} has a seasonal monthly pattern wherein the winter months are below $5.5 \text{ }^\circ\text{C}$, and the summer months are above $22 \text{ }^\circ\text{C}$ (Fig. 3.2). The monthly differences between T_{max} and T_{min} ranged between $12.0 \text{ }^\circ\text{C}$ and $16.6 \text{ }^\circ\text{C}$ with the highest values occurring between December and April. These data suggest that the winter months have a higher thermal oscillation than the summer months.

However, the temperatures show an important variation over the years (Fig. 3.3); we observed that the T_{mean} and T_{min} of the summer months increased up to $2 \text{ }^\circ\text{C}$ from 1941 to 2013. Additionally, we reported that the frequency of extreme events of

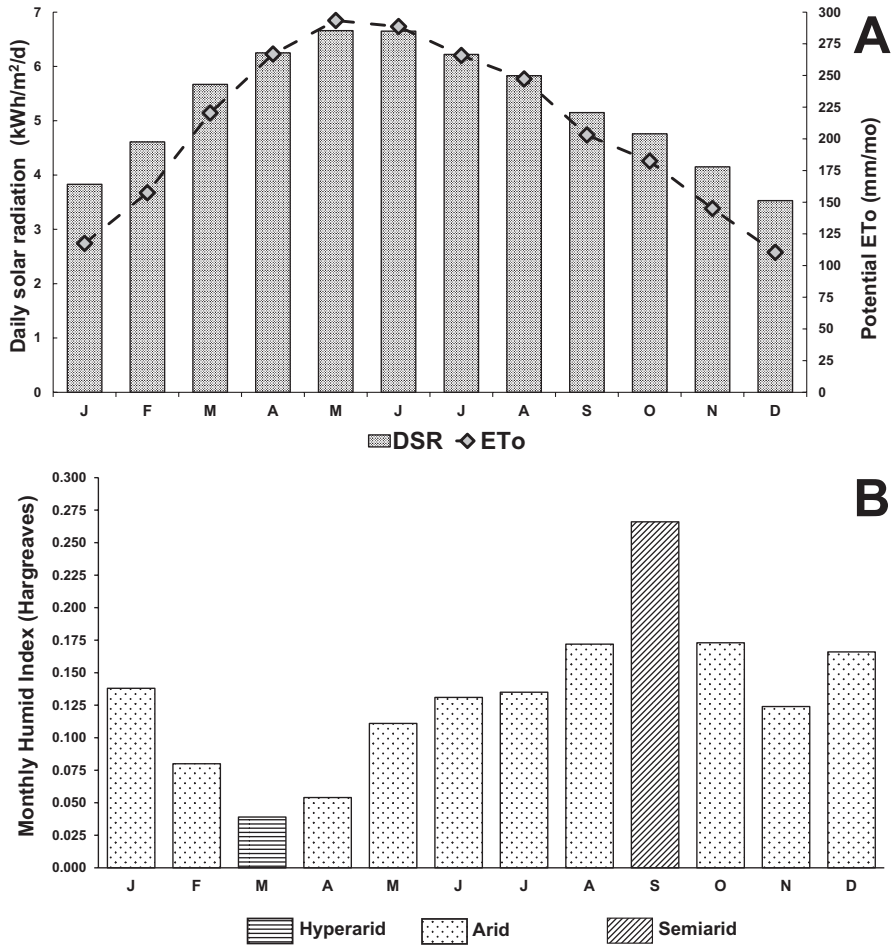


Fig. 3.1 The monthly average of (a) the daily solar radiation ($\text{kWh m}^{-2} \text{day}^{-1}$) and potential evapotranspiration (mm m^{-1}) from CCB (Dataset surface meteorology and solar energy, NASA 2018) and (b) Monthly Humid Index calculated by Hargreaves (Dataset SMN years1941–2017; Clic-MD software)

Tmin during the winter and extreme events of Tmax during the summer increased in the last 30 years (Montiel et al. 2017). These results suggest that the winters are becoming colder, while the summer months were becoming warmer, leading to an increase in the frequency of cold waves and heat waves in the last 30 years in CCB. This annual variability is associated with the North Atlantic Oscillation (NAO).

The NAO is a variation of the air surface pressure from north to south—between the Icelandic Low and the Bermuda-Azores High—that affects the wind direction and location of cold storms in the North Atlantic during the winter months (Scaife et al. 2014). The NAO consists of two phases, a positive and a negative (Archer and Predick 2008). There is an intensification of the pressure differences in the positive

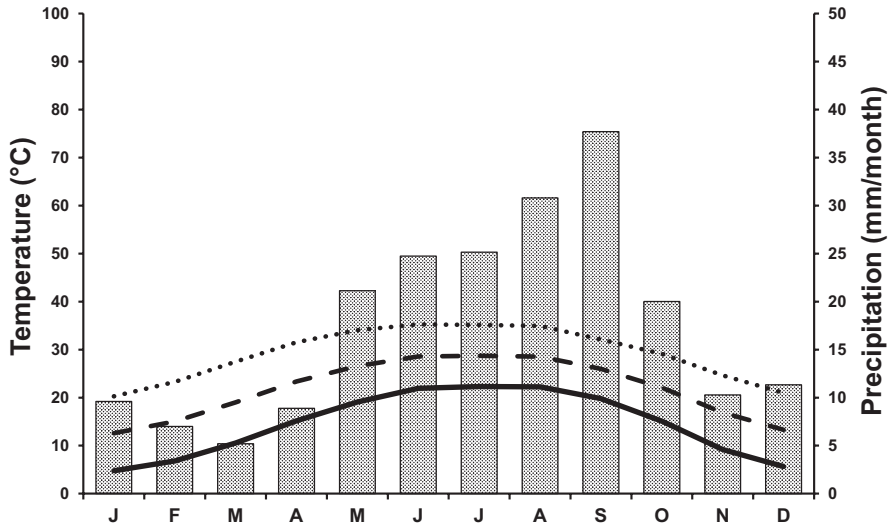


Fig. 3.2 Monthly average temperatures (T_{min} , minimum; T_{mean} , mean; and T_{max} , maximum values) and monthly average precipitation recorded from 1941 to 2017 (Dataset SMN; Clic-MD software)

NAO phase, because the Bermuda–Azores High pressure increases and the Icelandic Low pressure decreases. The pressure difference is reduced between both pressure centers in the negative NAO phase. In Northern Mexico, the positive NAO produces warmer winters while the negative phase produces extremely cold winters with frost and cold waves (Archer and Predick 2008).

Temporal Patterns of Evapotranspiration, Precipitation, and Aridity Index in the CCB

The annual averages of potential evapotranspiration and annual precipitation in the CCB are $2602 \text{ mm year}^{-1}$ and 211 mm year^{-1} , respectively, suggesting that the annual rainfall only represents about 8% of the annual water demand by evapotranspiration. Therefore, the aridity index proposed by UNEP (1997) is 0.08, corresponding to an arid climate.

The aridity condition of CCB is a consequence of its geographic location. The CCB is located at $26^{\circ} 50' 41'' \text{ N}$ and is strongly affected by a divergent wind zone with high pressure at 30° N (Bonan 2015). This divergent wind zone is produced by descending cold and dry winds generating dry conditions on the land surface (Bonan 2015). This arid wind belt in the continental southern sites creates arid conditions mainly during the winter season (Ahrens 2013; Bonan 2015).

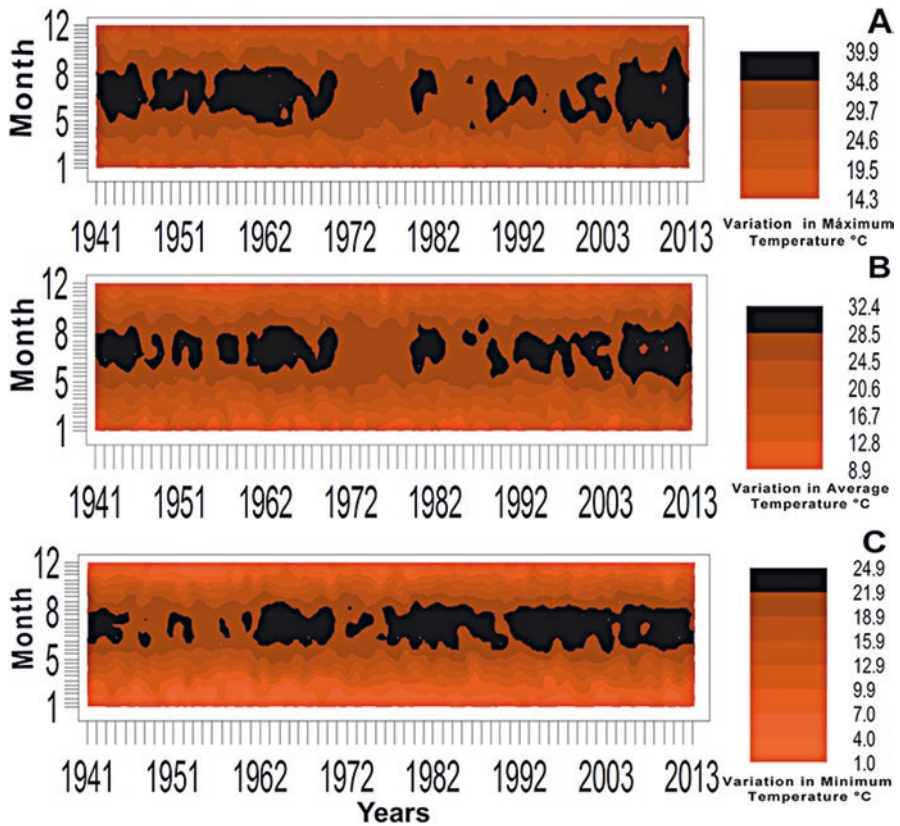


Fig. 3.3 The temporal temperature pattern in a 70-year period (1941–2013) taken from the weather station within CCB (<http://smn.cna.gob.mx/>): (a) maximum temperature (T_{max}), (b) mean temperature (T_{mean}), and (c) minimum temperature (T_{min})

As a consequence of the monthly solar radiation pattern, the water demand for evapotranspiration is high during the months with elevated solar radiation (April to July; Fig. 3.1a), when the annual rainfall is concentrated. The summer months contribute to about 90% of the annual precipitation, while the winter months contribute to about 9% (Fig. 3.2). According to the monthly humid index calculated with the Hargreaves equation, most months have arid conditions except for September and March which have semiarid and hyperarid conditions, respectively (Fig. 3.1b).

Additionally, the annual precipitation exhibits substantial variation. Therefore, the standardized drought-humid index changes greatly over the years (Fig. 3.4). We found several years to be exceptionally humid or exceptionally arid. Additionally, the frequency and intensity of these extreme events apparently increased after 1985. The variability in the arid conditions between years can be explained in part by El Niño Southern Oscillation (ENSO) and La Niña and the North Atlantic Oscillation (NAO). During El Niño years, the climate in Northern Mexico shows an increase in

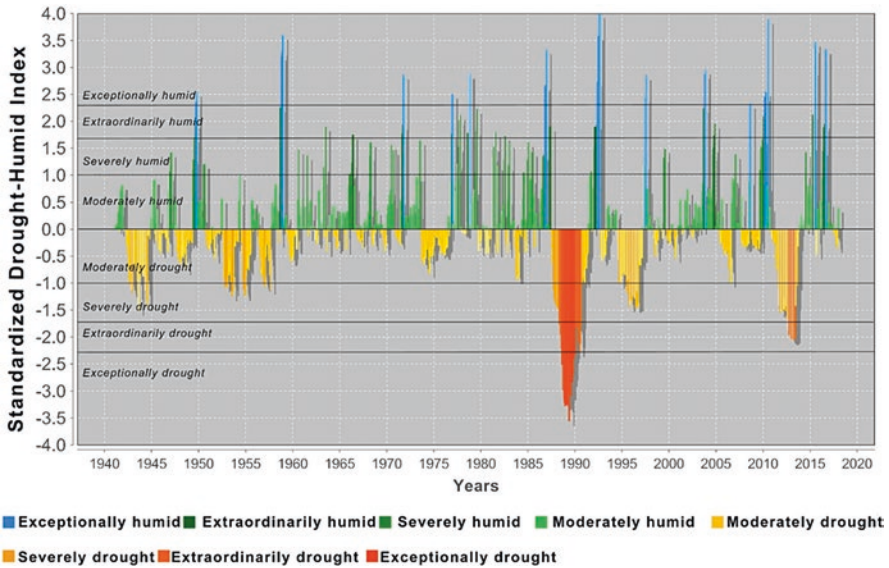


Fig. 3.4 Standardized drought-humid index. Positive values indicate standardized humid index, and the negative values indicate standardized drought index. The severe to exceptional events indicate a *Niño* or *Niña* year (Dataset SMN years 1941–2017; Clic-MD software)

precipitation and a decrease in temperature, especially during the winter months. However, this phenomenon produces less precipitation and hotter temperatures in the summer months, thus creating drought and heat waves (CONAGUA 2017; Magaña et al. 1998; Vose et al. 2014). During La Niña years, the climate in the Northern Mexico shows an increase in precipitation during the summer months. (Magaña et al. 1998). The frequency and intensity of El Niño (negative values in Fig. 3.4) and La Niña (positive values in Fig. 3.4) have strongly influenced the extreme events of drought and storms in the last two decades. Additionally, the positive NAO phase has produced wetter winters than normal (Archer and Predick 2008).

The CCB climate type, according to Köopen and modified by García (1981), is BWhwx'(w)(e') calculated from 30 years of climate records (between 1977 and 2013). This climate type is very dry and semi-warm with an annual average temperature of 21.9 °C. Thermal oscillation is very extreme. Summer rains contribute about 90% of the annual precipitation.

Climate Scenarios Under Global Climate Change

According to the IPCC (Stocker et al. 2013), the average global temperature increased 0.85 °C from 1880 to 2012, but global changes in precipitation show no clear temporal trend (Stocker et al. 2013). Similarly, heat waves have increased in

intensity since the mid-twentieth century in most of the world, but the temporal pattern of torrential rains and drought remains unclear at the global level (Stocker et al. 2013). It is projected that under the worst scenario of greenhouse gas emissions (RCP8.5 model), the average temperature could increase by 3 or 4 °C, and the average annual precipitation could decrease by 10–20% by 2099 in the arid zones of Northern Mexico (SEMARNAT-INECC 2016).

Likewise, extreme weather events are expected to be more frequent and more extreme (IPCC 2012). An increase in drought, heat wave, and frost events is projected for 2100 in the arid zones of Mexico (SEMARNAT-INECC 2016). These results suggest that the climate of CCB will become drier and warmer with a high frequency of extreme climatic events, resulting in an even more extreme climate.

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