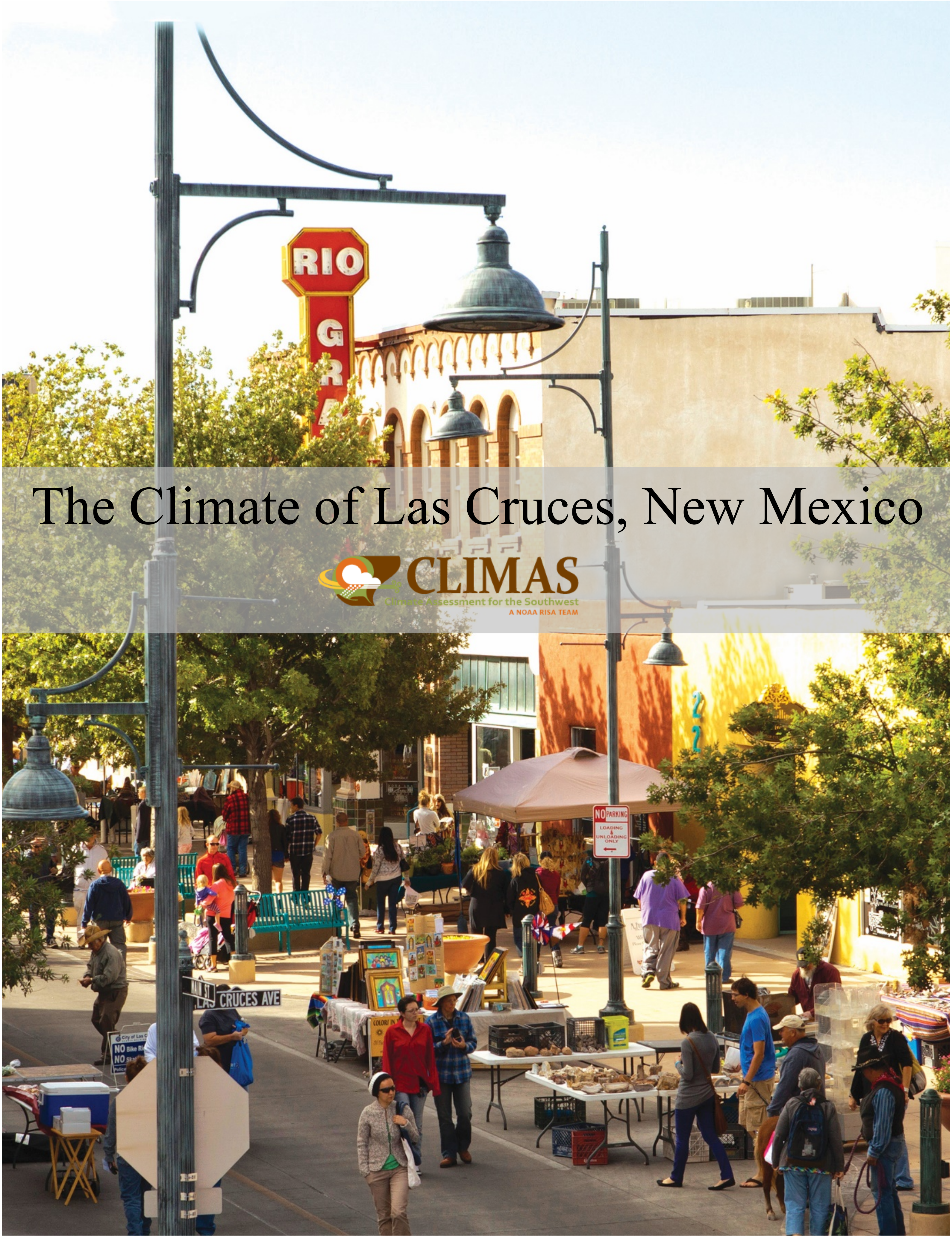


# The Climate of Las Cruces, New Mexico

CLIMAS
Climate Assessment for the Southwest
A NOAA RISA TEAM

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Climate Assessment for the Southwest

University of Arizona

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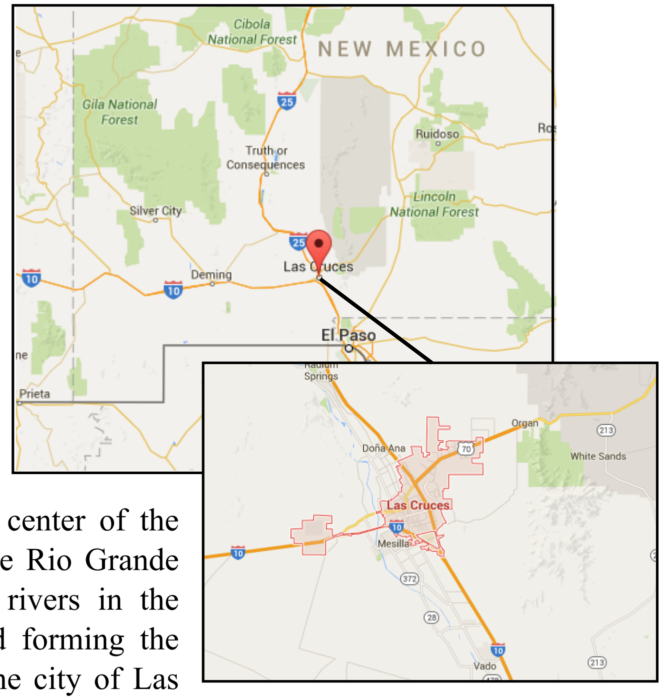
*The goal of this report is to provide a concise summary of the climate and extreme weather events that affect the City of Las Cruces. This information could be used to help inform planning and preparedness for extreme weather events now and in the future.*

## OVERVIEW




The city of Las Cruces is located in south-central New Mexico, 48 miles northwest of El Paso, Texas and 46 miles north of the Mexican Border. The county seat of Doña Ana County, Las Cruces is the second largest city in the state, with a population slightly over 100,000, and a metropolitan population a little over 200,000. Between April 1, 2010 and July 1, 2014 the city's population increased by 3.9%. Principal employers in the area include New Mexico State University (NMSU) and the White Sands Missile Range.

Las Cruces lies in the Chihuahuan Desert, with the Doña Ana Mountains to the north, and the Organ Mountains to the east. The city is the economic and geographic center of the Mesilla Valley—an important agricultural region of the Rio Grande floodplain. The Rio Grande is one of the principal rivers in the Southwest U.S., originating in southern Colorado and forming the border between Texas and Mexico. It flows through the city of Las Cruces and bisects the Mesilla Valley, providing irrigation water for agriculture in the region, including but not limited to pecans, alfalfa, cotton, and corn.

The climate of Las Cruces is characteristic of an arid desert climate, with large diurnal (day-night) and moderate annual temperature ranges, variable precipitation, low relative humidity, and abundant sunshine (averaging more than 80% of days in an average year). The majority of precipitation falls during July–September, when monsoon thunderstorms can dump inches of rain in a single storm, resulting in flash flooding.

## TEMPERATURE

The annual average maximum temperature in Las Cruces is 77.3°F and the annual average minimum temperature is 46.1°F, based on data from April, 1959 through December, 2005. June and July are the hottest months, with monthly average maximum temperatures of 94.6°F and 94.9°F, respectively. December and January are the coldest months with monthly average minimum temperatures of 28.3°F and 28.1°F, respectively. The average diurnal range of temperature in Las Cruces is quite large (32.5°F), which is typical of high elevation deserts.

Summers can be hot. An average of nine days per year reach 100°F, mostly in June and July. There have been five years in which Las Cruces experienced more than 30 days with 100+ degree temperatures: 32 days in 1951, 33 days in 1978, 32 days in 1980, 31 days in 2005, and 34 days in 2002. The highest temperature ever recorded was 110°F on June 28, 1994.

Temperatures in the winter months (December, January, February) range from a monthly average low of 29.3°F to a monthly average high of 59.8°F. Temperatures can fall below 0°F, and have done so eight times since 1892. The coldest temperature ever recorded for Las Cruces is -10°F on January 11, 1962.

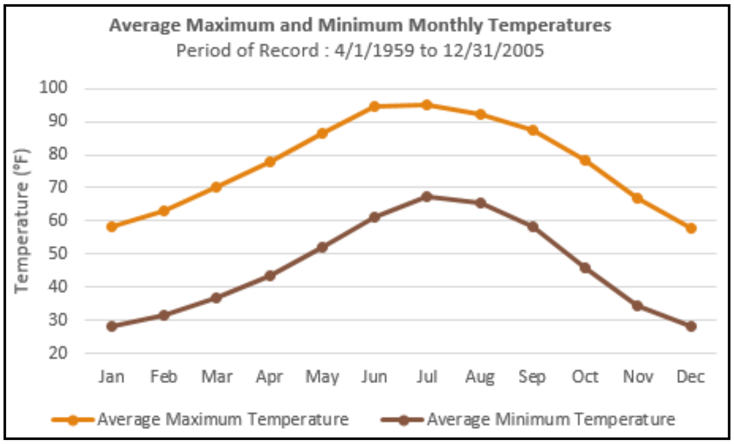



**Figure 2:** Variation in monthly average maximum and average minimum temperatures. Source: Western Regional Climate Center.

Annual average temperatures for Climate Division 8, in which Las Cruces lies, can vary as much as 2°F above or below the long-term average (1895–2015). Since 1992, annual temperatures have only been above the long-term average and have been trending upward (see Figure 3). The hottest years on record from 1895–2015 were 2012 and 2003, with average temperatures 2.6°F and 2.4°F above the mean, respectively. Both of these years coincided with severe drought conditions in the region.

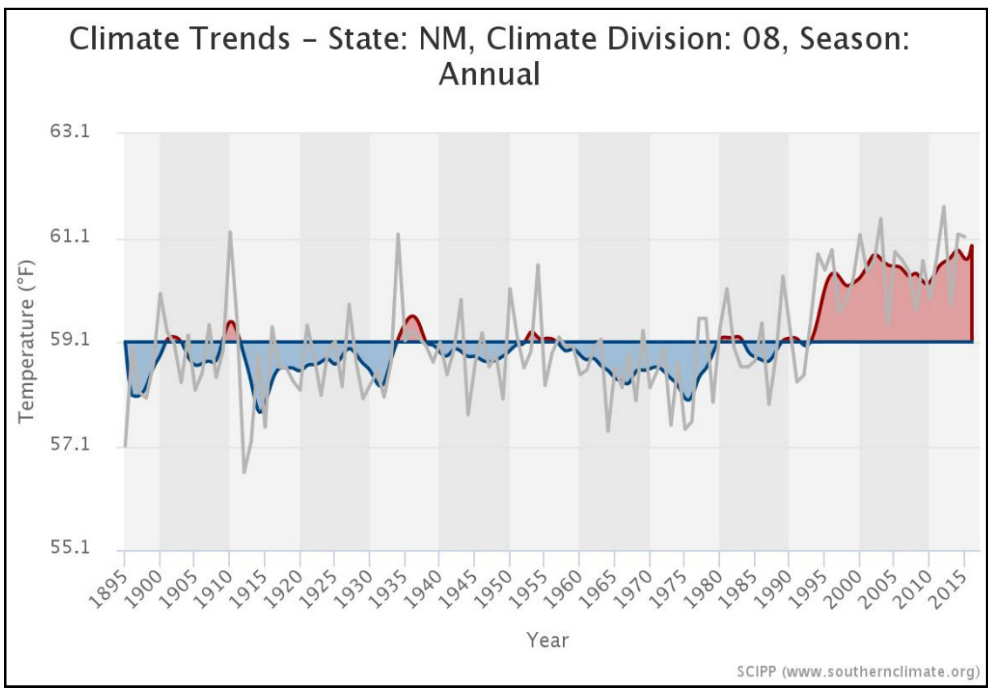



**Figure 3:** Annual average temperatures from 1895-2015, in degrees F, for Climate Division 8 in southern New Mexico. Shaded areas represent 5-year weighted mean temperatures above (red) or below (blue) the 1895-2015 average.

## PRECIPITATION

Annual precipitation in Las Cruces averages 8-9 inches. More than half of the annual precipitation falls from July through September, including brief and sometimes heavy monsoon thunderstorms. On average, 42 thunderstorms occur each year in the area (based on data for nearby El Paso, TX). These thunderstorms regularly result in severe flooding that can lead to millions of dollars in damages, such as during the extreme flood events in Las Cruces in July, 1994 and August, 2006.

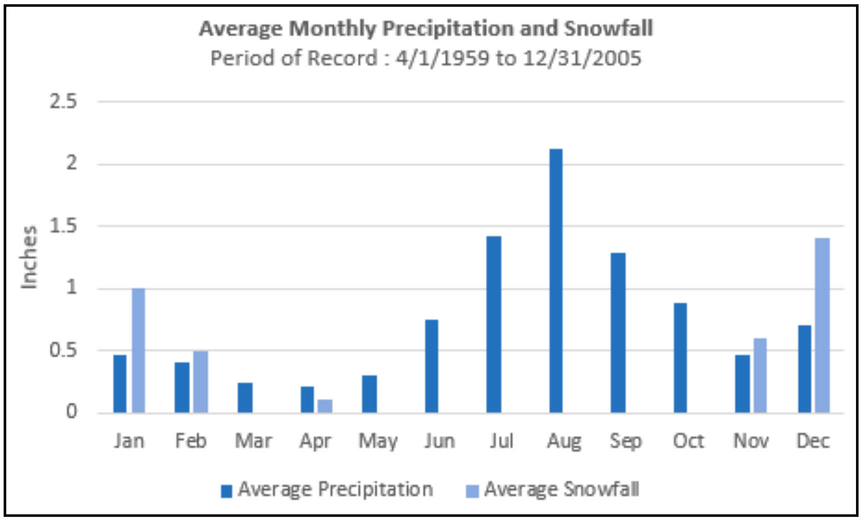



**Figure 4:** Variation in monthly precipitation and snowfall. Source: Western Regional Climate Center.

The primary source of summer monsoonal moisture is the Gulf of Mexico, due to a high-pressure center in the Atlantic Ocean (the Bermuda High) that feeds a shift in prevailing winds and brings moisture from the Gulf into New Mexico. When this high-pressure center recedes in early fall, the winds shift again and the summer rainy season ends.

Remnants of tropical storms and hurricanes can reach New Mexico and cause substantial rainfall and flooding. During July and August, these storms originate in the Gulf of Mexico, then in September and October, as the prevailing winds begin to shift, tropical storms can move in from the eastern subtropical Pacific Ocean.

The dry season is November through May, with precipitation averaging 0.5 inches or less each month based on records from 1892 to 2000. Although rainfall is sparse during this time of year, snowfall averages 3.2 inches per year. About one year in three receives no measurable snowfall. The largest amount of snowfall in one season was 16.4 inches during the winter of 1931-1932. The high snowfall winters of 1982-1983 and 1984-1985 delivered 16.3 and 16.2 inches of snow, respectively.

Annual precipitation can vary as much as 7 inches above or below the long-term average. Precipitation is much more variable than temperature in the region and, unlike the case with temperature, there is no observable long-term precipitation trend (Figure 5). Las Cruces lies in New Mexico Climate Division 8, the Southern Desert, made up of all or parts of Caltron, Chaves, Doña Ana, Eddy, Grant, Hidalgo, Lincoln, Luna, Otero, Sierra, and Socorro Counties. The driest year on record for this climate division was 1956, with about 4.5 inches. The wettest year on record for Las Cruces, just one point in the much larger climate division, was 1941, with 19.6 inches of precipitation, and the driest year was 1970, with 3.4 inches.

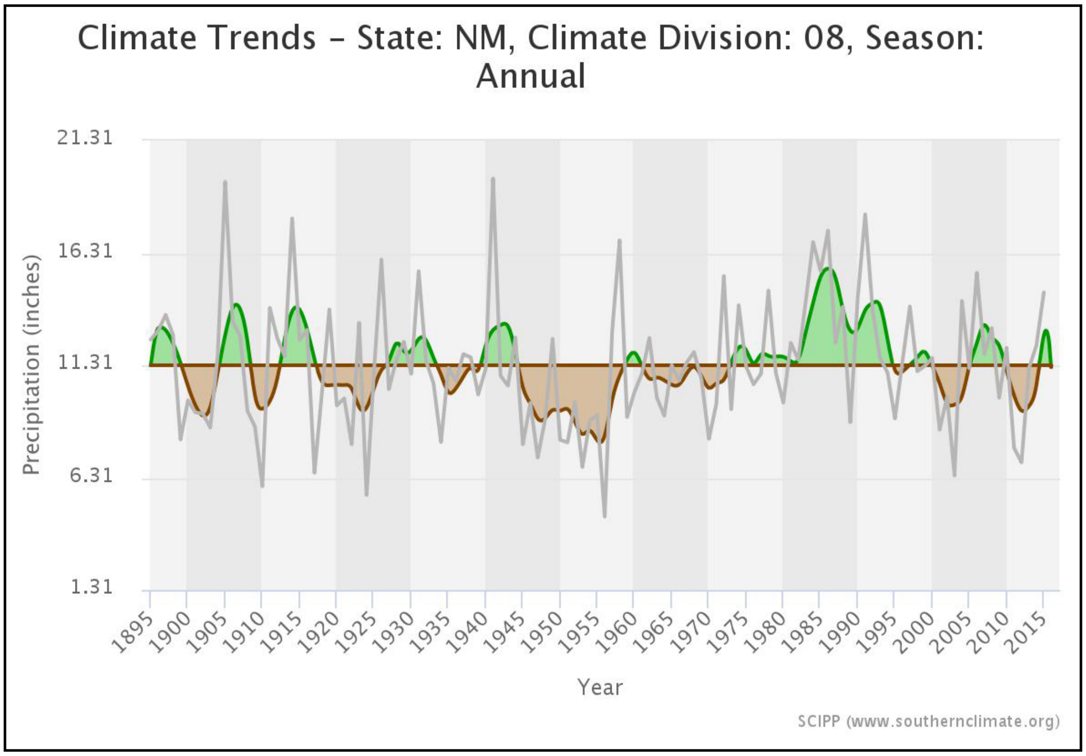



**Figure 5:** Annual precipitation from 1895 to 2015 for Climate Division 8 in southern New Mexico. Shaded areas indicate the 5-year weighted mean is above average (green) or below average (brown).

The El Niño-Southern Oscillation (ENSO)—an atmospheric and oceanic phenomenon in the equatorial Pacific Ocean—affects weather around the world, including Las Cruces, on yearly to multi-year timescales. During El Niño winters, the region tends to be wetter than normal (1941, the wettest year on record for Las Cruces, was an El Niño year, see gray line in Figure 5), and La Niña winters tend to be drier than normal. The La Niña event in 2010-2012 corresponded with severe drought conditions in southern New Mexico (see drought discussion below).

Variability in precipitation in the region also occurs on multi-decadal timescales, which leads to long-term droughts, such as in the 1940s and 50s, and wet periods, such as that in the 1980s and early 1990s (see Figure 7). This variability is driven by long-term trends in ocean temperatures and associated atmospheric conditions, which drive storms one way or another over the course of one or more decades.

## WIND AND RELATIVE HUMIDITY

Winds in the Las Cruces area are generally light, with an annual average speed of 6 miles per hour. The windiest period is late winter through spring (February through May). Since this is the driest time of the year, moderately strong winds can cause blowing dust and sand. For example, on March 7, 2011, the passing of a backdoor cold front caused high winds and blowing dust, prompting state police to issue an advisory against driving on the interstates and highways in the area. The strongest winds, however, typically occur during monsoon thunderstorms, where winds commonly reach 80 miles per hour. Winds can even reach 100 miles per hour, such as on June 13, 1989, when wind gusts reached 102 miles per hour at the Las Cruces Airport. Blowing dust from gusty winds can also occur in advance of these thunderstorms.

Relative humidity is the amount of moisture in the air, measured as a percentage of what the air can "hold" at that temperature. Since relative humidity depends on temperature, it varies considerably between night and day, as do temperatures in the region. On a daily basis, maximum relative humidity values occur in the early morning, and minimum values occur in mid-afternoon. Annually, the highest values occur in both midwinter and midsummer, and the lowest values occur from April through June.

## EXTREME WEATHER EVENTS

Southern New Mexico is susceptible to many different extreme weather events. Blowing dust storms that can drastically reduce visibility are common. Drought conditions also occur in the region, and winter weather can bring temperatures far below freezing (which can wreak havoc on local vegetation and water pipes) and winter storms can bring snow and wind. Given the hot, desert climate, heat waves, with temperatures above 100°F are also common, as well as heavy rainfall, hail, and flooding from thunderstorms and the occasional tropical storm. Although very rare, tornadoes have occurred in the area.

### *Blowing Dust*

Dust storms can occur at any time of year, but they are most common during the dry winter and spring months, and at the front edge of summer thunderstorms. A key predisposing factor in dust storms is soil disturbance, often from fallowed agricultural land, or land in the process of being developed. These dust storms, also known as *haboobs* (the Arabic name, used by meteorologists, for intense Saharan dust storms), are a particular threat to public health, as particles in the air can affect respiratory health and transportation, where blindingly thick dust storms lead to deadly multi-vehicle accidents.


**Figure 6:** Dust storm on Jornada Road, Las Cruces, NM. March 2011. Photo by Justin Van Zee/NMSU.

Dust levels are typically determined using a measure called "$PM_{10}$" (for particulate matter smaller than 10 micrometers). Exceedance of $PM_{10}$ levels from high winds and blowing dust occurs multiple times per year in the region, but the highest $PM_{10}$ levels occur during the region's driest and warmest years, such as 2003 and 2011. When dust levels are particularly high, visibility can be reduced to less than a half mile, such as on December 8, 2009. In response to high dust levels, state police will issue warnings advising drivers against traveling on highways and interstates in the area.

***Drought***

In addition to the arid climate of Las Cruces, the city and the region can experience drought, from multiple years of below-average precipitation. The Standardized Precipitation Evapotranspiration Index (SPEI) is one of several tools that can be used to estimate the duration and severity of drought. It takes into account both precipitation and, unlike other indices, potential evapotranspiration (or loss of moisture from bodies of water, soils, and through vegetation). The addition of potential evapotranspiration allows the SPEI to capture the main impact of temperature on water demand.

Based on this index, drought conditions have been prevalent in southern New Mexico since about 2000, with only a few years of above-average SPEI values in this recent period. Since 1960, there have been four years of extreme to exceptional drought (2001, 2003, 2011, and 2012), based on the U.S. Drought Monitor definition of SPEI values less than -1.6. Note that all four of these years have been since 2000, a period in which regional temperatures have been rising. The two years with the lowest SPEI values (2003 and 2012) are also the two hottest years on record for Doña Ana County.

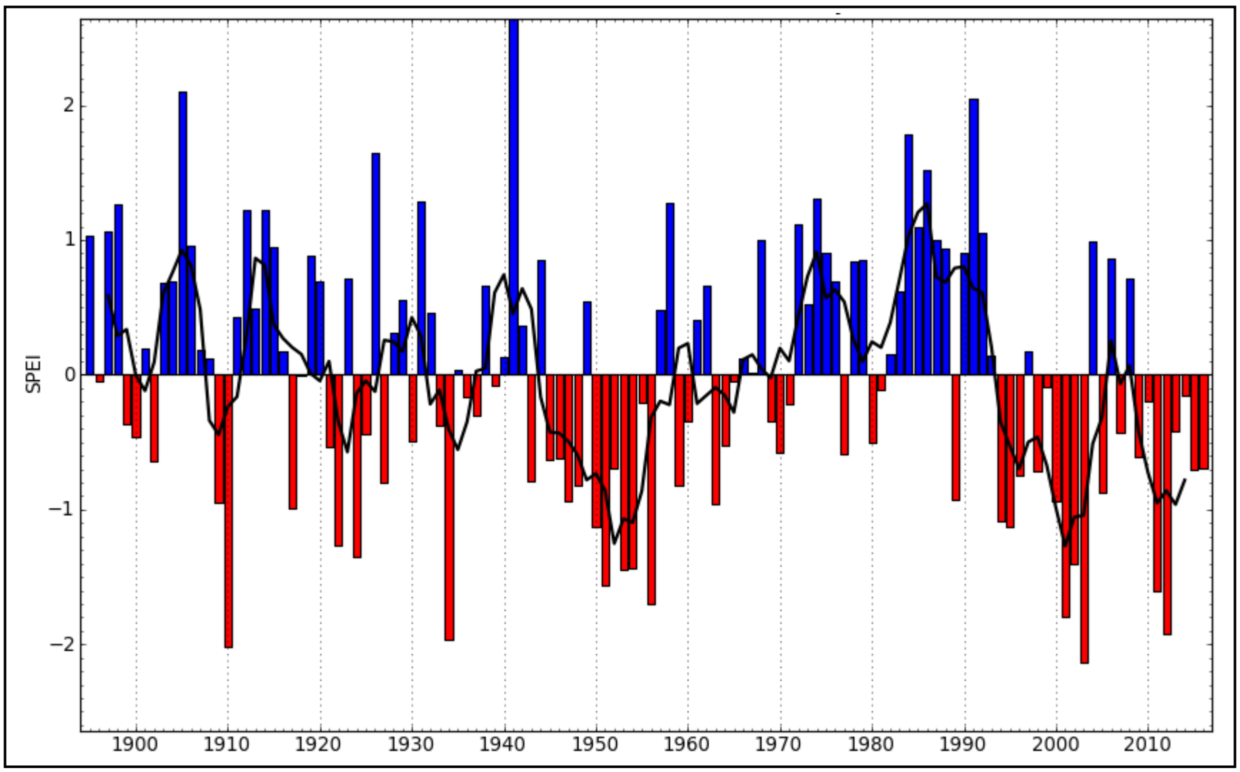



**Figure 7:** SPEI values for Doña Ana County. Black line is the 5-year running mean. Source: WestWide Drought Tracker, Western Regional Climate Center.

The percent area of Doña Ana County experiencing drought conditions, as observed by the U.S. Drought Monitor, tells a similar story to the SPEI index described above (Figure 8). During the winter of 2003-2004, the entire county was categorized as experiencing exceptional drought (the most severe drought category), and during most of 2011 (a La Niña year) almost the entire county experienced extreme to exceptional drought.

Agriculture is a very important part of the regional economy, and it relies primarily on water from the Rio Grande. The cumulative impact of the current drought has drastically reduced Rio Grande streamflow, to the point that farmers have had to sell off land because there was not enough water to grow their crops. As of October, 2016, Elephant Butte Reservoir, which provides power and irrigation to south-central New Mexico, was at about 7% of its capacity.

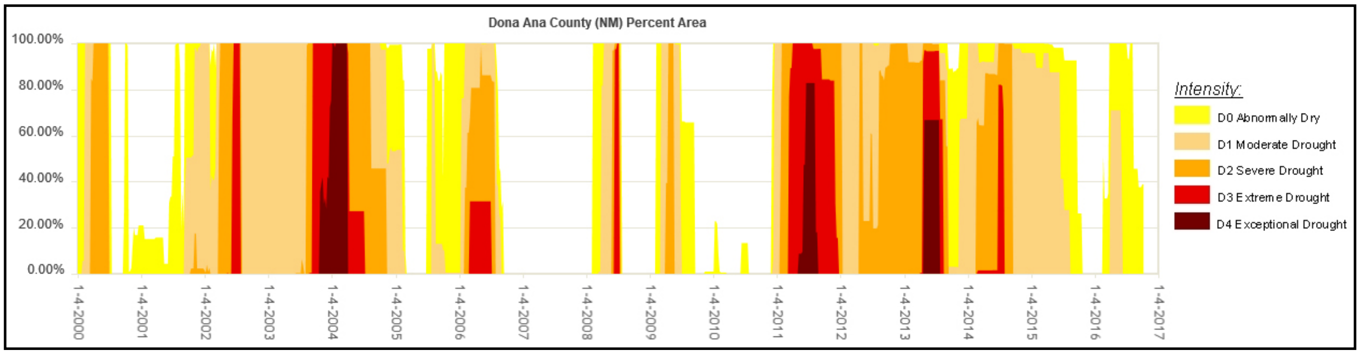



**Figure 8:** U.S. Drought Monitor Percent of Doña Ana County, NM in drought from 2000–2017. The color shows the intensity of drought, the height of the bar shows the percent of the county in drought during a certain time period (along the bottom). For example, on January 4th, 2005, about 50% of the county was in moderate drought, and about 50% was abnormally dry.

### *Extreme Cold*

Extreme cold temperatures, relative to the average, can wreak havoc on any region. Sustained, below freezing temperatures can result in economic losses from frozen crops, downed power lines, or ruptured water pipes. Extreme cold temperatures can also pose a health risk, especially to vulnerable populations and animals. If increased demand for heating puts too much stress on a power plant in the region, that power plant may be forced to shut down, limiting the ability of residents to heat their homes and further affecting vulnerable populations.

Temperatures in Las Cruces regularly dip below freezing. As stated earlier, the average monthly low temperature for December and January is about 28°F. Sustained temperatures well below this average occur less often, but are still common in the region. In fact, temperatures have fallen below 0°F eight times since 1892, in late November, early December, and January.

Below-zero temperatures in 1962 and 1976 caused schools and businesses to close, froze water pipes, and resulted in the failure of gas and electricity deliveries. The most recent occurrence of extreme freezing temperatures was in early February, 2011, when temperatures dropped below zero in many areas of the county. The event lasted three days, and the prolonged severe cold had a substantial impact on the city and the NMSU campus. Campuses closed, because of dangerous driving conditions from snow-packed roads, then had to stay closed for two more days because of power outages and low pressure in natural gas lines.

In addition to cold temperatures, snow and sleet have also affected the region. On January 6, 1997, a major winter storm brought heavy snow to southern New Mexico, stranding motorists on I-25 north of Las Cruces, and closing I-10 between El Paso, TX and the Arizona border. Other highways were also closed due to the storm or traffic accidents. Hundreds of people were forced to stay overnight at NMSU due to the road closures.

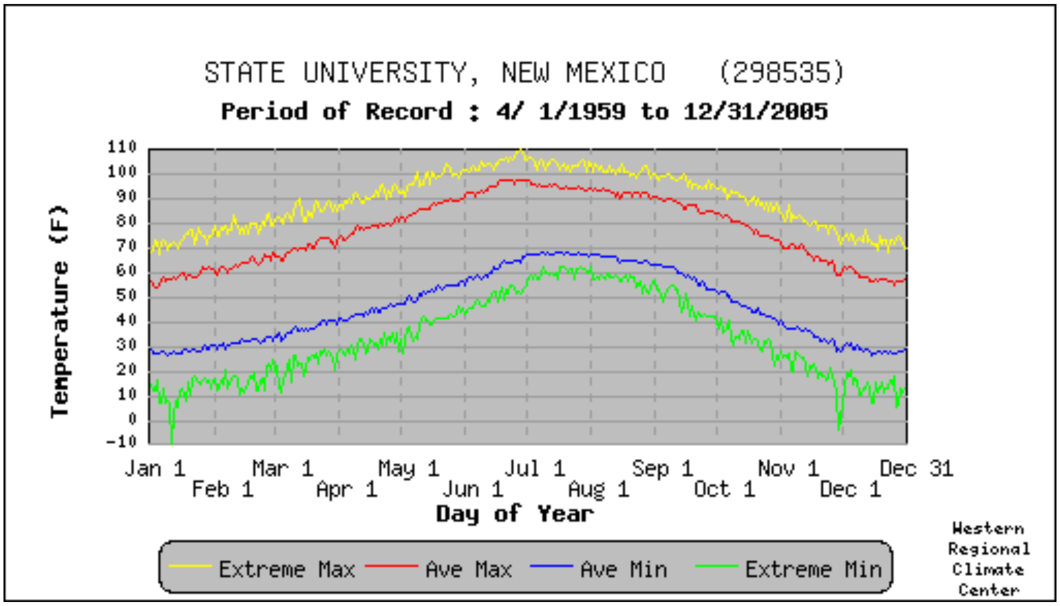



**Figure 9:** Daily average minimum (blue) and extreme minimum (green) temperatures.

***Extreme Heat***

The leading weather-related cause of death in the United States is heat stress. The most common impacts of extreme heat are health-related, such as dehydration, heat stress, and heat stroke, but extreme heat can also lead to brownouts and blackouts, due to excessive use of electric power, often associated with the need to use air conditioners, evaporative coolers, and fans. Extreme heat can lead to airport closures, flight delays or cancellations, roads buckling, and damaged crops. It can even exacerbate the impacts of drought, as in 2003 and 2012.

| **Table 1:** Top fifteen hottest days in Las Cruces (in °F) | |
|---|---|
| June 28, 1994 | 110 |
| July 8, 1951 | 109 |
| June 26, 1994 | 109 |
| June 27, 1994 | 109 |
| June 29, 1994 | 109 |
| June 28, 1951 | 107 |
| July 9, 1951 | 107 |
| June 21, 1960 | 107 |
| June 25, 1978 | 107 |
| June 23, 1981 | 107 |
| July 3, 1989 | 107 |
| June 26, 1990 | 107 |
| July 2, 1994 | 107 |
| June 7, 2010 | 107 |
| June 28, 2013 | 107 |

Citizens are accustomed to the extreme heat associated with Las Cruces' arid, desert climate. This, however, does not diminish the impact that consecutive days of above-normal temperatures can have on the city and its residents. Compounded with this is the impact of consecutive nights of above-average minimum temperatures. These can sometimes be more impactful than high daytime temperatures, because human body temperatures cannot sufficiently cool, in the absence of adequate artificial cooling, such as air conditioning.

From 1892 to 2015, the highest temperature ever recorded in Las Cruces was 110°F on June 28, 1994. Four of the five hottest days on record (Table 1) occurred during this heat wave, in which temperatures were over 105°F for 7 consecutive days (June 26–July 2, 1994). There have been five years in which Las Cruces experienced more than 30 days with 100+ degree temperatures: 32 days in 1951, 33 days in 1978, 32 days in 1980, 31 days in 2005, and 34 days in 2002. Most of the high temperatures in 1951 were associated with a prolonged spell of extremely hot weather from June 18 to July 12, when temperatures were at or above 100°F for 21 of the 25 days, and reached as high as 109°F.

The increasing trend of temperatures in the Southwest region, including Las Cruces, will likely result in more heat waves and fewer cold waves in the region. In addition, as the population of the region grows, many more people are exposed to extreme heat. Land use changes—paving and building—amplify nighttime temperatures occurring in urban areas, such as Las Cruces. This is known as the urban heat island effect (UHI), where buildings and roads retain heat more than vegetated areas, thus urban temperatures are higher than surrounding rural areas.

### *Flooding*

Heavy rainfall from monsoon thunderstorms, July through September, spurs the most common type of flooding in the Las Cruces area. These storms bring large amounts of moisture in exceedingly short periods of time, generating *flash floods*. The greatest amount of rainfall in a 24-hour period recorded for Las Cruces is 6.49 inches from August 29-30, 1935. Almost 6 inches of rain fell in 4 hours. More recent examples of extensive damage from monsoon thunderstorm flooding are described below.

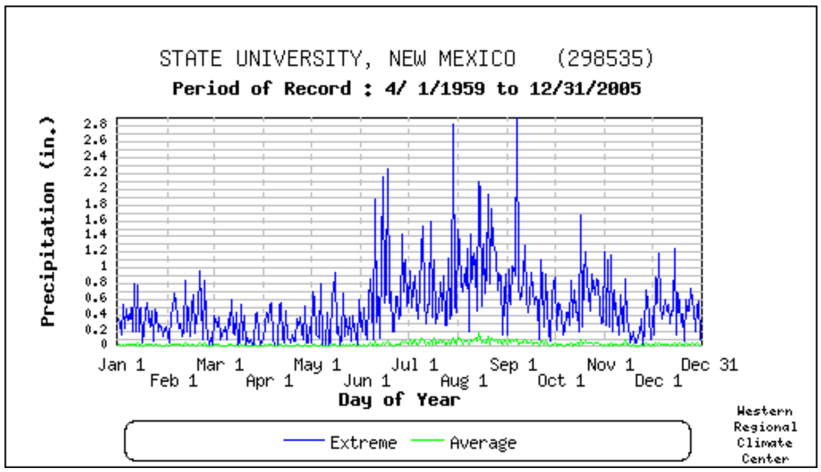



**Figure 10:** Daily average (green) and extreme (blue) precipitation for Las Cruces.

- July 28, 1994: 3 inches of rain fell, flooding businesses, homes, and a day care center; there was almost $6 million in damage to crops and properties.
- August 1, 2006: 3 inches of rain fell, closing I-10, forcing the evacuation of over 1,000 county residents, and causing $3 million in infrastructure damage.
- August 28, 2006: Water runoff from heavy rain falling over the Uvas Valley flooded I-10 between Las Cruces and Deming with water up to three feet deep, closing the highway and resulting in traffic jams and travel disruptions.

**Figure 11:** Interstate 10 between Las Cruces and Deming on August 28, 2006, closed due to flooding. Photo by Bruce Bradley/NWS.

During the warm half of the year, tropical storms can deliver moisture to the region, directly, if there is a land-falling storm, or indirectly, if the remnants of a moisture-laden tropical storm get incorporated into the prevailing winds across the region. Tropical storms usually soak large areas over the course of several days, which saturates soil and sets up conditions for extensive flooding. Examples of tropical storm floods include September 1-4, 2006, when rain from tropical moisture flooded homes and created mudslides, and on September 18, 2014, when remnants from Hurricane Odile dropped over an inch of rain (measured at the airport) overnight, flooding roads and homes.

A less common type of flooding is from winter storms. During El Niño years, when the eastern tropical Pacific Ocean is warmer than normal, winter to spring precipitation, particularly during January through March, tends to be much higher than normal and has led to flooding in the region.

***Tornadoes***

Although tornadoes are not common in southern New Mexico, they occur occasionally and have been known to leave damage in their wake, if they touch ground near a developed area. They usually occur during the warm months of the year (May–September), in situations when cold, dry air, usually through a cold front, overrides warm, moist tropical air and creates intense atmospheric instability. Most tornadoes in Doña Ana County last less than 30 minutes, and are category F0 or F1—the lowest grades of tornado strength.

The tornado that caused the most damage occurred on September 13, 2006. In combination with severe wind and hail, the storm caused $10 million in damages. Roofs and automobiles were damaged, the U.S. Border Patrol Checkpoint was evacuated, and the state fairgrounds west of Las Cruces were damaged.

| **Table 2:** Tornado occurrences in Doña Ana County |
|---|
| July 29, 1959 |
| September 7, 1966 |
| September 19, 1972 |
| July 31, 1979 |
| July 22, 1987 |
| September 22, 1988 |
| July 28, 1989 |
| June 19, 2001 |
| August 2, 2002 |
| September 13, 2006 |
| May 2, 2007 |
| July 13, 2011 |

***Thunderstorms***

Given the strong summer precipitation peak in Las Cruces, and its relative nearness to the Gulf of Mexico and to the tropical Pacific Ocean, thunderstorms are very common. The average number of thunderstorms each year is about 42 (based on data from El Paso, TX, the nearest station with this information). They typically occur in the summer months, during the monsoon season (July through September), and also from remnants of tropical storms, which can occur as late in the year as November. These thunderstorms can produce heavy rainfall, flooding, hail, and intense winds.

Impacts from thunderstorms, which are mostly from severe wind, range from downed trees and power lines, to infrastructure damage and flooding. There are several examples of thunderstorms resulting in damage to the Las Cruces area. In June, 1989, winds associated with a thunderstorm gusted to 102 miles per hour, knocking several traffic lights to the ground. On July 1, 1991, a thunderstorm damaged telephone lines, blew a large canopy into a semi-trailer truck along I-25, and blew out windows and roofing material. On June 3, 2004, damaging winds and golf-ball sized hail knocked down a tower at the Las Cruces Airport, damaging several aircraft, including a helicopter ambulance.

## CLIMATE MODELS

For cities and their departments charged with managing and maintaining public infrastructure and services, climate change matters, because it introduces changes to the Earth's climate system that cannot be predicted, based only on an asssessment of historical data. Infrastructure, building codes and many other types of planning are all built on the assumption that past climate can reliably predict the range of future conditions expected in a given place: the hundred-year flood event, the risk of summer heat waves, even the length of the growing season. For many decades, that assumption has been relatively accurate. Today, however, climate is changing so rapidly and affecting dynamics in the Earth's climate system so profoundly that, one thing we know for sure is that using the past as a guide to the future will give us the wrong answer.

These rapid changes in the climate system are the motivation for developing long-term climate projections for Las Cruces. Through relying on a combination of long-term historical observations, global climate model simulations, and "downscaling" methods that transfer the global simulations to time scales and geographic scales that are locally-relevant, it is possible to identify the direction of future trends. For some factors, it is even possible to identify the likely magnitude of expected changes, within a range of natural variability, scientific uncertainty, and range of human choices.

*The need for models*. Scientists use climate models, or "virtual Earths," to better understand the Earth's climate. Since conducting experiments on another Earth is impossible, scientists must rely on their extensive accumulated knowledge of how the climate system works, such as oceanic and atmospheric circulation, vegetation changes, and interactions between the land surface and the overlying atmosphere. They then use this knowledge to build climate models and run model experiments to learn more about how the Earth's climate has responded to past changes, such as major volcanic eruptions, or develop projections of future changes, such as how the climate system will respond to atmospheric changes driven by humans, through increased population, and/or increased use of renewable energy or fossil fuels (Walsh et al. 2014b).

*What models do*. "Climate models are based on mathematical and physical equations representing the fundamental laws of nature and the many processes that affect the Earth's climate system. When the virtual atmosphere, land, and ocean are divided into small grid cells and these equations are applied to each grid cell, the models can capture the evolving patterns of atmospheric pressures, winds, temperatures, and precipitation. Over longer timeframes, these models simulate wind patterns, high and low pressure systems, and other weather characteristics that make up climate" (Walsh et al. 2014b).

*Why we use scenarios*. Future emissions of heat-trapping gases will be driven by human choices including population, energy, technology, economics, and policy. Regardless of which choices society makes, climate will continue to change, due to two primary reasons. First, some heat-trapping gases remain in the atmosphere for many decades and their indirect impacts, such as the absorption of extra heat by the slow-moving deep ocean, may not be felt in the climate system for many decades; this is important, because human activities, such as the burning of fossil fuels, convey much heat-trapping gases to the atmosphere. Second, the effects of transitioning the global economy from carbon-emitting to clean sources of energy may not be felt for many years. In order for atmospheric concentrations of heat-trapping gases to decline prior to mid-century, there would need to be a net uptake of carbon from the atmosphere—humans would need to take up more carbon than they emit (National Research Council 2011).

Beyond around the year 2050, however, the amount of future climate change depends on human emissions of carbon dioxide and other heat-trapping gases. Higher scenarios of emissions of heat-trapping gases assume continued dependence on fossil fuels such as coal, gas, and oil, and produce greater amounts of temperature change (Figure 12). Lower scenarios` envision a transition from fossil fuels to non-carbon-emitting renewable energy sources; this puts fewer gases in the atmosphere, trapping less heat, resulting in smaller amounts of temperature change.

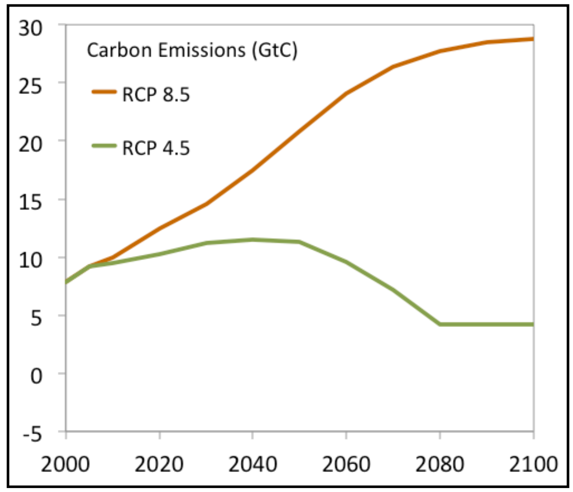



**Figure 12:** Climate change projections were developed for two scenarios: the higher scenario (RCP 8.5), where human emissions of carbon dioxide and other heat-trapping gases continue to rise, and the lower scenario (RCP 4.5), where emissions peak and then begin to decline by mid-century. This figure compares the carbon emissions corresponding to each scenario.

To quantify the range of plausible human choices over this century, in this analysis we use two scenarios from the IPCC Representative Concentration Pathways (RCPs) (Moss et al. 2010): the higher RCP 8.5 and lower RCP 4.5 scenarios. At the higher end of the range, carbon dioxide levels in the atmosphere increase by more than three times compared to pre-industrial (before about 1750) levels, by 2100. At the lower end, carbon emissions peak around 2050 and then decline, with atmospheric carbon dioxide levels approximately double that of pre-industrial levels by 2100. Global average temperature changes resulting from lower and higher scenarios range from 4°F (under lower) to 9°F (under higher) by 2100. A 9°F change may not seem like much, but it is approximately the same as the change in global temperature from the last Ice Age to the present.

These model- and scenario-based projections of future climate can inform long-term planning by providing information on possible future conditions. In some cases, that information is qualitative (identifying the existence or direction of a trend), while in others it can be quantitative (estimating the numerical difference between a near-term and future time period, or between the changes expected under a higher vs. a lower future scenario).

*Why we downscale*. Global climate models, able to capture the geographical details of climate, are run by powerful supercomputers that require enormous computing resources, allowing climate scientists to study changes in climate, and how these changes will impact the world (Walsh et al. 2014b). Yet, global climate model output is usually at a geographic scale where the sides of a grid cell are approximately 200 miles—much larger than the size of most counties, no less a city. For that reason, our project used a method, generally referred to as "statistical downscaling," to generate locally-relevant information. Downscaling incorporates new information—here, long-term observations for the local university weather station—into Global Climate Model (GCM) projections, to produce local-scale projections of temperature, precipitation, and other variables at a given location. Over the next decade, scientists expect computer speeds to increase another 100-fold or more, permitting the exploration of even more details of the climate system. For readers interested in the details of the method that we used, see below for the bibliographic reference to the peer-reviewed journal article by A. Stoner and colleagues (2012).

*Confidence in model projections*. Several factors affect our confidence in climate model projections. Some important physical processes in climate models are not fully understood, or they are at a scale that a climate model cannot directly represent, and are thus represented in the models by approximate relationships (Walsh et al. 2014b). Examples include the representation of individual clouds, or the small-scale aspects of the process of convection—these important processes occur at scales much smaller than the resolution of current global climate models. Approximations, based on evidence from the best available science, are used to address these issues; however, approximations lead to *scientific uncertainties* in model simulations of climate (Walsh et al. 2014b). Since climate models differ in the way they represent various processes, different models produce slightly different projections of change. In this project, we apply the best practice of using multiple models in order to represent this range of projected outcomes. Research shows that the average of a large set of model simulations is nearly always closer to reality than any individual model or subset of models.

Internal (natural) variability of the climate system is the result of interactions between different components of the climate system, such as the exchange of heat energy between the ocean and the atmosphere. Research shows that the range of natural variability is most important over the next few decades. Beyond these time frames, longer-term climate trends, such as increases in average global temperature, are more important in driving changes in the climate system. We account for natural variability by averaging climate variables and projected impacts over 20-year periods.

Even though natural variability will continue to occur, by the second half of the century, human choices—such as the ones mentioned above—will become the key determinant of future climate change, through their influence on temperatures and ocean and atmospheric circulation patterns (Walsh et al. 2014b). Yet we cannot predict human behavior—especially over the course of decades. Society may choose to reduce emissions or to continue to increase them; scientists use scenarios of future emission pathways to address this form of uncertainty about the future (Walsh et al. 2014b). To encompass the range of possible futures, we developed projections for a higher and lower climate change scenario. (Note: these scenarios are referred to as Representative Concentration Pathways or RCPs).

To produce plausible projections of the future climate of Las Cruces, we average multiple models, examine projections based on multiple scenarios of emissions of heat-trapping gases, average the data over longer (20-year) time periods, and downscale the global model outputs to locally-relevant scales. To further ensure that the projections are valid, we: 1) assess the ability of the models to represent the processes of the past; 2) review whether the model output conforms with our expectations, based on the laws of physics, chemistry, and other basic sciences; and 3) examine the agreement between trends in current phenomena (such as an observed decrease in snowpack) and projected future trends.

Below are references that provide details about the procedures we used. Full citations can be found in the references section at the end of this document.

- Moss et al. 2010. Detailed information on the two climate change scenarios (RCP 4.5 and 8.5).
- Stoner et al. 2012. The project used credible, well-replicated statistical methods to make the global model output relevant to local spatial scales. This reference provides details of this method, called the Asynchronous Regional Regresson Model version 1.
- The relationship between emissions and atmospheric concentrations of heat-trapping gases is discussed in detail in the 2011 National Research Council report, "Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia" http://dels.nas.edu/Report/Climate-Stabilization-Targets-Emissions-Concentrations/12877.
- Melillo et al. 2014 (known as the Third National Climate Assessment); http://nca2014.globalchange.gov/. The National Climate Assessment (NCA) is produced every four years by agencies in the U.S. government, and in particular the U.S. Global Change Research Program (USGCRP). The NCA, written by hundreds of experts and reviewed by other experts and the public, outlines the current and future impacts of climate change in the U.S. The NCA as a

whole is a great resource, but the specific chapters and appendices below provide more details about the procedures we used:

- o Walsh et al. 2014a (Chapter 2; http://nca2014.globalchange.gov/highlights/report-findings/our-changing-climate). This chapter describes how and why the climate is changing, and what projections show for the future, for the U.S. and the world. It also summarizes what has happened, in terms of the science and impacts of climate change, since the previous NCA in 2009.
- o Appendix 3 (http://nca2014.globalchange.gov/report/appendices/climate-science-supplement) expands on the material outlined in Chapter 2, and gives more details on attribution and physical mechanisms of climate change. It also provides more details on model simulations.
- o Walsh et al. 2014b (Appendix 4; http://nca2014.globalchange.gov/report/appendices/faqs). This appendix contains frequently asked questions about climate change, including specific questions about climate models, such as downscaling and reliability. The quotations in the Climate Models section of this document are from Appendix 4 of NCA3.

## CLIMATE PROJECTIONS FOR LAS CRUCES

The previous section outlined the methods and models used to develop high-resolution climate projections for Las Cruces. Below we show specific projections for Las Cruces, using the RCP 4.5 (lower) and RCP 8.5 (higher) scenarios described in the previous section. In the figures below, the range of models in the higher scenario is shown in shaded pink, with the mean of the models shown as a red line, and the range of models in the lower scenario is shown in shaded pale orange, with the mean of the models shown as an orange line. The black line in the figures show historical observations from 1950 to 2016.

### *Warm Temperatures*

Temperatures in Las Cruces are projected to increase, both during the day and at night, and heat waves will become longer and more severe. Additionally, consecutive days that are both dry and hot will become more frequent.

*Daytime temperatures*

Historically, daytime temperatures reach 100°F or more in Las Cruces an average of 9 days per year, with a range of 0 to about 30 days per year, meaning some years have no days that reach 100°F and some years have 30 days (Figure 13, black line). As stated at the beginning of this report, temperatures in Las Cruces have been rising since the early 1990s, and this can also be seen in the observations in Figure 13. Models project

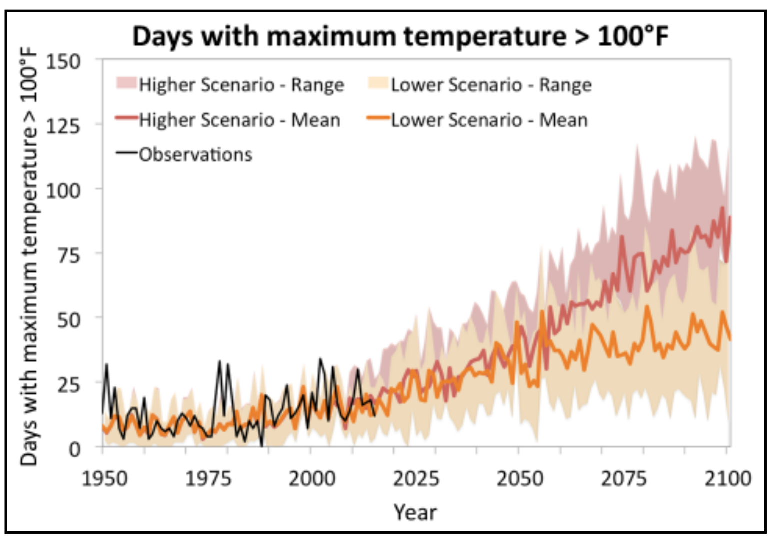



**Figure 13:** Projections of days with a maximum temperature at or above 100°F for a lower emissions scenario (orange line) and higher scenario (red line). Shaded areas indicate the range of model projections, and colored lines indicate the average of all models. Black line shows historical observations.

this trend to continue. Under a lower future climate scenario, the number of days that reach 100°F or more will continue to increase until about the year 2050, at which point the average number of days that reach 100°F or more will approximately stay steady at about 40 days per year, with some years possibly experiencing 75 or more days per year above 100°F (Figure 13, orange line and shaded area). Temperature changes based on the higher emissions scenario are similar to those from the lower scenario until about the year 2050; after 2050 the days per year reaching 100°F or more keeps increasing, to an average of about 80 days per year, with some years possibly experiencing over 100 days per year of 100°F or more (Figure 13, red line and shaded area).

Similarly, the number of days per year that reach at least 105°F are projected to increase by the year 2100 (figure not shown). Historically, there are very few days each year that reach temperatures this high, and in some years temperatures never reach this high. Based on the lower scenario, there will be about 10 days per year that reach 105°F or more by the year 2050, and about 15 days per year by the year 2100; some years may experience temperatures this high for more than 25 days per year. Based on the higher scenario, the number of days per year that reach 105°F or more will continue increasing to an average of about 45-50 days per year, with some years experiencing as many as 75 days per year, with temperatures 105°F or higher, by 2100.

*Heat waves*

For some decisions related to public health or energy consumption, it is not as important how many days per year reach a certain temperature, but how many *days in a row* reach that temperature. Historically in Las Cruces, the average length of heat waves—where each day reaches at least 100°F—is about 3 days. By the year 2050, this is projected to double, based on both low and high emissions scenarios, with the average length of 100°F heat waves lasting about 6 days. By the year 2100, the average length of heat waves could be as high as 10 days, based on the higher scenario. The maximum length of heat waves is also projected to increase. Currently, the longest heat waves (in which every day reaches at least 100°F) are as long as 15 days. By the year 2050, the longest heat waves in which consecutive days have temperatures at or above 100°F will be about 20 days; by 2100 this could be as long as 40 days, based on the higher scenario.

*Dry heat waves*

Consecutive days that are both hot and dry (no precipitation) increases evapotranspiration (evaporation from water, plants and soils) and can impact water resources. Currently, Las Cruces experiences an average of about 1–2 events per year in which there are 5 consecutive days with the maximum temperature at or above 100°F and no precipitation. By 2050, the average is projected to be closer to 2–3 events per year, and by 2100, 3–4 events, based on the higher emissions scenario.

*Nighttime temperatures*

While maximum temperatures are important for public health, water, and other concerns, greater impacts to public health can be caused by warm nighttime temperatures, because there is little opportunity for people, especially those who lack adequate cooling or who are in a frail condition, to recover from the depletion that comes with prolonged exposure to heat. Historically, Las Cruces has not experienced any nights in which the minimum temperature has stayed at or above 80°F (Figure 14). By 2050, climate models project that there will be about 2 nights/year in which the temperature does not cool below 80°F, and by 2100 this number rises to about 4 nights/year—based on the lower scenario. Based on the higher scenario, however, Las Cruces could experience as many as 40 nights/year in which the minimum temperature stays at or above 80°F.

Heat waves, during which the nighttime temperature stays at or above 80°F for multiple days in a row, are also projected to increase. As stated previously, Las Cruces does not currently experience nights like this, but by the year 2050, the region may experience an average of 3 consecutive nights of temperatures at or above 80°F, and an average 7 consecutive nights by the year 2100, based on the higher scenario. The longest heat waves will also get even longer; by 2050 the longest heat wave with consecutive days with minimum temperatures staying at or above 80°F will be about 4-5 days long, and as high as 20 days in a row by the year 2100, based on the higher scenario. This many consecutive nights where temperatures do not drop below 80°F, coupled with daytime temperatures above 100°F, could result in many more heat-related illnesses and deaths, and could affect wildlife, the availability and integrity of their habitat, and the functioning of ecosystems.

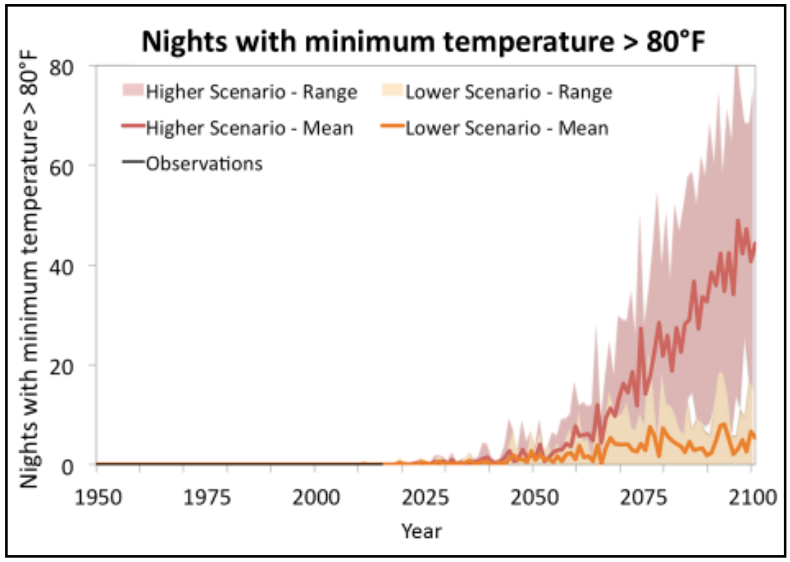



**Figure 14:** Projections of nights with a minimum temperature at or above 80°F for a lower emissions scenario (orange line) and higher scenario (red line). Shaded areas indicate the range of model projections, and colored lines indicate the average of all models. Black line shows historical observations.

### *Cold Temperatures*

If warm temperatures are projected to increase, it is no surprise then that cold temperatures are projected to decrease. Figure 15 shows changes in cold temperatures by 30-year periods to illustrate the trend in decreasing frequency of nights with minimum temperatures below freezing (32°F). From 1950–1979, Las Cruces experienced an average of about 100 nights per year that dropped below

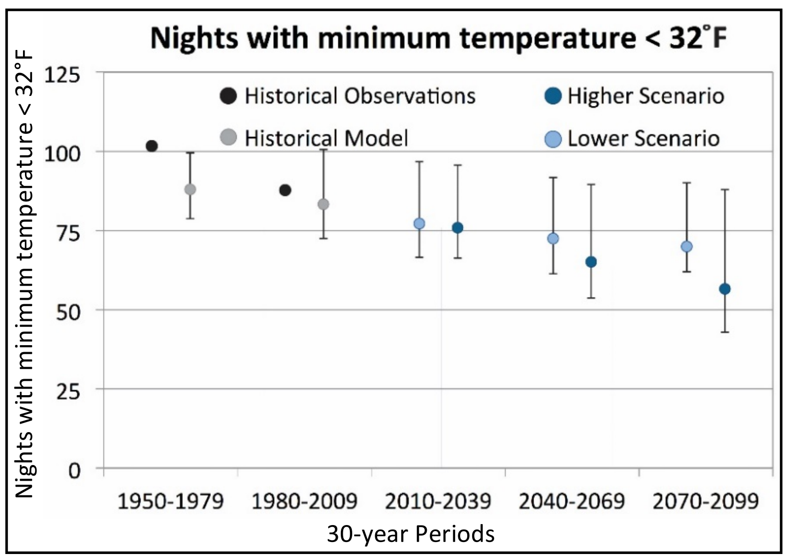



**Figure 15:** Projections of nights with a minimum temperature below freezing (32°F). Each dot shows the average, over the 30-year period, of historical observations (black), model simulations of historical temperatures (gray), and model simulations of future temperatures based on the lower climate change scenario (RCP 4.5; light blue) and the higher climate change scenario (RCP 8.5; dark blue). The vertical, thin black lines show the range of all the model simulations.

freezing, and by 1980–2009 this number dropped to about 87 nights per year. This trend is projected to continue, with an average of about 65 freeze nights per year by 2050, and 55 nights by 2100 based on the higher scenario. The trend shown in Figure 15 is the same for hard freeze nights (nights with temperatures below 28°F); currently there are about 50 nights per year that drop below 28°F, and by 2050 there will be about 40 nights per year, and about 35 nights per year by 2100 based on the higher scenario.

*Cold spells*

Interestingly, even though the number of cold nights is projected to decrease, the average length of cold spells—consecutive nights below freezing—is projected to stay about the same (figure not shown). This means that the weather patterns that bring multi-night cold events are not predicted to change. There are still projected to be plenty of nights below freezing, and this just indicates that when those nights do occur, they will likely occur as multi-night cold events. The models, however, project a slight decrease in the longest cold spells, from about 16 consecutive nights below freezing, currently, to about 12 nights by 2100; this is what accounts for the overall decrease in nights below freezing. In other words, on average, cold spells will stay about the same, but they won't be as long as they have been historically.

*Growing season indicators*

We are defining the growing season, in this document, as the period of time between the last freeze (32°F) in spring and the first freeze in autumn, or the freeze-free season. According to the historical observations for Las Cruces, the date of the last freeze in spring is already occurring about a month earlier, from about April 7th in the 1950s to about March 7th currently (Figure 16). Even more interesting, is that this change has been occurring even faster than climate models have projected. This is also seen in the date of the first freeze in autumn, which is occurring about two weeks later now than it did in the mid- 20th century; again the changes are occurring faster than projected by climate models (Figure 17). In both cases, this trend is projected to continue, with the date of the last freeze in spring occurring around late-February to early-March by the year 2100, and the date of the first freeze in autumn occurring around late November. There are similar trends for dates of first and last hard freezes (28°F) in autumn and spring, and these trends are also projected to continue through the year 2100 (figure not shown).

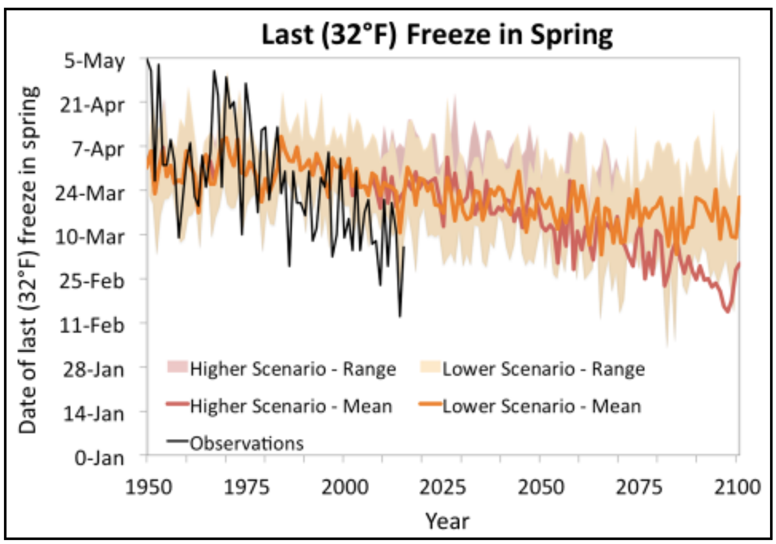



**Figure 16:** Projections of date of last freeze (32°F) in spring for a lower emissions scenario (orange line) and higher scenario (red line). Shaded areas indicate the range of model projections, and colored lines indicate the average of all models. Black line shows historical observations.

While a longer growing season may be beneficial to some plants and crops, fewer freeze days may be harmful to some tree crops, such as pecans, that require a minimum amount of cold days (chilling hours) in order to bud in spring (Frisvold et al., 2013).

### *Precipitation*

Unlike with temperature, there is no observable trend in average precipitation in Las Cruces. This is also represented in the model simulations that show extreme variability in precipitation (figure not shown). Even with this large variability, the models suggest that there may be a slight increase in extreme precipitation events by 2100, which is consistent with atmospheric dynamics, given that warmer air holds more moisture. Similarly, the length of wet spells—consecutive days with precipitation—is not projected to substantially change in the future.

### *Drought*

It is difficult to model drought, given the interactions of the many factors involved, such as temperature, precipitation, and soil moisture. However, we can model precipitation, and determine how often models project conditions as dry as, or drier than, the driest year in the historic record. We focused on the summer season, as this is when Las Cruces receives the majority of its annual precipitation.

In Figure 18, the driest summer on record is identified by the gray circle (1970), and that value is represented by the gray straight line. According to model projections, summers drier than the driest summer on record may occur (represented by values that drop below the gray line), but not any more or less frequently than they have occurred in the past.

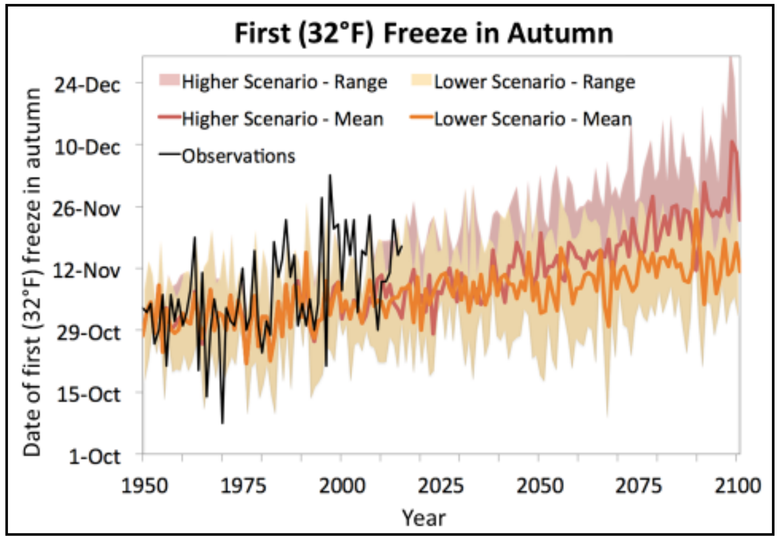



**Figure 17:** Projections of date of first freeze (32°F) in autumn for a lower emissions scenario (orange line) and higher scenario (red line). Shaded areas indicate the range of model projections, and colored lines indicate the average of all models. Black line shows historical observations.

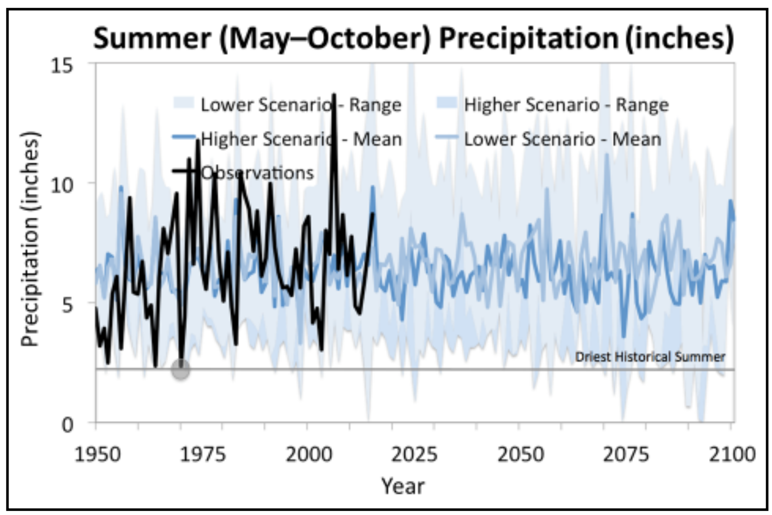



**Figure 18:** Projections of summer (defined here as May–October) precipitation, to illustrate the probability of the occurrence of a summer drier than the driest on record. Gray circle identifies the driest summer on record. The black line shows observations, the dark blue line represents projections based on the higher scenario, and the light blue line represents projections based on the lower scenario. Corresponding shading represents the range of models for each scenario.

### ***Summary***

Model projections for Las Cruces are consistent with observed trends and projections for the Southwest U.S. Current trends of increasing temperatures are projected to continue, resulting in more frequent extreme heat days and warm nights, and many less cold nights. There is also a greater risk of prolonged, multi-day heat events, based on the occurrence of daytime maximum and nighttime minimum temperatures. Consistent with projections of warmer temperatures is the projection of a longer freeze-free season, with the last freeze in spring projected to occur up to 4 weeks earlier by the end of the century and the first frost in autumn projected to occur up to 2 weeks later.

The projections of changes in precipitation are not as consistent. Projections show a potential slight increase in days with heavy rainfall, but no change in the duration of wet spells. Projections also show little change in average summer precipitation, compared with historic summer precipitation variations, and the risk of a future summer as dry as the driest summer in the historical record is not projected to substantially change. However, even though precipitation may remain about the same, higher temperatures will increase evaporation, drying out soils.

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# About the Project

### The Issue

Many cities already experience a variety of extreme weather and climate related events from ice storms and floods to heat waves and droughts. Frequently, when they look at projections of future environmental conditions, those projections present either *a)* averages that don't help with the wide swings in extreme events that will actually cause problems, or *b)* such wide differences between minimum and maximum values that planning is difficult. One way to address this challenge is to use the concept of thresholds. The threshold concept helps users define at what points weather events have caused problems historically, determine when projected future changes could cause problems, and helps translate climate projections into decision and action points that managers can use on a daily basis.

### The Project

Thanks to the generous support of the National Oceanic and Atmospheric Administration (NOAA), the City of Las Cruces worked collaboratively with the project team to identify critical extreme weather thresholds for the City and community, analyze the best available climate projections to identify potential future changes relative to those thresholds, interpret that information, and develop and implement strategies to prepare for those impacts.

### The Project Team

In addition to City leadership and expertise, this project brought together an experienced team from six organizations:

- ***Adaptation International*** and the ***Institute for Social and Environmental Transition (ISET)***, two organizations experienced in working with communities to increase climate resilience and prepare for the impacts of a changing climate;
- Three of NOAA's Regionally Integrated Science and Assessment Programs (RISAs): the ***Western Water Assessment (WAA)***, the ***Climate Assessment for the Southwest (CLIMAS)*** and the ***Southern Climate Impacts Planning Program (SCIPP)***;
- ***ATMOS Research***, with extensive experience in developing and applying high-resolution climate projections to impact analyses in cities, regions, and states across the United States.

### The Results

Las Cruces received relevant climate and extreme weather information that is customized and specific to the thresholds identified during the project, an opportunity for multi-sector and inter-departmental collaboration convened and facilitated by an outside organization, and seed funding to facilitate use of thresholds in a climate preparedness project. Community leaders and City staff can use the climate and extreme weather information to support climate action, motivate participation, increase general climate literacy, and ultimately increase community resilience.

This report was developed under a grant from NOAA Sectoral Applications Research Program (SARP), NA14OAR4310248, in association with Adaptation International (Sascha Petersen, Lead Investigator), the Institute for Social and Environmental Transition (ISET), Atmos Research, the Southern Climate Impacts Planning Program (SCIPP) and the Climate Assessment for the Southwest (CLIMAS).