CLIMATE PROFILE OF
GILA RIVER INDIAN COMMUNITY

CLIMATE PROFILE OF GILA RIVER INDIAN COMMUNITY

DEVELOPED FOR:
Gila River Indian Community Department of Environmental Quality

COMPILED BY:
University of Arizona's Center for Climate Adaptation Science and Solutions, Native Nations Climate Adaptation Program, and Climate Assessment for the Southwest

WITH FUNDING FROM:
The Agnese Nelms Haury Program in Environment and Social Justice

Alison M. Meadow
University of Arizona
Institute of the Environment

Sarah LeRoy
University of Arizona
Institute of the Environment

Valerie A. Small
University of Arizona
Native Nations Climate Adaptation Program

Jeremy Weiss
University of Arizona
School of Natural Resources and the Environment

Mary Black
University of Arizona
Center for Climate Adaptation Science and Solutions

Michael A. Crimmins
University of Arizona
Department of Soil, Water and Environmental Sciences

Daniel B. Ferguson
University of Arizona
Climate Assessment for the Southwest

SUGGESTED CITATION:
Meadow, A., S. LeRoy, V. A. Small, J. Weiss, M. Black, M. A. Crimmins, and D. B. Ferguson (2017) Climate Profile. Native Nations Climate Adaptation Program; University of Arizona. www.ccass.arizona.edu/nncap

For More Information Contact:
Alison Meadow
Staff Scientist
Institute of the Environment - University of Arizona
meadow@email.arizona.edu
520-626-0652

COVER PHOTO COURTESY OF THE GILA RIVER INDIAN COMMUNITY

CONTENTS

COURTESY OF THE GILA RIVER INDIAN COMMUNITY

INTRODUCTION

Decisions that require the use of climate and weather information, such as how to best manage water resources or adapt to a changing climate, often need long-term records–or data–about daily ***weather***[1]. The most basic form of weather data is made up of measurements of temperature and precipitation taken at least once a day. When collected at the same locations for a long time, weather data give us a lot of information about the ***climate*** of a place. For example, by looking at many years of weather data we can see how prone a region is to droughts, floods, heat waves or cold spells. These historical weather records also reveal ***climate trends*** like whether a place is getting wetter, drier, warmer, or cooler over a long period of time. Climate researchers also use computer models to create estimates of future climate conditions, commonly referred to as ***climate projections***. All of this information can be useful in helping a community make decisions about natural resources or economic development opportunities. Historical data can reveal the kinds of weather events that have impacted the community in the past, while climate model projections can be helpful for planning for the future. This climate profile has been created for the Gila River Indian Community (GRIC) in central Arizona (Figure 1) using available current and historic weather data and computer model projections of future climate.

Here we provide:

a. Information that summarizes what the climate at GRIC has been like since around 1900 and identifies recent trends in temperatures;

b. Background information on climate change trends in the United States and Arizona;

c. Projections of possible changes in Arizona's climate (including GRIC);

d. A discussion about why the climate is changing and possible impacts; and

e. General information on climate adaptation planning.

---

[1] Bolded terms are included in the Glossary

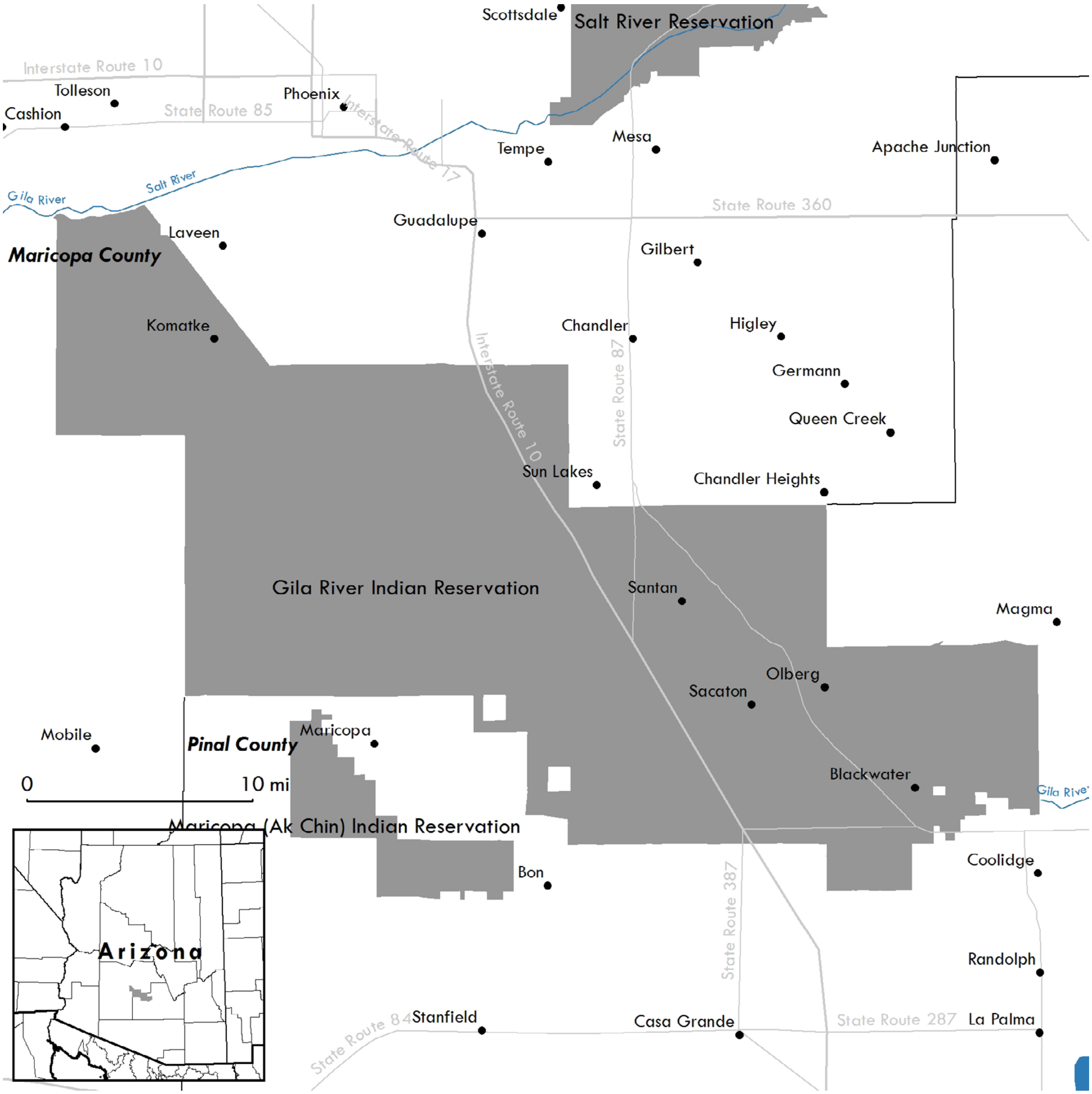

Figure 1: Location of the Gila River Indian Community (GRIC)

BASELINE CLIMATE DATA FOR THE GILA RIVER INDIAN COMMUNITY

To analyze the climate of the Gila River Indian Community, we relied on the PRISM (Parameter-elevation Regression on Independent Slopes Model) dataset (http://prism.oregonstate.edu/). PRISM is a method that uses those weather-station observations that are available in a particular region to estimate climate variables for 2.5-mile (4-km) areas in a continuous grid across the United States[2]. The stations used in PRISM mainly come from the National Weather Service Cooperative Observer Program of the National Oceanic and Atmospheric Administration.

PRISM allows for an accurate analysis of climate across large areas because, in addition to the data generated by weather stations, it accounts for variations in weather and climate due to complex terrain, rain shadows, elevation, and ***aspect*** all of which affect weather patterns for GRIC. PRISM data begin in 1895 with the first consistently recorded instrumental climate records.

[2] See Appendix B for more on gridded datasets.

Climatologists refer to the period from 1895 to the present as the “instrumental record” period. Because of the way PRISM models use information from multiple weather stations and calculate the areas between weather stations it is possible to generate climate information for areas even when individual weather stations do not have long periods of record.

Temperature in Historical Perspective

Between 1895 (the earliest recorded temperature) and 2015 the annual average temperature across GRIC was 70° F (represented by the bold orange line in Figure 2). However, year-to-year averages range from 67.5° F to 73° F (represented by the jagged orange line). Although year-to-year changes in temperature–what climate scientists call ***variability***–is natural, we see a fairly consistent rising trend in annual temperatures since the early 1980s, which is likely a result of anthropogenic ***greenhouse gas*** (GHG) emissions. Since the late 1980s, almost all years have been above average.

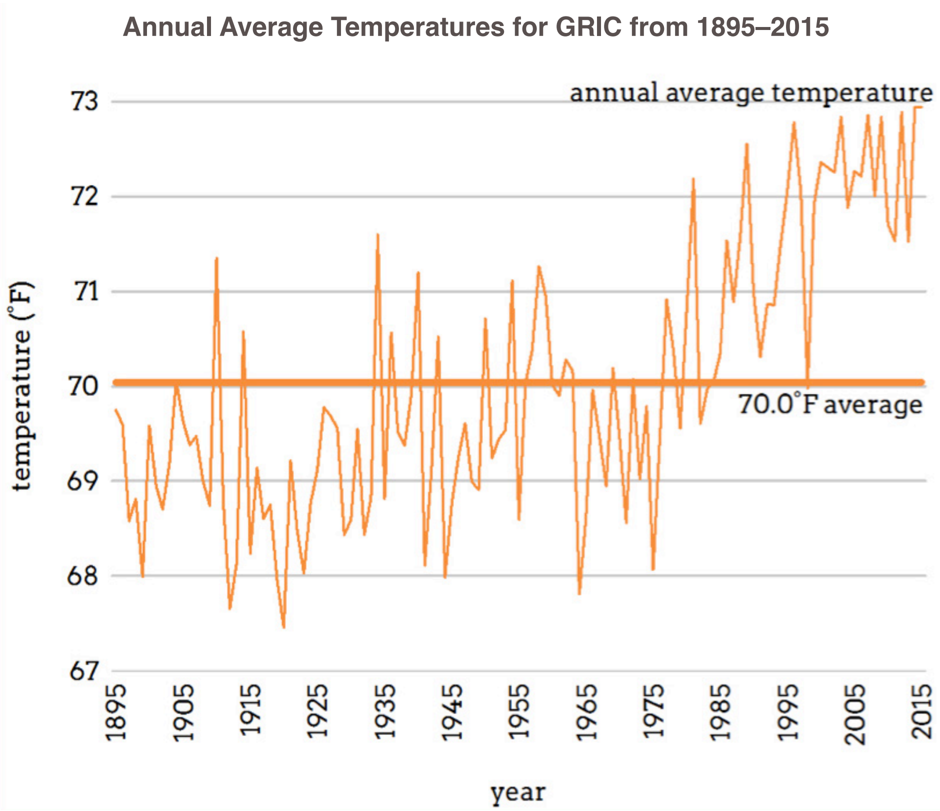

Figure 2: Annual average temperatures for the instrumental record (1895 through 2015) at GRIC. The long-term average temperature is 70° F (represented by the bold orange line), but has ranged from 67.5° F to 73° F (each peak in the jagged orange line represents an individual year’s average temperature). While year-to-year variability in temperature is normal, we see a fairly consistently rising trend in annual temperatures since the early 1980s.

Disaggregating temperatures as average daily maximum, average daily minimum, and overall average allows us to identify patterns in the ways in which warming is impacting a region. *Maximum* annual average temperature tells us the average of all the warmest (typically afternoon) daily temperature readings in an area. *Minimum* annual average temperature tells us the average of the lowest temperature readings, which typically occur in the early morning. Annual average is the average of both maximum and minimum temperatures for an area over a given time.

In Figure 3, we see that annual average minimum temperatures (yellow lines) at GRIC have been rising faster than maximums (red lines); the long-term average low temperature is 54.3° F, but in recent years has risen as high as 60° F. This pattern indicates that the coolest times of the day are now warmer and overall warming is being driven by the rise in low temperatures.

The year with the lowest annual *average* temperature (67.5° F) was 1920. The year with the highest annual *average* temperature, of 72.9° F, was 2015. The highest annual average *maximum* temperature was 88.6° F in 1934. The highest *minimum* temperature was 59.9° F in 2015. The recent trend in rising annual average *minimum* temperatures correlates with the trend in rising annual *average* temperatures.

Annual Average Maximum, Average, and Average Minimum Temperatures for GRIC from 1895 - 2015

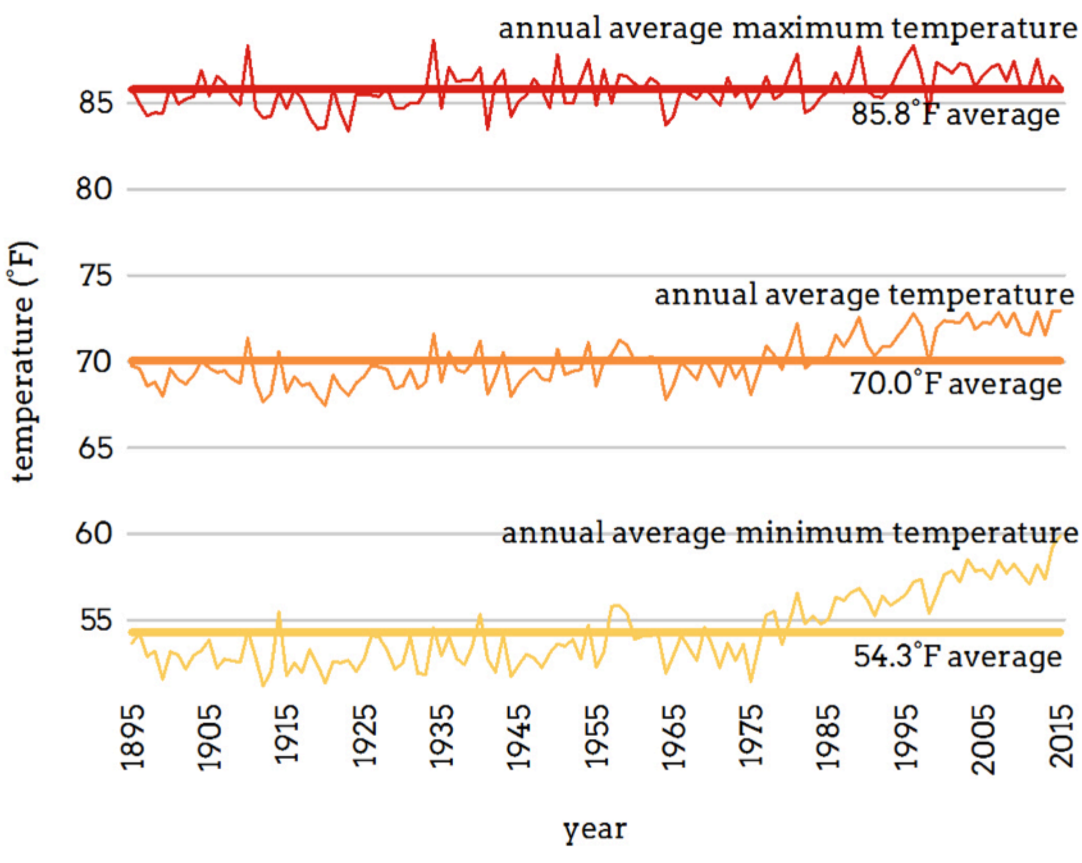

Figure 3: Annual average maximum, average, and average minimum temperatures at GRIC from 1895 through 2015. Annual average minimum temperatures (yellow lines) at GRIC have been rising faster than maximums (red lines); the long-term average low temperature is 54.3° F, but in recent years has risen as high as 60° F. It is likely not cooling as much overnight as in the past. The rise of lower temperatures is what is pushing overall average temperatures higher.

Precipitation in Historical Perspective

In the Sonoran Desert we expect to see most precipitation falling within two periods each year—what climatologists call a ***bi-modal*** precipitation pattern—generally during the summer monsoon and with winter storms. How often we get that precipitation and how much we get is highly variable from year to year. Figure 4 shows the average total precipitation at GRIC from 1895 through 2015, which was just over 8 inches per year, but has been as high as 18.3 inches (in 1905) and as low as 3.2 inches (in 1956). GRIC has experienced two periods of generally above-average precipitation (***pluvials***) with intervening drought periods. The most distinct pluvials occurred from 1905 through the mid-1940s (with some dry years during that period) and again in the late 1970s through the mid-1990s. Multi-year drought periods (multiple years with below average precipitation) occurred in the early 1900s, 1950s, and early 2000s.

Annual Average Precipitation for GRIC from 1895–2015

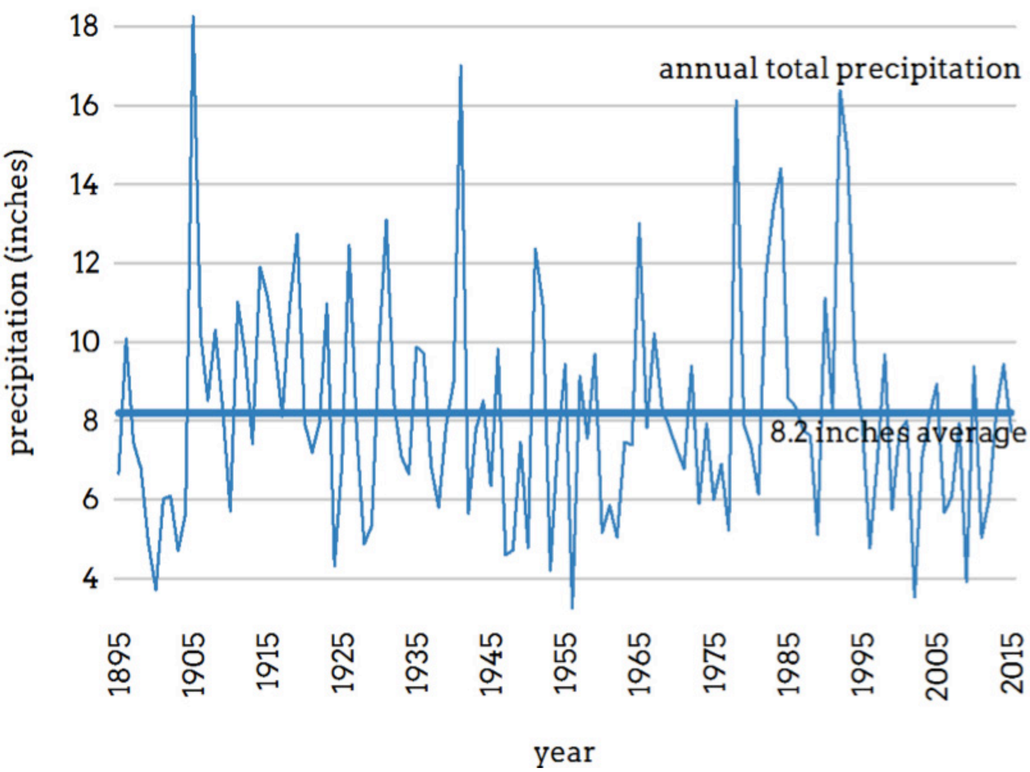

Figure 4: The annual total precipitation from 1895 through 2015 averages 8.3 inches per year at GRIC. Precipitation in the Sonoran Desert is typically variable – which we see represented in the figure (each peak of the jagged blue line represents one year of the record). Precipitation at GRIC has been as high as 18 inches (in 1905) and as low as less than 4 inches in 1956. Over the past 100 years GRIC has experienced two periods of generally above-average annual precipitation with intervening drought periods. The most distinct wet periods, or pluvials, occurred from about 1905 through the mid-1940s and again in the late 1970s through the mid-1990s. Multi-year drought periods are evident in between these wet periods with the early 1900s, 1950s, and early 2000s as the driest periods in the 1895–2015 timespan.

Figure 5 depicts the bi-modal precipitation pattern at GRIC by showing which months tend to be the rainiest. July, August, and September normally bring about 1 inch of precipitation each, then precipitation peaks again from December through March, when winter storms bring moisture to the region.

Average Precipitation by Month for GRIC from 1895–2015

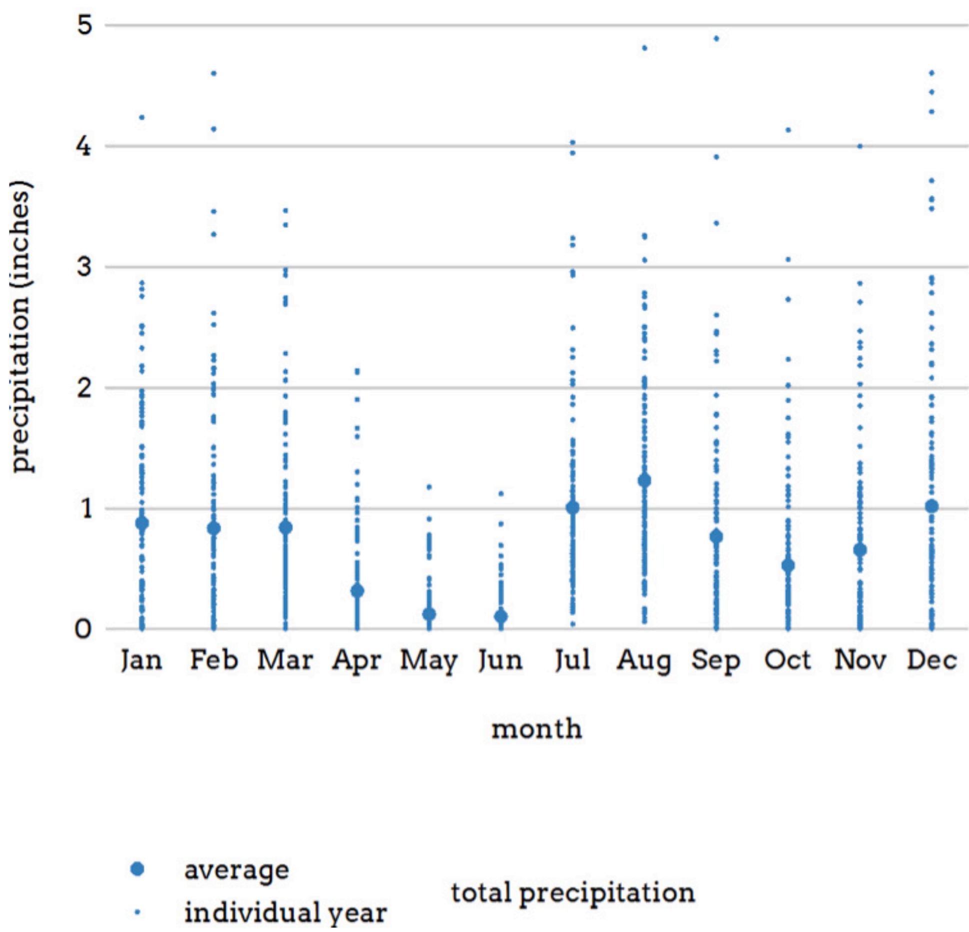

Figure 5: Monthly summary of total precipitation by month for 1895–2015. Precipitation in the Sonoran Desert region typically comes in two distinct time periods: the summer monsoon and the winter rainy season. July, August, and September normally bring about 1 inch of precipitation each, then precipitation peaks again from December through March, when winter storms bring moisture to the region.

El Niño-Southern Oscillation (ENSO)

The El Niño-Southern Oscillation (or ENSO) is a climate phenomenon that can impact the amount of winter precipitation in Arizona. ENSO is a shift in Pacific Ocean surface temperatures along the equator that happens about every two to seven years. Normally, temperatures are cooler in the eastern Pacific and warmer in the western Pacific due to persistent winds blowing from east to west across the ocean—what are called ***easterlies***—causing cool, deeper water to flow upward toward the ocean's surface in the east and the movement of warmer surface water to the west. These conditions occur during the neutral phase of ENSO. In some years, stronger than average easterly winds intensify this pattern of cooler-in-east/warmer-in-west sea-surface temperatures, which is called a La Niña event. During El Niño events, on the other hand, these easterly winds weaken, causing warm water to slosh back to the central and eastern Pacific, resulting in warmer than average sea-surface temperatures in these regions.

Across the continental United States, ENSO's impact is strongest in winter. During El Niño events, a strong airstream splits off from the polar jet stream and steers storms across the southern states, causing above-average precipitation in this region (Figure 6). In contrast, during La Niña events the winter storm track is more likely to affect the Pacific Northwest and leave the southwest United States with less than normal winter precipitation.

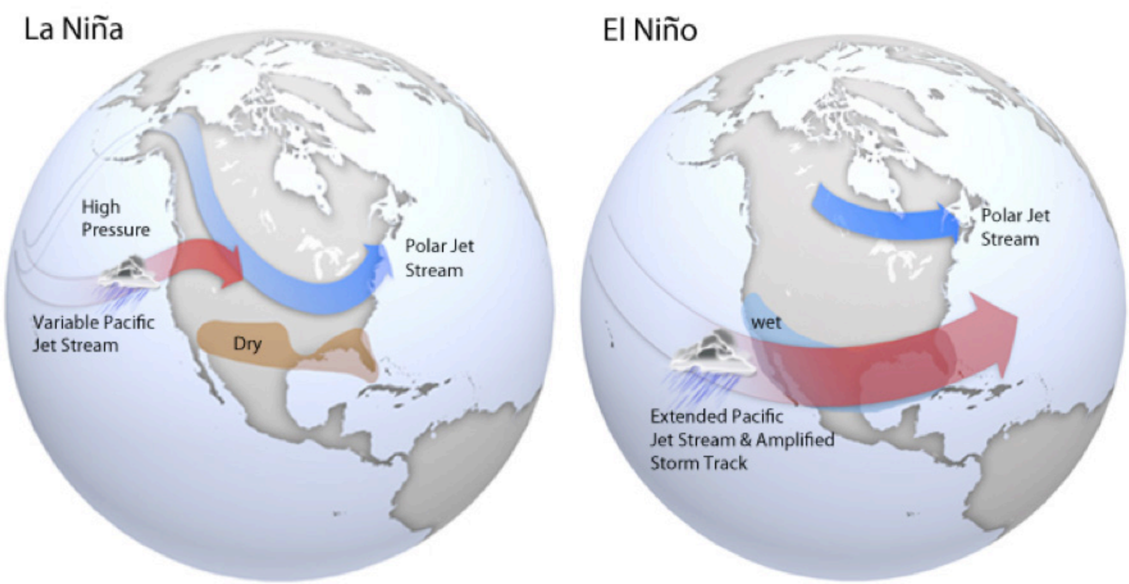

Figure 6: Typical wintertime ENSO impacts across the continental United States. A strong stream of air (red arrow) splits off from the polar jet stream (blue arrow) and steers storms across the southern states, causing above-average precipitation in this region.

Although El Niño years increase the likelihood of wetter winters in this region, it is not a guarantee of increased precipitation. Figure 7 shows the amount of precipitation at GRIC during different ENSO phases from 1950 to 2015 (those years for which good ENSO data are available). In fact, the two wettest winters—both about 5 inches above average (1978 and 1993)—occurred during neutral ENSO years. But, as the red bars indicate, the region does experience higher-than-average precipitation more often in El Niño years.

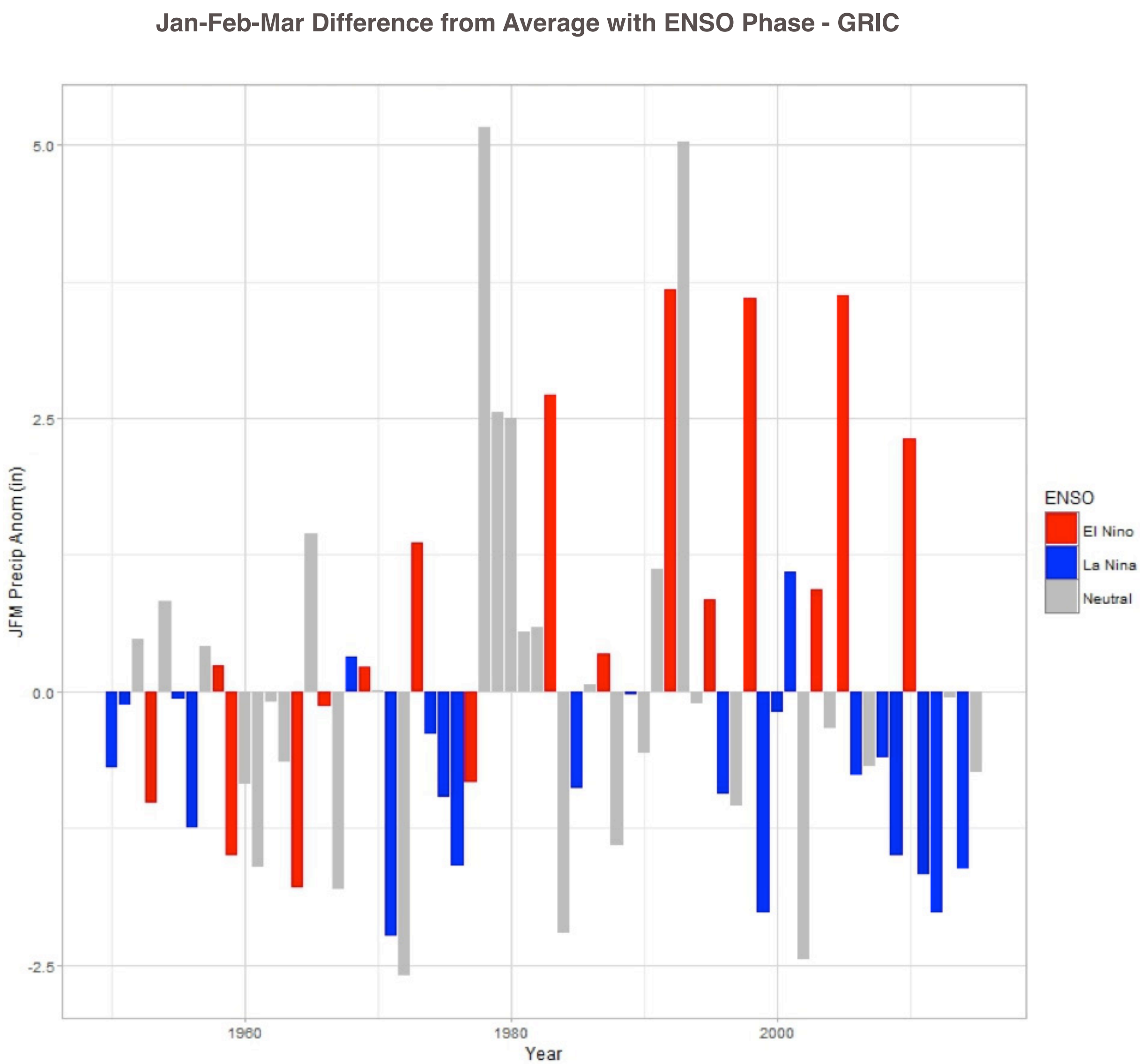

Figure 7: Amount of precipitation at GRIC during different ENSO phases (El Niño (red), La Niña (blue), and neutral (grey) from 1950 to 2015. The two wettest winters—both about 5 inches above average (1978 and 1993)—were during neutral ENSO years. But, as the red bars indicate, the region does experience higher-than-average precipitation more often in El Niño years.

CLIMATE TRENDS AND CLIMATE CHANGE

Global average temperatures are rising. They do not rise everywhere or every year in exactly the same amount, but overall, the whole world is warming up. Figure 8 shows some of the changes scientists and others have observed about the ways in which the Earth is changing. The white arrows indicate increasing trends, like rising temperatures and sea levels. The black arrows indicate decreasing trends, such as the amount of snow in northern and mountain regions.

Ten Indicators of a Warming World

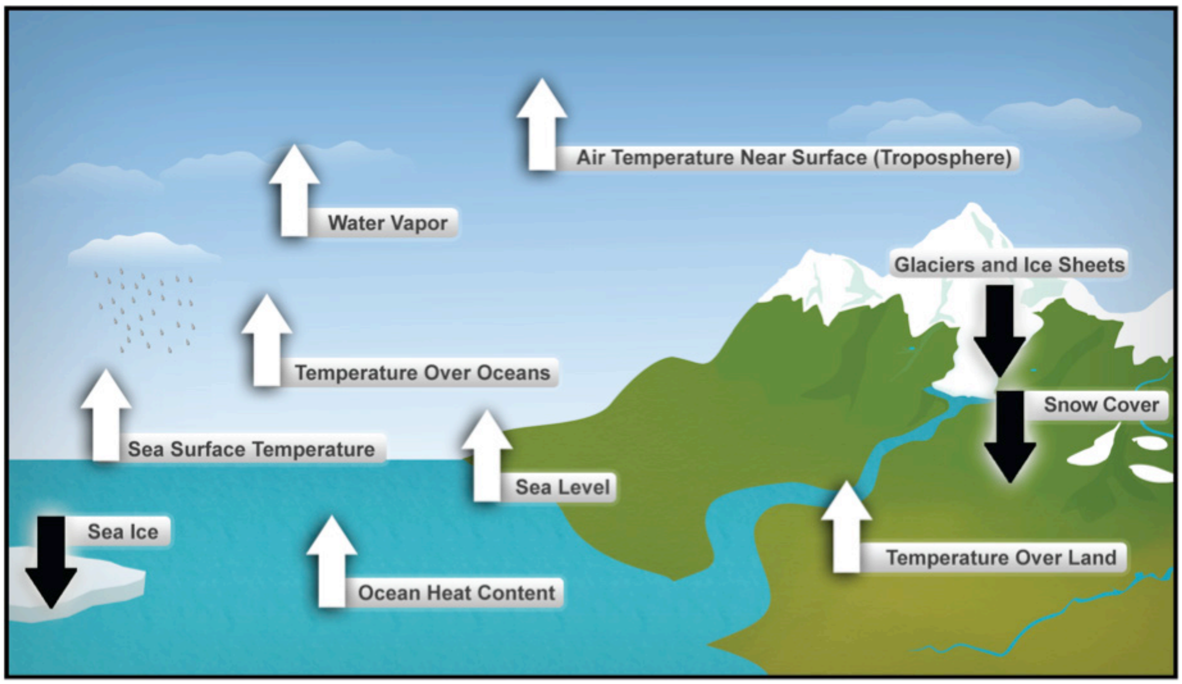

Figure 8: Some of the indicators that the world, as a whole, is warming up. The white arrows indicate increasing trends, like rising temperatures and sea levels. The black arrows indicate decreasing trends, such as the amount of snow in northern and mountain regions. Source: http://nca2014.globalchange.gov/report/our-changing-climate/observed-change#tab2-images.

Figure 9 shows temperature changes from 1991to 2012 in the United States compared to the average temperatures from 1901 to 1960. The darker the red color, the greater the difference between 1901–1960 and 1991–2012: these areas have experienced more warming. While most areas of the United States have warmed in recent decades, not every area has experienced (or will experience) a constant rate of warming. In the southeastern United States there are several areas that appear to have cooled instead of warmed. Researchers have linked this period of cooling to a combination of factors including: thick clouds, which decrease the amount of sunlight reaching the land surface; unusually high soil moisture, which contributes to high evaporation rates; lower daytime temperatures in those areas (Kennedy 2014); sea-surface temperatures in the central Pacific, which affect storm patterns (Meehl et al. 2015); and air pollution from aerosols that scatter or reflect sunlight (Leibensperger et al. 2012). This pattern, sometimes called the “warming hole” (i.e. a hole in the warming trend) has reversed since the year 2000 and the southeastern United States is now warming at a rate similar to surrounding regions (Meehl et al. 2015).

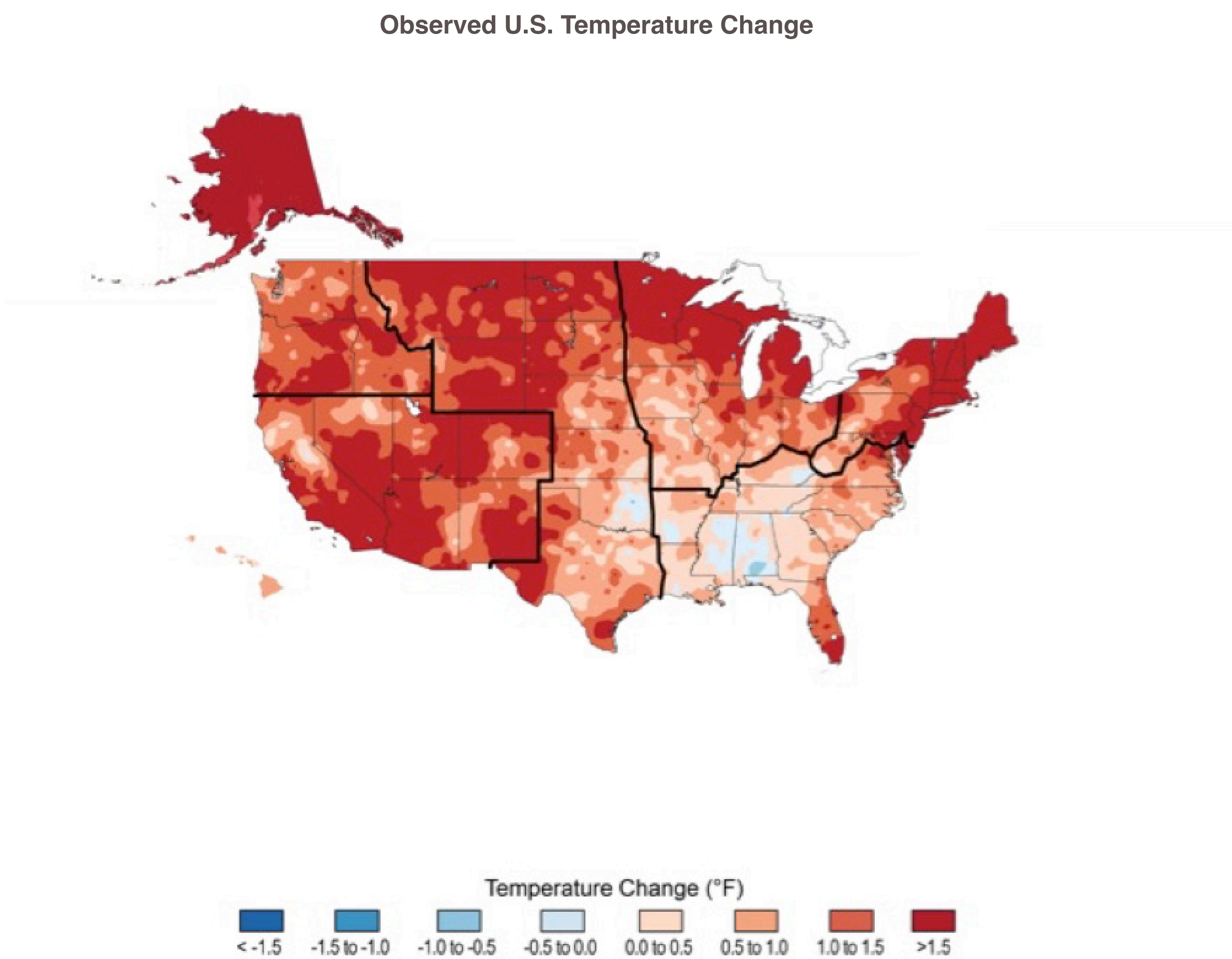

Figure 9: Observed temperature changes from 1991–2012 in the United States compared to the average temperatures from 1901–1960. The darker the red color, the greater the difference between 1901–1960 and 1991–2012: these areas have experienced more warming. (Source: http://nca2014.globalchange.gov/report/our-changing-climate/recent-us-temperature-trends#tab2-images)

Another way to look at temperature trends is shown in Figure 10, a bar chart that depicts temperatures in Arizona from 1895–2015. The straight black horizontal line in the middle of the image is the average temperature from a select period of record known as the ***normals period*** (1981–2010), which was just over 60° F and has been extended backwards to 1895. Blue bars indicate years that were below average and red bars indicate years that were above average. In most years, temperatures have been below the 1981–2010 average, but almost every year since 1994 has been above average. 2014 was the warmest year on record.

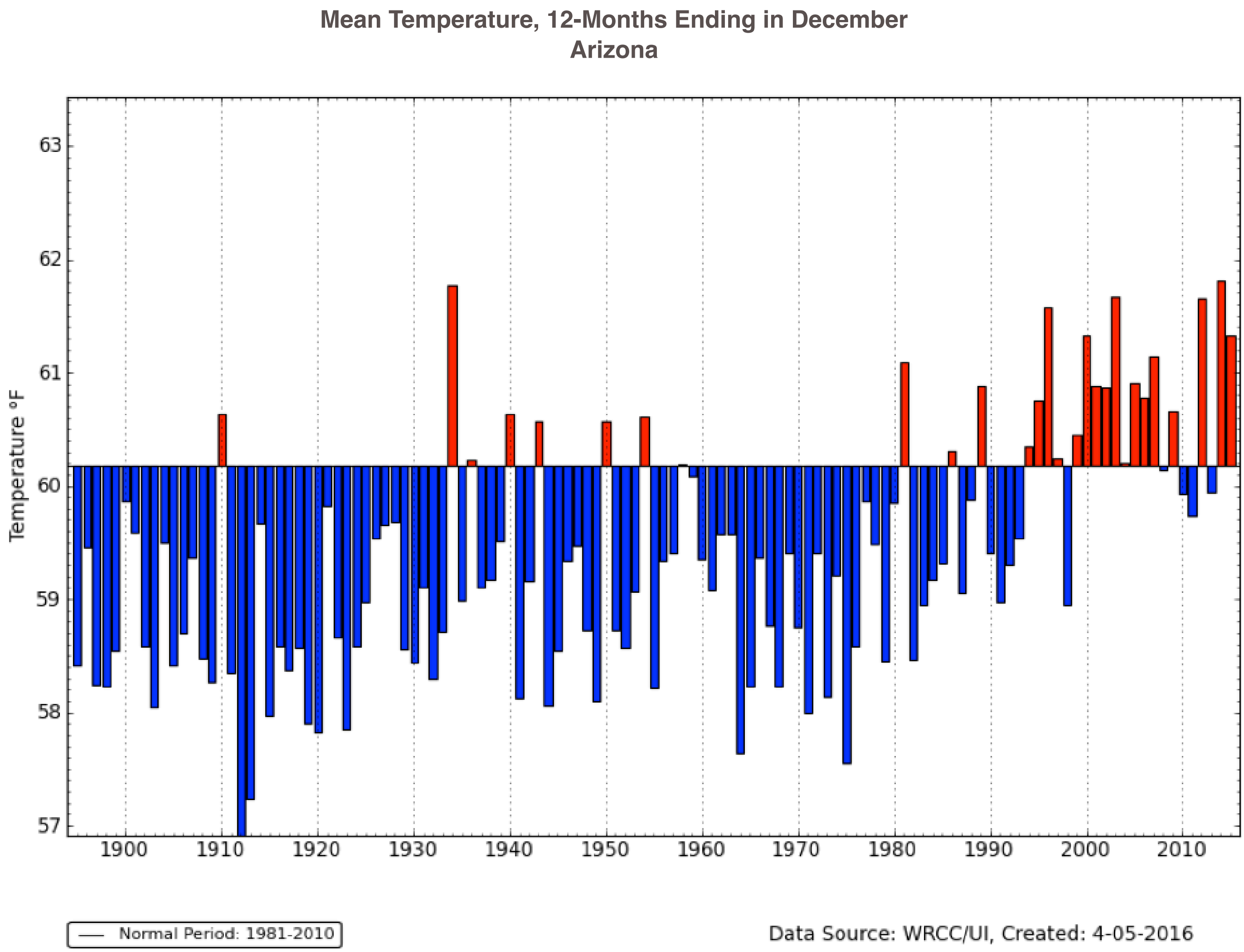

Figure 10: Annual average temperature in Arizona from 1895 to 2015. The straight black horizontal line in the middle of the image is the average temperature from a select period of record known as the 'normals' period (1981–2010), which was just over 60° F and has been extended backwards to 1895. Blue bars indicate years that were below average and red bars indicate those that were above average. In most years, temperatures have been below the 1981–2010 average, but almost every year since 1994 has been above average. 2014 was the warmest year on record.

Why Is the Climate Changing?

The sun's energy enters the Earth as short-wave radiation. The Earth and its atmosphere reflect some of this energy back to space, while some of it naturally passes through the atmosphere and is absorbed by the Earth's surface (Figure 11). This absorbed energy warms the Earth's surface, and is then re-radiated back out to space as long wave radiation. However, some of the long-wave radiation doesn't make it to space and is absorbed in the atmosphere by GHGs, warming the surface and keeping the planet warmer than it would be without an atmosphere. This process is what makes the earth habitable. However, while GHGs are naturally occurring in the atmosphere, human activity is increasing the amounts emitted directly to the atmosphere. Carbon dioxide, methane, and nitrous oxide are important and abundant GHGs. Carbon dioxide (CO_2) is released through the burning of fossil fuels such as coal, natural gas, and gasoline, and accounts for about 75% of the warming impact of these emissions. Methane (from such sources as livestock, fossil fuel extraction, and landfills) accounts for about 14% of the warming impact from GHG emissions, and has a much more potent effect on global warming per unit of gas released. Agriculture contributes nitrous oxide to the atmosphere from fertilizers and livestock waste; it is the most potent GHG and accounts for about 8% of the warming.

By increasing the amount of GHGs emitted to the atmosphere, humans are intensifying the natural effect of warming the planet. Heat from the sun can still get in, but more and more of it cannot get back out. A similar but shorter-term effect can be noticed on cloudy and humid nights when overnight temperatures do not fall to normal lows. The humidity in the atmosphere and cloud layer absorb and release energy, trapping warmth close to the Earth's surface, in contrast to clear and dry nights when heat can escape and surface temperatures quickly fall.

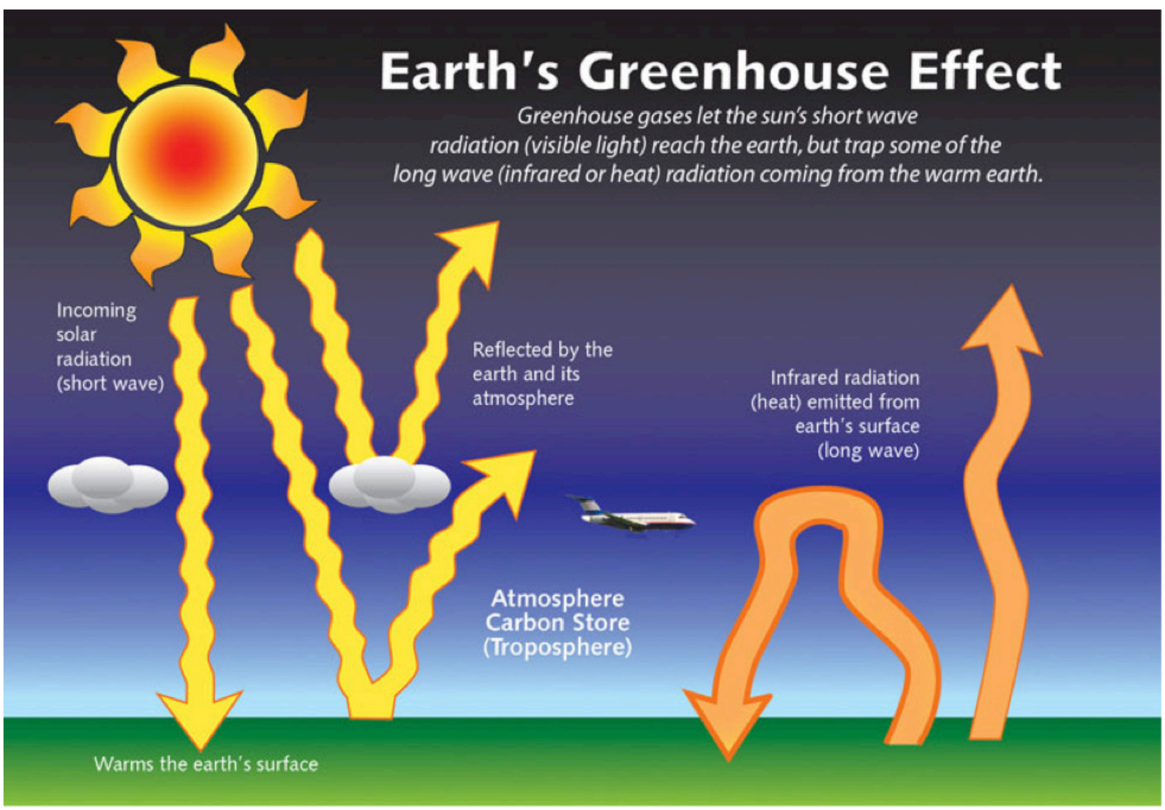

Figure 11: Source: New York State *Department of Environmental Conservation*; http://www.dec.ny.gov/energy/76533.html

By comparing the amount of carbon dioxide in the atmosphere to changes in temperatures, we can see that the rising global temperatures are the result of increasing GHGs. In the graph below (Figure 12), the blue bars represent years with an average temperature lower than the long-term global average of 57° F and the red bars are years in which the temperature was warmer than average. The black line shows the amount of carbon dioxide in the atmosphere (in parts per million, or ppm). As the black line goes up, global average temperatures closely follow. Although we see a long-term trend toward higher temperatures, there are still year-to-year variations in temperature that are due to natural processes such as the effects of ENSO, which can cause global temperatures to quickly rise during El Niño years and cool during La Niña years.

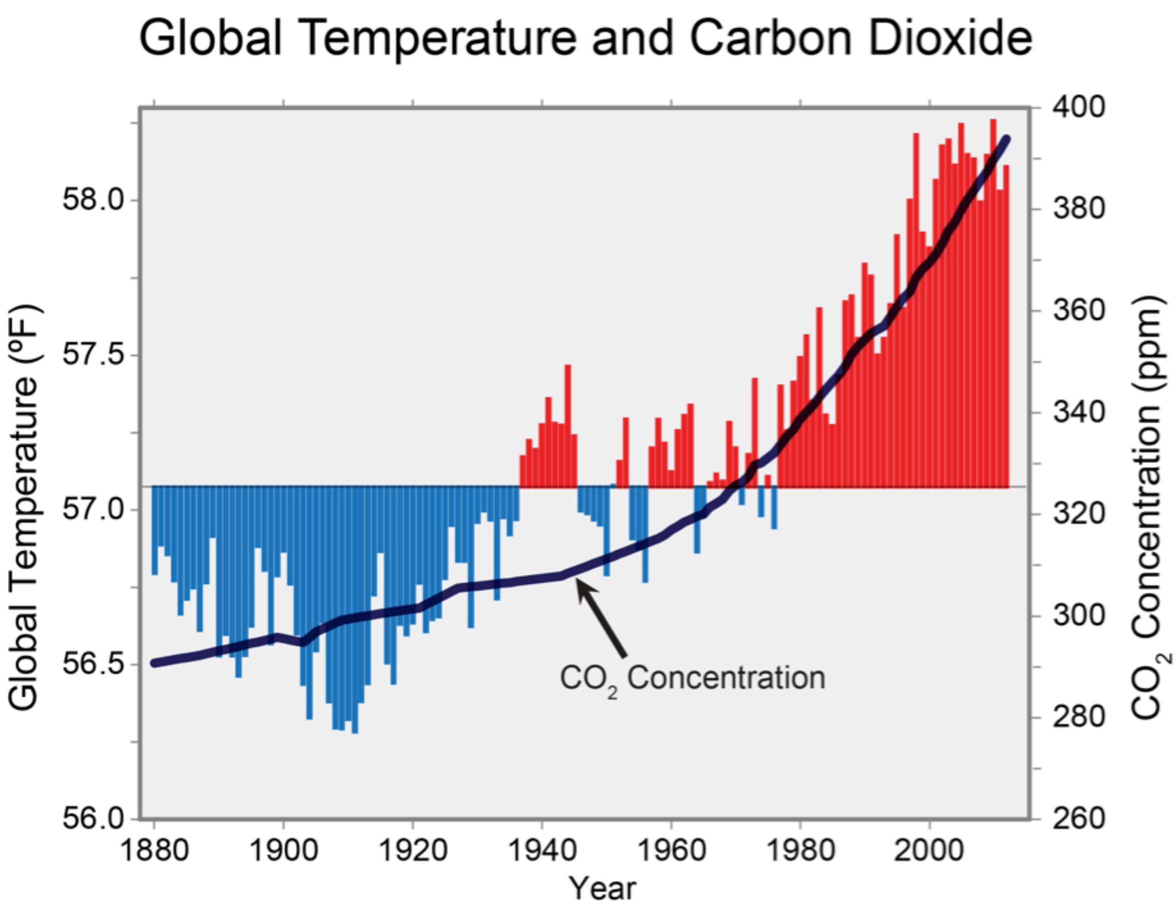

Figure 12: We can trace the corresponding rise in CO_2 and global temperatures. Blue bars represent years with an average temperature lower than the long-term global average of 57° F, and the red bars are years in which the temperature was warmer than average. The black line traces the amount of carbon dioxide in the atmosphere (in parts per million, or ppm). As the black line goes up, global average temperatures closely follow. Year-to-year variations in temperature are due to natural processes such as the effects of ENSO and volcanic eruptions; there are always variations year-to-year. Source: http://nca2014.globalchange.gov/report/our-changing-climate/observed-change#tab2-images

The strong relationship between temperature and amount of carbon dioxide is apparent, and scientists have been able to perform more detailed experiments to confirm that the increasing amounts of GHGs are the cause of the warming. Since a controlled experiment cannot be conducted in the real world by raising and lowering overall GHGs, scientists build mathematical models of the Earth's systems using computers. The graph in Figure 13 shows results of an experiment with climate models in which scientists compared natural warming factors such as periodic changes in how much energy the Earth receives from the sun and volcanic eruptions with the temperatures that had been observed since 1895. They found that the natural warming factors (the green shaded area) do not match the observed temperatures. But when they added in human causes—GHG emissions—along with natural processes (the blue shaded area) they found that their results matched very well with the observed temperatures.

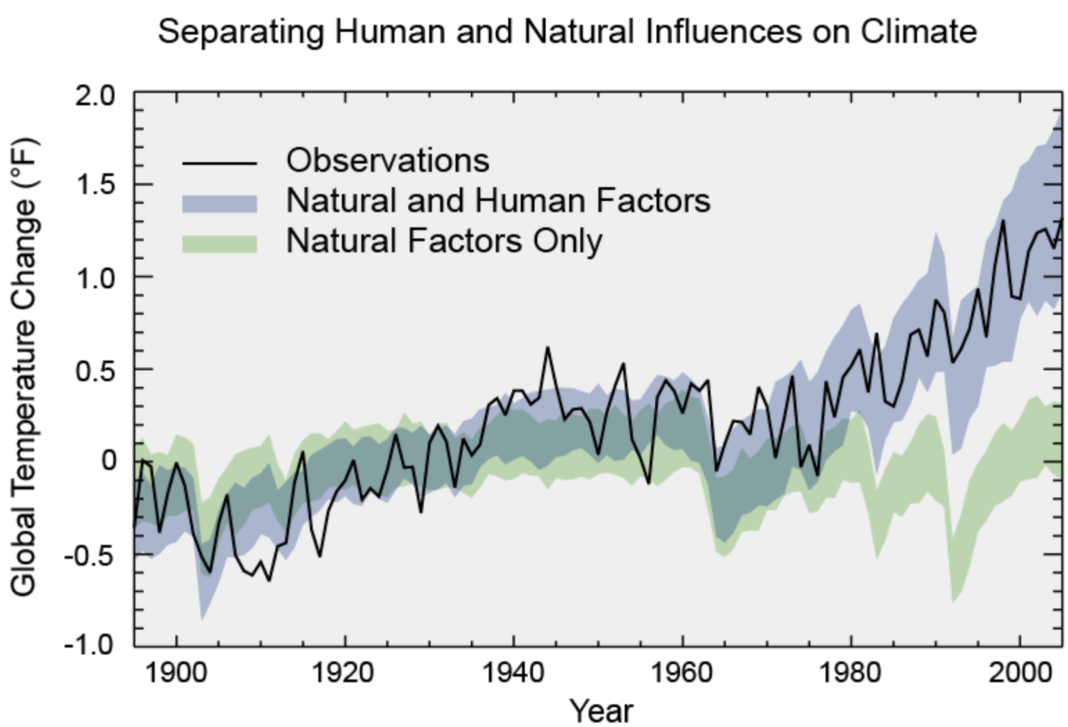

Figure 13: When model experiments are conducted to compare natural warming factors, such as solar radiation or volcanic eruptions (represented by the green shaded area), with observed temperature changes (solid black line), scientists find that natural factors alone cannot explain the actual changes in temperature. However, when natural factors are combined with human-caused GHG emissions (blue shaded area), they align with observed temperature records—leading scientists to conclude that the global temperature change is due to a combination of natural and human-caused factors. Source: Third National Climate Assessment, http://nca2014.globalchange.gov/report/our-changing-climate/observed-change#tab2-images

GRIC Greenhouse Gas Emissions Inventory

In 2011, GRIC published the findings from a baseline inventory (2007–2009) of GHG emissions within the boundaries of the community. The analysis found that the biggest source of GHGs is vehicle miles traveled along I-10, which runs through the reservation; however, community members do not generate all (or even most) of these emissions. Rates of per household energy use, which does measure community members' GHG emissions, decreased over the timespan of the analysis.

When we look at per capita emissions from all sources (including I-10 vehicle miles) the resulting 59.5 tons of CO_2 released per person per year in GRIC appears high. The U.S. annual average per person is 17 tons. To calculate a rough estimate of per person emissions that is likely to more accurately reflect community members' emissions, we exclude the mobile sources of emissions (I-10 vehicle miles). Without the mobile sources of emissions, the data show that GRIC emissions are actually 15.6 tons per person per year, which is less than the U.S. average. This is merely an estimate, but does help point to the fact that many of the emissions that occur within GRIC boundaries are likely to come from external sources.

Source	Year of Data Used	Tons of CO2 Emitted
Mobile Sources	2007	526,572.68
Electricity Usage	2007–2010	151,931.80
Natural Gas Usage	2009	8,736.12
Propane Usage	2007	1,567.75
Agricultural	2007	14,634.07
Electricity Transmission	2007	2,555.95
Wastewater Treatment	2007	8,991.06
Total		**714,089.43**

Table 1: Baseline Summary of Calculated CO_2 Emissions on GRIC; from Gila River Indian Community Greenhouse Gas Emissions Inventory: 2007 Baseline Year (Blair and Antone III 2011).

Future Temperature and Precipitation Projections for Arizona

The Intergovernmental Panel on Climate Change (IPCC), which is the international body convened to assess climate changes and impacts across the globe, has developed a set of four ***scenarios*** to project possible future climates for the world as a whole. Different levels of GHGs released into the atmosphere will have different impacts on warming temperatures. In order to show this range of possible outcomes, climate scientists use ***Representative Concentration Pathways*** (RCPs), which are scenarios of different levels of future GHG emissions. These scenarios are then used in Global Climate Models (GCMs) to estimate future global average temperatures.

GCMs cannot firmly predict future climate patterns, but they are useful tools that point us toward likely futures, based on the best currently available science. There are two main sources of uncertainty regarding climate projections that should be kept in mind when considering future climate scenarios. First, there is a range of possible ways humans will choose to manage our emissions of greenhouse gases in the future. The four different RCPs are one way to explore these different possible emissions scenarios and generate climate projections for each one. Another source of uncertainty is the ability of the GCMs to capture the complex global climate system. No single climate model can perfectly imitate such a complex system. For example, climate scientists tend to trust models to project the *direction* of change (such as temperatures rising), but they have less confidence in the ability of models to project the ***magnitude of change*** (exactly how much temperatures will rise). The approach to reducing this source of uncertainty is to use the average projections from many different models rather than rely on any single model.

The following summaries of projections—both for the globe and for Arizona—use both RCPs and an average of multiple climate models to reduce uncertainty and provide reasonable estimates of possible future climates for both scales of analysis.

Figure 14 shows the projected global temperature increases using the four RCPs. The green line that runs from 1900 (far left of the timeline) through 2014 represents the observed global average temperature for that period of time.

The first scenario—RCP 2.6 (blue line and shading)—assumes there will be an immediate and rapid reduction in GHG emissions worldwide (approximately 70% reduction in emissions as compared to the baseline scenario used to develop the RCPs (van Vuuren et al. 2011). Despite that aggressive move away from GHG pollution, the global annual average temperature in this scenario is projected to increase by about 2.5° F (1° C) by the year 2100. The darker line represents the average of all the models, while the shaded area represents the spread of all the model results.

The next scenario—RCP 4.5 (aqua bar shown only to the right of the chart)—assumes that GHG emissions will peak in about 2040 and then fall, leading to an estimated global temperature increase of about 4° F (1.8° C) by 2100.

The third scenario—RCP 6.0 (yellow bar shown only to the right of the chart)—assumes that emissions will peak in 2080 before falling, and result in an average temperature increase of about 5o F (2.2° C) by 2100.

The last scenario and the one that most closely resembles the pathway we are currently on—RCP 8.5 (red line and shading)—assumes GHG emissions continue to grow at their current rate, leading to more than 8° F (3.7° C) in global warming by 2100.

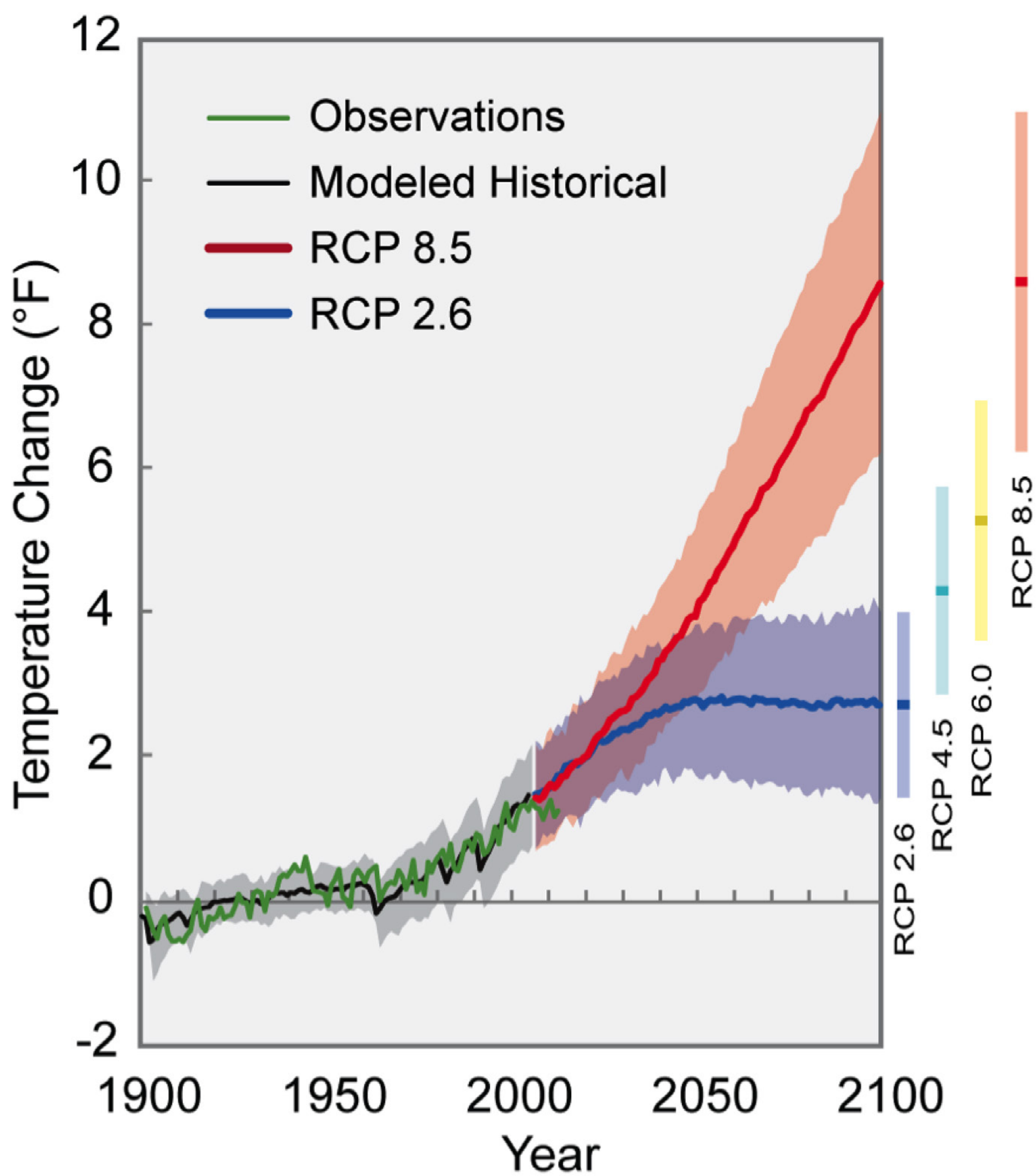

Figure 14: Projected global temperature increases using the four Representative Concentration Pathways (RCP) scenarios.

Climate models that were built to cover the whole globe can be focused in on smaller regions through processes called ***downscaling***. While downscaling can give us information about particular areas, the process is not perfect and the projections are usually not as certain in a downscaled model. For example, a model that was built to represent the climate of the whole Earth does not usually capture the unique weather patterns of a particular place very well – this is true for the Southwest, where climate models have trouble representing our local weather events associated with the summer monsoon season. One way climate scientists increase their confidence in model projections is to use the average of several models, rather than relying on just one. (See also Appendix C.)

Despite not being perfect representations of climate and weather, these models are the best tools we have to understand possible changes in our climate. We used ***statistically downscaled climate models*** to compile climate projection data for the state of Arizona, which is a small enough area to capture the trends expected to happen at GRIC, but big enough that we still have confidence in the accuracy of the projections.

Downscaled model projections for Arizona (Figure 15) show a range of possible future temperature increases, from just over 2° F higher than the 1986–2005 average for RCP 2.6 (orange dots), to almost 10° F higher for RCP 8.5 (red dots). If GHG emissions continue at their current rate, the state could be significantly warmer, as indicated by RCP 8.5 scenario. The projections of Arizona's average temperature are even higher than projections for the global average temperature. The Southwest as a whole is one of the fastest warming regions in the country. This is likely due in part to drought conditions and an observed decrease in soil moisture, since the air and ground warm faster when there is little water.

The long-term average annual temperature across GRIC is about 70° F; an increase of 10° F means a potential for average annual temperatures of 80° F, with much of the increase coming from rising low temperatures.

The small dots in Figure 15 each represent a separate climate model. Climate scientists rely on an average of multiple models to project future climate conditions, but use the results of individual models to understand the range of possible futures.


ZACK GUIDO

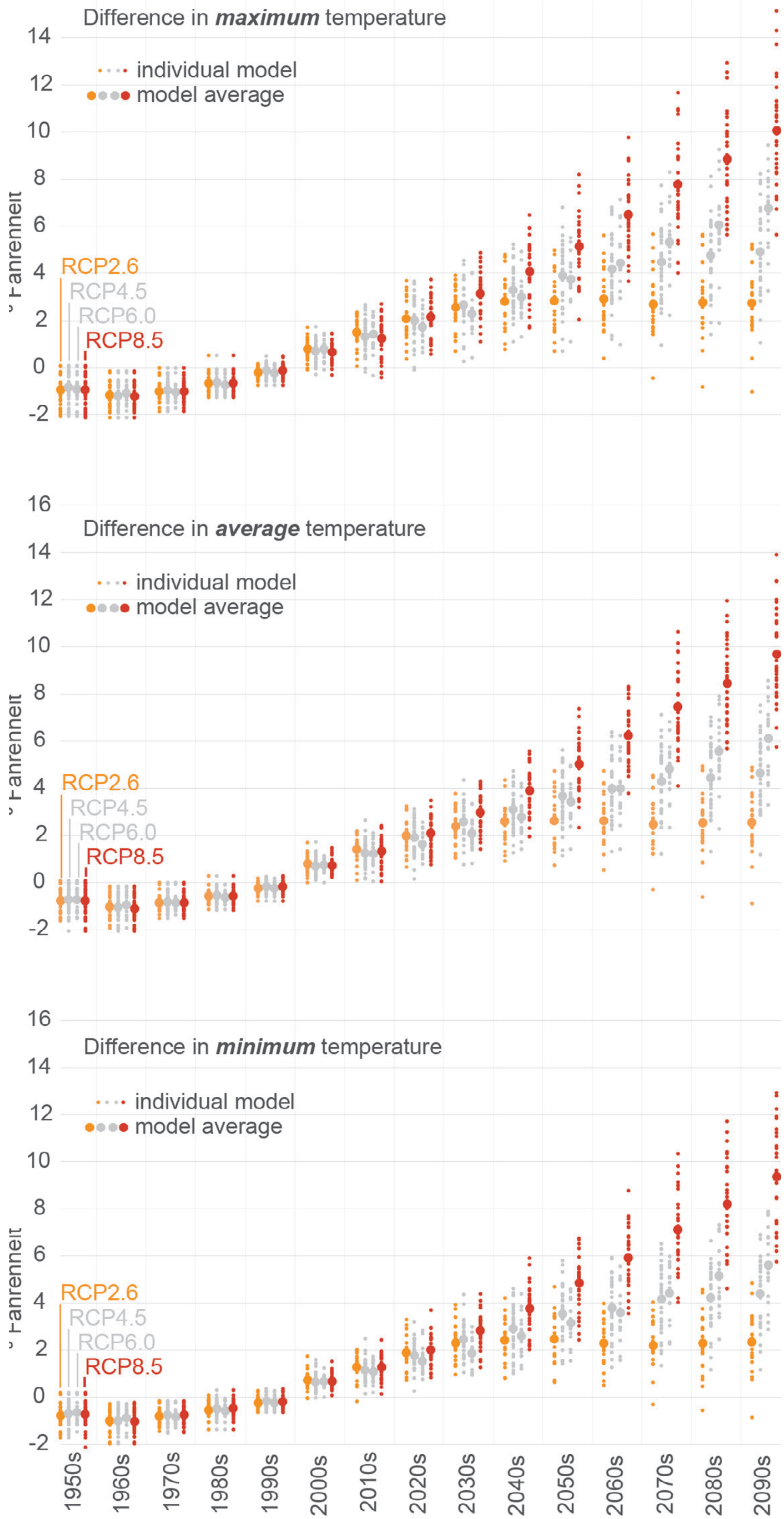

Figure 15: Downscaled model projections for Arizona show a range of possible future temperature increases, from just over 2° F higher than the 1986–2005 average for RCP 2.6 (orange dots), to almost 10° F higher for RCP 8.5 (red dots). If GHG emissions continue at their current rate, the state could be significantly warmer, as indicated by RCP 8.5 scenario. The projections of Arizona's average temperature are even higher than projections for the global average temperature; Arizona could warm more than the rest of the world.

While the projections of temperature show possible increases in all four scenarios, the projections show little-to-no change in annual average precipitation for Arizona (Figure 16). However, projections about precipitation are highly uncertain because scientists have found it difficult to model the behavior of the North American Monsoon, which brings this region a significant portion of its annual precipitation (Cayan et al. 2013). Figure 16 shows the projected percent change in total precipitation for Arizona from the 1986–2005 average. The average of all the models (the standard climate scientists use) shows no more than a few percentage points of change in either direction (more or less rain). For GRIC, this means the difference between the current annual average of 8 inches and possible future averages of between 7.5 inches (about 5% lower) and 8.5 (about 5% higher). The projections do not show a trend, but reflect the variable precipitation we are already familiar with. However, even with no change in total precipitation, Arizona could become much drier as warmer temperatures mean more evaporation over surface water and more transpiration (use of water by plants), which will further dry the soils.

While annual average precipitation may not change in this region, we do have the potential for changes in extreme precipitation events. A warmer atmosphere, as we are expecting, can hold more moisture, which can lead to more extreme precipitation events. Extreme precipitation events that on average have occurred every twenty years in the past could occur every 10 years in the future (Gershunov et al. 2013). Another study found that winter storms could increase in intensity by 13 to 14% under the high emissions scenario (RCP 8.5) (Gershunov et al. 2013).

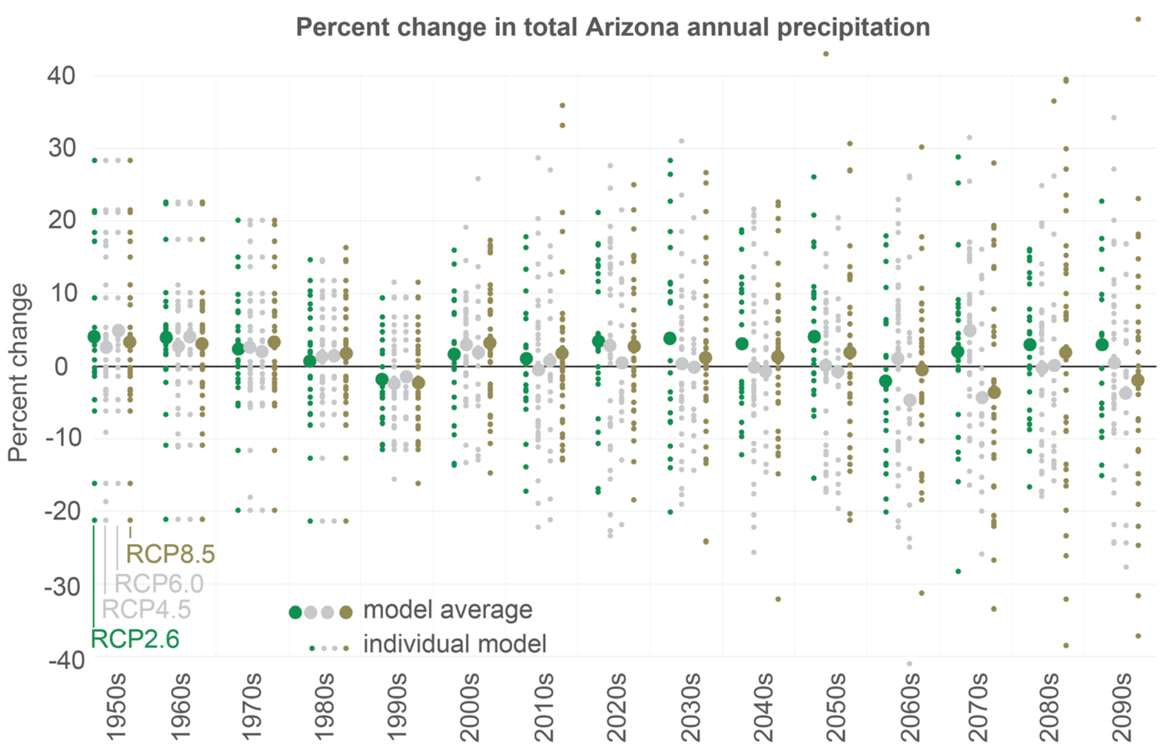

Figure 16: Projected percent change in total precipitation for Arizona from the 1986-2005 average. An increase or decrease of about 5%, which is the most change projected by the climate models, would mean annual average precipitation at GRIC of between 7.5 inches (5% decrease) and 8.5 inches (5% increase). The projections do not show a trend, but reflect the variable precipitation we are already familiar with. In addition, the further in the future, the less consistent the models become with each other, which gives climate scientists less certainty about long-term future precipitation.

Human Health

The U.S. Global Change Research Program (USGCRP), which is tasked with assessing present and future impacts of climate change on the United States, provides examples of seven specific climate change impacts on human health: extreme heat, outdoor air quality, flooding, vector-borne infection, water-related infection, food-related infection, and mental health and well-being (Crimmins et al. 2016). In this summary, we focus on heat, air quality, and vector-borne diseases.

Heat

As temperatures rise, heat waves in the Southwest United States are predicted to become longer, more frequent, and more intense (Gershunov et al. 2013). Extreme heat events (EHEs)[3] during June, July, and August, in the Phoenix Metropolitan Area, are likely to occur about six times more often in 2041-2070 than in the past (Grossman-Clarke et al. 2014). Currently, EHEs occur on average once every three years; by 2041-2070 they are projected to occur on average twice per year. They will also become about twice as long—from about 6.3 days in the period 1971-2000 to 12.6 days in the period 2041-2070.

Extreme heat places greater stress on the body, especially when combined with humidity (Brown et al. 2013). Older adults, children, those who work outside, those with chronic illnesses, and those who are socially isolated tend to be at greater risk. Between 2003 and 2013, 1574 people in Arizona died due to exposure to excessive natural heat; 483 of those deaths occurred in Maricopa County (Arizona Department of Health Services 2015).

Crimmins et al. (2016) concluded that the higher temperatures expected with climate change are likely to contribute to thousands of premature deaths each year. In Maricopa County, researchers found that, for every 1º F increase in maximum temperature, the heat-related mortality rate increased 9% (Yip et al. 2008).

[3] EHEs are defined here as events that are characterized by: 1) maximum temperature above 109° F (42.8° C) for every day of the period, 2) average maximum temperature above 113.4° F (45.2° C) for the entire period, or 3) maximum temperature above 113.4° F (45.2°C) for at least 3 days.

Energy Costs

Human tolerance for heat has been increasing, due to a combination of improved social responses, physiological acclimatization, and technology (air conditioning) (Crimmins et al. 2016). Increased use of air conditioning (AC), however, from both higher temperatures and improved access to technology, will increase energy consumption. This can stress the electrical grid, increasing the risk for brownouts. Additionally, if the energy comes from the burning of fossil fuels, then it will release more GHGs, increasing temperatures further, which will in turn increase demand for cooling (AC), and so on. This is referred to as a positive feedback loop.

Furthermore, several studies have shown that AC use in cities enhances the ***urban heat island effect*** (UHI), due to the release of waste heat from the systems themselves (for example, de Munck et al. 2013; Ohashi et al. 2007). The effect is more profound at night when heat emitted from AC systems can increase surface temperatures by up to 1.8° F (1° C) in the Phoenix Metro area (Salamanca et al. 2014). This is another positive feedback loop, as higher nighttime temperatures increase AC use, heating the air even further.

The projected increases in AC use will also produce impacts at the residential level. Looking to the past, urbanization in Phoenix has increased average daily temperature at Sky Harbor Airport by 5.6° F (3.1° C) from 1948 to 2000, which, according to models, increased net energy consumption in a two-unit townhouse style building by about 30% (Baker et al. 2002). Due to the need for additional cooling, by 2080–2099, electric consumer energy will cost an estimated $164 million more per year in the state of Arizona, compared to 2008–2012; on a household basis, this equates to about $100 per household per year (Huang and Gurney 2017).

In addition to the human health effects of heat, there can be additional burdens placed on our natural resources. In a study of the effects of the UHI in Phoenix, one study found that the more an area was affected by the UHI—specifically if the low temperature in the neighborhood was higher than other areas of Phoenix—the more water was used by households in that neighborhood. A 1° F increase in a neighborhood's low temperature increased water use per household by 290 gallons per month (Guhathakurta and Gober 2007). This study is a good analogy for climate change-driven warming because we expect warming to be pushed largely by higher low temperatures (see Figure 3).

Air Pollution

Climatic changes are also affecting air quality, with implications for human health. Ground-level ozone pollution, fine particulate matter 2.5 (PM2.5; particulate matter smaller than 2.5 microns), and particulate matter 10 (PM10; particulate matter between 2.5 and 10 microns) are several of the air pollutants likely to be affected by climatic changes. The overall rise in air pollutants associated with climate change is expected to contribute to rising rates of asthma and other allergic diseases (Crimmins et al. 2016). The current rate of emergency room visits for asthma in Arizona (between 2003 and 2012) is 3.8 per 1000 people. In Maricopa County, the rate is slightly higher at 3.9 visits per 1000 people and in Pinal County the rate is 3.06 per 1000 people (http://webhost244.asu.edu/sustainability/asthma).

Increased temperatures will increase ground-level ozone pollution in many areas of the United States. Although ozone in the stratosphere protects the earth from harmful UV radiation, ozone that forms close to the ground is a danger to human health. Ground-level ozone is produced when nitrogen oxides and hydrocarbons, often called ozone precursors, from sources such as automobile exhaust, power plant and industrial emissions, gasoline vapors, chemical solvents, and some natural sources (certain plants) react in heat and sunlight (Figure 17). Meteorological conditions that influence ozone levels include air temperatures, humidity, cloud cover, precipitation, and wind direction. Higher temperatures can increase the chemical rates at which ozone is formed as well as increase ozone precursor emissions from human and plant sources (Crimmins et al. 2016). Exposure to ground-level ozone is linked to reduced lung function and respiratory problems such as pain associated with deep breathing, coughing, and airway inflammation (Brown et al. 2013). Rising temperatures, combined with the existing sources of ground-level ozone (listed above), are expected to contribute to higher levels of ozone and increases in deaths due to exposure (Crimmins et al. 2016).

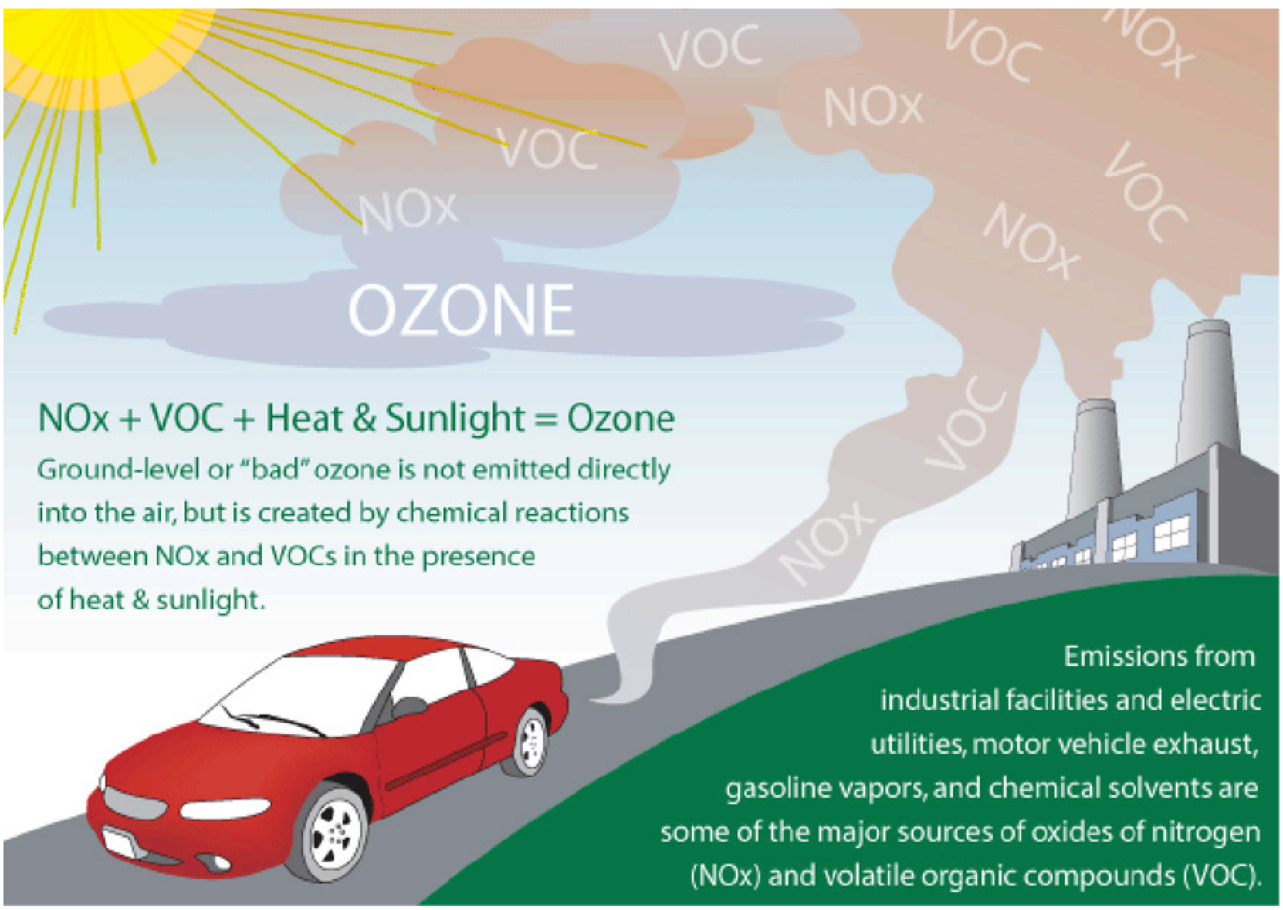

Figure 17: Sources and formation of ground-level ozone. Source: http://www.deq.state.ok.us/aqdnew/airreport2013/o3.html

A study in Phoenix found that combustion-related pollutants, such as carbon monoxide, nitrogen oxides, and sulfur dioxide, were strongly associated with rates of death among those aged 65 or older due to cardiovascular disease. Between 1995 and 1997 an average of 3.85 cardiovascular-related deaths per day occurred among Phoenix residents aged 65 or older (Mar et al. 2000).

While ozone exceedance days have fallen in Maricopa and Pinal Counties since the early 2000s (see Figures 18 and 19), ozone peaks in the hotter summer months – May through August (see Figure 20). As temperatures rise and heatwaves become more common, it is reasonable to expect that ozone exceedance days may also rise.

PM 2.5 is often generated by vehicle exhaust and power plant emissions (Environmental Protection Agency 2013). Another source of PM2.5 is wildfires, which are expected to become larger and more frequent as climate conditions become hotter and drier. High levels of PM2.5 are associated with mortality related to cardiovascular problems, particularly among the elderly, and reduced lung function and growth, increased respiratory stress, and asthma in children (Brown et al. 2013). Current air quality standards require that annual averages of PM2.5 in the air not exceed 15 micrograms per meter-cubed (µg/m^3) within a three-year period. As of late 2016, western Pinal County has not met the air quality standard requirements for PM 2.5 Changes in wildfire regimes, which have implications for air quality and human health, are discussed below.

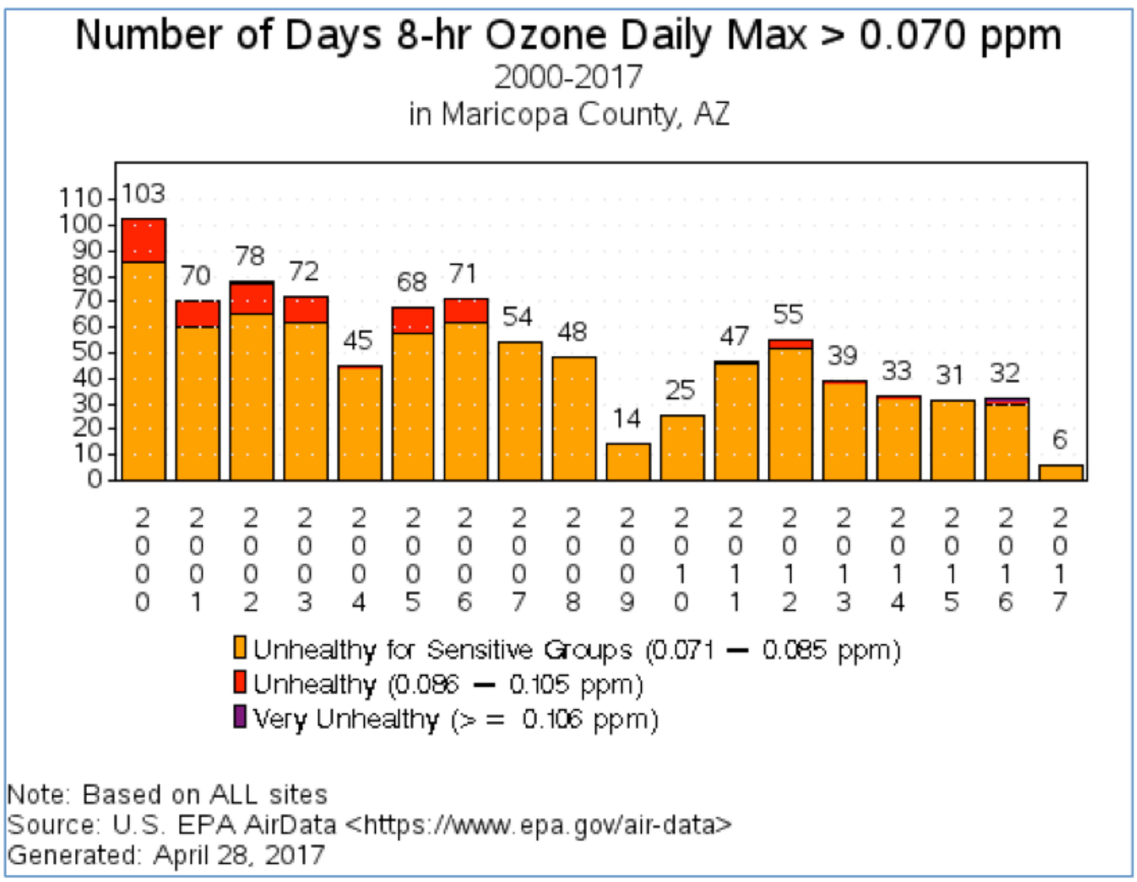

Figure 18: Ozone exceedance days have fallen in Maricopa County since the early 2000s, when the county regularly experienced over 70 exceedance each year. In 2016, the county had 32 exceedance days.

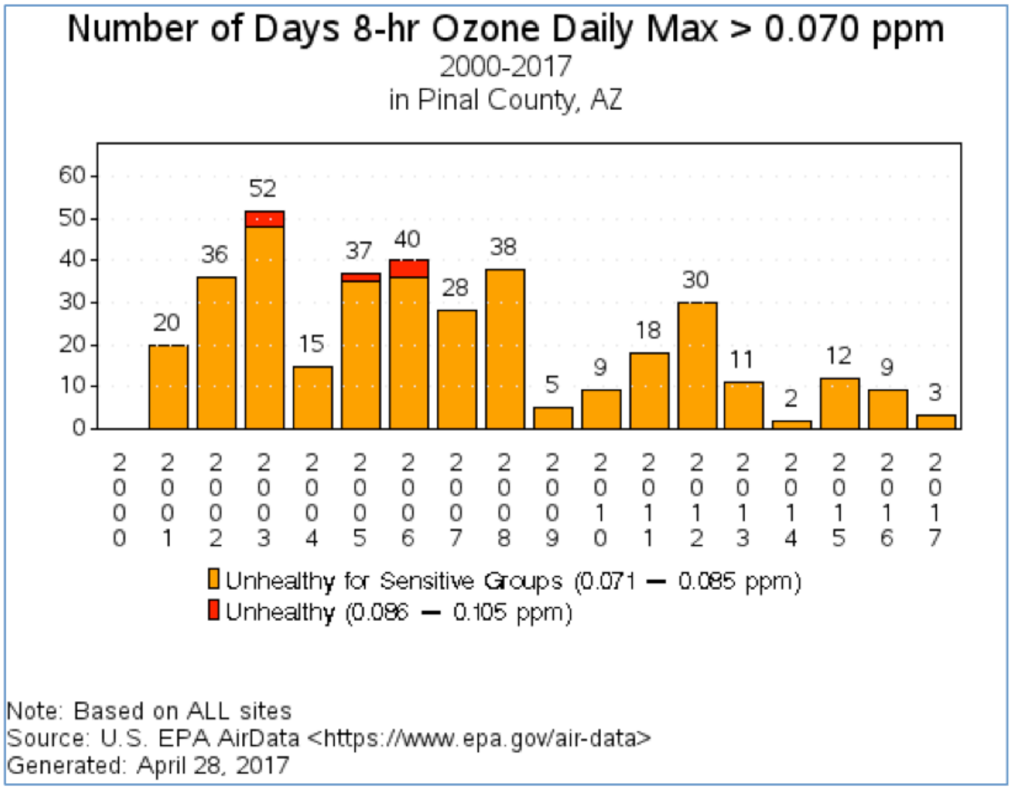

Figure 19: Pinal County's highest number of ozone exceedance days was in 2003, with 52 days. In 2016, the county experienced 9 exceedance days.

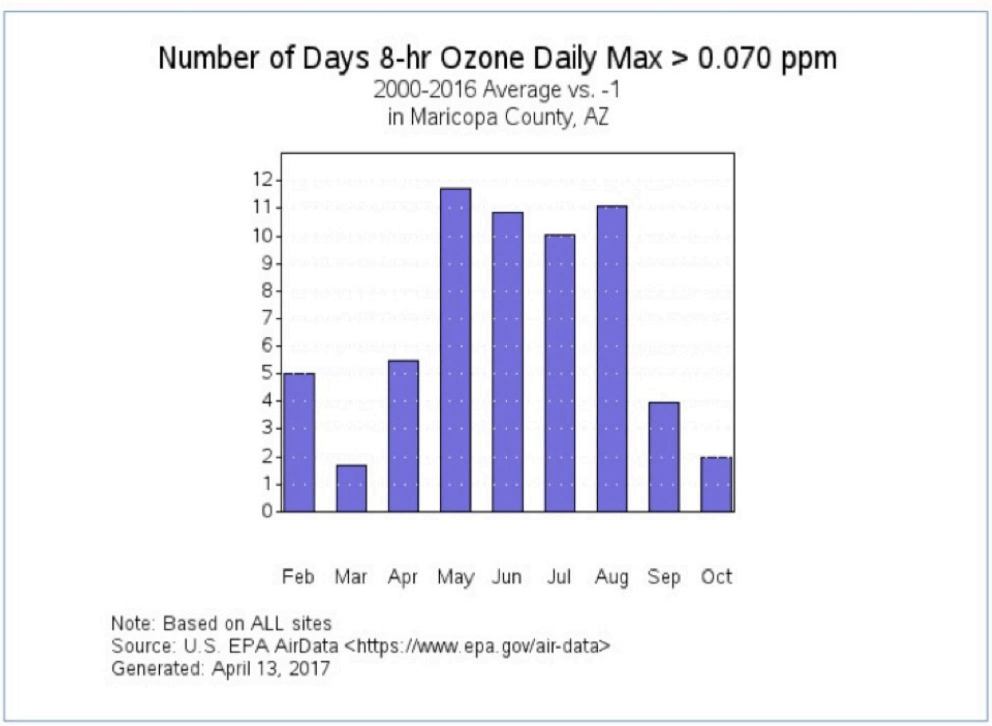

Figure 20: Average number of days from 2000 to 2016 in which ozone exceeded 0.070 ppm in each month. May through August, the warmest months, had the highest number of ozone days.

Dust Storms

One source of PM10 in this region is dust from dust storms, which have been occurring more frequently and over a longer season in recent years in Arizona due to drought conditions (Figure 21) (Harlan et al. 2014; Tong et al. 2017). Dust from unpaved roads, construction sites, fires, and abandoned fields combined with smog, soot, smoke and ash can enter the nose and lungs and create serious health problems. For PM10, the Environmental Protection Agency (EPA) requires that an area not exceed particulate concentrations greater than 150 $\mu g/m^3$ (averaged over 24 hours) more than once per year over three years, unless declared an exceptional event, such as the haboob experienced in the Phoenix area in 2012. As of late 2016, portions of Maricopa and Pinal counties had not met the EPA air quality PM10 criteria.

Dust Storms and Valley Fever

A particular threat posed by dust storms is the possibility that the fungal spores that carry Valley fever will become windborne during a storm. Inhalation of the spores can cause a person to become infected with Valley fever (Arizona Department of Environmental Quality 2009; Yin et al. 2005). Tong et al. (2017) found a correlation between increased frequency of dust storms and incidents of Valley Fever. However, as discussed below, it is not yet possible to predict exactly where the spores occur or which communities are most likely to be affected.

Dust Storms and Transportation

Dust storms are a significant factor in highways accidents and deaths, particularly on interstate highways. Figure 22 compares dust storm-related accidents to other natural hazards and shows that dust storms lead to the highest number of injuries and are the third deadliest hazard overall, behind extreme temperatures and flooding (Lader et al. 2016). The researchers explain that population growth and increased traffic on the state's major highways have contributed to rising rates of injuries and fatalities.

The study found that Interstate 10 (I-10) accounted for roughly 42% of the total fatalities. The deadliest stretch ranges from Phoenix to Red Rock (Figure 23), an area particularly prone to dust storms because of land use practices in Pinal County (Lader et al. 2016).

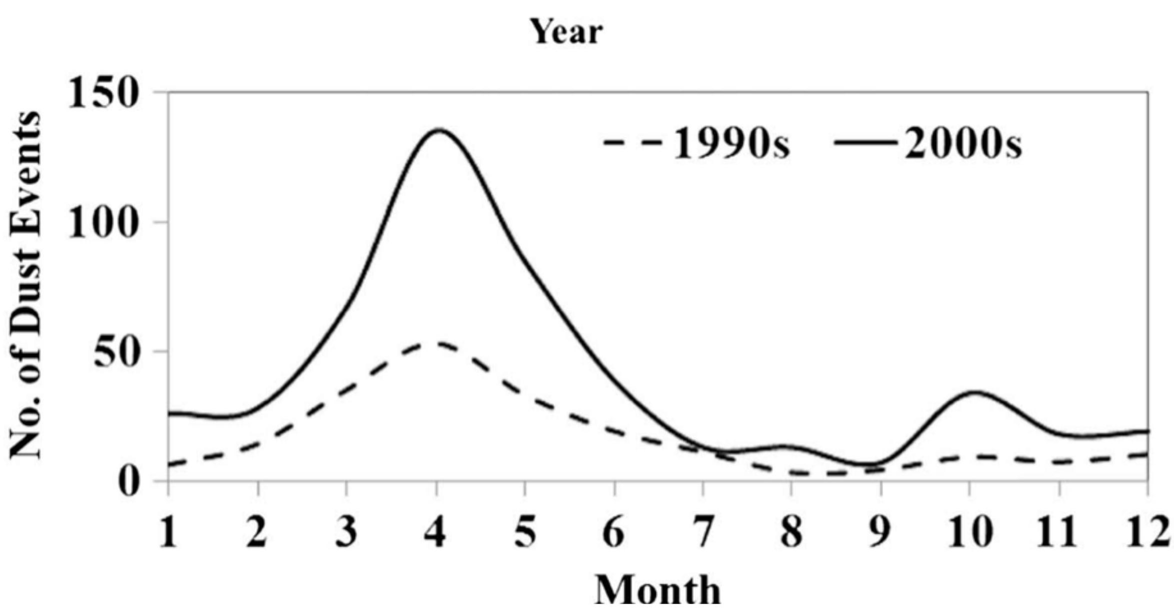

Figure 21: Monthly distribution of dust events across the western United States in the 1990s and the 2000s. Most dust storms occur in the spring months. The decade of the 2000s saw significantly more dust storms than in the 1990s. Source: Tong et al. (2017).

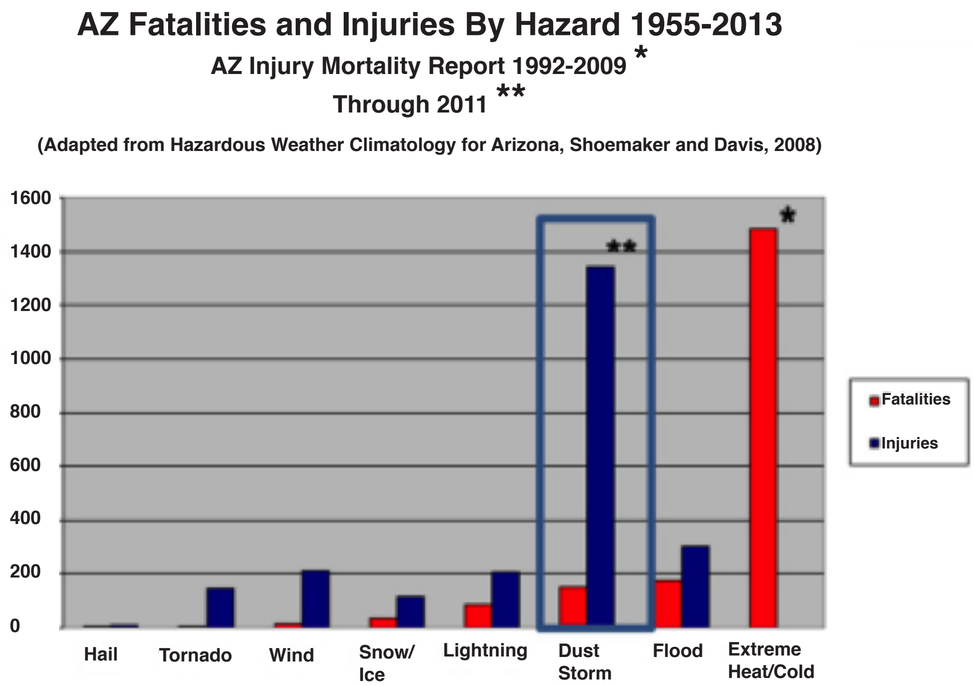

Figure 22: Arizona fatalities and injuries by hazard between 1955 and 2013. Dust storm related fatalities/injuries are highly significant (**) for the years 1955-2011. Extreme heat/cold data are only from 1992-2009. All other hazardous weather events reflect data from 1955-2013. Source: (Lader et al. 2016).

Figure 23: The deadliest corridor of Interstate 10, from dust-related traffic accidents, stretches from Phoenix southeast to Red Rock, shown in the image above. This area is particularly dust-prone due to soil disturbance from changes in agricultural practices, especially in Pinal County (Lader et al. 2016).

Diseases and Vector-Borne Diseases

Current scientific knowledge about the impacts of climate change on the potential spread of specific climate-sensitive diseases is limited. One significant challenge for estimating how a warming climate may impact disease is the need to first understand how climate affects weather-sensitive disease vectors such as different mosquito species. A significant amount of research is being conducted that seeks to better understand how the warming climate will change where mosquitos are and how long they will live.

Improved understanding of broad patterns of mosquito abundance will, however, not be sufficient to determine whether a specific city or town might be impacted by a vector-borne disease. Unfortunately, predicting local disease abundance requires not only highly uncertain estimates of changing local weather conditions, it also requires predicting how humans will respond to those changing conditions (e.g., will people use mosquito repellent more frequently?). Therefore accurate predictions will be extremely difficult to make about how climate change will ultimately change patterns of vector-borne diseases like West Nile virus, dengue fever, and Zika.

Because of the challenges of estimating disease risk, scientists who work on vector-borne diseases as they relate to climate commonly focus on mosquitos—changes in their abundance and timing of emergence—since their presence is required to transmit these diseases. For example, recent studies by the Arizona Department of Health Services and the University of Arizona focused on how climate change may impact the spread of West Nile virus (WNV) in Arizona (Roach et al. 2017).

To project the spread of WNV, the researchers used a mosquito life-cycle model to try to better understand how mid-21st century climate may change abundance of the mosquito species that carries the disease. Two findings emerged that are likely to be relevant to GRIC: 1) the season during which mosquitos can survive and breed may become longer; and 2) in areas that get as hot as the Phoenix area, temperatures in mid-summer may be high enough to substantially reduce mosquito populations, thus possibly reducing the prevalence of WNV, although the researchers have not yet determined a specific heat threshold. In other words, the mosquito season may expand, but there may be a reduction in number of mosquitos during the hottest months of the year in the future.

The same study examined changes in Valley fever prevalence due to climate change, which is much harder because it is spread through a fungus in soils and the fungus is notoriously hard to detect. In reviewing the current state of the science, therefore, Roach et al. (2017) were unable to draw any confident conclusions about the future of Valley fever in Arizona, other than to suggest that there is some reason to expect that changes in the distribution and annual incidence of Valley fever will occur.

Drought

As discussed above, even without changes to annual average precipitation, rising temperatures are likely to make drought conditions worse because of increased evaporation of water from surface sources and evapotranspiration from plants. Both streamflow levels and soil moisture levels (which can be used as drought indicators) are likely to be impacted.

One way to assess potential future drought impacts is to look to paleoclimate records to understand past conditions. Tree ring records can be used to track past climate variability by examining the size and timing of growth rings. In the Southwest, these tree ring records indicate that in the past, droughts lasting multiple decades (termed "megadroughts") have occurred in this region, with aridity as bad or worse than the worst droughts of the 20th century. For more information about the use of tree ring research in drought studies, see Appendix A.

Historically, these megadroughts, lasting at least 35 years, occurred about once or twice per thousand years. If temperatures rise by more than 9° F (5° C) – which is projected for Arizona under the RCP 8.5 scenario (see Figure 15), the risk of megadrought in the Southwest will be almost 100% by 2100 (Ault et al. 2016). Megadroughts could occur an average of once every 200 years, based on moderate and high emissions scenarios (RCP 4.5 and 8.5), and once every 400 years under the low emissions scenario (RCP 2.6) (Ault et al. 2014). Shorter—but still significant—droughts lasting at least 11 years could occur 1.5 to 1.75 times per 100 years, under all future emissions scenarios.

Sonoran Desert Ecosystems and Species

Increased minimum temperatures, combined with a decrease in freezing temperatures and a lengthened frost-free season, will likely lead to an expansion of the boundaries of Southwestern deserts to the north and the east, migration of communities to higher elevations, susceptibility to insect infestations and pathogens, and establishment of invasive annual grasses (Archer and Predick 2008; Sonoran Desert Network Inventory and Monitoring Program 2010). As these communities move further upslope, species that currently live on "Sky Island" mountain tops would have no higher habitats in which to migrate (Archer and Predick 2008; Sonoran Desert Network Inventory and Monitoring Program 2010).

Plants and animals in arid regions already live near their physiological limits, and small changes in temperature and precipitation will change the distribution, composition, and abundance of species (Archer and Predick 2008).

Warmer temperatures will decrease populations of velvet mesquite (*Prosopis velutina*) and increase some cactus species (Munson et al. 2012). The range and abundance of saguaros, however, will potentially decline due to drought and reduced native perennial grass and shrub cover (Archer and Predick 2008).

Invasive plant species represent a serious threat to natural ecosystems because they: 1) displace native plants and animals; 2) alter ecosystem function; and 3) change fire regimes. Invasive species, such as cheatgrass, can have a high fire potential, introducing fire where it normally doesn't occur, causing fires to burn more intensely, and leading to an earlier onset to the fire season and a longer window during which conditions are prime for fire ignition (Abatzoglou and Kolden 2011; Sonoran Desert Network Inventory and Monitoring Program 2010).

The Sonoran Desert Network Inventory & Monitoring Program monitors the conditions of ecosystems within its network of parks in the Sonoran Desert. The following are changes already observed in the parks:

- Elegant trogons (*Trogons elegans*) are nesting north of their historical range, likely because of milder winters and springs
- Vegetation is shifting at Saguaro National Park from deeper rooted trees and shrubs to warm-season plants, including shallow-rooted subshrubs, grasses, and other herbs
- There is a sharp decline in four amphibian species (Chiricahua leopard frog, Mexican spadefoot toad, Woodhouse's toad, and red-spotted toad) at Gila Cliff Dwellings National Monument

Water Availability

Central Arizona Project Allocation

GRIC has an allocation of 311,800 acre-feet (AF) per year of water from the Central Arizona Project (CAP). Climate scientists have projected future climatic impacts to water resources, such as the Colorado River, in the West. Studies of the Colorado River using land surface models indicate that for every 1° F of warming there is a decrease in streamflow at Lees Ferry (where Colorado River flows are measured) of 2.8 to 5.5% (Udall 2013). The same study also indicates that even if temperatures do not change - a one percent change in precipitation (either up or down) will change runoff by one to two percent (Udall 2013).

These potential physical changes to the amount of runoff in the Colorado River system is in addition to a pre-existing stressor: the river is over-allocated and in a structural deficit stemming from a combination of losses from evaporation and water use (Central Arizona Project 2014). The water use in the lower basin—Arizona, California, and Nevada—is 1.2 million AF greater than the inflows to Lake Mead (located on the Arizona and Nevada state line) that supply the region. This means that as long as more water is released from the reservoir than comes in on an average basis, the water levels will continue to decrease.

Water levels in Lake Mead have been dropping since 2000 (Central Arizona Project 2014). To address the deficit, the lower basin states agreed to a set of interim guidelines, developed by the Bureau of Reclamation. These guidelines were designed to provide greater certainty for water users during times of shortages in Lakes Mead and Powell by creating a series of thresholds and related reductions to water deliveries to guide decisions about water delivery (Jerla and Prairie 2009). These reductions were intended to prevent Lake Mead from reaching a critical shortage through 2026. The delivery reductions will take place when the water level in Lake Mead reaches three different thresholds: Tier 1 - 1,075 feet above mean sea level (amsl), Tier 2 - 1,050 amsl, and Tier 3 - 1,025 amsl. One thousand feet amsl is considered the critical level for Lake Mead when both water and energy availability are at risk. Each threshold will trigger a tier reduction.

A Tier 1 reduction requires Arizona to reduce CAP water deliveries by 320,000 AF per year. At this level, the CAP will make cuts to the excess storage deliveries and to the agriculture pool. A Tier 2 reduction requires 400,000 AF of reductions each year to the excess and agricultural pools. A Tier 3 will require 480,000 AF of reductions in Arizona but will not impact Municipal and Industrial (M&I) or Indian Priority deliveries.

If Lake Mead falls to the critical 1,000 feet amsl level, this will trigger new round of consultation between the Secretary of the Interior and the basin states to discuss further measures (Central Arizona Project 2014). Climate projections for the Colorado River Basin have ranged from a 6 to 45% reduction in flow by the middle of the 21st century (Vano et al. 2014). The wide range of the estimates is due to differences in the methodologies used in the various studies and the natural variability of the Colorado River (Vano et al. 2014). However, management policies put in place starting in 2016 that encourage water users to leave water in Lake Mead have helped to avoid a shortage so far (Cooke 2016).

Although uncertainty exists in the climate projections, there is scientific consensus that can help guide future planning efforts. Temperatures will continue to rise in the basin, which will affect evaporation rates. Precipitation in the basin seems likely to decline, but scientists do not know by how much. Future GHG emissions will determine the extent of temperature and precipitation changes. Adding to the complexity, the paleoclimate record indicates that multi-decadal droughts, which occur in this region, will result in much lower stream flows than have been observed over the past 100 years. Available water from the Colorado River is likely to decrease in the future. The exact point at which GRIC's CAP water is at risk remains unclear due to the uncertainty in predicting future events.

Gila River Streamflow

A portion of GRIC's water allocation comes from the Gila and Salt Rivers, both of which are within the larger Colorado River Basin. According to the Bureau of Reclamation, which recently completed a study of streamflow projections across the entire Colorado River basin, streamflow is likely to decrease in the second half of the 21st century and the peak timing of flow is likely to shift to earlier in the spring (U.S. Department of the Interior Bureau of Reclamation 2016b). These changes are due to a combination of rising temperatures, declining snowpack, and rising demand for water especially in the M&I use tier (U.S. Department of the Interior Bureau of Reclamation 2016a). Figure 24 displays the average streamflow projections in the Reclamation Colorado River Basin study for the decades 2020s, 2050s, and 2070s. A reduction in streamflow becomes evident in the 2050s (green line) and both a reduction in streamflow and change in peak flow timing are evident in the 2070s (red line), when compared to the 1990s (black line).

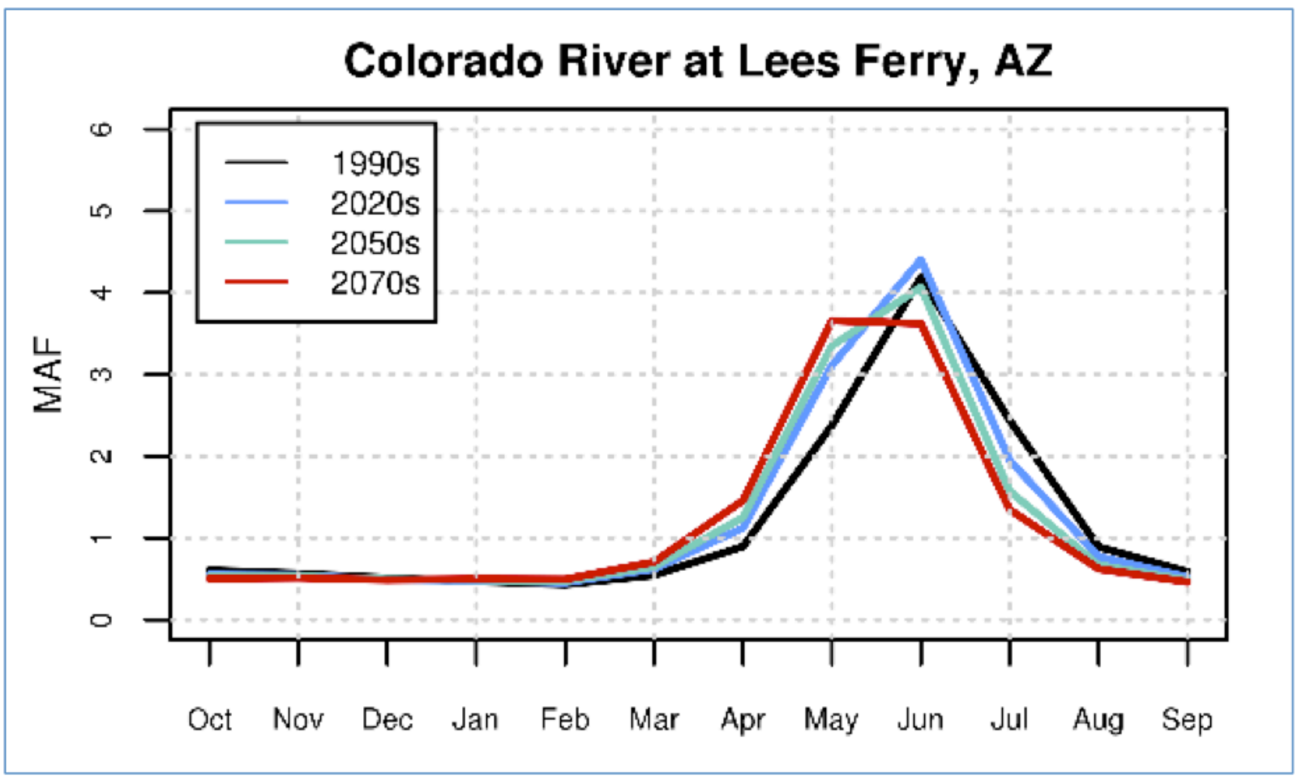

Figure 24: Projected streamflow for the Colorado River at Lees Ferry, AZ. Source: (U.S. Department of the Interior Bureau of Reclamation 2016a)

While the Reclamation study clearly projects a decline in streamflow for the whole Colorado River Basin, emerging research from University of Arizona (including the Salt River, but not the Gila) points to the possibility of even more severe declines in streamflow than projected by Reclamation. Using dynamically downscaled streamflow projections (as opposed to the more common statistical methods used by Reclamation), Castro and colleagues at University of Arizona (Castro 2017) have tentatively found larger decreases in streamflow—as much as 20% on average, with individual climate models projecting even larger declines. These findings are still considered tentative, but we will update GRIC as more information becomes available.

There is an indirect impact from dust storms on streamflow and water availability because dust accumulation on snow affects snowmelt. Udall (2013) notes that the deposition of dust on snowpack in the Colorado River Basin can reduce runoff from snowpack by up to 5%. Dust accumulation carried through the atmosphere and deposited in higher elevations and in mountainous regions during the winter months can cause earlier snowmelt and increase soil and dust deposits in waterways, reducing water quality in streams and rivers. Painter et al. (2007) found that increased dust deposition in the San Juan Mountains of Colorado reduced the reflective properties of snow and contributed to snow melting 18 to 35 days earlier. In a separate follow-up study, Painter et al. (2010) found that earlier spring runoff in waterways increased evapotranspiration by 5% annually.

Water Quality

More frequent and longer droughts, and their associated low stream and reservoir levels, increase the concentrations of nutrients in streams, such as ammonia and nitrate, potentially raising the likelihood of harmful algal blooms and low oxygen conditions (Geogakakos et al. 2014). Additionally, with higher temperatures, more precipitation falls as rain instead of snow, increasing the amount of pollutants that wash from the ground and paved services into streams and reservoirs as compared to what would derive through slow percolation from snowmelt (Geogakakos et al. 2014).

Wildfires, especially very large fires, can significantly alter landscapes and watersheds. When rainfall occurs up to a few years after a fire, erosion increases and changes in runoff greatly increase the amount of sediment that is transported downstream, in some cases up to 20 times (Garfin et al. 2016). Runoff from a burned area can produce many changes in water quality, including concentrations of trace elements, organic carbon, pH and nitrates and sulfates, impacting both water quality and supply downstream (Smith et al. 2011).

Wildfire

Climate strongly influences wildfire processes in the western U.S. About 94% of fires in the West occur between May and October (Westerling et al. 2003). In Arizona, fire season usually starts in May or June and ends around August (Westerling et al. 2003). Climate model projections, combined with data on invasive species, suggest that the fire season in the Sonoran Desert will begin up to four weeks earlier than in the past (Abatzoglou and Kolden 2011).

Fire in desert ecosystems in the Southwest has been historically rare, however increased frequency of drought combined with the spread of invasive plant species has had a major impact in arid ecosystems in Arizona (Archer and Predick 2008). Low soil moisture is associated with more severe fire seasons in shrub and grasslands (Westerling et al. 2003). Non-native plant species such as red brome (*Bromus rubens*), cheat grass (*Bromus tectorum*), and buffelgrass (*Pennisetum ciliare*) have helped to increase the frequency of fire in the Sonoran desert region, transforming once diverse rangelands into "monocultures of non-native grasses" (Archer and Pedrick, 2008).

Climate model projections for the southwestern U.S. indicate warmer spring and summer average temperatures in the future (Cayan et al. 2013; Westerling et al. 2003). Climate models are not as reliable for projecting future precipitation trends. However, even with no reduction in precipitation in this area, the anticipated increased temperatures will still lower soil moisture levels, increasing the risk of wildfire.

While rising temperatures and drought conditions are major drivers of wildfire, other factors such as the spread of insects, land use, fuel availability, and management practices, including fire suppression, also play an important role in wildfire frequency and intensity. These factors vary greatly by region and over time. Understanding changes in fire characteristics, such as frequency and intensity, requires long-term records, a regional perspective, and consideration multiple factors (Environmental Protection Agency 2016).

CLIMATE CHANGE ADAPTATION PLANNING

Climate change adaptation planning refers to the process of planning to adjust to new or changing environments in ways that take advantage of beneficial opportunities and lessen negative effects (Melillo et al. 2014).

The process of climate change adaptation planning can be similar to other resource management planning processes and generally includes the following steps:

- Identifying risks and vulnerabilities
- Assessing and selecting options
- Implementing strategies
- Monitoring and evaluating the outcomes of each strategy
- Revising strategies and the plan as a whole in response to evaluation outcomes

Key questions to ask community members, resource managers, decision makers, and elected officials when considering climate adaption are:

- What are the community's goals and objectives in the future?
- What resources or assets need to be protected from climate change impacts?
- How will the resources be protected?
- What actions are necessary to achieve the community's goals?

Adaptation strategies can range from short-term coping actions to longer-term, deeper transformations. They can meet more than just climate change goals alone and should be sensitive to the community or region; there are no one-size-fits-all answers (Moser and Eckstrom 2010).

The process of planning for climate change adaptation has already begun in many places. The federal government has required each federal agency to develop an adaptation policy (Executive Office of the President 2013). Fifteen states and 176 cities have climate change adaptation plans. Approximately 10 tribes have adaptation plans that have been approved by their governing bodies. President Obama's Climate Action Plan identified the Bureau of Indian Affairs as the lead agency to support tribes in this effort and has issued a number of funding opportunities to support this work.

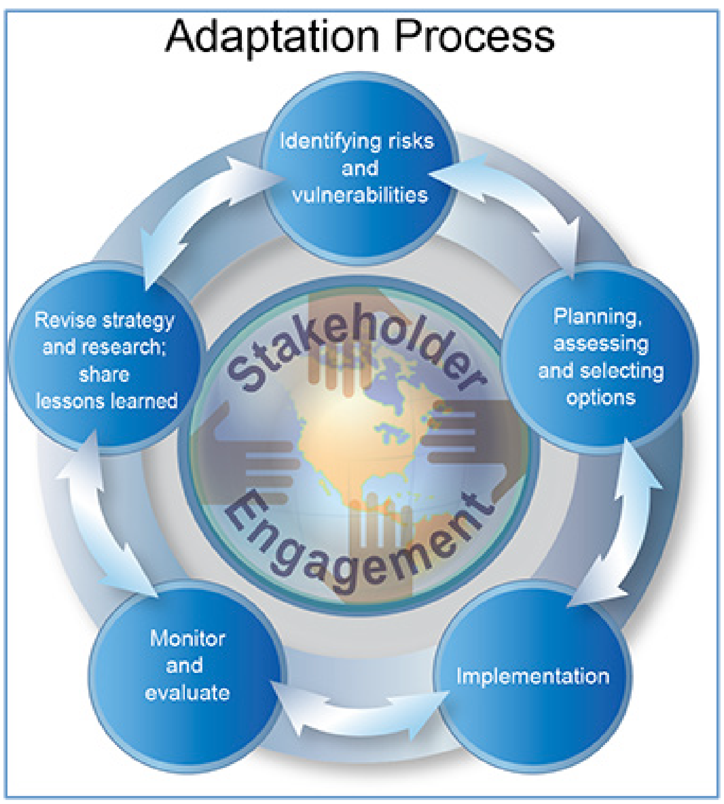

Figure 25: Source http://nca2014.globalchange.gov/report/response-strategies/adaptation

ADDITIONAL RESOURCES TO SUPPORT CLIMATE CHANGE ADAPTATION PLANNING

The National Climate Assessment; Adaptation Chapter
http://nca2014.globalchange.gov/report/response-strategies/adaptation

BIA Tribal Climate Resilience Program
http://www.indianaffairs.gov/WhoWeAre/BIA/climatechange/

University of Arizona Center for Climate Adaptation Science and Solutions/Native Nations Climate Adaptation Program
http://www.ccass.arizona.edu/nncap

Institute for Tribal Environmental Professionals Climate Change Program
http://www7.nau.edu/itep/main/ClimateChange/

Climate Adaptation Knowledge Exchange
http://www.cakex.org/

APPENDIX A: TREE-RING SCIENCE CAN HELP WITH A LONG-TERM VIEW OF CLIMATE*

Scientists have many tools available to them for understanding the ways that climate has changed in a particular location in the past. One useful tool is to study the rings that develop each year as trees grow to understand what kinds of environments those trees have experienced over their often very long lives. Dendrochronology—the study of tree rings—has been especially useful for understanding how much water flowed in rivers over long periods of time. By looking at many trees in a particular river basin, tree-ring scientists are able to create estimates of how much water flowed in that river each year. These reconstructions of streamflow can be used for water resource planning and management in many different ways, depending on the needs and technical resources available. The way tree-ring reconstructions of streamflow can be useful tends to fall into three basic categories:

- As informal guidance for water managers, stakeholders, and decision makers. For example, as a graphic in a brochure to inform irrigators about long-term drought variability.
- For more scientific assessments of long-term analysis of water availability. For example, assessing the severity and/or duration of a drought in the instrumental record in the context of the longer reconstructed record.
- As direct inputs into hydrologic models of a water system. Used in this way, water managers can model system performance with a much longer record—perhaps 1,000 years—than they can with records from stream gauges—perhaps only 100 years.

---

* The information presented here is adapted from the work of Connie Woodhouse and her colleagues on the TreeFlow website, available here: http://treeflow.info/applications.

APPENDIX B: BENEFITS AND CHALLENGES OF GRIDDED DATASETS

Despite the value, sophistication, and widespread use of gridded climatic datasets that are currently available, some limitations with these data still exist. The shortcomings of PRISM and all gridded datasets are primarily related to the observational data used and their spatial scale. For example, the data they use are from station networks that have limited spatial coverage or may be compromised by instrumentation changes or interrupted observations.

Although these datasets are suitable for use over geographic areas that range from states to individual watersheds, they cannot model with complete accuracy the influence that fine-scale variations in the land surface have on temperatures and precipitation. Variations in elevation and minimum temperatures within a single grid cell, for example, will not be represented in these datasets.

These limitations have implications when it comes to using the datasets for weather and climate data applications in Arizona. In general, maximum temperature models may be more accurate than minimum temperatures (because of problems with representing cold-air drainage in small areas). Also, representation of precipitation during the cool season, when storms are broader in size, may be more accurate than precipitation during the warm season, which often falls in highly localized storms.

Users should carefully consider such limitations in using these datasets (Daly 2006). However, for the type of historical overview useful in climate change adaptation planning, where identifying past patterns and current trends in overall climate and weather data is the most important function, PRISM data have proven to be more accurate than other datasets and have the longest record of the datasets (1895-present). Because they are used so widely in this region and beyond, data from GRIC can also more easily be compared or linked to other regions or communities.

APPENDIX C: GUIDANCE ON THE USE AND USEFULNESS OF CLIMATE PROJECTIONS

We know that what has happened in the past provides many clues about what may happen in the future, but unfortunately with climate change what has happened in the past can no longer be relied upon to help us plan for the future (Parris et al. 2012). Climate models cannot firmly predict future climate patterns, but they are useful tools that point us toward likely futures, based on the best available science.

Despite the usefulness of tools such as climate models, the future climate is uncertain. Some of that uncertainty comes from the range of possible ways we do or do not deal with our emissions of greenhouse gases in the future. Uncertainty also stems from the many different global climate models that are used to project future climate, and some of it comes from our incomplete knowledge of how the entire global climate system works. Knowledge on this subject is rapidly evolving, but is not perfect. It is these uncertainties that led climate scientists and decision makers to use the RCPs (discussed previously) to explore possible different futures.

With this understanding of the strengths and weaknesses of climate projections, decision makers can use projections as important tools in adaptation planning that allow them to examine and test their management options under several plausible futures.

COURTESY OF THE INSTITUTE OF THE ENVIRONMENT

GLOSSARY

Aspect: A surface feature of land: the direction a slope faces. A slope's aspect determines the amount of sun exposure it receives, so aspect affects temperature, humidity, and the type and amount of vegetation in a particular place.

Bi-modal precipitation: A pattern in which the majority of precipitation comes to a region in two distinct times of the year, for example summer and winter rains.

Climate: The averages and patterns of weather over time for a particular area, such as temperature, precipitation, humidity, and wind.

Climate projections: Estimates of future climatic conditions, usually made with mathematical models using different rates of greenhouse gas emissions to create different possible future scenarios.

Climate trends: Changes in climate in a particular area that have been observed over time, such as increases or decreases in average temperatures or the amount of annual precipitation.

Downscaling: Various methods that use data from global climate models to derive climate information for smaller areas of the world, such as specific regions (U.S. Southwest, for example).

Easterlies: Prevailing winds (also called Trade Winds) that blow from the east toward the west in the tropical Pacific Ocean.

Greenhouse gas (GHG): Any of the atmospheric gases that absorb longwave, or infrared, radiation that otherwise would pass from the Earth's surface through the atmosphere and into outer space. They include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NO_2), and water vapor.

Magnitude of change: In climate models, the magnitude of change is how much the climate is projected to change over a given period of time. Climate scientists generally have more confidence in models' ability to project the *direction* of change, such as whether it will be hotter in the future; but not exactly how much hotter it will be.

Normals period: A reference period that is used to create standard climate statistics. A 30-year period was recommended by the World Meteorological Organization in the early 1900s as the minimum number of years to use in the calculation of climate averages. The current normal period is updated each decade to reflect the most recent 30 years. The current normal period is 1981–2010 and will be updated again in 2021 for the period of 1991–2020.

Pluvial: A period of time, often multiple years, in which a particular area experiences abundant or well-above average precipitation.

Representative Concentration Pathways (RCP): Scenarios of different levels of greenhouse gas emissions that are used to estimate future global temperatures. The four RCPs used by the Intergovernmental Panel on Climate Change are 2.6, 4.5, 6.0, and 8.5; the numbers represent changes in radiative forcing, or the amount of outgoing infrared radiation relative to incoming shortwave solar radiation, at the top of the atmosphere.

Scenario: A description of a possible future state of the world. Scenarios do not represent what will happen; they represent what could happen, given our activities and choices.

Statistical downscaling: Correlating historical local and regional observations with data from global climate models to derive climate projections at local and regional scales.

Urban heat island (UHI): A built-up (urban) that is hotter than nearby rural areas. Buildings, roads, and other infrastructure replace open land and vegetation. Surfaces that were once permeable and moist become impermeable and dry. These changes cause urban regions to become warmer than their rural surroundings, forming an "island" of higher temperatures in the landscape.

Variability: A term to describe year-to-year changes in climatic conditions such as annual temperature and precipitation.

Weather: The day-to-day conditions in a particular area, such as temperature, precipitation, humidity, and wind.

REFERENCES CITED

Abatzoglou, J. T., and C. A. Kolden, 2011: Climate Change in Western US Deserts: Potential for Increased Wildfire and Invasive Annual Grasses. *Rangeland Ecology and Management*, **64**, 471-478.

Archer, S. R., and K. I. Predick, 2008: Climate Change and Ecosystems of the Southwestern United States. *Rangelands*, **30**, 23-28.

Arizona Department of Environmental Quality, 2009: The Impact of Exceptional Events 'Unusual Winds' on PM10 Concentrations in Arizona.

Arizona Department of Health Services, 2015: Deaths from Exposure to Excessive Natural Heat.

Ault, T. R., J. S. Mankin, B. I. Cook, and J. E. Smerdon, 2016: Relative impacts of mitigation, temperature, and precipitation on 21st-century megadrought risk in the American Southwest. *Science Advances*, **2**.

Ault, T. R., J. E. Cole, J. T. Overpeck, G. T. Pederson, and D. M. Meko, 2014: Assessing the Risk of Persistent Drought Using Climate Model Simulations and Paleoclimate Data. *Journal of Climate*, **27**, 7529-7549.

Baker, L. A., and Coauthors, 2002: Urbanization and warming of Phoenix (Arizona, USA): Impacts, feedbacks and mitigation. *Urban Ecosystems*, **6**, 183-203.

Blair, D. C., and W. W. Antone III, 2011: Gila River Indian Community Greenhouse Has Emissions Inventory, 8 pp.

Brown, H. E., A. C. Comrie, and D. M. Drechsler, 2013: Human Health. *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment*, G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, Eds., Island Press, 312-330.

Castro, C. L., 2017: Colorado River Basin streamflow projection under IPCC scenarios: from the global to basin scale using an integrated dynamic modeling approach. Southwest Climate Science Center. https://swclimatehydro.wordpress.com/project-data/streamflow-projection-data/

Cayan, D. R., and Coauthors, 2013: Future Climate: Projected Average. *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment*, G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, Eds., Island Press, 101-120.

Central Arizona Project, 2014: State of the Colorado River.

Cooke, T., 2016: Colorado River Shortage Update. Central Arizona Project,.

Crimmins, A., and Coauthors, 2016: *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*. U.S. Global Change Research Program, 312 pp.

Daly, C., 2006: Guidelines for assessing the suitability of spatial climate data sets. *Int. J. Climatol.*, **27**, 707-721.

de Munck, C., and Coauthors, 2013: How much can air conditioning increase air temperatures for a city like Paris, France? *Int. J. Climatol.*, **33**, 210-227.

Environmental Protection Agency, cited 2017: Particulate Matter. [Available online at http://www.epa.gov/airquality/particlepollution/index.html.]

——, 2016: Climate Change Indicators in the United States Fourth Edition https://www.epa.gov/climate-indicatorsEPA 430-R-16-004., 96 pp.

Executive Office of the President, 2013: The President's Climate Action Plan. *Executive Order 13514*.

Garfin, G., S. LeRoy, D. Martin, M. Hammersley, A. Youberg, and R. Quay, 2016: Managing for Future Risks of Fire, Extreme Precipitation, and Post-fire Flooding. Report to the U.S. Bureau of Reclamation, from the project Enhancing Water Supply Reliability., 33 pp.

Geogakakos, A., and Coauthors, 2014: Water Resources. Climate Change Impacts in the United States: *The Third National Climate Assessment*, J. M. Melillo, T. Richmond, and G. W. Yohe, Eds.

Gershunov, A., and Coauthors, 2013: Future Climate: Projected Extremes. A*ssessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment*, G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, Eds., Island Press.

Grossman-Clarke, S., S. Schubert, T. A. Clarke, and S. Harlan, 2014: Extreme summer heat in Phoenix, Arizona (USA) under global climate change (2041 - 2070). *Die Erde*, **145**, 49-61.

Guhathakurta, S., and P. Gober, 2007: The Impact of the Phoenix Urban Heat Island on Residential Water Use. *Journal of the American Planning Association*, **73**.

Harlan, S., G. Chowell, S. Yang, D. Petitti, E. Morales Butler, B. Ruddell, and D. Ruddell, 2014: Heat-Related Deaths in Hot Cities: Estimates of Human Tolerance to High Temperature Thresholds. *International Journal of Environmental Research and Public Health*, **11**, 3304.

Huang, J., and K. R. Gurney, 2017: Impact of climate change on U.S. building energy demand: Financial implications for consumers and energy suppliers. *Energy and Buildings*, **139**, 747-754.

Kennedy, C., 2014: Does "global warming" mean it's warming everywhere? *ClimateWatch Magazine*, NOAA Climate.gov.

Lader, G., A. Raman, J. T. Davis, and K. Waters, 2016: Blowing Dust and Dust Storms: One of Arizona's Most Underrated Weather Hazards.

Leibensperger, E. M., and Coauthors, 2012: Climatic effects of 1950 - 2050 changes in US anthropogenic aerosols; Part 2: Climate response. *Atmos. Chem. Phys.*, **12**, 3349-3362.

Mar, T. F., G. A. Norris, J. Q. Koenig, and T. V. Larson, 2000: Associations between air pollution and mortality in Phoenix, 1995-1997. *Environ. Health Perspect.*, **108**, 347-353.

Meehl, G. A., J. M. Arblaster, and C. T. Y. Chung, 2015: Disappearance of the southeast U.S. “warming hole” with the late 1990s transition of the Interdecadal Pacific Oscillation. *Geophysical Research Letters*, **42**, 5564-5570.

Melillo, J., T. C. Richmond, and G. W. Yohe, Eds., 2014: *Climate change consequences in the United States: The third national climate assessment*. U.S. Global Change Research Program, 841 pp.

Moser, S., and J. A. Eckstrom, 2010: A framework to diagnose barriers to climate change adaptation. *PNAS*, **107**, 22026-22031.

Munson, S. M., R. H. Webb, J. Belnap, J. Andrew Hubbard, D. E. Swann, and S. Rutman, 2012: Forecasting climate change impacts to plant community composition in the Sonoran Desert region. *Global Change Biology*, **18**, 1083-1095.

Ohashi, Y., Y. Genchi, H. Kondo, Y. Kikegawa, H. Yoshikado, and Y. Hirano, 2007: Influence of Air-Conditioning Waste Heat on Air Temperature in Tokyo during Summer: Numerical Experiments Using an Urban Canopy Model Coupled with a Building Energy Model. *Journal of Applied Meteorology & Climatology*, **46**, 66-81.

Painter, T. H., J. S. Deems, J. Belnap, A. F. Hamlet, C. C. Landry, and B. Udall, 2010: Response of Colorado River runoff to dust radiative forcing in snow. *Proc. Natl. Acad. Sci.*, **107**, 17125-17130.

Painter, T. H., and Coauthors, 2007: Impact of disturbed desert soils on duration of mountain snow cover. *Geophysical Research Letters*, **34**, n/a-n/a.

Parris, A., and Coauthors, 2012: Global Sea Level Rise Scenarios for the US National Climate Assessment. NOAA Tech Memo OAR CPO-1. 37.

Roach, M., and Coauthors, 2017: Projections of Climate Impacts on Vector-Borne Diseases and Valley Fever in Arizona. A report prepared for the Arizona Department of Health Services and the United States Centers for Disease Control and Prevention Climate-Ready States and Cities Initiative.

Salamanca, F., M. Georgescu, A. Mahalov, M. Moustaoui, and M. Wang, 2014: Anthropogenic heating of the urban environment due to air conditioning. *Journal of Geophysical Research: Atmospheres*, **119**, 5949-5965.

Smith, H. G., G. J. Sheridan, P. N. J. Lane, P. Nyman, and S. Haydon, 2011: Wildfire effects on water quality in forest catchments: A review with implications for water supply. *Journal of Hydrology*, **396**, 170-192.

Sonoran Desert Network Inventory and Monitoring Program: Climate Change in the Sonoran Desert. [Available online at https://www.nps.gov/articles/climate-change-in-the-sonoran-desert.htm.]

Tong, D. Q., J. X. L. Wang, T. E. Gill, H. Lei, and B. Wang, 2017: Intensified dust storm activity and Valley fever infection in the southwestern United States. *Geophysical Research Letters*, n/a-n/a.

U.S. Department of the Interior Bureau of Reclamation, 2016a: SECURE Water Act Section 9503(c) Report to Congress.

——, 2016b: West-Wide Climate Risk Assessments: Hydroclimate Projections.

Udall, B., 2013: Water: Impacts, Risks, and Adaptation. *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment*, G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, Eds., Island Press, 197-217.

van Vuuren, D. P., and Coauthors, 2011: RCP2.6: exploring the possibility to keep global mean temperature increase below 2°C. *Climatic Change*, **109**, 95.

Vano, J. A., and Coauthors, 2014: Understandng Uncertainties in Future Colorado River Streamflow. *Bull. Amer. Meteor. Soc.*, **95**, 59-78.

Westerling, A. L., A. Gershunov, T. J. Brown, D. R. Cayan, and M. D. Dettinger, 2003: Climate and Wildfire in the Western United States. *Bull. Amer. Meteor. Soc.*, **May 2003**, 595-604.

Yin, D., S. Nickovic, B. Barbaris, B. Chandy, and W. A. Sprigg, 2005: Modeling wind-blown desert dust in the southwestern United States for public health warning: A case study. *Atmospheric Environment*, **39**, 6243-6254.

Yip, F. Y., and Coauthors, 2008: The impact of excess heat events in Maricopa County, Arizona: 2000-2005. *International Journal of Biometeorology*, **52**, 765-772.

Native Nations Climate Adaptation Program

THE UNIVERSITY OF ARIZONA
Agnese Nelms Haury
Program in Environment and Social Justice

Gila River Indian Community
Department of Environmental Quality

Center for **Climate Adaptation Science** and **Solutions**

Gila River Indian Community
1939
Arizona

CLIMAS
Climate Assessment for the Southwest
A NOAA RISA TEAM

Institute of the ENVIRONMENT