CLIMATE PROFILE FOR THE
FORT MCDOWELL YAVAPAI NATION

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DEVELOPED FOR:
Fort McDowell Yavapai Nation Environmental Department

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

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INTRODUCTION

The Fort McDowell Yavapai Nation (FMYN) is located in northeastern Maricopa County of Arizona. The Nation has 24,680 acres of land and is bordered by the town of Fountain Hills, the communities of Rio Verde and Goldfield Ranch, and the Tonto National Forest. The Salt River Pima-Maricopa Indian Community lies to the south of FMYN. The Verde River runs lengthwise (about 10 miles north to south) through FMYN (see Figure 1). The following analysis was done over an area that includes FMYN and a 4-km (2.5-mile) mile buffer around it so as to include relevant influences on its climate.

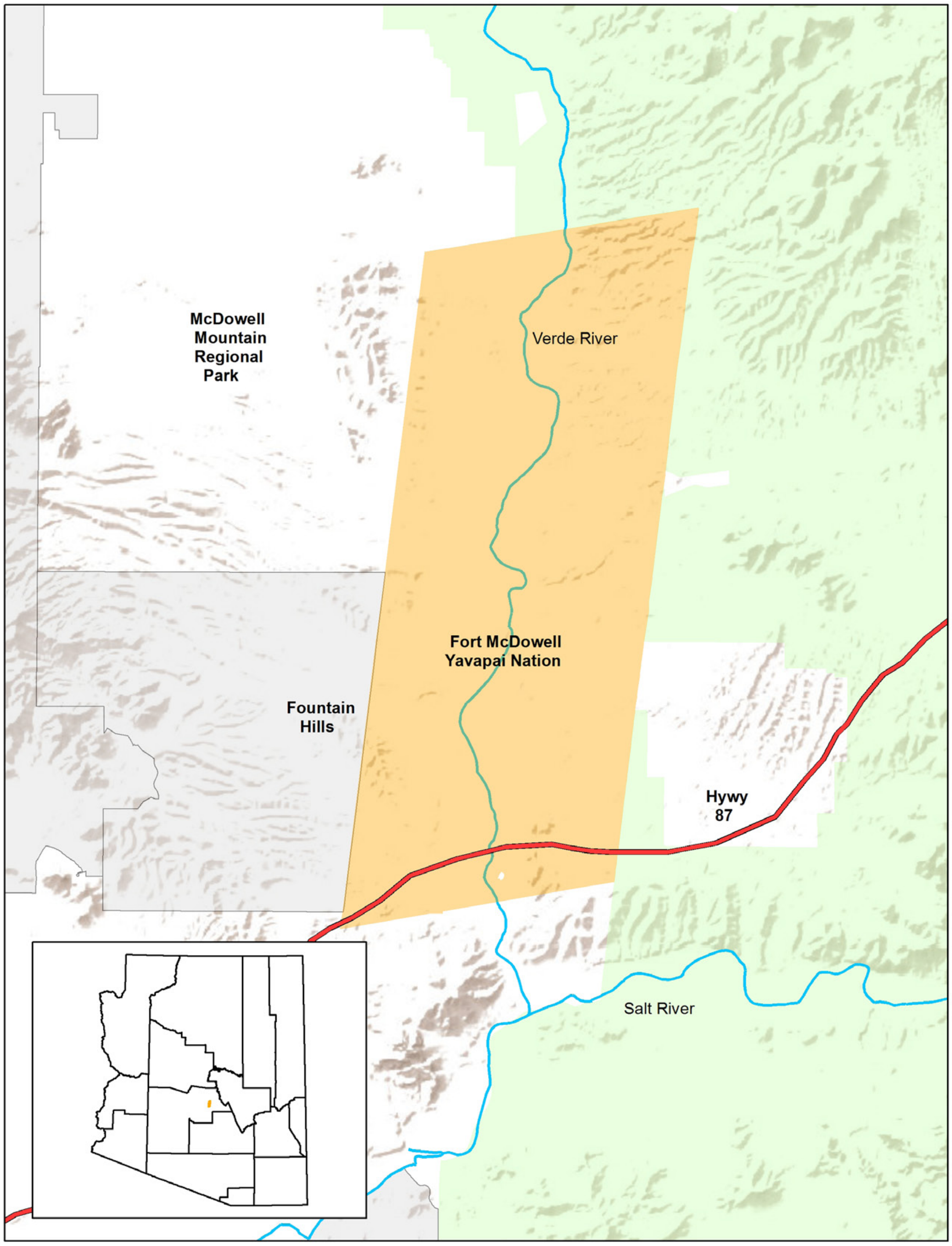

Figure 1: Fort McDowell Yavapai Nation. Map by University of Arizona Advanced Resource Technology (ART) Lab.

BASELINE CLIMATE DATA FOR THE FORT MCDOWELL YAVAPAI NATION

To analyze the climate across the FMYN, we relied on the PRISM (Parameter-elevation Regression on Independent Slopes Model) dataset (http://prism.oregonstate.edu/). PRISM is a method that uses the 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. The stations used in PRISM mainly come from the National Weather Service Cooperative Observer Program of the National Oceanic and Atmospheric Administration, which have the longest continuous record of weather data. However, data from other weather stations are included if they have at least 20 years of data.

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***[1] and ***climate*** due to complex terrain, rain shadows, elevation, and ***aspect*** – all of which affect weather patterns on the Nation, as discussed below in the section on Precipitation. PRISM data begins in 1895 with the first consistently recorded instrumental climate records. Climatologists refer to the period from 1895 to the present as the "instrumental record" period.

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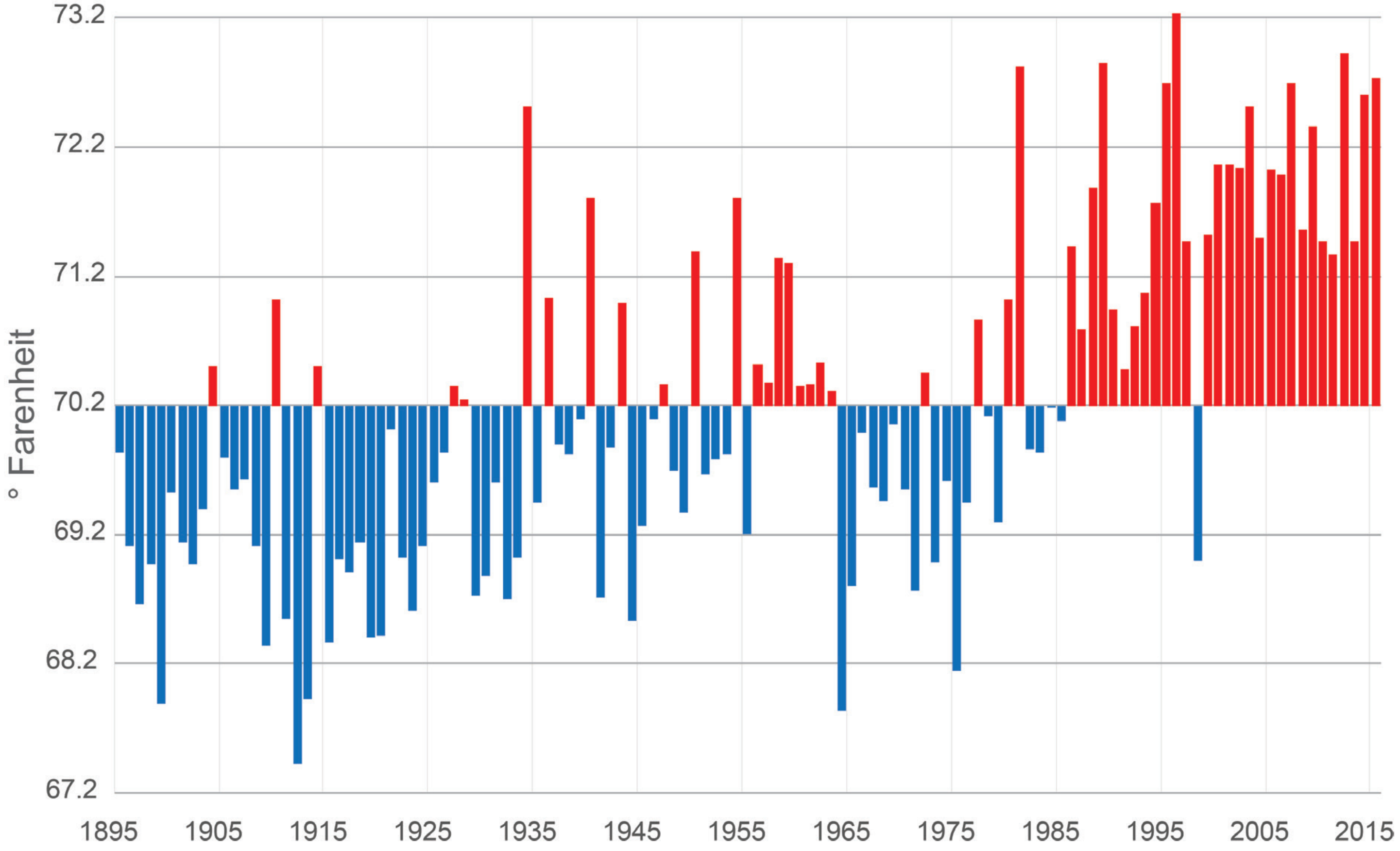
[1] Bolded terms are included in the Glossary

CHRIS ENGLISH

Temperature in Historical Perspective

Between 1895 and 2015, the annual average temperature across the FMYN was 70.2° F (represented by the straight horizontal line in Figure 2). However, year-to-year the averages have ranged from 67.4° F in 1912 to over 73° F in 1996. Years with average temperatures below 70.2° F are represented by blue bars; years with average temperatures above 70.2° F are represented with red bars. Although year-to-year changes in temperature are natural and expected in this region, we see a fairly consistent rising trend in annual temperatures since the mid-1980s, which is likely a result of anthropogenic ***greenhouse gas*** (GHG) emissions. Since 1985 almost all years have had average annual temperatures above the long-term average.



Annual Average Temperatures for the Fort McDowell Yavapai Nation 1895–2015

Figure 2: Average annual temperatures for FMYN from 1895 – 2015.

Disaggregating temperatures as average daily maximum, average daily minimum, as well as 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. Overall average is the average of both maximum and minimum temperatures for an area over a given time.

In Figure 3, below, we see that minimum annual average temperatures (shown in yellow) for FMYN have been rising faster than maximums (shown in red). This pattern indicates that the warming trend is being driven by rising low temperatures – temperatures are not dropping as much as they used to in the past.

Maximum, Minimum, and Average Temperatures for the Fort McDowell Yavapai Nation 1895–2015

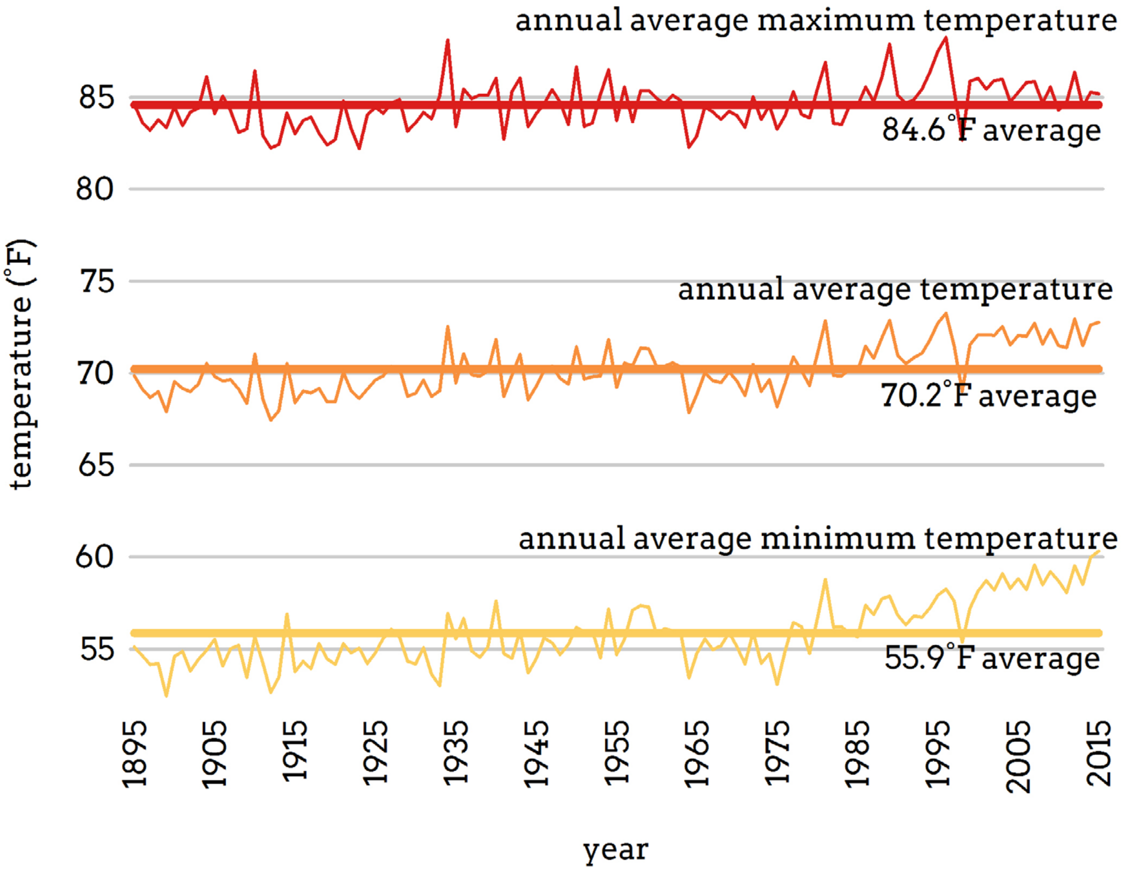


Figure 3: Annual average maximum, minimum, and overall average temperatures for FMYN from 1895 – 2015.

Precipitation in Historical Perspective

Figure 4, below, shows that the average precipitation across FMYN between 1895 and 2015 was 11.1 inches per year. Based on conversations with the FMYN Environmental Department about the geographic area that influences the climate and ecosystem of FMYN, in our analysis we used a geographic area that includes a 2.5-mile (4km) buffer around the boundary of the Nation. By including areas higher in elevation that surround the Nation, we have captured higher precipitation levels than might be recorded at weather stations placed directly on FMYN. The larger area of analysis was chosen to represent the wider area that influences FMYN.

As is normal in the Sonoran Desert, precipitation across FMYN is highly variable and has ranged from 23.6 inches in 1992 to as little as 4.6 inches in 1956. Years with above-average precipitation are represented with green bars; years with below-average precipitation are represented with brown bars. FMYN 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 the Fort McDowell Yavapai Nation 1895–2015

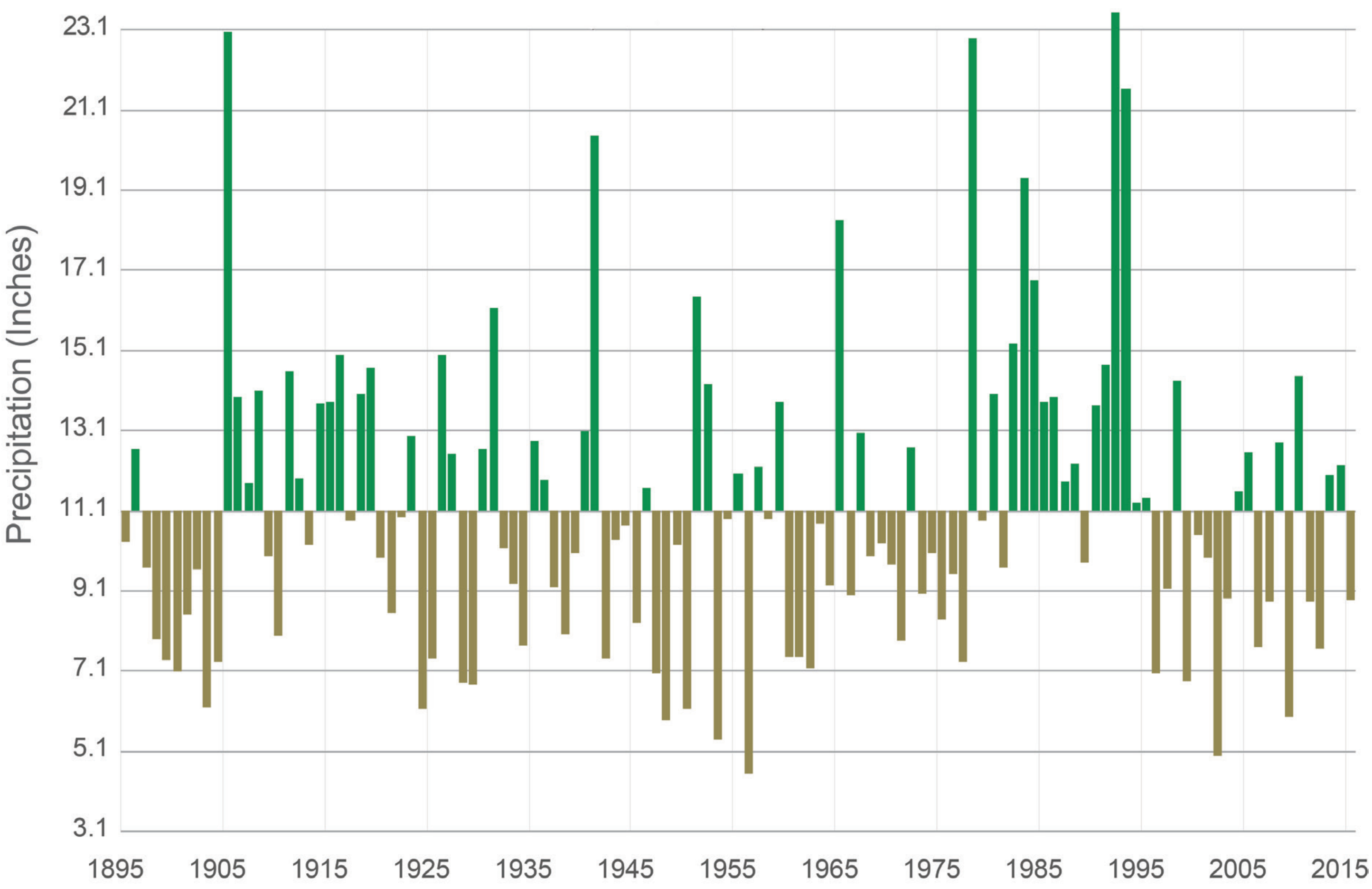


Figure 4: Average annual precipitation across the FMYN from 1895 – 2015.

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 5 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.

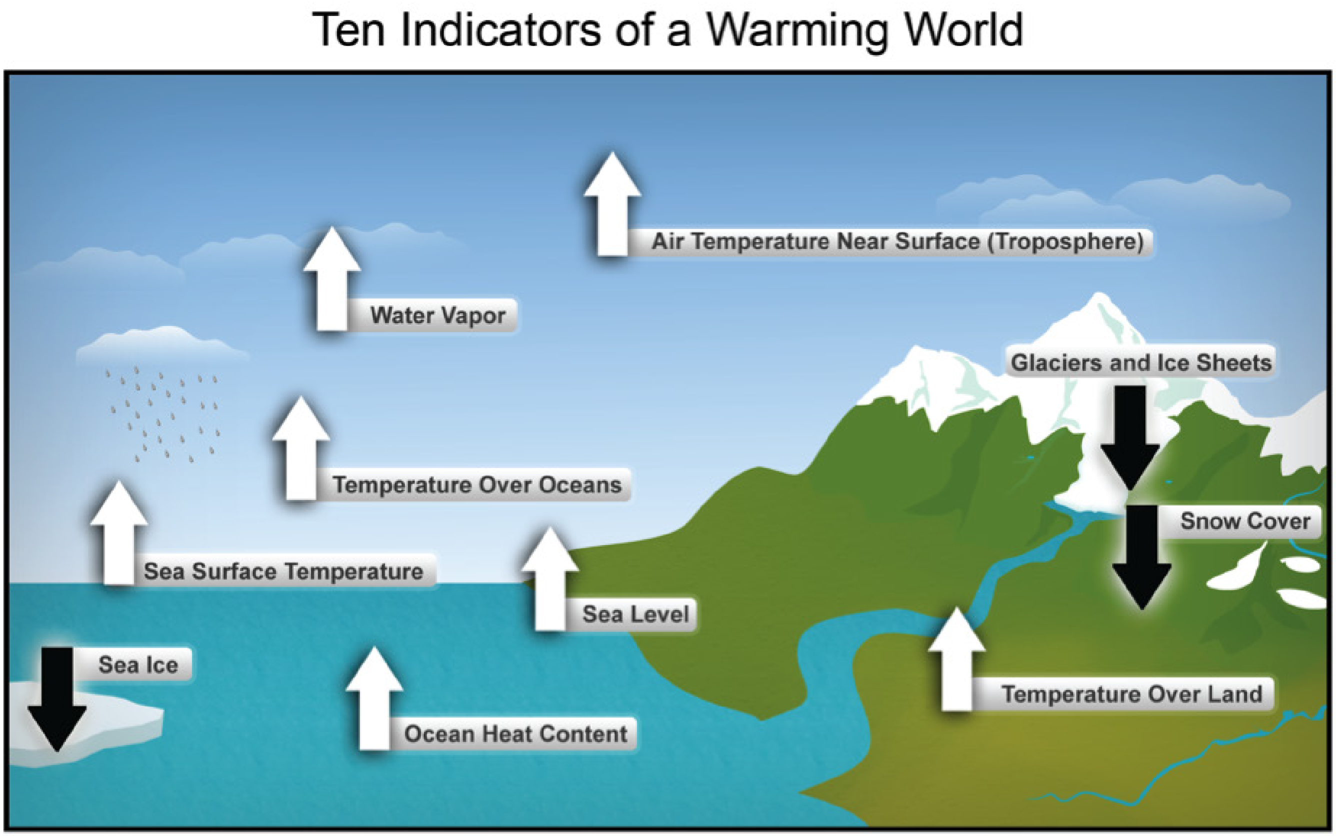


Figure 5: Some of the indicators that the world, as a whole, is warming up. The white arrows indicate increasing trends, like rising temperatures and sea levels. The black arrows indicate decreasing trends, such as the amount of snow in northern and mountain regions. Source: http://nca2014.globalchange.gov/report/our-changing-climate/observed-change#tab2-images.

Figure 6 shows temperature changes from 1991 to 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 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; and 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).

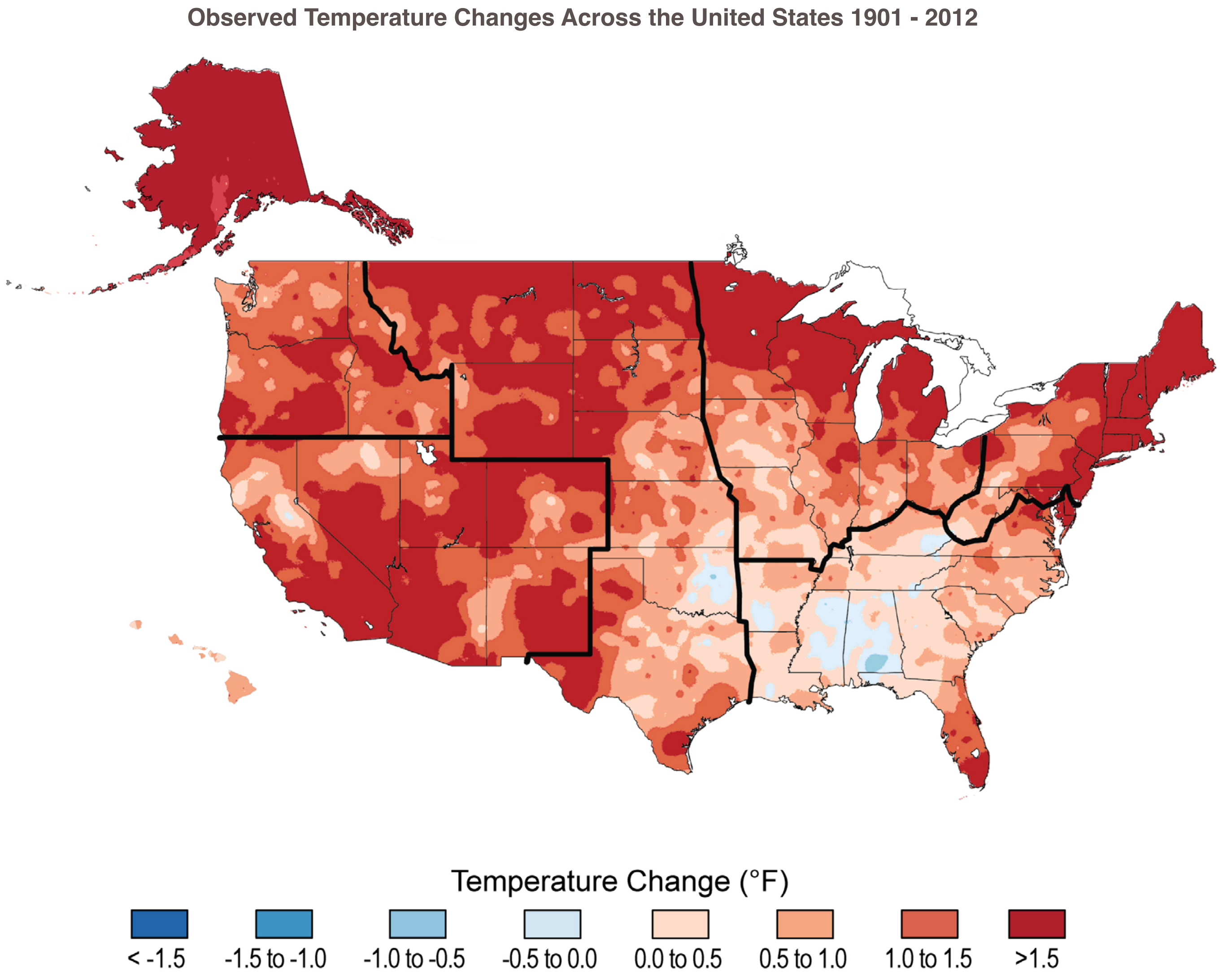
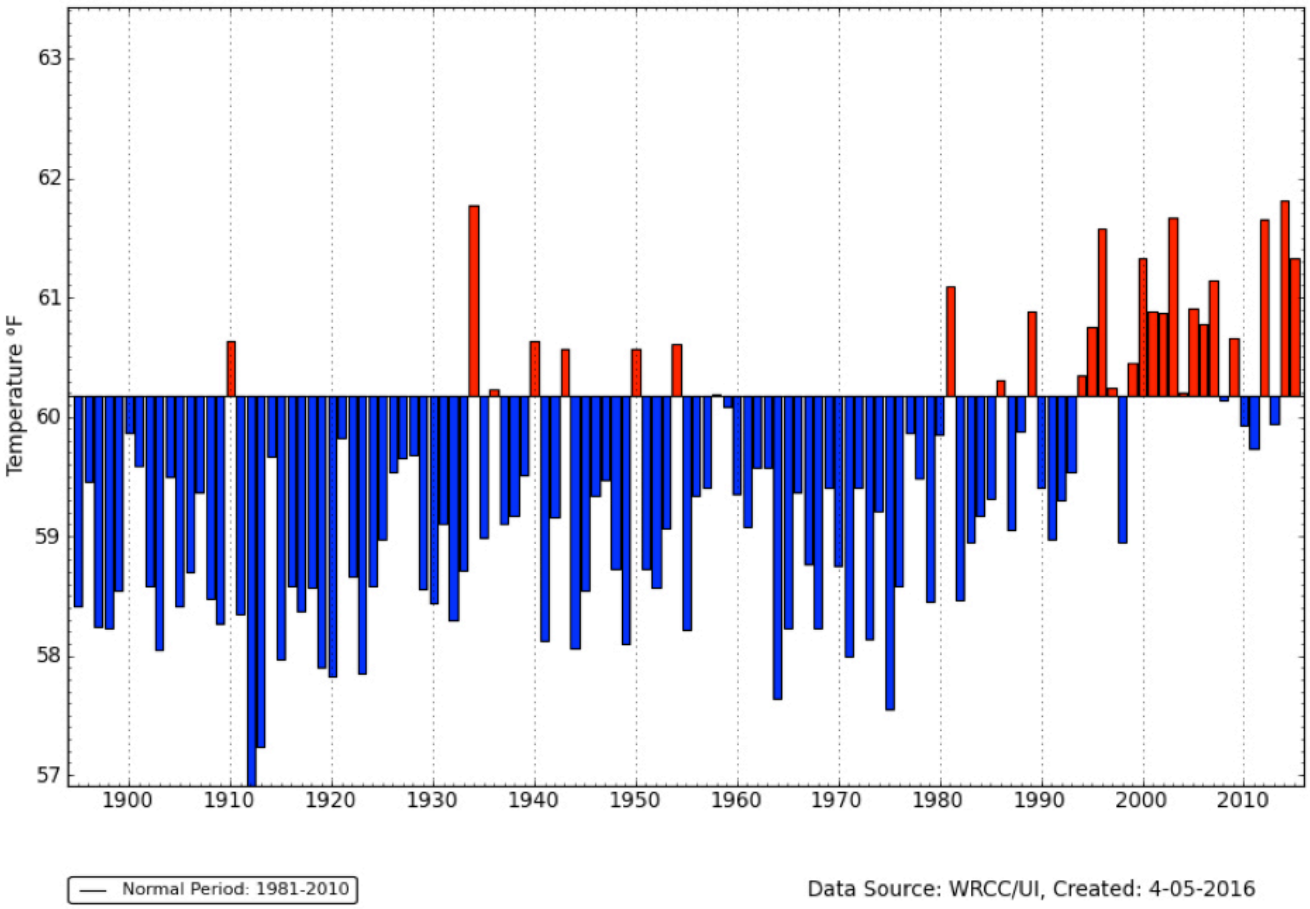


Figure 6: Observed temperature changes from 1991–2012 in the United States compared to the average temperatures from 1901–1960. The darker the red color, the greater the difference between 1901–1960 and 1991–2012: these areas have experienced more warming. (Source: http://nca2014.globalchange.gov/report/our-changing-climate/recent-us-temperature-trends#tab2-images)

Arizona has experienced similar temperature trends as those observed for FMYN. Figure 7 displays the annual average temperature for the state for each year 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 in Arizona. However, globally, 2016 was the warmest year on record.

Annual Average Temperature for Arizona 1895–2015



Data Source: WRCC/UI, Created: 4-05-2016

Figure 7: 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 8). 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 major 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 levels of GHGs, 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 again. 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.

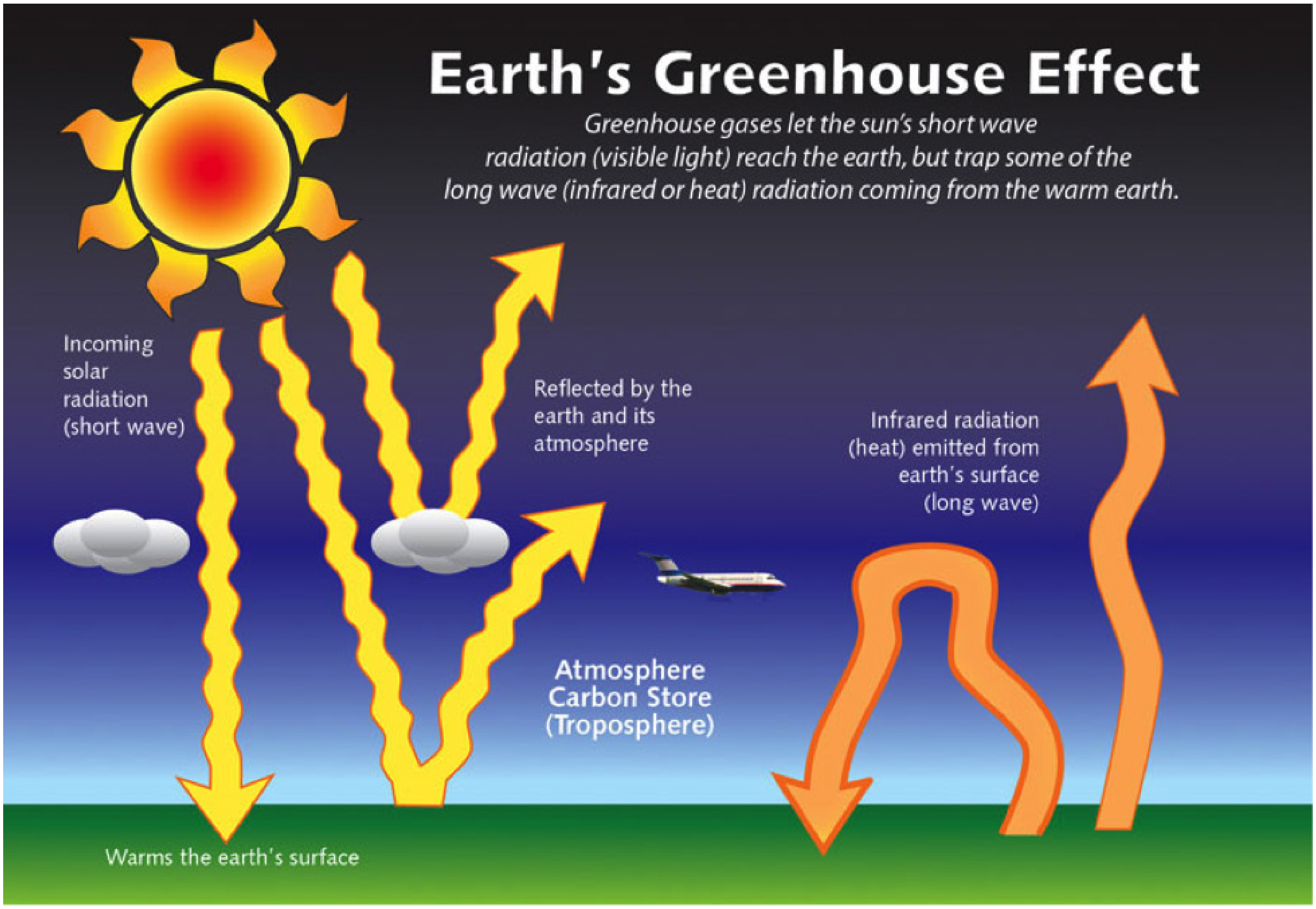


Figure 8. Source: New York State Department of Environmental Conservation; http://www.dec.ny.gov/energy/76533.html.

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 9), 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 the El Niño-Southern Oscillation (ENSO, a shift in global atmospheric circulation patterns), which can cause global temperatures to quickly rise during El Niño years and cool during La Niña years.

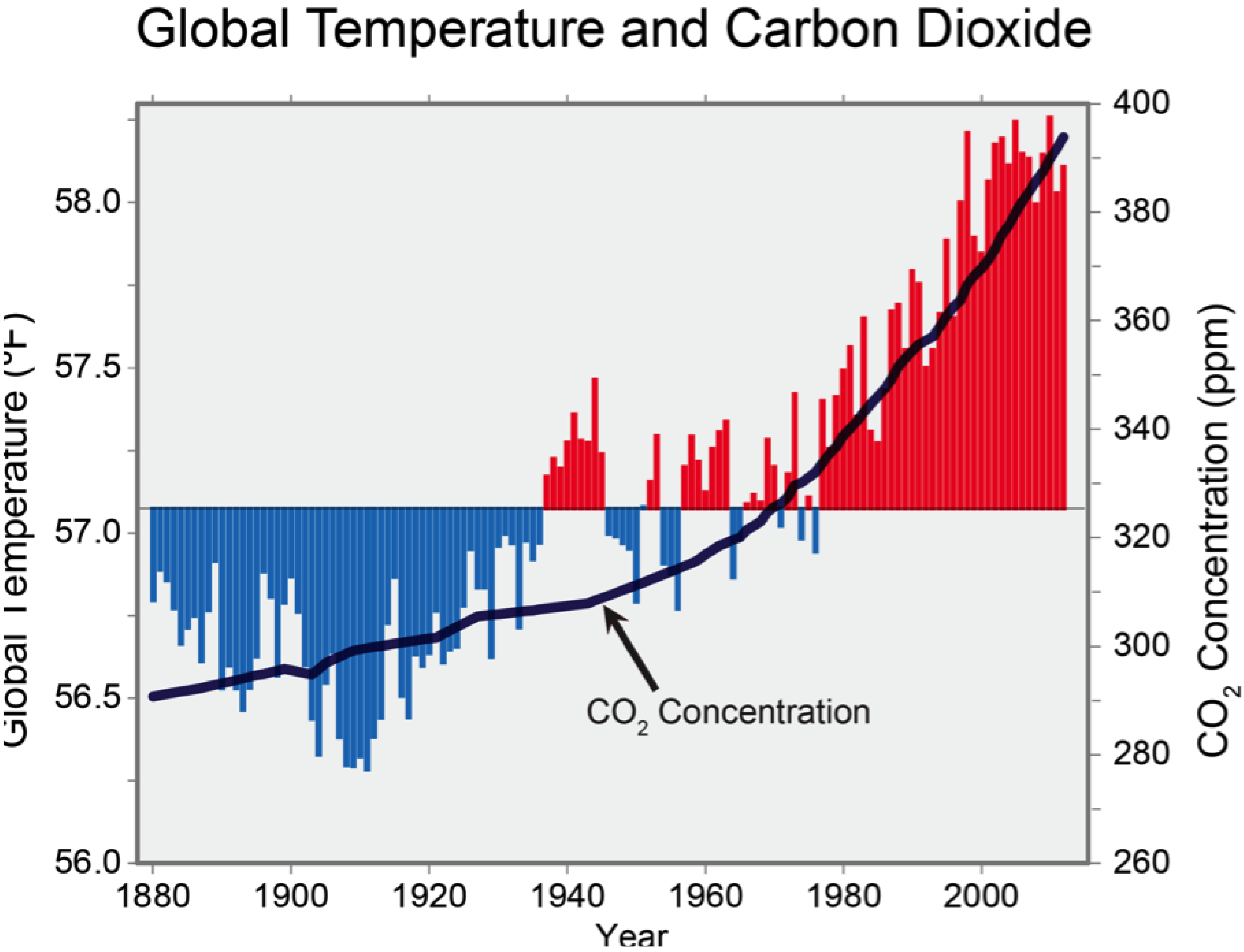


Figure 9: We can trace the corresponding rise in CO$_2$ and global temperatures. Blue bars represent years with an average temperature lower than the long-term global average of 57° F, and the red bars are years in which the temperature was warmer than average. The black line traces the amount of carbon 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 10 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 up with 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.

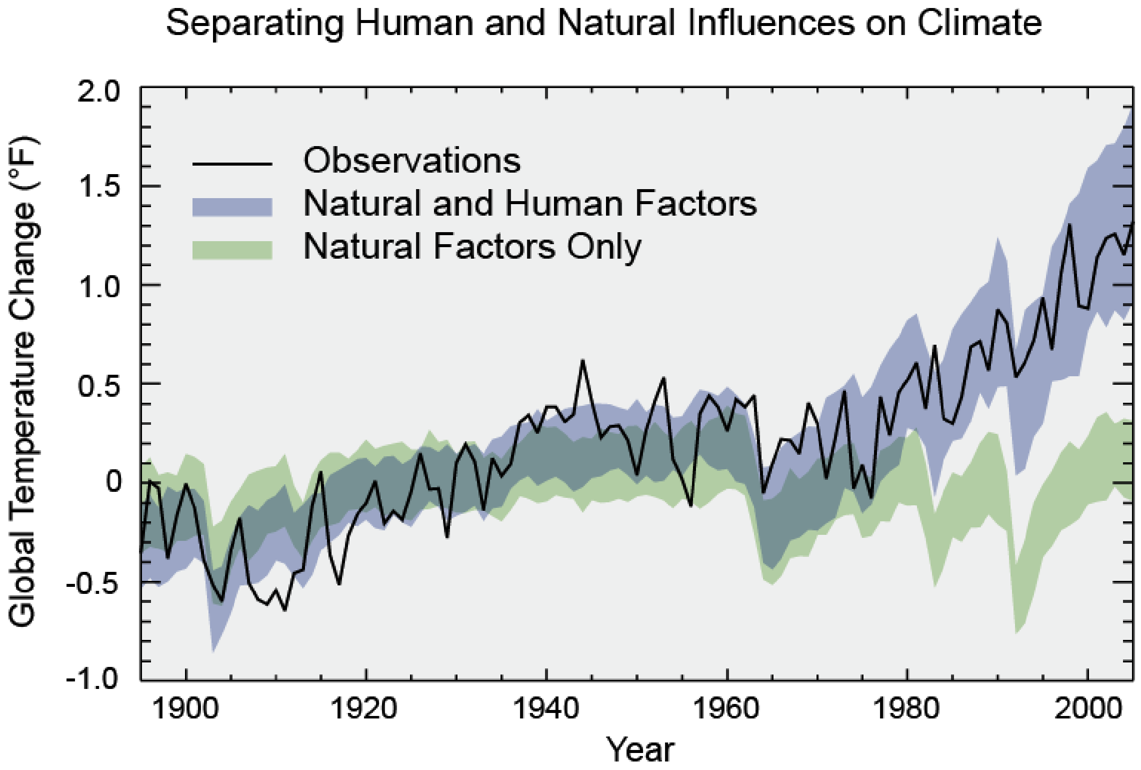


Figure 10: When model experiments are conducted to compare natural warming factors, such as solar radiation or volcanic eruptions (represented by the green shaded area), with observed temperature changes (solid black line), scientists find that natural factors alone cannot explain the actual changes 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.

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 11 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 this 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 5° 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.

GCMs that were built to cover the whole globe can be focused on smaller regions through a process of ***downscaling***. 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 affect the FMYN, but big enough that we still have confidence in the accuracy of the projections. In this study, we analyzed downscaled climate projection data from one model run of each global model using the four scenarios described in Figure 11.

Projected Global Temperature Changes Through 2100

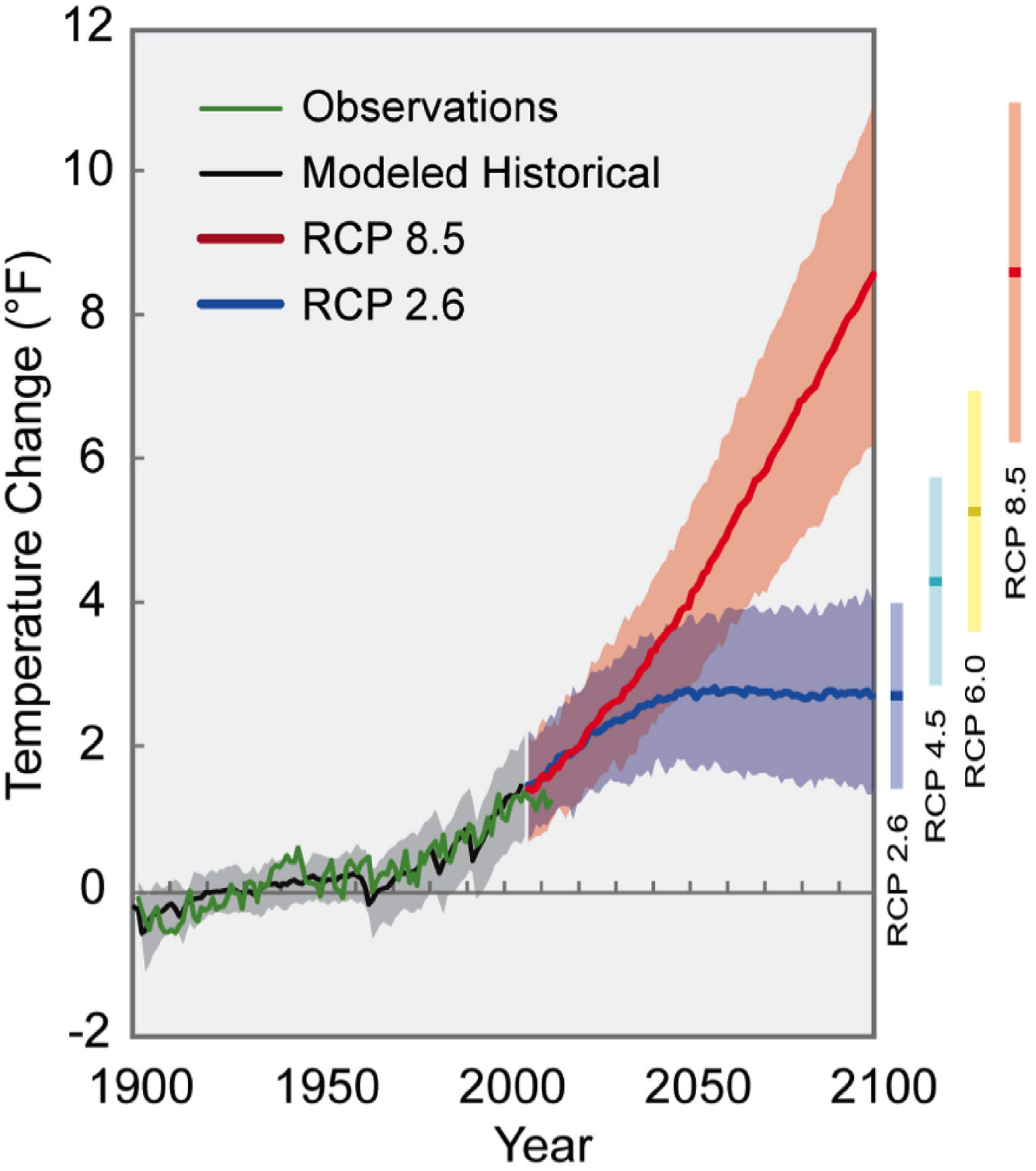


Figure 11: Projected global temperature increases using the four Representative Concentration Pathways (RCP) scenarios.

Downscaled model projections for Arizona (Figure 12) 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. The long-term average annual temperature across the Fort McDowell Yavapai Nation is about 70° F; an increase of 10° F means a potential for average annual temperatures of 80° F. The average maximum temperature (average highest temperature of each day) is about 85° F and is projected to rise to 95° F. The average minimum temperature (average of the lowest temperatures of each day) is currently 56° F, but could rise to almost 66° F by the end of the century.

The small dots in Figure 12 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.

Projected Change in Temperature for Arizona

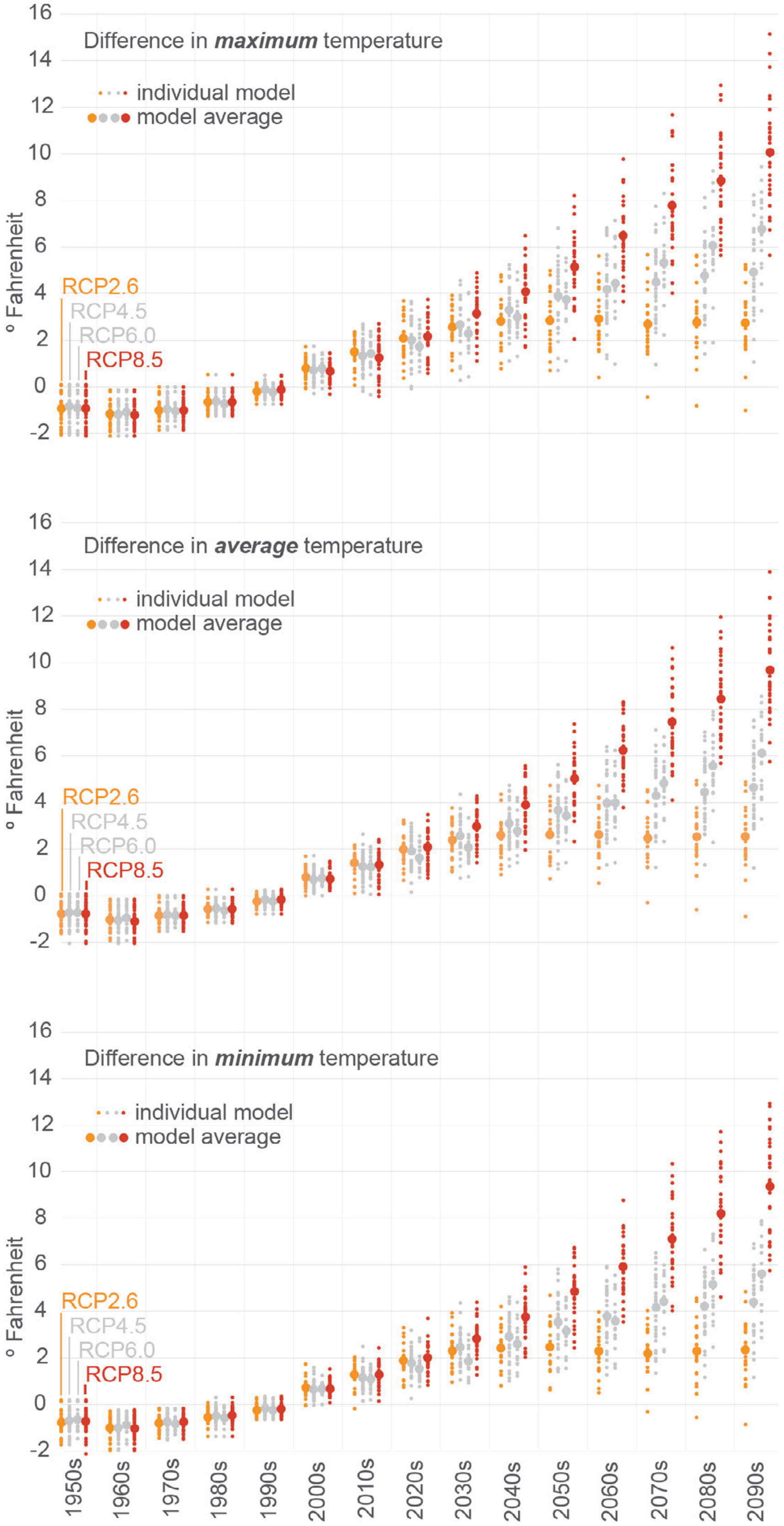


Figure 12: Downscaled model projections for Arizona show a range of possible future temperature increases, from just over 2° F higher than the 1986–2005 average for RCP 2.6 (orange dots), to almost 10° F higher for RCP 8.5 (red dots). If GHG emissions continue at their current rate, the state could be 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 for *temperature* show possible increases in all four scenarios, the projections show little-to-no change in annual average *precipitation* for Arizona, even under the “worst case” RCP 8.5 scenario (brown dots in Figure 13). Figure 13 shows the projected percent change in total precipitation for Arizona from the 1986–2005 average. None of the models show more than a few percentage points of change in either direction (more or less rain). The projections do not show a trend, but reflect the variable precipitation we are already familiar with. The current average precipitation in the state is about 11 inches per year. The model projections show a possible change of about 5% in either direction (higher or lower), which translates to about half an inch more or less each year. Because approximately half of this region’s annual precipitation comes from the North American Monsoon, it is important to note that modeling the monsoon has proven very difficult, making future projections about precipitation in this region much less certain than projections of future precipitation in other parts of the country (Gershunov et al. 2013). However, even if there is no change in total precipitation, Arizona could become much drier as warmer temperatures mean more evaporation over surface water and more evapotranspiration (use of water by plants), which will further dry the soil.

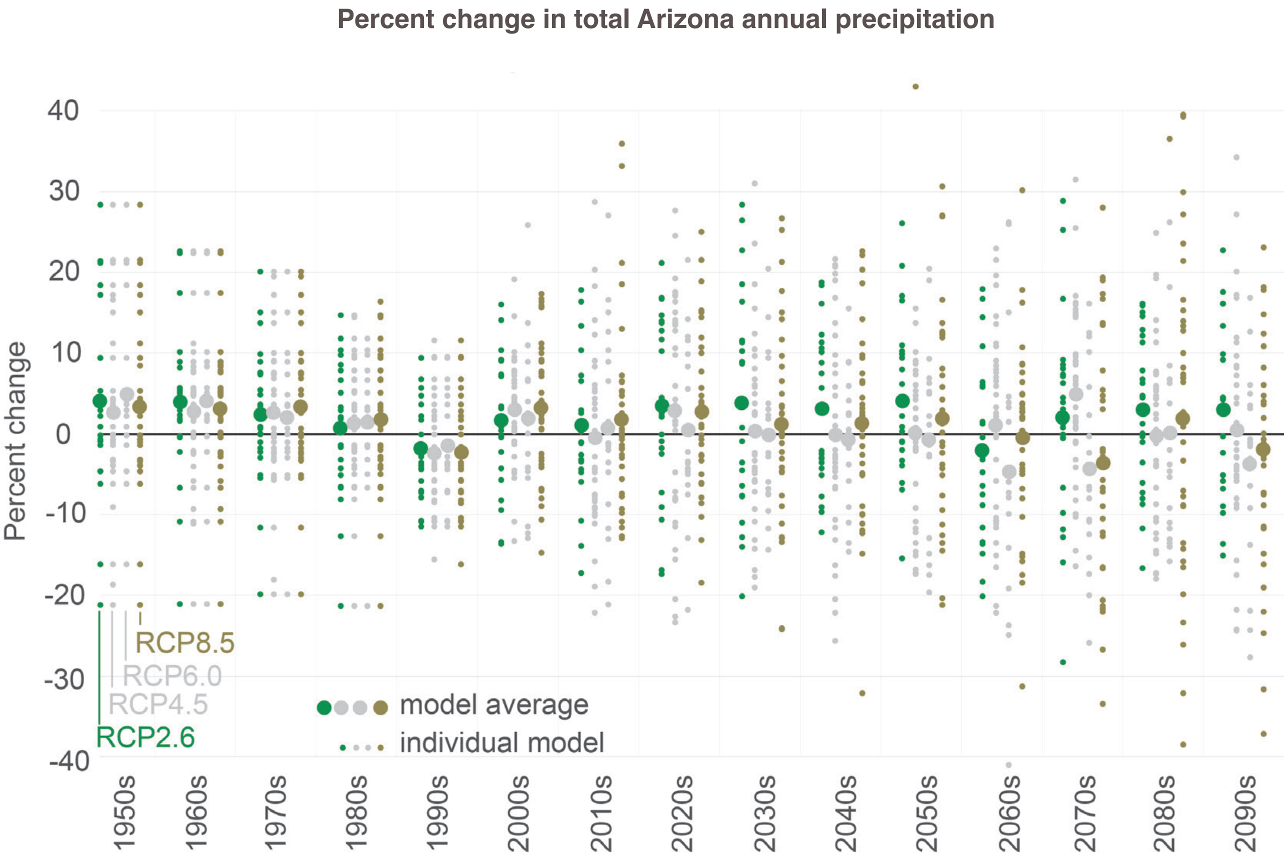


Figure 13: Downscaled projections of annual average precipitation for Arizona, using the four RCPs.

CLIMATE CHANGE IMPACTS FOR FMYN

Agriculture

In general, agriculture and ranching in Arizona are experiencing increased drought events with rising seasonal and diurnal temperatures and pest damages that will compound to reduce yields and productivity (Eakin and Liverman 1997). The 2,000-acre FMYN Farm depends upon irrigation for crop production, and as temperatures increase, water demand for crops may also increase. Longer periods of extreme heat combined with longer frost-free seasons may cause early ripening and reduce some crop yields. Some studies suggest that as the effects of a warming climate continue to escalate, crops currently grown in this region may no longer be sustainable (Garfin et al. 2016). Marketable yields for crops grown on the FMYN Farm are more sensitive to climate change as even short-term stresses can negatively affect visual color and flavor quality of perennial fruit and nut crops. These crops will be more sensitive to winter as well as summer temperatures as the current warming trend continues and increased drought events become more common in the Southwest (Hatfield et al. 2008).

One thousand acres of the FMYN Farm are devoted to growing the Western Schley variety of pecans (*Carya illinoinensis*). Pecans in general are at risk of vivipary, which is a premature ripening of the seed that causes crop failure, due to rising temperatures. There are, however, some actions that can reduce the occurrence of vivipary such as increasing soil moisture content to the field's capacity during the kernel filling stage (Wood 2003). Ambient temperatures are not the sole cause of premature ripening of the nut. Scientists have identified the combination of high and low temperatures in the kernel filling stage as a potential driver of vivipary (Wood 2003). As temperatures rise, the threat of fire increases in tandem. Pecan trees are extremely susceptible to fire damage at all stages of growth, particularly due to their barks' low insulating capacity (Wasser 1982).

The FMYN Farm also grows 300 acres of Cibola alfalfa and 340 acres of barley. As temperatures rise, alfalfa yields may increase up to certain thresholds and then decrease if temperatures rise more than 1° C; the highest crop losses are likely during the stem elongation growth phase (Berardy and Chester 2017). Elevated CO_2 will likely affect the quality of alfalfa by reducing its protein and nitrogen content (Hatfield et al. 2008).

Citrus grown on the FMYN consists of 30 acres of Fairchild mandarin oranges, 10 acres of Rio Red grapefruit and 30 acres of Minneola tangelos. Citrus crops respond relatively well to warming temperatures as fruit quality and color can actually improve under conditions of mild water stress (Mortenson 2004). However, higher temperatures increase evaporation, which in turn increases irrigation demands by approximately 2.6% per 1° C on average. Thus, future irrigation demands will continue to increase as overall average temperatures rise. Fruit development in the fall may also be negatively affected with increasing temperatures due to a breakdown of chlorophyll affecting fruit flavor and color (Hatfield et al. 2008). Managing water quantity in order to meet the demands for citrus crops may be a challenge in the future (Eakin and Liverman 1997; Eakin and Conley 2002; Eden et al. 2008).

Human Health

The U.S. Global Change Research Program (USGCRP), which is tasked with assessing present and future impacts of climate change in 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, vector-borne disease, and (in the emergency management section) flooding, at the request of FMYN.

Extreme Heat and Energy Use

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)[2] during June, July, and August in the Phoenix Metropolitan Area are likely to occur about six times more often by 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. The average number of EHE days per summer may also increase by a factor of 12: from an average 2 days per summer in 1971-2000 to 24.4 days per summer in 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).

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[2] EHEs are defined in this instance 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, and 3) maximum temperature above 113.4° F (45.2° C) for at least three days.

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

The USGCRP also noted that human tolerance for heat has been increasing, due to a combination of improved social responses, physiological acclimatization, and technology (air conditioning). 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 (for example, de Munck et al. 2013; Ohashi et al. 2007) 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. 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 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 1948–2000, 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).

Higher temperatures may also influence how much water households use. 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—households in those neighborhoods tended to use more water. A household in a neighborhood where low temperatures were 1° F higher than others in Phoenix tends to use an average of 290 gallons of water during the month of June (the month for which the analysis was conducted) (Guhathakurta and Gober 2007). While much of the water use in this study was found to be for outdoor use, the researchers also found that water use for evaporative coolers was a significant contributor to household use. 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).

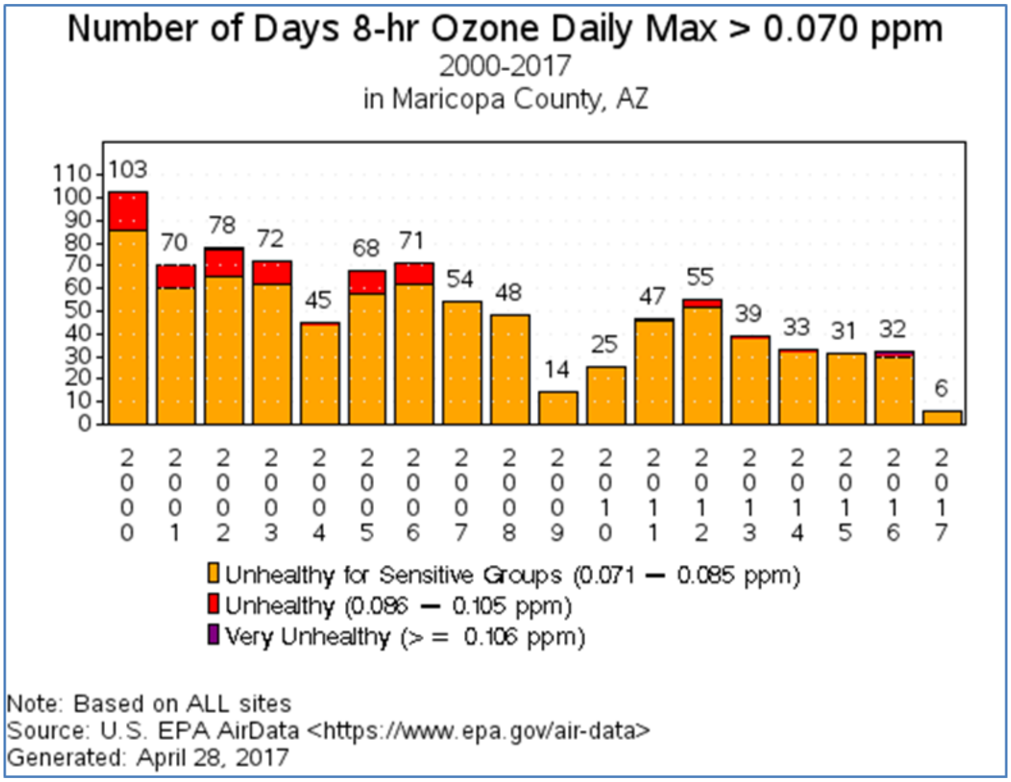
Air Pollution

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 (http://pub.azdhs.gov/health-stats/hip/index.php).

Increased temperatures will increase ground-level ozone pollution in many areas of the United States. Ground-level ozone is produced when nitrogen oxides and hydrocarbons from automobile exhaust, power plant and industrial emissions, gasoline vapors, chemical solvents, and some natural sources react in heat and sunlight. Exposure to ground-level ozone is linked to reduced lung function and respiratory problems such as pain with deep breathing, coughing, and airway inflammation (Brown et al. 2013). Rising temperatures, combined with the existing sources of ground-level ozone, are expected to contribute to higher levels of ozone and increases in deaths due to exposure (Crimmins et al. 2016).

Ozone exceedance days have fallen in Maricopa County since the early 2000s (Figure 14). FMYN's Air Quality Department reports a similar trend of falling exceedance days (personal communication, Karen Shaw). However, ozone tends to peak in the hotter summer months – May through August (Figure 15). As temperatures rise and heatwaves become more common, it is possible that ozone exceedance days may also rise.

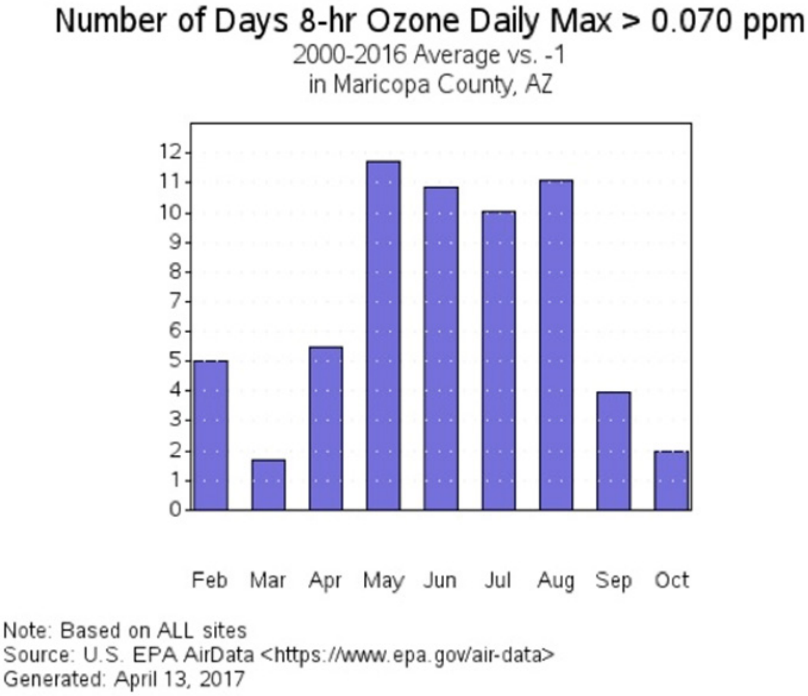
PM 2.5 is often generated by vehicle exhaust and power plant emissions (Environmental Protection Agency 2013). Another source of PM 2.5 is wildfires, which are expected to become larger and more frequent as climate conditions become hotter and drier. High levels of PM 2.5 are associated with mortality 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 PM 2.5 in the air not exceed 15 micrograms per meter-cubed ($\mu g/m^3$) within a three-year period. FMYN's Air Quality Department reports that recorded levels of PM 2.5 are well below EPA standards (personal communication, Karen Shaw). Changes in wildfire regimes, which have implications for air quality and human health, are discussed in the section on wildfire impacts to emergency management.



Number of Days 8-hr Ozone Daily Max > 0.070 ppm
2000-2017
in Maricopa County, AZ

Note: Based on ALL sites
Source: U.S. EPA AirData <https://www.epa.gov/air-data>
Generated: April 28, 2017

Figure 14: Number of days ozone levels have exeeded 0.07 parts per million (ppm), which is unhealthy for sensitive groups; 0.086 ppm, which is unhealthy for all; and 0.106, which is very unhealthy for all, in Maricopa County since 2000.



Number of Days 8-hr Ozone Daily Max > 0.070 ppm
2000-2016 Average vs. -1
in Maricopa County, AZ

Note: Based on ALL sites
Source: U.S. EPA AirData <https://www.epa.gov/air-data>
Generated: April 13, 2017

Figure 15: Average number of days from 2000 to 2016 in which ozone exceeded 0.070 ppm in each month. May – August, the warmest months, also had the highest number of high ozone days. FMYN days for ozone exceedance are considerably lower than those in Maricopa County (personal comment, Karen Shaw).

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 16) (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 µg/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 County had not met the EPA air quality PM10 criteria. FMYN's Air Quality Department reports PM10 levels significantly lower than Maricopa County levels and well below the EPA standards (personal communication, Karen Shaw).

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 in the section on diseases and vector-borne diseases 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 highway accidents and deaths, particularly on interstate highways. Lader et al. (2016) combined data from earlier studies to create a dataset of natural hazard-related injuries and fatalities from 1955 – 2013; although data on extreme heat and cold were only available from 1992 – 2009 and data on dust storm-related accidents were only available through 2011. Figure 17 compares dust storm-related accidents to other natural hazards and shows that dust storm-related injuries are the highest of all the hazards and are the third deadliest hazard overall (Lader et al. 2016). The researchers explain that population growth and increased traffic on the state's major highways have also 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, an area particularly prone to dust storms because of land use practices in Pima County (Lader et al. 2016).

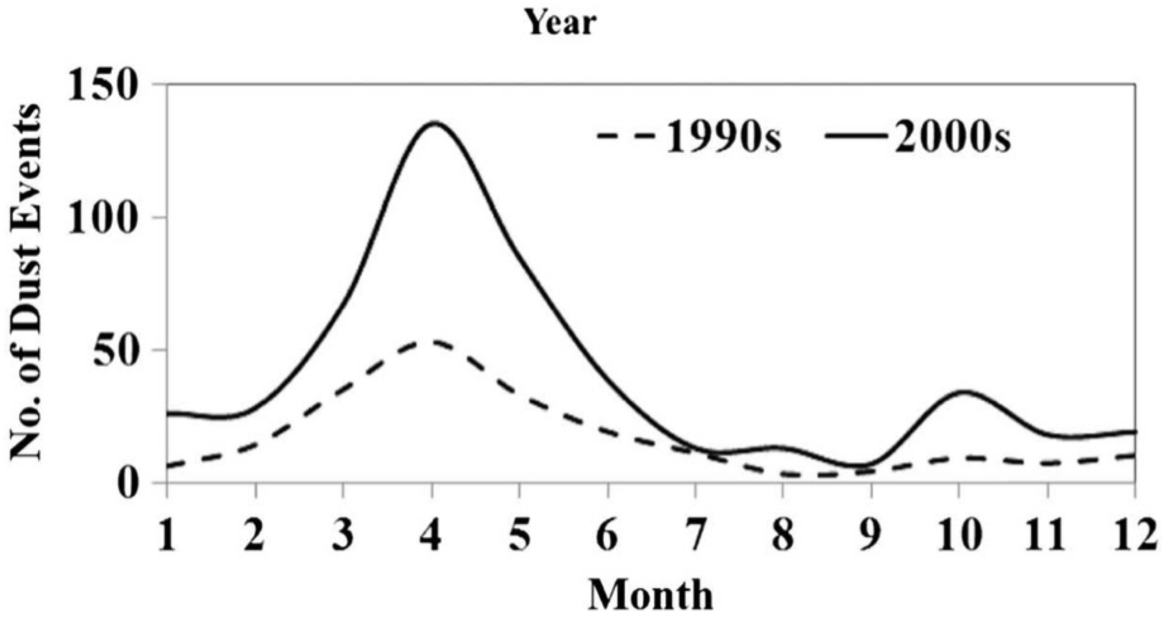


Figure 16: Monthly distribution of dust events across the western United States in the 1990s and the 2000s. Most dust storms occur in the spring months. The decade of the 2000s saw significantly more dust storms than in the 1990s. Source: Tong et al. (2017).

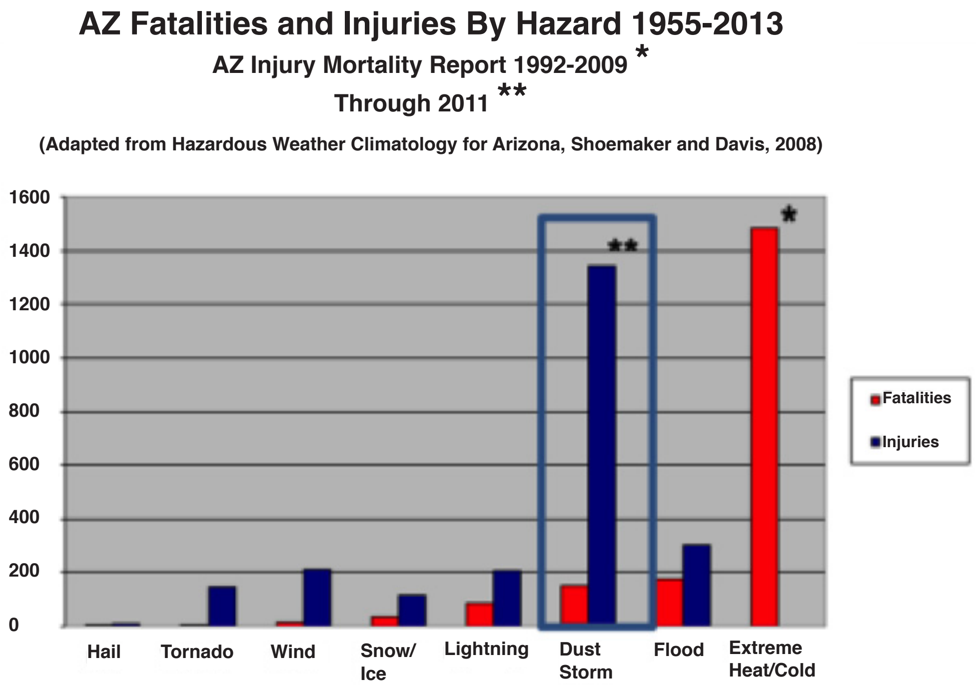


Figure 17: Arizona fatalities and injuries by hazard between 1955 and 2013. Dust storm related fatalities/injuries are reported for the years 1955-2011. Extreme heat/cold data are only from 1992-2009. All other hazardous weather events reflect data from 1955-2013. Source: (Lader et al. 2016)

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 two specific diseases in Arizona: West Nile virus (WNV) and Valley fever (Roach et al. 2017). The research team chose these two diseases because of their prevalence in Arizona and their potential to be influenced by climate change.

For West Nile virus, the team 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 the Fort McDowell Yavapai Nation: 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 the number of mosquitos during the hottest months of the year in the future. But, mosquito populations may rebound once temperatures cool in the late summer and early fall – so the reduction may be temporary.

Predicting changes in Valley fever prevalence due to climate change 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.

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 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.
- 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.

Protected Species

Protected species at FMYN, such as the Sonoran Desert tortoise, the Roundtail chub, and Sonora sucker, are likely to feel the impacts of climate change. Although the Sonoran Desert tortoise is well-adapted to living in high temperatures, using burrowing and shifting its active times to cooler times of day as adaptation strategies, precipitation changes and increased drought frequency and severity will be more of a challenge to the species than higher temperatures. A recent study (Zylstra et al. 2013) confirms this assumption. Using 22 years of capture-recapture data, they found that "survival of Sonoran desert tortoises was associated strongly and negatively with drought severity." They also observed more severe effects in more arid regions, suggesting that tortoises in these regions may be closer to their drought-tolerance limit and more vulnerable to drought effects. Given projections of future drought, they predict survival of adult tortoises to decrease by an average of 3% during 2035-2060 relative to 1987-2008, with "survival dropping well below projected means during short periods of extreme drought." In another study modeling future distributions of a related tortoise species (*Gopherus agassizii*) at the Mojave-Sonoran desert interface in California, the author found that increased drought frequency and severity will reduce suitable habitat for the tortoise by nearly 88% in the Sonoran Desert, forcing it to shift its range to higher elevations, away from its distribution in the Sonoran Desert (based on a moderate climate change scenario of temperatures 2° C higher than today and precipitation of 50 mm less) (Barrows 2011).

Native fishes in the Southwest U.S. already live at the upper limits of their temperature tolerance, and warmer water temperatures could reach lethal levels for these species, providing a competitive advantage for non-native fishes that can tolerate higher temperatures (Archer and Predick 2008). Changes in river flows may also favor non-native species who are unaffected by severe droughts, unlike native fish species who experience reduced abundance during severe drought (Ruhí et al. 2015). In the Verde River basin, the frequency and duration of stream drying events will likely increase by mid-century, and flowing regions of the Basin will decline during the spring and early monsoon seasons. This will reduce hydrologic connectivity of the river network, which is crucial for many native species, including Roundtail chub and Sonora sucker, to reproduce and seek refuge in the summer months. The year-round connectivity of Roundtail chub habitat will likely decline by 5% by mid-century, and connectivity during spawning months may decline up to 10%. For the Sonora sucker, connectivity may decline by 4% over the course of a year, and 7% during spawning months (Jaeger et al. 2014).

Culturally Significant Species

Most nesting of bald eagles in Arizona happens along the Salt and Verde Rivers, which would seem to make the FMYN lands more vulnerable to changes in this population. However, 66 young bald eagles fledged in 2016, breaking the record in 2013 of 58. Breeding pairs number 59, compared with eleven in 1978, according to AZ Game and Fish's Fall 2016 report.

There is disagreement on the extent to which climate change will impact populations of bald (*Haliaeetus leucocephalus*) and golden eagles (*Aquila chrysaetos*). Defenders of Wildlife, for example, does not list climate change as a threat. The Audubon Society has softened its earlier dire predictions of impacts on the bald eagle's breeding range; they have an interactive map at http://climate.audubon.org/birds/baleag/bald-eagle. Golden eagle populations seem to be declining fairly precipitously (Paprocki et al. 2014), but this may be due to redistribution.

Other studies also express ambiguity about projected impacts of climate change on bird populations throughout the United States. A study by Langham et al. (2015) noted that projections under IPCC's "A2" scenario[3] showed that bird populations will be generally pushed toward higher elevations through the end of the century (by 22 meters in the breeding season and 29 meters in the non-breeding season) but that many others are projected to move downslope. The article also noted that there was surprisingly little difference in the change forecasted between the A1B, A2, and B2 emissions scenarios, which vary substantially in projected levels of GHG emissions.

Invasive Plant Species

Native species within riparian systems of the Southwest are currently threatened due to the invasion of tamarisk (*Tamarix, sp.*) Russian olive (*Elaeagnus sp.*), tree of heaven (*Ailanthus altissima* Mill.) and giant reed (*Arundo donax* L.). The expansion of giant reed and tamarisk, which are both fire-adapted species, increases the risk of fires along riparian corridors. Tree of heaven is highly adaptable and can grow under limiting or harsh conditions, including drought and floods. Prolonged drought conditions and/or increasing temperatures could accelerate its invasion, as the tree of heaven is capable of growing in saline or nutrient poor soils. Highly prolific, the toxins exuded from its leaves, bark, and roots are detrimental to native species.

Plant vegetation systems within arid ecosystems on FMYN have not co-evolved with a fire cycle and the continued loss and threat to native species is high. In particular, Red Brome (*Bromus rubens*) is an invasive grass that has invaded the upper Sonoran Desert and has caused significant ecological damage to native species in recent years due to its high fire potential. Continued warming and increased drought are likely to hasten the spread of this species (Curtis and Bradley 2015). Cheatgrass (*Bromus tectorum*) invasions grow along roadways and disturbed areas in general, and also have a high fire potential. Early maturation during late winter and early spring allows late spring germination, enhancing this species' ability to outcompete its native plant counterparts for soil moisture. Dense and large populations growing along roadways and degraded rangelands promotes spread and fosters fire events along the side of roadways and within highway meridians. According to FMYN Fire Chief, Mark Openshaw, the majority of fire events occur within highway meridians and alongside roadways (personal communication, Mark Openshaw). Cheatgrass invades pastures and rangeland ecosystems, outcompeting native plants, and may continue to invade these ecosystems in response to increasing temperatures and levels of CO_2 (Ziska and George 2004; Ziska et al. 2005).

Buffelgrass (*Penssisetum cillare*) is a shrubby grass that was introduced into the southwestern United States from Africa, to be used as forage. This species has since escaped cultivation and spread into the Sonoran Desert region where it currently threatens saguaro cacti (*Carnegiea gigantea*), palo verde (*Parkinsonia microphylla*), and other plants native to the Sonoran desert. Buffelgrass tends to grow in dense populations, which effectively crowds out native grasses and plant species. Water competition from this species tends to affect larger native desert plants for water as it grows dense roots. Buffelgrass is an extremely drought-tolerant perennial. This species burns at a higher temperature than red brome, and a single fire event will destroy all native plants within the burn area. Invasion is not limited to lower elevations, as it proliferates in steep hillsides. Buffelgrass-induced fires reduce native plant abundance more than those involving native grasses. The seeds of buffelgrass will sprout within a few days of a fire, unlike native species such as saguaro cactus or palo verde trees, which require years to re-establish (McDonald and McPherson 2013).

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[3] A2 assumes high population growth, slow economic development, slow technological change, and slightly less fossil fuel use lower than historical records.

Garlic mustard (*Alliaria petiolata*) and African mustard (*Brassica tournefortii* Gouan) also threaten desert ecosystems because they displace native vegetation by outcompeting native species for light, nutrients, and soil moisture. Both species tend to grow in arid habitats and spread in areas with disturbed soils and within riparian systems. A study conducted on African mustard (*Brassica tournefortii* Gouan) modeled current and future climate suitability for plant establishment, using current locations in their model (impact niche). *Brassica tournefortii* presence with high abundance will continue to spread by 29%. The model further predicts that future spread of red brome (*Bromus rubens*) is expected to expand by 65% (Curtis and Bradley 2015). Although climate models for the Southwest region indicate that there is some variability in their predictions, both garlic and African mustard are expected to continue to spread in a warming and drier climate.

Salt cedar, or tamarisk, was introduced in the mid-1900s to stabilize soil and streambanks. It has now spread to most drainage systems in the Southwest (see Figure 18). Zavaleta (2000) found excessive water usage by this species, with stands consuming on average 3,000 to 4,600m^3 per hectare per year which is four times greater than water use of its native riparian counterparts. Salt cedar reduces water available for native vegetation and has an estimated cost of $133 to $285 million in lost ecosystem services. In a study on distribution of salt cedar compared to cottonwood associated with streamflow, increases in temperature will increase abundance of *Tamarix* and *Elaeagnus* (Russian olive), and dam releases will increase both *Tamarix* and *Elaeagnus* when compared to *Populus* (cottonwood).

Although use of the leaf beetle (*Diorhabda* spp.) as a biological control has met with success in reducing salt cedar through defoliations, areas with salt cedar are often infested with other invasive plant species that will likewise continue to spread in a warming climate, despite variations in precipitation and or streamflow.

Giant reed (*Arundo donax* L.) is an invasive grass common to riparian areas throughout the Southwest. It grows in dense stands and outcompetes native vegetation for water and soil nutrients. Its growth rate often outpaces native plants, with the shoots and stems growing as much as 4 inches per day during the spring and monsoon seasons in Arizona (Iverson 1993). Its shallow root systems, when established along streams, likewise undercut banks, forcing plant shoots to float downstream and propagate new populations.

During the dry season, this species creates an extreme fire danger in riparian systems. Giant reeds result in warmer stream temperatures and affect water quality due to algae photosynthesis. Giant reed populations reduce wildlife biodiversity due to a lack of food source and cover. Defensive compounds in its stems and leaves inhibit growth of native species. *Arundo donax* seems to respond favorably to increasing ambient and water temperatures, and continued spread of this species may negatively affect the ecological integrity of riparian ecosystems, wetlands, streams and drainages within the FMYN (Iverson 1993).

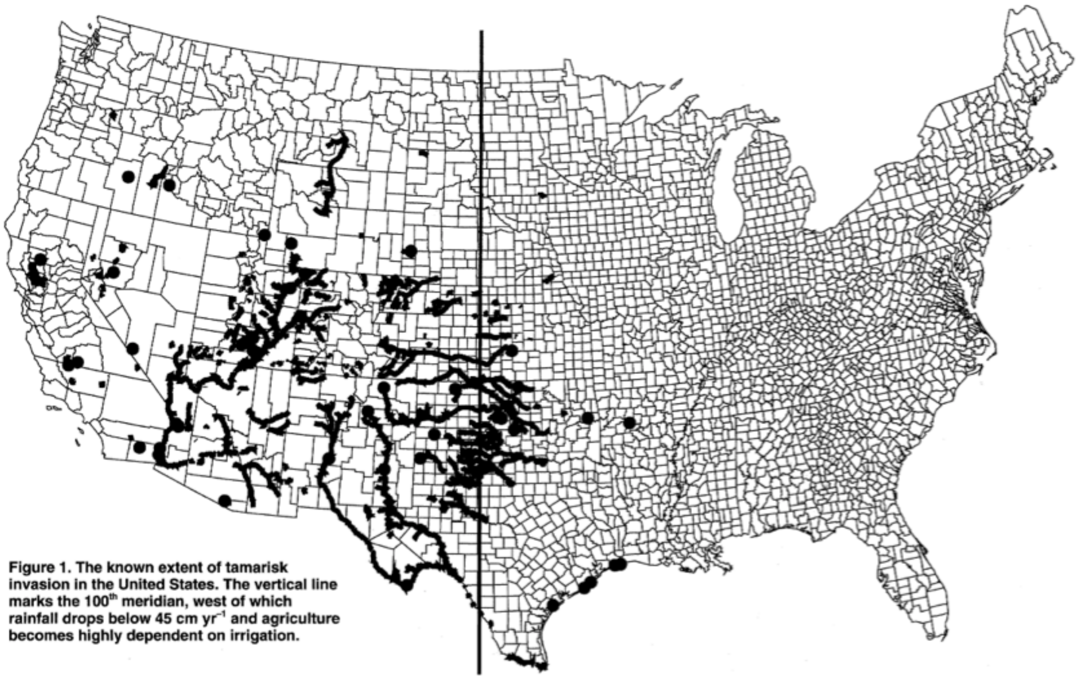

Figure 18: Extent of salt cedar invasion in the U.S. The vertical line marks the 100th meridian, west of which rainfall drops below 45 cm/yr and agriculture becomes highly dependent on irrigation. Image from Zavaleta (2000, 463).

Water Availability

Central Arizona Project Allocation

Although water resources in the western United States are being affected by rising temperatures, earlier snowmelt, more rain and less snow, and changes in storm tracks, total annual precipitation and daily extreme precipitation have not changed significantly (Udall 2013). 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 2.8-5.5% (Udall 2013). The same study also indicates that even if temperatures do not change, changes in precipitation are magnified in the Colorado River system in such a way that a 1% change in precipitation (either up or down) changes runoff by 1 to 2% (Udall 2013). An additional stressor on Colorado River water is the effect of dust on snowpack in the region, which can reduce runoff from snowpack by up to 5% (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—there is greater use of the water than there is water available in the river system. Water use in the lower basin—Arizona, California, and Nevada—is 1.2 million acre-feet (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 2015). To address the deficit, the states in the Lower Basin of the Colorado River (California, Arizona, and Nevada) 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. These reductions were intended to prevent Lake Mead from reaching a critical shortage through 2026. The water delivery reductions will take place when the water level in Lake Mead reaches three different thresholds: 1,075 feet above mean sea-level (amsl), 1,050 amsl, and 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 the amount of water it takes from the Central Arizona Project (CAP, which diverts water from the Colorado River to municipalities in Arizona) by 320,000 AF per year. At this level, the CAP will make cuts to the water it stores and to agriculture. A Tier 2 reduction requires 400,000 AF of reductions each year for these uses. A Tier 3 reduction requires an additional 480,000 AF of reductions in Arizona but does not impact deliveries for municipal and industrial uses or to tribes.

If Lake Mead falls to the critical 1,000 feet amsl level, the Secretary of the Interior is to consult all seven Colorado Basin states to discuss further measures. Climate projections for the Colorado River Basin have ranged from a predicted 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 in 2016 that encourage water users to leave water in Lake Mead have helped to avoid a shortage so far (Cooke 2016).

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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 Colorado River basin, which will affect evaporation rates. Unlike precipitation projections for southern and central Arizona, which are relatively uncertain, projections for the upper Colorado River basin are more certain in terms of direction; precipitation in the basin seems likely to decline, but the magnitude of decline is still uncertain (Vano et al. 2014). 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 FMYN's CAP water is at risk remains unclear due to the uncertainty in predicting future events.

Verde River Streamflow

FMYN currently has an allocation of 17,158 AF of water from the Verde River, which cuts through the Nation. According to the Bureau of Reclamation, which recently completed a study of streamflow projections across the entire Colorado River basin, streamflow is likely to be reduced 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 2016a). These changes are due to a combination of rising temperatures, falling snowpack, and rising demand for water especially for municipal and industrial use (U.S. Department of the Interior Bureau of Reclamation 2016b). Figure 19, below, displays the average streamflow projections for the decades 2020s, 2050s, and 2070s from the Reclamation's Colorado River Basin study. 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).

While the Reclamation study clearly projects a decline in streamflow for the whole Colorado River Basin, emerging research from University of Arizona (including the Verde River specifically) 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 (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 FMYN as more information becomes available.

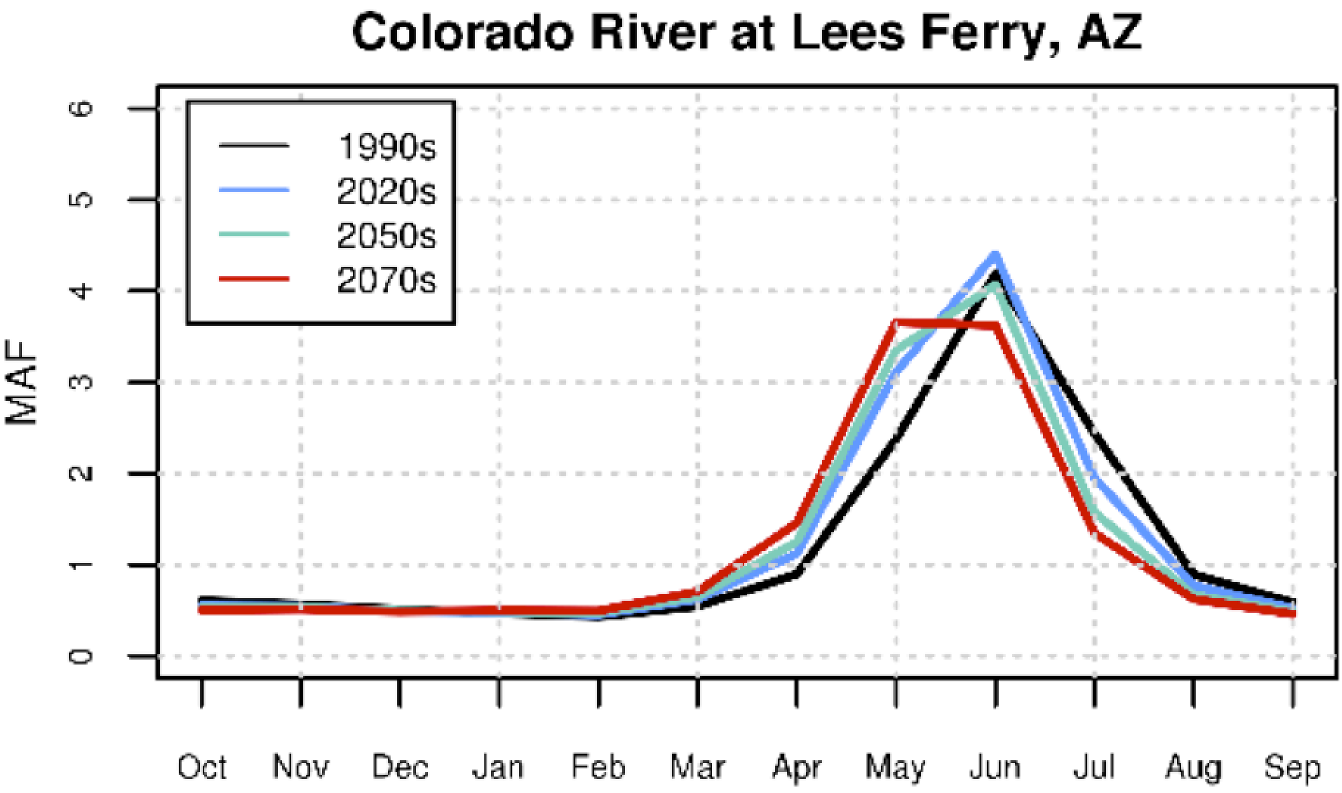

Figure 19: Projected Streamflow for the Colorado River at Lees Ferry, AZ. Source: (U.S. Department of the Interior Bureau of Reclamation 2016b)

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).

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 (both of 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.

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 8.5 RCP scenario (see Figure 11), 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.


USGS

Emergency Management

Flooding

Although overall precipitation at FMYN may remain steady or decline slightly, precipitation events may become more extreme because warmer air holds more moisture (Gershunov et al. 2013). While there may be fewer storms, they have the potential to be larger and stronger in magnitude because of more moisture in the atmosphere.

The Verde River is regulated by the Bartlett Dam, approximately eight miles north of the Nation. Releases from the dam are controlled by the Salt River Project (SRP). Large water releases, if required due to high precipitation events, may stress FMYN's water infrastructure, such as the four community water system wells close to the river. Large releases could also disrupt commercial, cultural, and traditional activities along the river (personal communication, Mark Frank).

Wildfire

Climate strongly influences wildfire processes in the western U.S., along with human-induced fire regimes and management practices. About 94 percent 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 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 such as red brome (*Bromus rubens*), cheat grass (*Bromus tectorum*), and buffelgrass (*Pennisetum ciliare*), has had a major impact in arid ecosystems in Arizona (Archer and Predick 2008). These non-native plant species have increased the frequency of fire in the Sonoran desert region, transforming these once diverse rangelands into "monocultures of non-native grasses" (Archer and Pedrick, 2008).

Low soil moisture is associated with more severe fire seasons in shrub and grasslands (Westerling et al. 2003). 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 of these many factors (Environmental Protection Agency 2016).

U.S. FOREST SERVICE

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 adaptation 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. About 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 20: 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
https://www.indianaffairs.gov/WhoWeAre/BIA/climatechange/

BIA Tribal Climate Resilience Fact Sheet
https://www.indianaffairs.gov/WhoWeAre/BIA/climatechange/Resources/Tribes/TribalFactSheet/index.htm?tcrp=FortMcDow

Climate Adaptation: The State of Practice in U.S. Communities
http://kresge.org/climate-adaptation

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/

CHRIS ENGLISH

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.

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).

Greenhouse gas (GHG): Any of the atmospheric gases that absorbs 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.

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.

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