Climate Trends Summary

Introduction

This brief summarizes observed and projected changes in climate for the City of Columbia and the surrounding region. It particularly focuses on temperature, heat waves, precipitation, flooding, drought, air quality, and severe storms.

This summary draws from existing datasets and literature, and therefore is subject to the scope and limitations of those sources of information.[1] In addition, since various sources are referenced, the time periods and spatial scales of the information varies. Where possible, information specific to Columbia was sought out and utilized, but other spatial scales frequently used in this summary are the state of Missouri and the Midwest. Most projections are for mid-century (generally the 2050s) and end of century (2100) and use high and low emissions scenarios, described in more detail in the section on projected changes in climate.

Historical Climate and Observed Trends

Columbia's climate is generally characterized as temperate. The average high temperature during the year is 87.9°F (in July), and the average low is 20.9°F (in January) [1]. There is natural variability that creates temperature and precipitation extremes; the record minimum temperature is -26°F, and the record maximum is 113°F [1]. Rainfall is typically heaviest in May, which sees 5 inches of rainfall on average, while January is typically the driest month of the year, with 1.9 inches on average [1]. During the winter months, precipitation often comes in the form of snow. On average, Columbia gets 18.4 inches of snowfall in the year [1].

The following sections describe the changes that have been observed in Columbia and/or the surrounding region to date.

[1] Much of the information included in this summary was based on the Climate in the Heartland report analysis, which used historical climate data from the Columbia Regional Airport weather station, 28 National Weather Service cooperative stations across Missouri, and climate change projections completed by Iowa State University scientists based on downscaled data from the international Coupled Model Intercomparison Project 3 (CMIP3) and nine different global climate models [1].

TEMPERATURE

OBSERVED CHANGES

Annual temperatures in the Midwest are now 1.3°F warmer on average, and the coldest day of the year is now 2.9°F warmer, compared to the 1900-1950 average. In Columbia, winters and springs have had the most warming, with fewer cold waves since the mid-1980s. Meanwhile, summer nights in Columbia have been getting warmer and more humid.

Across the Midwest, the annual average temperature has increased by 1.3°F since the first half of the 20th century [3]. The greatest change has been in the annual lows, which have increased by 1.8°F on average, with the temperature on the very coldest day of the year in the Midwest now 2.9°F warmer [3]. In Missouri, average temperatures are about 0.5°F warmer now than they were in the early 20th century [4]. So far, the 21st century has had warmer temperatures than any other period in the historical record, except for the 1930s Dust Bowl [4].

Like the rest of the region, Columbia has experienced increasing annual temperatures in the last century (see Figure 1) [5].[2] About 12 of the past 20 years have been warmer than the historical average between 1895 and 1998. The year 2012 was the warmest year on record since 1895 [1].

Winter and spring are the seasons that have shown the most warming in Missouri. Three out of the five warmest winters on record have occurred since 1991 [5]. During the past 25 years, the number of extremely cold days (with a minimum temperature below 0°F) has been below the historic average [4]. This trend is observed in Columbia as well. Since 1970, the most notable increases in temperature compared to historical averages have been during the winter and spring [1]. There have been fewer cold waves since the mid-1980s and fewer heating degree days since 1970 when Columbia residents need to turn their heaters on at home [1].[3] In the last 30 years, the last spring frost has been occurring three to four days earlier in the year than it did historically, which farmers in the greater Columbia area have had to take into account in their planting decisions [1].

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[2] Trends in the temperature record for Columbia are most reliable between 1970 to present. Prior to this period, the weather instrumentation was relocated several times before arriving at its current location at the Columbia Regional Airport. It is also worth noting that the airport is in a rural area 11 miles southeast of Columbia, and the recorded temperatures have been notably lower than records taken at the University of Missouri-Columbia campus in the urban core. This suggests that an urban heat island (UHI) effect—which describes the way that developed urban areas tend to be hotter than nearby rural areas because roads, buildings, and other dry impermeable surfaces have replaced open land and vegetation—may be leading to warmer temperatures in Columbia than the surrounding area. More impervious surface area, as a measurement of urbanization, has been correlated with higher land surface temperatures in urban areas [25]. Across the U.S., the UHI effect has led to an average increase in urban temperatures of 5.2°F [24].

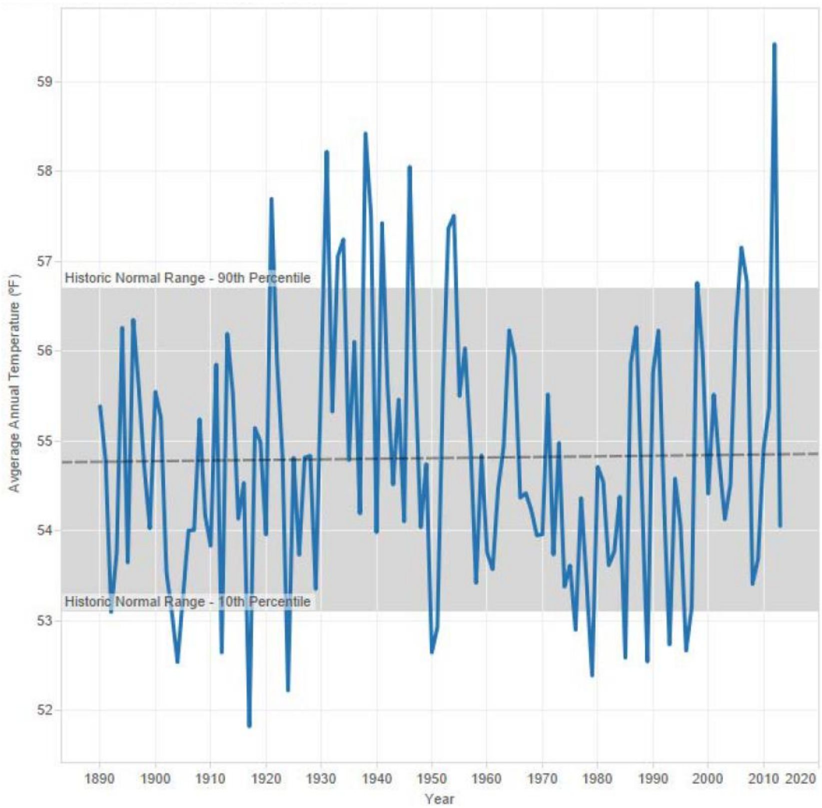
[3] Although the projected decrease in heating degree days is not available for Columbia, Kansas City is projected to see a 14 percent decrease by 2060 compared to the 1976-2015 historical average under a high emissions scenario [26].

Summers have also become warmer across the state over the past 120 years, and have been unusually hot since 2010 compared to other hot summers Missouri experienced before [1]. Specifically, the minimum daily temperatures during the summer have been increasing across the state as well as in the Columbia area, meaning summer nights are warmer [1, 4]. This change has driven a trend in more cooling degree days in Columbia since 1970, meaning more days when residents need to use air conditioning [1].[4]

Dew point temperatures—the point when water condenses—are also rising [6]. When the dew point is higher, the air usually feels more humid and it is harder for sweat to evaporate so people's bodies stay cool. Across the state, dew points have been above average for the past several decades [5]. Columbia has experienced above-normal summer dew point temperatures in more than three-quarters of the years since 1981 [1]. Warmer summer nights combined with higher dew points can lead to longer and more frequent periods of high heat indices, which in turn contribute to heat-related illnesses.

[4] The specific projected change in cooling degree days is not available for Columbia. For reference, Kansas City is projected to have over 45 percent more cooling degree days by 2060 compared to the 1976-2015 historical average under a high emissions scenario [26].

Figure 1. Recorded annual average temperature in Columbia, MO with trendline [1]. The average annual temperature in Columbia has been gradually increasing since 1895, as the trendline (gray dashed line) shows. Although there have been periods in the past, such as 1920-1955, when there were several years outside the normal historical range (gray bar), the recent warming trend since 1970 has been notable, with over half of the past 20 years being warmer than the 1895-2010 average.



HEAT WAVES

OBSERVED CHANGES

Available science is not conclusive about whether Columbia has seen more or fewer heat waves over time.

Heat waves are prolonged periods of extreme heat. In Columbia, the available data makes it difficult to identify a long-term trend in the frequency of heat waves [1]. Across the Midwest, there have generally been fewer heat waves since the 1960s, but this trend may be related to more intensive agricultural production, which can have a localized cooling effect by adding more vegetation [3, 7].

The impacts of heat waves can be exacerbated by high humidity. However, low humidity and drought conditions have also been known to support extreme, prolonged, and high-impact heat waves [6].

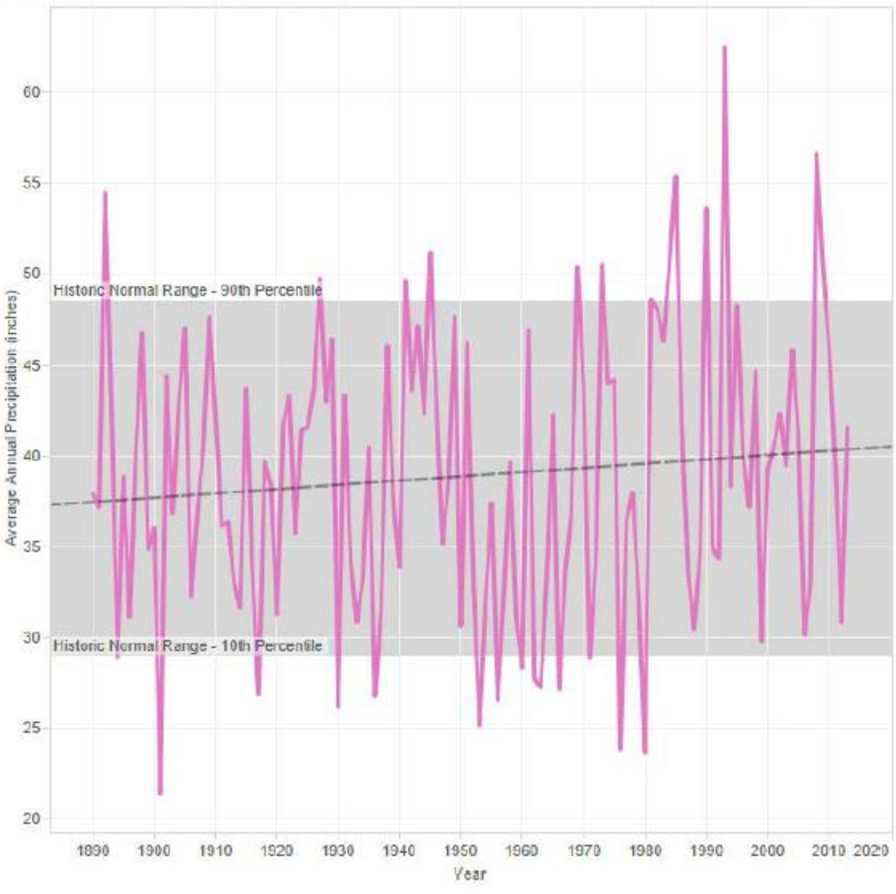
PRECIPITATION

OBSERVED CHANGES

Columbia is getting about 10 percent more precipitation, with more of that increase coming in the winter and spring. The biggest storms are bringing more rain than they used to. Heavy rain events are also happening more often—twice as often now as compared to 1890-1984. Increased rainfall has meant more frequent flooding.

Figure 2 shows recorded rainfall in Columbia since 1890. In the past 30 years, annual rainfall was nearly 10 percent more than the past century's average [1]. There has been more rainfall in all four seasons, but the most notable increase has been during winter and spring [1]. Heavy rain events have also become more frequent. During the past three decades, extreme rainfall events, with 3 or more inches of rain, are happening more than twice as often compared to the 1890-1984 average [1]. The Columbia area more often sees unusually heavy rainfall during spring and fall, rather than winter or summer.

Figure 2. Recorded annual average precipitation in Columbia, MO with trendline [1]. As the trendline (dashed gray line) indicates, average annual precipitation in Columbia has increased since 1895. Since 1980, there have been more extremely wet years that peak well above the historical normal range (gray bar). However, even with this change, there has still been seasonal variability in precipitation that is not shown in this figure.



Increases in heavy and extreme daily events and multi-day rainfall events compared to the long-term average have also been seen statewide [8]. Extreme rainfall has become more frequent in Missouri over the past 60 years. The biggest storms have become even larger during that time, such that they now hold 20 percent more rainfall [9]. Since the early 1970s, daily precipitation records have been broken at many weather stations across the state, which have been recording precipitation for 120 years [9].

One impact of these precipitation trends is more frequent flooding, which has been seen in rivers across the Midwest [8]. In Missouri, flooding has become more frequent for most flood-prone areas over the course of the last century [5]. During December 2015, for example, record rainfall in some parts of the state led to significant flooding—an unusual occurrence during the winter, as most rainfall usually occurs during the spring [10]. Flooding that can come from extreme rainfall events can damage or destroy buildings, bridges, and roads, such as what occurred during the spring of 2017 when a 1-in-1,000-year rainfall event caused historic flooding in some parts of Missouri [11].

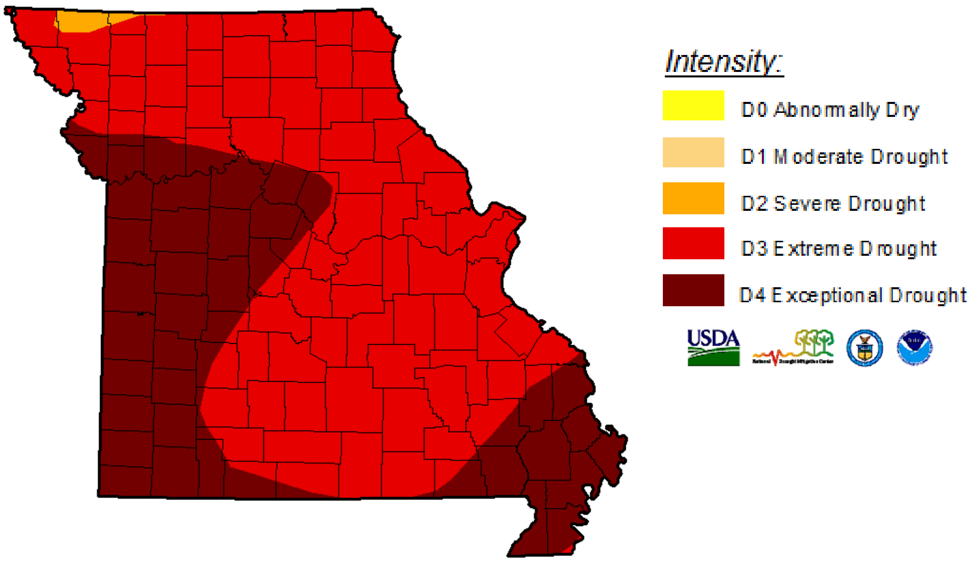
DROUGHT

OBSERVED CHANGES

Since there is limited historical data, it is not clear whether drought has become more or less frequent in Columbia.

There is limited historical data on local drought occurrence, which makes it difficult to determine a long-term trend and relate it to climate change. It is worth noting that in 2012, the Midwest/Great Plains region experienced the most severe summer drought ever recorded there [8]. Figure 3 shows the areas of drought by intensity across Missouri in August 2012. In Boone County, there were 35 consecutive weeks of severe or worse drought conditions between July 2012 and February 2013—far longer than any stretch since 2000, as shown in Table 1. Scientists have found that the 2012 drought was partly caused by an unusual series of weather patterns that limited thunderstorm activity during the summer, and some studies show that human-caused global warming may have also contributed [8].

Figure 3. Drought intensity in Missouri on August 21, 2012 [12]. The 2012 drought was the most severe drought on record in the Midwest region.



Author: Michael Brewer, NCDC /NOAA

Table 1. Consecutive weeks of severe drought or worse in Boone County between 2000 and 2017 [12]. Based on the drought intensity classification, under severe drought conditions, crop or pasture losses are likely to occur, water shortages are common, and water restrictions are often imposed.[5]

Start Date	End Date	Number of Consecutive Weeks
7/3/2012	2/26/2013	35
4/18/2000	5/23/2000	6
7/26/2005	8/23/2005	5
8/12/2003	8/26/2003	3
8/8/2006	8/22/2006	3
3/7/2017	3/21/2017	3

AIR QUALITY

OBSERVED CHANGES

Air quality in Boone County reached unhealthy levels on 13 days between 2012 and 2014. Long-term trends are unknown, but warmer air temperatures are known to increase ozone smog.

Warmer air temperatures can increase ozone smog, which can negatively affect lung and heart health. Between 2012 and 2014, Boone County had 13 days when the air quality was deemed unhealthy for people sensitive to poor air quality, such as older adults, children, and people with respiratory disease [13]. Ozone can also slow plant growth and reduce yields of soybean and winter

[5] The data presented here on drought occurrence is from the U.S. Drought Monitor and is best understood at the regional scale rather than inferring about specific local conditions [12]. Nevertheless, it can be a useful tool to contextualize what was experienced in a given year relative to historical conditions in the region.

wheat if ozone levels are high enough. In some areas of Missouri, ozone levels have been high enough to potentially reduce crop yields. [5].

SEVERE STORMS AND TORNADOS

OBSERVED CHANGES

The U.S. has seen fewer days with tornados since the 1970s, but more tornados have been forming on those days. In Columbia, limited data makes it difficult to determine if there is any local trend in tornado activity.

Historical data on tornado occurrence is limited since it relies on visual observations by eyewitnesses, and people are not always around to see every tornado. Reports are inconsistent and do not indicate a clear long-term trend in tornado frequency for Columbia [1]. National data indicates some trends: across the U.S. since the 1970s, there have been fewer days each year when tornadoes occur, but more tornadoes have been forming on those days [14]. In addition, the season of high tornado activity has been occurring earlier in the year [14]. These trends have not been attributed to climate change.

Projected Changes in Climate

Long-term trends indicate that the climate is changing driven by global greenhouse gas emissions. The concentration of carbon dioxide in our atmosphere has surpassed the level that was last observed millions of years ago [2]. If greenhouse gas emissions continue to grow at the current rate, the concentration of carbon dioxide in our atmosphere could reach a level well beyond anything that has been observed in tens of millions of years. Scientists broadly agree that as emissions warm the Earth at a faster rate, the risk of highly damaging and potentially irreversible impacts increases. Although short-term emission trends show variability, such as a slowing down in 2014 and 2015 when economic growth was not as carbon-intensive, this variability is not significant enough to alter the trajectory of warming [2].

The following sections describe the future changes in climate that have been projected for Columbia or the surrounding region and some of the potential impacts on our city and our resources. While Columbia will still experience variability in its climate, climate change will shift the range of that variability.

Scientists use emissions scenarios to model how the climate might change in the future. Scenarios make assumptions about future changes in population, technology, policy, and other factors that would influence human-caused greenhouse gas emissions. This climate trends summary relies on the scenarios used in the literature. Studies commonly use low and high emissions scenarios called Representative Concentration Pathway (RCP) scenarios 4.5 and 8.5, respectively. RCP 4.5 represents an increase in emissions from present day until 2100, after which emissions are stabilized. Under RCP 8.5, emissions increase at a greater pace through 2100 and continue to rise after that point.[6]

TEMPERATURE

PROJECTED FUTURE CHANGE

By the late century, temperatures in Columbia will regularly be outside what has been considered normal since 1970. Columbia could have over 50 days each year when the temperature is above 95°F, compared to fewer than 5 days that we currently experience on average.

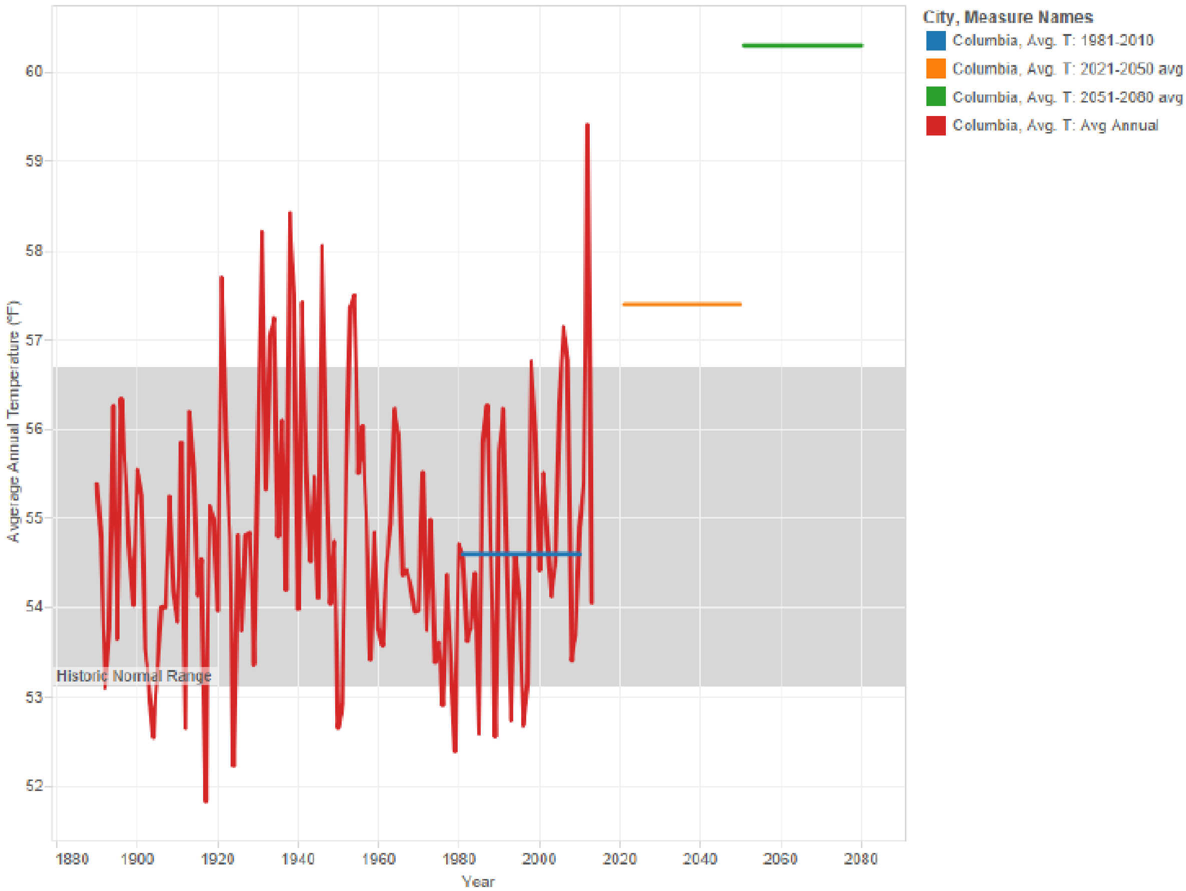
Across the Midwest, the annual average temperature is projected to increase 4.2-5.3°F by mid-century and 5.6-9.5°F by the end of the century under a low and high emissions scenario, respectively [3]. These projections hold for Columbia as well, with the greatest increases during spring, summer, and winter [1]. By the 2050s, average temperatures are expected to regularly exceed the normal temperature range Columbia has experienced since 1970, as shown by the green line in Figure 4 [1].

These changes will bring a continued shift in seasonal frosts. By mid-century, Columbia's last frost in spring is projected to occur more than one week earlier than it does today. Meanwhile, the first fall frost will happen slightly later [1].

Extreme temperatures are also projected to change in the Midwest. The coldest day of the year could be 9.5°F warmer and the hottest day of the year could be 6.7°F warmer by mid-century [3]. By the late century, Missouri is expected to have over 25 days per year when the temperature exceeds 95°F, compared to between 5-15 seen across the state in 2016 [5]. Under a high emissions scenario, Columbia is projected to see this change even sooner—reaching over 20 days per year above 95°F by 2050 and over 50 days by 2100, compared to less than 5 on average between 1997-2016 [15]. By 2080, maximum daily highs in the summertime could reach nearly 104°F and not dip below 80°F in Columbia, meaning warmer nights [1].

[6] A primary report included in our review (Climate in the Heartland Report) projects future climate conditions using scenarios from SRES (Special Report on Emissions and Scenarios) rather than the RCPs, which were developed later. Overall, the low (A1B) and high (A1F1) emissions SRES scenarios used are very similar to RCPs 4.5 and 8.5, respectively. The high emissions scenario most closely resembles the observed trend in global emissions through 2015. This future is consistent with no implementation of climate policies, a continued reliance on fossil fuels, and three times as many CO2 emissions in 2100 as we emit today [27]. RCP 4.5 is consistent with more stringent climate policies and a lower energy intensity in the future. The lowest-emission RCP scenario is 2.6, which includes achieving net negative carbon dioxide emissions before 2100 [28]. Many studies do not include this scenario.

Figure 4. Annual temperatures from the historic record (1895-2010) and projected future temperatures for Columbia, MO. By mid-century, the average annual temperature for the next 30 years (orange line) is expected to be approximately 3°F above the 1981-2010 average (blue line), and outside the historic normal range (grey area). By the second half of the century, the 30-year average (green line) is expected to increase again by about 3°F, far above today's typical range. Meanwhile, the most extreme temperatures will be much higher than the projected averages.



HEAT WAVES

PROJECTED FUTURE CHANGES

Heat waves in the Midwest are expected to become even hotter by 2050, with temperatures increasing by about 13°F. With that change, extreme heat in Columbia could more regularly reach temperatures well over 100°F, with the hottest periods exceeding 103°F by 2080.

During a period of extreme heat in June 2012, the temperature in Columbia reached 107°F [16]. These extremes will become more common in the next few decades as summer temperatures and humidity increase under climate change, and communities will likely feel even more heat stress. In the Midwest, temperatures during heat waves are projected to increase by about 13°F by mid-century [3]. In Columbia, the maximum temperature during the hottest 3-day period is expected to increase to 100°F by 2050 and further increase to over 103°F by 2080, compared to an average of 97°F between 1981-2010 [1]. Children, the elderly, those who are sick, and low-income households are especially vulnerable to heat stress [5]. Those living in Columbia's urban areas may be more vulnerable as well, as cities are denser and have more heat-trapping concrete than rural areas.

PRECIPITATION

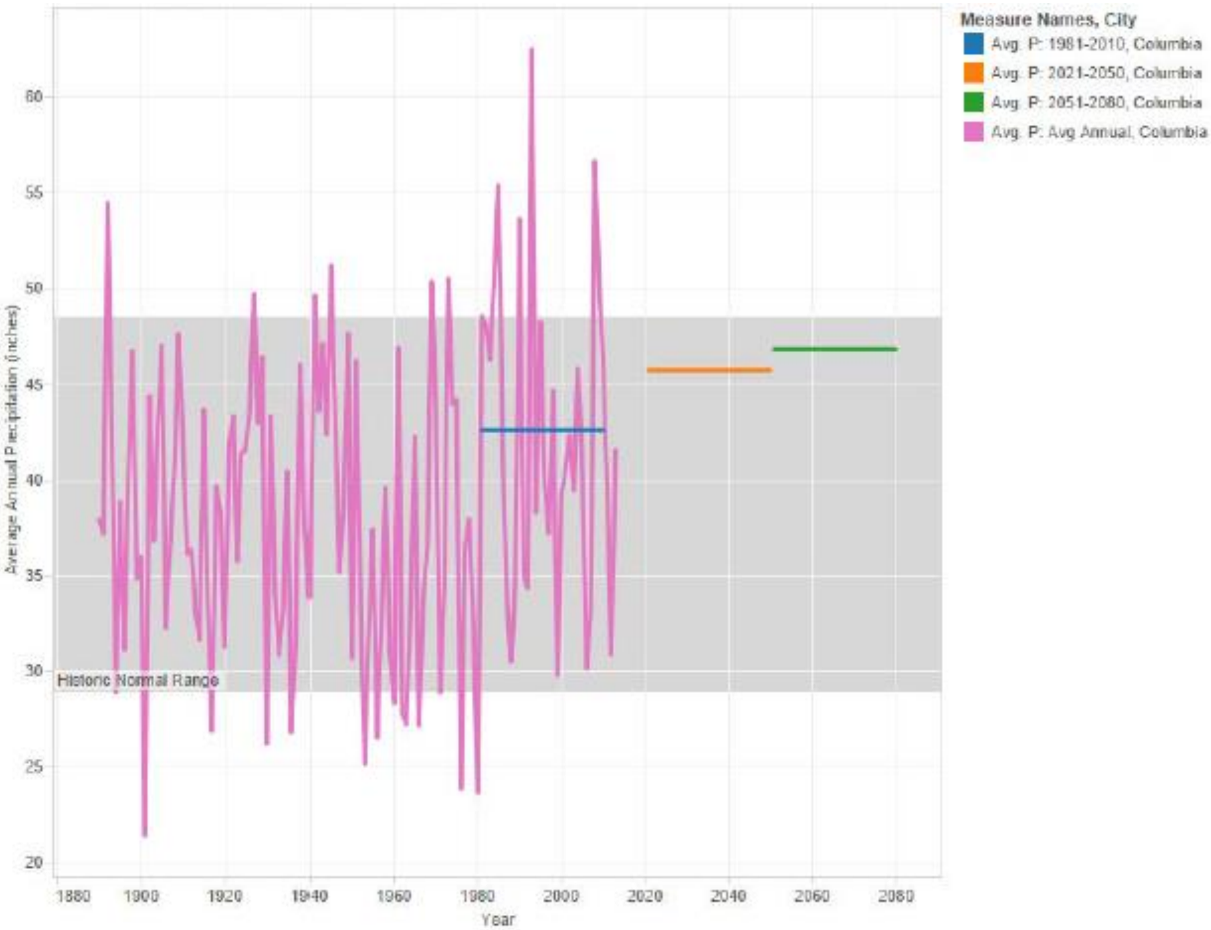
PROJECTED FUTURE CHANGES

Across the Midwest, annual precipitation is expected to increase. By mid-century, Columbia's annual average rainfall could be 7 percent more than the average in the last century. Heavier rain events are expected as well.

In the greater Midwest, average annual precipitation is expected to increase between now and 2100, in large part due to increases in spring rainfall [5]. Similarly, average annual precipitation in Columbia is projected to increase 7 percent by 2021-2050 compared to 1895-2010 and will continue to increase substantially beyond this period, as Figure 5 shows [1]. Between 2050 and 2081, annual precipitation is projected to be on par with the wettest years Columbia faces today in its current climate [1]. On a seasonal basis, spring and fall will experience the greatest increases in precipitation, while summertime precipitation is expected to decrease [1].

Heavy rain events are also projected to become more frequent in Columbia [1]. This is similar to what is expected for the Midwest at large, with severe rainstorms likely intensifying during this century [5]. More precipitation and especially heavy rainfall events will increase the risk of local flooding, which will require additional protection measures [5, 8]. Given the changes in rainfall expected in Missouri in the next 25 years, protection efforts will have to address flood events that usually occur at 500-year intervals, compared to what are now 100-year events, in order to maintain the current level of protection against high-risk flooding [17]. Flooding could be more of a problem if heavier rains occur in winter when soils are already saturated and there is little vegetation to help absorb the additional water [10]. Developed areas with more concrete that prevents rain from soaking into the ground will be more likely to experience flooding during heavy rain events [10].

Figure 5. Annual precipitation from the historic record (1895-2010) and projected temperatures into the future for Columbia, MO. Annual precipitation by mid-century (orange line) is expected to be in the higher range of what Columbia has seen since 1895. In the next 30 years (orange line), Columbia can expect to have about 3 more inches of precipitation annually than the 1981-2010 average (blue line). By 2051-2080 (green line), annual precipitation will increase by another inch. With this change, Columbia will still have extremely wet and dry years, but they will overall be slightly wetter than before. Seasonal precipitation will still vary, meaning that even in the wetter years, summers can be dry.



DROUGHT

PROJECTED FUTURE CHANGES
Summer drought will likely be more common in Missouri in the future.

While Missouri springs are expected to be wetter in the future, summers are expected to be drier, bringing more severe summer droughts [5]. During drought, rivers are more likely to have lower streamflow, which causes river navigation challenges and increases the risk of economic impacts on the shipping industry [5]. Drought can also reduce municipal water supply, decrease energy production that relies on water from rivers, and warm lakes and ponds that are used for recreation or cooling [10].

city of Columbia

Agricultural production may be negatively affected by drought, especially on farms without irrigation. In particular, surface soil is projected to be drier across the U.S., even in regions where precipitation is projected to increase, which will pose a challenge to crop production [8].

Drought may also reduce forest productivity by causing stress on trees and increasing their susceptibility to insects and disease. However, these losses may be offset by longer growing seasons and more carbon in the atmosphere, which can help plants use water more efficiently and protect them against drought [5].

AIR QUALITY

PROJECTED FUTURE CHANGES
Warmer temperatures may worsen air quality in parts of Missouri in the future. Days of poor air quality may become more common in Columbia, and the air quality may be worse on those days.

Rising temperatures and climate change will increase the risk of ozone smog pollution, especially for areas in Missouri that are currently experiencing higher ozone levels [9]. In Columbia, these impacts could mean more days each year with poor air quality and possibly worse air quality on high-ozone-risk days. In addition, warming temperatures may lengthen the pollen season statewide and make it more severe, given that pollen-producing plants grow better with more carbon dioxide in the atmosphere [9]. These changes could worsen allergy symptoms and possibly contribute to asthma attacks.

Warmer temperatures and lower humidity levels could also increase fire risk [18]. Smoke from natural cover fires could cause periods of lower air quality. Climate change is increasing wildfire risk in forests in other parts of the country, and this could have consequences for Missouri as well: in 2017, smoke from fires in the Western U.S. and Canada reached as far as Missouri [19].

SEVERE STORMS AND TORNADOS

PROJECTED FUTURE CHANGES
The Midwest could see more favorable conditions for storms by 2100. The science on tornados makes it hard to say what the future could hold for Columbia and Missouri specifically.

Severe thunderstorm conditions could become more frequent across the Midwest by the end of the century [14].[7] Under future climate conditions, there may be more lightning strikes—potentially increasing 12 percent or more for every 1°C of warming [20]. Lightening poses a fire risk as well as

[7] Projections of storm frequency use temperature, humidity, and wind conditions as a proxy for thunderstorms, rather than eyewitness reports.

a potential human safety hazard. Severe storms could also cause flash flooding, potentially damaging infrastructure, homes, and croplands [10].

When it comes to tornados, it is challenging to project future changes in frequency and severity as there are various factors at play. Tornadoes are more likely to occur when there is unstable air in the atmosphere, and when wind closer to the ground is moving at a different speed and direction than the wind above it, a situation known as wind shear. While rising humidity is likely to make air less stable in the future, wind shear is generally expected to decrease [5]. However, it is difficult to project changes in severe storms and tornados specifically for Columbia since the weather patterns and conditions that support these events occur at a much broader regional scale.

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