ATMOS Research & Consulting

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Climate Change Projections for the City of Austin

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Summary

This report summarizes the results of an initial assessment of how global climate change might affect Austin's climate, using the Camp Mabry weather station as an example. The analysis compares historical observations to projected changes under a higher and lower future scenario for three future time periods centered on the 2020s, 2050s, and 2080s. Summer temperatures are expected to increase, and days where maximum temperature exceeds 100°F and 110°F become more common. Nighttime temperatures that drop below freezing are projected to become increasingly more rare, while nighttime temperatures above 80°F will become more common. By the 2050s, projected changes in temperature are noticeably greater under the higher scenario as compared to the lower. Little change is expected in annual average precipitation, in the number of dry days per year, and in the average length of dry periods each year. All else being equal, though, warmer temperatures are expected to lead to drier conditions, particularly in summer. Heavy precipitation, measured in terms of days per year with more than 2 inches of rain and the amount of rainfall during the 5 consecutive wettest days of the year, is expected to increase. For precipitation, there is little difference between the changes projected under the higher as compared to the lower future scenario. For both temperature and precipitation, the changes reported here are consistent with those projected to occur throughout the Southern Great Plains region in response to human-induced climate change.

Introduction

Climate in Texas is changing. Average temperatures are increasing, the risks of extreme temperatures are changing, and precipitation patterns are shifting, with heavy precipitation becoming more frequent in many locations. These and other changes are consistent with trends across the United States and around the world that have been attributed to human-induced climate change, the result of human emissions of carbon dioxide and other heat-trapping gases released during fossil fuel combustion, deforestation, agriculture and other activities. These gases are building up in the atmosphere, as human emissions exceed the natural uptake rates of the ocean and biosphere. Increasing levels of heat-trapping gases in the atmosphere artificially exacerbate the naturally-occurring greenhouse effect, trapping more of the Earth's heat inside the atmosphere that would otherwise escape to space. This is what is causing the Earth to warm.

Global emissions of carbon dioxide and other heat-trapping gases continue to grow decade after decade (see Figure 1). Over the coming century, these emissions are projected to continue to alter temperature, precipitation, and other important aspects of climate in Texas, and around the world. Some amount of future change is inevitable, the result of inertia in both the physical climate system in responding to emissions that have already occurred, and inertia in the energy sector as it is impossible for a transition from traditional fossil-based energy to low or zero-carbon energy to occur overnight. Some amount of future change, however, can be avoided by following a lower future scenario with significant reductions in carbon emissions from human activities, as opposed to continuing on a carbon-intensive future pathway in which the world continues to rely on fossil fuels for the majority of its energy.

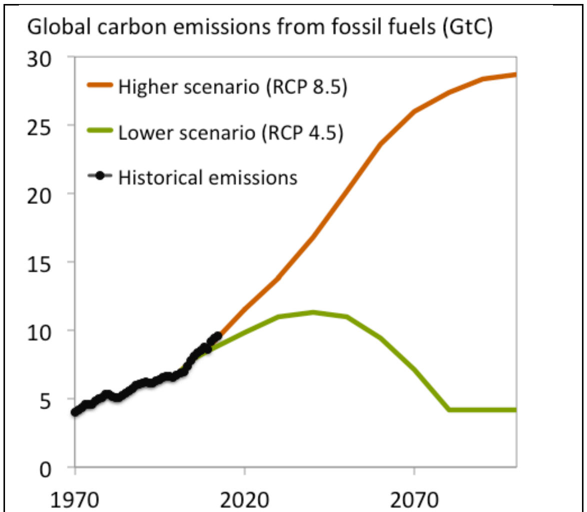


Figure 1. Historical carbon emissions (black) continue to increase from one decade to the next. This report examines how Austin's climate might change if the world follows Representative Concentration Pathway (RCP) 8.5, a higher scenario with continued dependence on carbon-intensive fossil fuels (orange) or RCP 4.5, a lower scenario where replacing fossil fuels with zero-carbon alternatives reduces and ultimately stabilizes global carbon emissions (green). Data: CDIAC, IIASA

Climate change is a concern to humans because much of human society is built on the assumption of a stable climate. The location of large cities on coastlines, the design of building codes, the distribution of agricultural regions around the world: all are predicated on the assumption that sea level will not rise, that average climate will remain fairly constant, and that the risks of flood and drought can be predicted based on past history. As climate changes, however, the past can no longer serve as a reliable guide to the future. That is why climate projections are needed: to assess the potential impacts of human-induced change on our communities and our natural resources.

This report summarizes the results of an initial assessment of how global climate change might affect Austin's climate, using the Camp Mabry weather station as an example. The analysis compares historical observations to projected changes in a range of indicators of average and extreme temperature and precipitation under a higher and lower future scenario for three future time periods centered on the 2020s, 2050s, and 2080s.

Methods

Projections for the United States and the Great Plains region are based on the draft results reported in the upcoming 2014 U.S. Third National Climate Assessment. Preliminary projections for Austin are based on the methods described below.

Future climate projections are uncertain for four main reasons:

1. **Natural variability**, which causes temperature, precipitation, and other aspects of climate to vary from year to year and even decade to decade;
2. **Scientific uncertainty**, as it is still uncertain exactly how much the Earth will warm in response to human emissions and global climate models cannot perfectly represent every aspect of Earth's climate;
3. **Scenario or human uncertainty**, as future climate change will occur largely in response to emissions from human activities that have not yet occurred; and
4. **Local uncertainty**, which results from the many factors that interact to determine how the climate of one specific location, such as Austin, will respond to global-scale change over the coming century.

To address the first source of uncertainty, **natural variability**, the climate projections summarized here are averaged over 30-year time scales: historical (1971-2000), near-term (2011-2040), mid-century (2041-2070) and end-of-century (2071-2100). In other words, the number of days per year over 100°F were first calculated for each year from 1960 to 2100, and were then averaged over the 30 years corresponding to each historical or future time period. Natural variability is an important source of uncertainty over shorter time scales. Averaged over longer time scales of multiple decades, the contribution of natural variability to overall uncertainty becomes virtually negligible.

To address the second source of uncertainty, **scientific uncertainty**, future projections are based on simulations from nine newer global climate models from the Coupled Model Intercomparison Project phase 5 (CCSM4, CNRM-CM5, CSIRO-Mk3.6.0, MPI-ESM-LR, HadGEM2-CC, INMCM4, IPSL-CM5A-LR, MIROC5 and MRI-CGCM3; Taylor et al. 2012). Differences between the models represent the limitations of scientific ability to simulate the climate system. Scientific uncertainty is an important source of uncertainty in determining the magnitude and sometimes even the direction of projected changes in average precipitation, as well as dry days and extreme precipitation.

To address the third source of uncertainty, that of **human activities** and heat-trapping gas emissions, future projections use two very different scenarios, the Intergovernmental Panel on Climate Change lower Representative Concentration Pathway (RCP) 4.5 scenario where global carbon emissions peak and then decline by end of century, and the higher RCP 8.5 scenario where continued dependence on fossil fuels means that carbon emissions continue to grow throughout the century (Moss et al. 2010; see Figure 1). Scenario labels (4.5 and 8.5) refer to the projected change in radiative forcing in units of watts per square meter. Radiative forcing is a measure of the magnitude of the human influence on the naturally-occurring greenhouse effect described previously. Scenario uncertainty is an important source of uncertainty in temperature-related projections, particularly over the second half of the century as the scenarios diverge (see Figure 1).

Finally, to address the fourth source of uncertainty, that of **local change**, global climate model simulations were downscaled to the Austin Camp Mabry long-term weather station using the Asynchronous Regional Regression Model as described in Stoner et al. (2012). As these projections are based on one location only, they are not intended to be used for anything except illustrative purposes. To generate robust projections for future planning purposes, it is recommended that a similar analysis be conducted for all long-term weather stations in the Austin area, and the results of this comprehensive analysis be used to calculate a broad range of secondary climate indicators identified by City departments as directly relevant to historical impacts and future planning.

Temperature

Over the coming century, climate change is expected to affect the United States and the state of Texas by increasing annual and seasonal temperatures. Projected increases in annual average temperatures across the South-Central Great Plains average +5-6°F under a lower and +9-10°F under a higher scenario by end of century. The number of days per year where minimum and maximum temperatures exceed the historical hottest 7 days of the year is also projected to increase, with proportionally greater increases for minimum temperature as compared to maximum, and for southeastern Texas as compared to the northwestern part of the state.

For the city of Austin, the projections below are based on a set of high-resolution climate projections downscaled to the Camp Mabry weather station using the **Methods** described in the previous section. These results are summarized below, as well as in bar charts on page 5 (Figure 2) and Table 1 on page 8.

Summer maximum temperatures are projected to increase by +2 to +3°F under both the lower and higher scenarios by near-century (2011-2040). By mid-century (2041-2070), temperatures are projected to increase by +3.5°F under the lower and +6°F under the higher scenario. By late-century (2071-2100), increases are projected to average +4°F under the lower and +9°F under the higher scenario.

Temperature extremes are also projected to change. Proportionally greater changes are seen in extremes as compared to means, such as the number of days above a given high temperature or below a given cold temperature threshold. Projected changes include:

- The number of **cold nights** (below 32°F), which historically occur on average about 15 times per year, is projected to drop to just under 11 days by 2011-2040 in both scenarios. By 2041-2070, there may be less than 8 days in the lower scenario and 6 days in the higher one. By end of century (2071-2100) there may be as few as 7 nights below freezing under the lower and 4 nights under the higher scenario per year.
- The number of **warm nights** (over 80°F), which historically occur on average only twice every ten years at the Camp Mabry location, is projected to increase to between 3 to 8 nights per year on average by 2011-2040. By 2041-2070 there could be between 10 (lower) and 40 (higher) such nights, while by end of century warm nights are projected to increase to, on average, 17 nights per year under a lower, and 85 nights per year under a higher, scenario.
- The number of **hot days** (over 100°F) is also projected to increase, particularly under a higher as compared to lower scenario and by later compared to earlier time periods. Historically, the Camp Mabry weather station averages 13 days per year over 100°F. This is projected increase by 15 to 20 days per year by 2011-2040. By 2041-2070 there are projected to be around 25 more days under a lower and 50 more days under a higher scenario. By end of century the range increases from between 35 more days under a lower up to 80 more days under a higher scenarios.
- **Very hot days** (over 110°F) are historically very rare, almost never occurring. However, by 2011-2040, the higher scenario predicts that one such day may occur on average anywhere from once every 10 years up to 2 times per year. By mid-century (2041-2070) the number of very hot days is projected to range from an average of two every 5 years under a lower scenario up to 12 per year under a higher scenario. By 2071-2100, an average of 1 day per year is projected under a lower, and as many as 20 days per year under a higher, scenario.

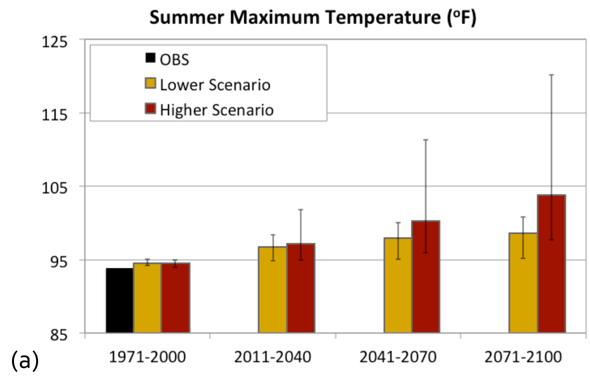
Temperature Projections for the Camp Mabry, Texas weather station

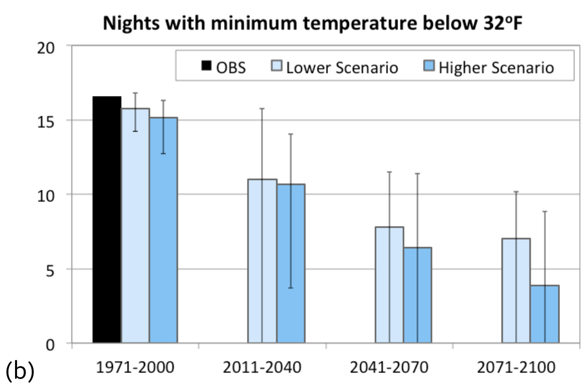
Figure 2. Projected climate change at the Camp Mabry weather station for **five temperature indicators**: (a) maximum daytime temperature, averaged across the entire summer from June 1 to August 31; (b) cold nights: the number of times per year minimum temperature falls below freezing; (c) warm nights: the number of time per year minimum temperature remains above 80°F; (d) hot days: the number of times per year maximum temperature exceeds 100°F; and (d) very hot days: the number of times per year maximum temperature exceeds 110°F.

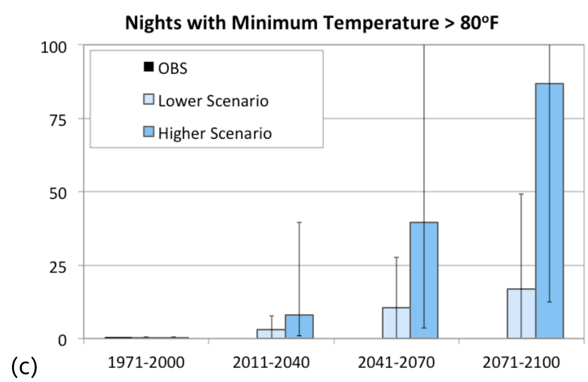
Projections were generated using the models and scenarios described in the Methods section and annual values were averaged over three future 30-year time periods: near-term, mid-century, and end of century.

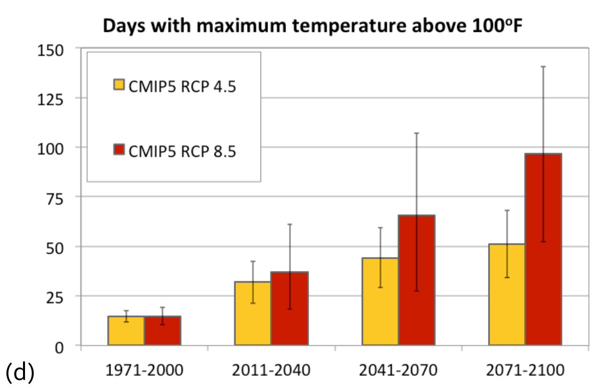
Scenario Uncertainty. Light-colored bars correspond to average conditions projected under the RCP4.5 lower scenario, while darker-colored bars correspond to average conditions projected under the higher RCP 8.5 scenario. Black bars correspond to historical observations.

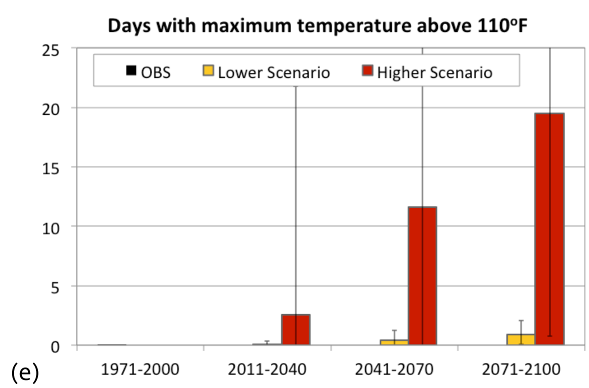
Scientific Uncertainty. The vertical black lines, or "whiskers", on each bar show the range in values projected by different climate models, while each bar shows the average of all the climate models.











Precipitation

As climate changes, precipitation patterns are also expected to shift. In general, wetter areas (including most higher latitudes) are projected to become wetter still, while drier areas (such as the U.S. Southwest) are projected to become drier. Situated as it is between the Southeast and the Southwest, along the Gulf Coast, Texas has historically seen some increase across the wetter eastern half of the state and little change to a slight decrease across the drier western half over the past century.

Projected future changes in precipitation depend strongly on season. In winter and spring, while the northern U.S. and Canada is projected to become much wetter, little change is expected across most of the central U.S. However, a decrease throughout Central America may extend up into southern Texas, particularly under higher scenarios as compared to lower. In summer, a slight decrease is projected throughout the Great Plains, and no change in fall.

Despite little change in total precipitation, the nature of precipitation is expected to change. Heavy precipitation days have already historically increased across the Great Plains region. In the future, days per year that exceed the current wettest 7 days of the year are projected to become more frequent across the eastern half of the state, while drought conditions in summer are likely to become more severe as global temperature increases.

For the city of Austin, the projections below are based on a set of high-resolution climate projections downscaled to the Camp Mabry weather station using the **Methods** described in the previous section. These results are summarized below, as well as in bar charts on page 7 (Figure 3) and Table 1 on page 8.

For the city of Austin, a preliminary set of high-resolution climate projections downscaled to the Camp Mabry weather station (see **Methods** section) suggest that **annual average precipitation** is projected to show little change, consistent with projected changes over the larger area of central Texas. A slight increase in the number of dry days per year is projected, ranging from 1% to 4%, but no significant change in the length of the longest dry period of the year, which currently averages around 70 days.

Rainfall extremes are projected to increase slightly, with no significant differences between the changes expected under a higher scenario as compared to a lower. This preliminary analysis compared two different indicators of extreme precipitation:

- The **number of days per year with more than 2 inches of rainfall** is projected to increase by about +1 day in every 2 years by end of century
- **Maximum 5-day rainfall** (otherwise known as the wettest five days of the year) currently averages just under 6 inches per year. This number is projected to increase slightly, by around +1 inch, by end of century.

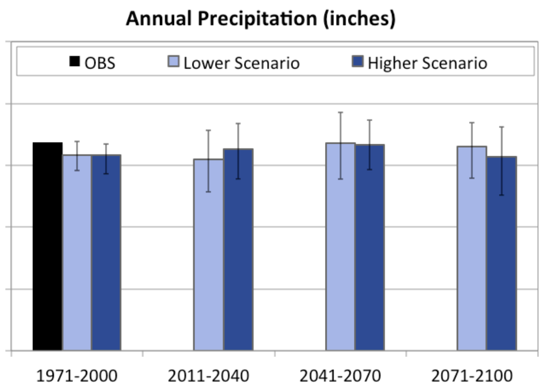
Precipitation Projections for the Camp Mabry, Texas weather station

Figure 3. Projected climate change at the Camp Mabry weather station for **five precipitation indicators**: (a) cumulative annual precipitation (in inches); (b) the number of days per year with less than 0.01 inches of precipitation in 24 hours; (c) the length of the longest period of time with less than 0.01 inches of precipitation per day; (d) the number of days per year with more than 2 inches of precipitation in 24 hours; and (e) the cumulative amount of precipitation falling during the 5 consecutive wettest days of the year (in inches)

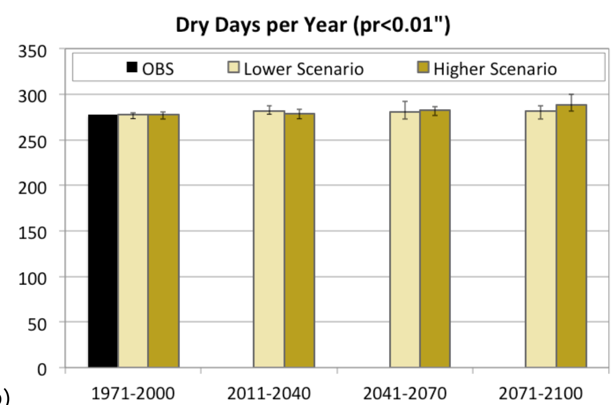
Projections were generated using the models and scenarios described in the Methods section and annual values were averaged over three future 30-year time periods: near-term, mid-century, and end of century.

Scenario Uncertainty. Light colored bars correspond to average conditions projected under the RCP4.5 lower scenario, while dark colored bars correspond to average conditions projected under the higher RCP 8.5 scenario. Black bars correspond to historical observations.

Scientific Uncertainty. The vertical black lines, or "whiskers", on each bar show the range in values projected by different climate models, while each bar shows the average of all the climate models.



(a)



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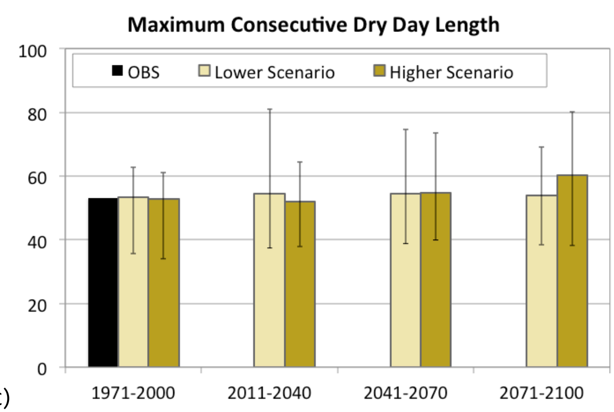

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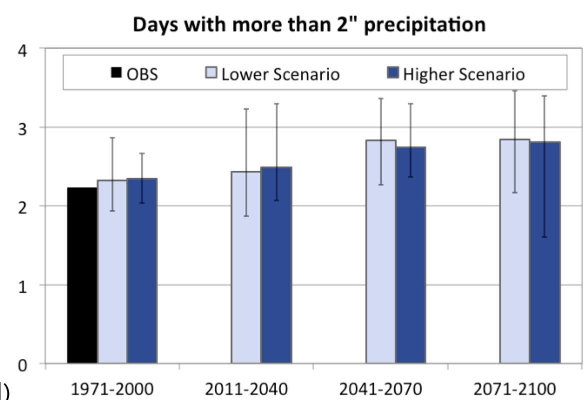

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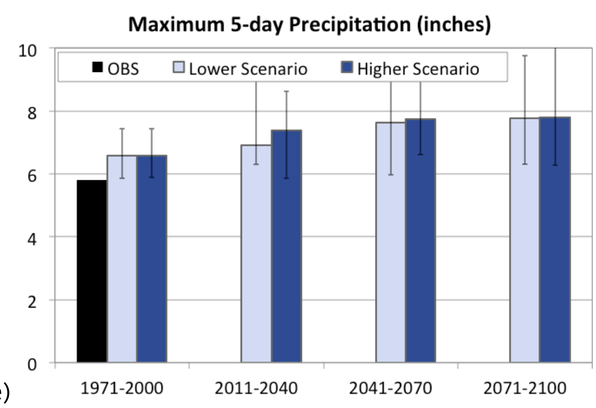

(e)

Temperature and Precipitation Projections for the Camp Mabry, Texas weather station

Table 1. Projected climate change at the Camp Mabry weather station for the **temperature and precipitation indicators** analyzed in this report. Projections were generated using the models and scenarios described in the Methods section and averaged over three future time periods: near-term, mid-century, and end of century.

This table accounts for *scenario uncertainty* by showing the projections expected under higher and lower scenarios for mid-century and beyond. For the near-term time period, there is no significant difference between the changes expected under a higher vs. a lower scenario.

This table shows values that correspond to the average conditions projected by multiple global climate models. *Scientific uncertainty*, as represented by the range of values projected by different global climate models, is not included here; it can be seen in Figures 2 and 3.

	Historical	Near-term	Mid-century (2041-2070)		End-of-century (2071-2100)	
	Observed	2011-2040	Lower Scenario	Higher Scenario	Lower Scenario	Higher Scenario
Temperature						
Summer average high temperature (^{o}F)	93.8	96.9	97.9	100.2	98.6	103.8
Cold nights (minimum temperature < 32^{o}F)	16.6	10.8	7.8	6.4	7.0	3.9
Warm nights (minimum temperature > 80^{o}F)	0.5	5.4	10.5	39.5	17.0	86.7
Hot days (maximum temperature > 100^{o}F)	11.7	31.4	40.1	63.2	46.5	92.3
Very hot days (maximum temperature > 110^{o}F)	0.0	1.3	0.4	11.6	0.9	19.5
Precipitation						
Annual precipitation (inches)	33.7	31.8	33.6	33.3	33.0	31.4
Dry days (PR<0.01 inches in 24h)	277.3	280.3	280.6	282.7	281.4	288.1
Longest dry spell (days)	53.1	53.3	54.4	54.7	54.0	60.4
Wet days (PR>2 inches in 24h)	2.2	2.5	2.8	2.7	2.8	2.8
Wettest 5 days (inches of precipitation)	5.8	7.2	7.6	7.7	7.8	7.8

Conclusions

Climate in Texas is already changing. Observed changes are consistent with larger-scale trends observed across the U.S. and the world. In the future, climate is expected to continue to change as a result of human emissions of carbon dioxide and other heat-trapping gases. For the Camp Mabry weather station in Austin, Texas, projected changes include:

- Increases in annual and seasonal average temperatures
- More frequent high temperature extremes
- Little change in annual average precipitation
- More frequent extreme precipitation
- A slight increase in the number of dry days per year
- More frequent drought conditions in summer due to hotter weather

There is **greatest certainty** in projected increases in annual and seasonal temperatures and increased frequency of high temperature extremes. These trends are already occurring today and are expected to continue over the coming century across the United States and around the world. Projected changes in these indicators are greater under the higher as compared to lower scenario, and by late-century as compared to more near-term projections.

There is **moderate certainty** in projected increases in extreme precipitation events. Observed trends and projected future increases in heavy precipitation events are consistent across the United States.

There is **less certainty** in projected changes in precipitation for central Texas. Precipitation projections vary regionally, with a general pattern of increases expected at higher latitudes and decreases in subtropical regions, moderated by local and regional topography. Texas is located between the Southwest, a region for which precipitation is expected to decrease, and the Gulf of Mexico, an important source of moisture, particularly in summer months. As such, average annual precipitation is not projected to change much in Central Texas, although decreases are expected to the southwest of Texas and increases to the northeast. The extent to which these changes may remotely affect Austin's water supply remains to be determined.

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