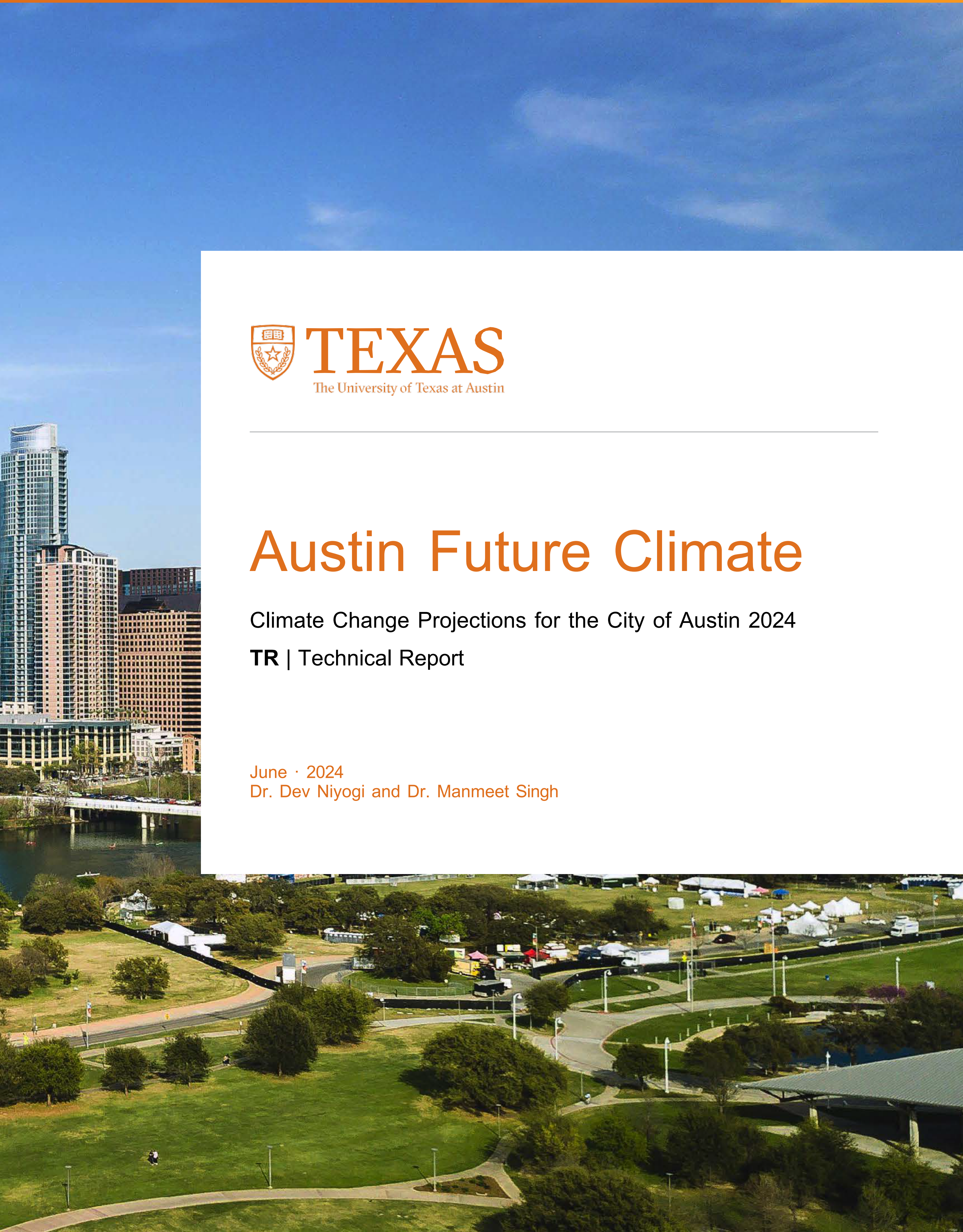

TEXAS
The University of Texas at Austin

Austin Future Climate

Climate Change Projections for the City of Austin 2024

TR | Technical Report

June · 2024

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TExUS

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Table of Contents

Summary of climate projections

In Austin, climate change is expected to cause hotter summers with more frequent heatwaves and fewer but longer cold spells. Precipitation projections are uncertain, but more wet days are likely. Projections for Austin also indicate fewer calm days with more wet days and windy days. These projections are based on high and status quo-emission scenarios. A “high emission scenario” refers to model estimates where emissions from human activities keep increasing rapidly. A “status quo emission scenario” envisions a path where our emissions remain the same. As is the norm for projections, the output is based on medians, not averages.

HEAT **Average, minimum, and maximum daily temperatures are projected to rise.**

Summers are projected to be hotter. Historically, temperatures above 110˚F were rare, but these temperatures are expected to become more frequent. Heatwaves, defined here as three or more consecutive days with excessively hot weather, have historically been numbered around 90 days per year in Austin, but are expected to become more common. The number of days classified as heatwaves per year is projected to nearly double for the high emission scenarios.

At the end of the century, up to 172 heatwave days per year are expected under the high emission scenario. A hot spell is a shorter version of a heatwave with extreme temperature changes. Austin has typically 59 hot spell days per year, and this is expected to increase by 1.5 to 3 times more per year under high emissions scenarios. Additionally, the heat index, which is the temperature after factoring in humidity, can increase by 2–12˚F in the future.

COLD **Fewer cold spells are expected, but they are projected to last longer.**

Austin cold spell durations are expected to increase from 1 day to 3 days in the future. However, fewer cold spells are expected, but they are projected to last longer. The number of frost days per year is also expected to decrease.

The number of cold spells per year is expected to steadily decrease to nearly 0 by the end of the century. Additionally, the number of consecutive cold, dry days and cold, wet days considered “extreme” are also projected to decrease to nearly 0 by the end of the century.

PRECIPITATION **The amount and intensity of precipitation is projected to decrease while the number of wet days are projected to increase.**

Because precipitation is generally a large-scale phenomenon, projections at the city scale are uncertain. In general, the number of wet days and the amount of extreme rainfall are expected to increase.

The number of wet days will increase from 85 per year to more than 105 in the future. We have low confidence in the amount of annual precipitation and the intensity of extreme precipitation. There is moderate to higher confidence in the number of wet days increasing due to the consistency of results from different models and domain sizes.

WIND **The number of windy days is projected to increase.**

“Calm” days with wind speeds of less than two meters per second are expected to occur on 55–62 days per year in the future, compared to the 107 days per year we currently have. While the number of windy days are expected to increase, the frequency of windy days may vary significantly year to year.

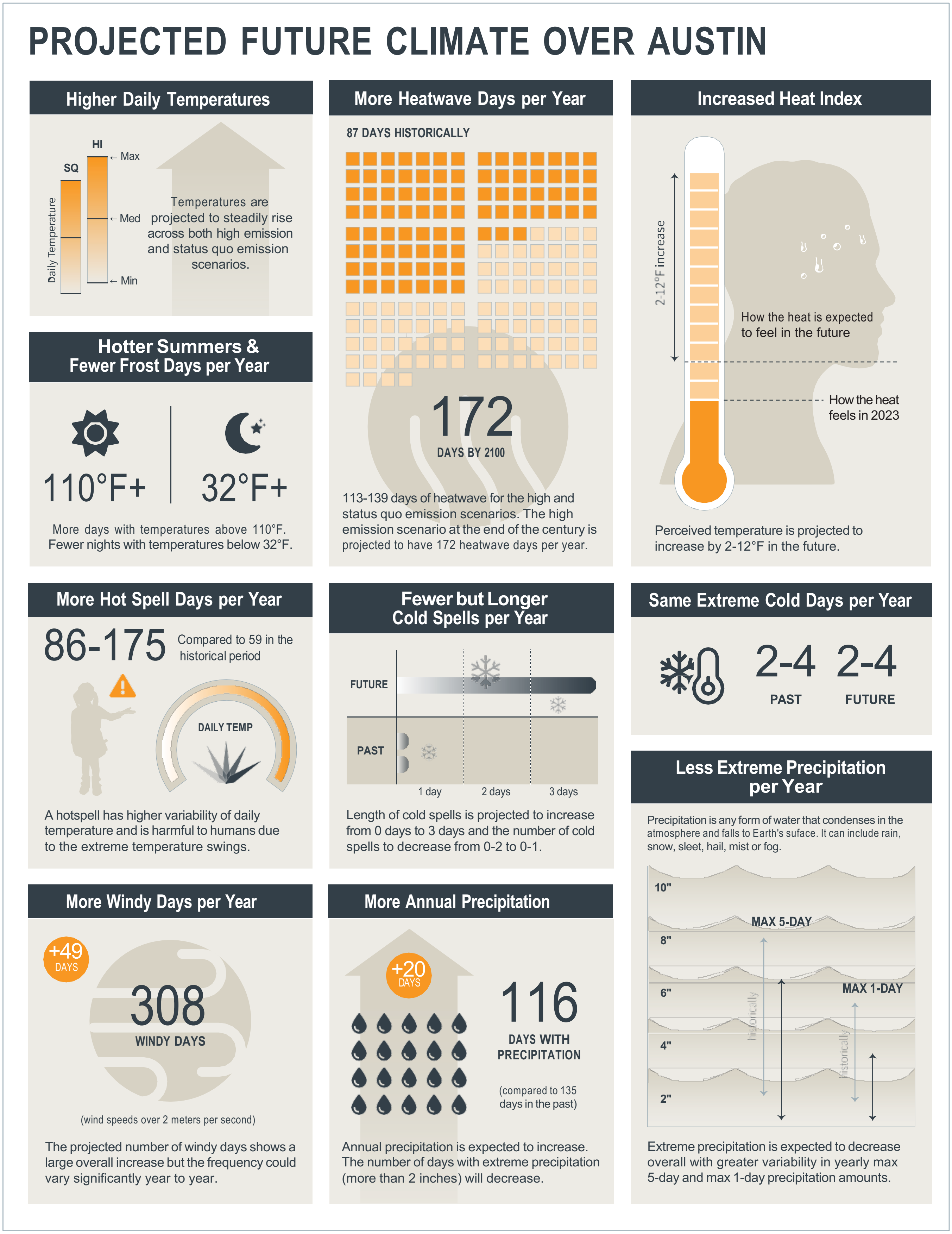

Figure 1 Summary of climate projections over Austin, Texas based on high and status quo emissions scenarios.

Preface

Human emissions of heat-trapping greenhouse gasses (GHGs) like carbon dioxide, methane and others have increased dramatically since the eighteenth century. When it comes to long-lived GHGs, carbon dioxide tops the list as the most significant one produced by human activities. As a result of human activity, carbon dioxide concentrations in the atmosphere have grown from 280 parts per million in 1850 to more than 420 parts per million in February 2022, mostly due to fossil fuel combustion, deforestation, and land-use changes. It is obvious that anthropogenic forcing has been a major contributor to the observed warming of the Earth's surface over the past 150 years, as recorded in IPCC global climate projections of regional long-term shifts in temperatures and weather patterns. In addition to melting glaciers and increasing sea levels, global warming is already causing changes in precipitation patterns and an increase in the frequency and severity of meteorological and climate extremes. Cities are uniquely affected as they must develop climate-resilient infrastructures to protect their residents and assets, enabling a sustainable and resilient future.

According to the IPCC's Sixth Assessment Report (AR6) over Texas, United States: In the historical period from 1960–2015, there was a change towards increasing temperature average and hot extremes, as well as an increasing strength of hurricanes over the East coast. This report takes a closer look at how climate change is affecting the city of Austin and how it relates to broader global trends. As a result of peer-reviewed research, this assessment report provides a comprehensive picture of the current state of the climate. The report is based on analyses of long-term observed climate records and climate model predictions from the Coupled Model Intercomparison Project Phase 6 (CMIP6).

Austin had a climate change assessment in 2014 based on the IPCC AR5/CMIP5 dataset. An updated and elaborative assessment is necessary since the global climate projections have been updated. Moreover, this report contains additional analysis relative to the previous report in the context of the recent extreme events occurring over Austin. The analysis includes temperature and precipitation changes as well as changes in heat waves, hot spells, cold spells, windy days and heat index.

This climate change assessment over Austin study contains valuable information for students and officials alike. As a result of its publishing, it will help to raise public awareness of the changing climate over Austin, as well as to inform adaptation and mitigation initiatives.

I. Introduction

In 2014, staff from the City of Austin Office of Sustainability requested an Austin-based climate projection from Dr. Katherine Hayhoe at Texas Tech University. In 2021, the Office of Sustainability approached the UT City & Climate CoLab to develop Austin-based climate projections as part of the IPCC 6th Assessment Report release. The UTCC CoLab and this report are a collaboration between UT faculty, City of Austin staff and community organizations. The UTCC CoLab develops Austin specific climate information, data products, tools, and assessments to drive innovation in research, policy and governance, funding, and education.

With its location between the arid Southwest United States and the green Southeast area, Texas' capital city Austin is amongst the fastest-growing urban areas in the USA. Austin experiences a humid subtropical climate according to the Köppen climate classification system. Summers are long and hot, and the winters are short and mild. Austin's summers, with typical highs in the 90s Fahrenheit (34–36°C) or more, are hot and humid. Every year, there are more than a hundred days with highs above 90°F. On an average day from March 6 to November 20, the high temperature is 70°F (21°C) or higher; between April 14 and October 24, it is 80°F (27°C) or higher; and between May 30 and September 18, it is 90°F (32°C) or higher on a daily average.

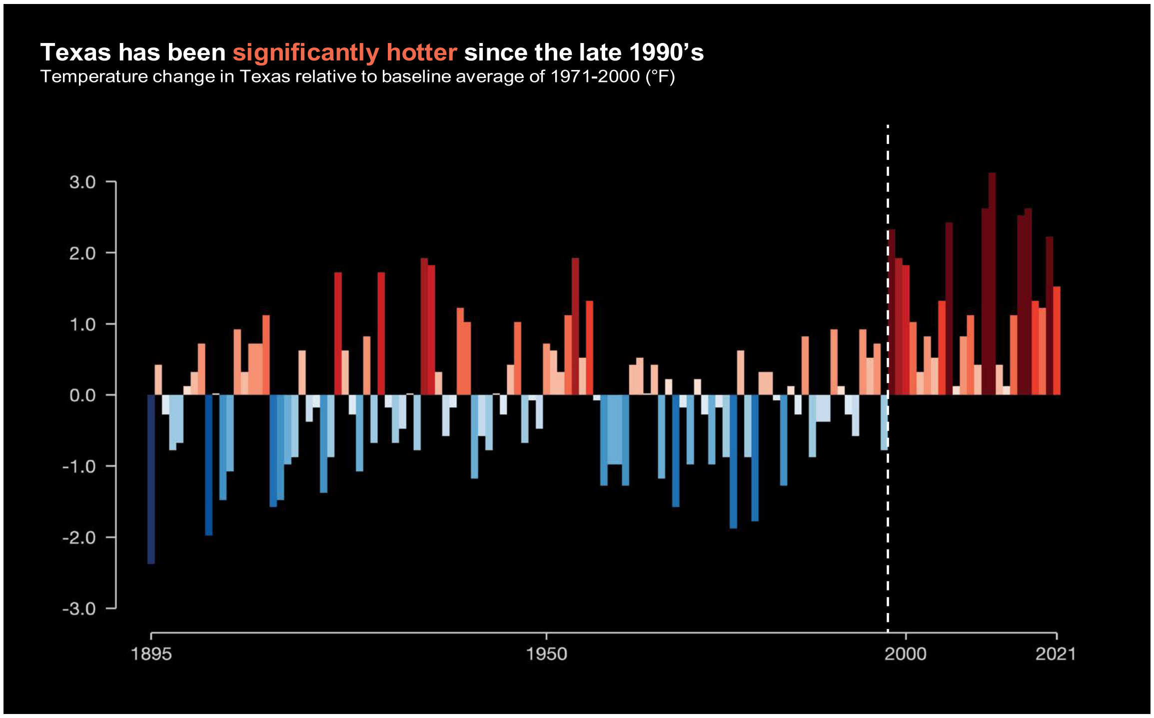

FIGURE 2 Temperature variance in most of the historical period (1895-2021) regularly included temperature drops below the baseline. This trend saw a sharp change from the late 1990s when the temperature change relative to the baseline no longer showed any drops in addition to regularly showing the highest increases.

Data Source: National Oceanic and Atmospheric Administration (NOAA)
*Note: Data from the period prior to 1971 is based on less accurate measurements.
https://showyourstripes.info/l/northamerica/usa/texas

When it comes to Austin's weather, it's highly variable since humidity fluctuates often in response to changes in winds. When the weather turns hot and humid, it's common to have many days of moderate weather followed by several days of high humidity. The opposite is also possible. Winds from the East or Southeast bring humid air from the Gulf of Mexico, whereas winds from the west or southwest bring drier air from the Chihuahuan Desert areas of West Texas or northern Mexico, resulting in lower humidity levels.

As is customary in this part of Texas, severe weather can strike at any time of year. Springtime is when it happens most frequently. According to the most recent statistics, Austin is located on the southernmost edge of Tornado Alley. A constant occurrence in the city is the threat of storms and supercell thunderstorms, which may bring high-speed winds and lightning as well as heavy rains and flash floods. Both May 4, 1922, and May 27, 1997 tornado outbreaks in Central Texas were the worst storms ever to hit the municipal boundaries. The year 2011 had been the driest year on record, with La Niña conditions in the Pacific. Drought-related wildfires erupted across Texas in the summer of 2011, most prominently the Bastrop County Complex Fire in the nearby city of Bastrop, which burned for over two weeks. Torrential rain and flash floods such as the 1981 Shoal Creek flood, 2013/2015 Halloween floods and 2018 floods following Hurricane Sergio have occurred in Austin and the surrounding areas.

At a period when Lake Travis reached 146% of its maximum capacity, the Lower Colorado River Authority released four floodgates at the Mansfield Dam (214.7 m). As a result of the Llano River's unprecedented flow of silt, dirt, and debris into the Highland Lakes, Austin's primary source of drinking water, the city issued a mandatory boil-water advisory that was in effect from October 22 to October 29, 2018. Austin Water's capacity to process 300 million gallons of water per day was cut in half, and the infrastructure simply couldn't keep up with the city's daily water consumption, which averaged 120 million gallons. The city's lowest temperature ever of -2°F (-19°C) was recorded on January 31, 1949. Every two years or so, Austin is hit by an ice storm that renders the city's roads unusable for 24 to 48 hours, significantly impeding daily life. On January 24, 2014, Austin saw 0.04 inches (1 mm) of ice, which resulted in 278 traffic accidents.

Snowfall in Austin is rare. Most of Texas and Oklahoma, including Austin, were blanketed in snow in February 2021 from the Winter Storm Uri, which dumped record-breaking amounts of snow. Snowfall of 6.4 inches (16 centimeters) was recorded at Camp Mabry near Austin in February 2021, the highest since records began in 1948. The previous record for snowfall in the area was a three-day period in January 1985, when more than one inch (25 mm) fell in the area. A lack of winterization of natural gas power facilities, which supply a significant amount of electricity to the Texas grid, plus an increase in energy demand necessitated the implementation of rolling blackouts between February 15 and 18. Some blackouts lasted more than 40 minutes while many people experienced outages that lasted several days, with an estimated 40% of Austin Energy customers without power at their peak. Water demand increased

Figure 3 Winter Storm Uri hits Austin on February 10, 2021 with catastrophic impacts to the community. The storm has been recorded as the costliest in Texas history.

from 150 millions of gallons per day (MGD) on February 15 to a peak of 260 MGD on February 16, according to Austin Water, following reports of pipe failures that began on February 15. Due to an increase in demand on Tuesday, February 17th, water pressure in the Austin area dropped to 330 MGD, necessitating a boil-water alert that lasted until Wednesday, February 23rd, when it was restored.

The 2021 freeze has been linked to the changes in the movement of the jet stream (strong winds in the Earth's upper atmosphere that blow from west to east) due to global warming-induced climate change. With a changing climate, there is a need to plan for the unpredictability of future weather. And for the development of policies guided by the need to plan, urban climate change assessments are required. The urban climate change assessments guide the city authorities on the plausible challenges and the actions that need to be taken to deal with them. This report is an urban climate change assessment for the city of Austin and is aimed to provide guidance on the climate for three decadal windows, viz, 2021–2040, 2041–2070 and 2071–2100.

1.1 Austin has a climate projection in 2014. Why is this new one being provided?

The Intergovernmental Panel on Climate Change (IPCC) prepares the assessment reports (AR) on the present and future climate at a global scale. The latest report AR6 was published in 2021. IPCC reports are based on the Coupled Model Intercomparison Project (CMIP) which is a coordinated activity with participants from several climate modeling centers across the globe. Every 5 years IPCC develops new assessments. In response, CMIP develops state-of-the-art modeling results that are coordinated globally by top research institutes. These are rigorous modeling studies that follow a well-documented experimental design which allows for intercomparison and transferability of results.

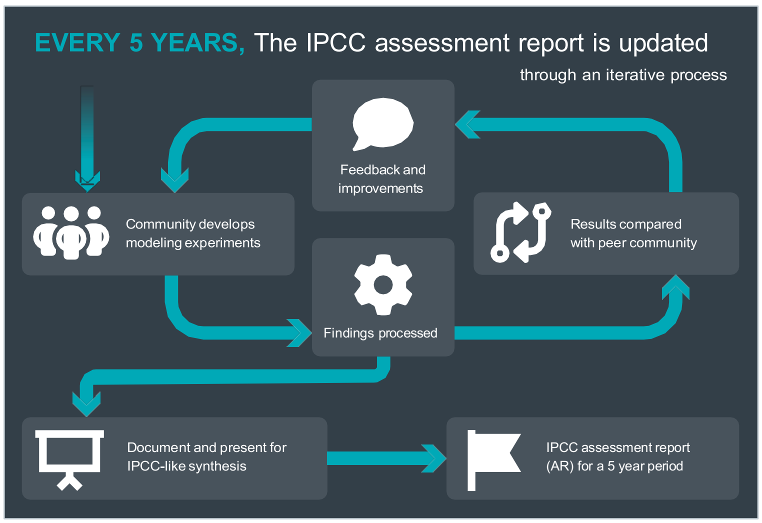

Figure 4 Multi-year process of natural variations and human-induced feedback to produce an IPCC AR Report for a 5 year period.

Understanding historical, present, and future climate changes that have been caused by natural unforced variability, or by changes in radiative forcing, is the primary purpose of the CMIP's activity. Model performance assessments from the past and quantifications of the components that contribute to forecast spread are included in this knowledge. In addition, idealized experiments are used to better understand the model's behaviors under various settings. The climate system's predictability is also studied, both on a temporal and spatial scale, and forecasts are carried out based on the current state of the climate.

One of the crucial goals of CMIP is to publish the findings of multi-model simulations in a standardized format to enable data sharing and comparison. In 1995, CMIP was formed as a joint project of the Working Group on Coupled Modeling (WGCM). One of the first CMIP experiments was to test the climate model's reaction compared to idealized forcing. The simulations were carried out by increasing CO2 emissions by one percent per year compounded over time. This was the first set of trials in which the model's reaction was compared to an increasing rate that was constant.

There have been several CMIP experiments since that time. The experiments still make use of simulations based on idealized forcings to reveal insights. As a result, these simulations must now be driven by estimates of previous changes in radiative forcing, as well as by estimations of future changes. The IPCC reports are updated every 5 years because the scientific understanding is rapidly changing and evolving in addition to the more accurate representation of processes. These processes are encoded as equations and consist of natural variations and human-induced feedback. This allows for the scientific community to develop the modeling experiments, process the findings, compare the results with the peer community, and provide continuous feedback while developing improvements off the feedback. The last phase is the documentation and presentation of findings for IPCC-like synthesis before the release of the IPCC assessment report for a 5-year period.

The IPCC and CMIP lifecycle require multi-year efforts and hence a 5-year update is considered. The 2014 assessment was developed from IPCC AR5 (5th assessment) which was a result of the 9 CMIP5 models. Since then, the CMIP6 results have been developed which were used in developing the IPCC 6th assessment released in August 2021. These assessments are available at a global scale and are used for developing future projections. Since the new CMIP and IPCC assessments are available, it is important to update the previous Austin climate assessments.

1.2 If IPCC assessments are available, why does the city need to have its own projection and this report?

The scope of IPCC AR6 is to conduct a global assessment. Its main purpose is to guide the global community on climate mitigation, adaptation, and the science of climate change. The document that gets developed is used in many follow-up negotiations and agreements between nations. They are also used for developing regional and national-scale policy goals and targets. Because of the size of the computational domain and intricacies of the computations, the climate information and model output is typically at a 1 x 1-degree latitude and longitude grid. This is roughly equivalent to 100 x 100-km grid (or 60 x 60-mi grid).

For city-scale assessments, additional processing of the global model grids is needed. Austin is covered by one grid square, so assessing the information within that area requires what is known as bias-corrected

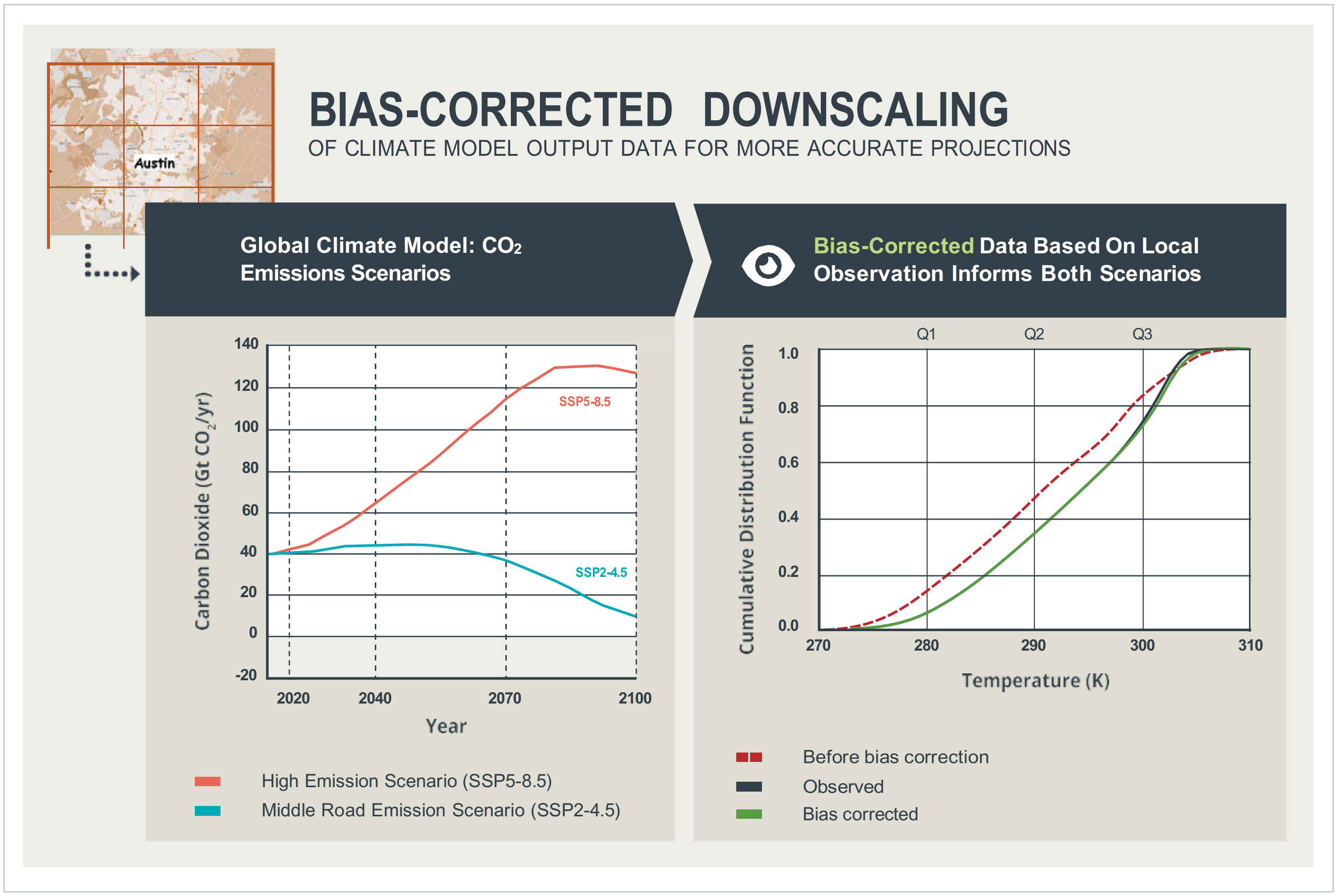

Figure 5 Additional processing of the global climate model grids for bias-corrected downscaling provides more accurate projections.

downscaling. This means the global model future years climate projection is used as guidance to extrapolate from the available observations over the city. For Austin, the observations at Camp Mabry and Austin-Bergstrom International Airport have been considered as representative sites in this study.

It is also important to highlight that climate projections from global models are different from weather forecasts. Weather forecasts are predictions and have a high degree of local reliability whereas climate model projections are likely scenarios for a range of human (anthropogenic) and natural processes interacting with each other over the next century. As a result, these projections are fraught with a wide range of uncertainties and possibilities. To bring them to a more usable and local-scale relevance, this downscaling assessment is needed. More broadly, the City of Austin has climate-sensitive operations and is mandated to have climate-resilient assessments and policies/frameworks in place. The Office of Sustainability, therefore, undertakes the coordination of these assessments as part of its operations.

1.3 What is different between the past and this updated assessment?

The major difference is the new CMIP and IPCC models and their scenarios. The older CMIP assessments were made by Representative Concentration Pathways (RCPs) and the updated assessment is based on the Shared Socioeconomic Pathways (SSPs). RCPs are designed to represent atmospheric concentrations of greenhouse gasses (GHG) and are consistent with a wide range of possible future changes in anthropogenic (i.e. human) GHG emissions. The RCPs are designed depending on the amount of GHGs that will be emitted in the years to come; a series of climate scenarios are considered possible. The RCPs were originally referred to as RCP2.6, RCP4.5, RCP6, and RCP8.5 based on a predicted range of radiative forcing levels in 2100.

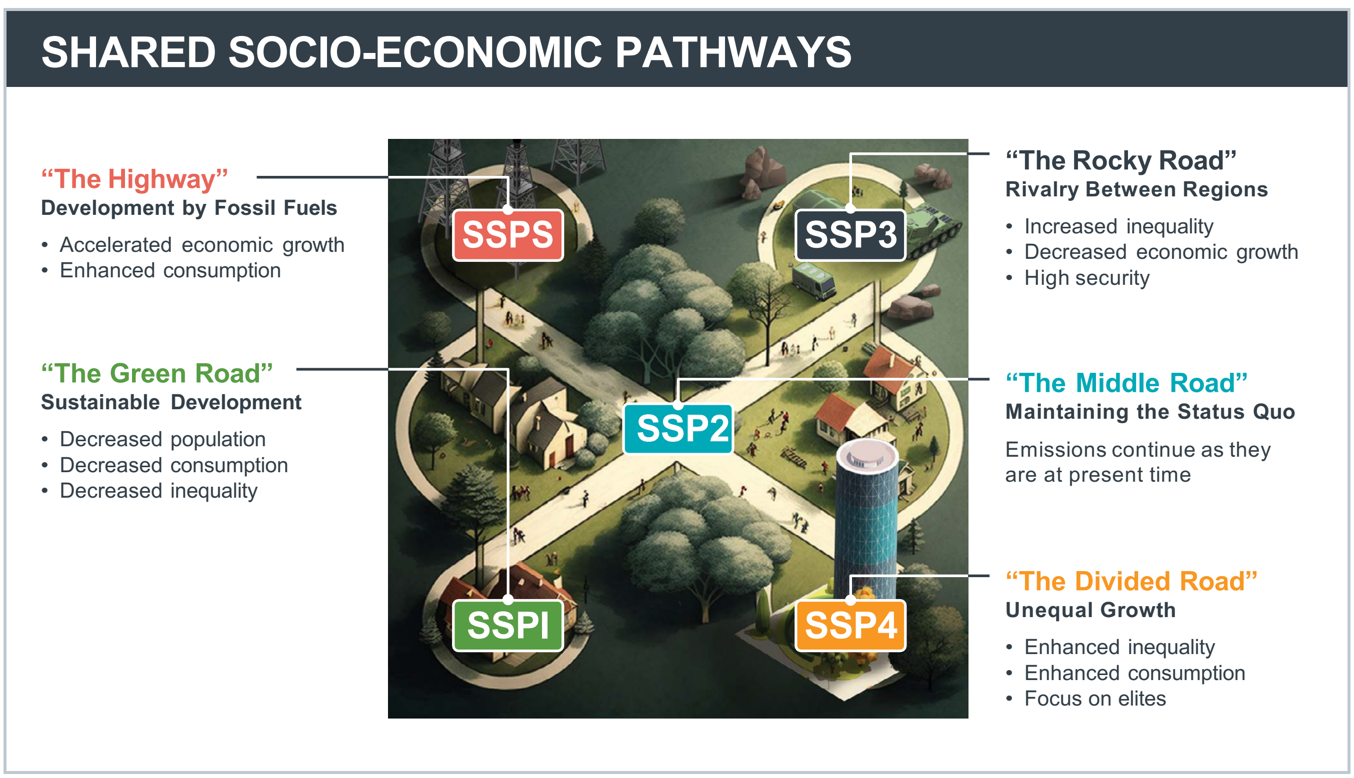

Figure 6 Detailed explanations of the different projections within IPCC/CMIP6 datasets. The pathways are collectively called shared socio-economic pathways and are focused on different rates of economic development and growth.

The term “Shared Socioeconomic Pathways” (SSP) refers to a series of narratives exploring plausible global socio-economic changes until 2100. As part of various climate policies, SSPs are used to produce emission scenarios. The scenarios consist of SSP1 (“The Green Road” / sustainable development), SSP2 (“The Middle Road” / maintaining the status quo), SSP3 (“The Rocky Road” / rivalry between regions), SSP4 (“The Divided Road” / unequal growth), and SSP5 (“The Highway” / development by fossil fuels). In this updated assessment we use SSP1-2.6 and SSP5-8.5 which correspond to the SSP1 scenario with 2.6 W/m2 radiative forcings and the SSP5 scenario with 8.5 W/m2 radiative forcing. They are comparable to the RCP2.6 and RCP8.5 pathways from the previous assessment.

II. Methodology

The bulk of the methodology involved a combination of data extraction, data processing, data analysis, and data visualization techniques to assess the correlation between NEX-GDDP-CMIP6 model outputs and observed data. The results helped identify the best models for further analysis and provided insights into the potential impacts of climate change in Austin.

2.1 How many models and scenarios are used in CMIP5 and what is used in CMIP6? What have we used?

For the variables of interest that we have considered in this study at a daily temporal scale (24-hour period), CMIP5 consisted of models from 19 global centers. The previous assessment for Austin used 9 models from CMIP5. In this report, we have considered the 6 best models from the NEX-GDDP-CMIP6 dataset which is a dynamically downscaled (~25 km spatial resolution) bias corrected product from raw CMIP6 outputs.

2.2 How was the data processed?

The initial step involved preparing the data for analysis. The analysis environment was connected to Google Drive, facilitating easy access and storage of data. Authentication with the Earth Engine API, a platform for analyzing and visualizing geospatial data, was then established. Essential Python libraries for data manipulation, analysis, and visualization were imported. Weather station data was downloaded and the nearest weather stations to Austin were identified. Camp Mabry was selected for further analysis, and weather data for that station, including information on precipitation, temperature, and other weather elements, was extracted.

This data was processed to create a structured dataset with a date-time index, enabling analysis over time. The values of various weather elements for the selected station were visualized to understand patterns and trends in the data. Specific weather elements, such as precipitation and temperature, were then selected for further analysis. The selected data was converted into a format suitable for climate

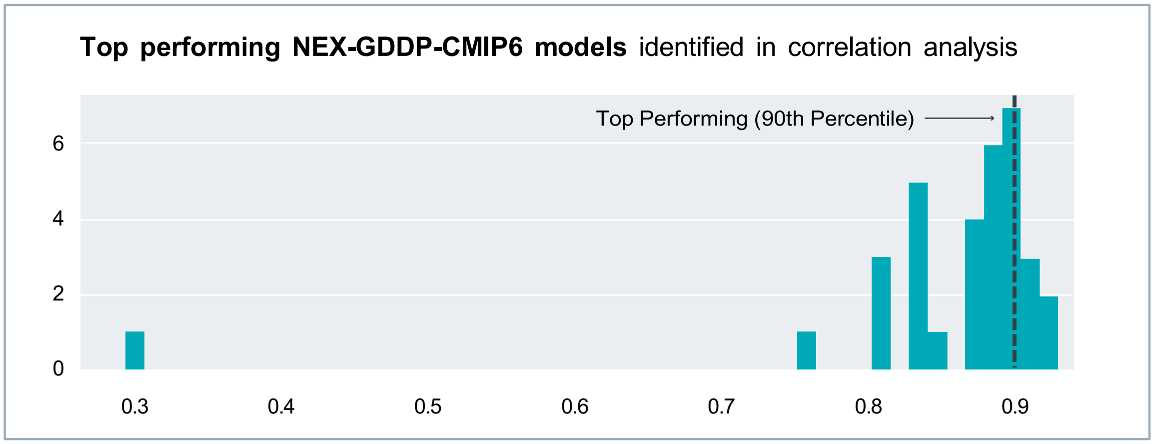

Figure 7 Histogram showing the correlation between CMIP6 data and observed monthly climatology precipitation at Camp Mabry.

analysis, known as NetCDF, which is commonly used in climate science for efficient handling of large datasets. The converted data was saved for subsequent use. The saved data was retrieved and the available climate models for analysis were listed.

Data for specific variables, scenarios, and models were extracted from the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6) dataset, which provides global, high-resolution, bias-corrected climate change projections. The correlation between the seasonal cycle of precipitation from the NEX-GDDP-CMIP6 models and observed data at Camp Mabry was computed. This analysis helped determine how well the models matched the observed data. Models were filtered based on a correlation threshold, and the best models for further analysis were identified. A histogram of the correlation values was created to visualize the distribution of correlations across models (Figure 7). The 90th percentile was annotated on the histogram to identify the top-performing models and the plot was saved for visualization.

Based on the correlation analysis, the best models were selected for further analysis. These models exhibited the highest correlation with observed data and are likely to provide more accurate projections for future climate change impacts in Austin. The selected models were used to analyze and interpret the potential impacts of climate change in Austin. Various scenarios and variables were considered to assess the potential effects on temperature, precipitation, and other climate-related factors.

2.3 How was the efficiency achieved?

A new package has been developed which generalizes the various processes involved such as subsetting, grid sizes, and calendars. The data was stored on the Texas Advanced Computing Cluster. The package runs on Google Colab and can be used by any user to develop an urban climate report for their city of interest.

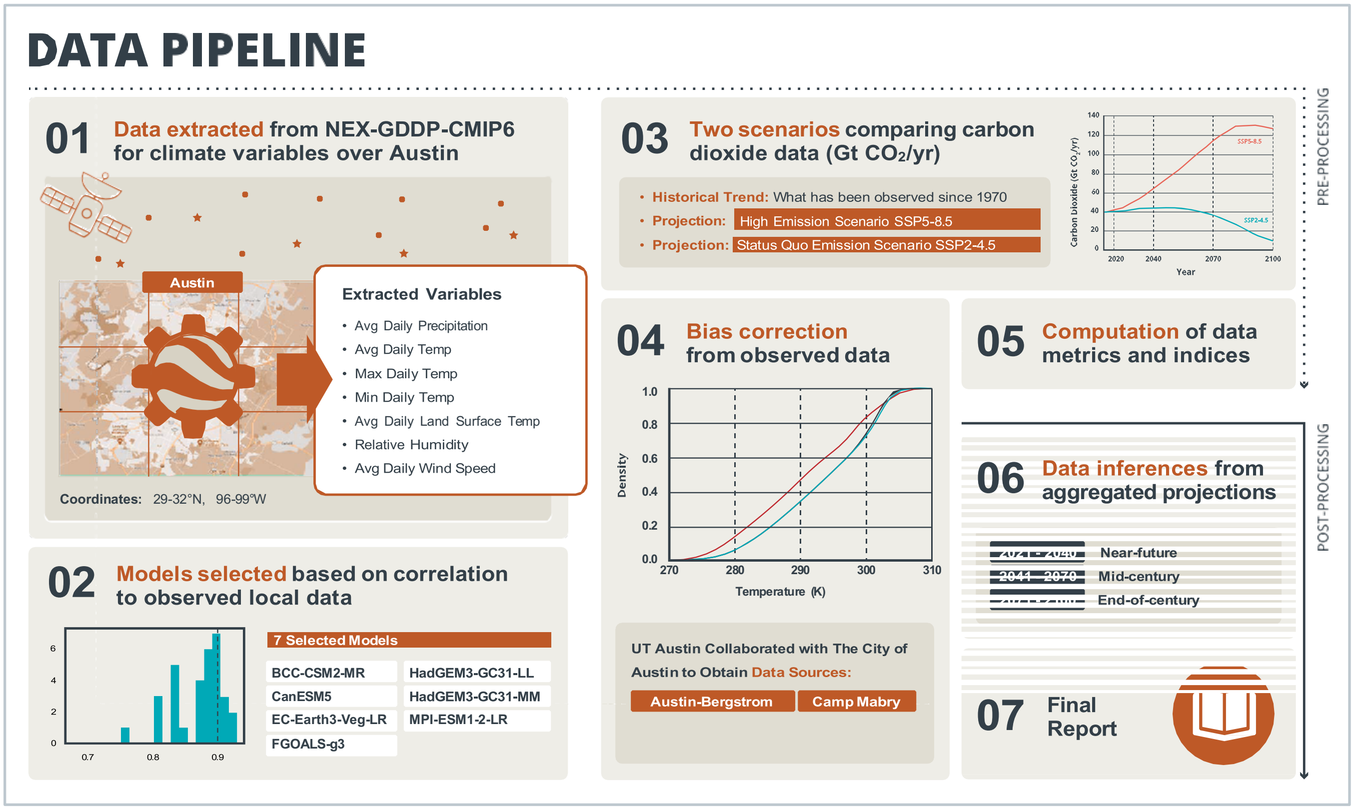

Figure 8 Pipeline of data extraction, data pre-processing, computation of metrics and indices, and data post-processing to generate the final report.

2.4 How are we representing the data?

A box and whisker plot is a simple way to show how data values are spread out by showing the median (middle value), quartiles (the data divided into quarters), and any outliers. It uses a box to represent the middle 50% of the data, or interquartile range (IQR), with a line inside the box showing the median (middle value). Lines called whiskers extend from the box to show the range of the data. Any points outside the whiskers (outliers) are considered unusual and are not represented on the charts in this report.

Quartiles on a box and whisker plot are values that divide a dataset into four equal parts and arranged in order from smallest to largest values. The quartiles help visualize the spread and distribution of the data values in the plot and are determined as follows:

The first quartile (Q1) is the value below which lies 25% of the data. So, it represents the boundary of the lower portion of the data.

The second quartile (Q2) is the middle value, or the median, of the entire dataset. It divides the data into two equal halves based on its position in the dataset. This is not the same as an average, which is the sum of all values divided by the total number of values.

The third quartile (Q3) is the value below which lies 75% of the data. It represents the boundary of the upper portion of the data.

The box shows where the majority of the data exists as it spans from the lower quartile (Q1) to the upper quartile (Q3), encompassing the IQR. The whiskers represent the full range of the data, excluding any unusual data. They extend from the box to the upper fence and lower fence values within a certain range. By using quartiles, the box and whisker plot gives a clear picture of how the data is spread out and helps us understand the overall pattern.

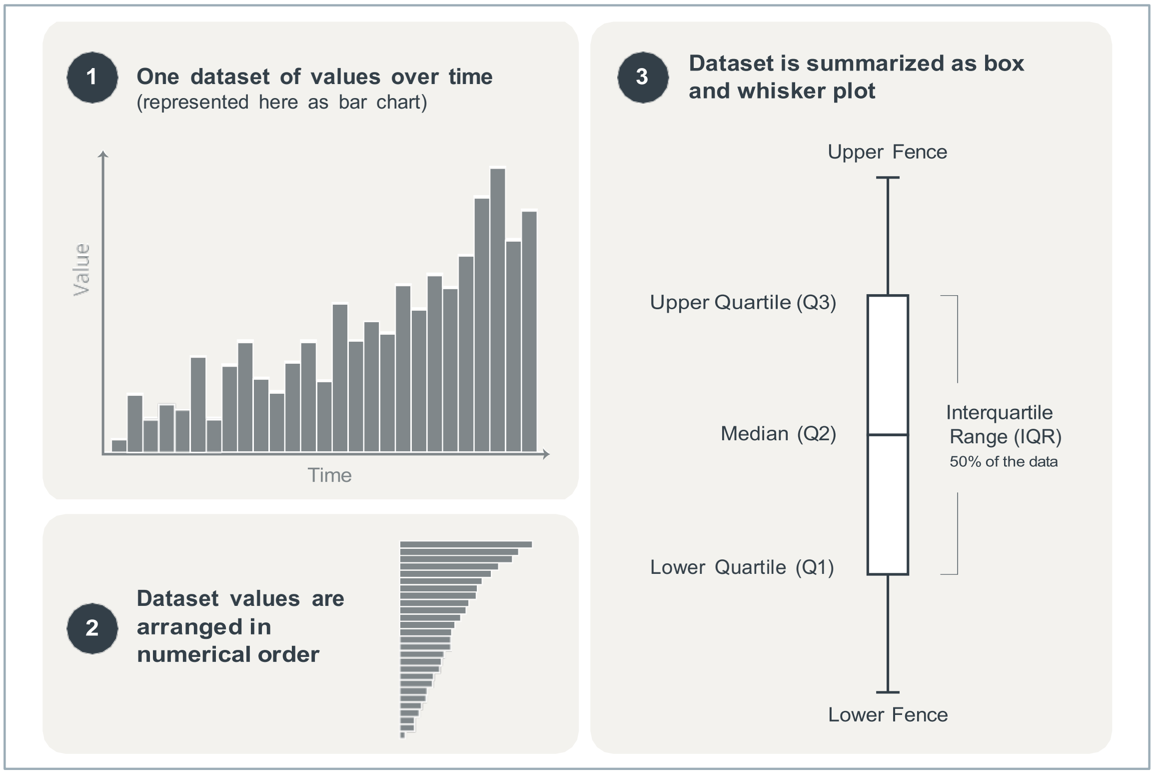

Figure 9 A box and whisker plot is a graph summarizing a set of data. The box shows how the middle 50% of the data values are distributed and the whiskers show the overall range.

2.5 What is the size of the data and where can we get this data?

A single file of 1-degree global resolution consisting of daily precipitation from the historical simulation (1850–2014) is 50 gigabytes (GB) and for the future projections (2015–2100) is 25 GB. Therefore, 450 ensemble members across all the models for historical and scenario simulations would amount to 35 terabytes (TB) of data per variable. We used 7 variables (average daily precipitation, average daily temperature, maximum daily temperature, minimum daily temperature, surface relative humidity, zonal and meridional winds) taking the total disk space requirements to 250 TB. Storing this global data is challenging for researchers with limited access to high-tech computational facilities. The global data can be retrieved from the Earth System Grid Federation (ESGF) servers and also the Pangeo Cloud computing service. We subsetted the NASA-NEX CMIP6 data from Google Earth Engine over Camp Mabry Station in Austin. Downloading the datasets is a time-consuming task as subsetting and preprocessing incur extra computational costs.

Figure 10 Data pre-processing and methodology for urban climate change assessment used for this report.

III. Assessment

3.1 How is the temperature projected to change?

Summer maximum daily temperature in the historical period had a median of 95˚F.

- *For the high emission scenario:* The summer maximum daily temperature is expected to increase by 3–4˚F in the near-future. Then, during the mid-century, it is projected to increase by 5–6˚F. By the end of the century (2070–2100), it is expected to increase by 9–10˚F.
- *In the status quo emission scenario:* The summer maximum daily temperature is expected to increase by 2–3˚F in the near-future, then by 4–5˚F through the mid century and by 6˚F at the end of the century.

Days with maximum temperature greater than 100˚F occurred at a median of 14 times per year across the historical period.

- *In the high emission scenario:* Projected to increase to 41 in the near-future (2021–2040), 62 in the mid-century (2041–2070), and 97 by the end of the century (2071–2100).
- *In the status quo emission scenario:* Projected to increase to 40 in the near-future, 53 in the mid-century, and 64 by the end of the century.

Days with maximum temperature greater than 110˚F, which are historically rare, are projected to start occurring more frequently in the high emission scenario for mid-century and the end of the century.

- *In the high emission scenario:* Projections are 0–15 per year during the mid-century (2041–2070) and could go up to 0–63 per year by the end of the century (2071–2100).
- *In the status quo emission scenario:* Projections are 0–10 per year during the mid-century (2041–2070) and could go up to 0–15 per year by the end of the century (2071–2100).

The number of days with minimum temperature below 32˚F occur at a median of 12 times per year at Austin Camp Mabry.

- *In the high emissions scenario:* Projected to increase to 15 in the near-future (2021–2040), decrease to 10 in the mid-century (2041–2070), and 5 by the end of the century (2071–2100).
- *In the status quo emissions scenario:* The number of days is projected to increase to 15 in the near-future, remain at 12 in the mid-century, and decrease to 9 by the end of the century.

3.2 How is precipitation projected to change?

Annual precipitation is any form of water that condenses in the atmosphere and falls to Earth's surface within the year. It can include rain, snow, sleet, hail, mist or fog. In the historical period, there was a median of 34 inches per year.

- *In the high emissions scenario:* Relative to the historical period in each projection, expected to decrease by 6% in the near-future (2021–2040), 6% in the mid-century (2041–2070) and 8% by the end of century (2071–2100).
- *In the status quo emissions scenario:* Projected to decrease by 6% in the near-future through the end of the century.

Dry days (days with less than 0.01 inches of precipitation) saw a median of 280–281 in the historical period.

- *In both emission scenarios:* The number of dry days is expected to decrease by 24–32 days in the future.

The number of days with precipitation greater than 2 inches had a median of 3 historically.

- *In both emissions scenarios:* Projected to decrease to 0 until the end of the century.

Amount of maximum 1-day and consecutive cumulative 5-day precipitation had historical medians of 3.12 inches and 4 inches, respectively.

- *In both emission scenarios:* Expected to decrease until the end of the century (2071–2100).

3.3 How are other climate variables expected to change?

Heat index is the level of discomfort that humans feel due to the combined effect of temperature and humidity. The heat index across the historical period had a median of 85°F.

- *In the high emissions scenario:* Expected to increase to 97°F by the end of the century.

Heat wave frequency is how often heat waves occur in a year.

- *In both emissions scenarios:* Frequency is expected to increase, with 8–9 heat waves occurring every year through the year 2100.

Total length of heat waves (or total number of days classified as heat waves)

- *In both emissions scenarios:* Projected to be in the range of 113–172 days per year until 2100.
- *In the high emission scenario:* Austin is expected to see around 6 months of heat waves per year by the end of the century.

Hot spells have a criterion only on the maximum temperature and no criteria on the minimum temperature. Therefore, they are associated with larger diurnal temperature swings (daily temperature variations), unlike heat wave events.

- *In the high emissions scenario:* The length of hot spells is projected to increase to 71 days in the near-future, 116 days in the mid-century, and 175 days per year by the end of the century.
- *In the status quo emissions scenario:* The length of hot spells is expected to increase substantially to 86–138 days per year until the end of the century.
- *In both emissions scenarios:* While there were 11 hot spells per year over Austin in the past, the future is projected to see 8–10 hot spells per year.

Cold spells over Austin are characterized by temperatures significantly below the normal or expected range for the time of year in the Austin region. They also last for at least two consecutive days with average daily temperature below 32°F. The historical period experienced 0–2 cold spells per year, each lasting about 2 days.

- *In both emissions scenarios:* Projected to increase in length to 3 days. However, the number of cold spell events are projected to decrease.

Compound events correspond to (i) cold and dry days and (ii) cold and wet days per year.

- *In both emission scenarios:* Compound events are expected to decrease from 0–2 per year in the past to 0 per year in the future.

Frost days are days that are cold enough that frost can form on the ground and outdoor surfaces.

- *In both emissions scenarios:* Expected to decrease from 12 per year in the historical period to 5–9 per year by the end of the century.

The number of calm days with wind speeds of less than two meters per second occurred about 110 days per year across the historical period.

- *In both emissions scenarios:* Expected to decrease from 106–107 per year to 55–62 per year in the future, resulting in more intense winds over Austin.

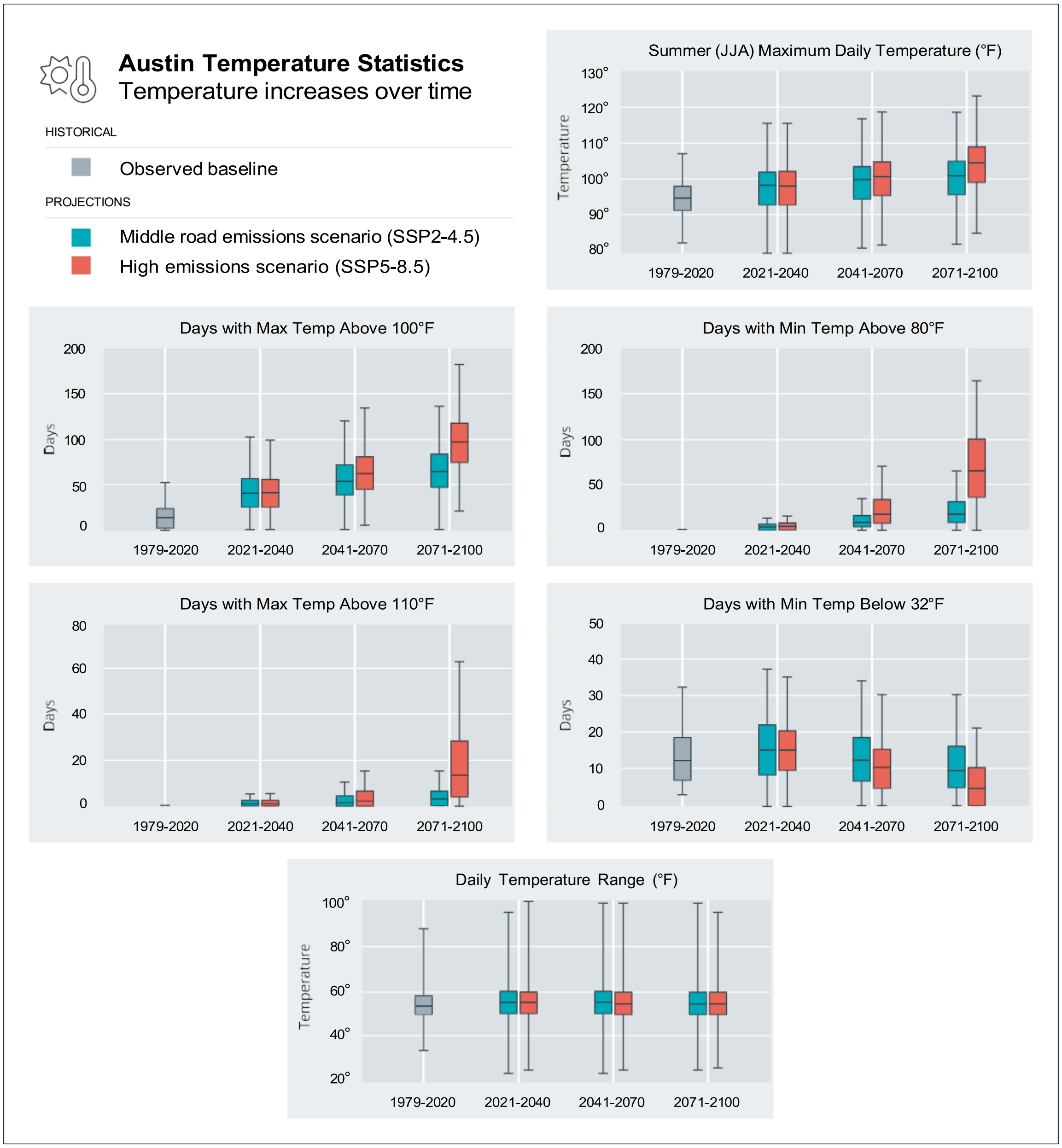

Figure 11 Temperature statistics over Austin plotted across 4 periods: historical (1979-2020), near-future (2021-2040), mid-century (2041-2070) and end of the century (2071-2100).

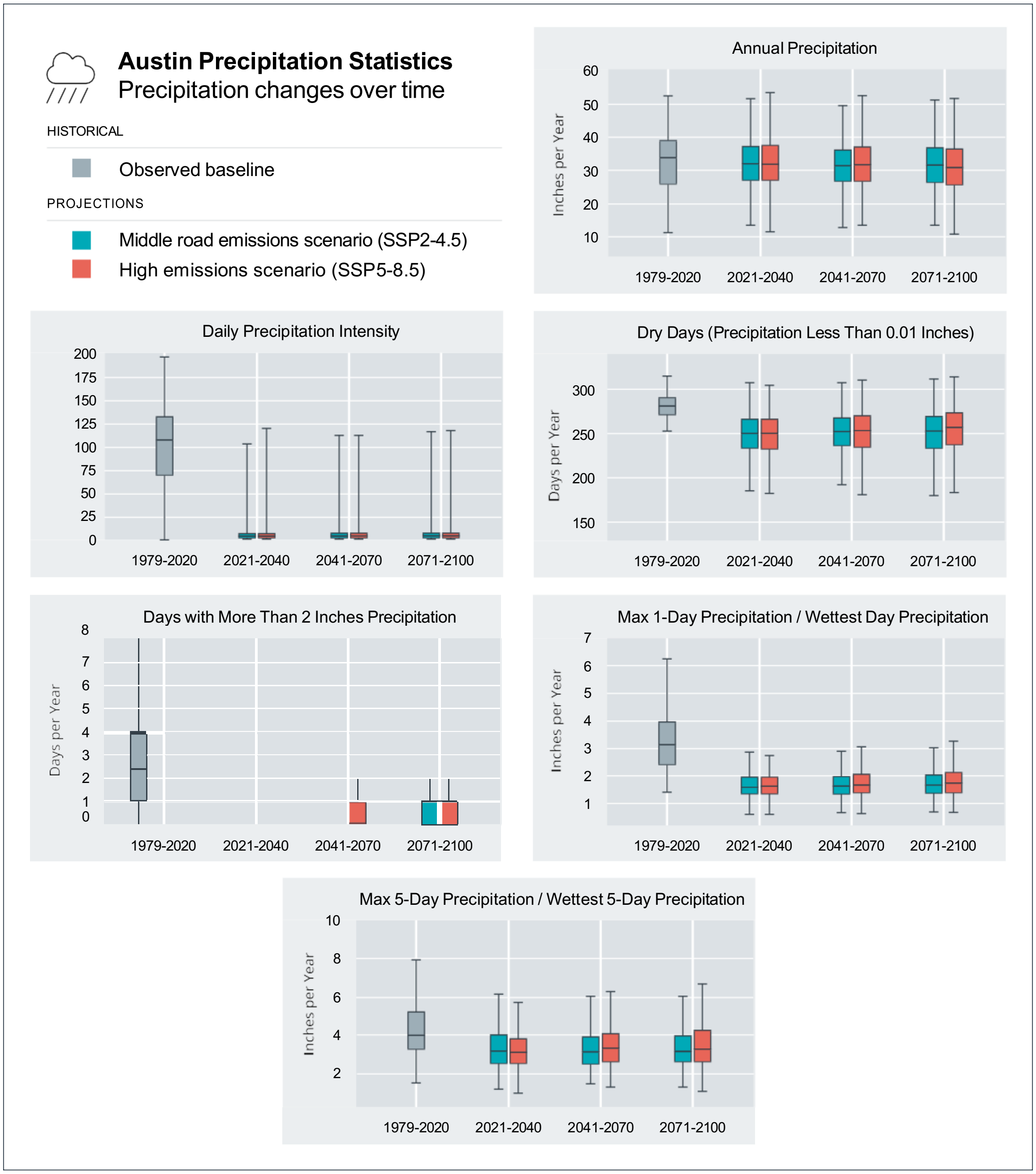

Figure 12 Precipitation statistics over Austin plotted across 4 periods: historical (1979-2020), near-future (2021-2040), mid-century (2041-2070) and end of the century (2071-2100).

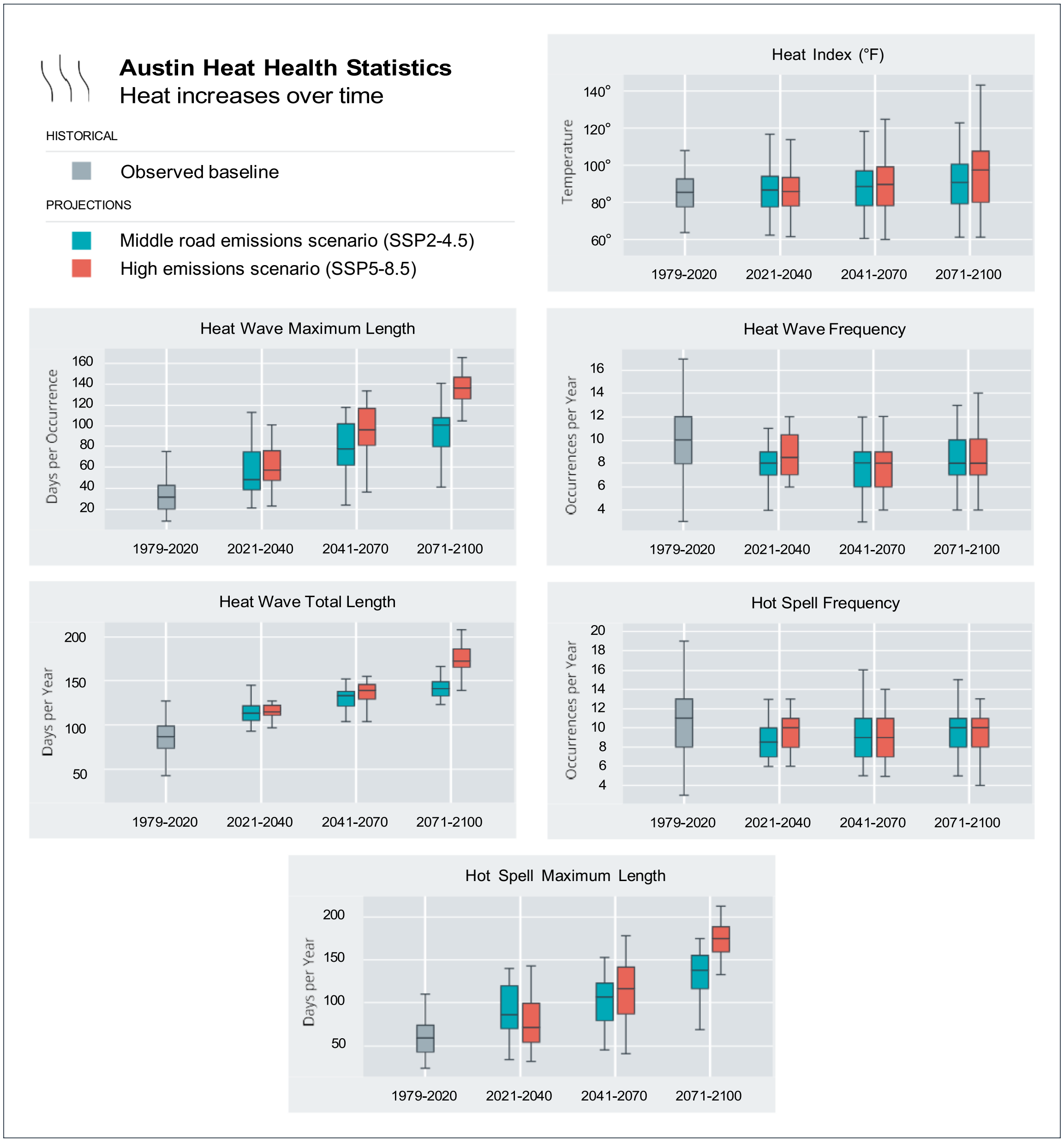

Figure 13 Heat health statistics over Austin plotted across 4 periods: historical (1979-2020), near-future (2021-2040), mid-century (2041-2070) and end of the century (2071-2100).

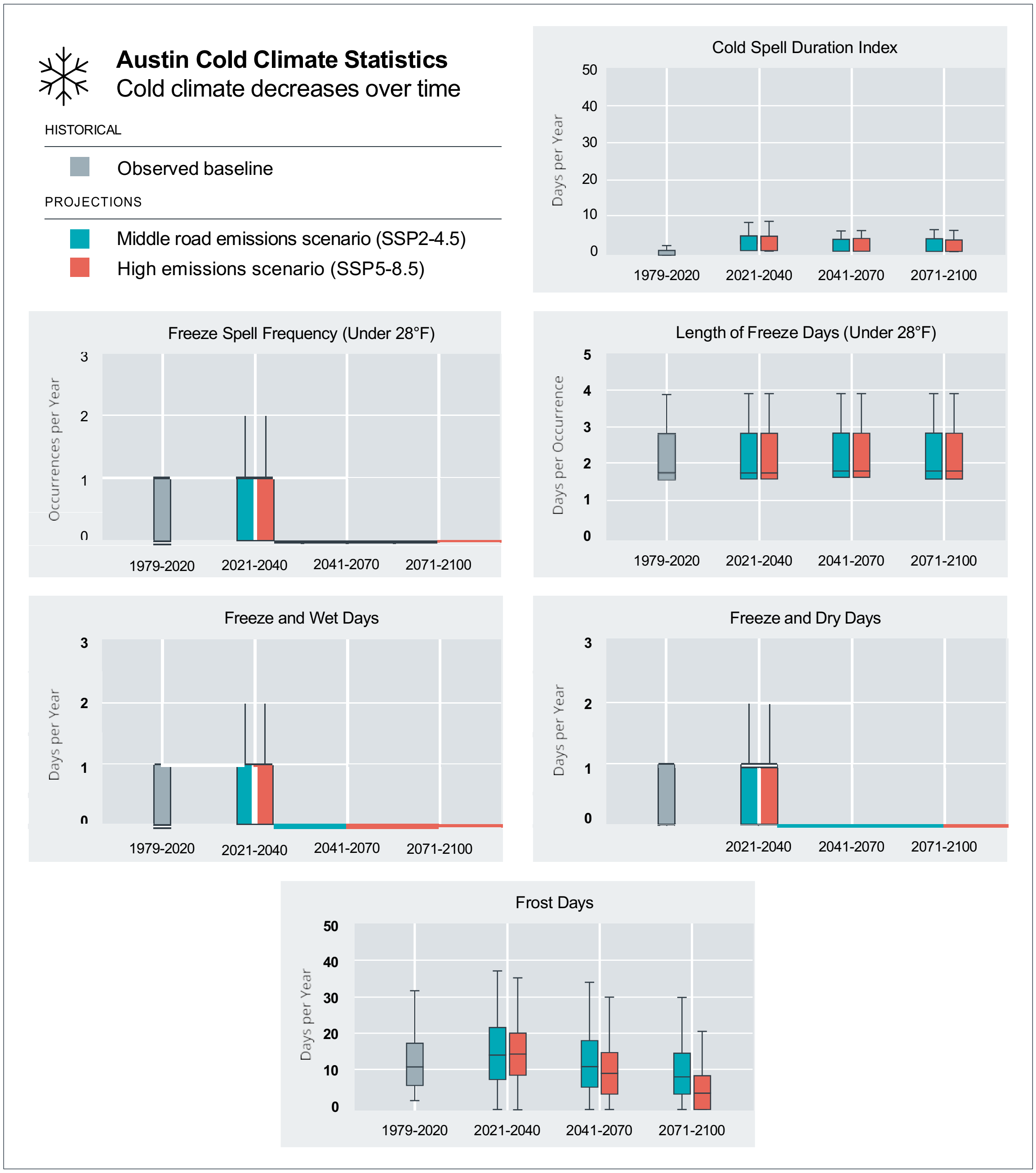

Figure 14 Cold climate statistics over Austin plotted across 4 periods: historical (1979-2020), near-future (2021-2040), mid-century (2041-2070) and end of the century (2071-2100).

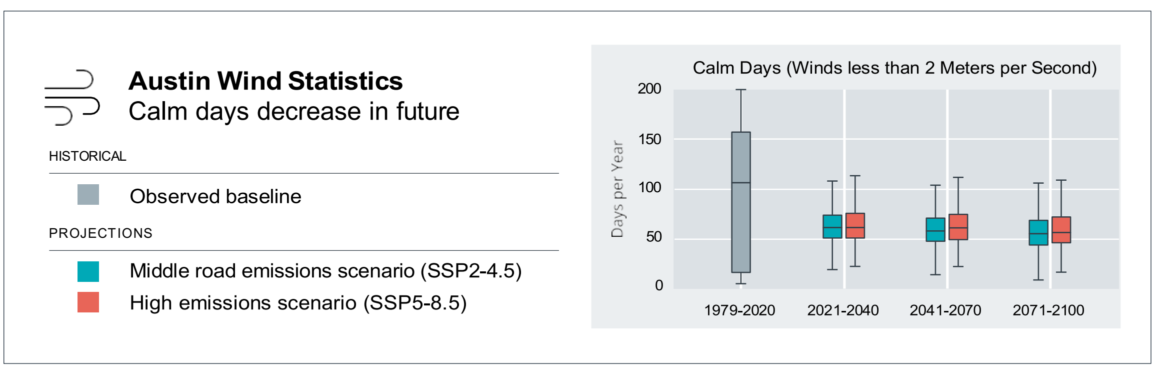

Figure 15 Wind statistics over Austin plotted across 4 periods: historical (1979-2020), near-future (2021-2040), mid-century (2041-2070) and end of the century (2071-2100).

Austin Temperature Statistics							
Summer (JJA) Maximum Daily Temperature (°F)							
Quartiles (Statistical Measures)	Historical Period (1979-2020)	Near Future (2021-2040)		Mid Century (2041-2070)		End of Century (2071-2100)	
		Middle Road	High	Middle Road	High	Middle Road	High
Upper Fence	107	115.3	115.4	116.8	118.5	118.4	122.9
Q3	**98**	**102**	**102**	**103.5**	**104.8**	**104.9**	**108.8**
Q2 (Median)	**95**	**98.3**	**98.2**	**99.8**	**100.9**	**101**	**104.7**
Q1	**91.9**	**93.2**	**93.2**	**94.7**	**95.7**	**95.9**	**99.4**
Lower Fence	82.9	79.9	79.9	81.5	82.1	82.3	85.3
Days with Max Temperature Above 110°F							
Quartiles (Statistical Measures)	Historical Period (1979-2020)	Near Future (2021-2040)		Mid Century (2041-2070)		End of Century (2071-2100)	
		Middle Road	High	Middle Road	High	Middle Road	High
Upper Fence	0	5	5	10	15	15	63
Q3	**0**	**2**	**2**	**4**	**6**	**6**	**28**
Q2 (Median)	**0**	**0**	**0**	**1**	**2**	**3**	**13**
Q1	**0**	**0**	**0**	**0**	**0**	**0**	**4**
Lower Fence	0	0	0	0	0	0	0
Days with Max Temperature Above 100°F							
Quartiles (Statistical Measures)	Historical Period (1979-2020)	Near Future (2021-2040)		Mid Century (2041-2070)		End of Century (2071-2100)	
		Middle Road	High	Middle Road	High	Middle Road	High
Upper Fence	52	102	99	120	134	136	182
Q3	**23**	**56**	**55**	**71**	**81**	**86**	**118**
Q2 (Median)	13.5	**40**	**41**	**53**	**62**	**64**	**97**
Q1	**2**	**25**	**25**	**38**	**45**	**47**	**75**
Lower Fence	0	0	0	0	5	0	21
Days with Min Temperature Above 80°F							
Quartiles (Statistical Measures)	Historical Period (1979-2020)	Near Future (2021-2040)		Mid Century (2041-2070)		End of Century (2071-2100)	
		Middle Road	High	Middle Road	High	Middle Road	High
Upper Fence	2	13	16	34	70	65	164
Q3	**1**	**6**	**7**	**16**	**33**	**31**	**99**
Q2 (Median)	**0**	**2**	**3**	**8**	**17**	**17**	**65**
Q1	**0**	**1**	**1**	**4**	**8**	**8**	**36**
Lower Fence	0	0	0	0	0	0	0
Days with Min Temperature Below 32°F							
Quartiles (Statistical Measures)	Historical Period (1979-2020)	Near Future (2021-2040)		Mid Century (2041-2070)		End of Century (2071-2100)	
		Middle Road	High	Middle Road	High	Middle Road	High
Upper Fence	32	37	35	34	30	30	21
Q3	18	**21.5**	**20**	**18**	**15**	**15**	**9**
Q2 (Median)	12	**15**	**15**	**12**	**10**	**9**	**5**
Q1	8	**9**	**10**	**7**	**5**	**5**	**1**
Lower Fence	3	0	0	0	0	0	0
Daily Temperature Range							
Quartiles (Statistical Measures)	Historical Period (1979-2020)	Near Future (2021-2040)		Mid Century (2041-2070)		End of Century (2071-2100)	
		Middle Road	High	Middle Road	High	Middle Road	High
Upper Fence	87.08	95.55	99.06	97.89	97.54	97.73	95.43
Q3	**57.92**	**60.44**	**60.25**	**60.43**	**60.24**	**60.43**	**60.24**
Q2 (Median)	**53.06**	**54.92**	**54.77**	**54.92**	**54.83**	**54.95**	**54.97**
Q1	**48.92**	**49.26**	**49.14**	**49.36**	**49.25**	**49.39**	**49.54**
Lower Fence	33.98	23.49	26.62	23.59	26.26	26.71	27.24

Table 1 Austin temperature statistics across 4 periods: historical (1979-2020), near-future (2021-2040), mid-century (2041-2070) and end of the century (2071-2100).

Austin Precipitation Statistics

Annual Precipitation (Inches)							
Quartiles	Historical Period (1979-2020)	Near Future (2021-2040)		Mid Century (2041-2070)		End of Century (2071-2100)	
		Middle Road	High	Middle Road	High	Middle Road	High
Upper Fence	52.2	51.5	53.4	49.6	52.4	51	51.5
Q3	38.9	**37.2**	**37.6**	**36.1**	**37**	**36.6**	**36.3**
Q2 (Median)	33.7	**31.9**	**31.7**	**31.4**	**31.7**	**31.4**	**30.7**
Q1	26	**27.2**	**26.9**	**26.6**	**26.7**	**26.4**	**25.6**
Lower Fence	11.3	13.5	11.7	12.7	13.5	13.4	10.8
Daily Precipitation Intensity							
Quartiles	Historical Period (1979-2020)	Near Future (2021-2040)		Mid Century (2041-2070)		End of Century (2071-2100)	
		Middle Road	High	Middle Road	High	Middle Road	High
Upper Fence	191.8	106.01	119.55	112.25	113.78	117.22	118.68
Q3	12.2	**8.38**	**8.48**	**8.37**	**8.41**	**8.31**	**8.21**
Q2 (Median)	3.6	**2.78**	**2.83**	**2.74**	**2.73**	**2.73**	**2.65**
Q1	1	**0.59**	**0.59**	**0.58**	**0.58**	**0.58**	**0.57**
Lower Fence	0.3	0.001	0.001	0.001	0.001	0.001	0.001
Dry Days per Year (Precipitation <0.01 inches)							
Quartiles	Historical Period (1979-2020)	Near Future (2021-2040)		Mid Century (2041-2070)		End of Century (2071-2100)	
		Middle Road	High	Middle Road	High	Middle Road	High
Upper Fence	315	307	304	307	310	311	314
Q3	290	**266**	**266**	**267**	**270**	**269**	**273**
Q2 (Median)	280.5	**249.5**	**250**	**252**	**253**	**252.5**	**257**
Q1	271	**233**	**232**	**236**	**234**	**233**	**237**
Lower Fence	253	185	182	192	181	180	183
Dry Spell Total Length							
Quartiles	Historical Period (1979-2020)	Near Future (2021-2040)		Mid Century (2041-2070)		End of Century (2071-2100)	
		Middle Road	High	Middle Road	High	Middle Road	High
Upper Fence	18	13	13	13	13	13	13
Q3	9	**7**	**7**	**7**	**7**	**7**	**7**
Q2 (Median)	5	**4**	**4**	**4**	**4**	**4**	**4**
Q1	3	**3**	**3**	**3**	**3**	**3**	**3**
Lower Fence	2	2	2	2	2	2	2
Days with >2 Inches Precipitation							
Quartiles	Historical Period (1979-2020)	Near Future (2021-2040)		Mid Century (2041-2070)		End of Century (2071-2100)	
		Middle Road	High	Middle Road	High	Middle Road	High
Upper Fence	8	0	0	0	2	2	2
Q3	4	**0**	**0**	**0**	**1**	**1**	**1**
Q2 (Median)	3	**0**	**0**	**0**	**0**	**0**	**0**
Q1	1	**0**	**0**	**0**	**0**	**0**	**0**
Lower Fence	0	0	0	0	0	0	0
Maximum 1-Day Precipitation / Wettest Day Precipitation per Year (Inches)							
Quartiles	Historical Period (1979-2020)	Near Future (2021-2040)		Mid Century (2041-2070)		End of Century (2071-2100)	
		Middle Road	High	Middle Road	High	Middle Road	High
Upper Fence	6.24	2.8	2.7	2.9	3	3	3.2
Q3	3.98	**1.9**	**1.9**	**1.9**	**2**	**2**	**2.1**
Q2 (Median)	3.12	**1.5**	**1.6**	**1.6**	**1.6**	**1.6**	**1.7**
Q1	2.38	**1.3**	**1.3**	**1.3**	**1.3**	**1.3**	**1.3**
Lower Fence	1.4	0.5	0.6	0.6	0.6	0.6	0.6
Maximum 5-Day Precipitation / Wettest 5-Day Precipitation per Year (Inches)							
Quartiles	Historical Period (1979-2020)	Near Future (2021-2040)		Mid Century (2041-2070)		End of Century (2071-2100)	
		Middle Road	High	Middle Road	High	Middle Road	High
Upper Fence	7.93	6.1	5.7	5.9	6.2	6.04	6.6
Q3	5.22	**4**	**3.8**	**3.9**	**4**	**3.9**	**4.2**
Q2 (Median)	3.97	**3.1**	**3.08**	**3.1**	**3.3**	**3.1**	**3.2**
Q1	3.27	**2.5**	**2.5**	**2.5**	**2.6**	**2.6**	**2.6**
Lower Fence	1.55	1.2	1	1.4	1.3	1.3	1.08

Table 2 Austin precipitation statistics across 4 periods: historical (1979-2020), near-future (2021-2040), mid-century (2041-2070) and end of the century (2071-2100).

Austin Heat Health Statistics

Heat Index (°F)							
Quartiles	Historical Period (1979-2020)	Near Future (2021-2040)		Mid Century (2041-2070)		End of Century (2071-2100)	
		Middle Road	High	Middle Road	High	Middle Road	High
Upper Fence	107.9	116.43	113.59	122.7	124.67	118.32	143.31
Q3	**92.36**	**94.13**	**93.3**	**100.81**	**99.13**	**96.85**	**107.67**
Q2 (Median)	**85**	**86.69**	**85.69**	**90.65**	**89.53**	**88.3**	**97.06**
Q1	**77.18**	**77.33**	**77.66**	**78.84**	**77.91**	**77.77**	**79.78**
Lower Fence	63.48	62.12	61.41	61.02	59.8	60.3	60.92

Heat Wave Maximum Length (Days per Occurrence)							
Quartiles	Historical Period (1979-2020)	Near Future (2021-2040)		Mid Century (2041-2070)		End of Century (2071-2100)	
		Middle Road	High	Middle Road	High	Middle Road	High
Upper Fence	75	113	101	118	134	141	166
Q3	**43**	**75**	**76**	**102**	**117**	**108**	**147**
Q2 (Median)	**31.5**	**48**	**57.5**	**78**	**96.5**	**101**	**136**
Q1	**20**	**38.5**	**47.5**	**62**	**81**	**80**	**126**
Lower Fence	9	21	23	24	36	41	105

Heat Wave Frequency (Occurrences per Year)							
Quartiles	Historical Period (1979-2020)	Near Future (2021-2040)		Mid Century (2041-2070)		End of Century (2071-2100)	
		Middle Road	High	Middle Road	High	Middle Road	High
Upper Fence	17	11	12	12	12	13	14
Q3	**12**	**9**	**10.5**	**9**	**9**	**10**	**10**
Q2 (Median)	**10**	**8**	**8.5**	**8**	**8**	**8**	**8**
Q1	**8**	**7**	**7**	**6**	**6**	**7**	**7**
Lower Fence	3	4	6	3	4	4	4

Heat Wave Total Length (Days per Year)							
Quartiles	Historical Period (1979-2020)	Near Future (2021-2040)		Mid Century (2041-2070)		End of Century (2071-2100)	
		Middle Road	High	Middle Road	High	Middle Road	High
Upper Fence	127	145	127	152	155	166	207
Q3	**99**	**122**	**122.5**	**138**	**146**	**149**	**186**
Q2 (Median)	**87**	**113.5**	**115**	**133**	**139**	**141**	**172**
Q1	**74**	**105.5**	**111.5**	**121**	**129**	**133**	**165**
Lower Fence	43	93	97	104	104	123	139

Hot Spell Frequency (Occurrences per Year)							
Quartiles	Historical Period (1979-2020)	Near Future (2021-2040)		Mid Century (2041-2070)		End of Century (2071-2100)	
		Middle Road	High	Middle Road	High	Middle Road	High
Upper Fence	19	13	13	16	14	15	13
Q3	**13**	**10**	**11**	**11**	**11**	**11**	**11**
Q2 (Median)	**11**	**8.5**	**10**	**9**	**9**	**10**	**10**
Q1	**8**	**7**	**8**	**7**	**7**	**8**	**8**
Lower Fence	3	6	6	5	5	5	4

Hot Spell Maximum Length (Days per Year)							
Quartiles	Historical Period (1979-2020)	Near Future (2021-2040)		Mid Century (2041-2070)		End of Century (2071-2100)	
		Middle Road	High	Middle Road	High	Middle Road	High
Upper Fence	110	140	143	153	178	175	213
Q3	**74**	**120**	**99.5**	**123**	**142**	**155**	**189**
Q2 (Median)	**59**	**86**	**71.5**	**106.5**	**116.5**	**138**	**175**
Q1	**43**	**70**	**54.5**	**79**	**87**	**116**	**159**
Lower Fence	24	34	32	45	41	69	133

Table 3 Austin heat health statistics across 4 periods: historical (1979-2020), near-future (2021-2040), mid-century (2041-2070) and end of the century (2071-2100).

Austin Cold Climate Statistics							
Cold Spell Duration Index (Days per Year)							
Quartiles	Historical Period (1979-2020)	Near Future (2021-2040)		Mid Century (2041-2070)		End of Century (2071-2100)	
		Middle Road	High	Middle Road	High	Middle Road	High
Upper Fence	2	9	9	7	7	7	7
Q3	1	**5**	**5**	**4**	**4**	**4**	**4**
Q2 (Median)	0	**3**	**3**	**3**	**3**	**3**	**3**
Q1	0	**2**	**2**	**2**	**2**	**2**	**2**
Lower Fence	0	2	2	2	2	2	2
Freeze Spell Frequency (Under 28°F) (Occurrences per Year)							
Quartiles	Historical Period (1979-2020)	Near Future (2021-2040)		Mid Century (2041-2070)		End of Century (2071-2100)	
		Middle Road	High	Middle Road	High	Middle Road	High
Upper Fence	2	2	2	0	0	0	0
Q3	1	**1**	**1**	**0**	**0**	**0**	**0**
Q2 (Median)	0	**0**	**0**	**0**	**0**	**0**	**0**
Q1	0	**0**	**0**	**0**	**0**	**0**	**0**
Lower Fence	0	0	0	0	0	0	0
Length of Freeze Days (Under 28°F) (Days per Occurrence)							
Quartiles	Historical Period (1979-2020)	Near Future (2021-2040)		Mid Century (2041-2070)		End of Century (2071-2100)	
		Middle Road	High	Middle Road	High	Middle Road	High
Upper Fence	4	4	4	4	4	4	4
Q3	3	**3**	**3**	**3**	**3**	**3**	**3**
Q2 (Median)	2	**2**	**2**	**2**	**2**	**2**	**2**
Q1	2	**2**	**2**	**2**	**2**	**2**	**2**
Lower Fence	2	2	2	2	2	2	2
Freeze and Wet Days (Days per Year)							
Quartiles	Historical Period (1979-2020)	Near Future (2021-2040)		Mid Century (2041-2070)		End of Century (2071-2100)	
		Middle Road	High	Middle Road	High	Middle Road	High
Upper Fence	2	2	2	0	0	0	0
Q3	1	**1**	**1**	**0**	**0**	**0**	**0**
Q2 (Median)	0	**0**	**0**	**0**	**0**	**0**	**0**
Q1	0	**0**	**0**	**0**	**0**	**0**	**0**
Lower Fence	0	0	0	0	0	0	0
Freeze and Dry Days (Days per Year)							
Quartiles	Historical Period (1979-2020)	Near Future (2021-2040)		Mid Century (2041-2070)		End of Century (2071-2100)	
		Middle Road	High	Middle Road	High	Middle Road	High
Upper Fence	2	2	2	0	0	0	0
Q3	1	**1**	**1**	**0**	**0**	**0**	**0**
Q2 (Median)	0	**0**	**0**	**0**	**0**	**0**	**0**
Q1	0	**0**	**0**	**0**	**0**	**0**	**0**
Lower Fence	0	0	0	0	0	0	0
Frost Days (Days per Year)							
Quartiles	Historical Period (1979-2020)	Near Future (2021-2040)		Mid Century (2041-2070)		End of Century (2071-2100)	
		Middle Road	High	Middle Road	High	Middle Road	High
Upper Fence	32	37	35	34	30	30	21
Q3	18	**21.5**	**20**	**18**	**15**	**15**	**9**
Q2 (Median)	12	**15**	**15**	**12**	**10**	**9**	**5**
Q1	8	**9**	**10**	**7**	**5**	**5**	**1**
Lower Fence	3	0	0	0	0	0	0

Table 4 Austin cold climate statistics across 4 periods: historical (1979-2020), near-future (2021-2040), mid-century (2041-2070) and end of the century (2071-2100).

Austin Wind Statistics							
Calm Days per Year (Winds <2 m/s)							
Quartiles	Historical Period (1979-2020)	Near Future (2021-2040)		Mid Century (2041-2070)		End of Century (2071-2100)	
		Middle Road	High	Middle Road	High	Middle Road	High
Upper Fence	199	108	113	104	112	106	109
Q3	**156.5**	**74**	**76**	**71**	**75**	**69**	**72**
Q2 (Median)	**106.5**	**61**	**62**	**58**	**61**	**55**	**57**
Q1	**17.5**	**51**	**51**	**48**	**50**	**44**	**47**
Lower Fence	6	20	23	15	23	9	17

Table 5 Austin wind statistics across 4 periods: historical (1979-2020), near-future (2021-2040), mid-century (2041-2070) and end of the century (2071-2100).

IV. Conclusion

This report is aimed towards assessing the future climate change over Austin, TX, United States. We used the largest available dynamically downscaled, bias corrected data (NASA-NEX CMIP6) from the updated IPCC AR6 CMIP6 global projections. We extracted the data over Austin and first chose models capable of simulating the seasonal cycle of precipitation over the city. On the selected models, bias correction was performed to eliminate systematic errors in the simulated dataset. Computation of climate indices was performed for the three periods in the future; (i) near-future: 2021–2040, (ii) mid-century: 2041–2070 and (iii) end of the century: 2071–2100 for the high and low emission scenarios. The results were computed for important climate indices for temperature, precipitation, heat health metrics, cold spells and winds.

Key findings indicate that overall temperatures are rising, with summer highs expected to exceed 110˚F more frequently. Heatwaves are expected to last longer, potentially reaching 172 days per year by the end of the century in the high emission scenario—almost 1.5 times the expected number in the near-future for the same scenario. The number of hotspell days, which are harmful to humans due to the extreme temperature swings, are expected to more than double in the future, reaching 175 per year. It will generally feel hotter in the future by up to 12˚F. The number of cold spells will decrease but each one will last ~3x longer. Extreme precipitation and annual precipitation are going to decrease. Lastly, the number of windy days per year are expected to increase by ~20%.

Meteorological factors are directly linked to humans via health, economy, and livability. Climate change is altering the lives of humans and local-scale assessment of the phenomena is the need-of-the-hour. This assessment provides The City of Austin and various stakeholders local-scale relevant information to plan for a sustainable future.

Figure 16 Lady Bird Lake along the Lady Bird Hike and Bike Trail in Austin, Texas.

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Appendix A

LIST OF FIGURES AND TABLES

Appendix B

ACRONYMS

AR	Assessment Report
CMIP6	Coupled Model Intercomparison Project Phase 6
GHGs	Greenhouse Gasses
IPCC	Intergovernmental Panel on Climate Change
IQR	Interquartile Range
RCPs	Representative Concentration Pathways
SSPs	Shared Socio-economic Pathways
WGCM	Working Group on Coupled Modeling