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Climate Projections for the City of San Antonio

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A. Introduction

The climate of Texas is changing, which is evident from gradually increasing average temperature, shifting patterns of precipitation, increasing frequency of heavy precipitation events, and changes in extreme temperatures. The general increase in temperature and shifts in precipitation statistics are consistent with trends in other parts of the United States as well as global trends.

Carbon dioxide emission from human activities, deforestation, agriculture, and fossil fuel combustion are some of the main human-induced contributors to climate change. Human emissions are exceeding the natural uptake rates of the ocean and biosphere, resulting in an excessive amount of heat-trapped gas in the atmosphere. Earth radiates part of its received heat through space and the heat-trapped gases present in the atmosphere strengthen the naturally occurring greenhouse effect by absorbing a portion of the radiated heat, causing the earth to warm. Concentration of carbon dioxide in the atmosphere has been increasing exponentially over the last few decades.

The emission of these gases has already been shown to impact temperature, precipitation, and other important aspects of climate and will continue to influence the climate throughout this century. It is impossible to change the existing fossil fuel-based energy system to low or zero-carbon energy overnight. Also, the emissions already existing in the atmosphere will continue to affect the physical climate system in the coming years, and some changes in the climate are inevitable even if the emissions are stopped. However, adopting practices that significantly reduce carbon emissions from human activities instead of continuing the existing carbon-intensive pathway will limit the amount of future change attributed to human activities.

Major cities develop plans for several decades into the future with the assumption that the future climate is not going to change much. The planning of large cities on coastlines, building codes for construction, distribution of agricultural lands, and constructions around seashores are based on assumptions of stable climate and constant sea level. The historical records of floods and droughts are used for future predictions. However, past records might not serve as a reliable source to guide the future due to the rapidly changing climate. Given the impacts of human-induced changes on natural resources, cities now need climate projections for a better understanding and prediction of future climate.

B. Methods

The LOcalized Constructed Analogs (LOCA) method (Pierce et al., 2014) was used to statistically downscale projections from 21 global climate models (GCMs) of the Coupled Model Inter-Comparison Project 5 (CMIP5, Taylor et al., 2012). Two projections were taken into consideration to encompass the uncertainty of human activities and heat-trapping gas emissions: the Intergovernmental Panel on Climate Change lower Representative Concentration Pathway (RCP) 4.5 scenario, and the higher RCP 8.5 scenario. The former assumes the global carbon emissions peak and then gradually decline by the end of century, whereas the latter assumes continued dependence on fossil fuels, i.e., continuously growing carbon emission throughout the century. Pathway labels (4.5 and 8.5) refer to the projected change in radiative forcing in units of watts per square meter. The naturally occurring greenhouse effect is exacerbated by human influence, and radiative forcing is a measure of the magnitude of this human influence. Human uncertainty is especially influential for temperature-related impacts for the last half of the 21st century.

Projections were averaged over 30-year periods (this is the period typically used to estimate climatic norms) so that the natural variability can be taken into account. The climate model projections are averaged over three 30-year time periods: near-term (2011-2040), mid-century (2041-2070), and end-of-century (2071-2100). When the time scale is shorter, natural variability is an important source of uncertainty. But when longer time spans are considered, climate model products are averaged over time scales of multiple decades, making the uncertainty for natural variability negligible. For example, when the number of days with temperatures greater than 110 °F were calculated for each 30-year time period, the number of days greater than 110 °F for each year were calculated first. These calculations were then averaged over 30 years to minimize the uncertainty introduced by natural variability.

Climate model projections averaged over each 30-year period are obtained from 21 different climate models (CCSM4, CESM1-BGC, CNRM-CM5, CSIRO-Mk3, GFDL-ESM2G, GFDL-ESM2M, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC-ESM-CHEM, MIROC5, MPI-ESM-LR, MPI-ESM-MR, MRI-CGCM3, bcc-csm-1-1, CanESM-2,

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NorESM1-M, MIROC-ESM, HadGEM2-AO, CESM1-CAM5, FGOALS-g2). The projections from the 21 models can be different from each other, which reflects the limitations of scientific ability and the differences in approaches to simulate the climate system. The figures represent an average of 21 climate models along with the full range of model results.

The downscaled products of global climate model simulations for the City of San Antonio, including San Antonio International Airport long-term weather station, were used for this analysis. For future planning purposes, other long-term weather stations around the San Antonio area should also be included to get robust products. Secondary climate indicators can be calculated from the results for comprehensive analysis by city departments as they are directly relevant and helpful tools for future planning.

C. Temperature Projections

Annual and seasonal temperatures are expected to increase for the United States and the State of Texas over the 21st century. By the end of this century, projected data indicate increases in annual temperatures across the South-Central Great Plains with an average +5-6 °F under the lower pathway and +9-10 °F under the higher pathway.

High-resolution downscaled climate projections for the City of San Antonio used in this study are based on the methods described in the previous section to minimize uncertainty. The results are summarized below along with bar charts.

Summer maximum temperatures are projected to increase by 4.2 °F for the lower emission scenario and by 4.4 °F for the higher-emission scenario from baseline to near term. They are projected to increase by 1.9 °F for the lower-emission scenario and by 3 °F for the higher-emission scenario from near-term to mid-century. From mid-century to the end-of-century, summer temperatures are projected to increase 0.6 °F for the lower pathway and 3.3 °F for the higher pathway.

Projections also indicate changes in temperature extremes, and the changes for extremes are more robust compared to changes for means. Projected changes include:

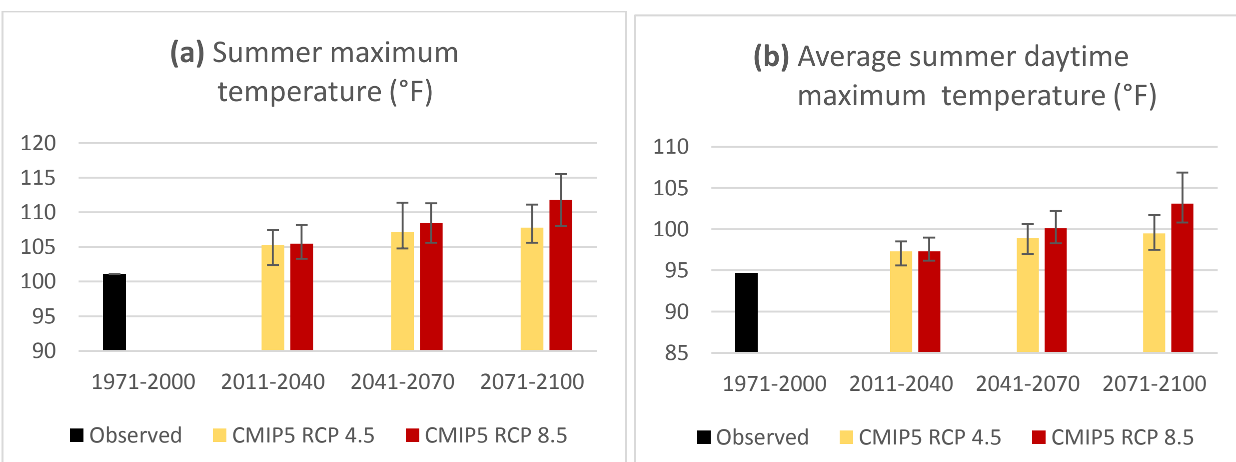
- Summer maximum temperatures are projected to increase over time (Figure 1a)

- Average summer daytime maximum temperatures are projected to increase over time (Figure 1b)
- The number of warm nights (over 80 °F) is projected to increase over time (Figure 1c)
- The number of hot days (over 100 °F) is projected to increase over time (Figure 1d)
- Very hot days (over 110 °F) will begin to occur in the future and will increase in frequency over time (Figure 1e)
- The number of cold nights (below 32 °F) is projected to decrease over time (Figure 1f)

See Table 1 on p. 9 for exact figures for all projections.

Projections were generated using the 21 models and scenarios described in the Methods section, and annual values were averaged over three 30-year time periods: near-term, mid-century, and end-of-century. Light-colored bars correspond to average conditions projected under the RCP 4.5 lower pathway, while dark-colored bars correspond to average conditions projected under the higher RCP 8.5 scenario. 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.

Figure 1: Temperature projections for the City of San Antonio



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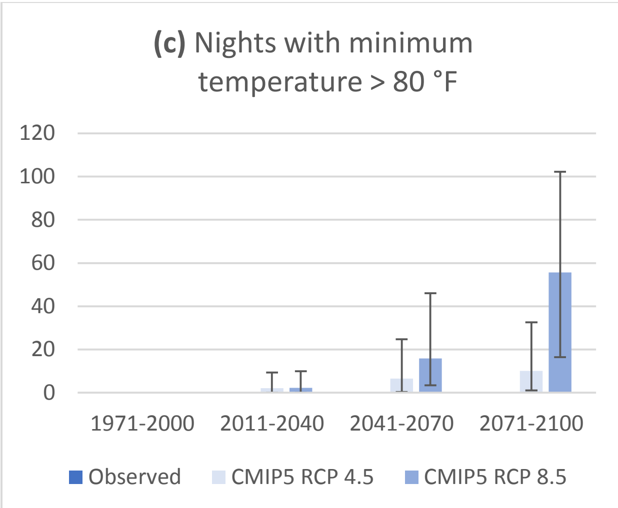

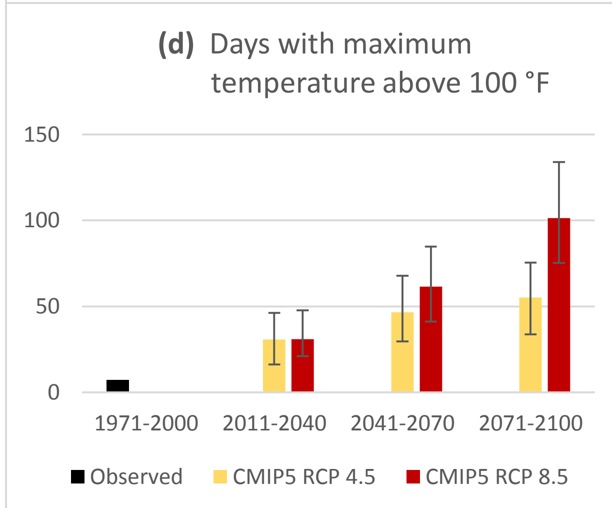

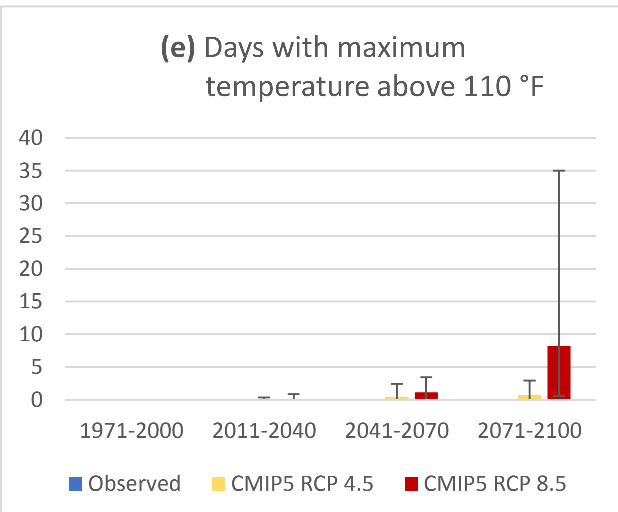

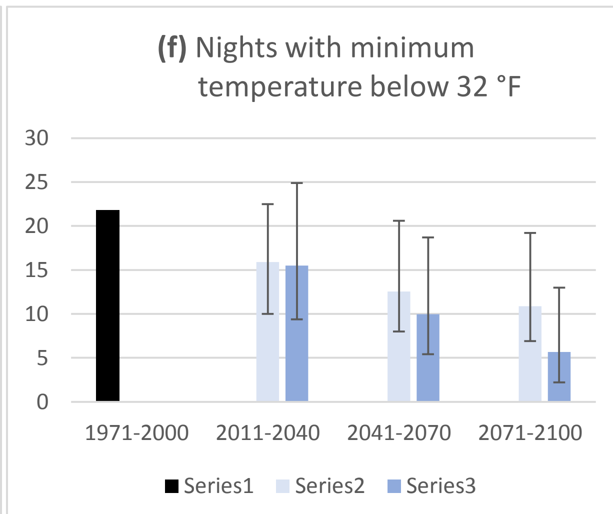

D. Precipitation Projections

High-resolution climate projections taken from the LOCA downscaled dataset are used in this study for the City of San Antonio based on the methods described previously. The results are summarized below along with bar charts. Analysis with the high-resolution downscaled climate projection shows little change in average annual precipitation throughout the 21st century, consistent with the projected changes over the larger area of central Texas. The uncertainty of precipitation changes is higher given that precipitation from convective storms has significant spatial and temporal variability.

The number of dry days may decrease for both lower and higher pathways while the decrease may be rapid between the near-term and mid-century periods compared to the decrease between the mid-century and end-of-century periods. Maximum consecutive dry days, however, will change a little between the near-term and mid-century periods while rapid change was observed between the mid-century and end-of-century stages for both lower and higher pathways. These results indicate that there will be high variability in the time periods with consecutive dry and wet days, especially during the end-of-century period.

A slight increase in **average** rainfall extremes is projected from the analysis with insignificant differences in changes under both lower and higher pathways. This does not preclude the possibility of higher dry and wet extremes in the future as observation already indicates. The preliminary analysis compared two different indicators of extreme precipitation:

- Number of days with more than 2 inches of rainfall, which is expected to increase from once in 2 years during the near-term stage to 4 times in 5 years by the end-of-century stage.
- Maximum 5-day rainfall (otherwise known as the wettest 5 days of the year), which is projected to be 4.5 inches during the near-term period for both scenarios, is expected to increase 0.5 inches for the lower pathway and 0.65 inches for the higher pathway by the end of century.

The following figures represent projected climate changes for the City of San Antonio for five precipitation indicators: (2a) cumulative annual precipitation (in inches); (2b) number of days per year with less than 0.01 inches of precipitation in 24 hours; (2c) length of the longest period of time with less than 0.01 inches of precipitation per day; (2d) number of days per year with more than 2 inches of precipitation in 24 hours; and (2e) cumulative amount of precipitation falling during the 5 consecutive wettest days of the year (in inches). See Table 2 on p. 10 for exact figures for all projections.

Projections were generated using the 21 models and pathways described in the Methods section, and annual values were averaged over three 30-year time periods: near-term, mid-century, and end-of-century.

Light-colored bars correspond to average conditions projected under the RCP 4.5 lower pathway, while dark-colored bars correspond to average conditions projected under the higher RCP 8.5 pathway.

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 climate models.

Figure 2: Precipitation projections for the City of San Antonio

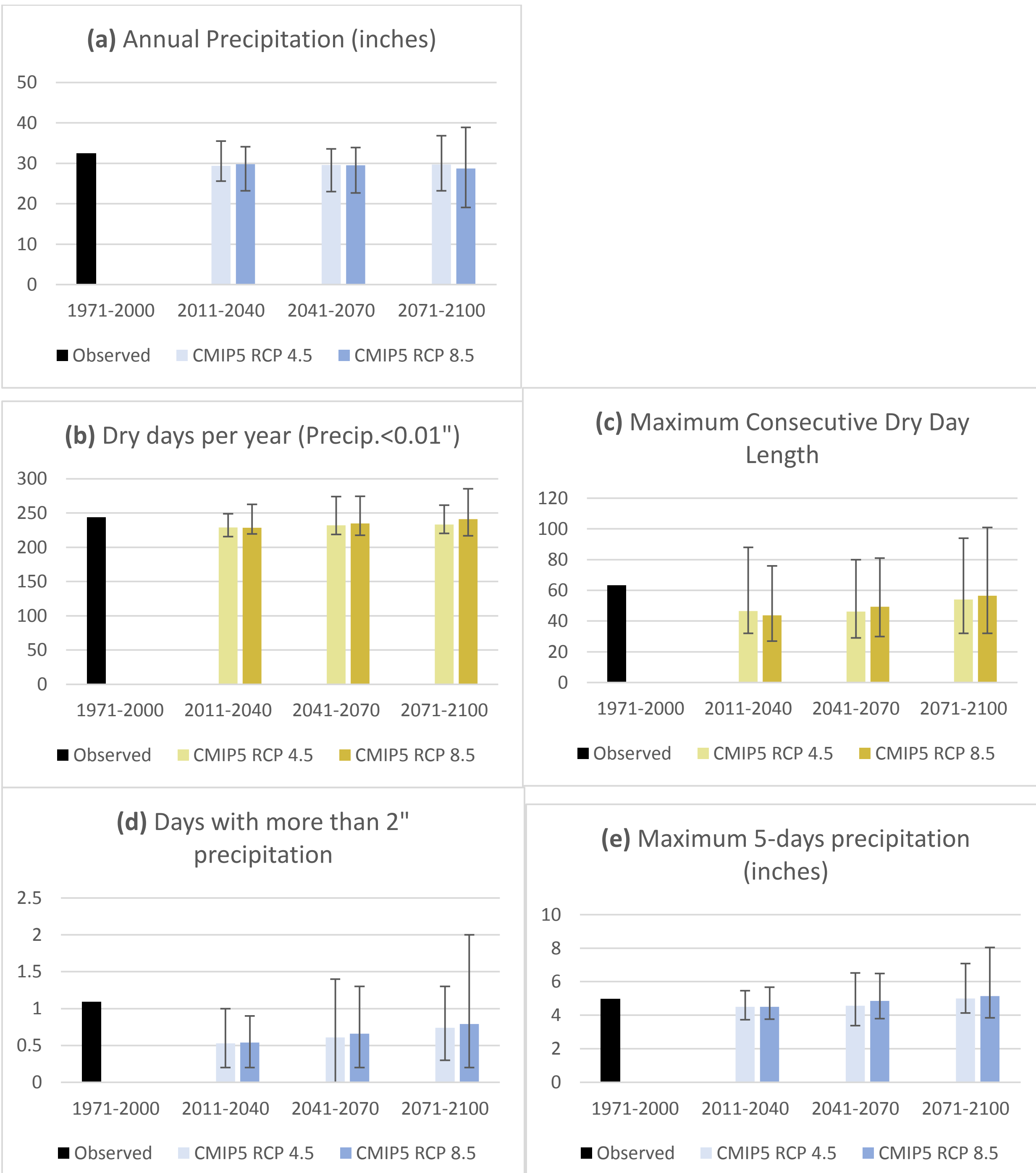

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Table 1: Temperature projections for the City of San Antonio

Temperature	Base-Line (1971-2000) Observed	Near-Term (2011-2040) Lower pathway	Near-Term (2011-2040) Higher pathway	Mid-Century (2041-2070) Lower pathway	Mid-Century (2041-2070) Higher pathway	End-of-Century (2071-2100) Lower pathway	End-of-Century (2071-2100) Higher pathway
Summer maximum temperature	101.1 °F	105.3 °F	105.5 °F	107.2 °F	108.5 °F	107.8 °F	111.8 °F
Average summer daytime maximum temperature	94.7 °F	97.3 °F	97.3 °F	98.9 °F	100.1 °F	99.5 °F	103.1 °F
Cold nights (min. temp.<32 °F)	21.8 days	15.9 days	15.5 days	12.6 days	10.0 days	10.9 days	5.7 days
Warm nights (min. temp.>80 °F)	0.03 days	2.1 nights	2.2 nights	6.5 nights	15.9 nights	10.1 nights	55.6 nights
Hot days (max. temp. >100 °F)	7 days	30.7 days	31.0 days	46.6 days	61.4 days	55.1 days	101.4 days
Very hot days (max. temp.>110 °F)	0 days	0.06 days	0.12 days	0.39 days	1.08 days	0.64 days	8.22 days

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Table 2: Precipitation projections for the City of San Antonio

Precipitation	Base-Line (1971-2000) Observed	Near-Term (2011-2040) Lower pathway	Near-Term (2011-2040) Higher pathway	Mid-Century (2041-2070) Lower pathway	Mid-Century (2041-2070) Higher pathway	End-of-Century (2071-2100) Lower pathway	End-of-Century (2071-2100) Higher pathway
Annual precip.	32.5 inch	29.4 inch	29.8 inch	29.6 inch	29.5 inch	29.7 inch	28.7 inch
Dry days (precip.<0.01" in 24 hours)	243.3 days	228.9 days	228.4 days	232.1 days	234.8 days	233.2 days	241.1 days
Longest dry period	63.4 days	46.6 days	43.7 days	46.2 days	49.3 days	54.1 days	56.6 days
Wet days (precip.>2" in 24 hours)	1.09 days	0.53 days	0.54 days	0.61 days	0.66 days	0.74 days	0.79 days
Wettest 5 days	4.96 inch	4.5 inch	4.5 inch	4.57 inch	4.86 inch	4.99 inch	5.14 inch

E. Extreme Precipitation Projections

The depth-duration frequency (DDF) of rainfall maxima in Texas were estimated using certain statistical tools (L-moments) and the Generalized Logistic (GLO) for 15min – 12hr durations and Generalized Extreme Value (GEV) for higher durations (daily) using approaches described in Asquith (1998) and later mapped in Asquith and Roussel (2004). The DDFs are used to compute design storm values for planning purposes such as estimating carrying capacities of the storm drainage systems and the extent of flooding associated with different storms. Estimating rainfall depths associated with design storms for future planning horizons is also important for San Antonio since design storms values are already changing in Texas (new values will be released this fall) and are projected to change further in terms of both intensity and frequency following climate trends.

The projected maximum rainfall depths associated with 24-hour duration design storms with return periods of 10, 100, and 500 years were estimated for three 30-year time frames for two climate scenarios (Table 3, Figure 3). These are based on the maximum values obtained from the precipitation projections. The return period for a storm refers to its probability of occurrence. For example, a "10-year storm," or a 1-in-10-year storm, is a storm that has a 10% probability of its rainfall amount being equaled or exceeded in any given year, and a "500-year storm"

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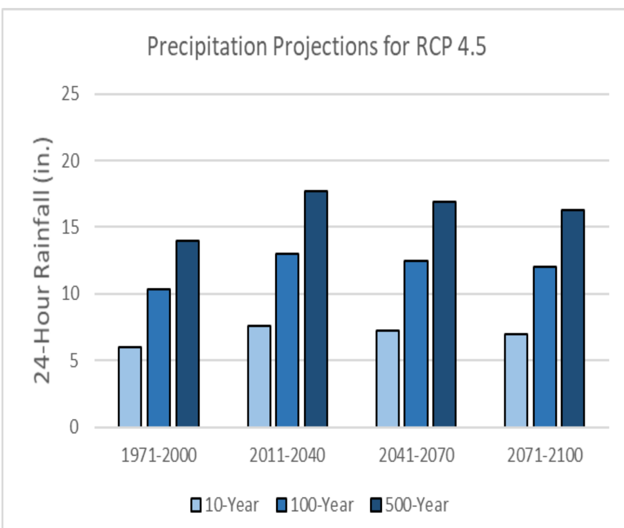
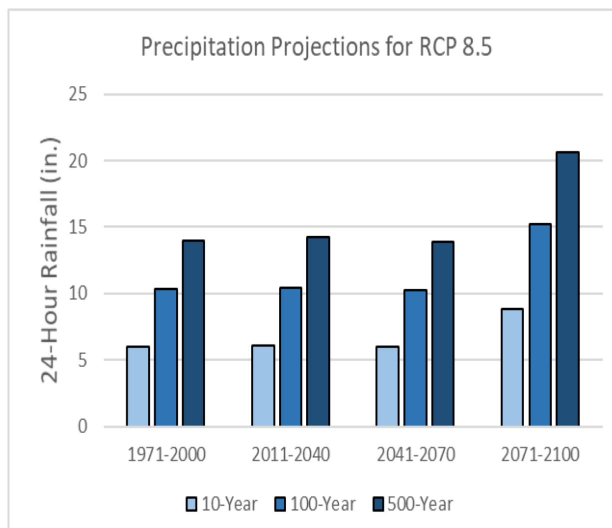
is one that has a 0.2% annual probability of occurrence. It can be observed from the results in Table 1 that for the 24-hour duration storms the most extreme storms might change more than the more frequent storms.

Table 3: Precipitation projections for 24-hr design storms

24-hr Design Storms	1971-2000	2011-2040		2041-2070		2071-2100	
	Baseline	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
10 yr	6.0	7.6	6.1	7.2	5.9	7.0	8.8
100 yr	10.3	13.0	10.4	12.4	10.2	12.0	15.2
500 yr	14.0	17.7	14.2	16.9	13.9	16.3	20.6

Figure 3: Precipitation projections for 24-hr design storms





F. Summary and Conclusion

Global climate change is affecting San Antonio's climate, and the results of an initial assessment have been summarized in this short document. This analysis describes projected changes for two future climate scenarios for the time periods 2011-2040, 2041-2070, and 2071-2100 based on averages for each period, respectively. Future summers are projected to become hotter, and the higher pathway provides comparatively higher projections than the lower pathway. The number of days where temperatures exceed 100 °F and 110 °F will increase under both scenarios. Nights with temperatures below freezing will become less frequent, and nights with temperatures greater than 80 °F will become more common. Temperature variations among the time periods are greater for the higher pathway than for the lower pathway. Annual average precipitation and number of dry days per year are expected to change slightly over the considered time period. However, dry and wet conditions will likely become more extreme. The number of consecutive dry days will likely increase slightly over time. Intense precipitation is described based on the following parameters: number of days per year with more than 2 inches of rainfall and cumulative rainfall during the 5 consecutive wettest days of the year. Heavy precipitation is expected to increase with time. The difference between projections for precipitation under higher and lower pathways is small.

Climate is changing across the U.S. and the world, and the change in the climate of Texas is consistent with the observed larger-scale trends. Climate is expected to continue to change in the future with human emissions of carbon dioxide and other heat trapping gases instigating the change. The observations from the high-resolution downscaled projections for San Antonio include:

- Increased annual and seasonal temperatures
- More frequent high-temperature extremes
- Fewer cold nights
- Slight changes in annual average precipitation
- Increases in the number of consecutive dry days per year
- Increases in extreme precipitation conditions
- More extreme drought conditions in the summer

There is great certainty in projected increases in extreme annual and seasonal temperatures and increased frequency of high-temperature extremes. These trends are already being experienced throughout the U.S. and all over the world and are expected to continue over the century. Projected changes for these aspects are greater for the higher pathway as compared to the lower pathway, and during end-of-century period as compared to mid-century period. There is moderate certainty in projected increases in extreme precipitation events. The projections for precipitation extremes are consistent with the observed trends across the U.S.

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II. Climate Projections Methodology

A. Introduction

Average temperatures are already increasing worldwide, and Texas and San Antonio are not exceptions. The warming trend is predicted to continue through the year 2100 and beyond. Precipitation trends generally appear to be increasing in the South Texas region, and the strength of the correlation between hydrologic variables (precipitation and runoff/flooding) and climatic indices (ENSO and PDO) varies by season and basin (Joseph et al., 2013).

Projections of future temperature and precipitation from global climate models can vary significantly by location, season, and type of precipitation. The spatial resolution of these projections is too coarse to offer usable information at the city level. More detailed analysis of downscaled climate model projections is needed to obtain a good idea about projected temperature and precipitation trends for San Antonio through the 21st century. The term "projection" is used because the predictions made are linked to assumed descriptions of the future and the pathways leading to it. Our methodology will try to reduce the uncertainty associated with these projections by using two plausible greenhouse gas concentration pathways, weighted output from 21 climate models, global mean temperature thresholds, and three downscaling approaches. Historical observations will be compared to future projections.

B. Methodology

Outputs from 21 global climate models (GCMs) of the Coupled Model Inter-Comparison Project 5 (CMIP5, Taylor et al., 2012) for the historical climate data (1951-2000) and future projections under Representative Concentration Pathways (RCP) 4.5 and RCP 8.5 will be used. RCP 4.5 represents a pathway where global greenhouse gas emissions peak and then decline by the end of the 21st century while RCP 8.5 represents a pathway where continued dependence on fossil fuels will lead to higher greenhouse gas concentrations throughout the century (Moss et al., 2010).

We will also analyze the projected changes not just by time period but also by global mean temperature thresholds (e.g., every 0.5 ^{0} C change) by extracting the 20-year period centered around the points in time at which these temperature changes are reached, which will help the policymakers and the public understand the impacts for any given temperature threshold reached.

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The climate models' output will be downscaled from the native resolution of the GCMS to a scale suitable for San Antonio using the LOcalized Constructed Analogs (LOCA) method (Pierce et al., 2014). The downscaled data will include daily outputs for the historical (1971-2000) period (validation) and near-term (2011-2040), mid-century (2041-2070), and end of century (2071- 2100) periods. The projections will be weighted and averaged at the local scale to represent the middle decade of each period. The resulting projections will be analyzed not only by time period but also by global temperature thresholds.

C. Key Outputs

The downscaled daily climate data will be processed to produce projected changes of important climate variables such as:

- Daily, seasonal, and annual maximum temperature
- Minimum night temperature
- Number of days above or below certain temperature thresholds such as 100 ºF and 32 ºF.
- Annual and seasonal precipitation
- Design storms (e.g. 100-year storm)
- N-day maximum precipitation
- Statistics of dry spells

These outputs will be utilized in the adaptation and preparation plan for various purposes including flood potential and impacts on critical services and infrastructure.

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