CLIMATE IN THE HEARTLAND

HISTORICAL DATA AND FUTURE PROJECTIONS FOR THE HEARTLAND REGIONAL NETWORK

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Climate in the Heartland: Historical Data and Future Projections for the Heartland Regional Network

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Table of Contents

1 Introduction

In recent decades, cities in the Great Plains have confronted an increasing frequency of extreme and damaging weather events. Historical climate patterns are changing, with hotter temperatures, exceptional floods and droughts, and erratic weather events. These factors affect city governments' ability to maintain normal daily operations and meet citizens' needs.

Weather has always affected municipal government operations. Heavy rainfall and floods, for example, have impacts that ripple across departments. Police and fire departments experience an increase in call volume, accompanied by decreased access throughout the city and more hazardous working conditions. Public infrastructure is at risk of damage, and water treatment facilities must deal with poorer water quality. Solid waste operations must process greater quantities of debris, and services such as public transportation can be disrupted. Other hazardous weather events, such as tornadoes, wind, hail, drought, heat waves, and winter storms come with their own range of impacts.

Over the past century, governments evolved to their environmental contexts, establishing policies, procedures, organizational structures, and budget allocations adaptive to their particular climate conditions. In recent years, as weather anomalies have become more frequent, governments have had to work harder and smarter to fulfill their routine obligations while responding to an increasing number of weather disasters. A recent spate of 100- and even 500-year floods in Great Plains cities has left governments scrambling to protect public safety in the short term and rebuild and repair infrastructure and facilities in the long term.

Yet, despite the effects already felt by many communities, some of the expected impacts of climate change have not yet emerged. Therefore, there is a need to evaluate historical and recent climate data and future climate change projections so that cities have sufficient opportunity to prepare for a changing climate in their strategic and operational planning.

While some work has been done to examine projected climate change impacts regionally, existing information is insufficient for municipal planning purposes for two reasons. First, the information is not specific enough. Most data are regional – applicable, for example, to the Midwest or the southern Great Plains. While there are commonalities across regions, climate change will vary among localities, and cities need data specific to their communities. Second, the existing data is generally conveyed in terms of metrics that are intended for meteorologists rather than local governments. There is a need for metrics that will help government departments plan for issues such as infrastructure or staffing needs. The present report begins to fill this gap.

The goal of this report is to assist participating cities as they prepare for climate change impacts, adapting their operations to better serve citizens in a changing environment. Historical climate data and future climate projections are provided to each city to inform municipal staff and elected officials of weather conditions that are anticipated to exceed historical bounds. Climate data are expressed in terms that are applicable to municipal leadership and management.

1.1 Participating Cities

Participating cities are all members of the Heartland Regional Network of the Urban Sustainability Directors Network (USDN) and include:

- Iowa City, IA
- Columbia, MO
- Lincoln, NE
- Lawrence, KS
- Oklahoma City, OK

1.2 Partnerships

This project was a partnership between municipal sustainability directors, state climatologists, and other experts in climate science, with work contracted to consultants for data analysis and report preparation. Participants in the project include the following people.

Sustainability Directors

- Brenda Nations, Iowa City, IA
- Barbara Buffaloe, Columbia, MO
- Milo Mumgaard, Lincoln, NE
- Eileen Horn, Lawrence, KS
- T.O. Bowman, Oklahoma City, OK

State Climatologists and Climate Scientists

- Gary McManus, State Climatologist, Oklahoma Climatological Survey
- Margret Boone, Program Manager, Oklahoma Climatological Survey
- Patrick E. Guinan, Missouri State Climatologist, University of Missouri
- Mary Knapp, Service Climatologist, Kansas State University
- Martha D. Shulski, Director, High Plains Climate Center, University of Nebraska
- Eugene S. Takle, Director, ISU Climate Science Program, Iowa State University

Consultants

- Chris Anderson, Assistant Director, ISU Climate Science Program, Iowa State University
- Jennifer Gooden, Environmental and Sustainability Consultant

1.3 Funding

This project was made possible by the Urban Sustainability Directors Network (USDN), which provided funding for a Regional Network Collaboration Project. USDN funding paid for a 1.5-day collaboration workshop in Iowa City, IA, in November 2014, during which state climatologists, climate scientists, and local government sustainability directors met to determine which data were useful to governments needed and available from climate scientists. The funding also covered personnel costs for the principal investigator for 1.5 months and a sustainability consultant for 1.25 weeks.

2 Methods

2.1 Introduction to Methods

This project was designed to supplement existing climate change data for the Heartland Regional Network area. Resources such as the National Climate Assessment (NCA) (Walsh and Wuebbles 2014) provide information about future impacts expected across regions of the United States. The NCA and other projects utilize global climate models (GCMs), which employ advanced computer modeling techniques provided with scenarios of global human greenhouse gas emissions (Nakićenović et al. 2000) to project future atmospheric conditions based on known factors and a variety of variables. While useful for discerning trends over broad areas, GCMs do not provide sufficiently localized data for municipal planning. For example, in the NCA, projections are regionalized to the northern Great Plains and southern Great Plains, with little data available at a finer grain. In addition, global-scale scenarios are developed from societal variables to which the GCMs respond. Scenarios are generally based on those adopted by the Intergovernmental Panel on Climate Change (Nakićenović et al. 2000), a program of the World Meteorological Organization and the United Nations Environment Program. These allow models to be adjusted based on different scenarios for factors such as future international policy collaboration and carbon emissions. Results from each model are applicable when the scenario is applicable.

The present project utilized GCMs but applied two additional techniques to make the data more usable for local governments. First, the project used not just one but nine GCMs, averaging results together. This means that the data are an average of different models and different scenarios, allowing climate scientists to identify signals that are strongest across a range of circumstances. The process used here is based on work done by Hayhoe (2014), which utilizes methods that are transparent and publicly accessible. Second, the present project uses a technique known as downscaling, which allows climate projections to be obtained from GCMs at a finer-grained, local scale (Stoner et al. 2013). More information about the modeling process used in this report is included in the Discussion.

2.2 Climate Metrics

Because the production of localized data for government planning is a new activity, output metrics were selected before extracting data from climate models output archives. These metrics were decided upon at a 1.5-day meeting of local government sustainability directors, university climate scientists, and state climatologists in November 2014. At this meeting, government directors described what types of data would be useful for planning purposes, and climate scientists described what was feasible with available data. It was determined that the following factors would be reported.

Climate Metrics Reported

Climate Condition	Climate Metric	Municipal Concern
Annual and Seasonal Temperature	Average, maximum, and minimum temperatures	General climate conditions
Annual and Seasonal Precipitation	Average rainfall	General climate conditions
Last Spring Frost and First Fall Frost	Dates when minimum temperature is less than 32°F	Parks and recreation; employees working outdoors; insect vectors
Heat Waves	Average, maximum, and minimum temperatures over a the hottest 3-day time period each year	Energy demand; public health
Cold Waves	Minimum temperature over the coldest 3-day time period each year	Energy demand; public health
Heavy Rainfall	Days with rainfall >1.25" Days with rainfall >4.00" Amount of rainfall in wettest 5-day period Amount of rainfall in wettest 15-day period	Stormwater management; floodplain planning; emergency response; infrastructure design
Snowstorms	Days with snowfall >3.0" Days with snowfall >6.0" Days with snowfall >12.0" Amount of snowfall in heaviest 3-day period	Snow and ice management; public safety; electricity and phone service outages
Thaw/Freeze Cycles	Days with temperatures >45°F followed by days <28°F	Street repair; parks and recreation; urban forest management

Climate metrics are further defined in Appendix B: Climate Metrics and Definition of Terms.

Some of the climate metrics for this report are not part of the standard data products provided by state climatologists or regional climate centers. To fill the void, university climate scientists developed analysis procedures in R code (open source statistical analysis software) and applied procedures to station data provided by state climatologists. The R code may be integrated into existing analyses by state climatologists and regional climate centers. State climatologists were welcomed to perform the analysis with their own software as well. The outcomes of the analysis procedure were data plots and data tables that were shared with the state climatologists who used the outputs as guidance in preparing historical climate variability narratives.

With climate metrics, special attention was given to whether future projected climate metrics fall outside the historical range. This determination was made by calculating the 10th percentile and 90th percentile values of the historical record. The future projection was determined to be outside the normal historical range if its value fell below the 10th percentile or above the 90th percentile. Throughout this report, projections such as these are described as outside the normal historical range or above the most extreme years (i.e., hottest, coldest, wettest, driest, etc.) of the historical record.

2.3 Historical Summaries

In each participating state, the state climatologist and/or his or her affiliates participated in this project by providing a narrative description of historical climate data for both the city's official weather station and the climate division in which the city is located. For each city, the official weather station is shown on a map and identified by latitude and longitude.

In this report, any disparities between station and climate division data are noted in the historical climate variability summaries.

Some damaging weather events were excluded from this analysis, if, for example, the historical data were unreliably collected (e.g., tornado, wind, and hail), historical data were collected over a very short period of time (e.g., radar estimates of hourly rainfall), or climate change projection data are not yet possible for these damaging weather events (e.g., tornado). Tornado projections are particularly difficult to determine because human-caused climate change may not affect all factors that cause a tornado. For instance, among other factors, a storm's intensity is affected by humidity and wind shear, which is the change in wind direction and speed with height of the storm that is often present when a tornado forms. Humidity is expected to increase, which will elevate thunderstorms' intensity, but it is not known if wind shear in thunderstorms will be affected.

Station Data

A representative weather station was selected for each municipality by the state climatologist. The quality of the station reports depends on the length of the station data series, with longer series capturing more variability; the extent to which the station has remained in one place and its immediate surroundings have remained unchanged; and regular maintenance of the weather station. State climatologists are responsible for climate data collection and data quality control and have a complete record of the station location and maintenance history, making them the best resource for determining the quality of station weather data. [See Discussion for more information about considerations in dataset selection.]

Climate Division Data

Because weather stations represent a single location, station data sometimes include isolated and rare damaging weather events not experienced widely in the area. Examining the context beyond the immediate city prevents interpretation of isolated events as broader changes in climate conditions. The best scale for looking at area context is the city's climate division, as this unit ensures that local anomalies are not overgeneralized yet avoids inclusion of climate variability across larger regions. Climate divisions were first established in the 1940s by the United States Weather Bureau and were aligned either by crop district or drainage basin. The data are aggregated over many weather stations within a climate division. Climate division data have been used by the National Climatic Data Center to assess large-scale climate change with respect to a long period of record. Climate division data are used for all cities in this report except Columbia, as addressed in that section.

2.4 Climate Projection Summaries

Climate change projection summaries were produced by climate scientists at Iowa State University utilizing data from the Coupled Model Intercomparison Project 3 (CMIP3), an internationally organized standard experimental protocol for studying the global climate's response to anthropogenic greenhouse gas increases. The CMIP3 was the basis for the Intergovernmental Panel on Climate Change Assessment Review 4, released in 2007. Our data products utilize nine global climate models (CCSM3, CGCM3, CNRM, ECHAM5, ECHO, GFDL2.1, HadCM3, HadGEM, and PCM), producing simulations of climate response to multiple specified future greenhouse gas emissions scenarios. Three scenarios were used for this study, reflecting different levels of international cooperation on emissions reduction resulting in scenarios with emissions rates that have moderate reductions (Scenario A1B), little to no reductions (A2), and increases (A1FI). The projections, therefore, detect signals that are robust across various circumstances.

In order to provide downscaled projections, the CMIP3 output was downscaled to stations with long-term weather reports using the Asynchronous Regional Regression Model as described in Stoner et al. (2013). This approach was recently used as the basis for a downscaled climate model data for the City of Austin, TX, on which the present study was partially based. The primary methodological difference is that Hayhoe (2014) used CMIP5 CGM data, which were the basis for the Intergovernmental Panel on Climate Change Assessment Review 5, released in 2013. The downscaled data from CMIP5 were constructed specifically for the Austin report and were not available in the Midwest. However, the CMIP3 data have not been determined to be of lower quality than CMIP5.[1]

Output data were summarized over two future 30-year periods, 2021-2050 and 2051-2080. Tabular summaries were distributed to state climatologists for review. Note that many of the figures showing climate change projections include data for three time periods: 1981-2010, 2021-2050, and 2051-2080. Data for 1981-2010 are actual recorded values, while data for 2021-2050 and 2051-2080 are the output of climate model projections. The broader data ranges for 1981-2010 values, compared to the others, are an artifact of the different data sources.

[1] The upper bound emissions scenarios used in this report (CMIP3 A1FI) and Austin's report (CMIP5 RCP8.5) are very similar. The main difference between the reports is the lower bound of the emissions scenario in the Austin report (CMIP5 RCP4.5) is much lower than this report's lower bound (CMIP3 A1B). The CMIP5 RCP4.5 scenario is an aggressive carbon reduction scenario that assumes stabilization of emissions by 2050 and reduction thereafter, requiring substantial international cooperation that does not yet exist. The CMIP3 A1B scenario assumes less international collaboration, with emissions stabilization near 2100.

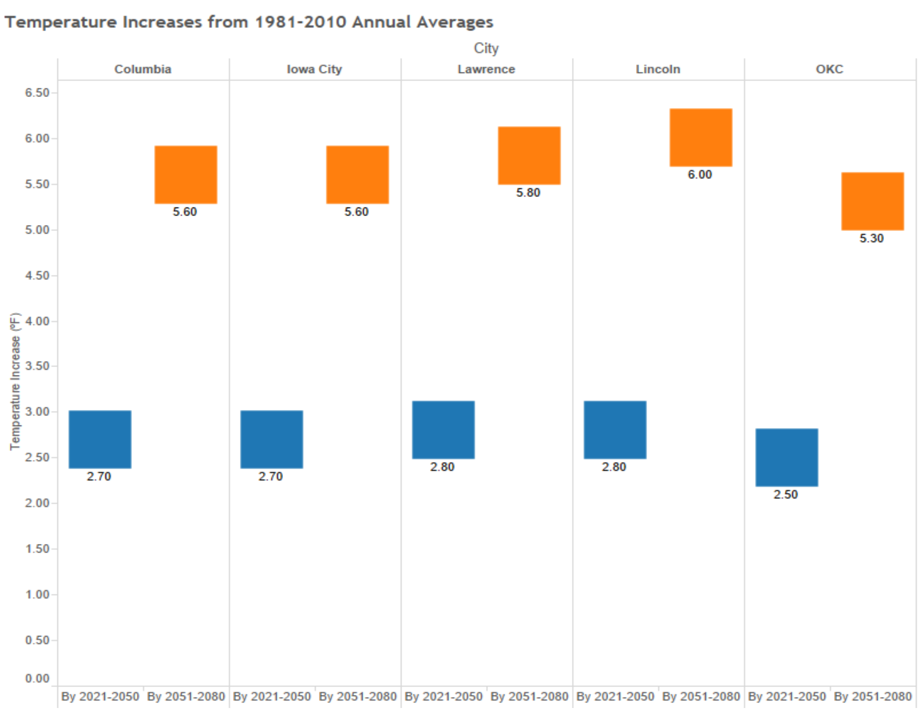
3 Results

Results common to the region are presented first, followed by results specific to each municipality.

3.1 Regional similarities

Similarities among the municipalities point to planning concerns that may benefit from broad alliances in the region. Historical and projected changes common throughout the region are discussed below.

- *Annual temperature* is projected to increase substantially for each municipality. For every city in the study, the 30-year average annual temperature in 2051-2080 is projected to exceed all but the hottest years from 1981-2010, and some cities will exceed this threshold by 2021-2050. This means that the average temperature in most future years will be higher than extremes that have recently occurred on average only once per decade.
- *Spring temperature* has increased in recent years in all municipalities. It is projected to increase further, in many cases at a rate in excess of recent change, and in many municipalities it will exceed all but the hottest spring temperatures on the historical record.
- *Summer temperature* has increased in many municipalities, with Columbia and Lawrence being the exceptions. In all municipalities it is projected to increase and exceed the top 10% of hottest summer temperatures on record.
- *Date of last frost in spring* has already shifted earlier in all municipalities except Lincoln. In all municipalities, the future projection data show an earlier date for the typical last frost in spring.
- *Date of first frost in fall* has shifted later in all municipalities, with the exception of Columbia and Lincoln. In all municipalities, future projection data show later date for first frost in fall.
- *Hottest 3-day maximum temperature* and *hottest 3-day minimum temperature* are projected to increase substantially for each municipality, indicating more extreme heat waves. However, cities' experiences in recent years show little commonality.
- *Spring precipitation* has increased recently in all municipalities except Oklahoma City. In the future, it is projected to increase in all municipalities except Oklahoma City.
- *Excessive daily rainfall* is projected to increase substantially in Iowa City, Columbia, and Lawrence, but recent historical increase is evident only in Iowa City and Columbia.

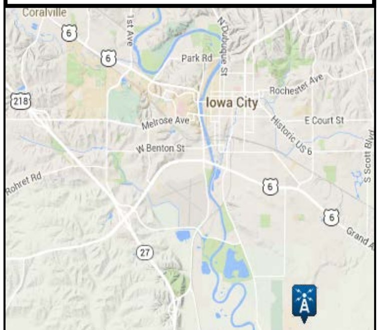


3.2 Results for each city

The following sections describe the results of the present research for each of the participating municipalities.

4 Iowa City, Iowa

Figure IA1



Iowa City station location indicated by radio tower symbol. Global Historical Climate Network ID USC00134101 (41.6093°N, -91.5051°W); Source

Nearly every metric computed for Iowa City shows substantial change in both recent weather and future projections. Annual temperature has already increased, and the rate of increase is projected to be even faster in the future. Beyond the next decade, average annual temperature is expected to exceed the hottest years the normal historical temperature range. Recent increases are also apparent in spring and summer rainfall, excessive daily rainfall frequency, growing season length, and temperature of heat waves, cold waves, and summertime nights. Climate projections indicate a continuation of the recent increasing trend of these damaging weather events.

4.1 Historical Climate Variability

Iowa City is in a humid continental climate zone, described as temperate with extremes of heat, cold, and precipitation.

The Iowa City climate station, located southeast of the city, has a period of record from 1893 to present. Since 1893, Iowa City annual temperature has averaged 61.9°F as a high and 51.2°F as a low. Annual rainfall is 37.64" and snowfall 28.0". Monthly temperature reaches its peak in July with average high temperature of 87°F. The annual low occurs in January with average minimum of 17°F. Rainfall is heaviest in June with an average of 5.08", and the least precipitation occurs in February with an average of 1.20".

Extreme daily conditions are inherent in the Iowa City climate record. The highest and lowest recorded temperatures range over 140°F, from a record minimum of -32°F to 108°F. The historical maximum daily rainfall and snowfall are 6.91" and 14.0".

4.2 Recent Weather Changes

In recent years, Iowa City has experienced seasonal changes in weather. These changes are summarized in the following table.

Recent Changes in Seasonal Weather

Season	Recent Changes in Seasonal Weather
Summer	Fewer cool summers and more frequent hot summers due to higher minimum temperature More frequent warm nights
Fall	More frequent warm falls Average date of first frost is one week later
Winter	No changes are apparent
Spring	Fewer cool and dry springs Average date of last frost is one week earlier

In addition, the last decade has seen changes in the frequency of hazardous weather events. These changes are summarized in the following table.

Recent Changes in Damaging Events

Damaging Event	Recent Changes in Damaging Events
Heat Waves	Higher average temperature and average minimum temperature in hottest 3-day period
Cold waves	Higher average minimum temperature is coldest 3-day period
Heavy rainfall	More years with unusually high number of days with rainfall >1.25" (8 days or more) Higher frequency of unusually high rainfall over wettest 5-day period (>5.5") Higher frequency of unusually high rainfall over wettest 15-day period (>8.7")
Snow Storms	No clear changes in frequency or snowfall accumulation during snow storms
Thaw/Freeze	3-4 per year, no clear change in frequency
Late/Early Freeze	Likelihood of unusually late spring or early fall freeze has not changed
Tornado, Wind, and Hail	Inconsistencies in reporting are more pronounced than long-term changes in frequency

4.3 Historical Context

To identify recent changes in weather, data from the past three decades were compared to the previous historical record. Here, the past three decades are generally defined as 1981-2010, though more recent data are incorporated into the analysis when available.

Changes in average temperature are already apparent in Iowa City. Temperature increases are most pronounced during summer, when the average temperature for 1981-2010 was 2.2ºF higher than the 1893-1980 average. Hot summers have occurred with higher frequency in the most recent 30-year period, during which Iowa City has experienced seven of the 12 hottest summers dating to 1893. Summer temperature increase is primarily due to an increase in minimum rather than maximum summer temperature. Eight of the 10 warmest summer average minimum temperatures have occurred since 1981. In fact, the summer average minimum temperature in 1981-2010 would rank above 80% of the years during 1893-1980.

Fall and spring average temperature were 1.5ºF and 3.8ºF higher during 1981-2010 than 1893-1980. However, year-to-year variability of temperature for these transition seasons is large, much larger than summer, so the transition season temperature change is not as pronounced.

Temperature changes can be expressed in terms of heating degree days and cooling degree days. Heating and cooling degree days serve as a proxy for energy use and are used to estimate and predict energy demand. One heating degree day is accumulated for every degree that the mean temperature is below 65°F; one cooling degree day is accumulated for every degree that the mean temperature is above 65°F. Heating degree days have decreased substantially due to recent increase in fall temperature. Cooling degree days have increased substantially due to recent increase in summer temperature.

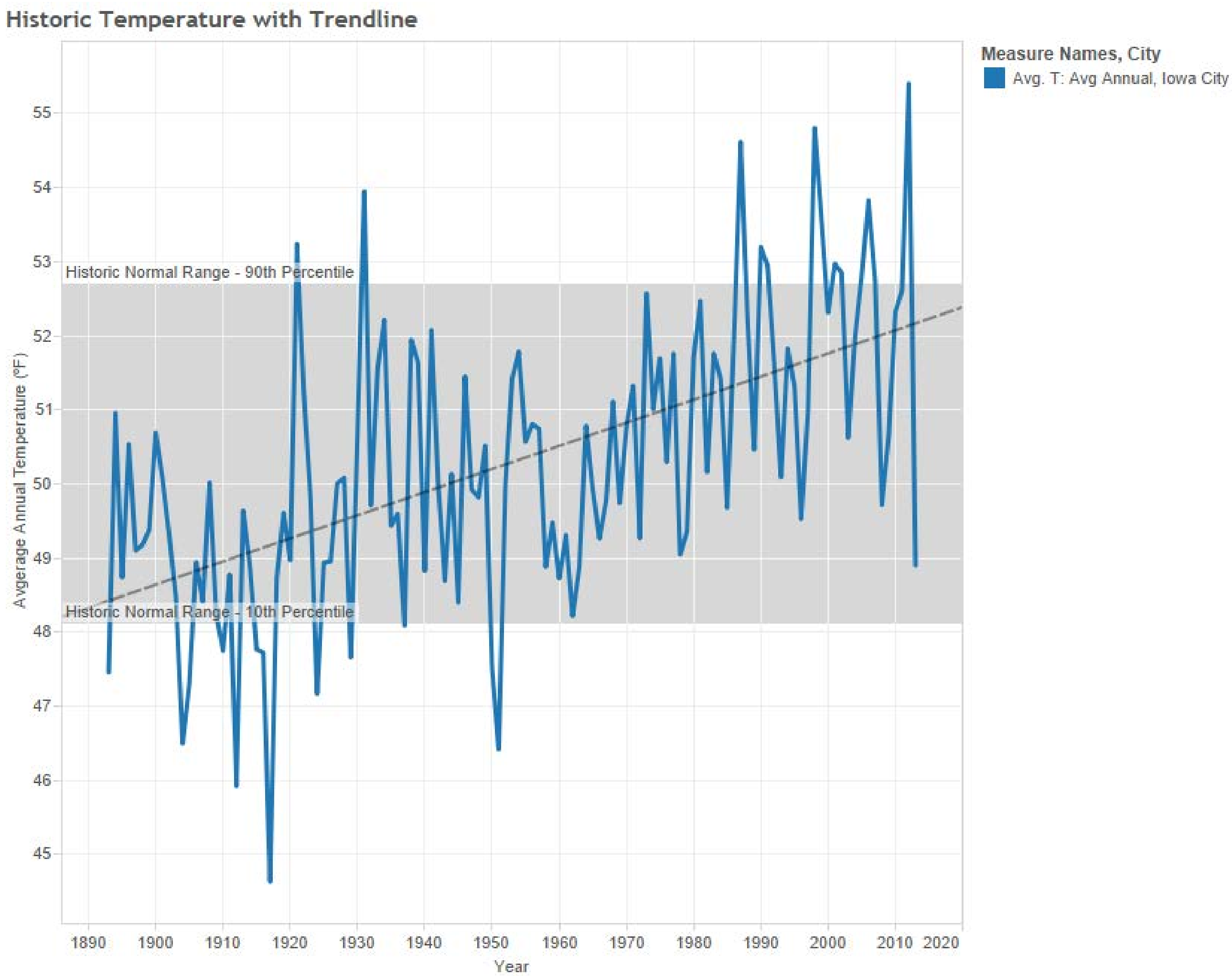


Figure IA2. Recorded annual average temperature with trendline.

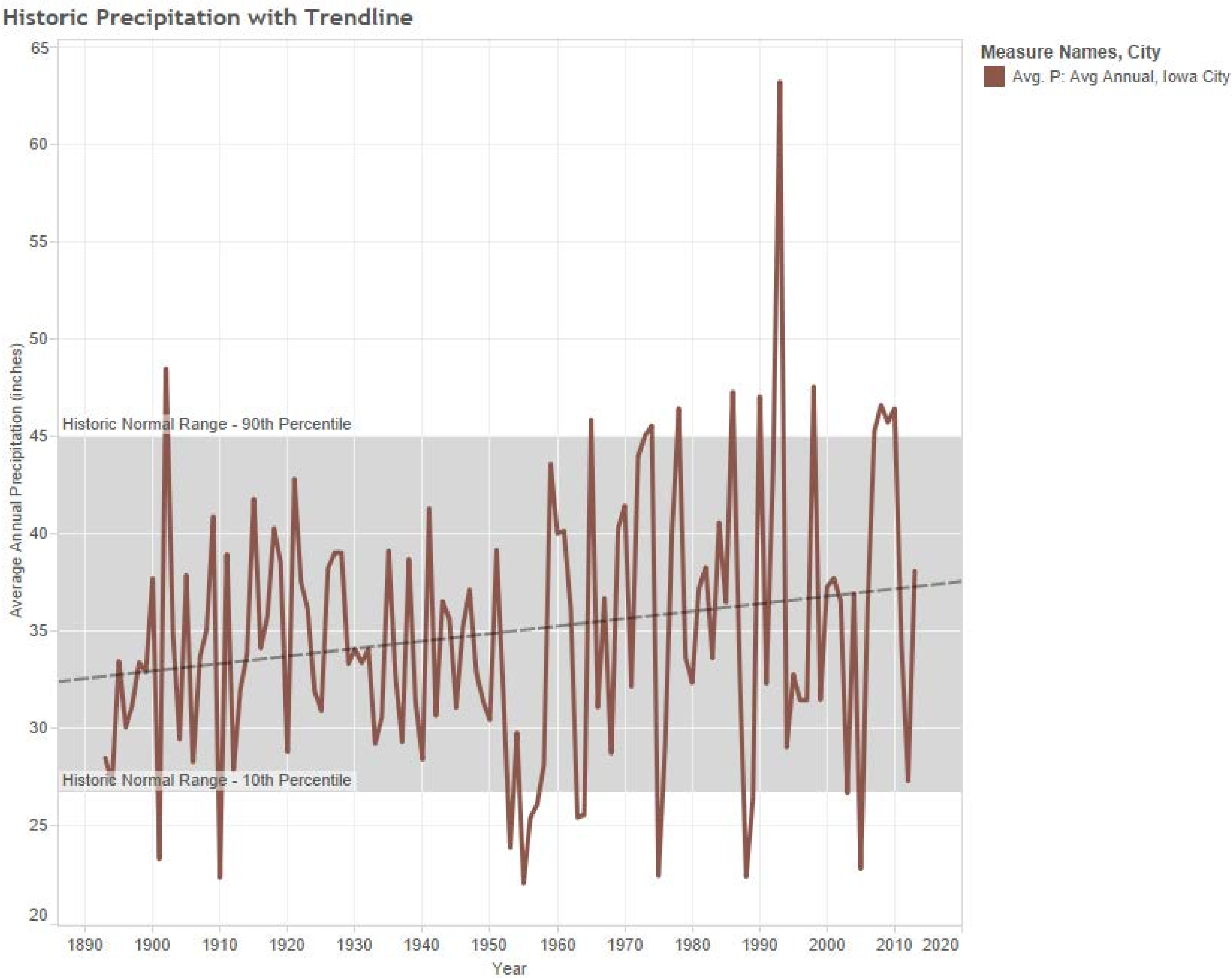


Figure IA3. Recorded annual average precipitation with trendline.

Spring and fall freeze dates have also changed during the last three decades. The last day in spring with low temperature less than 32ºF is now one week earlier, and, in fall, the first day with low temperature less than 32ºF is one week later. However, the spring freeze date in recent years has occurred much later in the spring than the average date. This is a clear reminder that the volatility of daily spring temperature is larger than the volatility of spring season temperature and large enough that any single year can be substantially different from the average of recent years.

4.4 Area Context

Iowa City is located in the East Central Iowa Climate Division (CD6). Comparing historical weather data from Iowa City with the surrounding area provides a better understanding of context. Slight differences in seasonal temperature and precipitation in Iowa City, compared to the East Central Iowa Climate Division, suggest some data might reflect local variability of weather. For the climate division, spring, summer, and fall temperature have increased substantially since 1995. Unlike Iowa City, spring and fall temperature increase is more pronounced than summer.

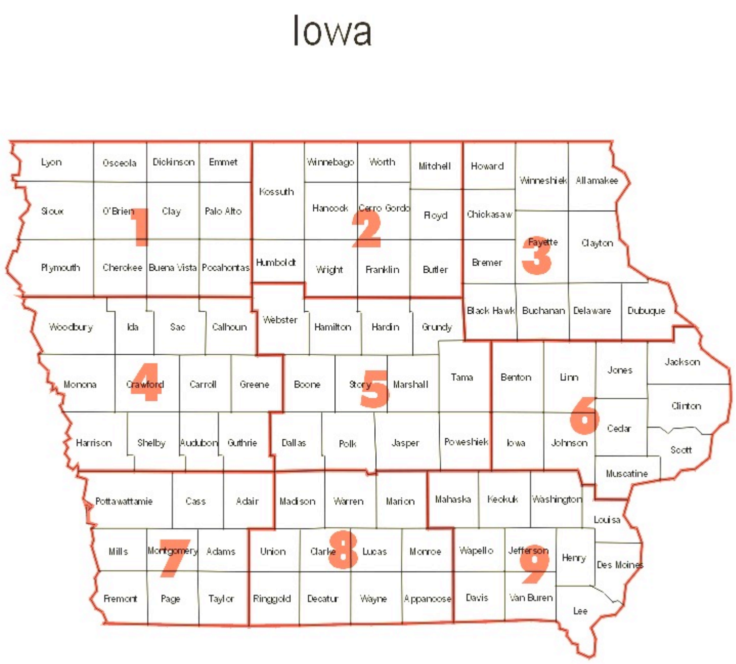


Figure IA4. Climate divisions: Source.

Seasonal rainfall change for the East Central Climate Division is also more pronounced than in Iowa City. For the climate division, spring rainfall has increased and fall rainfall has decreased since the early 1990s. While similar multi-decade stretches of dry fall conditions have occurred during 1892-1980, the recent stretch of wet springs in the last 20 years is unique. At the same time, summer rainfall has become more volatile with multi-year peaks and valleys exceeding its historical range.

4.5 Recent Change in Weather Hazards

The frequency of heavy rainfall events has increased over daily, multi-day, and seasonal scales, with multi-day rainfall being the best predictor of high stream flow. The number of days with rainfall greater than 1.25" has increased, with seven of the 12 wettest years occurring in the last three decades. The annual maximum of 5-day and 15-day rainfall had unusually high values in the recent 30-year period. The frequency of wetter than average spring seasons has also increased.

Weather hazards threaten Iowa City's infrastructure and the safety and well-being of its population, and these hazards have become more numerous since 1981. Iowa City's risk profile has expanded rather than narrowed due to both an increased frequency of some hazardous weather conditions and an increased range of weather conditions. Recent changes that have expanded the risk profile include:

- Increase in summer temperature, particularly the frequency of warm nights
- Hotter nights, higher average temperature, and higher heat index during heat waves
- Increase in frequency of number of days with excessive rainfall, excessively wet annual maximum 5-day and 15-day rainfall, and excessively wet springs and summers

Other weather threats have been less frequent in recent years but are projected to emerge going forward. Recent data series are too short to discern a permanent change in these weather threats, but with 10 to 20 years of monitoring, it may be possible to conclude exposure to the following threats has changed:

- Late spring freeze

- Early fall freeze
- Cold waves
- Extreme cold waves

The urban heat island effect may account for some of the difference in temperature change between Iowa City and the East Iowa Climate District. Additional study is needed to determine with certainty the impact of the urban heat island effect on changes in summer minimum temperature and the average and minimum temperature during heat waves.

4.6 Climate Projections

Iowa City's climate is projected to change significantly beyond the next decade. The annual temperature is projected to increase so much that the 30-year average temperature in the future will well above the hottest years of the normal historical temperature range. Annual precipitation will increase 10% by 2021-2050 and another 5% by 2051-2080, but, unlike temperature, 30-year average precipitation does not exceed the normal historical range, which is inherently large.

Temperature

Temperature is projected to increase substantially by the 2050s. By then, on a regular basis annual temperature will far exceed normal range of the recent climate. The greatest temperature increase is projected to occur in spring and winter, with moderate increases in summer.

While summer temperature is projected to increase less than spring and winter, year-to-year historical variability of temperature has been smaller in summer than spring and winter. This means the projected summer increase will cause the summer temperature to exceed the threshold temperature of the hottest years of normal range of the recent climate, while the spring and winter temperature remain below this threshold. From this perspective, the projected summer temperature increase is smaller but more extreme than projected spring and winter temperature increase.

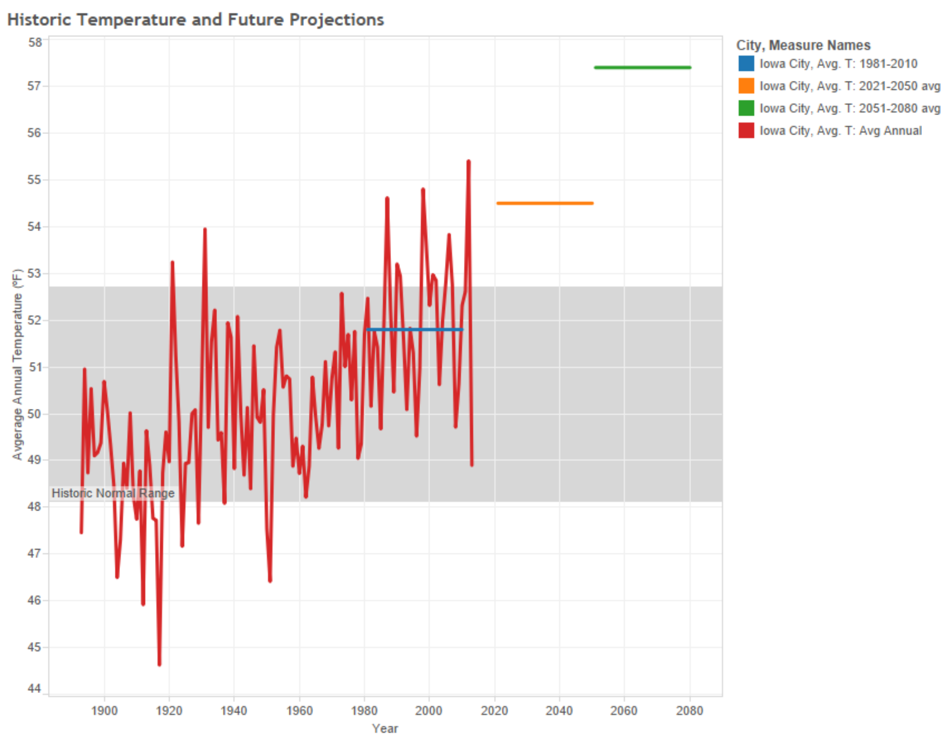


Figure IA5 illustrates the difference in annual temperature in the past and future. The line shows recorded temperatures from the historic record, and the 1981-2010 average is calculated from recorded temperatures. The 2021-2050 and 2051-2080 averages are calculated from climate models.

Precipitation

Precipitation is projected to increase substantially by the 2050s and beyond, which is consistent with recent change. By 2020-2051, the projected annual precipitation will be 11% higher than annual precipitation in 1981-2010, which was itself 7% higher than the 1893-2013 annual precipitation. The increase in precipitation will be largest in spring and fall, while the projected increase in summer precipitation levels off between 2021-2050 and 2051-2080.

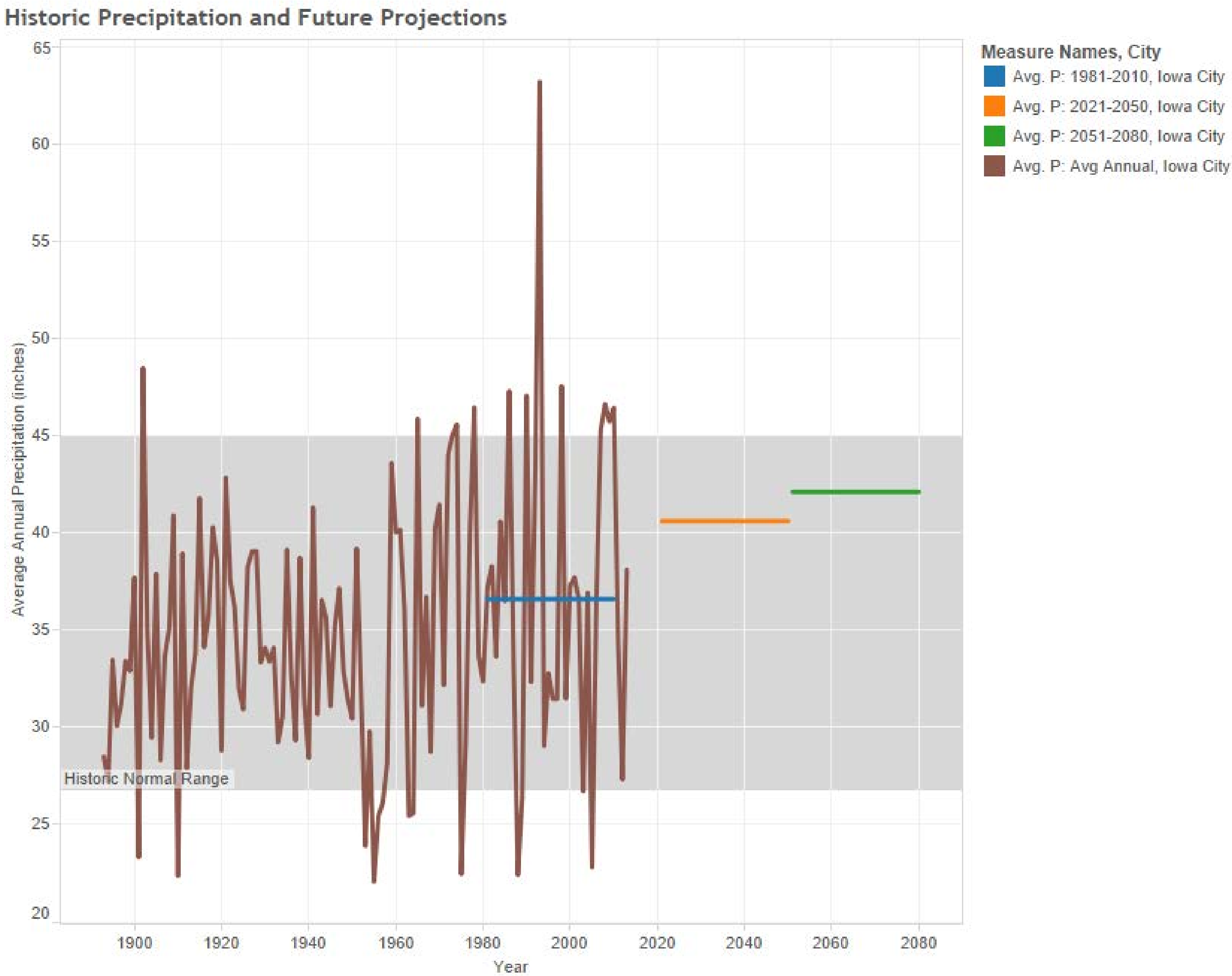


Figure IA6 illustrates the difference in annual precipitation in the past and future. The line shows recorded precipitation from the historic record, and the 1981-2010 average is calculated from recorded precipitation. The 2021-2050 and 2051-2080 averages are calculated from climate models.

Data

The following tables show projection data for temperature, precipitation, and hazardous events in coming decades, relative to the last 30 years.

Projected Changes in Climate

Season	Metric	1981-2010	2021-2050	2051-2080
Annual	Average	51.8ºF	54.5ºF	57.4ºF
	Maximum	61.9ºF	64.7ºF	67.6ºF
	Minimum	41.8ºF	44.4ºF	47.2ºF
	Precipitation	36.6″	40.6″	42.1″
Summer	Average	72.6ºF	75.3ºF	78.2ºF
	Maximum	85.4ºF	88.1ºF	90.8ºF
	Minimum	64.1ºF	66.9ºF	69.9ºF
	Precipitation	13.8″	14.5″	14.2″
Fall	Average	66.7ºF	68.0ºF	70.0ºF
	Precipitation	8.6″	9.8″	10.6″
	Frost Date	October 19	October 22	October 26
Winter	Average	27.7ºF	30.9ºF	34.1ºF
	Maximum	34.7ºF	38.1ºF	41.5ºF
	Minimum	18.1ºF	21.1ºF	24.1ºF
	Precipitation	4.0″	4.5″	4.7″
Spring	Average	39.7ºF	43.4ºF	46.7ºF
	Precipitation	10.2″	11.7″	12.6″
	Frost Date	April 14	April 6	March 29

Projected Changes in Hazardous Events

Damaging Event	Metric	1981-2010	2021-2050	2051-2080
Heat Waves	3-day average	85.2ºF	88.1ºF	91.5ºF
	3-day maximum	96.5ºF	99.7ºF	103.2ºF
	3-day minimum	74.6ºF	77.3ºF	80.6ºF
Cold Waves	3-day minimum	-7.1ºF	-2.9ºF	1.6ºF
Heavy Rainfall	Days >1.25″	5 days	6 days	7 days
	Days >4.00″	1 day per 10 years	1 day per 4 years	1 day per 3 years
	5-day	4.0″	4.8″	5.1″
	15-day	6.0″	7.0″	7.4″
Thaw/Freeze	Days >45ºF followed by days <28ºF	3.5 times per year	3.7 times per year	3.5 times per year

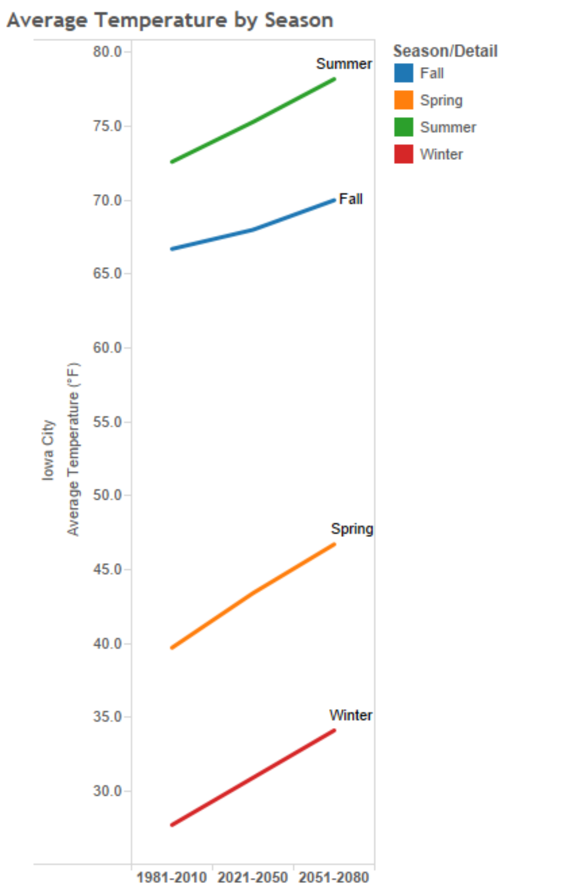


Figure IA7. Recorded and projected average temperature by season

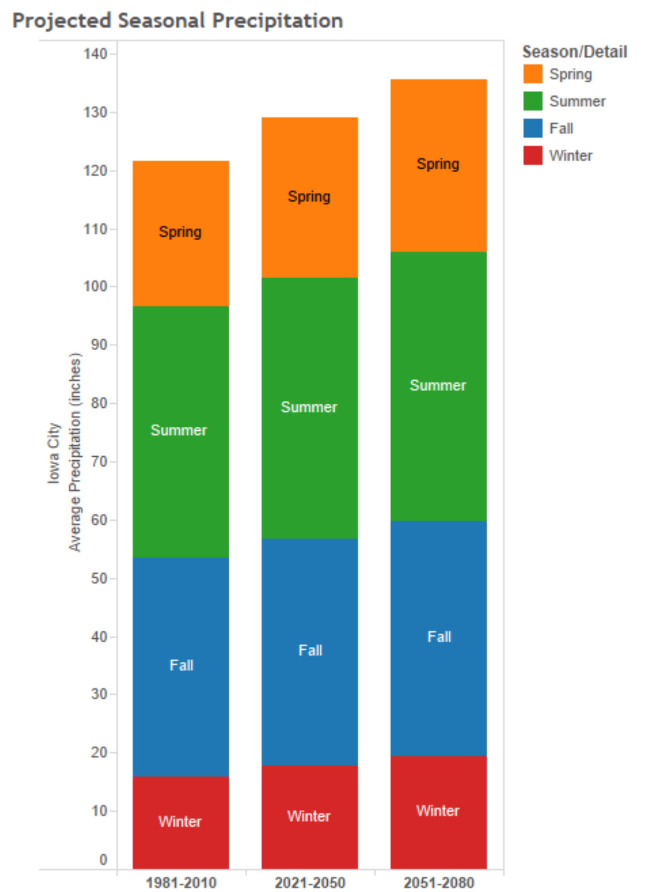


Figure IA8. Recorded and projected average precipitation by season

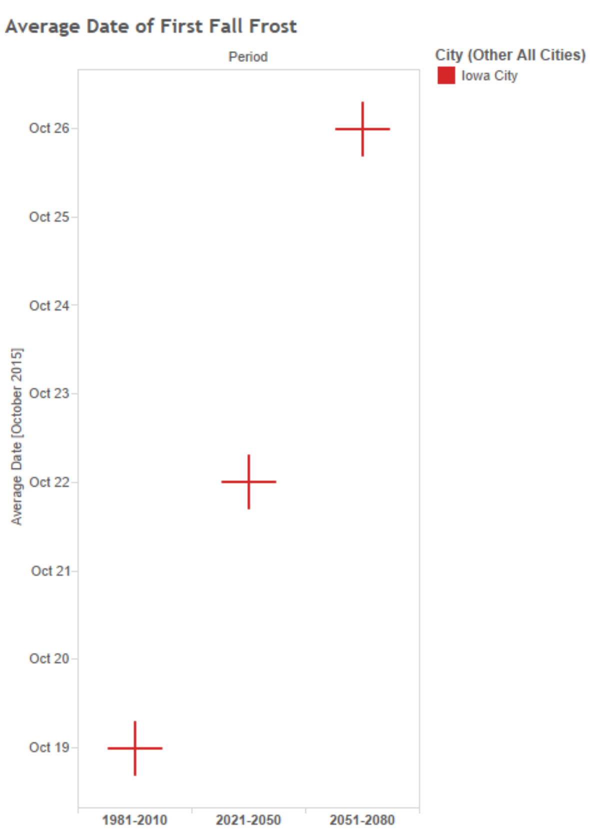


Figure IA9. Recorded and projected first fall frost dates.

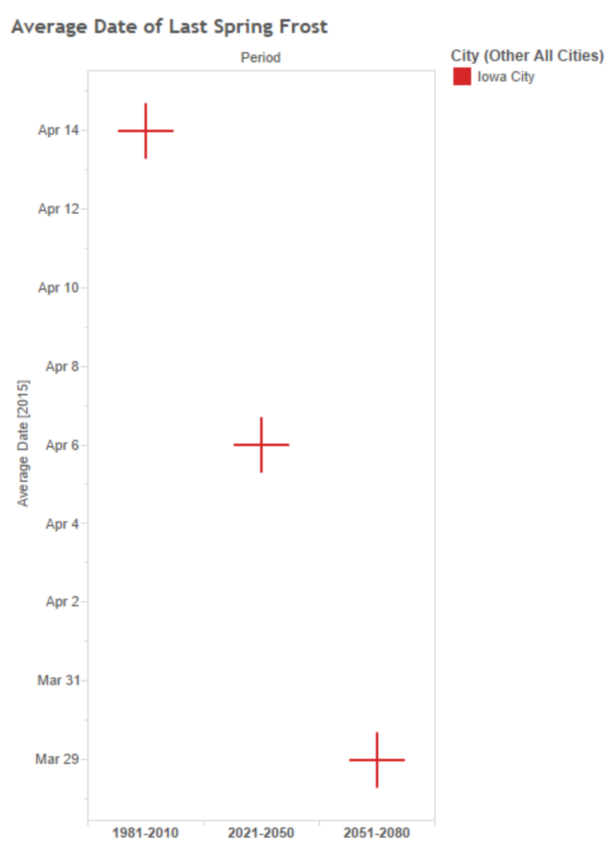


Figure IA10. Recorded and projected first spring frost dates

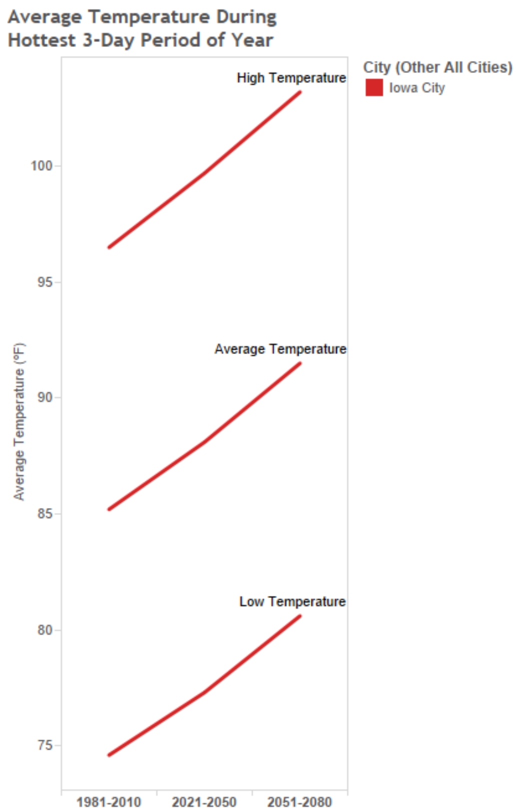


Figure IA11. Recorded and projected temperature during heat waves. Includes high (daytime), average, and low (nighttime) temperatures

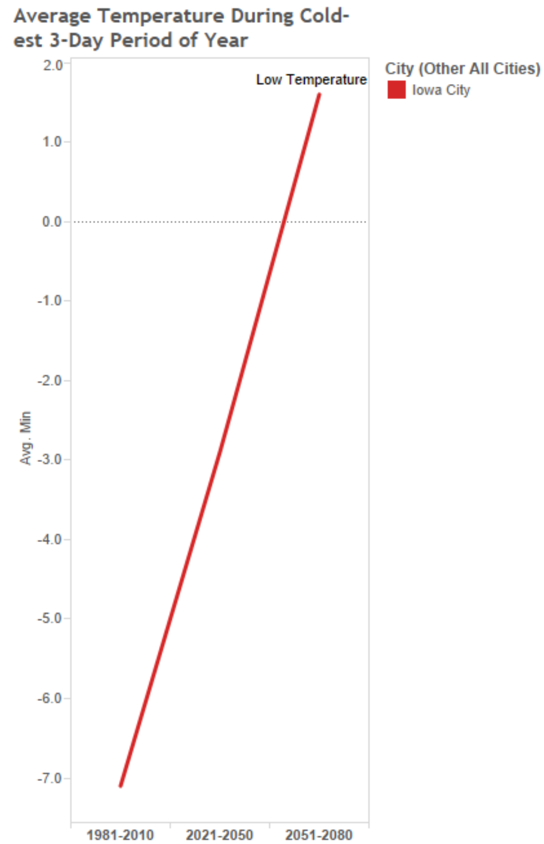


Figure IA12. Recorded and projected temperature during cold waves. Includes only low (nighttime) temperatures.

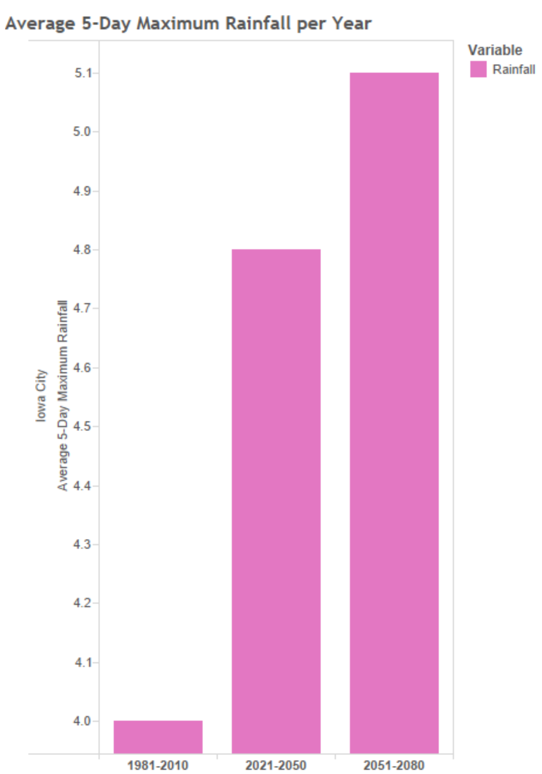


Figure IA13. Recorded and projected 5-day maximum rainfall per year

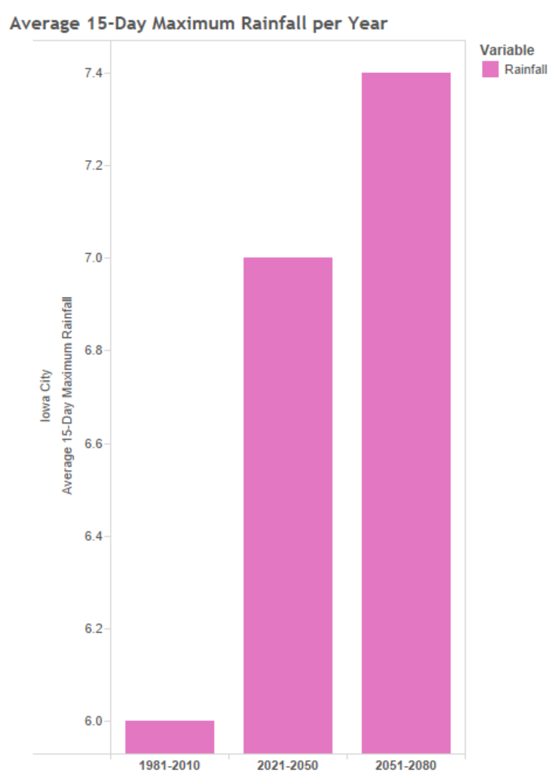


Figure IA14. Recorded and projected 15-day maximum rainfall per year

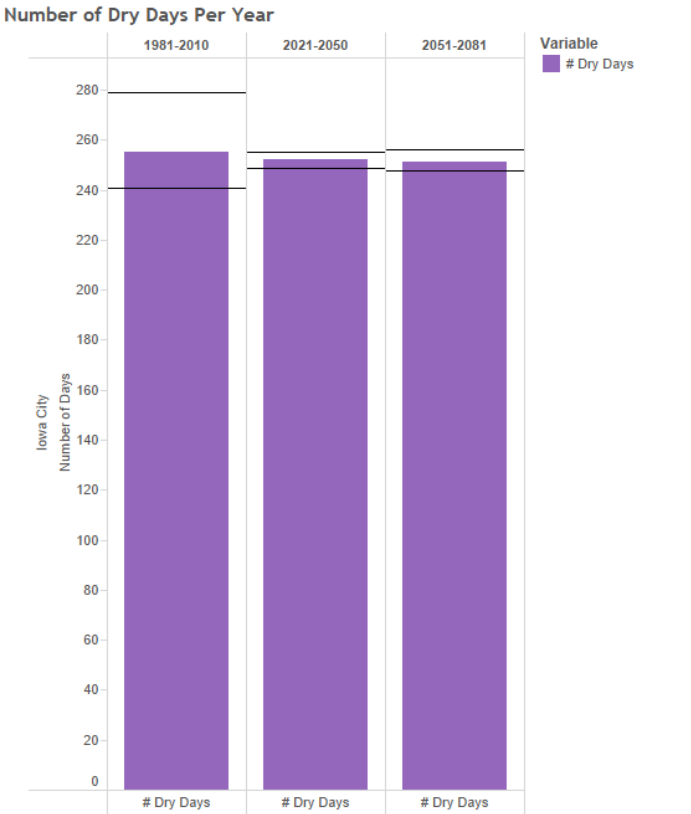


Figure IA15. Recorded and projected number of dry days per year. Horizontal lines indicate 10th and 90th percentile values.

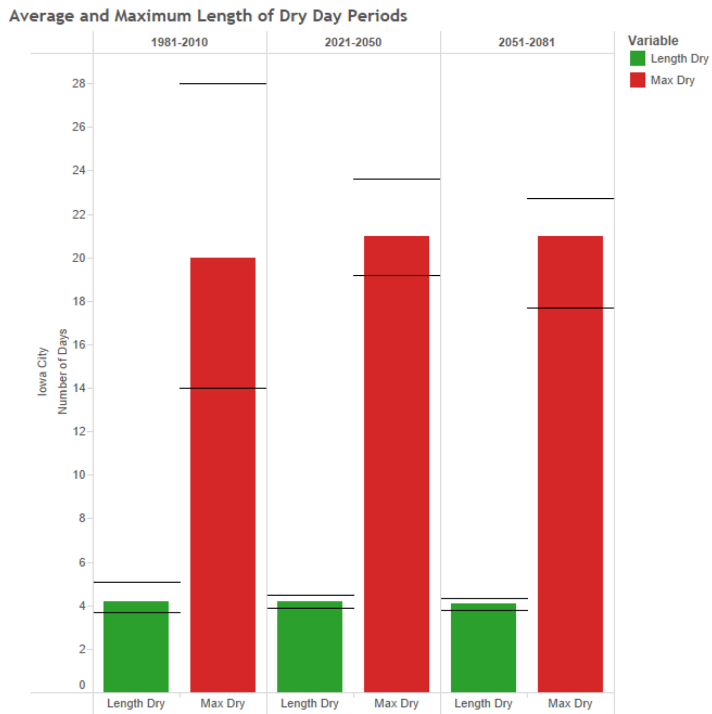


Figure IA16. Recorded and projected average and maximum length of dry periods. Horizontal lines indicate 10th and 90th percentile values.

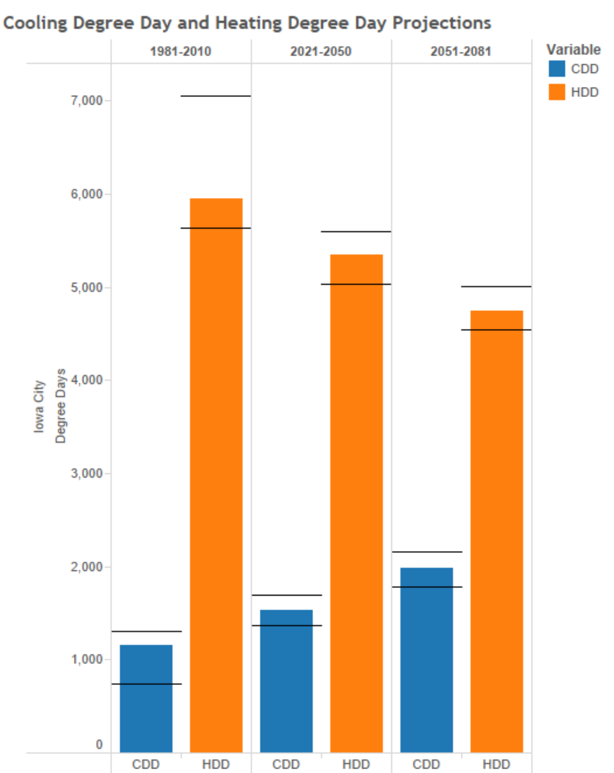


Figure IA17. Recorded and projected cooling degree days and heating degree days. Horizontal lines indicate 10th and 90th percentile values.

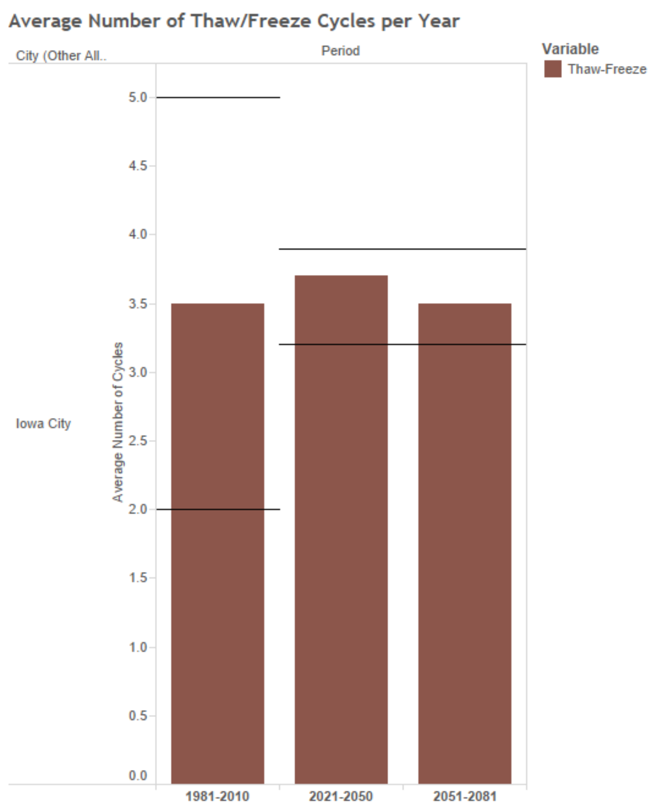


Figure IA18. Recorded and projected thaw/freeze cycles per year. Horizontal lines indicate 10th and 90th percentile values.

The following summary describes all climate change impacts, noting consistency, or lack thereof, with recent changes. See Discussion for information about the relationship between consistency and confidence.

- *Spring temperature* has recently increased by 2.4°F from 37.3°F to 39.7°F. It is projected to increase at a faster rate to 43.4°F in 2021-2050 and 46.7°F in 2051-2080.
- *Summer temperature* has recently increased by 1.4°F from 71.2°F to 72.6°F. It is projected to increase at a faster rate to 75.3°F in in 2021-2050 to 78.2°F in 2051-2080.
- *Winter temperature* has recently increased by 0.9°F from 26.7°F to 27.6°F. It is projected to increase at a faster rate to 30.9°F in 2021-2050 to 34.1°F in 2051-2080.
- *Fall temperature* has recently increased by 1.2°F from 65.5°F to 66.7°F. It is projected to increase at about the same rate to 68.0°F in 2021-2050 to 70.0°F in 2051-2080.
- *Date of last frost in spring* is projected to be earlier in the year by about one week (April 6) in 2021-2050 and a further 1½ weeks in 2051-2080 (March 29). This is the same direction of change in the historical data. The average date of last spring frost has shifted 6 days earlier in the year, from April 20 to April 14.
- *Date of first frost in fall* is projected to be a later by about 3 days in 2021-2050 (October 22) and 3 more days in 2051-2080 (October 26). The recent historical change in first frost in fall is in the same direction, occurring 5 days later (October 19 compared to October 14).
- The *hottest 3-day maximum* is projected to increase substantially. In 2021-2050, the maximum temperature of the hottest 3-day period is expected to increase to 99.7°F, and further increase to 102.2°F is projected in 2051-2080. The historical data show almost no change in maximum of hottest 3-day period.
- The *hottest 3-day minimum* has increased recently by 2.3°F from 72.3°F to 74.6°F. It is projected to increase at a slightly faster rate to 77.3°F in 2021-2050 to 80.6°F in 2051-2080.
- *Spring precipitation* is projected to increase substantially. This is in the same direction as recent change, which has increased from 9.8" to 10.2". The projected rate of change is greater than recent change, and it results in an increase from 10.2" to 11.7" in 2021-2050 and to 12.6" in 2051-2080.
- *Summer precipitation* is projected to increase modestly before leveling off. This is in the same direction as recent change, which has increased from 12.3" to 13.8". The projected rate of change is lower than recent change, resulting in an increase from 13.8" to 14.5" in 2021-2050 and then levels off to 14.2" in 2051-2080.

Excessive rainfall is projected to increase. The number of days with rainfall exceeding 1.25" and 4.00" is projected to increase, and the amount of rainfall during annual maximum rainfall during 5-day and 15-day periods is projected to increase. This is consistent with recent change.

5 Columbia, Missouri

Figure MO1

Columbia station location is indicated by radio tower symbol. Global Historical Climate Network ID USW00003945 (38.8169°N, -92.2183°W); [Source.]()

Daily rainfall, spring rainfall, summer dew point, and summer nighttime temperature have changed in Columbia in the past three decades. Looking forward, climate change projections show an emergence of substantial temperature increase. At the projected rate, beyond the next decade, average annual temperature is expected to exceed the hottest years in the normal historical temperature range. Temperature is projected to increase substantially in the summer, particularly during heat waves. Projections of rainfall change correspond with recent changes, with increases in spring precipitation and heavy inundation events.

5.1 Historical Climate Variability

Columbia is in a humid continental climate zone, described as temperate with extremes of heat, cold, and precipitation.

The Columbia climate station, located at the Columbia Regional Airport, has a period of record from 1889 to present. Since 1889, Columbia's annual temperature has averaged 64.8°F as a high and 44.5°F as a low. Annual rainfall has been 42.62" and snowfall is 18.4". Monthly temperature reaches peak value in July with average high temperature of 87.6°F. The annual low occurs in January with average minimum of 20.9°F. Rainfall is heaviest in May with an average of 4.98" and least in January with an average of 1.92".

Extreme daily conditions are inherent in the Columbia climate. The highest and lowest recorded temperatures range over 139°F, from a record minim of -26°F to a record maximum of113°F. The historical maximum daily rainfall and snowfall are 6.61" and 18.0", respectively.

It is important to note that subtle temperature discontinuities exist in the Columbia temperature record, which are attributable to microclimatic changes associated with five relocations of the official Columbia weather instrumentation. These moves impact the validity of assessments for long-term temperature trends specific to Columbia, such as changes in the growing season. As a result, temperature data are shown for Columbia's entire period of record, but temperature assessments are made only for the period during which instrumentation location has not changed, which is 1970 to present at the Columbia Regional Airport.

5.2 Recent Weather Changes

In recent years, Columbia has experienced seasonal changes in weather. These changes are summarized in the following table.

Recent Changes in Seasonal Weather

Season	Recent Changes
Summer	Increases in summer minimum temperatures since 1970, but negligible change in maximum temperature More frequent warm nights
Fall	Slight warming in fall maximum temperature since 1970, but negligible change in minimum temperature Negligible change in median date of first fall frost
Winter	Warming maximum and minimum temperature trends since 1970
Spring	Warming maximum and minimum temperature trends since 1970 Negligible change in median date of the last spring frost

In addition, the last three decades have seen changes in the frequency of hazardous weather events. These changes are summarized in the following table.

Recent Changes in Damaging Events

Damaging Event	Recent Changes
Heat Waves	Higher average minimum temperature during hottest 3-day period
Cold waves	Fewer cold waves since mid-1980s, measured by average minimum temperature during the coldest 3-day temperature
Heavy rainfall	Increasing long-term trend of heavy rain events; 13% increase in events ≥ 1.25" for period 1985-2014 compared to 1890-1984 period, 40% increase in events ≥ 2.00", and 118% for ≥ 3.0" Higher frequency of unusually high rainfall over wettest 5-day period (≥ 9.00") Higher frequency of unusually high rainfall over wettest 15-day period (≥ 9.00")
Snow Storms	No notable long-term trend
Late/Early Freeze	No clear change in frequency
Thaw/Freeze	Likelihood of unusually late spring or early fall freeze has remained unchanged since 1970
Tornado, Wind, and Hail	Inconsistencies in reporting are more pronounced than long-term changes in frequency

5.3 Historical Context

To identify recent changes in weather, data from the past three decades were compared to the previous historical record. Here, the past three decades are generally defined as 1981-2010, though more recent data are incorporated into the analysis when available.

Temperature change since 1970 is notable in Columbia and is most pronounced during winter and spring, with conditions milder than historical averages. Changes in summer and fall temperature trends have been less notable, although there is an observed warming trend average minimum temperature in summer.

The temperature changes since 1970 can be expressed in terms of heating degree days and cooling degree days. Heating degree days have decreased due to mild winters. Cooling degree days have increased slightly since 1970, mostly due to increasing summer minimum temperature.

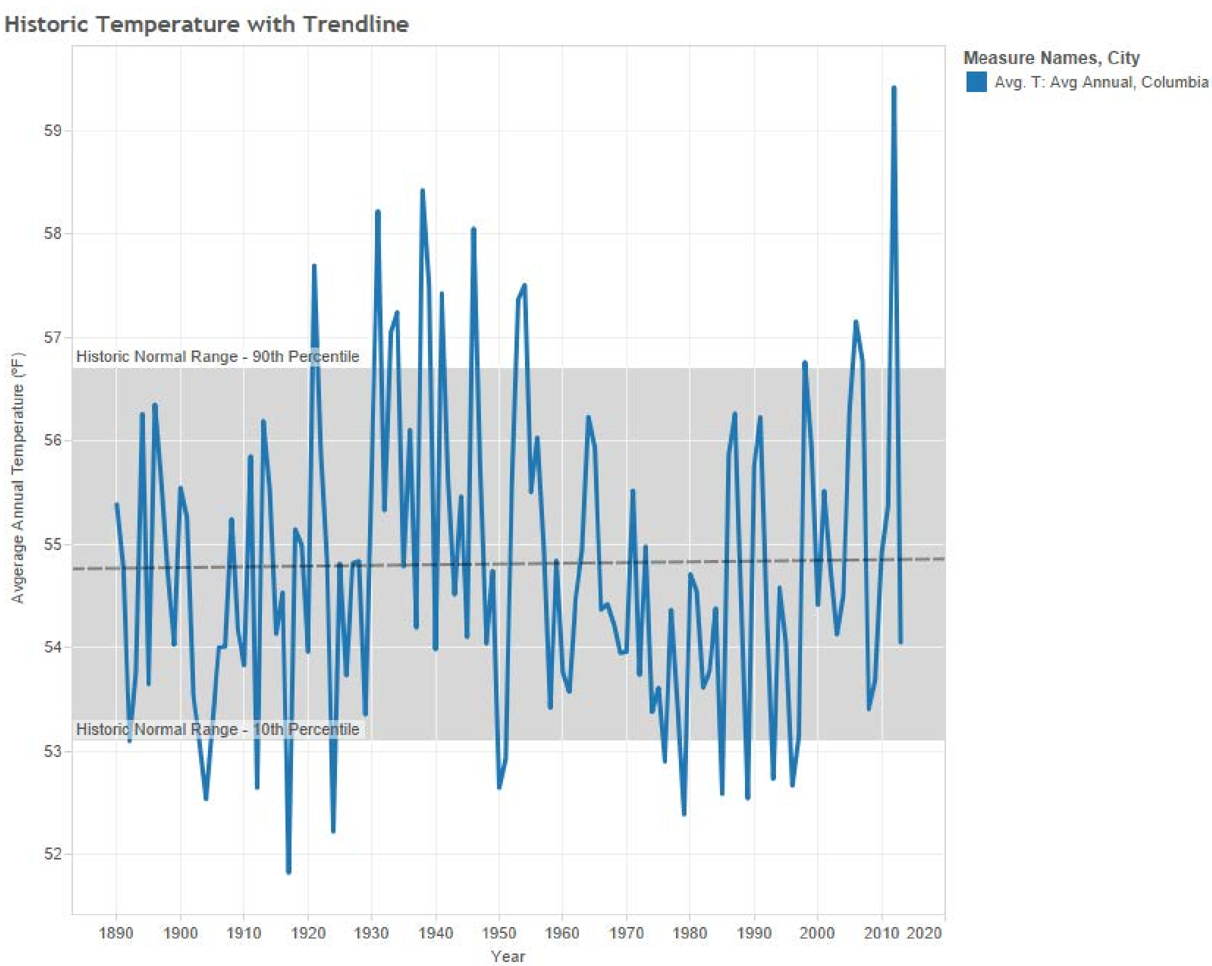


Figure MO2. Recorded annual average temperature with trendline.

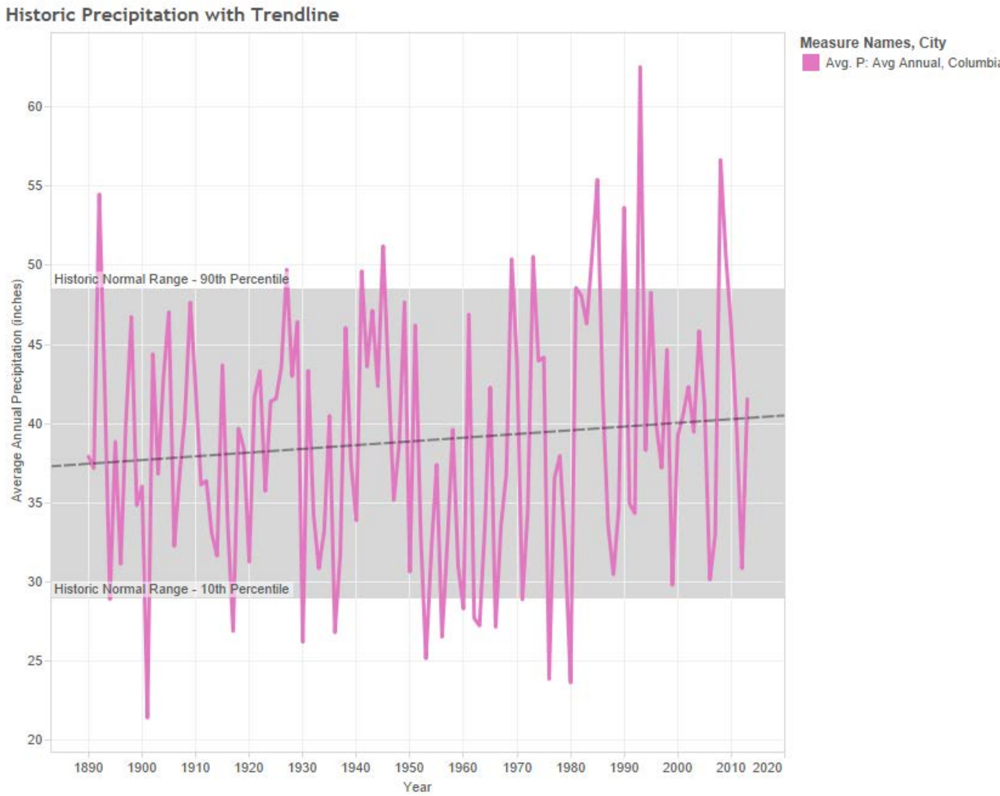


Figure MO3. Recorded annual average precipitation with trendline.

Spring and fall freeze dates have not changed notably for Columbia since 1970. However, when looking at a longer period of record for the region and state, 1895-2010, the last day in spring with temperatures less than 32°F occurred 3-4 days earlier during the 1981-2010 period than the 1895-2010 period. Changes in first fall freeze dates have been negligible in Columbia.

Precipitation trends in Columbia over the past few decades have shown increased rainfall in all four seasons, most notably in winter and spring. Frequencies of intense rain events have also increased for daily and multi-day periods. The 1985-2014 period averaged 13% more days with rainfall ≥1.25" compared to the 1890-1984 period. For the same time periods, there has been a 40% increase in events ≥2.00" and 118% increase for ≥3.00". The frequency of unusually high annual maximum 5-day (≥6.25") and 15-day rainfall (≥9.0") has also increased over the past few decades compared to the long-term trend.

5.4 Area Context

In Columbia, historical weather was compared with the rest of the state, rather than the climate division, to provide an understanding of context. [2] Twenty-eight National Weather Service cooperative weather stations in Missouri have been reporting weather since 1895. A comparison indicates long-term temperature trends in Columbia are similar to regional and statewide trends for Missouri over the past 120 years.

Missouri's recent warming annual temperature trend began in 1998; since 1998, 12 out of the past 17 years (71%) have been above normal. 2012 was the warmest year in the post-1895 record. Seasonally, Missouri winters and springs have experienced the greatest warming trend; 17 out of the past 25 winters (68%) have been above normal, and three out of the five warmest winters on record have occurred since 1991. Thirteen out of the past 17 springs (76%) have been above normal in Missouri.

The median last spring frost date in Missouri has occurred approximately three to four days earlier over the past 30 years than the historical average. The median first fall frost date in Missouri has varied little over the past 30 years compared to the long-term average.

Recent changes in temperature trends during summer and autumn have been weak. Until 2010-2012, Missouri summers had not been unusually hot compared to other hot summers in the past, such as 1901, 1934, 1936, 1954, and 1980.

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[2] According to Patrick Guinan, Missouri State Climatologist, Missouri climate divisions were delineated according to soil and topography and poorly represent climate differences that are typically categorized according to latitude, longitude, temperature, and precipitation. As a result, climate division data are less useful than state data for present purposes.

Columbia's long-term annual and seasonal precipitation trends are also similar to regional and statewide trends. All four seasons have experienced a wetter than usual period over the past few decades. Recent historical trends for Columbia and the state indicate an unprecedented multi-decadal wet period beginning in the early 1980s. For Missouri, 20 of the last 34 years (59%) have had above normal precipitation. In contrast, the historical record shows there have been multi-decadal dry periods in Columbia and statewide, such as the 1950s and 1960s. The most notable recent precipitation trend in Missouri has occurred in winter, with 20 the past 33 winters (61%) recording above normal precipitation.

In recent decades, Columbia and the state of Missouri have witnessed an above normal trend in heavy (≥1.25") and extreme (≥3") daily precipitation events compared to the long-term average. Similarly, trends in multi-day rainfall events (5-day and 10-day) have been above normal at the local and state level.

Of the 28 National Weather Service cooperative weather stations in Missouri that have been reporting daily precipitation for 120 years, 15 have broken all-time 24-hour precipitation records since 1973.

Dew point temperatures have trended above normal in the past few decades for Columbia and the state. Since 1981, 76% of the years have had above normal dew points for spring and summer in Columbia.

The Horticulture and Agroforestry Research Center in New Franklin, MO, has evaporation records from 1956,[3] which show that since the early 1980s, 70% of the years reported below normal evaporation for the April through September period. The five lowest pan evaporation years since 1956 occurred after 2007.

5.5 Recent Change in Weather Hazards

Over the past few decades, some climatological trends have emerged that may pose a risk to Columbia's infrastructure and the safety and well being of its population. These include:

- Increasing frequency of warmer summer nights
- Increasing summer dew point temperatures, which translate to longer and more frequent periods of high heat indices
- Increase in frequency of daily and multi-day heavy rain events
- Increase in number of days with extreme rainfall (≥3.00")

Other weather threats have been less frequent in recent years but are projected to emerge going forward. Recent data series are too short to discern a permanent change in these weather threats, but with 10 to 20 years of monitoring, it may be possible to conclude the exposure to the following threats has changed:

- Drought
- Heat waves
- Late spring freeze
- Early fall freeze
- Cold waves

There is an observed temperature difference between city of Columbia and the Columbia Regional Airport, located 11 miles south-southeast of Columbia. A National Weather Service cooperative weather station is located on the University of Missouri Columbia campus at the Sanborn Field Experiment Station research site, which is in an urbanized area and therefore may be subject to the urban heat island effect. Temperature monitoring at Sanborn Field has been ongoing since May 4, 1994. Over the past 20 years, annual average temperature differences have been notable between Sanborn Field and the Columbia Regional Airport. Annual average maximum, minimum and mean temperature for Sanborn Field and Columbia Regional Airport from 1995 through 2014 are as follows:

	Columbia Regional Airport 1995 - 2014	Sanborn Field, MO 1995 - 2014
Annual maximum temperature (°F)	65.1	65.9
Annual minimum temperature (°F)	44.8	46.3
Annual temperature (°F)	54.9	56.1

This difference suggests that the urban heat island effect may contribute to the increased temperature in Columbia, additional monitoring is needed to determine with certainty the impact of the urban heat island effect on changes in maximum and minimum temperatures throughout the year.

[3] Class A pan evaporation records utilize a 4' diameter pan to measure evaporation.

5.6 Climate Projections

Columbia's climate is projected to alter significantly beyond the next decade. The annual temperature is projected to increase so much that the 30-year average temperature in the future will be well above the hottest years in the normal historical temperature range. Precipitation is projected to increase substantially by the 2050s and beyond, and the projected annual precipitation for 2050-2081 is very close to the 10% wettest years of the current climate.

Temperature

Temperature is projected to increase substantially by the 2050s. By then, on a regular basis it will far exceed the normal range of the recent climate. However, changes in annual temperature are not apparent in the recent record, so the projected increase is more likely to occur beyond the next decade. The greatest temperature increases are projected to occur in spring, summer, and winter. Year-to-year variability of temperature is smaller in summer and spring than winter. This means that, while the projected increases in spring and summer increase cause those temperatures to approach historical extremes by 2021-2050, the winter temperature is projected to remain below this threshold until 2051-2080.

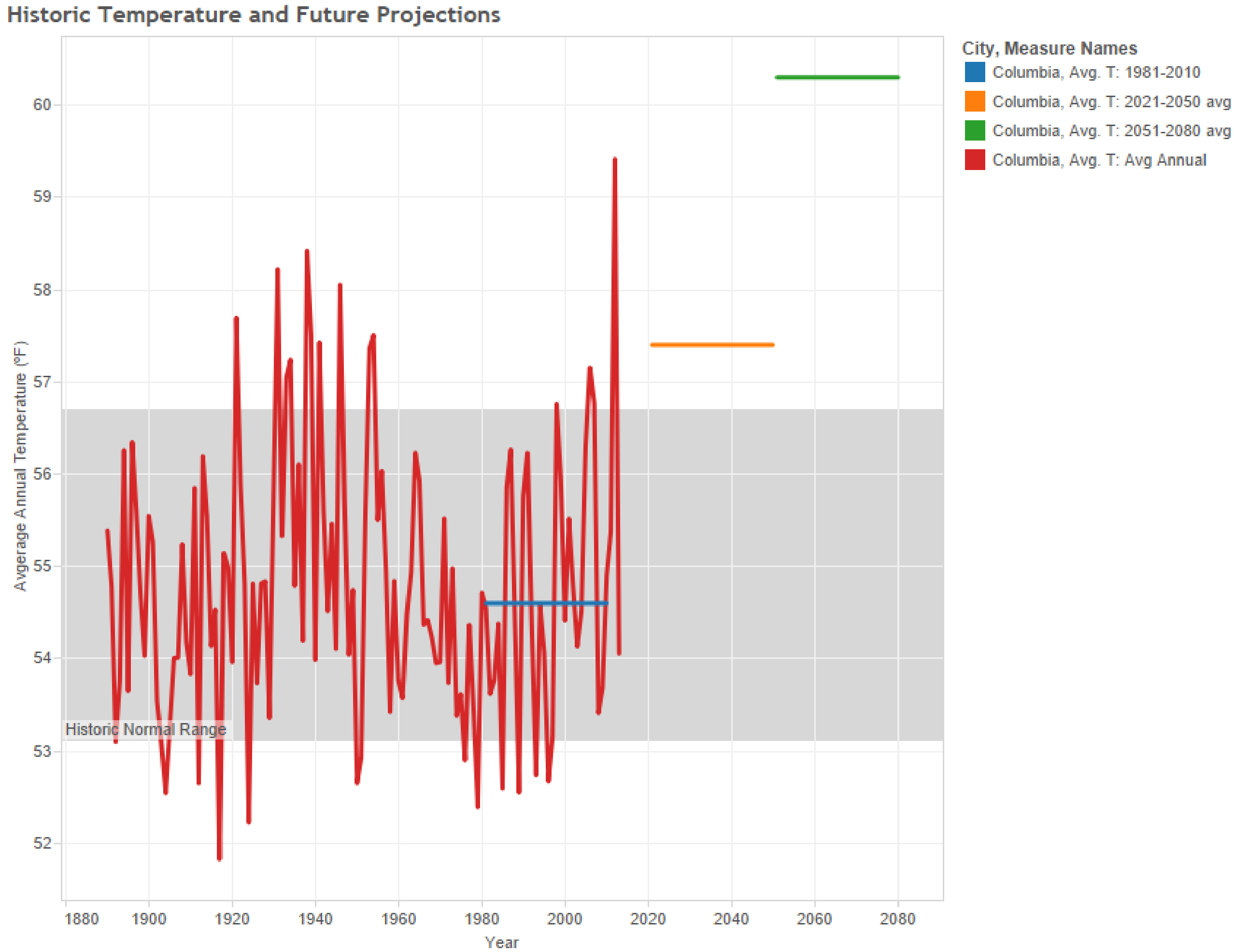


Figure MO4 illustrates the difference in annual temperature in the past and future. The line shows recorded temperatures from the historic record, and the 1981-2010 average is calculated from recorded temperatures. The 2021-2050 and 2051-2080 averages are calculated from climate models.

Precipitation

Annual precipitation is projected to increase 7% by 2021-2050. Unlike temperature, the 30-year average will not exceed the range of historical precipitation, which is inherently large.

Precipitation is projected to increase substantially by the 2050s and beyond, and the projected annual precipitation for 2050-2081 is very close to the 10% of wettest years of the current climate. The projected increase in precipitation is a change in the same direction as recent change. By 2020-2051, the projected annual precipitation will be 7.5% higher than annual precipitation in 1981-

2010, which is itself 9.7% higher than the 1890-2013 annual precipitation. The increase in precipitation will be greater in spring and fall than winter. Summer precipitation is projected to decrease.

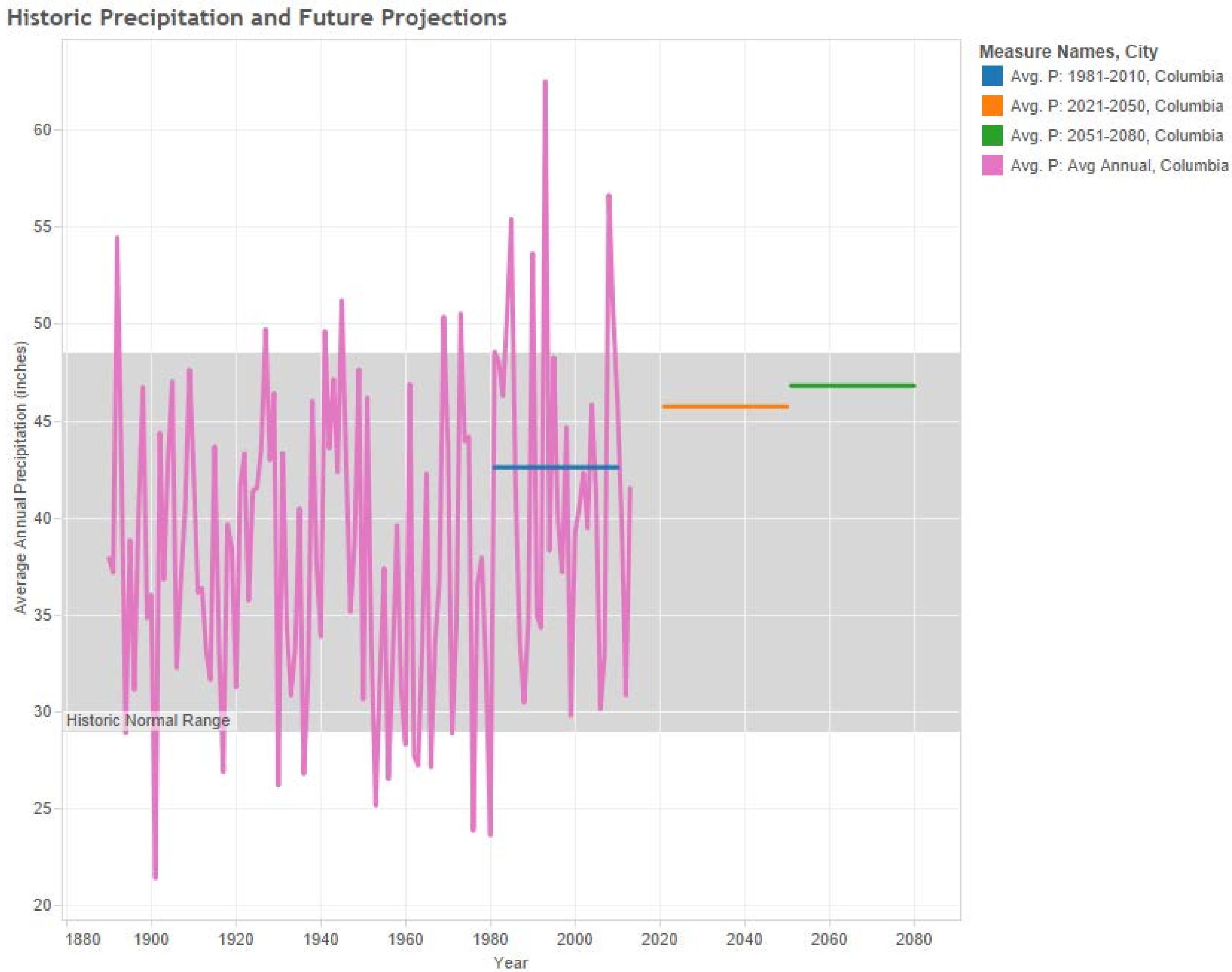


Figure MO5 illustrates the difference in annual precipitation in the past and future. The line shows recorded precipitation from the historic record, and the 1981-2010 average is calculated from recorded precipitation. The 2021-2050 and 2051-2080 averages are calculated from climate models.

Data

The following tables show projection data for temperature, precipitation, and hazardous events in the coming decades, relative to the last 30 years.

Projected Changes in Climate

Season	Metric	1981-2010	2021-2050	2051-2080
Annual	Average	54.7°F	57.4°F	60.3°F
	Maximum	64.8°F	67.6°F	70.7°F
	Minimum	44.5°F	47.1°F	50.0°F
	Precipitation	42.6"	45.8"	46.8"
Summer	Average	72.9°F	75.6°F	78.4°F
	Maximum	83.0°F	85.6°F	88.3°F
	Minimum	62.7°F	65.6°F	68.5°F
	Precipitation	13.2"	13.1"	12.7"
Fall	Average	67.6°F	68.8°F	70.9°F
	Precipitation	10.4"	11.5"	12.0"
	Frost date	October 24	October 28	November 1
Winter	Average	32.7°F	35.9°F	39.2°F
	Maximum	41.2°F	44.6°F	48.3°F
	Minimum	23.2°F	26.3°F	29.2°F
	Precipitation	6.6"	7.1"	7.3"
Spring	Average	44.6°F	48.2°F	51.8°F
	Precipitation	12.2"	14.0"	14.8"
	Frost date	April 6	March 29	March 21

Projected Changes in Hazardous Events

Damaging Event	Metric	1981-2010	2021-2050	2051-2080
Heat Waves	3-day average	85.3°F	88.1°F	91.4°F
	3-day maximum	97.4°F	100.3°F	103.6°F
	3-day minimum	74.2°F	76.9°F	80.1°F
Cold Waves	3-day minimum	-1.8°F	2.4°F	6.9°F
Heavy Rainfall	Days >1.25"	7 days	8 days	7 days
	Days >4.00"	1 day per 4 years	1 day per 2 years	1 day per 3 years
	5-day	4.9"	5.7"	6.0"
	15-day	7.2"	8.2"	8.7"
Thaw/Freeze	Days >45°F followed by days <28°F	4.5 times per year	4.8 times per year	4.8 times per year

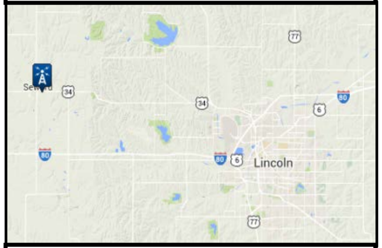
The following summary describes all climate change impacts, noting consistency, or lack thereof, with recent changes. See Discussion for information about the relationship between consistency and confidence.

- *Seasonal temperatures* have recently decreased in summer, fall, and winter. Spring temperature has recently increased by 0.6°F from 44.0°F to 44.6°F. With year-round temperatures projected to increase, this means future projections are in the opposite direction of recent change for all seasons except spring.
- *Summer temperature* is projected to increase from 72.9°F in 1981-2010 to 75.6°F in 2021-2050 to 78.4°F in 2051-2080. The current climate threshold for the top 10% of hottest summers is 76.8°F.
- *Winter temperature* is projected to increase from 32.7°F in 1981-2010 to 35.9°F in 2021-2050 to 39.2°F in 2051-2080. The current climate threshold of the top 10% of hottest winters is 38.8°F.
- *Spring temperature* is projected to increase at a faster rate than recent change and reach 48.2°F in 2021-2050 and 51.8°F in 2051-2080. The current climate threshold of the top 10% of hottest springs is 48.7°F.

- *Date of last frost in spring* is projected to be earlier in the year by over one week (March 29) in 2021-2050 and two weeks in 2051-2080 (March 21). This is consistent with recent weather changes, during which the average date of last spring frost has shifted three days earlier in the year (April 9 to April 6).
- *Date of first frost in fall* is projected to be a little later by 2021-2050 (November 13) and a further two days later by 2051-2080 (November 15). No change is evident in climate recent data (October 24).
- The *hottest 3-day maximum* is projected to increase substantially. In 2021-2050, the maximum temperature of the hottest 3-day period is expected to increase to 100.3°F, and further increase to 103.6°F is projected in 2051-2080. The historical data show almost no change in maximum of the hottest 3-day period.
- The *hottest 3-day minimum* is projected to increase from 74.2°F to 76.9°F in 2021-2050 to 80.1°F in 2051-2080. Recent historical data show almost no change in the minimum of the hottest 3-day period.
- *Spring precipitation* is projected to increase substantially. This is consistent with recent change, which has increased from 10.9” to 12.4”. The projected rate of change is nearly identical to the recent rate, and it results in an increase to 14.0” in 2021-2050 and 14.8” in 2051-2080.
- *Excessive rainfall* is projected to increase. Accumulation during annual maximum of 5-day and 15-day rainfall is projected to increase, which is consistent with recent change.

6 Lincoln, Nebraska

Figure NE1



Seward long-term station location is indicated by radio tower symbol. Global Historical Climate Network ID USC00257715 (40.89972°N, -97.09083°W); Source.

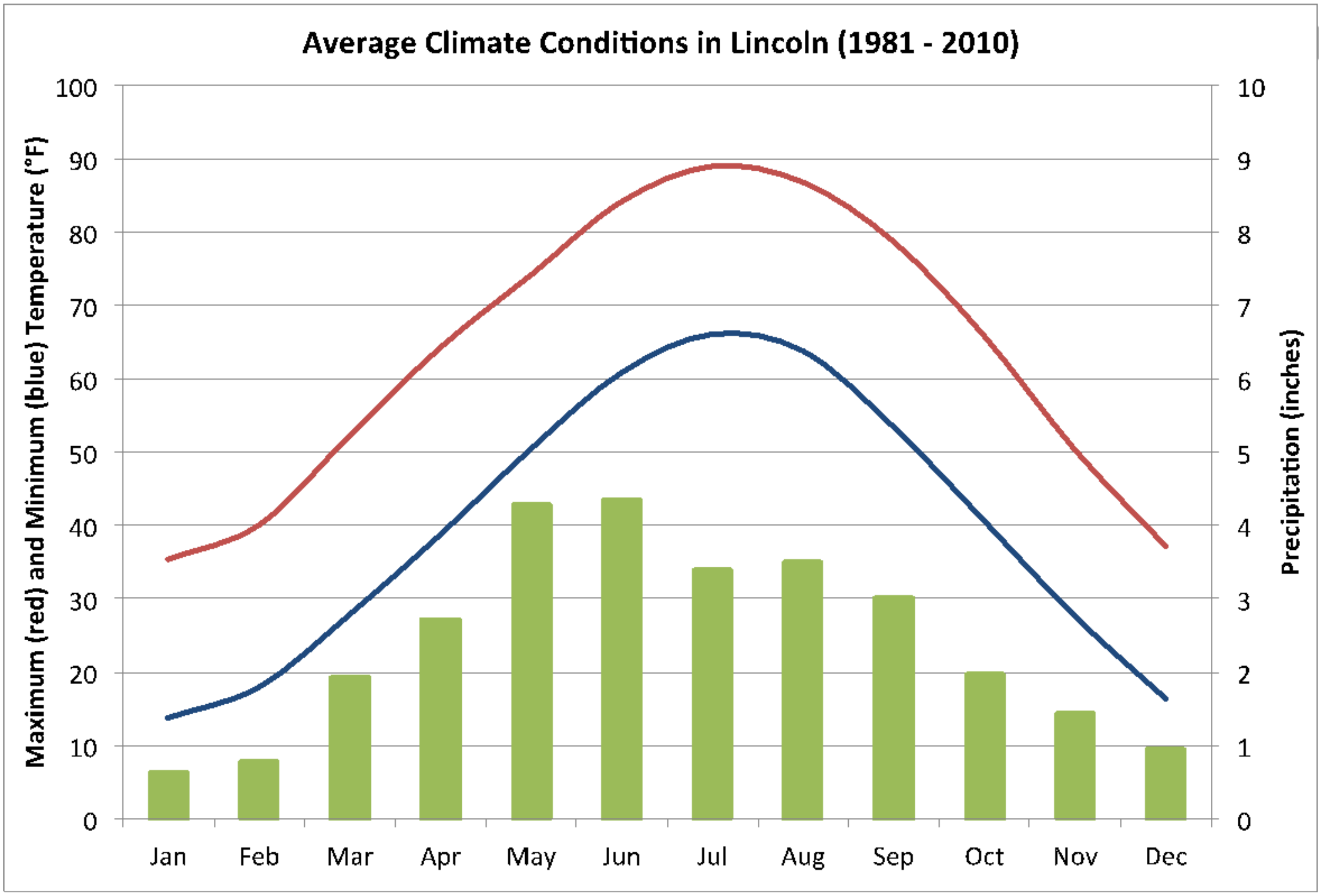
In recent decades, Lincoln has experienced a changing climate, with warmer winters and springs and higher summer nighttime temperatures. Climate change projections indicate the emergence of further temperature increases. At the projected rate, beyond 2021 the average annual temperature will exceed the 90th percentile of hottest years of the recent climate. Temperature is projected to increase several degrees during spring and summer, and heat waves are expected to be hotter. Rainfall is projected to increase modestly in spring, but there is no clear direction in summer.

6.1 Historical Climate Variability

Lincoln experiences a highly variable, four-season humid continental climate (Köppen Dfa classification): winters are cold but relatively dry, and summers are hot and occasionally humid. With little moisture during winter, precipitation is concentrated in the warmer months when thunderstorms frequently occur. These thunderstorms often produce severe weather such as hail, heavy downpours, and occasionally tornadoes.

The climate station in the city of Lincoln is unsuitable for a long-term climate analysis due to discontinuities in location and missing data. Therefore, a nearby station at Seward has been chosen for this analysis. This station is located east-northeast of Lincoln and has a period of record from 1893 to present.

During the period of record, Lincoln's annual temperature has averaged 64.9°F as a high and 40.5°F as a low. Annual rainfall has been 28.90" and snowfall 25.9". Monthly temperature reaches peak value in July with an average high temperature of 88°F. The annual low occurs in January with an average minimum of 14°F. Rainfall is heaviest in May and June, with an average of 4.29" and 4.35", respectively. The least precipitation occurs in January with an average of 0.64".



Extreme daily conditions are inherent in the Lincoln climate record. The highest and lowest recorded temperatures range over 140°F, from a record maximum of 108°F[4] to a record minimum of -33°F.[5] The maximum daily rainfall and snowfall were 5.42"[6] and 13.2",[7] respectively.

6.2 Recent Weather Changes

In recent years, Lincoln has experienced seasonal changes in weather. These changes are summarized in the following table.

Recent Changes in Seasonal Weather

Season	Recent Changes
Summer	Less variable daytime high temperatures Warmer nighttime low temperatures Fewer days with high temperatures above 95°F and 100°F
Fall	No changes are discernable
Winter	Warmer and dryer overall Fewer heating degree days
Spring	Fewer cool and dry springs; season becoming warmer and wetter Average date of last frost is earlier

In addition, recent decades have seen changes in the frequency of hazardous weather events. These changes are summarized in the following table.

Recent Changes in Damaging Events

Damaging Event	Recent Changes
Heat Waves	Cooler average temperature and average maximum temperature during hottest 3-day period Warmer average min temperature
Cold Waves	Higher average minimum temperature during coldest 3-day period
Heavy Rainfall	No changes apparent in daily, 5-day, or 15-day rainfall accumulation
Snow Storms	No clear changes in frequency or accumulation of snow storms
Thaw/Freeze	Fewer thaw/freeze cycles; 7-8 per year
Late/Early Freeze	Reduced likelihood of unusually late spring freezes
Tornado, Wind, Hail	Inconsistencies in reporting are more pronounced than long-term changes in frequency

6.3 Historical Context

To identify recent changes in weather, data from the past three decades were compared to the previous historical record. Here, the past three decades are generally defined as 1981-2010, though more recent data are incorporated into the analysis when available.

Temperatures have warmed overall on an annual average basis, particularly since about 1960. Precipitation has not changed significantly since the 1920s and variability is high from year to year. On a seasonal basis, the warming appears strongest during winter and spring. Winter has experienced a warming and drying trend, while spring has seen a warming and wetting since 1901. Both average temperature and precipitation do not show a trend during fall over the long-term record. Fall daily minimum temperatures have shown a decreasing trend over the last 15 years.

Summer has shown no discernible long-term trend in average temperature or total precipitation. However, minimum temperatures have increased 1.5°F on average since 1901. Conversely, extreme high temperatures (days with a daily maximum temperature above 95°F and 100°F) have decreased over time. The frequency of these days was particularly high during the 1930s drought

[4] The most recent occurrence of this temperature was July 19, 2006. It was also reached in 1995 and 1990. Source: Applied Climate Information System, http://rcc-acis.org.

[5] This record was set on January 12, 1974. Source: Applied Climate Information System, http://rcc-acis.org.

[6] This record was set on July 25, 1990.

[7] This record was set on October 26, 1997.

period. In addition, there has been a lower probability of a late spring freeze in the past 30 years, and all of the top 10 latest spring freezes occurred prior to 1980. There has been no change in the earliest spring freeze dates over time, though interestingly the last hard freeze date (28°F) in 2012 (March 10) was nearly 3 weeks sooner than the previous record earliest date – an astonishing record.

Unlike other parts of the country, Lincoln has not seen an increase in heavy rainfall events, such as daily precipitation amounts of more than 1.25”. Over the most recent 30-year period, 1981-2010, Lincoln experienced 4-5 events of this magnitude, on average. There has been no apparent change in the frequency of these events over time. Furthermore, high precipitation periods, such as the highest 5- and 15-day rainfall totals, do not show any significant trends in frequency over time.

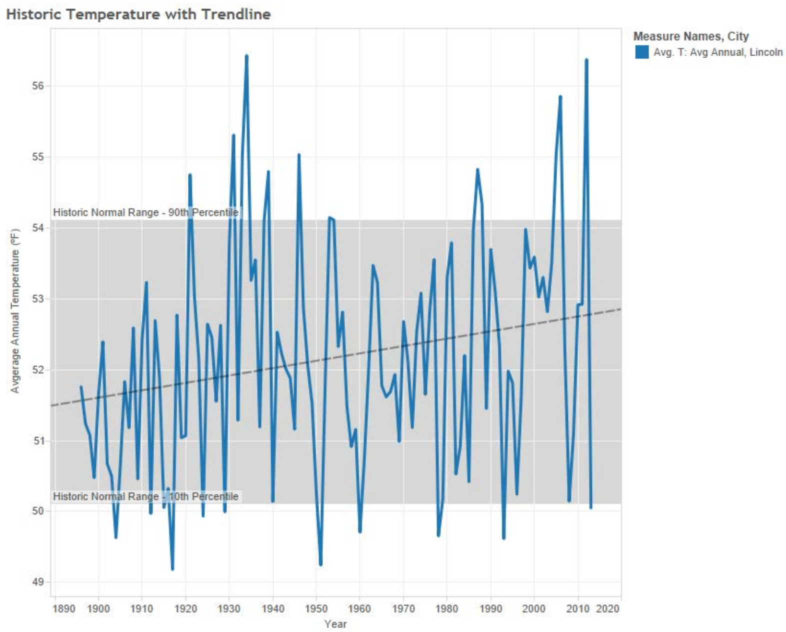


Figure NE2. Recorded annual average temperature with trendline.

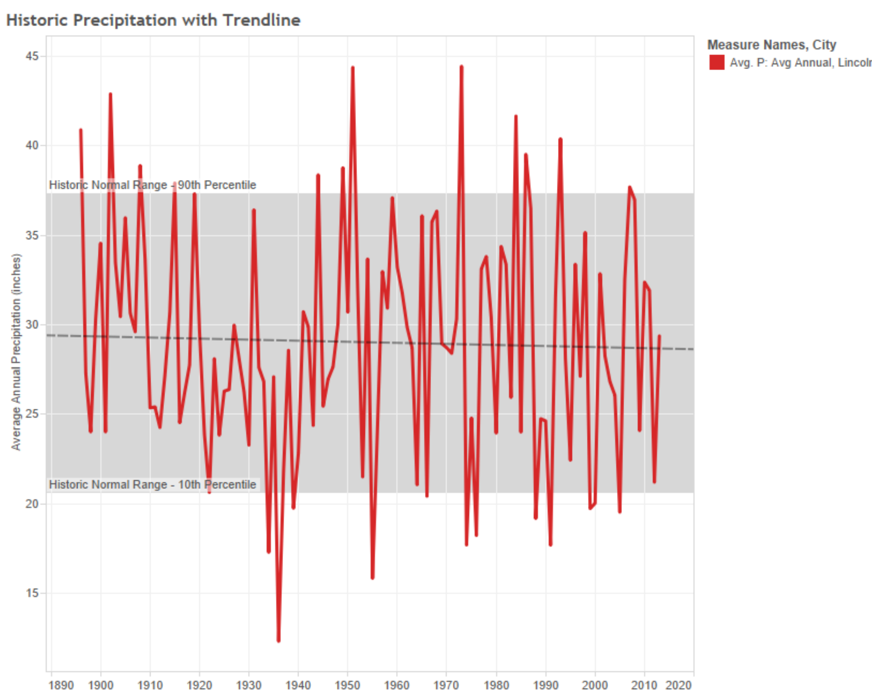


Figure NE3. Recorded annual average precipitation with trendline.

Heating degree days (HDD) have decreased by about 140 units since 1905. Nine of the lowest 10 HDD totals have occurred since 1970. Cooling degree days (CDD) do not show a trend in the annual totals over time. This is to be expected, since the CDD values are based on the average daily temperature, which has also shown no changing trend.

6.4 Area Context

Lincoln lies within the East Central Climate Division in Nebraska (CD6), and there are many similarities between local and area trends in temperature and precipitation. On a seasonal basis, winter, spring, and summer all show consistent patterns at the local and regional scales. There are slight differences during fall at the local and regional scales, but these differences are not statistically significant.

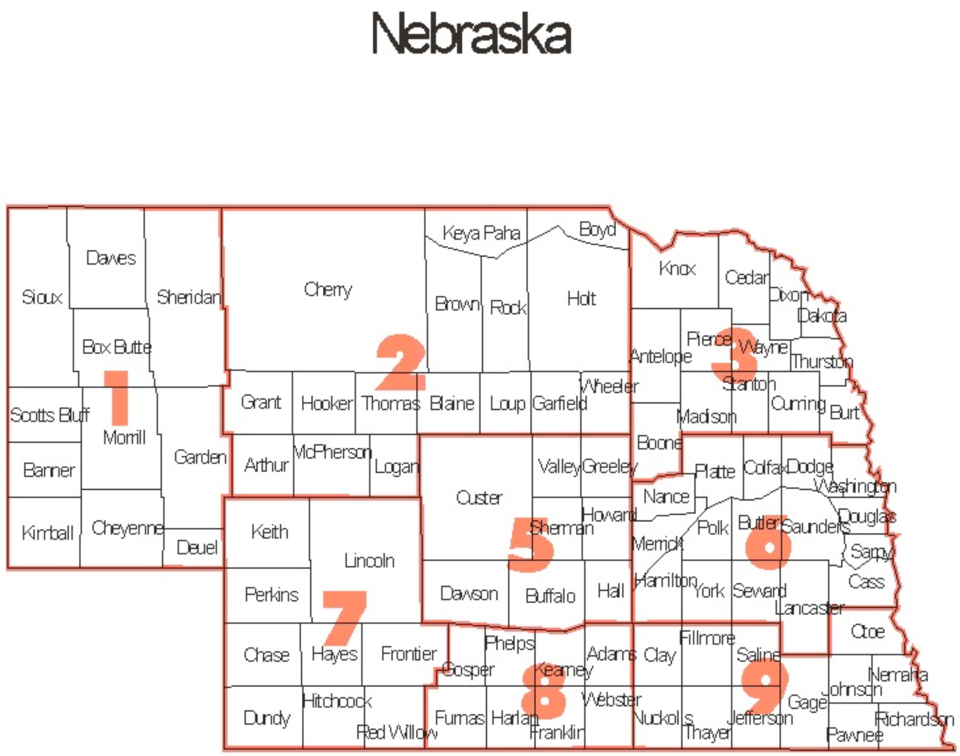


Figure NE4. Climate divisions; Source.

Given that Lincoln's water supply is sourced from areas around the Platte River, which has headwaters in the Rocky Mountains, it is important to consider changes going on outside of the Lincoln area. Climate trends for the Rocky Mountains are relevant, as this determines conditions at the source of Lincoln's water. Studies indicate that over the period 1955-2013, mountain snowpack has declined at a majority of locations in the basins that supply the Platte River.

6.5 Recent Change in Weather Hazards

Weather hazards threaten Lincoln's infrastructure and the safety and well being of its population, and the risk of these events has changed in recent decades. The areas in which Lincoln's risk profile have changed include:

- Hotter nights during summer, particularly during heat waves
- Fewer extremely warm days with high temperature 95°F and higher
- Warmer minimum temperatures during cold waves
- Less likelihood of unusually late spring freeze

Other weather threats have not yet appeared but are expected to emerge in coming decades. These metrics include:

- Frequency of heavy rain events with more than 1.25" in a day
- Accumulation and frequency of snowfall

It is possible that the urban heat island effect influences temperature conditions within the municipality, as compared to surrounding rural areas. This has not been directly investigated and additional studies would be needed to document the magnitude of this effect.

6.6 Climate Projections

Lincoln's annual temperature is projected to increase substantially, so much so that the 30-year average temperature in future decades is well above the hottest years in the historical temperature range. Annual precipitation is projected to change very little.

Temperature

Temperature is expected to increase substantially by the 2050s and beyond with much of the projected change occurring during spring, summer, and winter. By 2021-2050, the average summer and spring temperature are projected to nearly equal what is currently the threshold of the top 10% of hottest years. This is a much faster rate of increase than measured in the recent change.

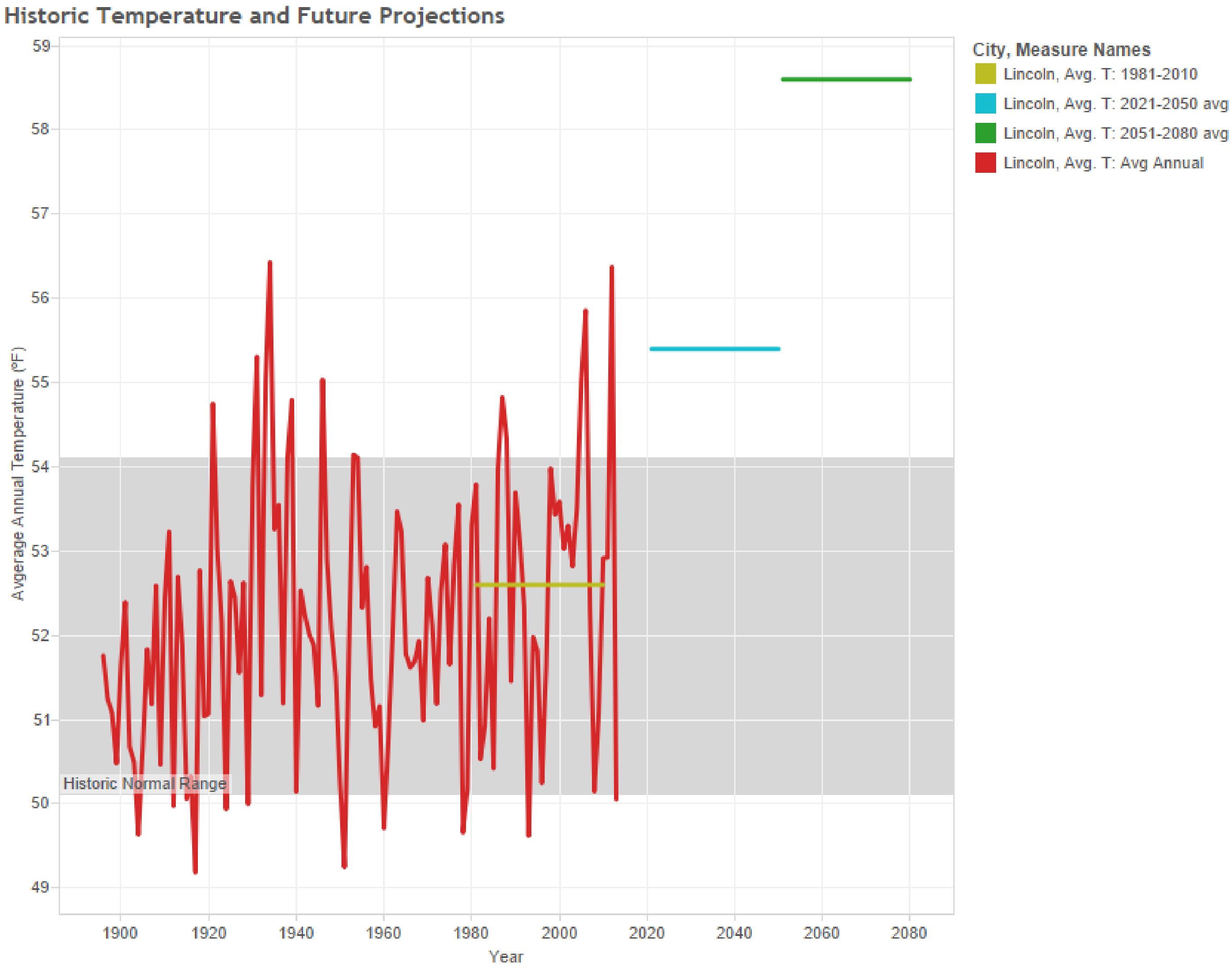


Figure NE5 illustrates the difference in annual temperature in the past and future. The line shows recorded temperatures from the historic record, and the 1981-2010 average is calculated from recorded temperatures. The 2021-2050 and 2051-2080 averages are calculated from climate models.

Precipitation

Precipitation is projected to continue the recent historical trend of modest increase. Unlike temperature, projections of precipitation do not indicate a change beyond the bounds of the wettest or driest 10% of current climate. The increase in projected precipitation is largest in spring, but the projected increase is small compared to year-to-year variability.

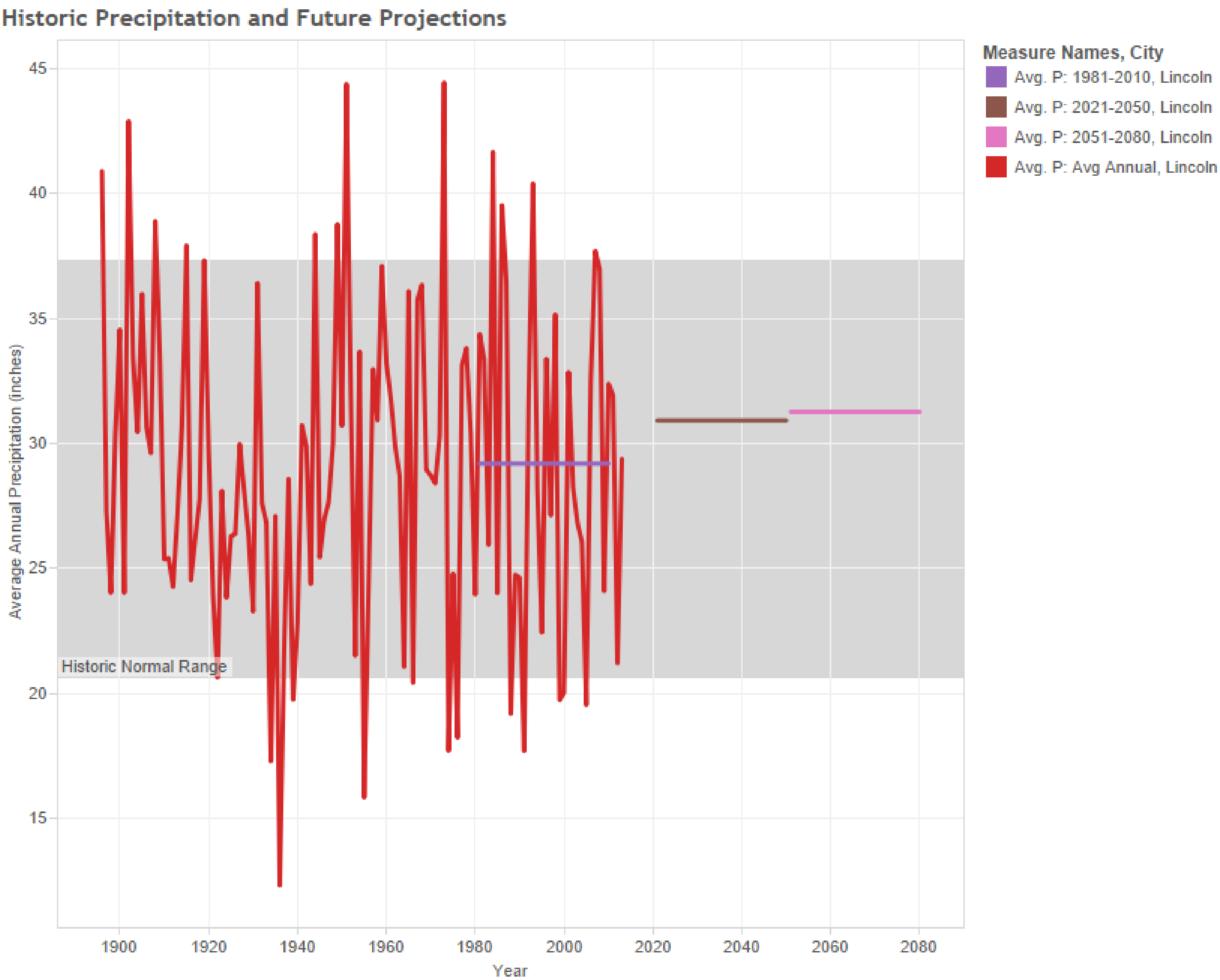


Figure NE6 illustrates the difference in annual precipitation in the past and future. The line shows recorded precipitation from the historic record, and the 1981-2010 average is calculated from recorded precipitation. The 2021-2050 and 2051-2080 averages are calculated from climate models.

Data

The following tables show projection data for temperature, precipitation, and hazardous events in coming decades, relative to the last 30 years.

Projected Changes in Climate

Season	Metric	1981-2010	2021-2050	2051-2080
Annual	Average	52.6°F	55.4°F	58.6°F
	Maximum	64.1°F	66.9°F	70.2°F
	Minimum	41.1°F	44.0°F	47.2°F
	Precipitation	29.2″	30.9″	31.3″
Summer	Average	72.5°F	75.4°F	78.6°F
	Maximum	83.9°F	86.9°F	90.0°F
	Minimum	61.1°F	64.0°F	67.3°F
	Precipitation	11.4″	11.9″	11.3″
Fall	Average	66.8°F	68.2°F	70.5°F
	Precipitation	6.7″	6.8″	6.8″
	Frost Date	October 12	October 16	October 20
Winter	Average	28.5°F	31.9°F	35.5°F
	Maximum	39.0°F	42.5°F	46.3°F
	Minimum	18.1°F	21.3°F	24.7°F
	Precipitation	2.1″	2.5″	2.6″
Spring	Average	41.4°F	45.2°F	49.0°F
	Precipitation	9.1″	9.7″	10.5″
	Frost Date	April 21	April 13	April 4

Projected Changes in Hazardous Events

Damaging Event	Metric	1981-2010	2021-2050	2151-2080
Heat Waves	3-day average	85.2°F	88.1°F	91.7°F
	3-day maximum	98.6°F	101.7°F	105.3°F
	3-day minimum	73.3°F	76.0°F	79.7°F
Cold Waves	3-day minimum	-6.8°F	-2.7°F	1.7°F
Heavy Rainfall	Days > 1.25″	5 days	5 days	6 days
	Days > 4.00″	1 day per 10 years	1 day per 10 years	1 day per 4 years
	5-day	3.8″	3.8″	4.1″
	15-day	5.8″	5.9″	6.2″
Thaw/Freeze	Days >45°F followed by days <28°F	4.3 times per year	4.4 times per year	4.2 times per year

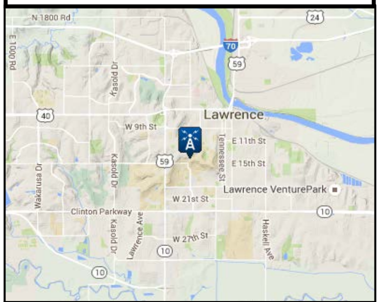
The following summary describes all climate change impacts, noting consistency, or lack thereof, with recent changes. See Discussion for information about the relationship between consistency and confidence.

- *Spring temperature* has recently increased by 1.4°F from 40.0°F to 41.4°F. It is projected to increase at a faster rate to 45.2°F in 2021-2050 and 49.0°F in 2051-2080.
- *Summer temperature* has recently increased by 0.5°F from 72.0°F to 72.5°F. It is projected to increase at a faster rate to 75.4°F in 2021-2050 to 78.6°F in 2051-2080.
- *Winter temperature* has recently been below the 1893-2013 average by 0.5°F, which is a decrease from 29.0°F to 28.5°F during 1981-2010. The projected change is in the opposite direction as historical change. It is projected to increase to 31.9°F in 2021-2050 to 35.5°F in 2051-2080.
- *Date of last frost in spring* is projected to be earlier in the year by more than one week in 2021-2050 (April 13) and almost three weeks in 2051-2080 (April 4). Recent change has been negligible.
- *Date of first frost in fall* is projected to be four days later by 2021-2050 (October 16) and eight days later by 2051-2080 (October 20). The recent historical change is negligible.

- The *hottest 3-day maximum* is projected to increase substantially. In 2021-2050, the hottest 3-day maximum is projected to increase to 101.7°F and increase further to 105.3°F in 2051-2080. The historical data show almost no change in the current value of 98.6°F.
- The *hottest 3-day minimum* has recently decreased by 0.5°F from 74.0°F to 73.2°F. In 2021-2050, the hottest 3-day minimum is projected to increase to 76.0°F and increase further to 79.7°F in 2051-2080.
- *Spring precipitation* has recently increased substantially by 1.1″ from 8.0″ to 9.1″. It is projected to increase modestly to 9.7″ in 2021-2050 and to 10.5″ in 2051-2080.
- *Summer precipitation* is projected to be less stable. It is projected to increase to 11.9″ in 2021-2050 and to decrease to 10.3″ in 2051-2080. The recent historical change in summer precipitation is negligible.

7 Lawrence, Kansas

Figure KS1



Lawrence station location is indicated by radio tower symbol. Global Historical Climate Network ID USC0014459 (38.9583°N, -92.2513°W); Source.

Recent change has been observed in summer warming, particularly at night, and warmer and wetter spring seasons. In recent years, summer rainfall has been volatile, with heavy precipitation in the 1990s followed by very low precipitation in the 2000s. Looking forward, climate change projections show the emergence of a substantial increase in temperature. At the projected rate, beyond the next decade, the average annual temperature will exceed the hottest years in the normal historical temperature range. Temperature is projected to increase several degrees during winter, spring, and summer, especially during heat waves. Projections of rainfall show continued increase in spring and winter but indicate no clear pattern for summer.

7.1 Historical Climate Variability

Lawrence is in a sub-humid continental climate zone, described as temperate with extremes of heat, cold, and precipitation.

The climate station in Lawrence is located [add location]. It has a period of record from 1890 to present and has been located with a similar exposure through the period. Since 1980, Lawrence has had annual high, low, and average temperature of 66.4°F, 46.2°F, and 56.3°F, respectively. Annual average rainfall and snowfall have been 38.80" and 17.0", respectively. Monthly temperatures reach their maximum in July with an average of 90°F and minimum in January at 20°F. Monthly rainfall peaks in June with 5.16" and is driest in January with 1.06" of precipitation. The record daily temperatures range over 139°F, from -25°F to 114°F, and maximum daily rainfall is 7.23". Lawrence accumulates on average 4,864 heating degree days and 1,155 cooling degree days per year.

7.2 Recent Weather Changes

In recent years, Lawrence has experienced seasonal changes in weather. These changes are summarized in the following table.

Recent Changes in Seasonal Weather

Season	Recent Changes
Summer	Fewer cool summers and more frequent hot summers due to higher minimum temperatures More frequent warm nights
Fall	Mixed temperature pattern; drier weather Average date of first frost is 9 days later
Winter	Milder winters with fewer sub-zero days
Spring	Increase in mild and wet springs April freeze more frequently occurs after a mild February and March

In addition, the last three decades have seen changes in the frequency of hazardous weather events. These changes are summarized in the following table.

Recent Changes in Damaging Events

Damaging Event	Recent Changes
Heat Waves	Higher average temperature and average minimum temperature in hottest 3-day period
Cold Waves	Higher average minimum temperatures in coldest 3-day period Fewer sub-zero temperatures
Heavy Rainfall	More years with frequent high intensity rainfall (8 days or more with >1.25"/day) Higher frequency of unusually high rainfall over wettest 5-day period (>6.28") Higher frequency of unusually high rainfall over wettest 15-day period (>10.25")
Late/Early Freeze	Likelihood unchanged, but complicated by warm spring temperatures
Tornado, Wind, Hail	Inconsistencies in reporting are more pronounced than long-term changes in frequency

7.3 Historical Context

To identify recent changes in weather, data from the past three decades were compared to the previous historical record. Here, the past three decades are generally defined as 1981-2010, though more recent data are incorporated into the analysis when available.

Temperature change has been uneven in Lawrence. Change has been most pronounced during the winter, with the 1981-2010 mean temperature being 1.2°F warmer than the 1890-1980 average. However, this increase is due to the increase in the low (nighttime) temperatures rather than the high temperatures, which have actually been 0.7°F cooler in winter, on average. There are also fewer days with sub-zero temperatures.

The average summer temperature for 1981-2010 is 0.6°F higher than the 1890-1980 average. More warm summers have occurred, and cool summers are not as common. In last 30 years, Lawrence has experienced four of the 10 hottest summers dating to 1893, but none of the 10 coolest summers. Like winter, summer temperature increase is primarily due to an increase in minimum rather than maximum summer temperature. Five of the 10 warmest average minimum temperatures have occurred since 1981, while only two of the average maximum temperatures rank in the top 10 warmest.

While spring temperatures are higher, fall temperatures are slightly cooler. However, year-to-year variability of temperature for these transition seasons is much larger than summer. One of the potential problems from this pattern is a mild spring coupled with a typical last spring freeze date. This causes vegetation to break dormancy early when it is more vulnerable to freeze damage.

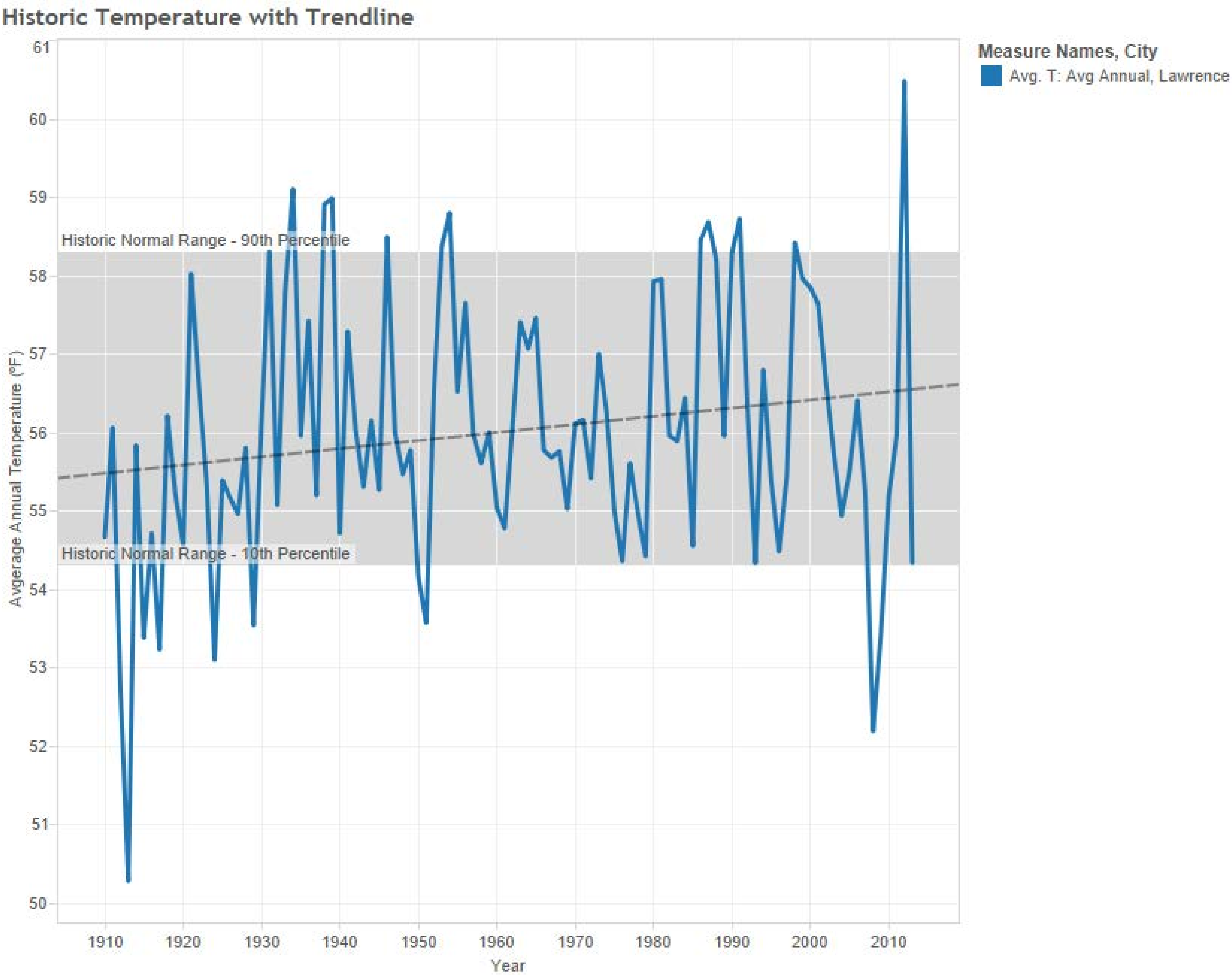


Figure KS2. Recorded annual average precipitation with trendline.

Heating degree days have decreased substantially due to recent increase in winter temperatures, and cooling degree days have increased slightly due to recent increase in spring temperatures. This has implications in future energy demands, as seasonal demand peaks shift.

Spring and fall freeze dates have also changed. Compared to 1890-1980, in 1981-2010 the last day in spring with low temperature <32°F was one week earlier, and, in fall, the first day with low temperature <32°F was one week later. However, the spring freeze date in the last few years has occurred much later in the spring than the average date. This is a clear reminder that the volatility of daily spring temperature is larger than the volatility of spring season temperature averages and is large enough that any single year can be substantially different from the average of recent years.

Rainfall change is pronounced in daily and extreme multi-day to seasonal rainfall. Frequency of wet spring and number of wet days per year are higher. The average number of days with rainfall >1.25" has not substantially changed. However, in the recent 30-yr period, Lawrence has experienced 4 of the top 10 years for number of days > 1.25".

Precipitation trends in Lawrence have shown increased rainfall. Frequencies of wet spring seasons and overall number of wet days per year is higher. The 1985-2014 period averaged 13% more days with rainfall ≥1.25" compared to the 1890-1984 period. Moreover, there has been a 40% increase in events ≥2.00" and 118% increase for ≥3.00". The frequency of 5-day and 15-day periods with unusually high rainfall (≥6.25" and ≥9.0", respectively) has also increased over the past few decades, compared to the long-term trend.

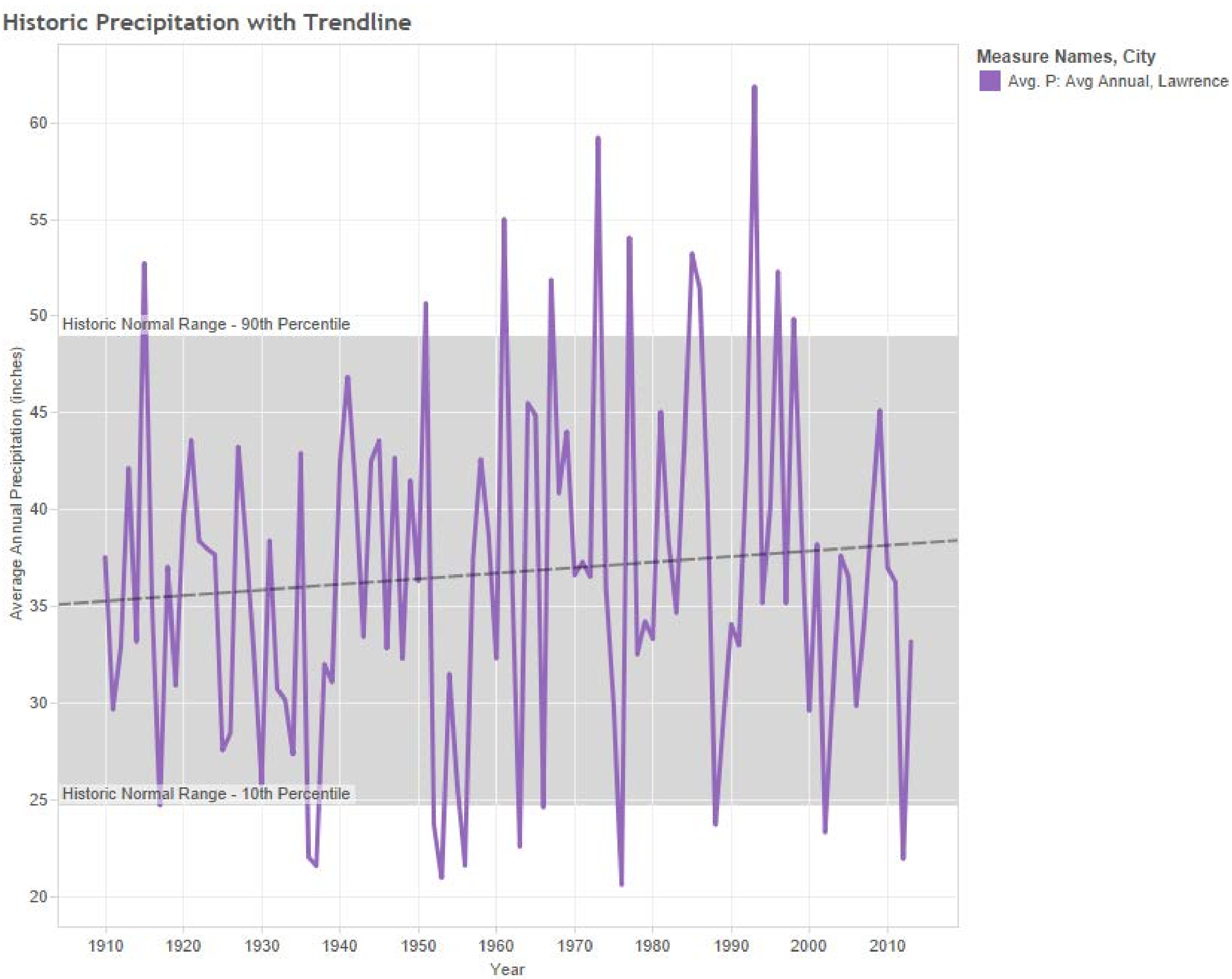


Figure KS3. Recorded annual average precipitation with trendline.

The average annual maximum of 5-day and 15-day rainfall events has increased slightly. In addition, for both accumulation periods, the frequency of rainfall events at or above the 90th percentile has increased. This is significant because it is not single-day maximum rainfall creates high stream flow events, but rather the increase in the total amounts during multi-day events.

7.4 Area Context

Lawrence is located in the East Central Kansas Climate Division (CD6), and records show there is little difference between the climate in Lawrence and the surrounding area. In both cases, precipitation has been higher in all seasons, with the greatest increase in the spring months. There are some slight differences in January and February, where the division data had higher precipitation totals during these months, while recent trends in Lawrence showed lower precipitation totals in January and February. No division data are available for snowfall, but in Lawrence the pattern appears to be inconsistent. Overall the 1981-2010 period averages less total snow by month and by year. However, this average is made up of extremes: seasons with little snow followed by heavy snow events. While 10 of the 15 years with lowest snowfall have occurred since 1980, six of the 15 snowiest seasons have also occurred since that date.

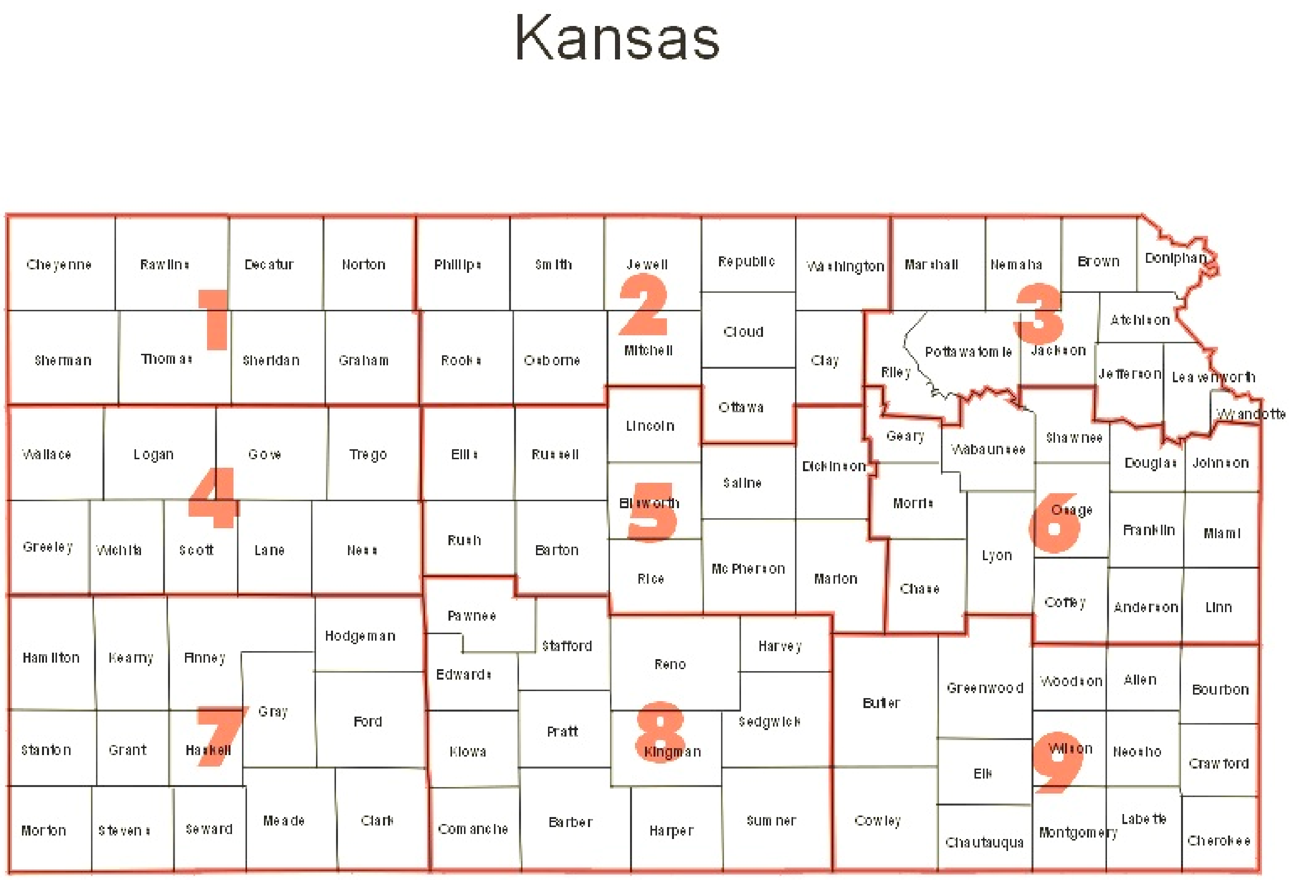


Figure KS4. Climate divisions; Source.

7.5 Recent Change in Weather Hazards

Weather hazards threaten Lawrence's infrastructure and the safety and well being of its population, and these hazards have become more numerous since 1981. Lawrence's risk profile has expanded rather than narrowed due to both an increased frequency of some hazardous weather conditions and an increased range of weather conditions. Recent changes that have expanded the risk profile include:

- Increase in the frequency of warm nights
- During heat waves, a trend toward hotter nights, higher average temperature, and higher heat index
- Increase in number of days with extreme rainfall
- Increase in frequency of extremely wet spring seasons, precipitation in the late winter, and increased accumulation during multi-day (5-day and 15-day) heavy rainfall events

Other weather threats have been less frequent in recent years but are projected to emerge going forward. Recent data series are too short to discern a permanent change in these weather threats, but with 10 to 20 years of monitoring, it may be possible to conclude exposure to the following threats has changed:

- Late spring freeze
- Early fall freeze
- Extremely cold waves

Additional study is needed to conclude with certainty the impact of the urban heat island effect on changes in summer minimum temperature, as well as the average and minimum temperatures during heat waves.

7.6 Climate Projections

Lawrence's annual temperature is projected to increase substantially. In the future, the 30-year average temperature is projected to be well above the 90th percentile of the normal historical temperature range. Annual precipitation is expected to change very little.

Temperature

Temperature is expected to increase substantially by the 2050s and beyond with much of the projected change occurring during spring, summer, and winter. By 2021-2050, the average annual temperature is projected to exceed the historical range and continue to increase into 2051-2080. This is a much faster rate of increase than measured in the recent historical change. Temperature increase is largest in summer and winter with the average summer and winter temperature in 2021-2050 projected to nearly equal what is currently the threshold of the top 10% hottest years.

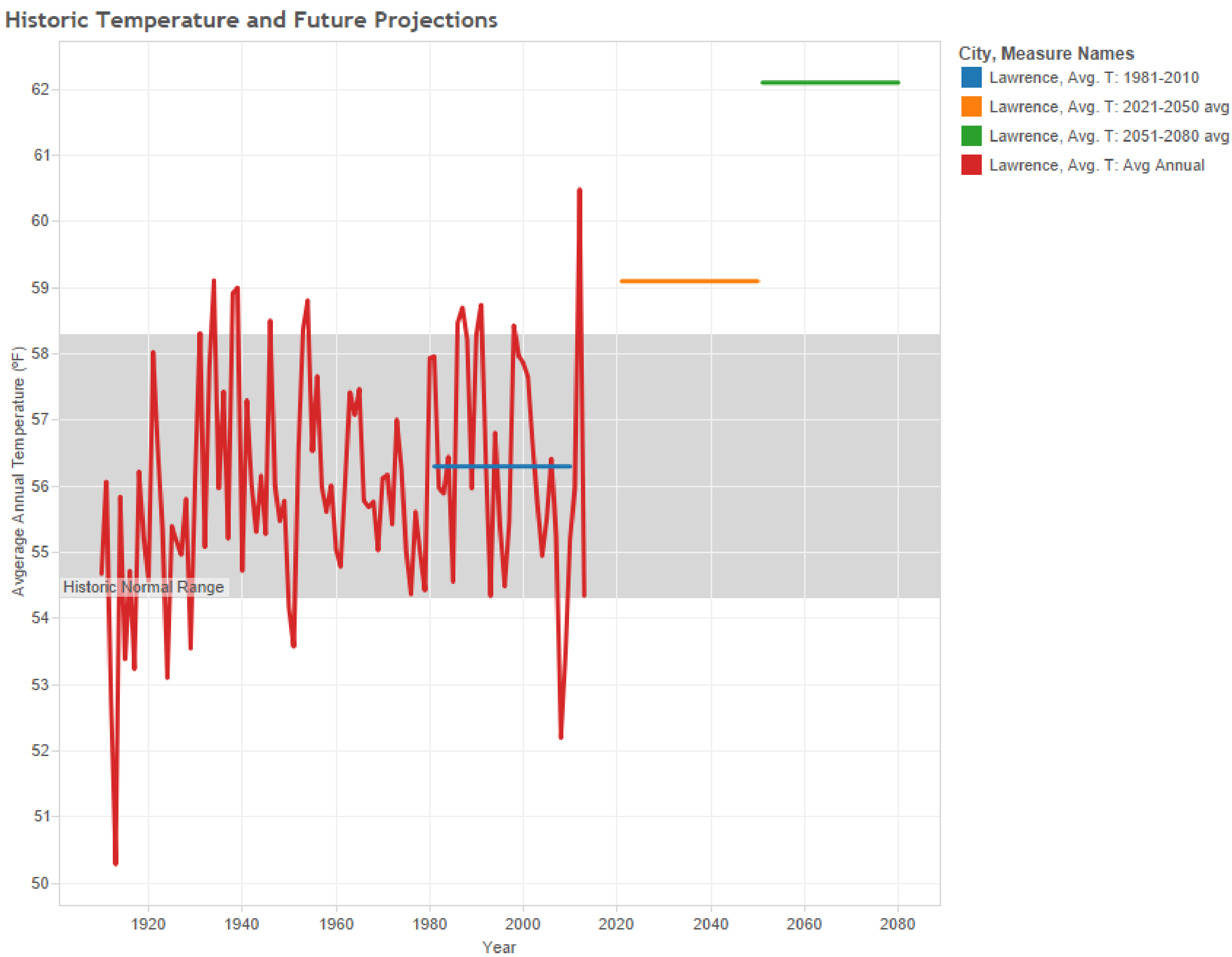


Figure KS5 illustrates the difference in annual temperature in the past and future. The line shows recorded temperatures from the historic record, and the 1981-2010 average is calculated from recorded temperatures. The 2021-2050 and 2051-2080 averages are calculated from climate models.

Precipitation

Precipitation is projected to increase modestly in the future, which is consistent with recent changes in weather patterns. In the last three decades, average precipitation has increased from 36.5" to 38.8", though most of the wet recent years occurred in the 1990s, while very low years of precipitation have occurred since 2000. The increase in projected precipitation is largest in spring, while summer and fall are projected to have variable change in average precipitation.

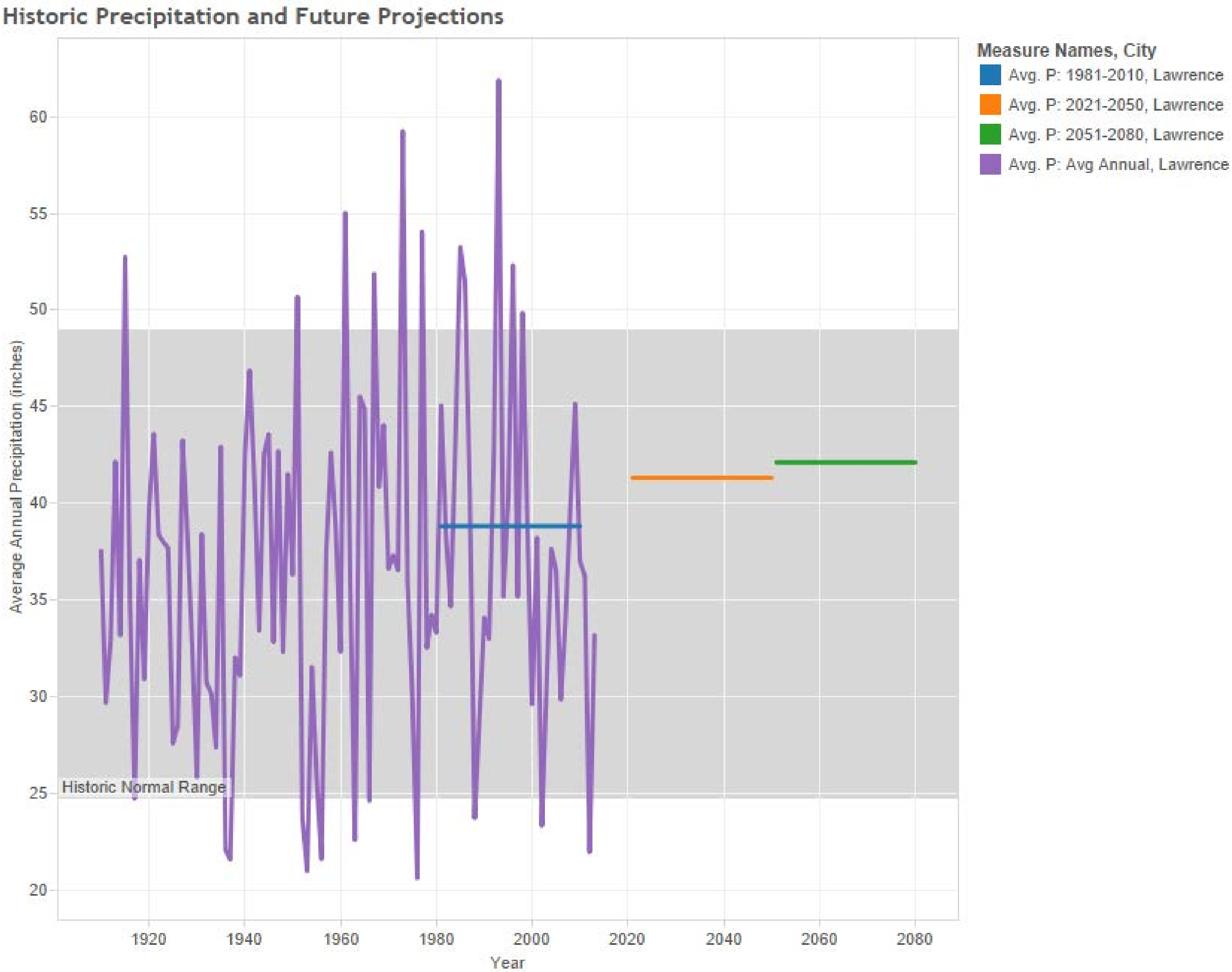


Figure KS6 illustrates the difference in annual precipitation in the past and future. The line shows recorded precipitation from the historic record, and the 1981-2010 average is calculated from recorded precipitation. The 2021-2050 and 2051-2080 averages are calculated from climate models.

Data

The following tables show projection data for temperature, precipitation, and hazardous events in the coming decades, relative to the last 30 years.

Projected Changes in Climate

Season	Metric	1981-2010	2021-2050	2051-2080
Annual	Average	56.3°F	59.1°F	62.1°F
	Maximum	66.4°F	69.3°F	72.5°F
	Minimum	46.2°F	48.8°F	51.7°F
	Precipitation	38.8"	41.3"	42.1"
Summer	Average	77.6°F	80.6°F	83.8°F
	Maximum	87.7°F	90.8°F	94.2°F
	Minimum	67.6°F	70.4°F	73.4°F
	Precipitation	13.8"	14.1"	13.4"
Fall	Average	57.7°F	59.0°F	61.2°F
	Precipitation	9.6"	10.3"	10.7
	Frost Date	October 31	November 4	November 7
Winter	Average	33.4°F	36.6°F	40.0°F
	Maximum	42.8°F	46.2°F	49.9°F
	Minimum	24.0°F	27.1°F	30.1°F
	Precipitation	3.8"	4.4"	4.4"
Spring	Average	56.1°F	59.6°F	63.0°F
	Precipitation	11.7"	12.7"	13.7"
	Frost Date	April 3	March 27	March 20

Projected Changes in Hazardous Events

Damaging Event	Metric	1981-2010	2021-2050	2051-2080
Heat Waves	3-day average	87.8°F	91.0°F	94.7°F
	3-day maximum	99.4°F	103.0°F	107.2°F
	3-day minimum	77.0°F	79.7°F	83.0°F
Cold Waves	3-day minimum	0.4°F	4.7°F	9.1°F
Heavy Rainfall	Days > 1.25"	7 days	8 days	9 days
	Days > 4.00"	1 day per 10 years	1 day per 4 years	1 day per 3 years
	5-day	4.8"	5.2"	5.5"
	15-day	7.2"	7.8"	8.3"
Thaw/Freeze	Days > 45°F followed by days < 28°F	4.3 times per year	4.2 times per year	3.9 times per year

The following summary describes all climate change impacts, noting consistency, or lack thereof, with recent changes. See Discussion for information about the relationship between consistency and confidence.

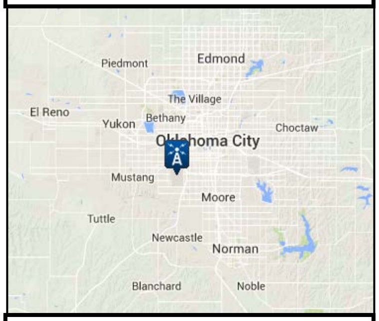
- *Spring temperature* has recently increased by 0.6°F from 55.5°F to 56.1°F. It is projected to increase at a faster rate to 59.6°F in 2021-2050 and 63.0°F in 2051-2080.
- *Summer temperature* is projected to increase from 77.6°F in 1981-2010 to 80.6°F in 2021-2050 to 83.8°F in 2051-2080. The projected average annual temperature exceeds the historical threshold of 80.5°F for the 10% hottest summers. Recent historical change has been due almost entirely to increased nighttime temperatures.
- Change in *winter temperature* has been negligible. In the future it is projected to increase from 33.4°F in 1981-2010 to 36.7°F in 2021-2050 to 40.0°F in 2051-2080.
- *Date of last frost in spring* has recently shifted three days earlier (April 6 to April 3). It is projected to move earlier in the year by more than one week (March 27) in 2021-2050 and more than two weeks (March 20) in 2051-2080.
- *Date of first frost in fall* has recently shifted two days later (October 29 to October 31). It is projected to be five days later by 2021-2050 (November 4) and eight days later by 2051-2080 (November 7).
- The *hottest 3-day maximum* is projected to increase substantially. In 2021-2050, the maximum average temperature of the hottest 3-day period is expected to increase to 103.0°F, and further increase to 107.2°F is projected in 2051-2080. This is in

the opposite direction of recent change, which has seen a decrease in the maximum temperature of the hottest 3-day period, from 100°F to 99.4°F.

- The *hottest 3-day minimum* has recently increased by 0.7°F from 76.3°F to 77.0°F. It is projected to increase substantially. In 2021-2050, the minimum average temperature of the hottest 3-day period is projected to be 79.7°F and increase further to 83.0°F in 2051-2080.
- *Fall precipitation* has recently increased substantially by 1.2" from 8.4" to 9.6". It is projected to increase to 10.3" in 2021-2050 and to 10.7" in 2051-2080.
- *Summer precipitation* is projected to remain unstable. It has recently increased by 1.1" from 12.7" to 13.8". The year-to-year variation of summer rainfall is large, and this recent increase is relatively small compared to year-to-year variation. Variability is projected to continue, with an increase to 14.1" projected in 2021-2050 and a decrease to 10.3" projected in 2051-2080.
- *Spring precipitation* has recently increased substantially by 1.5" from 10.2" to 11.7". It is projected to continue to increase at about the same rate to 12.7" in 2021-2050, then to 13.7" in 2051-2080. Of all seasonal rainfall projections, projected spring rainfall approaches most closely the historical threshold for the 10% wettest years, which is 15.2".
- *Excessive rainfall* is projected to increase. The amount of rainfall during the annual maximum 5-day and 15-day rainfall is projected to increase. This is the same direction of change as the recent historical change.

8 Oklahoma City, Oklahoma

Figure OK1



Oklahoma City station location is indicated by radio tower symbol. Global Historical Climate Network ID USC00252020 (35.3889°N, -97.6006°W); Source.

Recent climate change has been apparent in warmer and wetter winters, warmer springs, and warmer summer nights. In addition, summer rainfall has been volatile, with both very low and very high amounts in the 2000s. Looking forward, climate change projections predict a substantial temperature increase, particularly beyond the next decade. At the projected rate, beyond the next decade, average annual temperature will exceed the hottest 10% of years of the recent climate. Temperature is projected to increase several degrees during winter, spring, and summer, and heat waves are expected to be hotter. Projections of rainfall change continue the recent increase in fall precipitation. In summer, a small decrease is projected, and volatility will remain high.

8.1 Historical Climate Variability

Oklahoma City lies in a temperate humid subtropical climate (Köppen Cfa classification), with frequent variations in weather daily and seasonally, except during the consistently hot and humid summer months. Precipitation is often concentrated in the warmer months, though winter precipitation is highly variable and summers can have long dry stretches. Severe weather such as hail, heavy downpours, and tornadoes are not uncommon during spring and summer.

The Oklahoma City climate station has an official period of record from 1948 to present, with a station at Will Rogers World Airport. During that period Oklahoma City has had annual average high and low temperature of 72.2°F and 50.8°F. Average annual rainfall has been 36.5" and snowfall 7.8". Monthly temperature reaches peak value in July with an average high temperature of 94°F. The annual low occurs in January with average minimum of 29°F. Precipitation is heaviest in June with an average of 4.9" and least in January with an average of 1.40".

Extreme daily conditions are inherent in the Oklahoma City climate record. The highest and lowest recorded temperatures range over 120°F, from -8°F to 113°F. The record daily rainfall and snowfall are 7.62" and 13.5".

8.2 Recent Weather Changes

In recent years, Oklahoma City has experienced seasonal changes in weather. These changes are summarized in the following table.

Recent Weather Changes

Season	Recent Changes
Summer	Increased variability in seasonal precipitation totals More frequent warm nights in the last decade
Fall	More frequent dry falls Average date of first frost is 3 days later
Winter	Warmer and wetter winters
Spring	Fewer cool springs Average date of last frost is 4 days earlier

In addition, recent decades have seen changes in the frequency of hazardous weather events. These changes are summarized in the following table.

Recent Changes in Damaging Events

Damaging Event	Recent Changes
Heat Waves	No changes apparent
Cold Waves	Higher average minimum temperature during the coldest 3-day period
Heavy Rainfall	More years with unusually high number of days with rainfall >1.25" (11 days or more) Higher frequency of unusually high rainfall over wettest 5-day period (>7.5") Higher frequency of unusually high rainfall over wettest 15-day period (>10.8")
Snow Storms	No clear changes in frequency or snowfall totals of snow storms
Late/Early Freeze	Decreased likelihood of unusually late spring or early fall freeze
Tornado, Wind, and Hail	Inconsistencies in reporting are more pronounced than long-term changes in frequency

8.3 Historical Context

To identify recent changes in weather, data from the past three decades are compared to the previous historical record. Here, the past three decades are generally defined as 1981-2010, though more recent data are incorporated into the analysis when available. The official climate record for Oklahoma City at Oklahoma Will Rogers Airport has a relatively short period of record, dating back to 1948 and therefore misses important climate events in Oklahoma's past, such as the heat and drought of the 1930s and the relatively cool, dry weather from 1895-1920. (For a comparison with the surrounding area, see Area Context, page 45.)

While natural variability remains the dominating factor in Oklahoma's weather patterns, there have been clear changes Oklahoma City's climate over the last three decades compared to the previous 30-year period. The average summer high temperature for the 1981-2010 period is about one degree higher than the 1948-1980 average. Hot summers have been slightly more frequent in the last 15 years, punctuated by the drought in the summer of 2011, which ended as the warmest year in the city's history. Oklahoma City has also seen more frequent warm nights with five of the top 10 highest average minimum summer temperatures occurring in the last decade. Summer precipitation totals have also increased in the last three decades, compared to the previous three. Some of that difference is due to the recent drought regime Oklahoma entered in the 2010-2011 period, but a very wet summer of 2013 and above normal 2014 precipitation helped keep average summer temperatures below the previous two summers. With record rainfall in June 2015, the expectation from recent years is relatively cool, though humid, conditions in summer 2015.

Spring average temperatures are 1.0°F higher during 1981-2010 than 1948-1980, but the fall average temperature shows little difference between the two periods. The year-to-year variability of both seasons is quite large, however. Oklahoma City has experienced a decreased frequency of cooler springs in the last 30 years. Spring and fall freeze dates have also changed: during 1981-2010 compared to 1948-1980, the last day in spring with low temperature <32°F was four days earlier, and, in fall, the first day with low temperature <32°F was three days later. However, the earliest fall freeze on record for Oklahoma City occurred in 2012 and the second earliest occurred in 2000, indicating that the volatility of freeze dates is large and that any single year can be substantially different from the average year. Similarly, the three earliest last freeze dates in spring occurred within the last 14 years of the record, but the latest spring freeze date occurred in 2013, demonstrating the same volatility as the earliest fall freeze date. These exceptions should be considered anomalies to the overall trends.

The average winter temperature is 1.3°F higher for the 1981-2010 period than the 1948-1980 frame of reference. The average winter precipitation total has also increased by approximately 1.5 inches from 1948-1980 to 1981-2010.

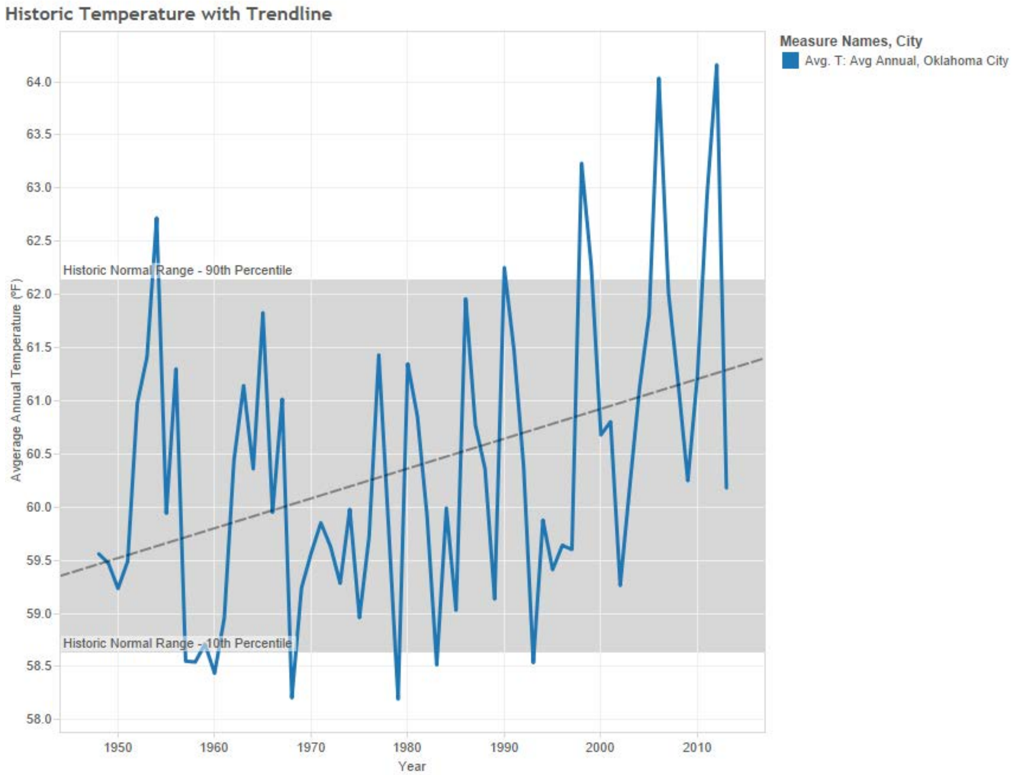


Figure OK2. Recorded annual average temperature with trendline.

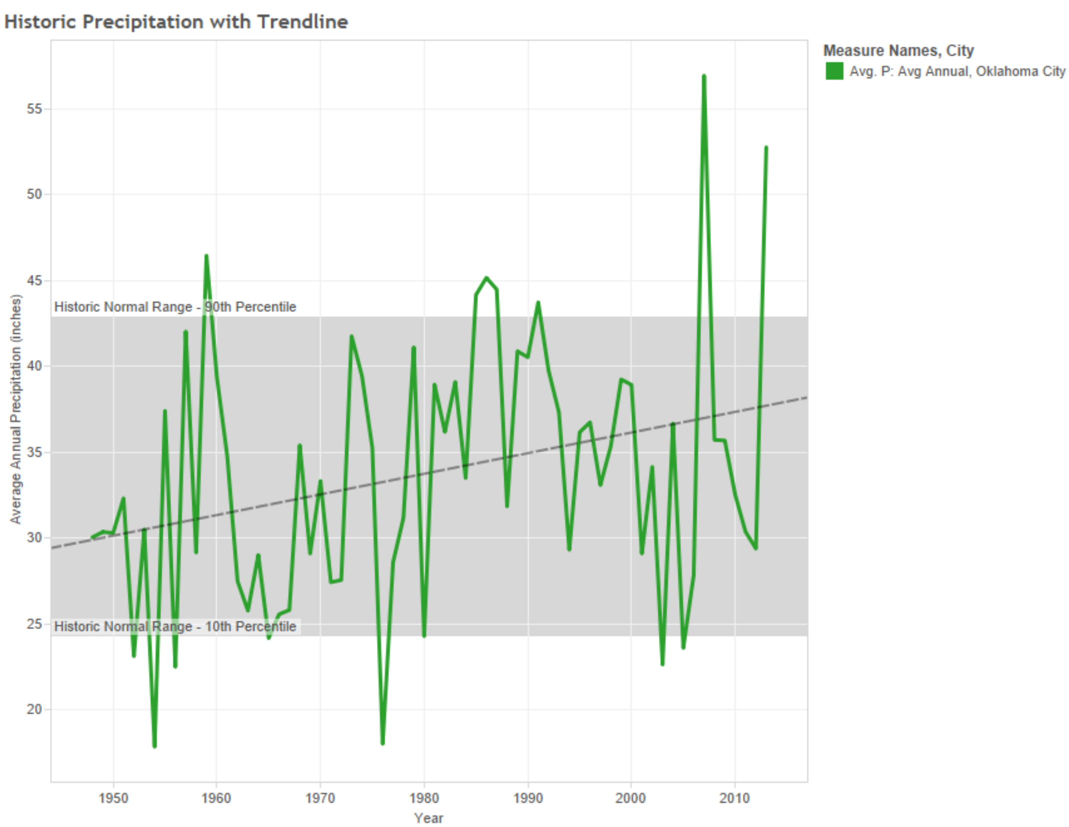


Figure OK3. Recorded annual average precipitation with trendline.

Heating degree days have decreased substantially (~240) due to a recent increase in winter temperature. Cooling degree days have increased somewhat due to recent increase in summer temperature.

The frequency of heavy rainfall events has increased over a daily scale and multi-day (5-day) and 15-day) scales, although the maximum 5-day average is skewed upwards in the 1980-2010 period due to a series of four years in the 1980s that were substantially higher than other recent years. Seven of the eight highest values have occurred since 1980.

8.4 Area Context

Oklahoma City is located in the center of the Central Oklahoma Climate Division (CD5). Its period of record as provided by the National Center for Environmental Information (NCEI) is from 1895 through the present, as opposed to the Oklahoma City official weather station, which only extends back to 1948.

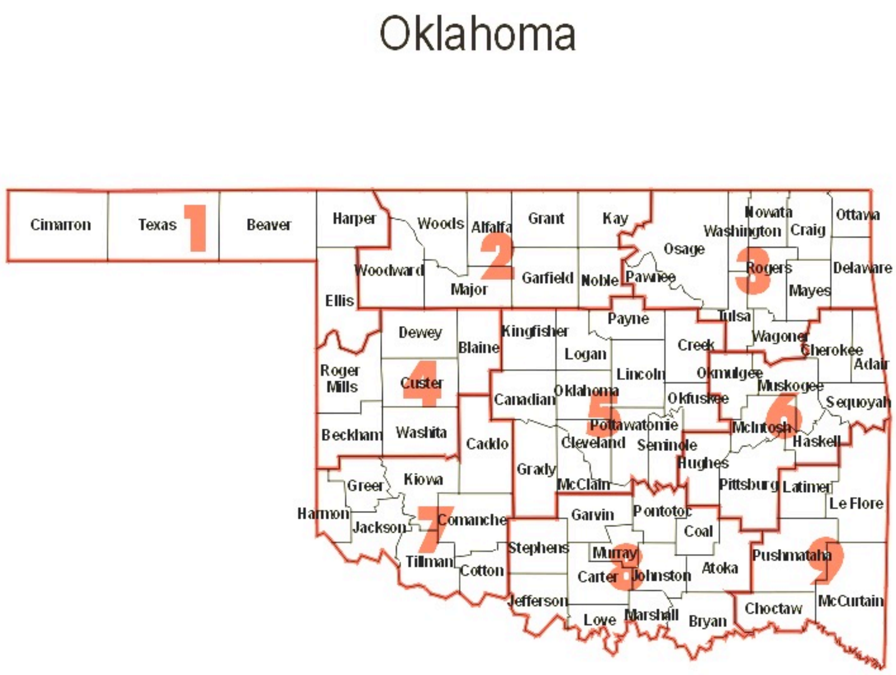


Figure OK4. Climate divisions; Source.

Despite the recent four- to five-year drought cycle experienced by Oklahoma, CD5 has experienced a warmer and wetter climate over the last 30 years. Of the 30 wettest years on record for CD5, 15 have occurred since 1985. Significant drought years did occur in 2003, 2005-2006, 2011-2012, and 2014, but 2007-2009 were significantly above normal, with 2007 standing as the second wettest year on record for CD5. Annual precipitation totals demonstrate a trend of +0.35"/decade since 1895. The temperature trend is static over that same time period, but the trend for the 1981-2010 period is +0.5°F/decade.

Winter temperatures have become consistently warmer than the long-term average over the last 30 years, following a colder than normal period from the 1960s through the 1980s. The temperature trend for the 1981-2010 period was 0.7°F/decade. Spring, summer, and fall also demonstrated positive trends in CD5 for the 1981-2010 period, although not of the magnitude of the winter temperatures. Summer's trend was smallest at 0.3°F/decade. Since 1981, summer temperatures in CD5 have actually been mostly below the long-term 1895-2014 average, but excessively hot years in 1998, 2001, 2006, and 2010 manufacture a false trend. The summer of 2011 was easily the warmest on record for CD5, but 2013 and 2014 were both below the long-term average. Summer maximum temperatures changed very little during the 1981-2010 period, and were in fact below the long-term average for the most part. Minimum temperatures displayed an increase of 0.4°F/decade over that same time.

Autumn temperatures have been highly variable, especially over the last 20 years, but spring temperatures, while similarly variable, have been mostly above the long-term average since 2000.

Winter precipitation averages for CD5 were consistently above normal for the 1980s through the early 2000s, following a significant dry signal for the 1950s through the 1970s. Since the early 2000s, winter precipitation has become quite variable. Autumn precipitation demonstrates the highest volatility throughout the 1895-2014 period, but shows a similar extended period of wetter seasons from the early 1980s through the early 2000s. Summer precipitation totals remain highly volatile for CD5 over the last 30 years, but thanks to some very wet years, on average summer precipitation increased 1.63"/decade for the 1981-2010 period.

8.5 Climate Projections

Average annual temperature is projected to increase substantially, to the extent that the 30-year average temperature in the future will be well above the hottest years in the normal historical temperature range. Annual precipitation is projected to change very little.

Temperature

Temperature is expected to increase rapidly by the 2050s and beyond with much of the projected change occurring during spring, summer, and winter. By 2021-2050, the average summer temperature is projected to exceed what is currently the threshold of the top 10% hottest years. This is a much faster rate of increase than measured in the recent change.

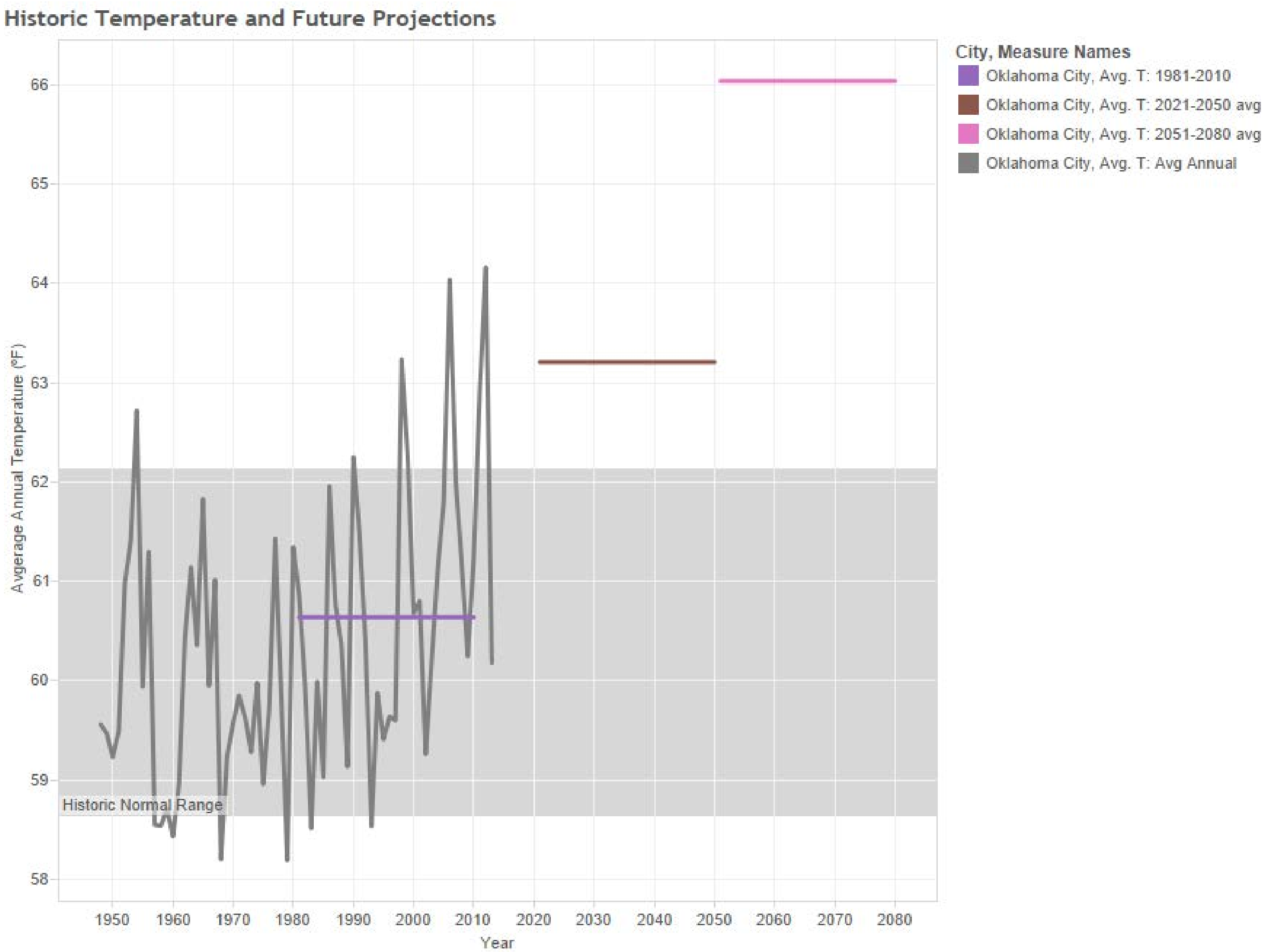


Figure OK5 illustrates the difference in annual temperature in the past and future. The line shows recorded temperatures from the historic record, and the 1981-2010 average is calculated from recorded temperatures. The 2021-2050 and 2051-2080 averages are calculated from climate models.

Precipitation

Annual precipitation is projected to continue the slight recent historical increase. The increase in projected precipitation is largest in fall with small increases in spring and winter. A small decrease in precipitation is projected for summer.

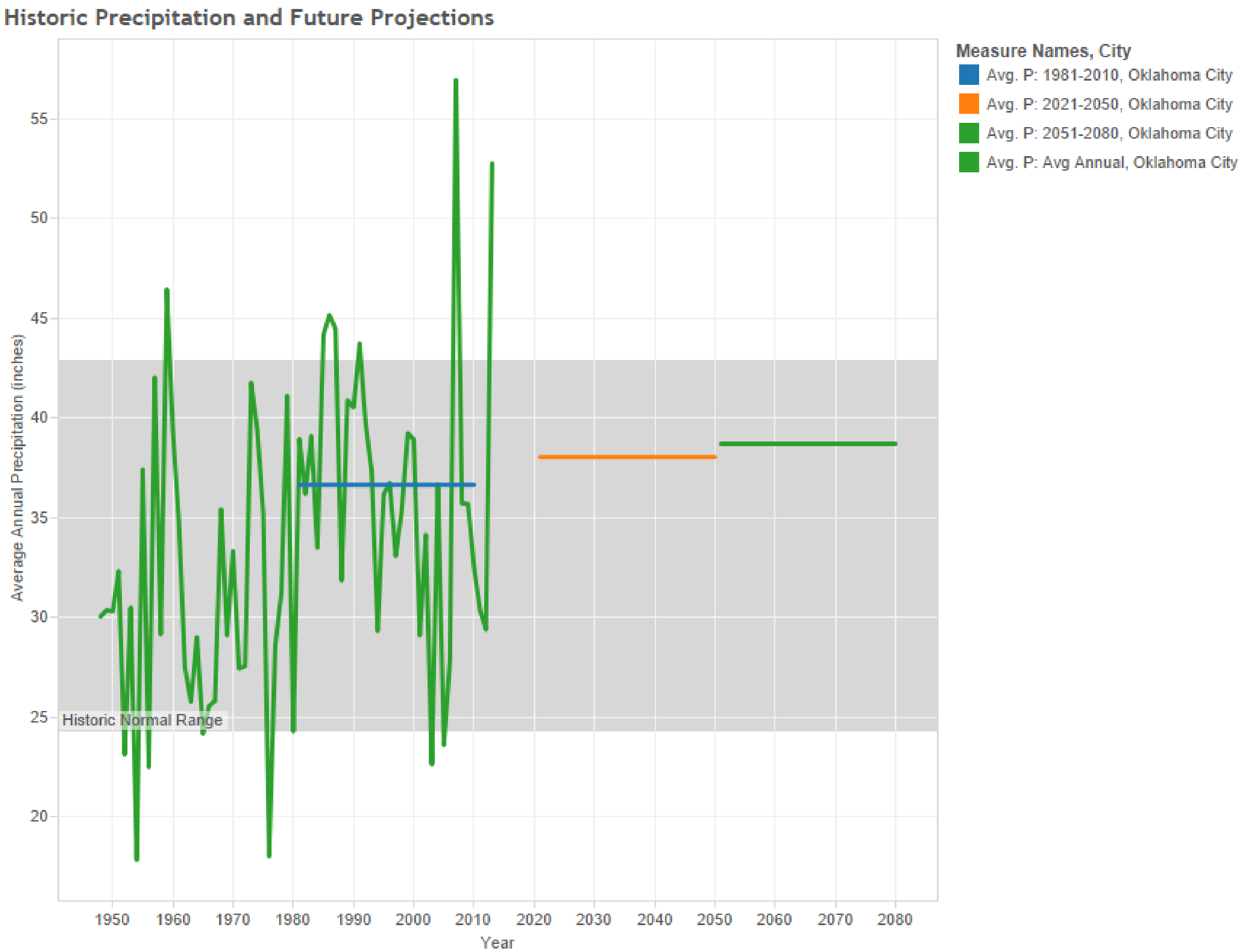


Figure OK6 illustrates the difference in annual precipitation in the past and future. The line shows recorded precipitation from the historic record, and the 1981-2010 average is calculated from recorded precipitation. The 2021-2050 and 2051-2080 averages are calculated from climate models.

Data

The following tables show projection data for temperature, precipitation, and hazardous events in coming decades, relative to the last 30 years.

Projected Changes in Climate

Season	Metric	1981-2010	2021-2050	2051-2080
Annual	Average	60.7°F	63.2°F	66.0°F
	Maximum	71.5°F	74.0°F	76.8°F
	Minimum	49.8°F	52.4°F	55.3°F
	Precipitation	36.6″	38.0″	38.7″
Summer	Average	77.1°F	79.8°F	82.5°F
	Maximum	87.4°F	90.1°F	92.7°F
	Minimum	66.8°F	69.6°F	72.3°F
	Precipitation	11.2″	11.0″	10.6″
Fall	Average	73.1°F	74.4°F	76.5°F
	Precipitation	9.8″	10.5″	11.5°F
	Frost Date	November 10	November 13	November 15
Winter	Average	39.8°F	42.5°F	45.4°F
	Maximum	50.0°F	52.8°F	56.1°F
	Minimum	29.6°F	32.2°F	34.8°F
	Precipitation	4.9″	5.3″	5.4″
Spring	Average	51.3°F	54.8°F	58.4°F
	Precipitation	10.7″	11.2″	11.2″
	Frost Date	March 27	March 21	March 14

Projected Changes in Hazardous Events

Damaging Event	Metric	1981-2010	2021-2050	2051-2080
Heat Waves	3-day average	88.5°F	91.3°F	94.2°F
	3-day maximum	102.0°F	105.0°F	108.2°F
	3-day minimum	76.3°F	78.7°F	81.6°F
Cold Waves	3-day minimum	9.9°F	13.2°F	16.3°F
Heavy Rainfall	Days > 1.25″	7 days	8 days	8 days
	Days > 4.00″	1 day per 3 years	1 day per 3 years	1 day per 3 years
	5-day	5.4″	5.7″	6.0″
	15-day	7.6″	7.9″	8.6″
Thaw Freeze	Days > 45°F followed by days < 28°F	3.5 times per year	3.1 times per year	2.4 times per year

The following summary describes all climate change impacts, noting consistency, or lack thereof, with recent changes. See Discussion for information about the relationship between consistency and confidence.

- *Spring temperature* has recently increased by 1.2°F from 50.0°F to 51.3°F. It is projected to increase at a faster rate to 54.8°F in 2021-2050 and 58.4°F in 2051-2080.
- *Summer temperature* is projected to increase from 77.1°F in 1981-2010 to 79.8°F in 2021-2050 to 82.5°F in 2051-2080. Recent change in summer temperature is negligible, despite having the two hottest summers on record within the most recent decade.
- *Date of last frost in spring* is projected to be earlier in the year by nearly one week (March 21) in 2021-2050 and two weeks in 2051-2080 (March 14). This is the same direction of change as in the historical data for which the average date of last spring frost has shifted four days earlier in the year.
- *Date of first frost in fall* is projected to be November 13 by 2021-2050 and November 15 by 2051-2080. The recent historical change in first frost in fall is in the same direction and is occurring 3 days later.
- The *hottest 3-day maximum* is projected to increase substantially. In 2021-2050, the hottest 3-day maximum is expected to increase to 105.0°F, and further increase is expected to 108.2°F in 2051-2080. The historical data show almost no change in the current value of 102.0°F.

- The *hottest 3-day minimum* is projected to increase substantially. In 2021-2050, the hottest 3-day maximum is expected to increase to 78.7°F, and further increase is expected to 81.6°F in 2051-2080. The historical data show almost no change in the current value of 76.3°F.
- *Fall precipitation* is projected to increase substantially. The projected increase is from 9.8" in 1981-2010 to 10.5" in 2021-2050 to 11.2" in 2051-2080. This is the same direction of change and about the same rate as measured in historical data.
- *Summer precipitation* is projected to decrease a small amount. This is substantially different than the recent change of summer precipitation for which an increase from 10.3" to 11.2" has been observed. The projected decrease reduces summer rainfall to 11.0" in 2021-2050 and to 10.6" in 2051-2080.

9 Discussion

9.1 Interpretation

The purpose of this report is to present climate projection data in terms of metrics that are readily applicable. This information includes sections on the level of scientific confidence in these metrics, as well as sources of uncertainty.

Confidence

For municipal planning purposes, it is important to understand the level of scientific confidence in future climate projections. Confidence levels can be determined by comparing the direction of change in the historical climate and future projection data. Highest confidence should be assigned when change is in the same direction in both data sets. When this happens, it means that recent change has factors going forward that may support further change in the same direction.

Confidence levels arise from the fact that normal historical climate range should be used to plan for the next decade; whereas, future climate projection data should be used for planning further into the future. The confidence level associated with different combinations of recent and projected direction of change is provided in the table below.

Confidence Levels for Climate Projections beyond the Next Decade

	No Predicted Change	Predicted Increase	Predicted Decrease
No Recent Change	No Change	Increase	Decrease
Recent Increase	No Change	Increase	Decrease
Recent Decrease	No Change	Increase	Decrease

Legend
- High Confidence
- Moderate Confidence

Uncertainty

There is a degree of uncertainty in any projection exercise. With climate projection, uncertainty arises from four sources, all of which are relevant to long-range municipal climate planning. The largest source of uncertainty is human behavior, particularly the amount of greenhouse gas emissions.[8]

- *Natural variability*, which causes temperature, precipitation, and other aspects of climate to vary from year to year and even decade to decade
- *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
- *Scenario uncertainty*, which results from the unpredictability of human behavior, particularly regarding policies on greenhouse gas emissions, as future climate change will continue in response to human activities that have not yet occurred
- *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.

This project has addressed these sources of uncertainty in the following ways.

- To address uncertainty from *natural variability*, the climate projections are summarized over two future 30-year periods, 2021-2050 and 2051-2080. Natural variability is an important source of uncertainty in the next two decades. Recent trends that are consistent with projected climate change in 2021-2050 are the strongest indicators of future climate conditions. Consistency, or lack thereof, between recent trends and future projections has been noted for each city.
- *Scientific uncertainty* is addressed by selecting projections from nine global climate models (CCSM3, CGCM3, CNRM, ECHAM5, ECHO, GFDL2.1, HadCM3, HadGEM, and PCM). Differences between the models are indicative of the limitations of scientific ability to simulate the climate system. Scientific uncertainty is an important source of uncertainty in

[8] Much of the content in this section is derived, paraphrased, or quoted with permission from Hayhoe (2014).

determining the magnitude and sometimes even the direction of projected changes in average precipitation, as well as dry days and extreme precipitation.

- *Scenario uncertainty* is addressed by selecting climate model projections under three future greenhouse gas emissions scenarios. The greenhouse gas emissions scenarios reflect different levels of international cooperation on emissions reduction resulting in scenarios with emissions rates that have moderate reductions (Scenario A1B), little to no reductions (A2), and increases (A1FI). Should greenhouse gas reductions be pursued aggressively, resulting in a significant reduction in atmospheric carbon, the future change summarized in this document may no longer be reasonable for planning. Through 2015, the observed trend in global emissions is most similar to A1FI scenario.
- Finally, *local uncertainty* is addressed by use of global climate model simulations downscaled to stations with long-term weather reports using the Asynchronous Regional Regression Model as described in Stoner et al. (2013). The data used for downscaling is the same data utilized to produce the historical weather reports in this document. These projections are based on a single location. In the future, to generate robust projections for planning purposes, it is recommended that a similar analysis be conducted for all long-term weather stations in the municipal area.

In addition to the uncertainty inherent in predicting the future, data sets must also be examined for validity. The ability to detect change in the historical weather record is the fundamental concern of climatologists, who have identified the following concerns regarding data validity.

- *Data record length*: A short data record makes it more difficult to ascertain whether recent weather extremes are outside the range of past extremes and whether recent change is large compared to past variability. Data record length is reported for each city, and, where the record is short, it is compared to a longer record from the nearby area.
- *Weather station conditions*: If the landscape surrounding a weather station becomes more urban, the record can reflect an increase in temperature due to changing land use, an increase that is not present where the landscape has remained rural. This is known as the urban heat island effect, and, where applicable, it can challenge data validity. Similarly, change in vegetation, such as from forest to cropland, can alter humidity and temperature. This has been addressed by comparing each station's data with data from the surrounding area.
- *Change in location*: When a station is moved, particularly from a higher to lower elevation or an urban to rural setting, the temperature and humidity can change substantially. Where this situation occurred, a nearby weather station with stable location was utilized instead.
- *Change in instrumentation or reporting procedure*: The time of reporting for daily maximum and minimum temperature has changed from afternoon to morning, and the instrumentation used for reporting has changed in some stations. This can alter the average maximum and minimum temperature by a degree or more.

This project addressed data validity by utilizing a team that included university climate scientists, who worked on the projections, in collaboration with state climatologists, who have set standards for data quality and control procedures of historical station data. For each municipality's historical report, the state climatologist selected the best available long-term record and situated any change in the municipality's record within the context of regional change.

The downscaled data used in this report were generated by the Asynchronous Regional Regression Model (Stoner et al. 2013). The following criteria were applied when selecting this dataset for downscaled climate projections.

Considerations in Selecting Downscaled Climate Datasets

Consideration	Comments
Temporal and Spatial Characteristics	Downscaled data available as daily data at locations of historical weather data.
Accuracy	Downscaled climate data has been evaluated against historical station data.
Methodological Assumptions	Fixed parameter assumptions have been evaluated by the perfect model framework developed at the Geophysical Fluid Dynamics Laboratory (http://gfdl.noaa.gov/esd_eval_stationarity_pg1).
Uncertainty	Downscaled climate data adequately samples uncertainty from natural variability, scientific uncertainty, human uncertainty, and local uncertainty.
Availability	Downscaled climate projections database was immediately available to our project through direct provision by Katharine Hayhoe, Texas Tech University High Performance Computing Center.
Use in other Assessments	The downscaled climate projection database has been used in assessments by other municipalities and federal agencies. This ensures we are using a well-reviewed data set and can draw from and contribute to learning of its best uses.

9.2 Application

Specific, localized climate projection information is useful information to local governments. The recorded record shows the climate throughout the Great Plains shows the climate was relatively stable for a long period, and government functions evolved to operate within that range. However, as cities have seen in recent years, when extreme weather events push the climate outside the normal range, it puts stressors on government organizations to respond to significant weather events while continuing to provide regular services. The impacts are immediate (e.g., personnel safety), medium range (e.g., cleanup and restoration), and long range (e.g., planning for infrastructure development).

While there are multiple ways to utilize this information, the particular strategy is outlined here based on recent work completed in Oklahoma City. This strategy is ideal for cities with limited staff time to dedicate to a project, as it does not require ongoing committee work. The method involves determining how current weather affects departmental operations and extrapolating to ascertain how the impacts will change over time.

Once support is obtained for the study, steps involved in this process include the following.

1. Develop a list of critical government functions that may be affected by weather. This should be done by staff who are familiar with municipal operations and may also include a review of other cities' plans. In Oklahoma City, critical functions included public safety, water utilities, solid waste, infrastructure, public facilities, public transportation, and personnel. An "other" category captured impacts that did not fit within these groupings.
2. Create a list of departmental representatives with operational knowledge about these government functions, particularly how they are affected by weather events.
3. Make a list of specific effects that may occur within each of the departments associated with the critical government functions. For example, in public safety, impacts may include personnel safety, response times, and call volume, among others.
4. Make a list of the weather events that impact operations.
5. Utilize the list of specific effects and list of weather events to create tables in preparation for interviews with departmental representatives. A sample table is included in
6. Schedule and conduct 30-90-minute interviews with departmental representatives. Utilize the tables as a starting point, but emphasize that not every cell must be completed and request support in identifying other important impacts not listed. It is useful to appoint one person as an interviewer and one as a notetaker. Begin with an assessment of how weather currently affects government functions, and follow with questions about how changing conditions may alter the impacts. (Note: if climate projections are not available at the time of interviews, as was the case in Oklahoma City, questions can be asked hypothetically. Future impacts can be extrapolated from current impacts once climate projections are received.)
7. Record interview notes. After the interview, organize notes, tagging impacts by the weather type and government function affected. Make note of general impacts on government, which may be the same regardless of the nature of the disaster. Note that impacts may be positive, negative, neutral, or mixed.
8. Prepare report and disseminate. Utilize information to develop an action plan to mitigate negative impacts. Incorporate results into other long-range plans, such as the comprehensive plan, hazard mitigation plan, capital improvement plan, or climate adaptation plan.

Utilizing this methodology, the City of Oklahoma City has completed an impact analysis of present and future climate conditions. For more information, contact the Sustainability Office at sustainability@okc.gov.

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Walsh, J. and Wuebbles, D., 2014: National Climate Assessment 2014. Accessed at http://nca2014.globalchange.gov/report.

Appendix A: Regional Changes in Temperature

Several broad similarities were apparent in the historical and projection data for cities in this report. Much of this consistency arises from the fact that they are all in the Great Plains region of the United States. Examining broad spatial patterns is useful because it helps explain these similarities. The National Climate Assessment 2014 (NCA 2014) (Walsh and Wuebbles 2014) contains information about two temperature metrics of relevance in this report: projection of change in future annual temperature and historical change in daily maximum and minimum temperature.

Two emissions scenarios analyzed in this report are included in NCA 2014, the A2 and A1B scenarios.[9] The A2 scenario is considered a "business as usual" scenario, while A1B is a scenario in which the rate of increase of greenhouse gas concentration is slowed slightly. The broad pattern illustrates why projections of temperature change are similar among the municipalities.

In Figure X, the projection of annual temperature change for 2071-2099, relative to 1970-1999, is shown for the A2 and A1B scenarios. The A2 scenario shows greater change than A1B in annual temperature. Importantly, the pattern of change is similar for most of the central United States. For the A2 scenario, the entire central United States is 8-9°F warmer; whereas, for the A1B scenario, the south central United States is warmed 5-6°F but the north central United States is warmed 7-8°F. This broad pattern of future change is the reason annual temperature increases well beyond the historical bounds of annual temperature are projected unequivocally for all municipalities in this report.

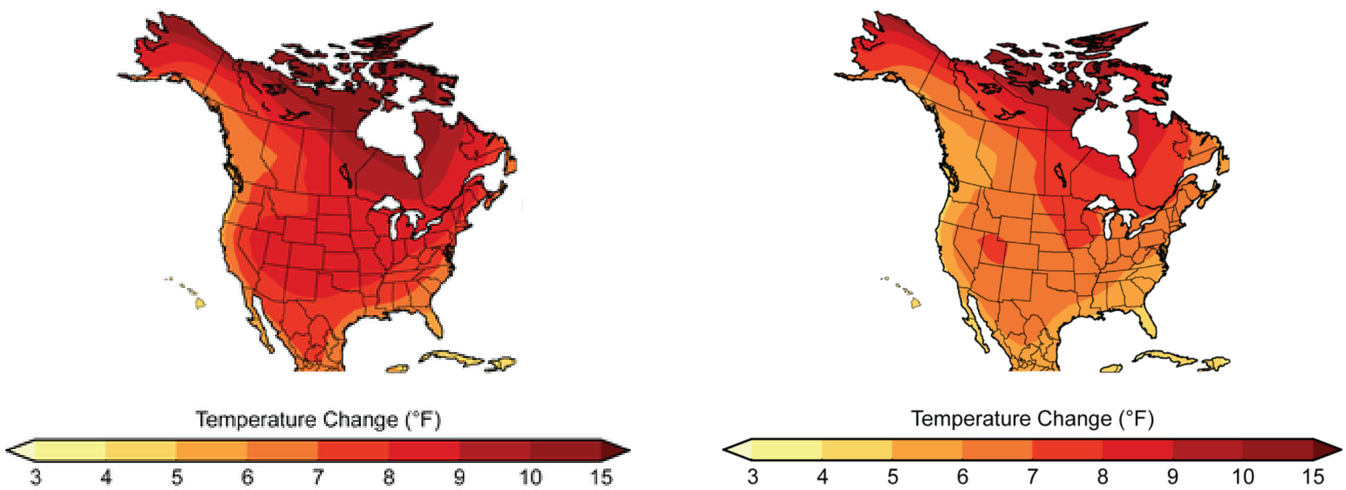

Figure A1: SRES projected change in surface air temperature at the end of this century (2071-2099) relative to the end of the last century (1970-1999). (Figure source: NOAA NCDC / CICS-NC).

At times, the direction of future change may be opposite of recent change, even over a broad region. For example, NCA 2014 summarized trends in annual maximum and annual minimum temperature (Figure C2) (Menne and Williams 2009; Walsh and Wubbles 2014)[10] and showed that annual maximum temperature has had decreasing trend over large portions of Iowa, Missouri, and Nebraska and mixed trend over Kansas and Oklahoma, although future projections predict a warming trend (Figure X). Annual minimum temperature is more consistent, with an increasing trend everywhere except southeastern Oklahoma.

These figures, taken together, illustrate that mean annual temperature increase in the future (Figure X [1st image]) will be an emerging trend for most of the central United States, whereas to date only annual minimum temperature has increased (Figure X [2nd image]).

[9] The scenarios are described under National Climate Assessment 2014 Supplemental Message 5 and in Figure 19, available at the following URL: http://nca2014.globalchange.gov/report/appendices/climate-science-supplement#statement-38715

[10] Descriptions of data and figures are available from National Climate Assessment 2014 Climate Science Supplement, using the following URL: http://nca2014.globalchange.gov/report/appendices/climate-science-supplement#statement-38713.

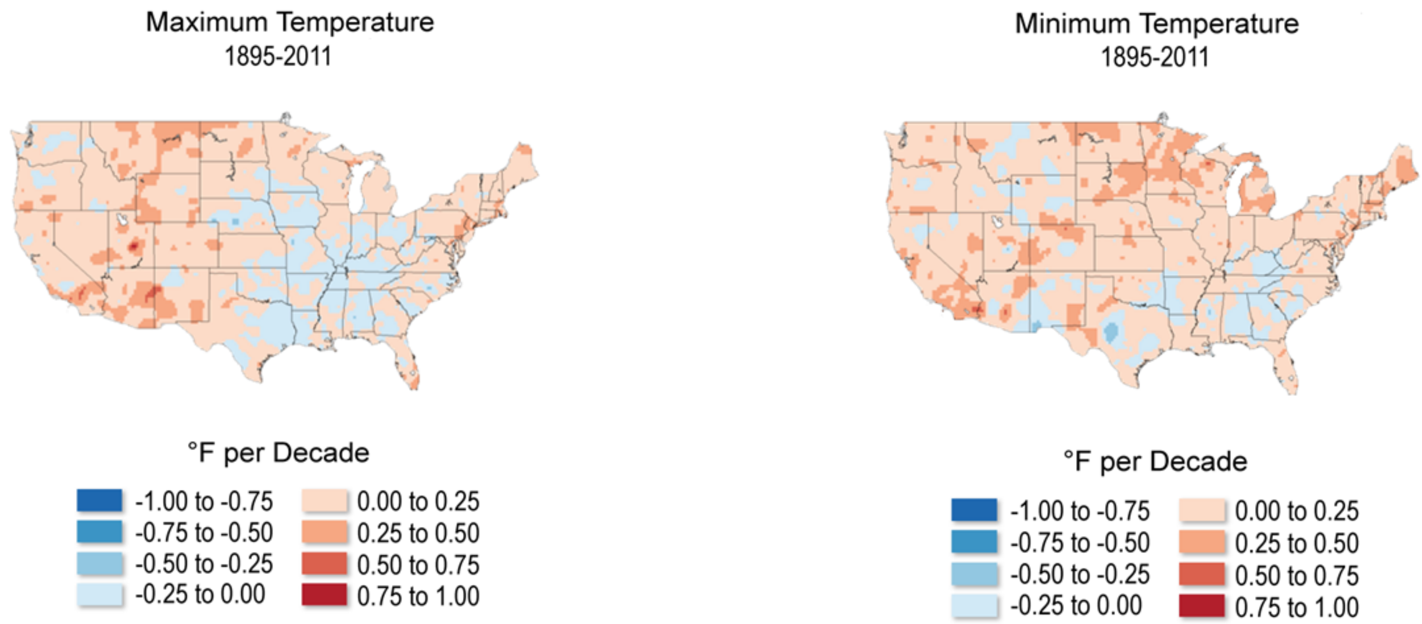

Figure A2: Trends in Maximum and Minimum Temperatures adjusted. Caption: Geographic distribution of linear trends in the U.S. Historical Climatology Network for the period 1895-2011. (Figure source: updated from Menne et al. 2009).

Appendix B: Climate Metrics and Definition of Terms

Several factors influenced the choice of climate metrics (TABLE X). For example, a standard meteorological definition doesn't exist for heat waves, but studies of the 1995 Chicago heat wave have identified 3-day temperature as an indicator of human survival. Similarly, concerning rainfall, engineers use 1.25" as a threshold for infiltration for storm water, and climatologists list maximum of 1-day and 5-day rainfall among internationally agreed upon extreme weather metrics.

The data in the climate data sets consists of daily entries for maximum temperature, minimum temperature, and precipitation. Metrics are combinations of these values and are defined in the table below. Seasonal averages follow the meteorological seasons:

- Summer values are averaged over June, July, and August.
- Fall values are averaged over September, October, and November.
- Winter values are averaged over December, January, and February.
- Spring values are averaged over March, April, and May.

Climate Metrics Definitions

Metric	Computation
Seasonal Accumulation or Average	Sum over days during meteorological season. For seasonal average, divide sum by number of days. Days included in each season are: Summer, days 152-243; Fall, days 244-334; Winter, days 335-365 and (following year) days 1-59; Spring, days 60-151.
Cooling Degree Days	Annual accumulation of difference between daily average temperature and 65°F when daily average is above 65°F. Daily average temperature above 65°F indicates the need for air conditioning to maintain indoor temperature of 70°F. Annual accumulation indicates the amount of demand for air conditioning over the entire year.
Heating Degree Days	Annual accumulation of difference between daily average temperature and 65°F when daily temperature is below 65°F. Daily average temperature below 65°F indicates the need for heating to maintain indoor temperature of 70°F. Annual accumulation indicates the amount of demand for heating over the entire year.
Spring Frost Date	Prior to July 1st, latest day of minimum temperature less than 32°F
Fall Frost Date	After July 1st, latest day of minimum temperature less than 32°F
Heat Waves	Annual maximum of running 3-day average maximum temperature; annual maximum of running 3-day average temperature
Cold Waves	Annual minimum of running 3-day average minimum temperature
Thaw to Freeze	Average daily temperature changes from >45°F to <28°F
Moderate Warm to Freeze	Average daily temperature changes from the range of 32°F-45°F to below 28°F
Number Rainfall Days Greater than Threshold	Annual sum of days exceeding 1.25" and 4.0"
Number Snowstorm Days Greater than Threshold	Annual sum of days with snow exceeding 3.0", 6.0", 9.0", and 12.0"
Maximum 5-day Rainfall	Annual maximum of running 5-day rainfall

Maximum 15-day Rainfall	Annual maximum of running 15-day rainfall
Maximum 3-day Snowfall	Annual maximum of running 3-day snowfall
Top 10% of Years; 90th Percentile	Years are sorted from lowest to highest; threshold is the value above which there are 10% of the years
Bottom 10% of Years; 10th Percentile	Years are sorted from lowest to highest; threshold is the value below which there are 10% of the years

Appendix C: Sample Interview Table

The table on following pages is representative of the type of table used in departmental interviews in Oklahoma City. Weather events are listed in rows, and potential functions impacted by weather are listed in columns. This example was utilized for an interview with the fire department.

	Personnel safety	Response times	Call volume	Road access	Elderly & vulnerable	Facilities, Equip, Budget
Floods, flash floods						
Heavy rainfall						

	Personnel safety	Response times	Call volume	Road access	Elderly & vulnerable	Facilities, Equip, Budget
Tornadoes						
Hail						

	Personnel safety	Response times	Call volume	Road access	Elderly & vulnerable	Facilities, Equip, Budget
Longer frost-free season						
Warmer Winters						

	Personnel safety	Response times	Call volume	Road access	Elderly & vulnerable	Facilities, Equip, Budget
Heat waves						
Drought						

	Personnel safety	Response times	Call volume	Road access	Elderly & vulnerable	Facilities, Equip, Budget
Wildfire/ brush fire						
Winter ice storms, blizzards						

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