

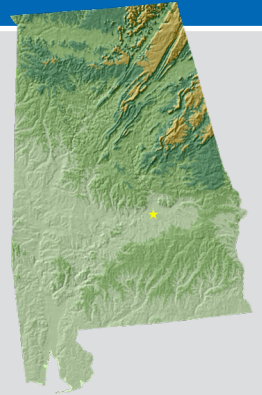
ALABAMA

Key Messages

Temperatures in Alabama have not risen since the beginning of the 20th century, one of the few areas globally to experience no net warming. However, recent years have been very warm, and the warmest consecutive 5-year interval was the most recent, 2016–2020. Under a higher emissions pathway, historically unprecedented warming is projected during this century.

There are no robust trends in total annual precipitation and the number of extreme precipitation events. Future changes in average precipitation are uncertain, while increases in the frequency and intensity of extreme rainfall are projected.

Global sea level is projected to rise, with a likely range of 1–4 feet by 2100. Sea level along the Alabama coast has risen at the rate of 1.6 inches per decade, faster than the global rate. Projected sea level rise poses widespread and continuing threats to both natural and built environments in coastal Alabama.



Alabama is located at subtropical latitudes between the Gulf of Mexico and the southern end of the vast, relatively flat plains of central North America, which extend from the Arctic Circle to the Gulf of Mexico. The state is therefore exposed to the influences of diverse air masses, including the warm, moist air from the Gulf of Mexico and dry continental air masses, which are cold in the winter and warm in the summer. Clockwise circulation of air around a semipermanent high-pressure system in the North Atlantic (known as the Bermuda High) causes a persistent southerly flow of air off the gulf during the warmer half of the year. Thus, relatively mild winters, hot summers, and year-round precipitation characterize Alabama's climate. In addition to serving as a predominant source of moisture, the Gulf of Mexico helps moderate temperatures along the coast. Alabama's mild climate is an important economic driver for agricultural production and tourism.

Temperatures in Alabama have not risen since the beginning of the 20th century, one of the few areas globally to experience no net warming. However, recent years have been very warm, and the warmest consecutive 5-year interval was the most recent, 2016–2020 (Figure 1). Temperatures in Alabama were highest in the 1920s and 1930s, followed by a substantial cooling of almost 2°F into the 1960s and 1970s. Since that cool period,

Observed and Projected Temperature Change

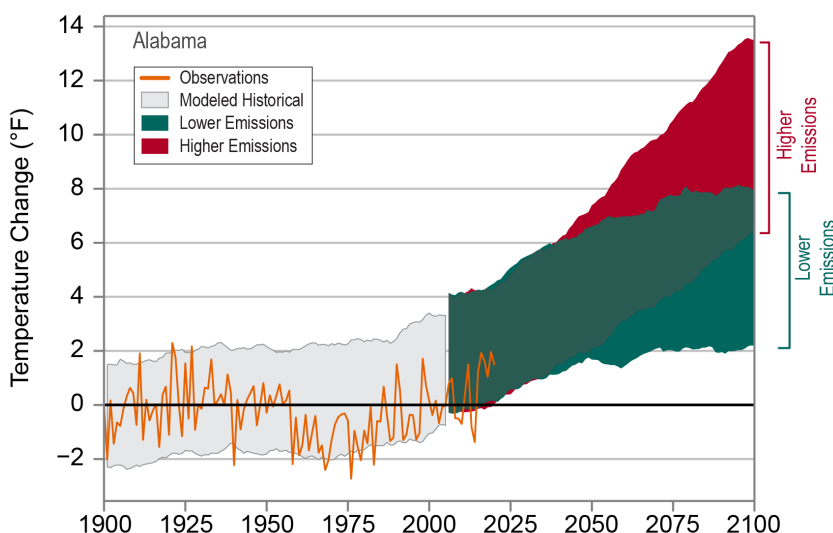


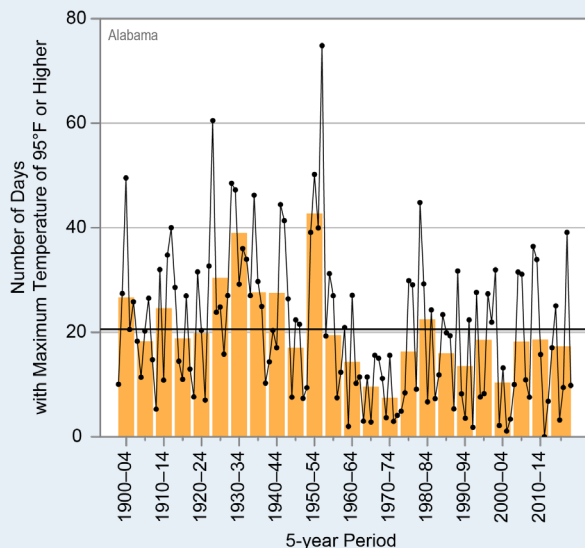
Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Alabama. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Alabama (orange line) have not risen since the beginning of the 20th century, one of the few areas globally to experience no net warming. However, recent years have been very warm, and the warmest consecutive 5-year interval was the most recent, 2016–2020. Shading indicates the range of annual temperatures from the set of models. Observed annual temperatures are generally within, but on the very low end of, the envelope of model simulations of the historical period (gray shading). However, for summer daytime maximum temperatures, which have decreased over the

20th century, this localized cooling is not well simulated by climate models. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about as warm as the hottest year in the historical record; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 11°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

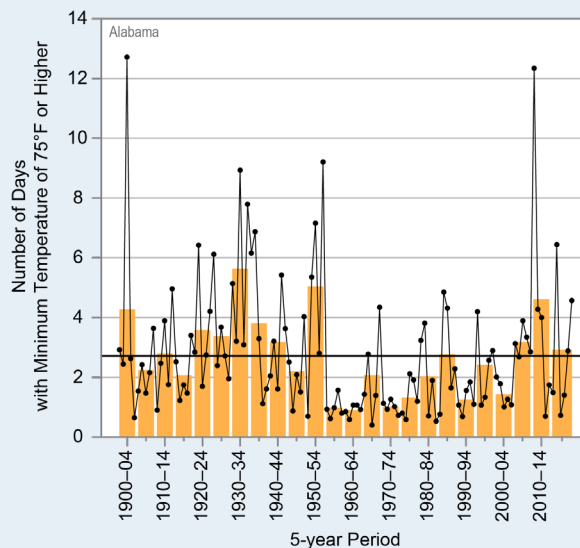
temperatures have risen by more than 2.0°F. The contiguous United States as a whole has warmed by about 1.8°F since 1900, although it also cooled from the 1930s into the 1960s but not by nearly as much as Alabama. Hypothesized causes for this difference in warming rates include increased cloud cover and

precipitation, increased small particles from coal burning, natural factors related to forest regrowth, decreased heat flux due to irrigation, and multidecadal variability in North Atlantic and tropical Pacific sea surface temperatures.

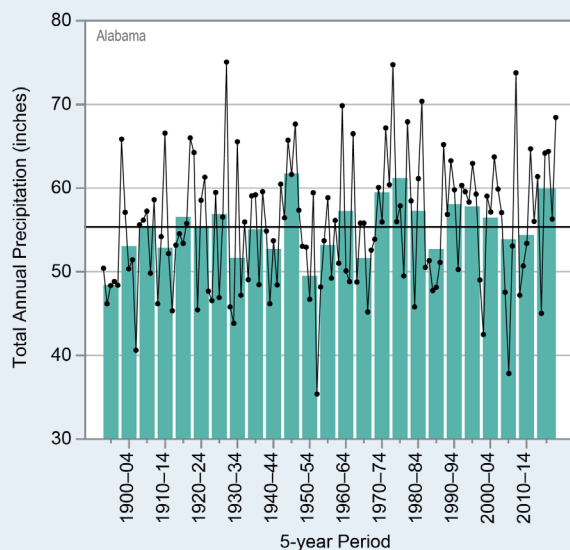
a) Observed Number of Very Hot Days



b) Observed Number of Very Warm Nights



c) Observed Annual Precipitation



d) Total Hurricane Events in Alabama

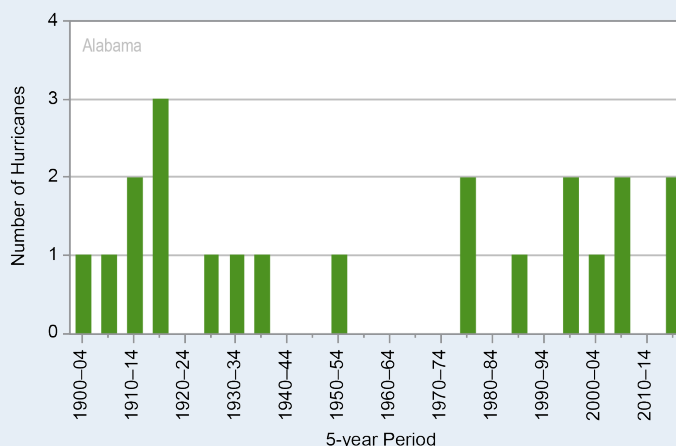


Figure 2: Observed (a) annual number of very hot days (maximum temperature of 95°F or higher), (b) annual number of very warm nights (minimum temperature of 75°F or higher), (c) total annual precipitation, and (d) total number of hurricane events (wind speeds reaching hurricane strength somewhere in the state) for Alabama from (a, b, d) 1900 to 2020 and (c) 1895 to 2020. In Figures 4a, 4b, and 4c, dots show annual values, bars show averages over 5-year periods (last bar is a 6-year average), and the horizontal black lines shows the long-term (entire period) averages: (a) 21 days, (b) 2.7 nights, (c) 55.4 inches. In Figure 4d, bars show totals over 5-year periods (last bar is a 6-year total). The number of very hot days has been below average since 1985, while the number of very warm nights has been near or above average since 2005. Total annual precipitation shows high year-to-year variability and no overall trend. Notably, the 2005 to 2009 period had the second-driest (2007) and third-wettest (2009) years on record. There is no long-term trend in the number of hurricane events. Since 2000, the state has been impacted by 5 storms. Sources: (a, b, c) CISESS and NOAA NCEI; (d) NOAA Hurricane Research Division. Data: (a, b) GHCN-Daily from 7 long-term stations; (c) nClimDiv.

Statewide summer average daytime high temperatures have historically ranged from about 87°F (in 1967) to about 95°F (in 1902), although daily temperatures exceeding 95°F are common. In recent decades, the number of very hot days has been well below the numbers experienced during the early 1930s and early 1950s (Figure 2a). Since 2005, the number of very warm nights has been near or above average but still below the numbers of the early 1930s and early 1950s (Figure 2b). In the winter, average nighttime low temperatures range from 30°F in the northern portion of the state to more than 45°F along the coast. The annual average (1991–2020 normals) number of nights at or below 32°F is 47 and 56 for Birmingham and Huntsville, respectively, compared to only 21 for Mobile.

Annual precipitation is highly variable from year to year (Figure 2c). Statewide annual average precipitation is 55.4 inches and is distributed rather uniformly throughout the year, except for a relatively dry period between August and October. While there is no long-term trend over the period of record (1895–2020), the 2015–2020 period was above average. The second-driest year on record (2007) and second-driest consecutive 3-year interval (2006–2008) were followed by the third-wettest year (2009). The driest multiyear periods were in the late 1890s and early 1950s and the wettest in the late 1940s and late 1970s. The driest consecutive 5-year interval was 1895–1899, with an annual average of 48.3 inches, and the wettest was 1971–1975, with an annual average of 63.7 inches. The combination of variable summer precipitation patterns and the prevalence of soils with poor water-holding capacity frequently gives rise to short-term drought conditions. **The number of 3-inch extreme precipitation events has been near or above average since 1995 but shows no statistically significant long-term trend** (Figure 3).

Tornadoes and hurricanes are two of the deadliest weather hazards in Alabama. Between 1895 and 2019, an estimated 43 tornadoes, typically occurring in the spring and fall, touched down in Alabama each year. In 2011, a deadly tornado outbreak swept across the southern, midwestern, and northeastern United States. Alabama was one of the hardest-hit states, suffering an estimated 238 tornado-related deaths and millions of dollars in property and infrastructure damages. Hurricanes and tropical storms can also cause massive property damage. On average (1900–2020), Alabama is directly impacted by a hurricane

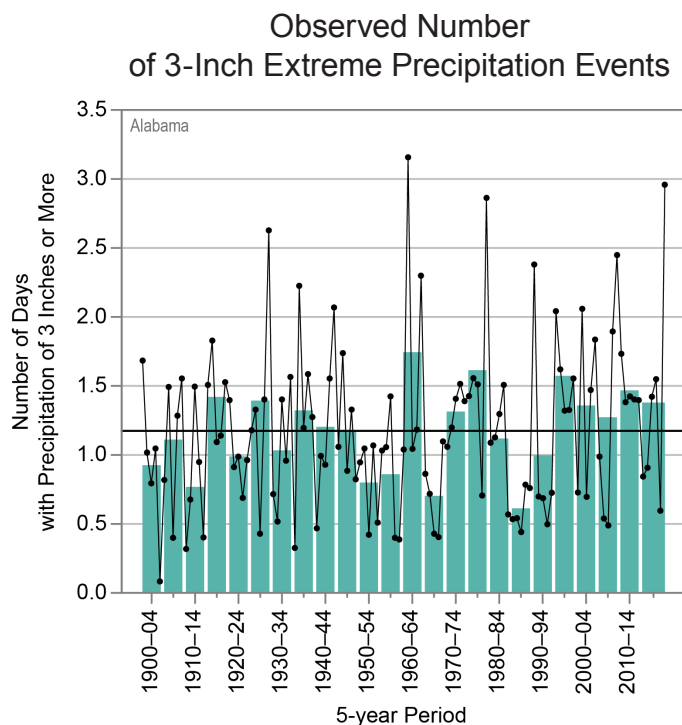


Figure 3: Observed annual number of 3-inch extreme precipitation events (days with precipitation of 3 inches or more) for Alabama from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 1.2 days. A typical reporting station experiences about 1 event per year. The number of 3-inch extreme precipitation events has been above average since 1995, but there is no statistically significant long-term trend. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 12 long-term stations.

about once every 6 years; however, there has been no long-term trend over the past century (Figure 2d). In 2005, Hurricane Katrina brought hurricane-force winds along the Alabama coastline, spawning tornadoes and causing widespread wind damage and flooding following a storm tide (storm surge combined with already-present tide) of 14 to 18 feet. In 2012, Hurricane Isaac resulted in a storm surge (the abnormal rise of water generated by a storm over and above the predicted astronomical tide) of 4.63 feet above normal tide levels in the Mobile Bay area and 3 to 5 feet of inundation (the total water level that occurs on normally dry ground as a result of storm tide) along the coast of Alabama.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of the century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly

warmer than historical records. Warming is projected despite the lack of a long-term temperature trend because the increased warming influence of greenhouse gases will become greater than the natural variations that have dominated Alabama's temperature climate.

Future changes in total annual precipitation are uncertain (Figure 4). However, any increase in temperature will accelerate the rate of soil moisture loss during dry periods and likely increase the intensity of naturally occurring droughts. **Increases in extreme precipitation are projected for Alabama, because it is virtually certain that atmospheric water vapor will increase in a warmer world.**

Increasing temperatures raise concerns for sea level rise in coastal areas. Since 1900, global average sea level has risen by about 7–8 inches. It is projected to rise another 1–8 feet, with a likely range of 1–4 feet, by 2100 as a result of both past and future emissions from human activities

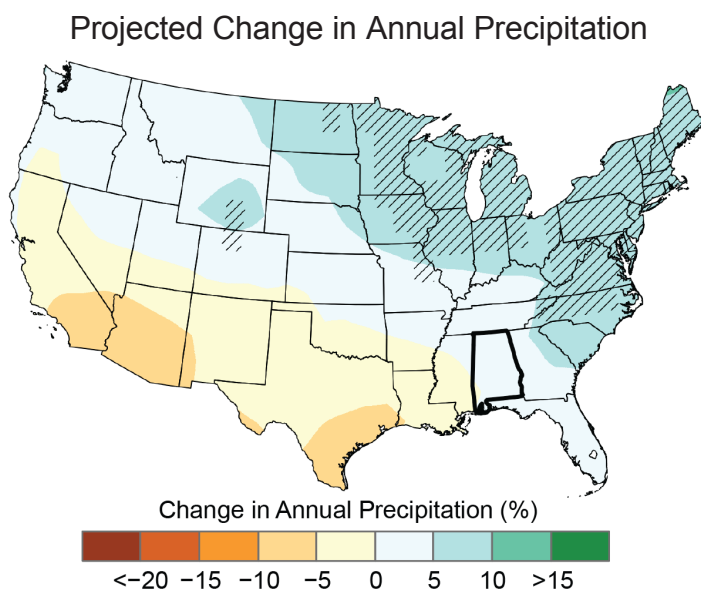


Figure 4: Projected changes in total annual precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. The southeastern United States, including Alabama, is in a transition zone between projected high-latitude increases and subtropical decreases in precipitation, and as such, future precipitation changes are uncertain. Sources: CISESS and NEMAC. Data: CMIP5.

(Figure 5). Based on observed data from 1966 to 2020, the local sea level at Dauphin Island has increased 1.6 inches per decade. Sea level rise has caused an increase in tidal floods associated with nuisance level impacts. Nuisance floods are events in which water levels exceed the local threshold (set by NOAA's National Weather Service) for minor impacts. These events can damage infrastructure, cause road closures, and overwhelm storm drains. Nuisance flooding has increased in all U.S. coastal areas, with more rapid increases along the East and Gulf Coasts. Nuisance flooding events in Alabama are likely to occur more frequently as global and local sea levels continue to rise.

Naturally occurring land subsidence (sinking) is a major contributor to increases in sea level rise in Alabama, with land in the Dauphin Island area projected to subside an additional 6.6 inches by 2100. A recent U.S. Department of Transportation study found that highways and port and marine waterway systems along the low-lying coast of Mobile, as well as coastal wetlands, are particularly vulnerable to storm surge and sea level rise. The percentage of critical ports exposed to sea level rise ranges from 46% under the study's lowest scenario (1 foot of sea level rise by 2050) to 92% under the highest scenario (6.6 feet by 2100).

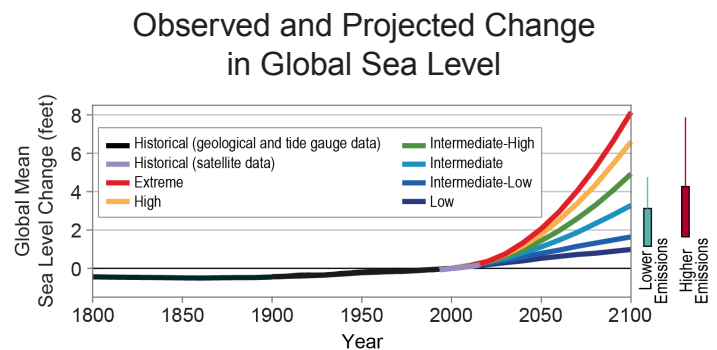


Figure 5: Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate-Low, royal blue; Intermediate, cyan; Intermediate-High, green; High, orange; and Extreme, red curves) relative to historical geological, tide gauge, and satellite altimeter GMSL reconstructions from 1800–2015 (black and magenta lines) and the very likely ranges in 2100 under both lower and higher emissions futures (teal and dark red boxes). Global sea level rise projections range from 1 to 8 feet by 2100, with a likely range of 1 to 4 feet. Source: adapted from Sweet et al. 2017.

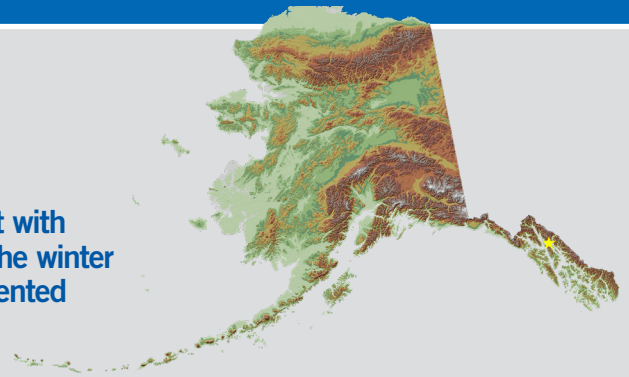
Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

ALASKA

Temperatures in Alaska have increased by about 3°F since 1925 but with large multidecadal variations. Most of the warming has occurred in the winter and spring. Under a higher emissions pathway, historically unprecedented warming is projected during this century.

Annual average precipitation is projected to increase by 10% or more across all of Alaska by the middle of this century under a higher emissions pathway.

Late-summer arctic sea ice extent and thickness have decreased substantially over the last several decades. Climate models project that before 2050 arctic waters will be virtually ice-free by late summer.



Alaska's vast expanse and geographical variation lead to a variety of climate types. Four main factors influence the state's climate: its northerly latitude crossing the Arctic Circle; its large elevation range, from sea level to the highest peak in the United States; regional variations in proximity to the ocean; and the seasonal distribution of sea ice along its western and northern boundaries. Annual average (1991–2020 normals) temperatures range from the mid-40s (°F) in the south, where moderating maritime influences are strong, to about 13° to 20°F in the Arctic region north of the Brooks Range (Figure 2); the coldest long-term reporting stations are along and near the Arctic Ocean north of 70°N latitude, with an annual average temperature of less than 15°F. The greatest seasonal changes in temperature occur in the state's Interior region, where summer average maximum temperatures are in the upper 60s (°F) and winter average minimums are 15° to 25°F below zero. The highest temperature ever recorded in Alaska was 100°F at Fort Yukon, in the Interior (June 27, 1915), and the coldest was –80°F at Prospect Creek, also in the Interior (January 23, 1971).

Alaska's temperature climate is highly variable. It was moderately warm from the 1920s into the 1940s, much cooler from the late 1940s into the 1970s, and warmer thereafter. **Since 1925 (the beginning of reliable records), temperatures in Alaska have increased by about 3°F (Figure 1), compared to about**

Observed and Projected Temperature Change

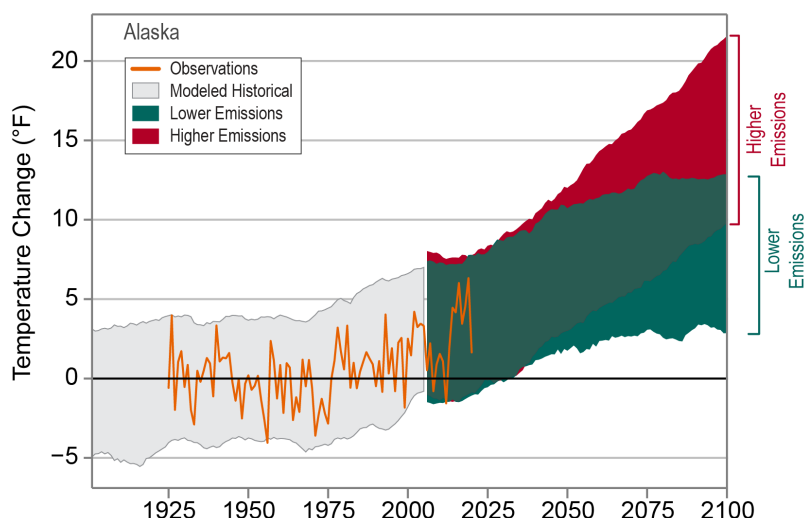


Figure 1: Observed and projected changes (compared to the 1925–1960 average) in near surface air temperature for Alaska. Observed data are for 1925–2020, while model simulations of the historical period are shown for 1901–2005. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Alaska (orange line) have increased by about 3°F since 1925 but with large multidecadal variations. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of the modeled historical simulations (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 2°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest years being about 15°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

Annual Average Temperature Normals (1991–2020)

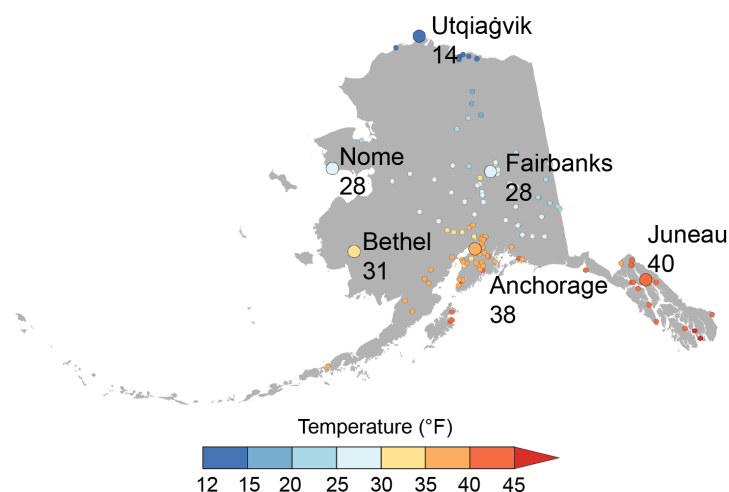


Figure 2. Annual average temperature normals (1991–2020) for long-term reporting stations in Alaska. Normals vary from less than 15°F in the far north to greater than 45°F at a few locations along the southeast coast. Sources: CISESS and NCEI. Data: NOAA NCEI U.S. Climate Normals.

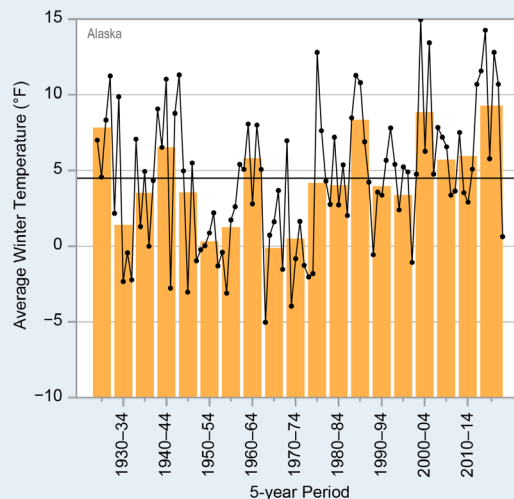
1.8°F since 1900 for the contiguous United States.

There is considerable regional variability in the warming, with the greatest warming occurring in the North Slope (about 4°F) and the least warming (less than 2°F) occurring in the Panhandle and the Aleutians. Most of the warming has occurred in the winter and spring and the least amount in the summer and fall. Summer temperatures have been above average since the late 1980s (Figure 3b), and winter temperatures have been mostly above average since 2001 (Figure 3a). The increase in summer temperatures is primarily due to a large increase in summer minimum temperatures (Figure 3c). The large decadal variability is caused in part by changes in hemispheric climate patterns. For example, a substantial increase in annual average temperature occurred around 1976, followed by gradual additional warming through 2020. Specifically, annual average temperature increased by about 1.5°F from the 1970s to the 1980s and then by about 2°F from the 1980s to the 2010s, with much higher values locally. At Utqiagvik, annual temperature has increased by more than 12°F since 1976. This warming coincided with a shift in a climate pattern known as the Pacific Decadal Oscillation (PDO). In the past, during the warm phase of the PDO, increased atmospheric flow from the south brought warm air into Alaska during the winter. Accelerated warming has occurred since mid-2013: 2016 and 2019 were the second-warmest and warmest years on record, respectively. The shift to warmer temperatures in the 1970s can be

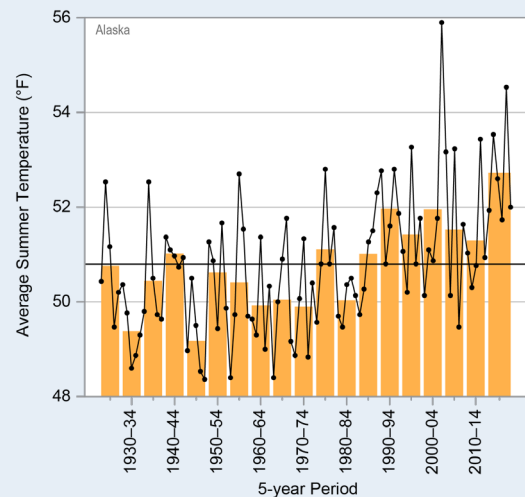
seen in the number of extremely cold nights (Figure 4), which has generally been below the long-term (1930–2020) average since 1980, with the lowest multiyear averages occurring in the 2000–2004 and 2015–2020 periods. The number of warm days was high during the early 1990s, early 2000s, and late 2010s; 2019 experienced the second-highest number of warm days, after 2004 (Figure 5). Over the past 100 years, the length of the growing season in Fairbanks has increased by 45%, and the number of snow-free days has increased by 10%.

Total annual precipitation amounts vary greatly across Alaska. Coastal mountain ranges in the southeastern Panhandle receive more than 200 inches per year, while totals drop to 60 inches south of the Alaska Range, 12 inches in the Interior, and less than 6 inches in the North Slope. The highest 24-hour rainfall total was 15.05 inches in October 1986 at Seward, in Southcentral Alaska. The highest 24-hour snowfall total was 78 inches on February 9, 1963, at Mile 47 Camp along Highway 4 in the southeastern portion of the state. The driest multiyear periods were in the 1950s, late 1960s, and early 1970s, and the wettest were in the late 1920s (Figure 6a). The driest consecutive 5-year interval was 1968–1972, and the wettest was 1928–1932. Since the late 1980s, total annual precipitation in Alaska has been near to above average, except for a dry period in the late 1990s. There is considerable regional variability, however, as portions of Interior and Arctic Alaska have observed a long-term

a) Observed Winter Temperature



b) Observed Summer Temperature



c) Observed Minimum Summer Temperature

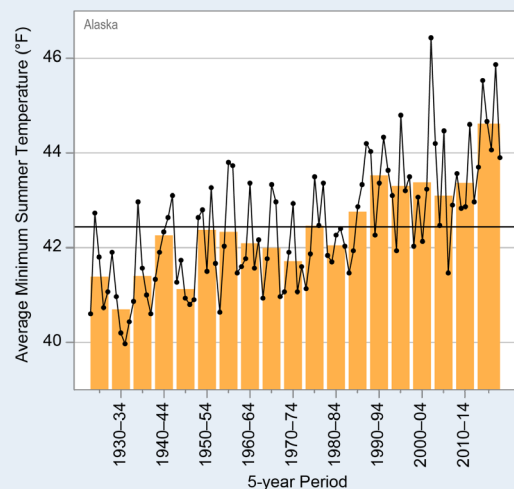


Figure 3: Observed (a) winter (December–February) average temperature, (b) summer (June–August) average temperature, and (c) summer minimum average temperature for Alaska from (a) 1925–26 to 2019–20 and (b, c) 1925 to 2020. Dots show annual values. Bars show averages over 5-year periods (first bar in Figure 3a is a 4-winter average, last bar in Figure 3a is a 6-winter average, and last bar in Figures 3b and 3c is a 6-summer average). The horizontal black lines show the long-term (entire period) averages: (a) 4.4°F, (b) 50.8°F, (c) 42.4°F. Winter and summer temperatures have been above average since 2000 and 1990, respectively. Summer minimum temperatures have been above average since 1985. Sources: CISESS and NOAA NCEI. Data: nClimDiv.

decrease in precipitation. Also, for the summer season, the 2010–2014 period was the wettest on record (Figure 6b). As with average precipitation, the occurrence of extreme precipitation events is highly variable and is both regionally and seasonally dependent. Most of Alaska has seen an increase in the heaviest 1% of 3-day precipitation totals since the mid-20th century; however, the number of daily precipitation events of 1-inch or more has been near to below average since 1990, and the highest values occurred in the 1930s (Figure 6c).

Late-summer arctic sea ice extent and thickness have decreased substantially over the last several decades, and the ice extent is approximately one-half of that observed at the beginning of satellite monitoring in 1979. The lowest minimum arctic sea ice extent occurred in 2012 (Figure 7). Arctic

sea ice plays a vital role in the climate of Alaska, the lives of its inhabitants, and the functionality of its ecosystems. Warming linked to ice loss influences atmospheric circulation and precipitation patterns both within and beyond the Arctic region. Alaskans rely on sea ice for hunting and fishing and as a protective barrier against severe coastal storms. With the late-summer ice edge located farther north than it used to be, storms produce larger waves and cause more coastal erosion. A significant increase in the number of coastal erosion events has been observed, as the protective sea ice embankment is no longer present during the fall months. In response to the increased erosion, several coastal communities are seeking to relocate.

Much of the Alaska Interior (between the Brooks and Alaska Ranges) is a zone of discontinuous

permafrost, and the area north of the Brooks Range is a zone of continuous permafrost. **Increasing temperatures result in permafrost thawing, which causes substantial repercussions for the ecology and infrastructure (e.g., damage to buildings, pipelines, roads, airports, and water supply and sewage systems from ground subsidence [sinking]), as well as an increase in greenhouse gas emissions.** As the climate continues to warm, snow in Alaska melts earlier each spring, lengthening the snow-free summer season.

Wildfires are also a particular concern for the state, especially in recent years. Drying of wetlands, increased frequency of warm, dry summers, and associated thunderstorms have led to a greater number of large fires during the 2000s than in any previous decade since record keeping began in the 1940s. From 2000 to 2020, the frequency of large (more than 2,000 square miles burned) wildfire seasons (35%) more than doubled compared to the 1955–1999 period (15%). The largest wildfire seasons (since 1955) were 2004 (10,500 square miles) and 2015 (8,000 square miles). **The area burned by wildfires may increase further under a warming climate.**

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of the century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records.

While historical precipitation trends are mixed, average precipitation is projected to increase in all seasons during this century, with the greatest increases expected in winter and spring. By the middle of the century, annual precipitation increases are projected to exceed 10% over the majority of the state (Figure 8).

Since 1900, global average sea level has risen by about 7–8 inches. However, in Alaska, sea level is actually falling along much of the southern coast

Observed Number of Extremely Cold Nights

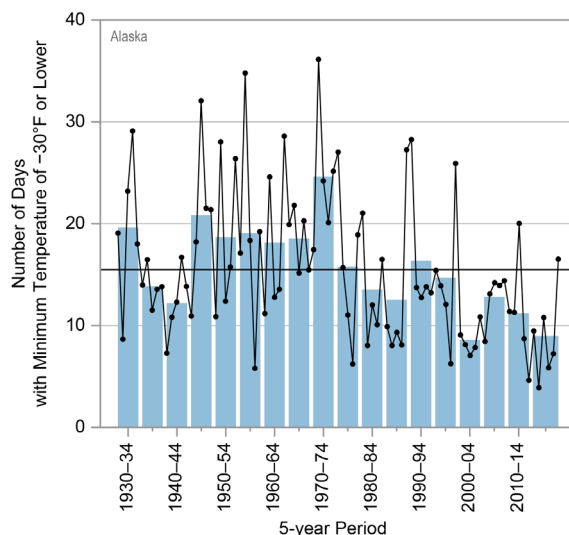


Figure 4: Observed annual number of extremely cold nights (minimum temperature of -30°F or lower) for Alaska from 1930 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 16 nights (note that the average for individual stations varies greatly because of the state's large elevation range). These values are averages from 10 of 14 long-term reporting stations. Four long-term stations located near the western and southern coasts have been excluded from the averaging because the moderating effects of the oceans prevent the occurrence of such low temperatures. Since 2000, all 10 stations have experienced numbers lower than the long-term average. The lowest multiyear averages occurred in the early 2000s and late 2010s. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily.

Observed Number of Warm Days

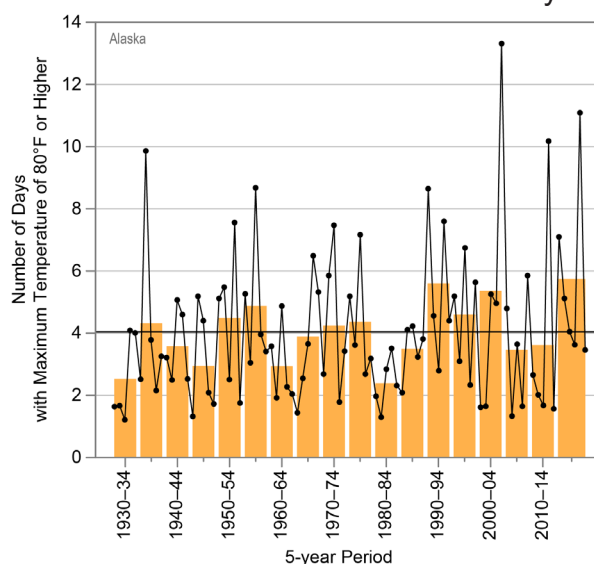
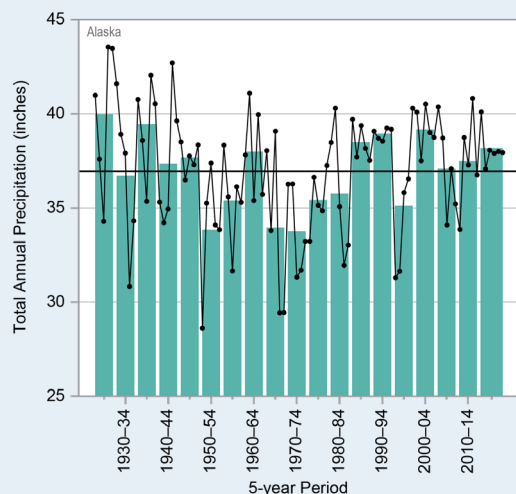


Figure 5: Observed (a) annual number of warm days (maximum temperature of 80°F or higher) for Alaska from 1930 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 4.0 days (note that the average for individual stations varies greatly because of the state's large elevation range). The highest number of warm days occurred during the early 1990s, early 2000s, and late 2010s. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 14 long-term stations.

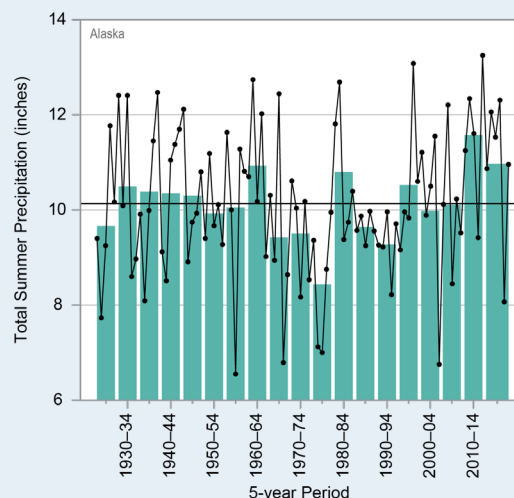
due to isostatic rebound (rising ground) from ice mass loss. In other parts of the coast, tectonic activity results in subsidence, exacerbating the effect of sea level rise. Although global sea level is projected to likely rise another 1 to 4 feet by 2100 as a result of both past and future emissions from human activities (Figure 9), the changes in coastal

erosion due to the combined effects of sea ice loss and permafrost thaw are likely to cause larger impacts well before the inundation associated with sea level rise. **Climate models project that Alaska's northern waters in late summer could be virtually ice-free before 2050.**

a) Observed Annual Precipitation



b) Observed Summer Precipitation



c) Observed Number of 1-Inch Precipitation Events

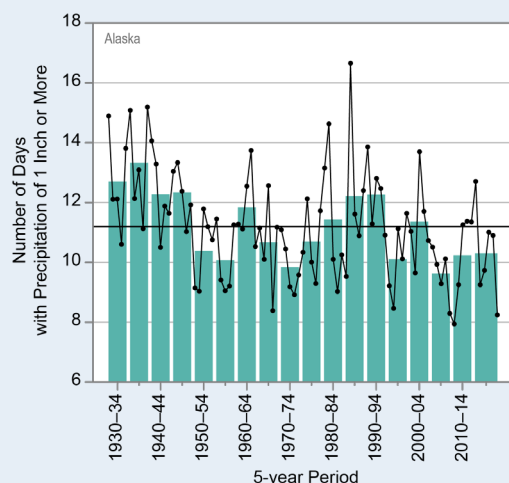


Figure 6: Observed (a) total annual precipitation, (b) total summer (June–August) precipitation, and (c) annual number of 1-inch extreme precipitation events (days with precipitation of 1 inch or more) for Alaska from (a, b) 1925 to 2020 and (c) 1930 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar in Figures 6a and 6c is a 6-year average, last bar in Figure 6b is a 6-summer average). The horizontal black lines show the long-term (entire period) averages: (a) 37.0 inches, (b) 10.1 inches, (c) 11 days. Annual precipitation has been variable with no long-term trend. For summer precipitation, the 2010–2014 period was the wettest on record. The number of 1-inch extreme precipitation events has been near or below average since the late 1990s. A typical reporting station experiences about 11 events per year, but in the diverse climate of Alaska, this number is highly variable from station to station. Sources: CISESS and NOAA NCEI. Data: (a, b) nClimDiv; (c) GHCN-Daily from 14 long-term stations.

March and September Arctic Sea Ice Extent

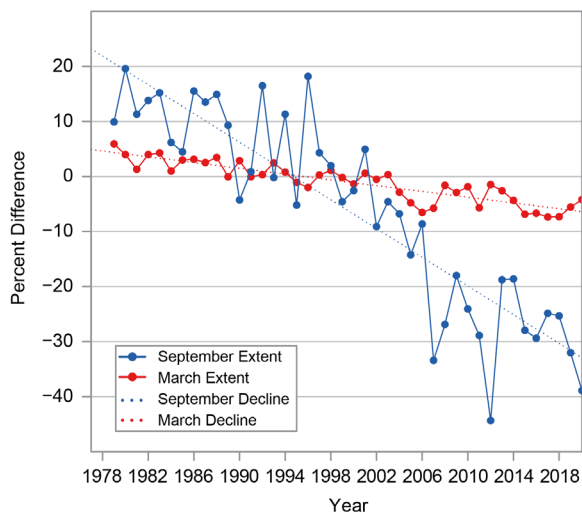


Figure 7: Time series of arctic sea ice extent anomalies in March (the month of maximum ice extent) and September (the month of minimum ice extent) from 1979 to 2020. The anomaly value for each year is the difference (%) in ice extent relative to the average values for the period 1981–2010. The red and blue dashed lines indicate ice losses of -2.6% and -13.4% per decade in March and September, respectively. Both trends are significant at the 99% confidence level. Sources: CISESS and NOAA NCEI. Data: NSIDC.

Observed and Projected Change in Global Sea Level

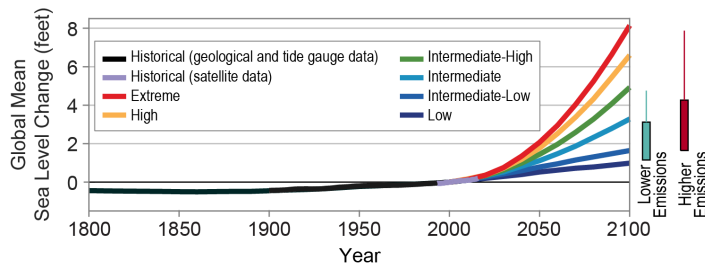


Figure 9: Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate-Low, royal blue; Intermediate, cyan; Intermediate-High, green; High, orange; and Extreme, red curves) relative to historical geological, tide gauge, and satellite altimeter GMSL reconstructions from 1800–2015 (black and magenta lines) and the very likely ranges in 2100 under both lower and higher emissions futures (teal and dark red boxes). Global sea level rise projections range from 1 to 8 feet by 2100, with a likely range of 1 to 4 feet. Source: adapted from Sweet et al. 2017.

Projected Change in Annual Precipitation

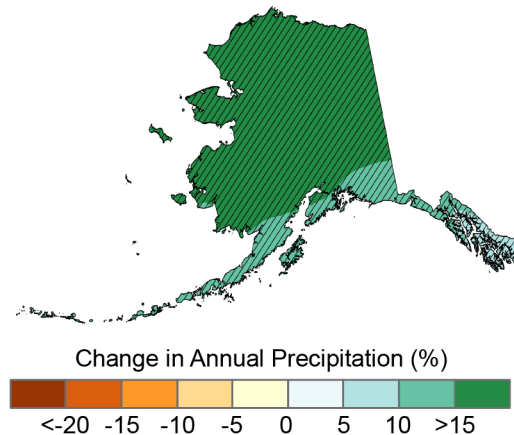


Figure 8: Projected changes in total annual precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. Projected increases in Alaska's annual precipitation are consistent with a large pattern of projected increases at high latitudes. Sources: CISESS and NEMAC. Data: CMIP5.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

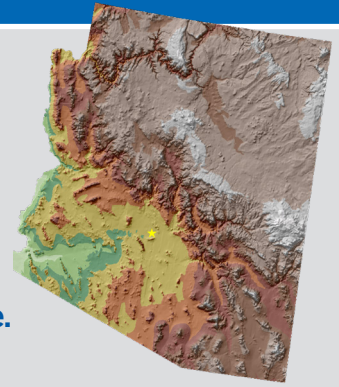
ARIZONA

Key Messages

Temperatures in Arizona have risen about 2.5°F since the beginning of the 20th century. Recent upward trends in average temperatures and extreme heat are projected to continue. Under a higher emissions pathway, historically unprecedented increases in annual average temperature are projected during this century.

Droughts are a serious threat in this water-scarce state. The potential for more extended droughts in the future will pose a major challenge to Arizona's environmental, agricultural, and human systems. The risk of very large wildfires is projected to increase.

The summer monsoon rainfall, which provides much-needed water for grazing lands and their ecosystems, varies greatly from year to year. Future trends in average monsoon rainfall are highly uncertain, while high variability is expected to continue. Warmer temperatures may lead to reductions in late-season snowpack accumulation and negative impacts on valley communities that rely on the melting snowpack for summer water supplies.



Arizona, the sixth-largest U.S. state, encompasses diverse climates and topography. The deserts in the south are some of the hottest and driest areas of the country, while the higher terrain of the Colorado Plateau in the northeast has a cooler climate, with cold winters and mild summers. The mountain ranges that run from the northwest to the southeast experience heavier precipitation and wide temperature variations. Annual average (1991–2020 normals) temperatures range from the 40s (°F) at the highest elevations in the mountains to the mid-70s (°F) in the lower elevations of the south. The southern deserts frequently experience summer temperatures between 105°F and 115°F. Phoenix has the hottest climate of all major U.S. cities. Extreme temperatures in Arizona range from a record high of 128°F at Lake Havasu City (June 29, 1994) to a record low of –40°F at Hawley Lake (January 7, 1971). The hottest year on record was 2017, with a statewide annual average temperature of 63.0°F, which is 3.3°F above the long-term (1895–2020) average.

Observed and Projected Temperature Change

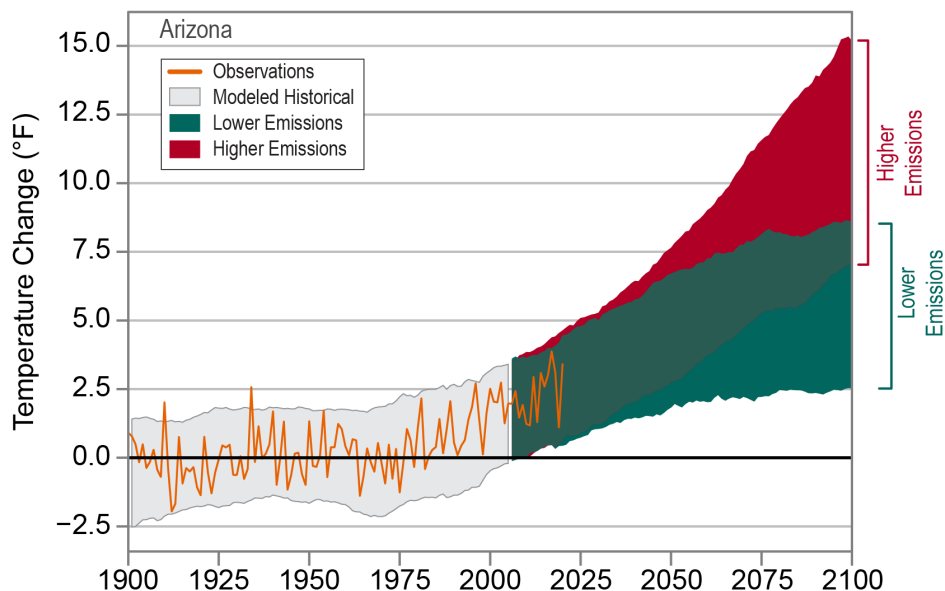
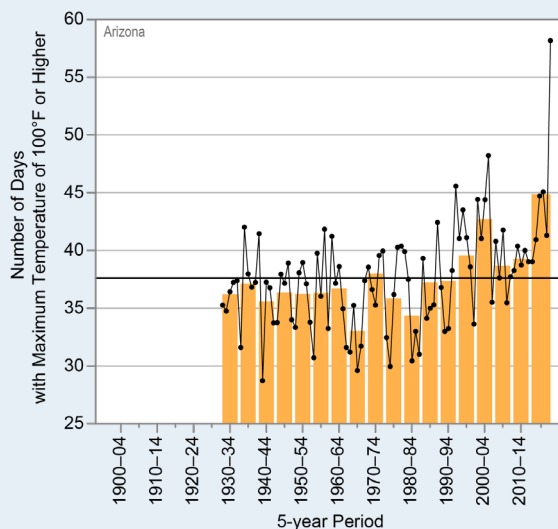


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Arizona. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Arizona (orange line) have risen about 2.5°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 2°F warmer

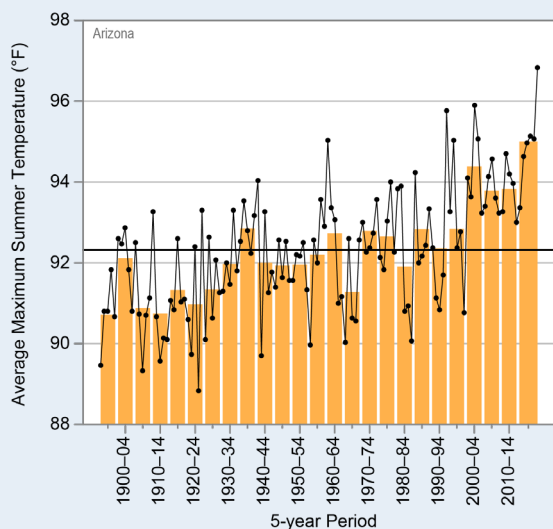
than the historical average; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 11°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

Figure 2: Observed (a) annual number of extremely hot days (maximum temperature of 100°F or higher), (b) summer (June–August) average maximum temperature, (c) summer average minimum temperature, (d) total annual precipitation, and (e) annual number of 1-inch extreme precipitation events (days with precipitation of 1 inch or more) for Arizona from (a, e) 1930 to 2020 and (b, c, d) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 38 days, (b) 92.3°F, (c) 63.0°F, (d) 12.3 inches, (e) 2.0 days. (Note that for Figures 2a and 2e, the average for individual reporting stations varies greatly because of the state's large elevation range.) The number of extremely hot days has been above average since 1995, with the highest number occurring during the 2015–2020 period. Both summer average maximum (daytime) and minimum (nighttime) temperatures show an upward trend, with the highest values for both occurring since 2000. Total annual precipitation varies widely but has been below average since 1995. The annual number of 1-inch extreme precipitation events shows no long-term trend; a typical reporting station experiences 2 events per year. Sources: CISESS and NOAA NCEI. Data: (a) GHCN-Daily from 18 long-term stations; (b, c, d) nClimDiv; (e) GHCN-Daily from 30 long-term stations.

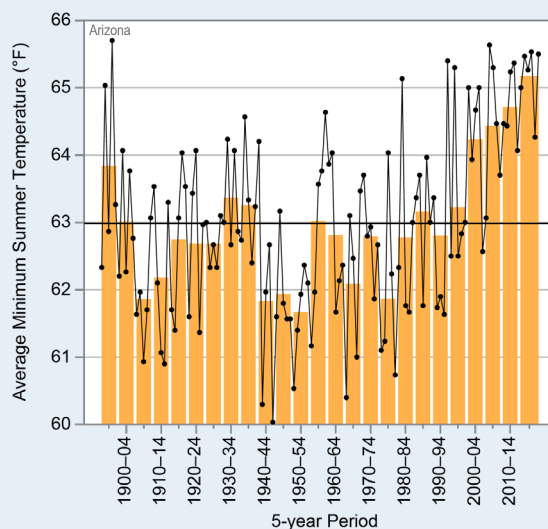
a) Observed Number of Extremely Hot Days



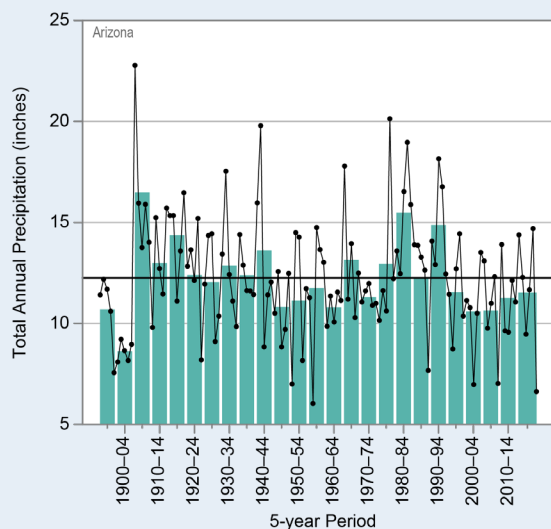
b) Observed Maximum Summer Temperature



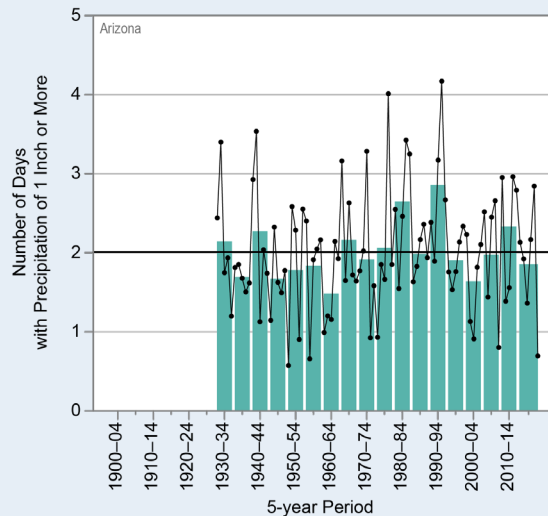
c) Observed Minimum Summer Temperature



d) Observed Annual Precipitation



e) Observed Number of 1-Inch Extreme Precipitation Events



Temperatures in Arizona have risen about 2.5°F since the beginning of the 20th century. The first 21 years of this century have been the warmest period on record for the state (Figure 1). Since 1995, the number of days with a maximum temperature of 100°F or higher has been near to above average, reaching a record high during the 2015 to 2020 period (Figure 2a). The number of nights with a minimum temperature of 80°F or higher has been trending upward since 1995, also reaching a record high during the 2015 to 2020 period (Figure 3); this increase in high nighttime minimums is observed statewide, but the increase is much larger in the Phoenix metropolitan area. The number of nights with a minimum temperature of 0°F or lower has been below average since 1980 (Figure 4). One notable trend is an increase in both daytime high and nighttime low summer temperatures, which has implications for the intensity of future heat waves in a state that already experiences very hot conditions (Figures 2b and 2c).

Much of Arizona is characterized as arid to semiarid, with annual average precipitation ranging from less than 4 inches in the southwest to around 40 inches in the White Mountains in the east-central region. Precipitation is highly variable from year to year, with statewide total annual precipitation ranging from a low of 6.0 inches in 1956 to a high of 22.8 inches in 1905. The driest multiyear period occurred during the early 1900s and was immediately followed by the wettest multiyear period (Figure 2d). The driest consecutive 5-year interval was 1899–1903, with an annual average of 8.3 inches of precipitation, and the wettest was 1905–1909, with an annual average of 16.5 inches. The years since 1995 have also been relatively dry, with 17 of the last 26 years experiencing below average precipitation. Snowfall is rare in the southern desert region but does occur at the higher elevations, where it can reach depths of more than 100 inches. Snowpack plays a critical role in supplying water for both urban and agricultural areas in the lower Salt River valley and the lower Gila River valley and is vital for forest health and groundwater recharge across the entire state.

An important feature of Arizona's summer climate is the North American Monsoon, which causes large amounts of rain to fall from late June or early July to mid-September. Precipitation during the monsoon season is highly variable from year to year (Figure 5). Since 2000, monsoon precipitation has been below

Observed Number of Extremely Warm Nights

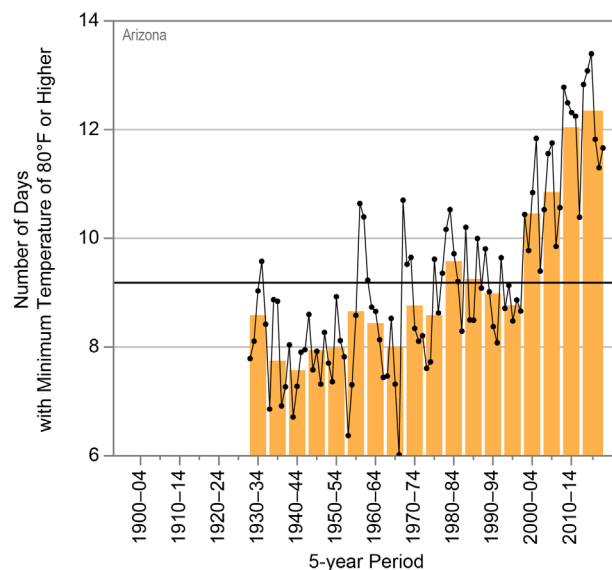


Figure 3: Observed annual number of extremely warm nights (minimum temperature of 80°F or higher) for Arizona from 1930 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 9.2 nights (note that the average for individual reporting stations varies greatly because of the state's large elevation range). The number of extremely warm nights has been trending upward since 1995. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 18 long-term stations.

Observed Number of Very Cold Nights

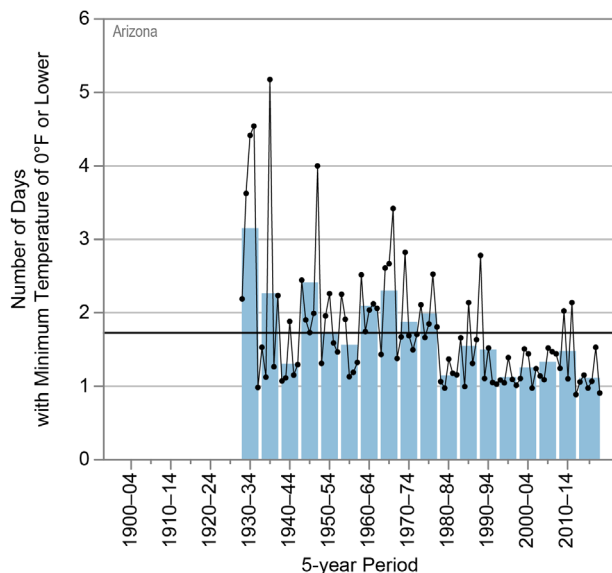


Figure 4: Observed annual number of very cold nights (minimum temperature of 0°F or lower) for Arizona from 1930–2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 1.7 nights (note that the average for individual reporting stations varies greatly because of the state's large elevation range). The number of very cold nights has been below average since 1980, indicative of warming in the region. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 18 long-term stations.

average, with the exception of the 2010–2014 period, which was above average due to warmer sea surface temperatures off the Pacific coast and a very active hurricane season in 2014. In the southernmost portion of the state, monsoon rainfall accounts for more than half of the annual precipitation and plays an important role in supporting agriculture and ecosystems.

The monsoon rains are highly beneficial but can occasionally be destructive. On September 8, 2014, extremely heavy monsoon rain associated with a decaying eastern Pacific hurricane caused significant damage and flooding around the Phoenix area. The record for single-day rainfall was broken, with several stations reporting more than 4 inches. **The 2020 monsoon season was the driest on record**, with only 1.5 inches of precipitation, well below the previous record low of 2.8 inches in 2009.

The historical record indicates periodic prolonged wet and dry periods (Figure 6). Arizona is currently in a long-term drought that has lasted more than 20 years. Multiyear periods of high and low precipitation

can cause significant variations in reservoir supplies.

The latest western U.S. drought has resulted in record-low water levels in Lake Mead, which is a critical water resource for Arizona, as well as southern Nevada, southern California, and northern Mexico. Since reaching high levels in the late 1990s, water levels have been falling, reaching historic lows in 2015 and 2016 (Figure 7). Long-term droughts also raise the risk of wildfires, already a concern for this arid state. In 2011, the Wallow Fire consumed more than 500,000 acres in eastern Arizona, making it the state's largest wildfire on record.

Unlike many areas of the United States, Arizona and other southwestern states have not experienced an upward trend in the frequency of extreme precipitation events. The number of 1-inch extreme precipitation events has been variable throughout the period of record (Figure 2e). Since the 1990s, the number of these events has been near to below normal, with the exception of the 2010–2014 period.

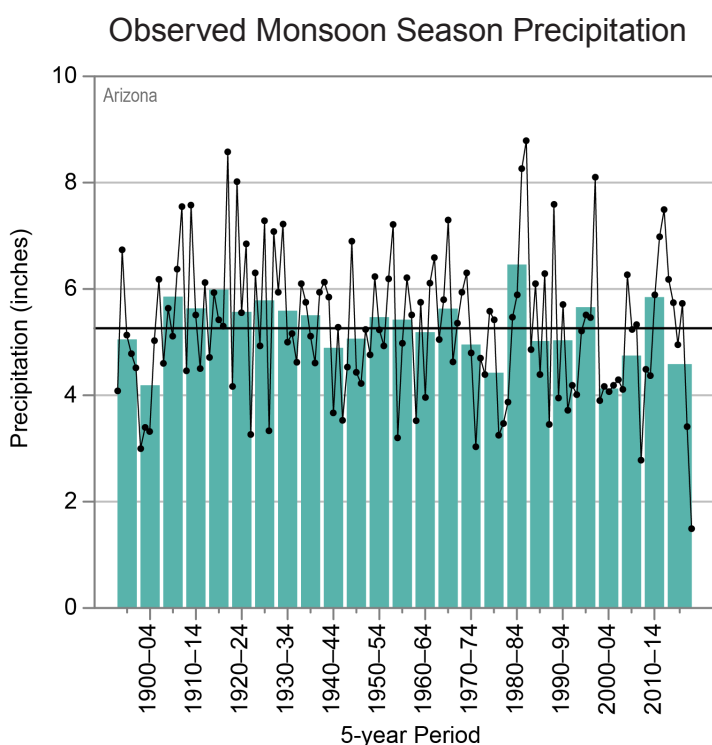


Figure 5: Observed total monsoon-season (June–September) precipitation for Arizona from 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-season average). The horizontal black line shows the long-term (entire period) average of 5.3 inches. Monsoon precipitation is highly variable from year to year. Since 2000, monsoon precipitation has been below average, with the exception of the 2010–2014 period. Sources: CISESS and NOAA NCEI. Data: nClimDiv.

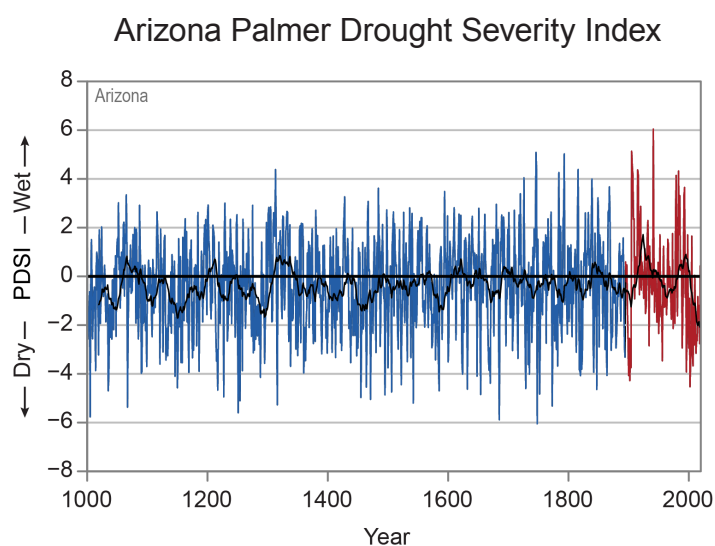


Figure 6: Time series of the Palmer Drought Severity Index for Arizona from the year 1000 to 2020. Values for 1895–2020 (red) are based on measured temperature and precipitation. Values prior to 1895 (blue) are estimated from indirect measures such as tree rings. The fluctuating black line is a running 20-year average. In the modern era, the wet periods of the early 1900s and the 1980s to 1990s and the dry periods of the 1950s and 2000s are evident. The extended record indicates periodic occurrences of similar prolonged wet and dry periods. Sources CISESS and NOAA NCEI. Data: nClimDiv and NADAv2.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of the century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. Extreme heat is a particular concern for Phoenix and other urban areas, where the urban heat island effect raises summer nighttime temperatures. Rising temperatures will increase the intensity of future heat waves, which is a concern for a state that already experiences extremely hot conditions.

Although projections of overall annual precipitation are uncertain, there is a risk of decreases in spring precipitation (Figure 8); Arizona is on the northern fringe of an area of projected decreases over Mexico and Central America. Additionally, projected rising temperatures will raise the snow line—the average lowest elevation at which snow falls. This will increase the likelihood that precipitation will fall as rain instead of snow, reducing water storage in the snowpack, particularly at lower mountain elevations that are now on the margins of reliable snowpack accumulation. Higher spring temperatures will also result in earlier melting of the snowpack, further decreasing water resources needed for irrigation during the hot summer months.

Naturally occurring droughts are expected to become more intense during the cool season. As noted above, future projections of overall precipitation are uncertain, including those related to the North American Monsoon. However, even if precipitation does not decrease, higher temperatures will intensify naturally occurring droughts by increasing water evaporation. This will further reduce streamflow, soil moisture, and water supplies. Drought will not only challenge limited agricultural resources but also increase the frequency of dust storms and the frequency of the risk of very large wildfires.

Lake Mead Water Levels at Hoover Dam

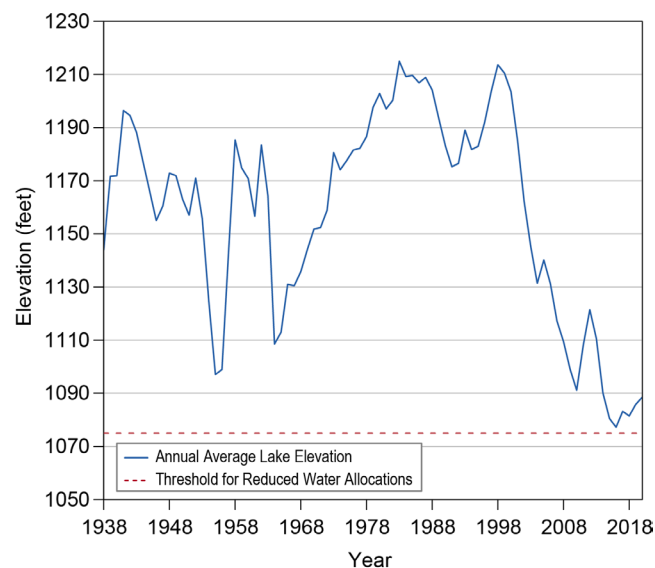


Figure 7: Time series of the annual average water level (blue line) of Lake Mead at Hoover Dam from 1938 to December 2020. Water levels in Lake Mead have varied widely over the years. Low levels in the 1950s and 1960s were due to drought and the filling of Lake Powell, respectively. Recent years have seen the lowest recorded levels since the original filling of Lake Mead. The red-dashed line indicates the threshold (1,075 feet) below which a federal shortage will be declared, resulting in reduced water allocations for Nevada and Arizona. Source: USBR.

Projected Change in Spring Precipitation

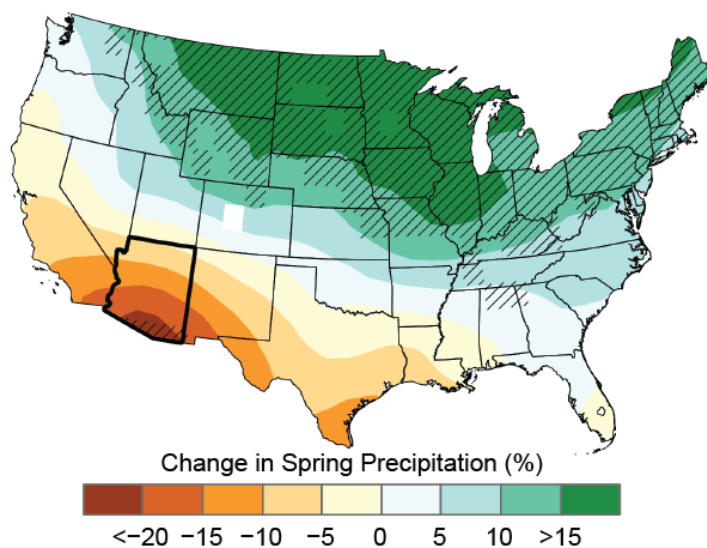


Figure 8: Projected changes in total spring (March–May) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. The white-out area indicates that the climate models are uncertain about the direction of change. Hatching represents areas where the majority of climate models indicate a statistically significant change. Sources: CISESS and NEMAC. Data: CMIP5.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

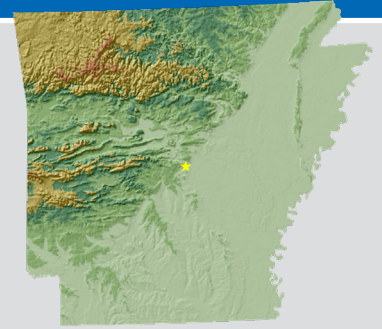
ARKANSAS

Key Messages

Temperatures in Arkansas have risen by 0.5°F since the beginning of the 20th century, less than a third of the warming for the contiguous United States, but the warmest consecutive 5-year interval was 2015–2019. Historically unprecedented warming is projected during this century.

Increases in evaporation rates due to rising temperatures may increase the rate of soil moisture loss and the intensity of naturally occurring droughts.

The frequency and intensity of extreme heat and extreme precipitation events are projected to increase, while the intensity of extreme cold events is projected to decrease.



Arkansas is located in the interior southern United States. The state is close but not adjacent to the Gulf of Mexico, resulting in a climate with moderately large variations in temperature and abundant precipitation. Summers are hot and humid, while winters are typically short and cool with occasional episodes of cold arctic air. Northern and western Arkansas includes the Ozark Mountains and is generally higher in elevation, particularly in the Boston Mountains portion of the range, where some peaks exceed 2,500 feet. Thus, temperatures are generally cooler in this area; for example, the July average (1991–2020 normals) high temperature at Deer (elevation: 2,375 feet) in the northwest is 83°F, while it is 91°F at Jonesboro (elevation: 260 feet) in the northeast. January average low temperatures range from 23° to 26°F in the northwestern part of the state to 27° to 32°F in the northeast and 30° to 35°F in the southwest. Extreme temperatures range from a record high of 120°F at Ozark (August 10, 1936) to a record low of –29°F at Gravette (February 13, 1905). Precipitation is abundant throughout the year. Heavy rains can produce totals in excess of 10 inches. Winter and spring are the wettest seasons. Since comprehensive record keeping began in 1895, the driest year was 1963, with a statewide average of 32.8 inches of precipitation, and the wettest was 2009, with 72.2 inches.

Observed and Projected Temperature Change

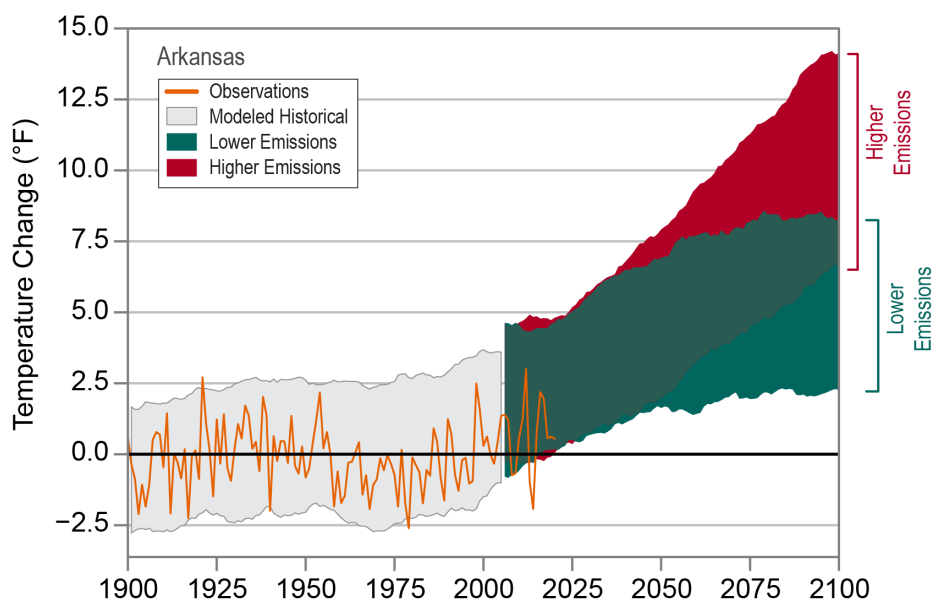
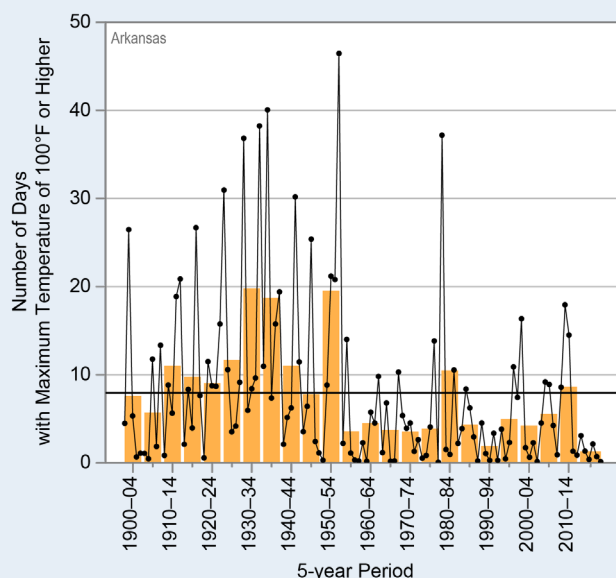


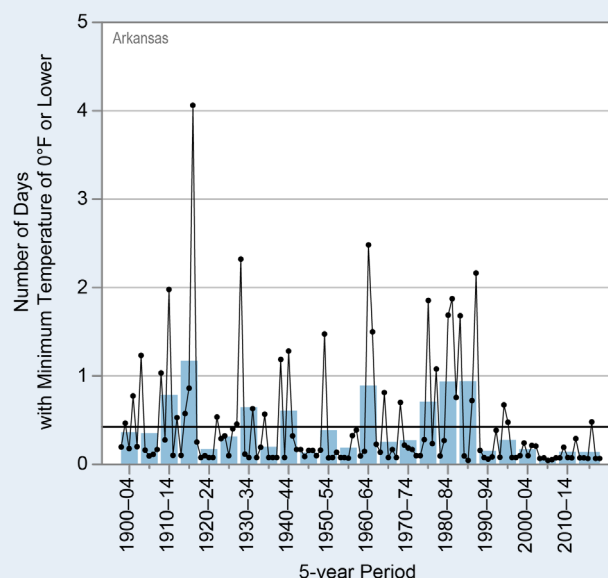
Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Arkansas. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Arkansas (orange line) have risen by 0.5°F since the beginning of the 20th century, less than a third of the warming for the contiguous United States, but the warmest consecutive 5-year interval was 2015–2019. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming

is expected under a lower emissions future (the coldest years in the colder end-of-century projections being about 2°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest years in the hotter end-of-century projections being about 11°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

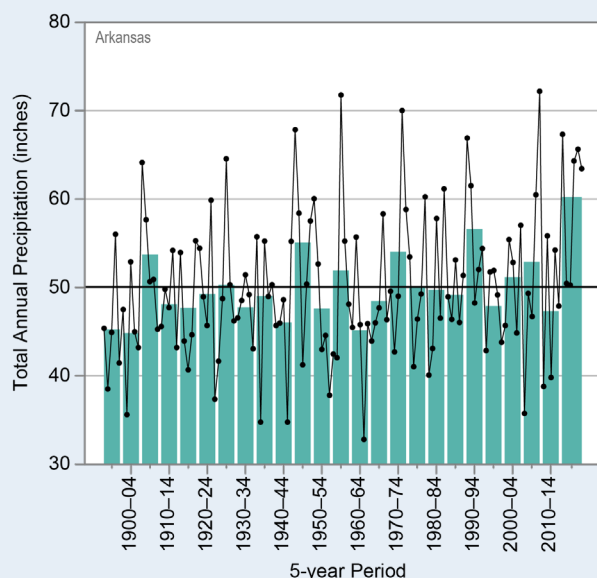
a) Observed Number of Extremely Hot Days



b) Observed Number of Very Cold Nights



c) Observed Annual Precipitation



d) Observed Summer Precipitation

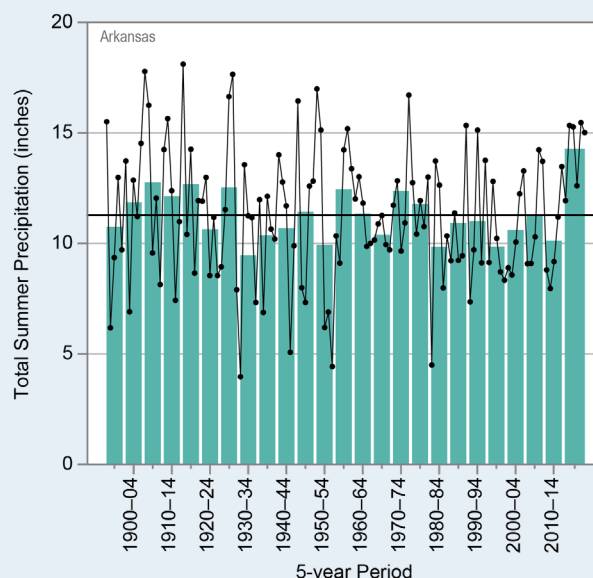


Figure 2: Observed (a) annual number of extremely hot days (maximum temperature of 100°F or higher), (b) annual number of very cold nights (minimum temperature of 0°F or lower), (c) total annual precipitation, and (d) total summer (June–August) precipitation for Arkansas from (a, b) 1900 to 2020 and (c, d) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 8.0 days, (b) 0.4 nights, (c) 50.1 inches, (d) 11.3 inches. The number of extremely hot days and very cold nights has generally remained below average since 1990. While annual and summer precipitation shows substantial year-to-year variability, the 2015–2020 period had the highest multiyear average for both. Sources: CISESS and NOAA NCEI. Data: (a, b) GHCN-Daily from 16 long-term stations; (c, d) nClimDiv.

Temperatures in Arkansas have risen by 0.5°F since the beginning of the 20th century, less than a third of the warming for the contiguous United States, but the warmest consecutive 5-year interval was 2015–2019 (Figure 1). Arkansas warmed from the early 20th century into the 1930s, followed by a substantial cooling of about 2°F into the 1970s. Gradual warming has occurred since the 1970s (a total of about 1.6°F, similar to the rest

of the United States), and recent higher temperatures (well above the long-term [1895–2020] average) have exceeded those of the 1930s. Because of the cooling in the mid-20th century, the southeastern United States is one of the few locations globally that has experienced little warming since 1900. The contiguous United States as a whole has warmed by about 1.8°F since 1900, although it also cooled from the 1930s into the 1960s

but not by nearly as much as Arkansas. Hypothesized causes for this difference in warming rates include increased cloud cover and precipitation, increased small particles from coal burning, natural factors related to forest regrowth, decreased heat flux due to irrigation, and multidecadal variability in North Atlantic and tropical Pacific sea surface temperatures.

The number of extremely hot days peaked during the 1930s and early 1950s, coinciding with periods of drought; however, since the mid-1950s, the number of such days has generally been below average (Figure 2a). Summer average temperatures and the number of very warm nights, however, approximated or exceeded previous record levels during the 2010–2014 period because of a string of three very warm summers (2010–2012). The 2010–2014 multiyear average for very warm nights was double the long-term average (Figure 3), and the multiyear average for summer temperatures was 1.4°F above average (Figure 4). The number of very warm nights in 2015 and 2016 was also well above average. A winter warming trend is reflected in a below average number of very cold nights since 1990 (Figure 2b).

Over the historical record, annual and summer precipitation has been highly variable. While there is no overall significant trend, the most recent period (2015–2020) had the highest multiyear average for both (Figures 2c and 2d). There is an overall upward trend in the number of 3-inch extreme precipitation events, primarily due to very high values during the 2015–2020 period, which averaged 1.8 days per year compared to the long-term average of 1.1 days (Figure 5); exceptionally high values occurred in 2008, 2009, 2015, and 2018, the 4 highest years on record. A vitally important characteristic of Arkansas's precipitation climatology is its high variability. Severe drought episodes during 2005–2007 and 2010–2012 were interrupted by the wettest year on record (2009) and followed by the fifth wettest (2015). The driest consecutive 5-year interval was 1952–1956, with annual average precipitation of 42.0 inches, and the wettest was 2015–2019, with 59.6 inches. Arkansas was one of the hardest hit southeastern states during the 2012 drought, with every one of its 75 counties receiving a drought-related disaster declaration. Since the creation of the United States Drought Monitor map in 2000, Arkansas has been completely drought-free

Observed Number of Very Warm Nights

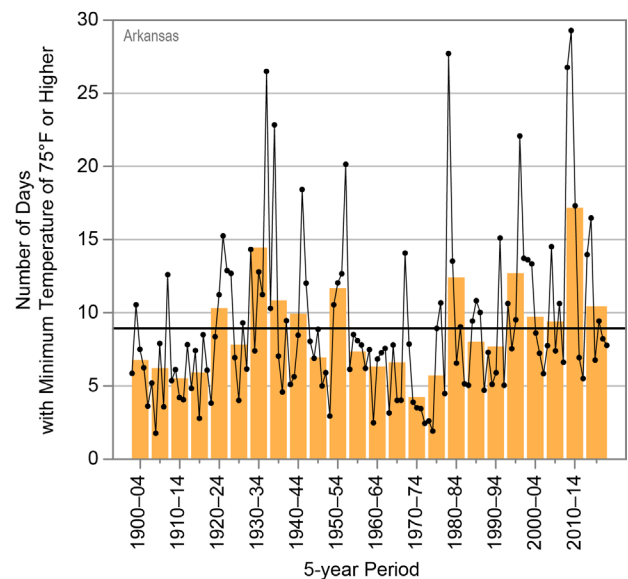


Figure 3: Observed annual number of very warm nights (minimum temperature of 75°F or higher) for Arkansas from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 8.9 nights. The number of very warm nights has been above average since 1995. The 2010–2014 period has the highest multiyear average because of very high annual values in 2010, 2011, and 2012. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 16 long-term stations.

Observed Summer Temperature

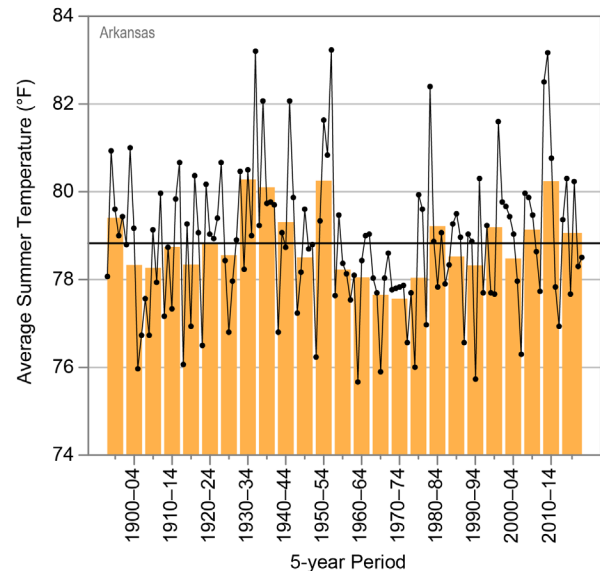


Figure 4: Observed summer (June–August) average temperature for Arkansas from 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-summer average). The horizontal black line shows the long-term (entire period) average of 78.8°F. Summer average temperatures have been mostly near average since 1980. Notably, the 2010–2014 period is well above average because of very warm summers in 2010, 2011, and 2012. Sources: CISESS and NOAA NCEI. Data: nClimDiv.

for approximately 21% of the time (2000–2020), and at least half of the state has been in drought conditions approximately 32% of that time.

Extreme weather events in Arkansas include severe thunderstorms, tornadoes, flood-producing extreme precipitation events, and winter ice storms. The most destructive flood in U.S. history, the Mississippi River Flood of 1927, inundated 36 counties in Arkansas, with floodwaters as deep as 30 feet in some places. This flood resulted from persistent heavy rainfall across the central United States from August 1926 through the spring of 1927. The unprecedented amounts of rainwater runoff overwhelmed the protective levees. This event led to the Flood Control Act of 1928, allowing for federal government authority to contain the Mississippi River and resulting in mitigation efforts that have helped prevent other flooding events of this magnitude. In May 2011, floods submerged more than 1 million acres of Arkansas farmland, causing approximately \$500 million in damages to the state's agricultural industry. During 2011–2020, the Federal Emergency Management Agency granted 13 disaster declarations to the state for severe thunderstorms, tornadoes, and flooding. **Arkansas regularly experiences tornadoes.** Over the past 36 years (1985–2020), Arkansas has averaged approximately 32 tornadoes and 5 tornado fatalities per year. Tornado impacts vary widely from year to year. On April 27, 2014, the Mayflower/Vilonia tornado killed 16 and injured 193 over its 41-mile-long track, but there were only four additional tornado-related fatalities in Arkansas during the next several years.

Under both emissions pathways considered here, historically unprecedented warming is projected during this century (Figure 1). Even under the lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of the century, with only a few of the coolest years thereafter being similar to historical temperatures. Heat wave intensity is projected to increase, while cold waves are projected to be less severe.

Wintertime precipitation is projected to increase in Arkansas by midcentury (Figure 6), with the increase being in the form of rain rather than snow. In the other seasons, precipitation changes are uncertain. Increases in evaporation rates due to rising temperatures may increase the rate of soil moisture loss during dry spells. As a result, **naturally occurring droughts are projected to be more intense.**

Observed Number of 3-Inch Extreme Precipitation Events

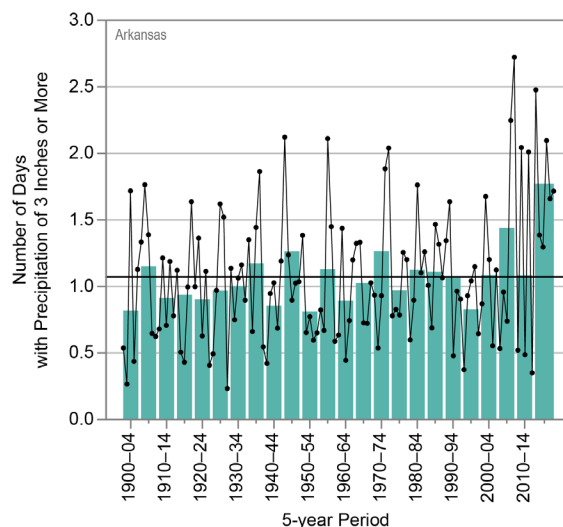


Figure 5: Observed annual number of 3-inch extreme precipitation events (days with precipitation of 3 inches or more) for Arkansas from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 1.1 days. A typical reporting station experiences 1 event per year. The number of 3-inch extreme precipitation events shows an upward trend. The most recent period (2015–2020) had the highest multiyear value due to very high annual values in 2015 and 2018. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 24 long-term stations.

Projected Change in Winter Precipitation

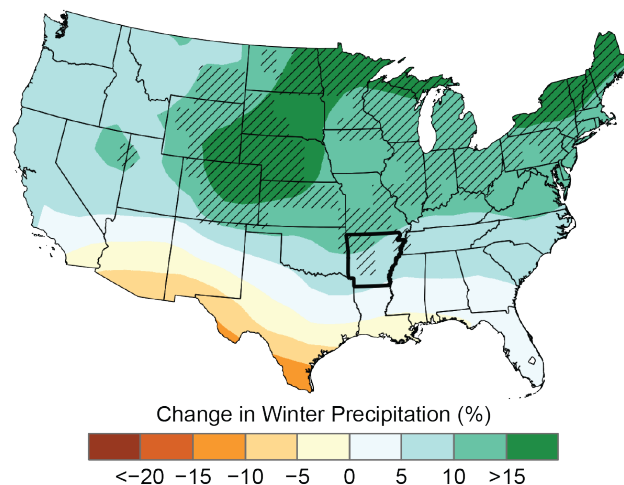


Figure 6: Projected changes in total winter (December–February) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. Arkansas is part of a large area of projected increases in winter precipitation across the United States. Sources: CISESS and NEMAC. Data: CMIP5.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

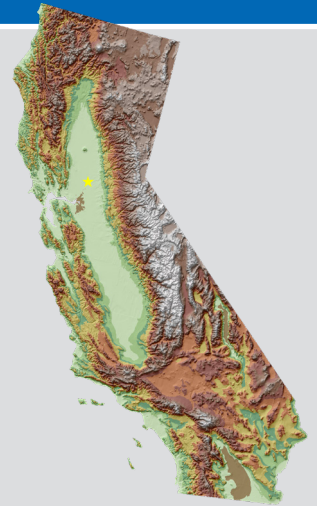
CALIFORNIA

Key Messages

Temperatures in California have risen almost 3°F since the beginning of the 20th century. The six warmest years on record have all occurred since 2014. Under a higher emissions pathway, historically unprecedented warming is projected during this century.

California snowpack plays a critical role in water supply and flood risk. Projected earlier melting of the snowpack due to rising temperatures could have substantial negative impacts on water-dependent sectors and ecosystems.

Global sea level is projected to rise, with a likely range of 1–4 feet by 2100. This will increase coastal flooding and impact management of water supplies and transportation.



California, the most populous and third-largest U.S. state, has a diverse climate. The deserts in the south are some of the Nation's hottest and driest areas, while higher elevations can experience low temperatures and heavy snowfall. **The North Pacific High, a semipermanent high-pressure system off the Pacific Coast, and the mid-latitude jet stream play dominant roles in California's seasonal precipitation patterns.** During summer, the North Pacific High and the jet stream move northward, keeping storms north of the state and resulting in dry summers. In winter, this system moves southward, allowing storms to bring precipitation to the state. Due to the moderating effect of the Pacific Ocean, coastal locations experience mild year-round temperatures, while inland locations experience a wider range of temperatures. Annual average (1991–2020 normals) temperatures vary from less than 40°F at the highest mountain elevations to less than 50°F in the northeast and greater than 70°F in the southeast. Because of its large north–south extent and the existence of several mountain ranges, extreme climate events often affect only a portion of the state. For example, strong El Niño events often cause excessive precipitation in Southern California, but the effects in Northern California are inconsistent.

Temperatures in California have risen almost 3°F since the beginning of the 20th century (Figure 1). In the 126-year period of record (1895–2020), the six warmest years have all occurred since 2014 (2014, 2015, 2016, 2017, 2018, and 2020). The 2015–2020 period saw the highest number of extremely hot days, slightly exceeding the record set in the early 1930s, and included the years with the second- and third-highest values (2017 and 2020; Figure 2a). The greatest number of very warm nights has occurred since 2005, including the six years with the highest values (2006, 2013, 2015, 2017, 2018, and 2020; Figure 3). The number of cold nights has been below average since 1995 (Figure 4).

Observed and Projected Temperature Change

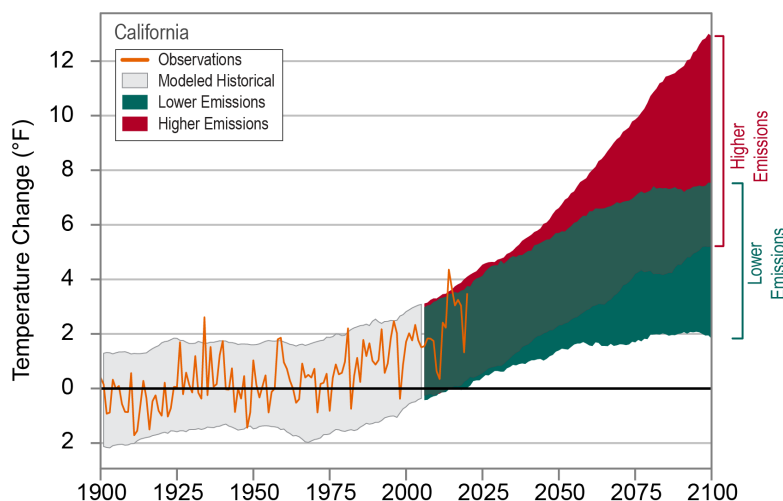


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for California. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in California (orange line) have risen almost 3°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 1°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 9°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

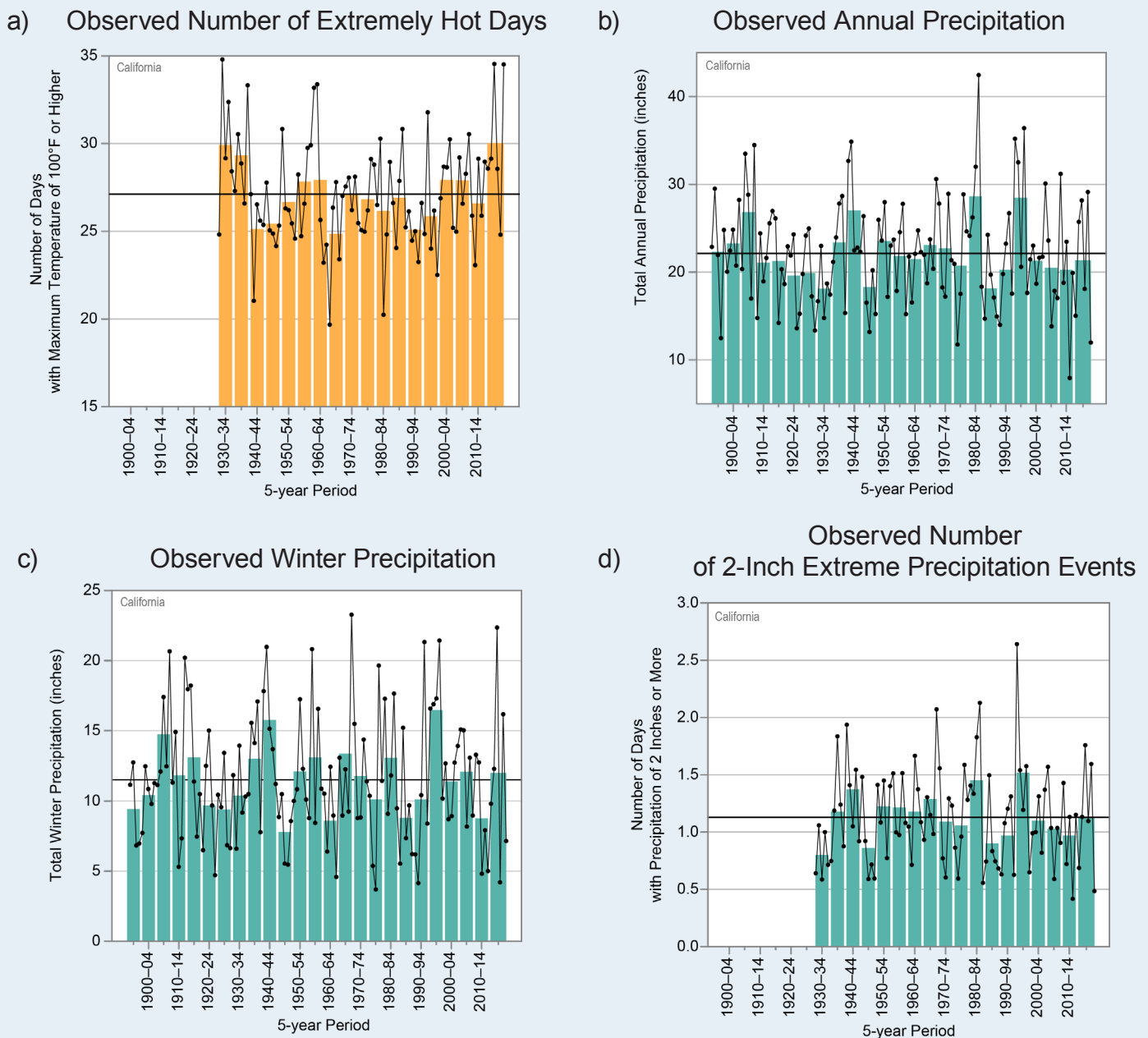


Figure 2: Observed (a) annual number of extremely hot days (maximum temperature of 100°F or higher), (b) total annual precipitation, (c) total winter (December–February) precipitation, and (d) annual number of 2-inch extreme precipitation events (days with precipitation of 2 inches or more) for California from (a, d) 1930 to 2020 and (b, c) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 27 days, (b) 22.1 inches, (c) 11.5 inches, (d) 1.1 days. (Note that for Figures 2a and 2d, the average for individual reporting stations varies greatly because of the state's large elevation range.) The greatest number of extremely hot days occurred during the 2015–2020 period. Annual precipitation shows wide variability but has been below average since 2000. There is no long-term trend in winter precipitation. Two-inch extreme precipitation events also show no overall trend; a typical station experiences 1 event per year. Sources: CISESS and NOAA NCEI. Data: (a) GHCN-Daily from 75 long-term stations; (b, c) nClimDiv; (d) GHCN-Daily from 104 long-term stations.

Annual precipitation varies from less than 3 inches in Death Valley in the southeast to more than 100 inches near Eureka in the northwest. Precipitation is also highly variable from year to year, with statewide totals ranging from 7.9 inches in 2013 to 42.5 inches in 1983. The driest multiyear periods were in the early 1930s, late 1940s,

late 1980s, and early 2010s, and the wettest were in the early 1940s, early 1980s, and late 1990s (Figure 2b). The driest consecutive 5-year interval was 1928–1932, and the wettest was 1979–1983. Winter precipitation, which accounts for about half of total annual precipitation, has also been highly variable (Figure 2c).

One of California's most serious climate hazards is flooding. Extreme precipitation events resulting in damaging flooding occur periodically. In particular, atmospheric rivers, a weather phenomenon in which a narrow band of very moist air is transported from tropical latitudes of the Pacific Ocean to the West Coast, are capable of causing torrential rainfall. From December 1996 to January 1997, heavy rains and snow fell in northern California. Precipitation was particularly heavy between December 26 and January 3, with some weather stations reporting as much as 25 inches. In addition to the large amounts of rainfall, unusually warm temperatures caused tremendous snowmelt. Lake Tahoe reached its highest level since 1917. Notable locations that experienced massive flooding included Yosemite Valley (first time since 1861–62) and areas along the Russian, Klamath, and San Joaquin Rivers. The late 1990s had the highest number of 2-inch extreme precipitation events because of this and other events (Figure 2d). The 2016–17 winter was the second-wettest on record. The resulting flooding caused more than \$1 billion in losses and damaged the Oroville Dam spillway; however, the precipitation also recharged reservoirs depleted by years of drought.

Drought is another serious climate hazard. Because snowpack plays an important role in the management of California's complex water system, some of the most impactful droughts have coincided with years of abnormally low snowpack accumulation during the winter months. The historical record indicates periodic prolonged wet and dry periods (Figure 5). Drought conditions can be exacerbated by warm temperatures. The record warmth in 2014 and 2015, in combination with multiple years of below average precipitation (Figure 2b), led to one of California's most severe droughts.

California is the most productive agricultural U.S. state. Its agricultural industry relies heavily on reservoir water supplied by snowmelt and rainfall runoff. Yearly variations in snowpack depths, and the resulting snowmelt that feeds a network of reservoirs, have implications for water availability. Spring snowpack at Donner Summit reached record-low levels in 2014, which were exceeded in 2015 by a remarkable April 1 snow water equivalent (SWE) value of only 5% of average (Figure 6). The same drought contributed to near-record-low storage levels in the Shasta Dam

Observed Number of Very Warm Nights

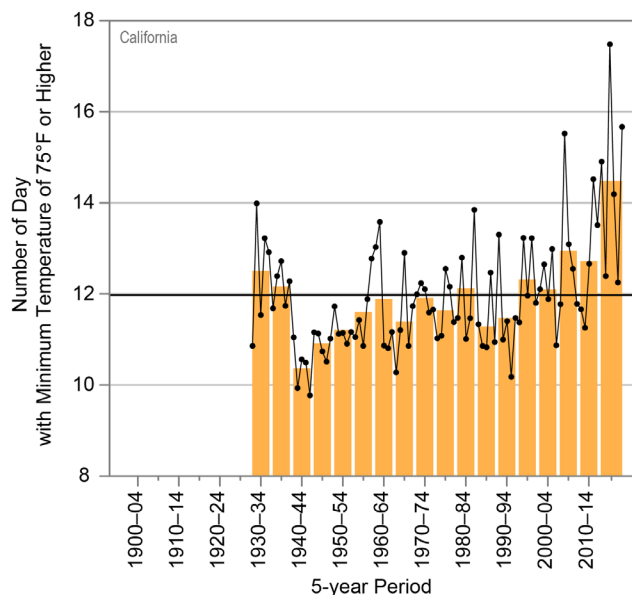


Figure 3: Observed annual number of very warm nights (minimum temperature of 75°F or higher) for California from 1930 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 12 nights (note that the average for individual reporting stations varies greatly because of the state's large elevation range). The highest number of very warm nights has occurred since 2005. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 75 long-term stations.

Observed Number of Cold Nights

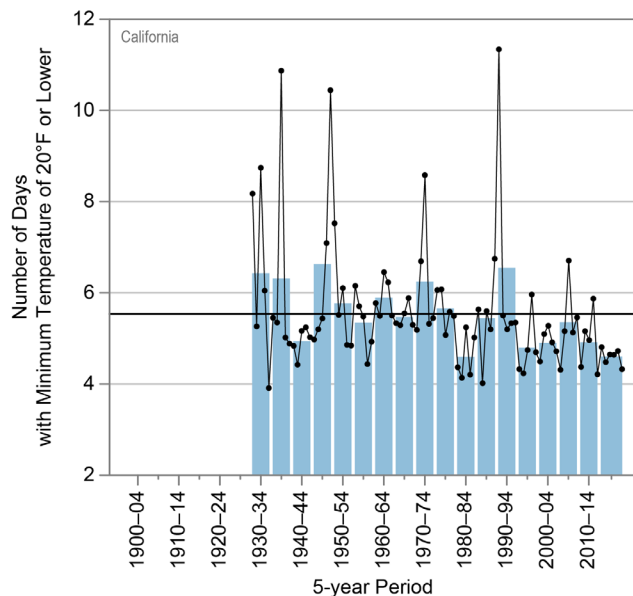


Figure 4: Observed annual number of cold nights (minimum temperature of 20°F or lower) for California from 1930 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 5.5 nights (note that the average for individual reporting stations varies greatly because of the state's large elevation range). The number of cold nights has been below average since 1995, indicative of warming in the region. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 75 long-term stations.

Reservoir in 2014 (Figure 7). Low reservoir levels force many agricultural producers to turn to groundwater. The recent dry years and resulting groundwater pumping have caused large drops in groundwater levels in some areas of the Central Valley.

Because summer is the dry season, wildfires are a common occurrence, particularly toward the end of summer. Downslope winds, such as the Santa Ana winds of Southern California that can gust to 80 mph, are often associated with the most destructive wildfires. Because they usually occur after the summer dry season, when there is ample dry vegetation for fuel, they can cause small fires to quickly burn out of control. These Santa Ana winds have been associated with some of the state's largest fires, including those in October 2003 and October 2007, when more than 800,000 and 1,000,000 acres burned, respectively. In the San Francisco Bay area, the comparable Diablo winds can be equally devastating, as evidenced by the Oakland Firestorm of 1991, which killed 25 people and caused more than \$1 billion in damages. The year 2020 saw a record number of acres burned and several of the largest fires, including the largest single fire and the largest fire complex in the state's history. The denuding of vegetation by wildfires increases the risks of mudslides and flooding when heavy rain occurs.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of the century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. Overall, warming will lead to increased heat wave intensity but decreased cold wave intensity. Future heat waves could particularly stress coastal communities that are rarely exposed to extreme temperatures and therefore are not well adapted to such events, such as San Francisco.

Winter precipitation projections range from slight decreases in Southern California to increases in Northern California, but these changes are smaller than natural variations (Figure 8). **Projected rising temperatures will raise the snow line—the average lowest elevation at which snow falls.** This will increase

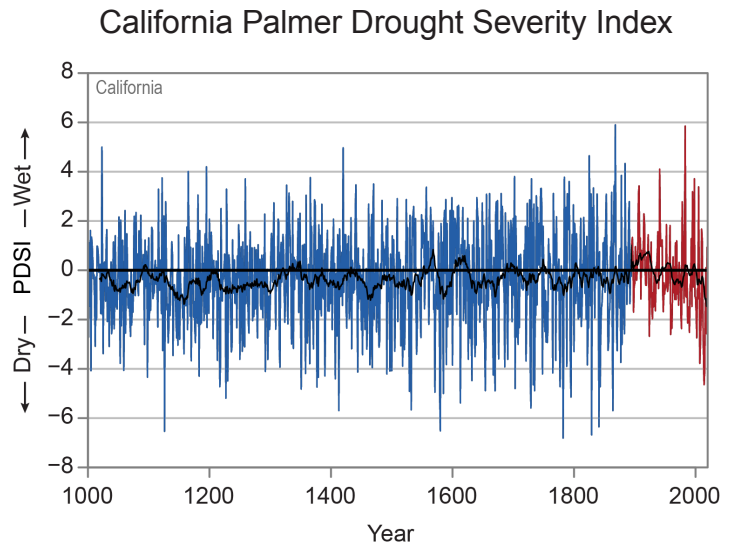


Figure 5: Time series of the Palmer Drought Severity Index for California from the year 1000 to 2020. Values for 1895–2020 (red) are based on measured temperature and precipitation. Values prior to 1895 (blue) are estimated from indirect measures such as tree rings. The fluctuating black line is a running 20-year average. The extended record indicates periodic prolonged wet and dry periods. In the modern era, the wet period of the 1900s and the recent dry period of the 2000s are clearly evident. Sources: CISESS and NOAA NCEI. Data: nClimDiv and NADAv2.

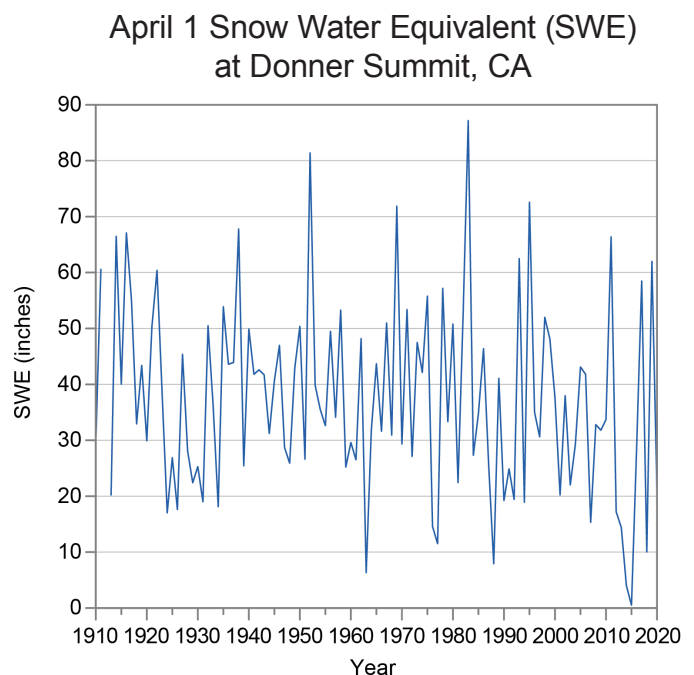


Figure 6: Variations in the April 1 snow water equivalent (SWE) at the Donner Summit, California, snow course site. SWE, the amount of water contained within the snowpack, varies widely from year to year. Snowpack levels decreased between 2011 and 2015 due to unusually low precipitation and warm temperatures during the first three months of the year, reaching record lows in 2014 and 2015. The 2015 value was only 5% of the long-term average, a dramatic indication of the severity of the drought. Source: NRCS NWCC.

the likelihood that precipitation will fall as rain rather than snow, reducing water storage in the snowpack, particularly at those lower mountain elevations that are now on the margins of reliable snowpack accumulation. Higher spring temperatures will also result in earlier melting of the snowpack. This shift in snowmelt timing has critical implications for California's water supply because of flood control rules requiring that water be allowed to flow downstream and prohibiting the storage of water in reservoirs for use in the dry season. A new management strategy called Forecast-Informed Reservoir Operations is being tested to address such challenges.

Naturally occurring droughts are expected to become more intense. Even if precipitation increases in the future, rising temperatures will increase the rate of soil moisture loss during dry spells, further reducing streamflow and water supplies. **As a result, wildfires are projected to become more frequent and severe.**

Rising temperatures also raise concerns for sea level rise in coastal areas. **Since 1900, global average sea level has risen by about 7–8 inches. It is projected to rise another 1–8 feet, with a likely range of 1–4 feet, by 2100** as a result of both past and future emissions from human activities (Figure 9). Sea level rise has caused an increase in tidal floods associated with nuisance-level impacts. Nuisance floods are events in which water levels exceed the local threshold (set by NOAA's National Weather Service) for minor impacts. These events can damage infrastructure, cause road closures, and overwhelm storm drains. As sea level has risen along the California coastline, the number of tidal flood days (all days exceeding the nuisance-level threshold) has also increased. La Jolla experienced its highest number of tidal flood days (8) in 2008 and 2015, and San Francisco recorded its highest number (6) in 1982 (Figure 10). **Continued sea level rise will present major challenges to California's water management system.** The Sacramento–San Joaquin delta is the hub of California's water supply system. Water from reservoirs in Northern California flows through the delta, where it is then pumped into aqueducts to Central and Southern California. As a result of sea level rise, salty ocean water will intrude into the delta through San Francisco Bay, requiring increased releases of water from upstream reservoirs to keep the salty water out of the delta. This, in turn, will reduce water supply amounts.

Storage Levels in the Shasta Dam Reservoir

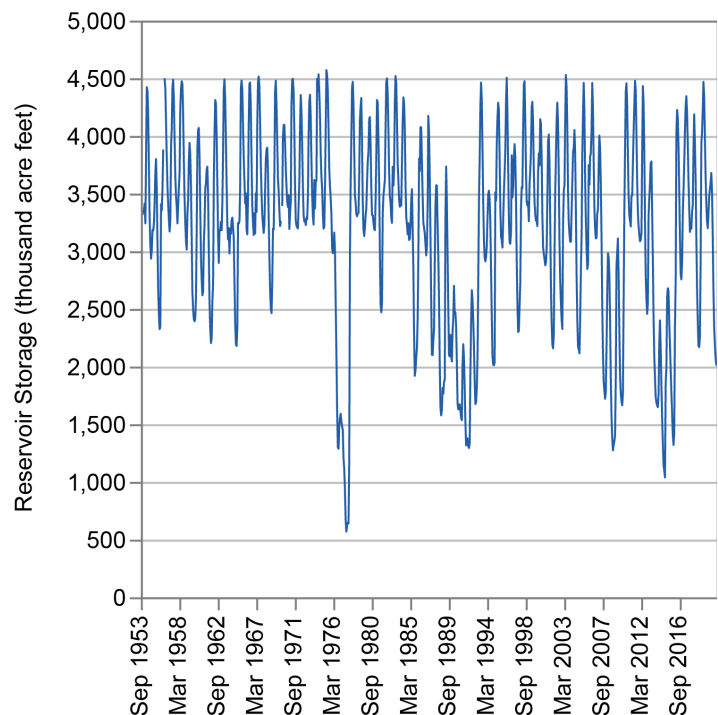


Figure 7: Monthly time series of the average water storage levels in the Shasta Dam Reservoir, California, from September 1953 to December 2020. The Shasta Dam Reservoir generally experiences similar seasonal cycles in water levels from year to year. However, water levels have dropped significantly several times over the past 68 years. In 2014, the reservoir reached its second-lowest levels, surpassed only by extremely low levels during the 1977 drought. Source: California DWR.

Projected Change in Winter Precipitation

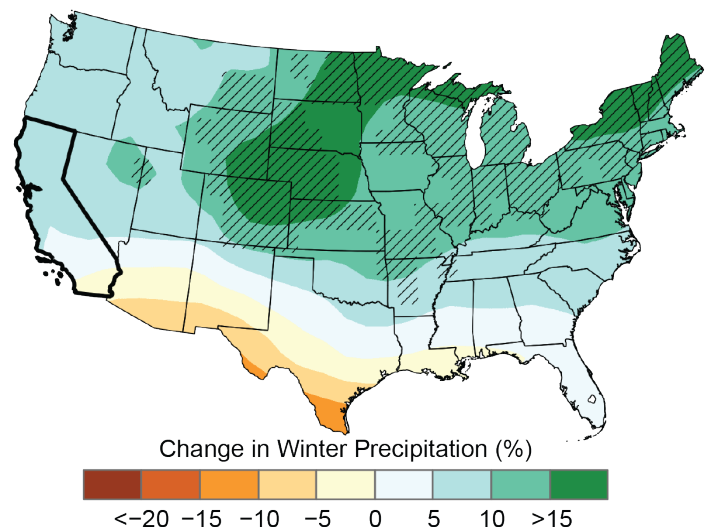


Figure 8: Projected changes in total winter (December–February) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. Winter precipitation is projected to increase slightly in the central and northern parts of the state and decrease in the south, but these changes are small relative to the natural variability in this region. Sources: CISESS and NEMAC. Data: CMIP5.

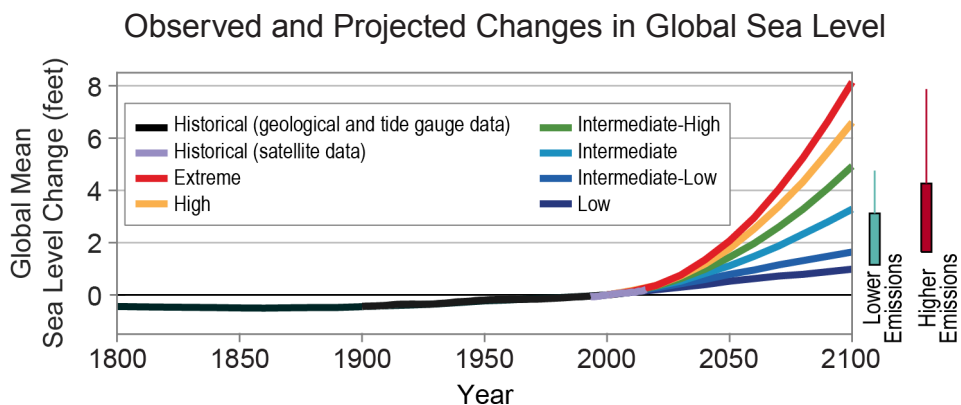


Figure 9: Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate-Low, royal blue; Intermediate, cyan; Intermediate-High, green; High, orange; and Extreme, red curves) relative to historical geological, tide gauge, and satellite altimeter GMSL reconstructions from 1800–2015 (black and magenta lines) and the very likely ranges in 2100 under both lower and higher emissions futures (teal and dark red boxes). Global sea level rise projections range from 1 to 8 feet by 2100, with a likely range of 1 to 4 feet. Source: adapted from Sweet et al. 2017.

Observed and Projected Annual Number of Tidal Floods for La Jolla and San Francisco, CA

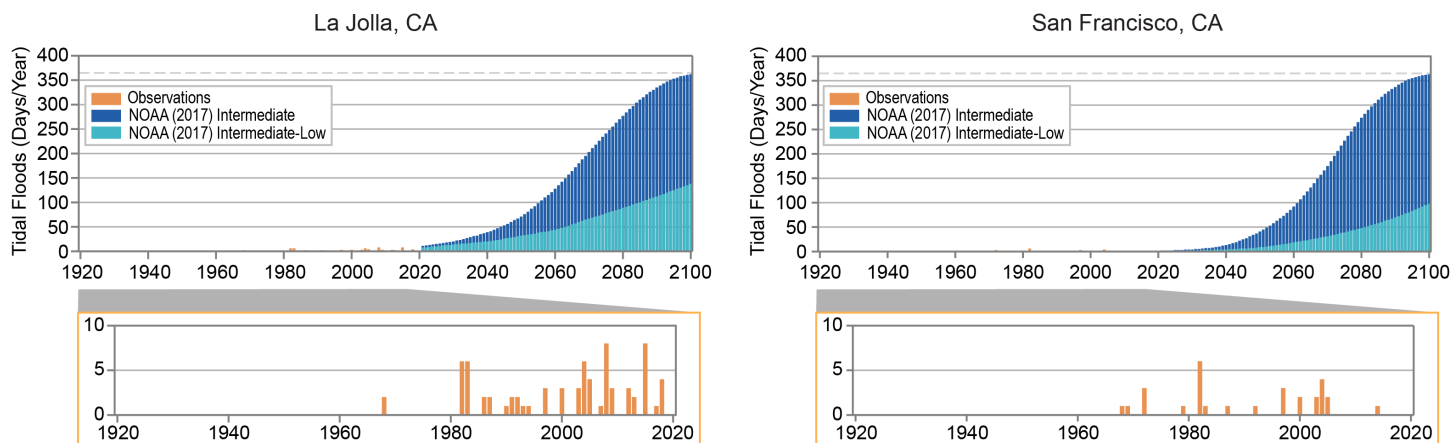


Figure 10: Number of tidal flood days per year at La Jolla and San Francisco, California, for the observed record (1925–2020 for La Jolla and 1920–2020 for San Francisco; orange bars) and projections for two NOAA (2017) sea level rise scenarios (2021–2100): Intermediate (dark blue bars) and Intermediate-Low (light blue bars). The NOAA (2017) scenarios are based on local projections of the GMSL scenarios shown in Figure 9. Sea level rise has caused a gradual increase in tidal floods associated with nuisance-level impacts. The greatest number of tidal flood days (all days exceeding the nuisance-level threshold) occurred in 2008 and 2015 at La Jolla and in 1982 at San Francisco. Projected increases are large even under the Intermediate-Low scenario. Under the Intermediate scenario, tidal flooding is projected to occur nearly every day of the year by the end of the century. Additional information on tidal flooding observations and scenarios is available at <https://statesummaries.ncics.org/technicaldetails>. Sources: CISESS and NOAA NOS.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

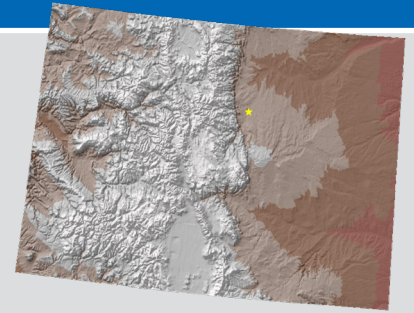
COLORADO

Key Messages

Temperatures in Colorado have risen about 2.5°F since the beginning of the 20th century. Warming has occurred in all 4 seasons, and it has been characterized by an above average occurrence of very hot days since 2000. Under a higher emissions pathway, historically unprecedented warming is projected during this century.

Colorado's mountains are the headwaters of 4 major rivers that supply water to 18 other states downstream. While future changes in annual precipitation are uncertain, warming temperatures are projected to exacerbate the recent trend of reduced overall water availability and earlier snowmelt and runoff.

Severe droughts have occurred in recent years. Projected warming will increase the rate of soil moisture loss during dry spells, increasing the intensity of future naturally occurring droughts. As a result, the frequency and severity of wildfires are projected to increase in Colorado.



Due to its inland continental location and wide range of topography, Colorado's climate is varied. Major geographic features include the High Plains in the east, the high mesas and canyons in the far west, and the Rocky Mountains in the central part of the state. Due to Colorado's semiarid climate and changes in elevation across the state, temperatures vary widely from day to night and over short distances. Colorado has 58 mountain peaks higher than 14,000 feet, and it has the highest average elevation of any U.S. state, at 6,800 feet.

Temperatures in Colorado have risen about 2.5°F since the beginning of the 20th century (Figure 1) and have remained consistently higher than the long-term (1895–2020) average since 1998. Since 2000, the state has experienced the highest summer and spring average temperatures in the historical record (Figures 2a and 2b). The hottest year on record was 2012, with an average temperature of 48.3°F, which was 3.4°F above the long-term average. Six of the 8 warmest years on record for Colorado have occurred since 2012. In addition to the overall trend of higher average temperatures, the number of very hot days has been above average since 2000 (Figure 3), and the number of very cold nights has been near or below average since 1990 (Figure 4). Colorado rarely experiences warm nights due to its high elevation and generally dry climate. The greatest number of warm nights occurred in the 1930s, and in recent years, Colorado, along with other parts of the United States, has had an above average number of such nights (Figure 5a). A new state record for maximum temperature (115.0°F) was set at John Martin Dam on July 20, 2019.

Observed and Projected Temperature Change

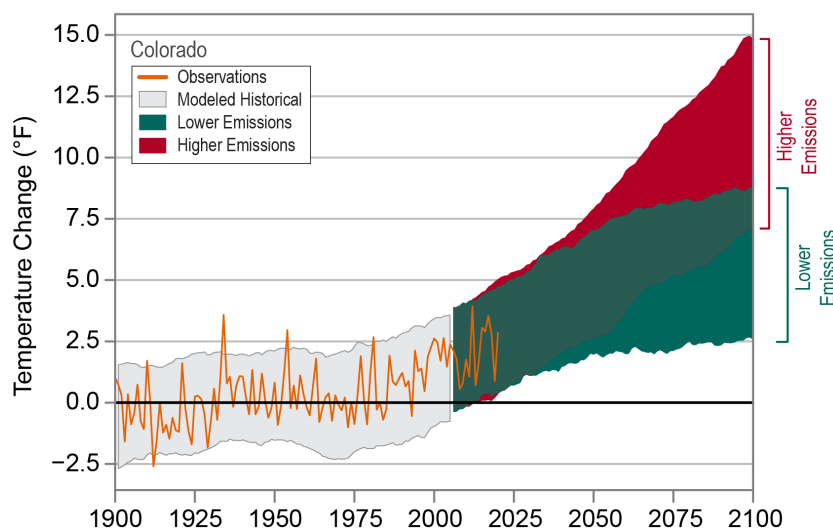


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Colorado. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Colorado (orange line) have risen about 2.5°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 2°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 11°F warmer than

the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

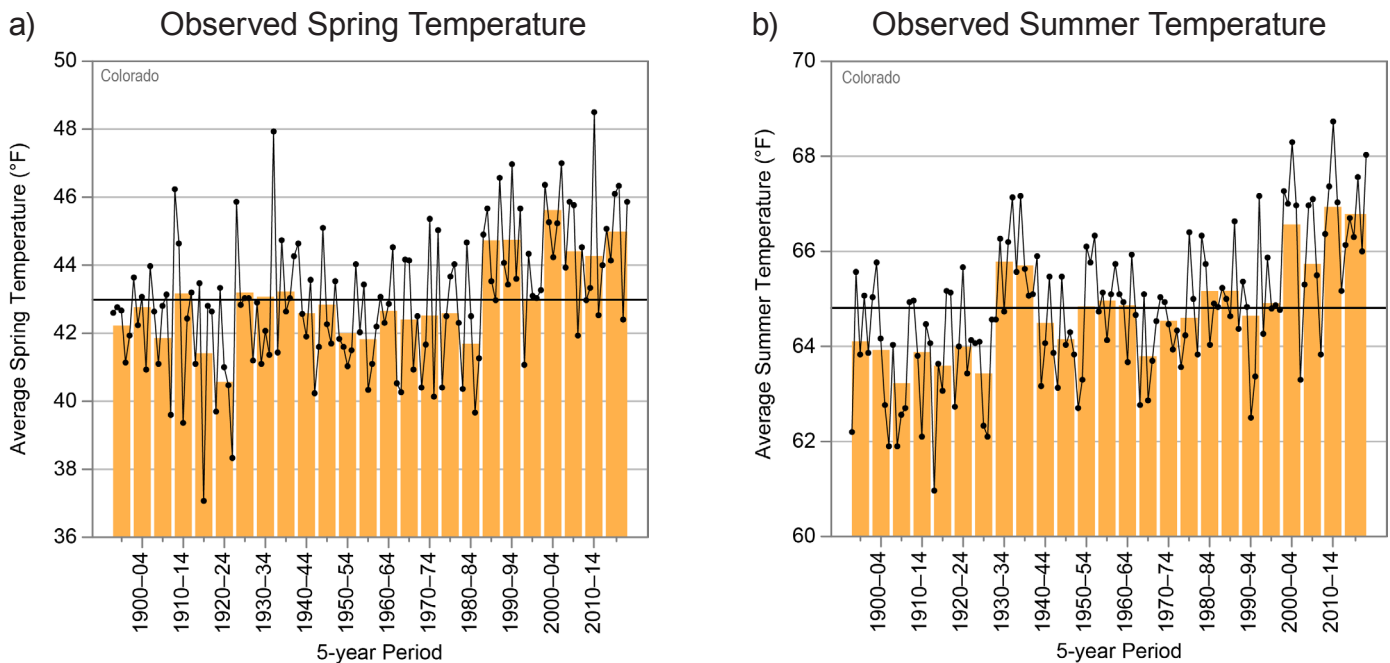


Figure 2: Observed (a) spring (March–May) average temperature and (b) summer (June–August) average temperature for Colorado from 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages of (a) 43.0°F and (b) 64.8°F. Since 1985, Colorado has experienced some of its highest springtime average temperatures, and since 2000, summer average temperatures have been even higher than the extreme heat of the 1930s Dust Bowl era. Sources: CISESS and NOAA NCEI. Data: nClimDiv.

Statewide total annual precipitation is 18.0 inches on average but has ranged from a low of 11.9 inches in 2002 to a high of 25.5 inches in 1941. The driest multiyear periods were in the 1930s and 1950s, and the wettest were in the 1940s, 1980s, and 1990s (Figure 5b). The driest consecutive 5-year interval was 1952–1956, and the wettest was 1995–1999. Local annual precipitation varies widely, from about 7 inches in the middle of the San Luis Valley to more than 60 inches in a few mountain locations. Seasonal patterns also vary: in the eastern plains and valleys, most precipitation falls during spring and summer, but the mountain peaks receive the most precipitation during the winter months. Statewide, seasonal average precipitation has been variable. With the exception of the 2015–2020 period, Colorado has experienced mostly above average fall precipitation since 1980 (Figure 5d) and below average spring precipitation since 2000 (Figure 5c). Snowfall totals also vary across the state, with the high mountains receiving 150 inches to more than 400 inches per year. **Occasional blizzards can have significant impacts.** In March 2019, a “bomb cyclone” produced widespread blizzard conditions and record-high wind gusts and caused avalanches and major travel disruptions. This storm also set a state record for lowest atmospheric sea level pressure (970.4 hPa) on March 13 in Lamar.

Since Colorado is a headwaters state, changes in precipitation can impact a much larger area than just the state itself. Four major U.S. rivers have their source in Colorado: the Colorado, the Rio Grande, the Arkansas, and the Platte. Yearly variations in snowpack depths have implications for water availability across the West and the Plains, as snowmelt from the winter snowpack feeds many rivers and streams. For example, low snowpack levels in 2012 resulted in low spring runoff across the southern Rockies. However, in years with heavy snow cover, a combination of snowmelt and widespread spring rains has the potential to cause spring flooding. Overall, there have been declines in snowpack throughout the western United States. In Colorado, there have been slight declines in northern Colorado and larger declines in southern Colorado (Figure 6), where the average April 1 snow water equivalent has been 9.7 inches since 2000 (compared to 12.3 inches for 1937–1999).

Thunderstorms are common in the eastern plains and eastern mountain slopes, with the more intense storms bringing damaging hail and occasional flash floods. The mountains are effective thunderstorm generators, especially during the summer months, when humidity is highest. Northeastern Colorado lies in Hail Alley, the most hail-prone area in the entire

country, with an average of 7 to 9 hail days per year. One of the most damaging hailstorms occurred on May 8, 2017, in Denver and surrounding communities. Hail size exceeded 2 inches in some places, damaging homes, businesses, and more than 100,000 vehicles. This was the costliest hailstorm in Colorado history, with insured losses exceeding \$2 billion. On August 13, 2019, a hailstone that fell 8 miles northwest of Bethune set state records for hail weight (8.5 ounces), circumference (12.875 inches), diameter (4.83 inches), and volume (16.55 cubic inches). Locally, intense thunderstorms can also cause flash flooding, particularly in the lower foothills east of the mountains. **Unlike many areas of the United States, Colorado and other southwestern states have not experienced an upward trend in the frequency of heavy precipitation events** (Figure 5e). However, these events can be devastating when they do occur. During September 10–16, 2013, heavy rainfall from a nearly stationary weather system caused extensive river flooding across the foothills and the Front Range, some of the worst in state history. More than 15 inches of rain fell in some locations, and the storm caused more than \$1.5 billion in damages. A new state record for 24-hour precipitation (11.9 inches) was set on September 12 at the U.S. Geological Survey Rod and Gun station at Fort Carson.

Colorado frequently experiences droughts, which can increase the risk of wildfire. During the summer and fall of 2020, Colorado had one of its worst wildfire seasons. Warm and extremely dry conditions, combined with high winds and low relative humidities, led to the ignition and spread of numerous wildfires. Three of these grew to become the largest ever recorded in Colorado—the Cameron Peak Fire, the East Troublesome Fire, and the Pine Gulch Fire, which collectively burned more than a half million acres. Other western states had record-breaking wildfire seasons in 2020, and collectively, these fires cost more than \$16 billion in damages, and the smoke created unhealthy air quality conditions for millions of people.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of this century. However, a large range of temperature increases is projected under both pathways, and under the lower

Observed Number of Very Hot Days

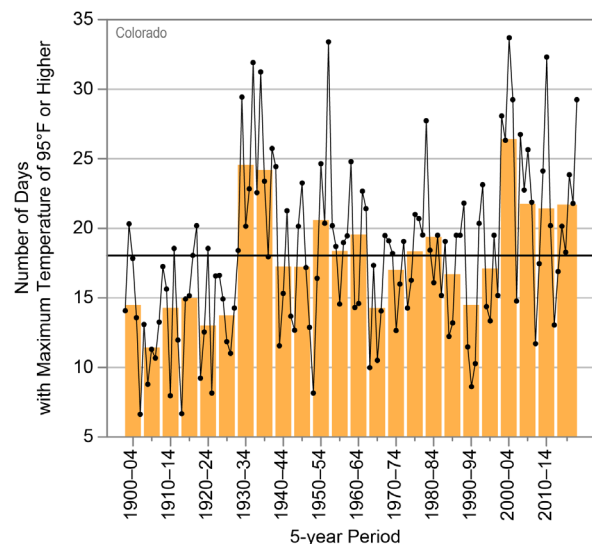


Figure 3: Observed annual number of very hot days (maximum temperature of 95°F or higher) for Colorado from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 18 days (note that the average for individual reporting stations varies greatly because of the state's large elevation range). The number of very hot days is highly variable. Statewide, the highest number of such days occurred during the 2000–2004 period, surpassing the previous highs of the 1930s. However, the frequency of very hot days varies across the state. In southeast Colorado, the number of such days was substantially higher in the early 1930s than in the 2000s. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 14 long-term stations.

Observed Number of Very Cold Nights

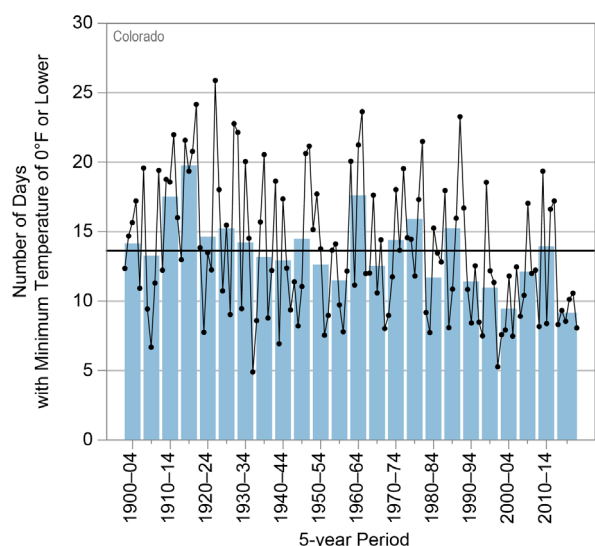
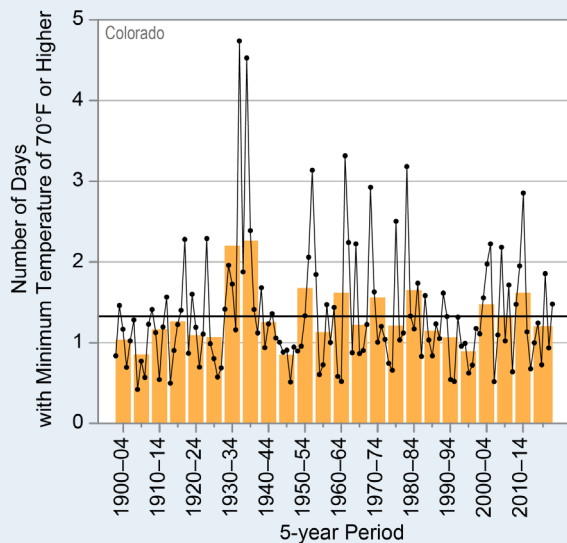
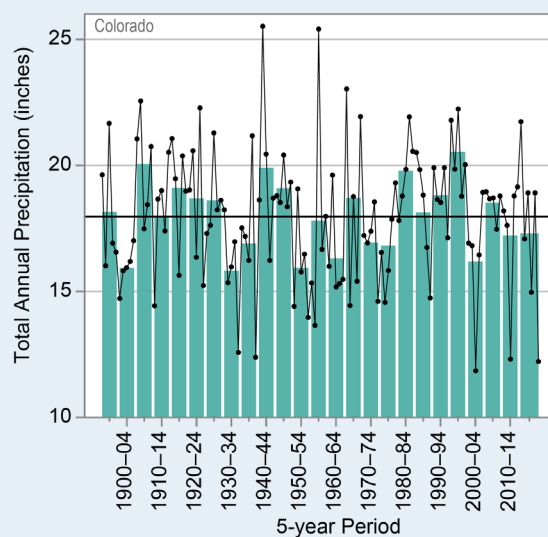


Figure 4: Observed annual number of very cold nights (minimum temperature of 0°F or lower) for Colorado from 1900–2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 14 nights (note that the average for individual reporting stations varies greatly because of the state's large elevation range). Since 1990, the number of very cold nights has generally been below average, indicative of warming in the region. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 14 long-term stations.

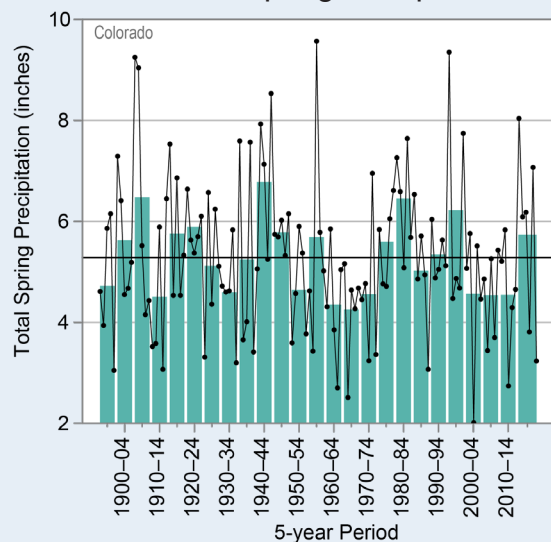
a) Observed Number of Warm Nights



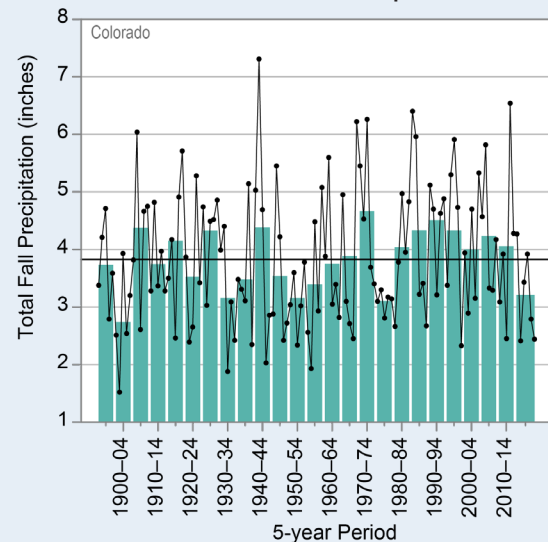
b) Observed Annual Precipitation



c) Observed Spring Precipitation



d) Observed Fall Precipitation



e) Observed Number of 1-Inch Extreme Precipitation Events

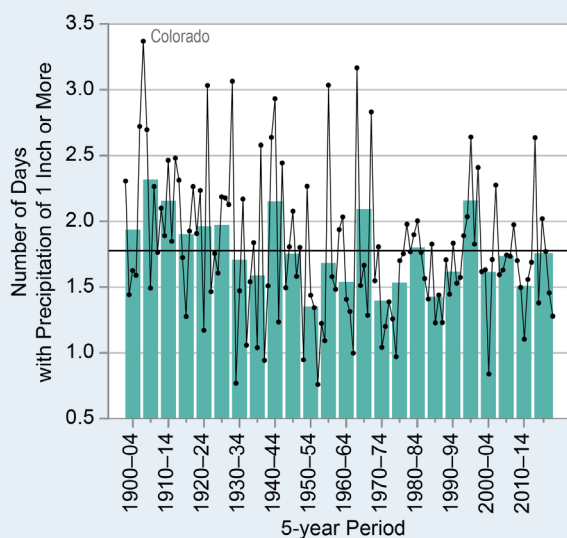


Figure 5: Observed (a) annual number of warm nights (minimum temperature of 70°F or higher), (b) total annual precipitation, (c) total spring (March–May) precipitation, (d) total fall (September–November) precipitation, and (e) annual number of 1-inch precipitation events (days with precipitation of 1 inch or more) for Colorado from (a, e) 1900 to 2020 and (b, c, d) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 1.3 nights, (b) 18.0 inches, (c) 5.3 inches, (d) 3.8 inches, (e) 1.8 days. (Note that for Figures 5a and 5d, the average for individual reporting stations varies greatly because of the state's large elevation range.) Colorado rarely experiences warm nights but has had an above average number in recent years. Precipitation varies widely from year to year. Since 2000, annual and spring precipitation totals have been generally below average. Fall precipitation was near to above average since the 1980s, until the 2015–2020 period. The number of 1-inch precipitation events has been near or below average since 2000; a typical reporting station experiences 1 to 2 events per year. Sources: CISESS and NOAA NCEI. Data: (a) GHCN-Daily from 14 long-term stations; (b, c, d) nClimDiv; (e) GHCN-Daily from 21 long-term stations.

pathway, a few projections are only slightly warmer than historical records. Increases in heat wave intensity are projected, but the intensity of cold waves is projected to decrease, continuing recent trends (Figure 4).

Although projections of overall annual precipitation are uncertain, precipitation is projected to increase in the winter (Figure 7) and possibly decrease in the summer. Although heavier winter precipitation could provide important water for the water-scarce Southwest, projected rising temperatures will raise the snow line—the average lowest elevation at which snow falls. More precipitation will likely fall as rain instead of snow, which will reduce water storage in the snowpack, particularly at those lower mountain elevations that are now on the margins of reliable snowpack accumulation. Warmer temperatures will also result in an earlier melting of the snowpack, increased evaporation rates, and decreased soil moisture, further decreasing water availability during the already-dry summer months. Increases in atmospheric water vapor (due to rising sea surface temperatures in the oceanic regions that are the moisture sources for Colorado precipitation) may increase the frequency and intensity of heavy precipitation events.

The intensity of droughts, a natural part of Colorado's climate (Figure 8), is projected to increase, and with so many river basins originating in the state, any changes in precipitation patterns pose a risk to water supplies for cities and farms across the region. Colorado has almost constantly been in drought since 2001, with 3 historic droughts occurring in the past 20 years, beginning in 2002, 2012, and 2018. Three of the 5 driest years on record for Colorado have occurred since 2002. Higher temperatures will increase the rate of soil moisture loss, leading to more intense drought conditions. Increased drought intensity, along with possibly decreased summer precipitation, will increase the risk of wildfire occurrence and severity.

April 1 Snow Water Equivalent (SWE)

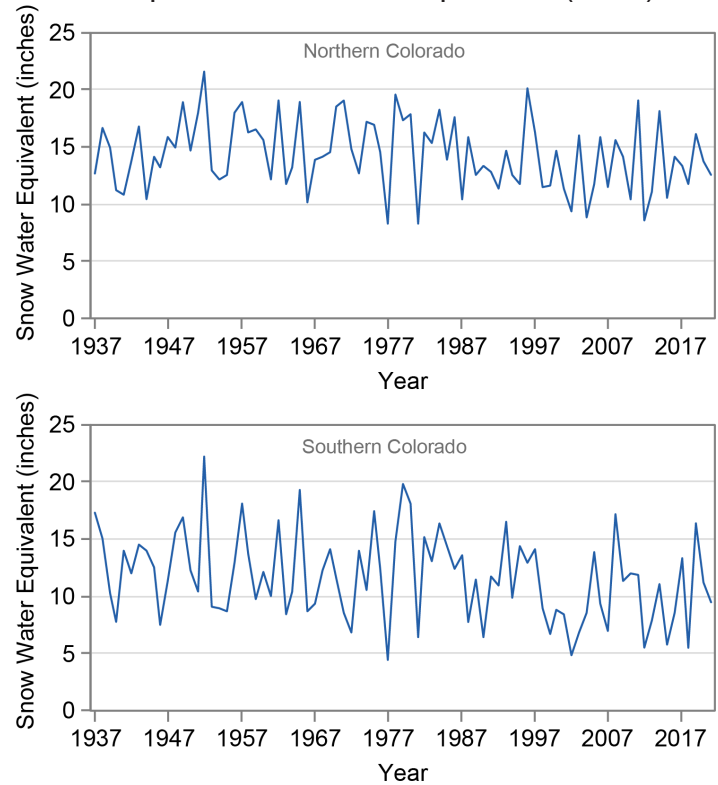


Figure 6: Variations in the annual April 1 snow water equivalent (SWE) Colorado snow course sites from 1937 to 2021 averaged over northern Colorado (top) and southern Colorado (bottom). SWE, the amount of water contained within the snowpack, varies widely from year to year. There is slight downward trend (about 0.26 inches per decade) in northern Colorado and a larger downward trend (0.42 inches per decade) in southern Colorado. The low levels seen in 2012 were exacerbated by warm and dry conditions during the month of March. Source: NRCS NWCC.

Projected Change in Winter Precipitation

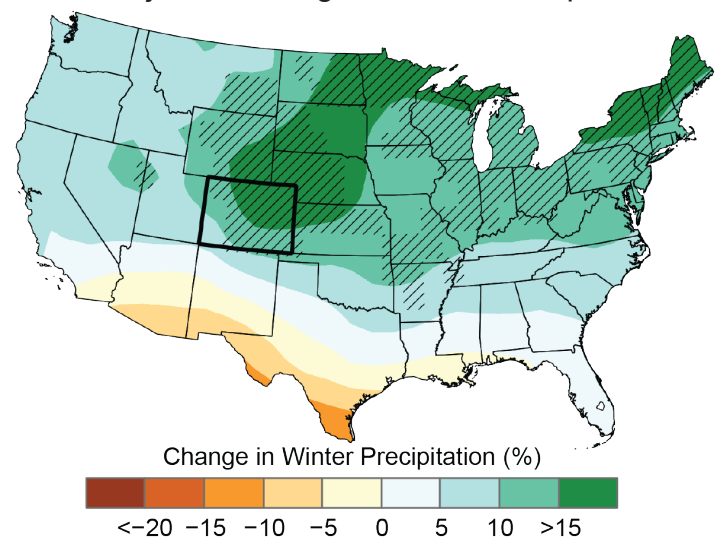


Figure 7: Projected changes in total winter (December–February) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. Colorado is part of a large area of projected increases in winter precipitation across the northern United States. Sources: CISESS and NEMAC. Data: CMIP5.

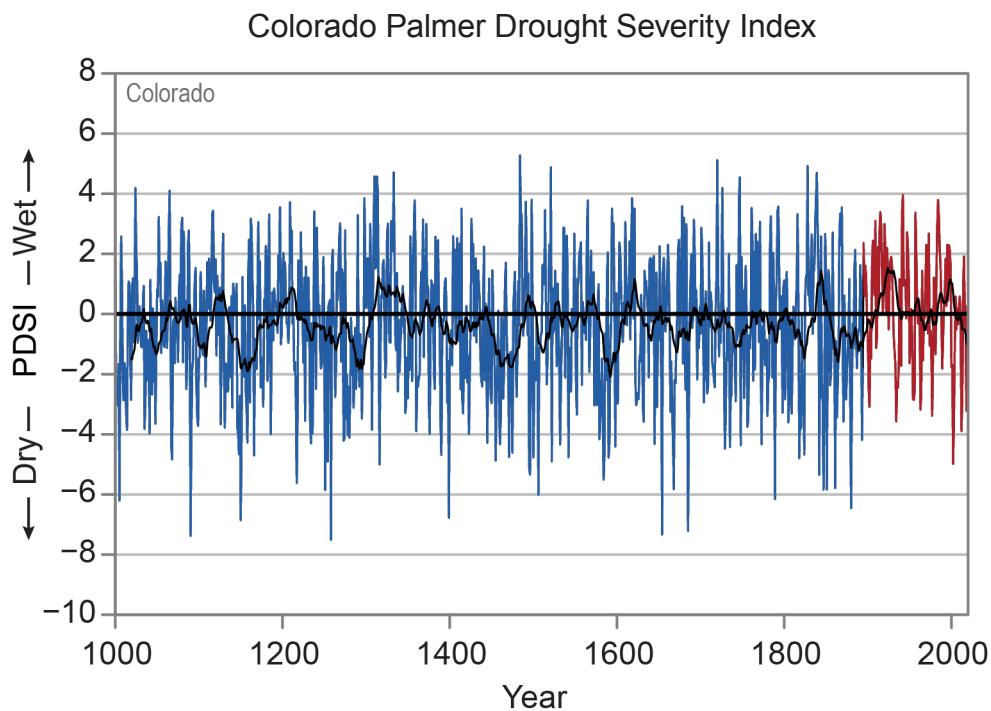


Figure 8: Time series of the Palmer Drought Severity Index for Colorado from the year 1000 to 2020. Values for 1895–2020 (red) are based on measured temperature and precipitation. Values prior to 1895 (blue) are estimated from indirect measures such as tree rings. The fluctuating black line is a running 20-year average. In the modern era, the wet periods of the early 1900s and the 1980s to 1990s and the dry period of the 1950s are evident. The extended record indicates periodic occurrences of even more extreme wet and dry periods. Sources: CISESS and NOAA NCEI. Data: nClimDiv and NADAv2.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

WWW.NCEI.NOAA.GOV | [HTTPS://STATESUMMARIES.NCICS.ORG/CHAPTER/CO/](https://STATESUMMARIES.NCICS.ORG/CHAPTER/CO/) | LEAD AUTHORS: REBEKAH FRANKSON, KENNETH E. KUNKEL
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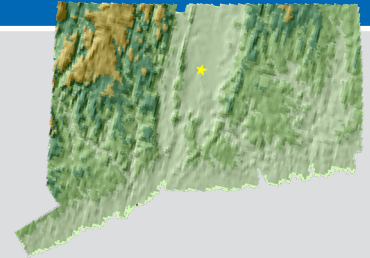
CONNECTICUT

Key Messages

Temperatures in Connecticut have risen almost 3.5°F since the beginning of the 20th century. Under a higher emissions pathway, historically unprecedented warming is projected to continue through this century, with associated increases in heat wave intensity and decreases in cold wave intensity.

Annual precipitation has been highly variable, with a slight increase since 1895. The highest number of extreme precipitation events occurred during 2005–2014. Increases in the frequency and intensity of extreme precipitation events are projected, as are increases in winter and spring precipitation.

Sea level has risen at a rate of 10–12 inches per century along the Connecticut coast, faster than the global rate. Global sea level is projected to rise, with a likely range of 1–4 feet by 2100. Even greater rises are possible for Connecticut.



Connecticut is located on the eastern coast of the North American continent. Combined with its northerly latitude, its geographic location exposes the state to both the moderating and moistening influence of the Atlantic Ocean and the effects of the hot and cold air masses from the interior of the continent. The topography varies from hilly slopes in the northwestern portion of the state to diverse sections of rocky high points and marshes along the Long Island Sound of the southeastern coast. Its climate is characterized by cold, snowy winters and warm, humid summers. The jet stream, often located near the state, gives it highly variable weather patterns and generally abundant precipitation throughout the year. Coastal areas experience warmer winters and longer frost-free seasons than inland areas. The annual average temperature is 49.9°F, with average temperatures of 27.2°F in January and 72.4°F in July. Extreme temperatures vary across the state. Days with temperatures above 90°F vary from an annual average of 8 days in Falls Village, in the northwest, to 13 days in Hartford (Hartford Brainard Field), in the central part of the state, and 4 days in New Haven, along the coast in the south. Days with temperatures below 0°F range from an annual average of 7 days in Falls Village to 2 days in Hartford and 1 day in New Haven.

Observed and Projected Temperature Change

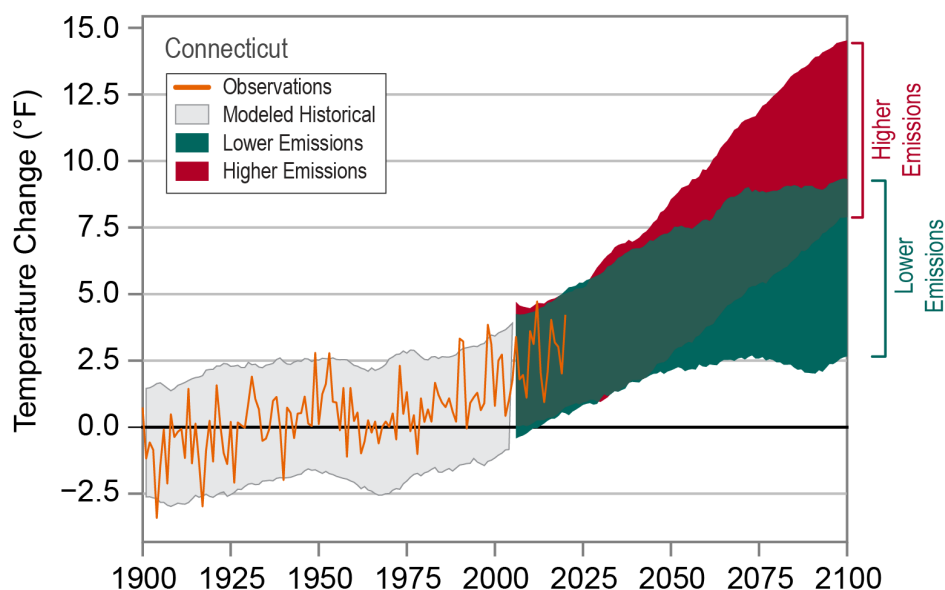


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Connecticut. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Connecticut (orange line) have risen almost 3.5°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected to continue through this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 2°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 10°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

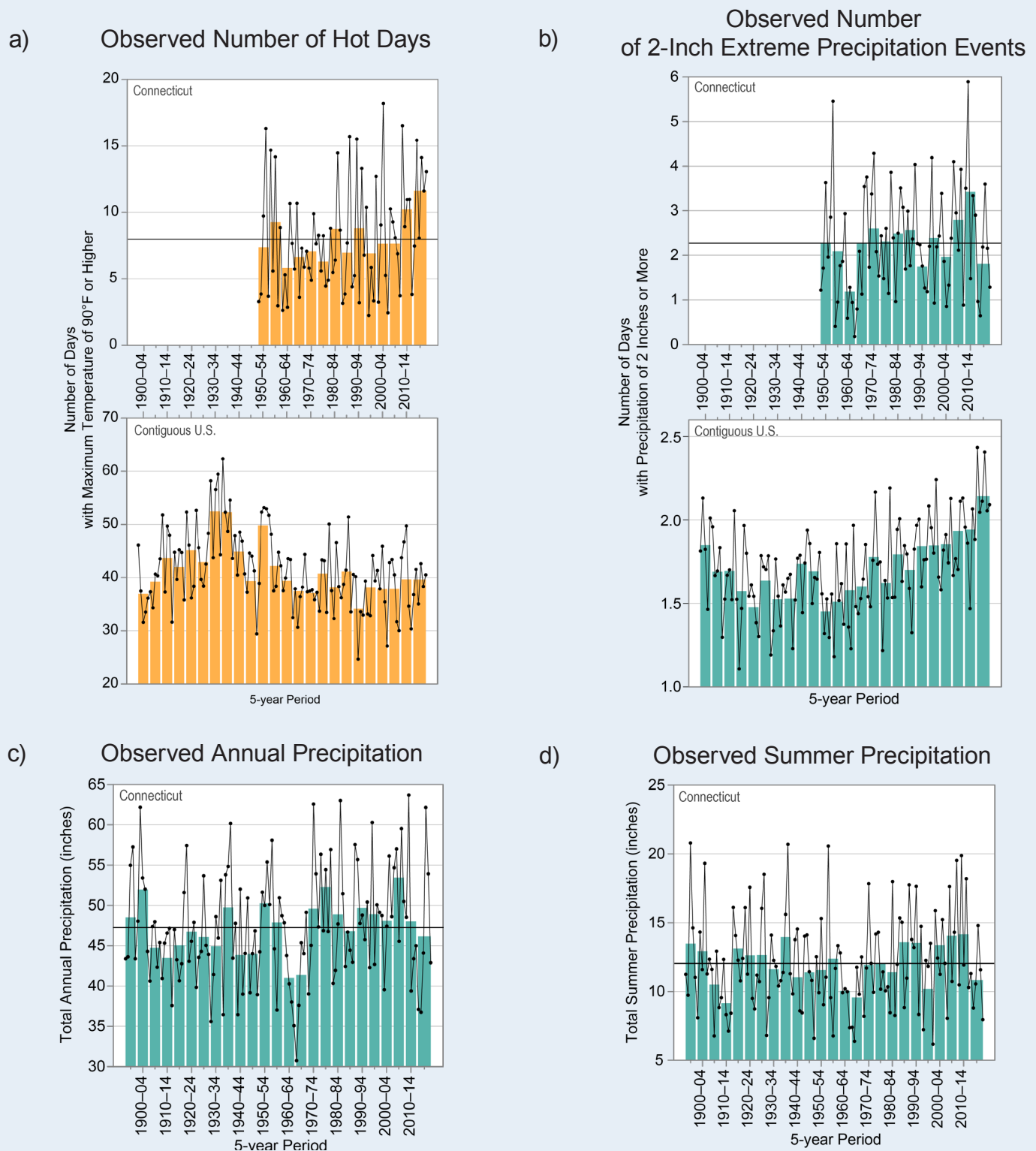


Figure 2: Observed (a) annual number of hot days (maximum temperature of 90°F or higher), (b) annual number of 2-inch extreme precipitation events (days with precipitation of 2 inches or more), (c) total annual precipitation, and (d) total summer (June–August) precipitation for Connecticut from (a, b) 1950 to 2020 and (c, d) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages for Connecticut: (a) 8.0 days, (b) 2.3 days, (c) 47.3 inches, (d) 12.0 inches. Values for the contiguous United States (CONUS) from 1900 to 2020 are included for Figures 2a and 2b to provide a longer and larger context. Long-term stations dating back to 1900 were not available for Connecticut. The greatest number of hot days occurred over the last two multiyear periods (2010–2014 and 2015–2020). The number of 2-inch extreme precipitation events has varied, with the greatest number occurring during the 2005–2009 and 2010–2014 periods; a typical station experiences between 2 and 3 events per year. Annual and summer precipitation varied widely throughout the period of record; however, both have been generally above average since the 1970s. Sources: CISESS and NOAA NCEI. Data: (a) GHCN-Daily from 5 (CT) and 655 (CONUS) long-term stations, (b) GHCN-Daily from 8 (CT) and 832 (CONUS) long-term stations, (c, d) nClimDiv.

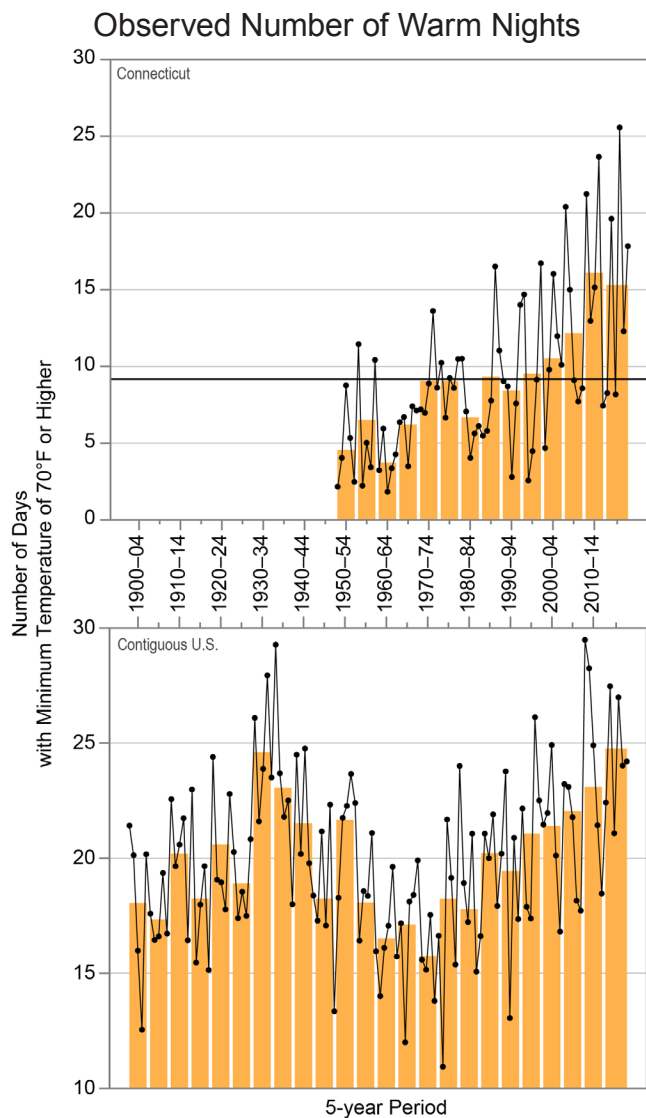


Figure 3: Observed annual number of warm nights (minimum temperature of 70°F or higher) for Connecticut from 1950 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average for Connecticut of 9.2 nights. Values for the contiguous United States (CONUS) from 1900 to 2020 are included to provide a longer and larger context. Long-term stations dating back to 1900 were not available for Connecticut. The number of warm nights in Connecticut has been steadily increasing since the 1950s; the most recent multiyear period (2015–2020) had the second-highest average. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 5 (CT) and 655 (CONUS) long-term stations.

Temperatures in Connecticut have risen almost 3.5°F since the beginning of the 20th century (Figure 1). The greatest number of hot days occurred during the last two multiyear periods (2010–2014 and 2015–2020; Figure 2a). The number of warm nights has been consistently above the long-term (1895–2020) average since 1995; the most recent multiyear period had the second-highest average (Figure 3). The number of very cold nights has been below average since the mid-1980s, with the lowest multiyear average occurring during the 2010–2014 period (Figure 4).

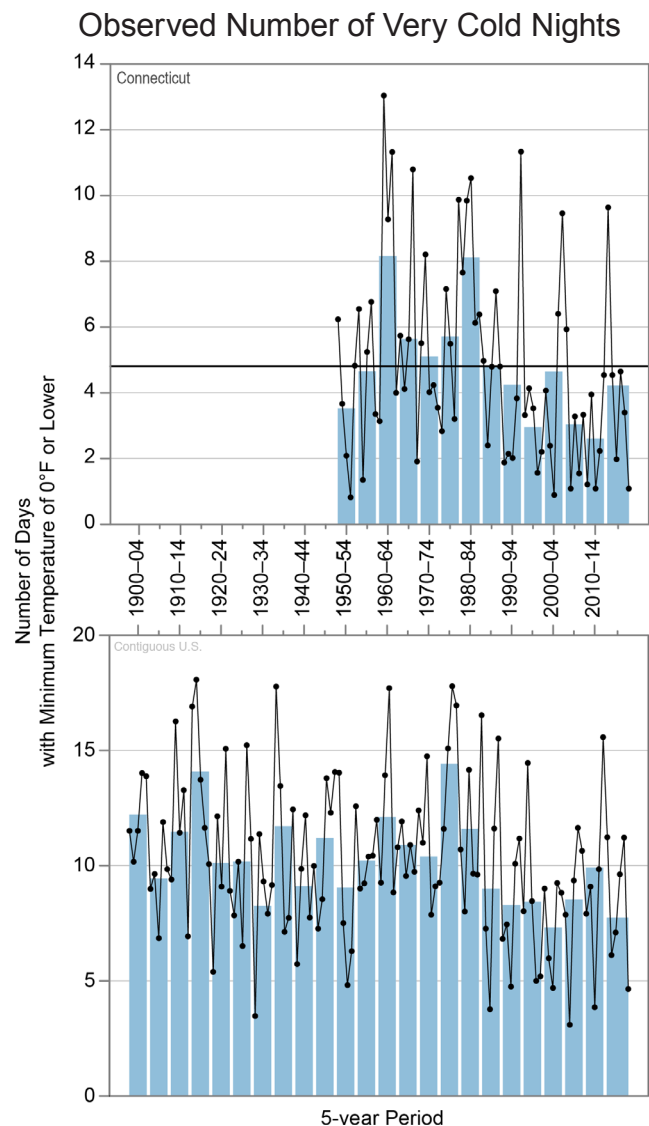


Figure 4: Observed annual number of very cold nights (minimum temperature of 0°F or lower) for Connecticut from 1950–2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average for Connecticut of 4.8 nights. Values for the contiguous United States (CONUS) from 1900 to 2020 are included to provide a longer and larger context. Long-term stations dating back to 1900 were not available for Connecticut. The number of very cold nights has been below average since the mid-1980s. The lowest multiyear average occurred during the 2010–2014 period. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 5 (CT) and 655 (CONUS) long-term stations.

Precipitation in Connecticut is abundant but highly variable from year to year. Generally, annual precipitation has been above average since the 1970s. The driest multiyear periods were the in the 1960s and the wettest in the late 1970s and late 2000s (Figure 2c). The wettest consecutive 5-year interval on record (2007–2011) averaged 53.6 inches per year, while the driest (1962–1966) averaged about 36 inches per year. The single driest year was 1965, with a statewide average of 30.7 inches, while the wettest year was

2011, with 63.7 inches. Seasonal snowfall ranges from between 30 and 35 inches along the coast to 50 inches in the Northwest Hills. The highest number of 2-inch extreme precipitation events was recorded between 2005 and 2014 (Figure 2b). Summer precipitation was generally above average in the 2000s and early 2010s (Figure 2d). Connecticut experienced extreme drought in 2016–2017 and again in 2020, straining water supplies.

Heat and cold waves, extreme precipitation events, inland flooding, nor'easters, winter storms, tornadoes, and hurricanes are all part of Connecticut's climate. Over the past decade, the state has experienced numerous disaster declarations for severe winter storms, severe thunderstorms and flooding, and hurricanes and tropical storms. In 2011, Hartford was affected by an unusual snowstorm contributing to an all-time January snowfall record of 54.3 inches (at Hartford Bradley International Airport). Later that year, a Halloween nor'easter impacted New England with snowfall ranging from 12.3 inches in Hartford to 21 inches in Norfolk, the snowiest October on record for both stations. Storm damage costs for the state, especially to power lines, were in the millions of dollars. More than 700,000 residents in Connecticut lost power, and in some areas, outages lasted for more than a week. A blizzard in February 2013 brought heavy snowfall, which caused more than a dozen roofs to collapse; Ansonia recorded 36 inches of snow in 24 hours, breaking the state record. Landfalling hurricanes produced hurricane-force winds 7 times in Connecticut from 1900 to 2019. The Great New England Hurricane of 1938 (the "Long Island Express") was the first catastrophic hurricane to impact New England since 1869. Storm tides of 14 to 18 feet were recorded along the Connecticut coastline, with 18- to 25-foot tides from New London east to Cape Cod. To date, the 1938 hurricane holds the record for the worst natural disaster in the state's history. In 2012, the state was also impacted by damaging storm surge when Superstorm Sandy (a post-tropical storm) made landfall. Coastal inundation levels ranged from 5 to 6 feet in the state, with 5.3 feet recorded at New Haven. An impact analysis by the Federal Emergency Management Agency demonstrated that more than 10,000 coastal residents in Connecticut were exposed to high and very high levels of storm surge.

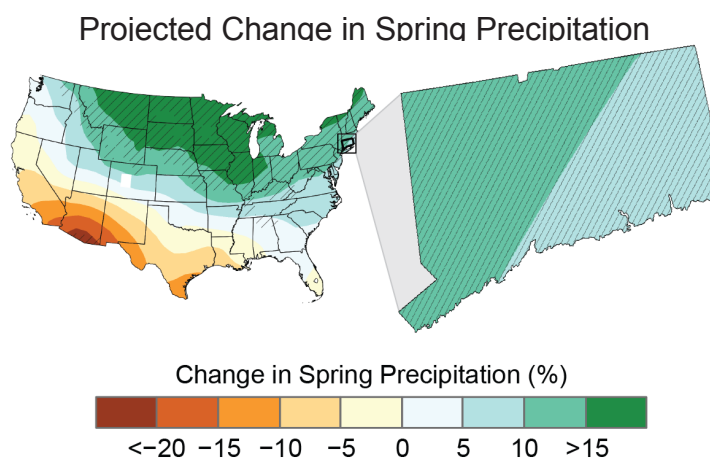


Figure 5: Projected changes in total spring (March–May) precipitation (%) by the middle of the 21st century compared to the late 20th century under a higher emissions pathway. The white-out area indicates that the climate models are uncertain about the direction of change. Hatching represents areas where the majority of climate models indicate a statistically significant change. Spring precipitation is projected to increase in Connecticut by mid-century. Sources: CISESS and NEMAC. Data: CMIP-5.

Under a higher emissions pathway, historically unprecedented warming is projected to continue through this century. Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of the century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than the recent historical average (Figure 1). The intensity of heat waves is projected to increase, and the intensity of cold waves is projected to decrease.

Annual average precipitation is projected to increase, with increases most likely occurring in spring (Figure 5) and winter. Increases in total precipitation and in the number of extreme precipitation events (e.g., storms) may also increase coastal and inland flooding risks. Coastal communities, characterized by many rivers, are particularly vulnerable to increases in total precipitation and the number of extreme precipitation events.

Increasing temperatures raise concerns for sea level rise in coastal areas. Since 1900, global average sea level has risen by about 7–8 inches. It is projected to rise another 1–8 feet, with a likely range of 1–4 feet, by 2100 as a result of both past and future emissions from human activities (Figure 6). Even greater increases can

be expected along the northeastern U.S. coast, following historical trends. Along the Connecticut coast, sea level has risen at the rate of 10–12 inches per century, faster than the global rate. Sea level rise has caused an increase in tidal floods associated with nuisance-level impacts. Nuisance floods are events in which water levels exceed the local threshold (set by NOAA’s National Weather Service) for minor impacts. These events

can damage infrastructure, cause road closures, and overwhelm storm drains. As sea level has risen along the Connecticut coastline, the number of tidal flood days (all days exceeding the nuisance-level threshold) has also gradually increased. The most recent decade (2011–2020) had the greatest number (43) of any 10-year period (Figure 7). Rising sea levels will have important coastal and floodplain impacts on local communities concentrated in these hazard-prone areas.

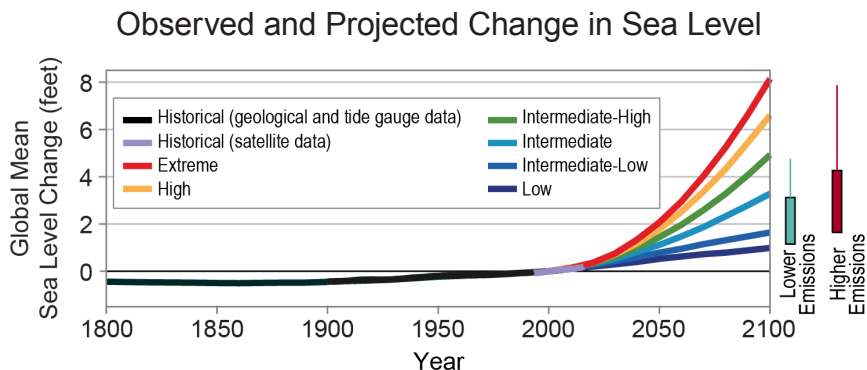


Figure 6: Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate-Low, royal blue; Intermediate, cyan; Intermediate-High, green; High, orange; and Extreme, red curves) relative to historical geological, tide gauge, and satellite altimeter GMSL reconstructions from 1800–2015 (black and magenta lines) and the very likely ranges in 2100 under both lower and higher emissions futures (teal and dark red boxes). Global sea level rise projections range from 1 to 8 feet by 2100, with a likely range of 1 to 4 feet. Source: adapted from Sweet et al. 2017.

Observed and Projected Annual Number of Tidal Floods for New London, CT

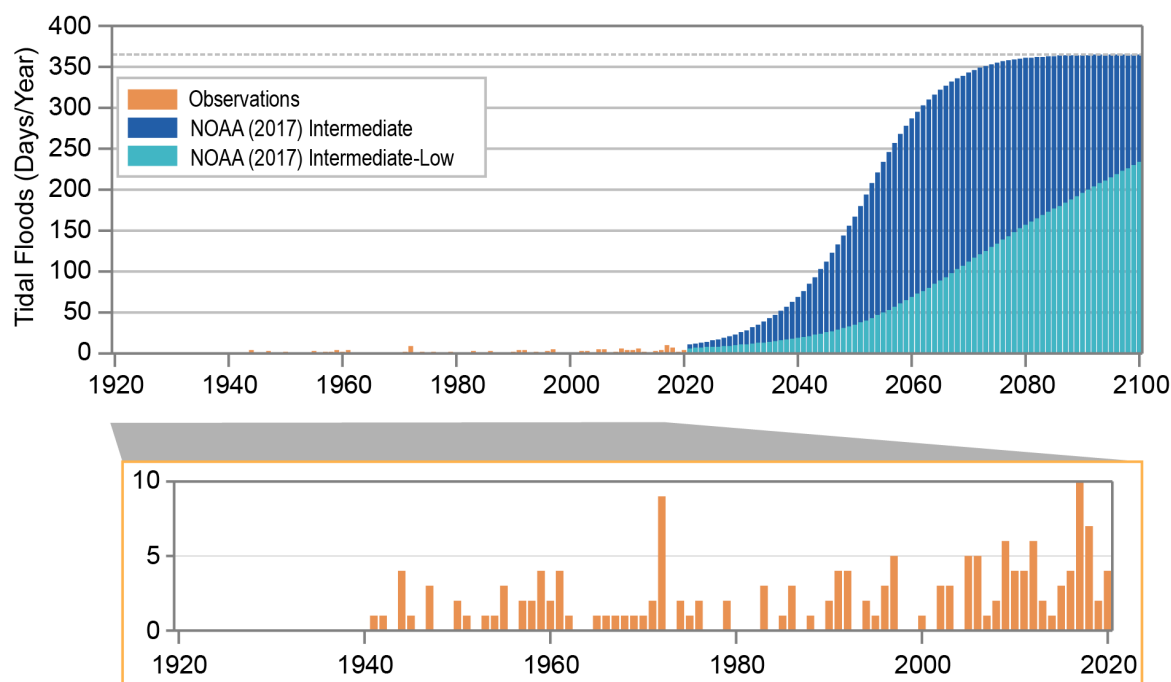


Figure 7: Number of tidal flood days per year at New London, CT, for the observed record (1938–2020; orange bars) and projections for two NOAA (2017) sea level rise scenarios (2021–2100): Intermediate (dark blue bars) and Intermediate-Low (light blue bars). The NOAA (2017) scenarios are based on local projections of the GMSL scenarios shown in Figure 6. Sea level rise has caused a gradual increase in tidal floods associated with nuisance-level impacts. The greatest number of tidal flood days (all days exceeding the nuisance-level threshold) occurred in 2017 at New London. Projected increases are large even under the Intermediate-Low scenario. Under the Intermediate scenario, tidal flooding is projected to occur every day of the year by the end of the century. Additional information on tidal flooding observations and scenarios is available at <https://statesummaries.ncics.org/technicaldetails>. Sources: CISESS and NOAA NOS.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

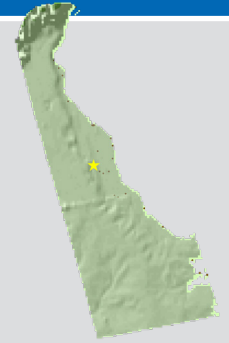
DELAWARE

Key Messages

Temperatures in Delaware have risen more than 3°F since the beginning of the 20th century. Under a higher emissions pathway, historically unprecedented warming is projected during this century. Heat waves are projected to be more intense and cold waves less intense.

Precipitation is projected to increase, as are the number and intensity of extreme precipitation events.

Since 1900, global sea level has risen by about 7–8 inches and is projected to continue to rise, with a likely range of 1–4 feet. Delaware sea level rise has been higher due to land subsidence (sinking). The number of tidal floods has been increasing. The low-elevation areas of Delaware are highly vulnerable to sea level rise.



Delaware is located on the eastern coast of the North American continent. Its mid-latitude location and proximity to the Atlantic Ocean greatly influence its climate, which is characterized by cold winters and warm summers. The jet stream is often located near the state, particularly in winter and spring. Storm systems associated with the jet stream bring frequent precipitation and fluctuating temperatures. The state often experiences strong winter storms known as nor'easters, which derive their energy from the contrast between cold air in the continental interior and warmer air over the western Atlantic Ocean. Delaware, with the lowest average elevation of all the U.S. states, experiences land subsidence. Its shoreline spans more than 250 miles. The entire state is classified as a coastal zone due to the proximity of inland areas to tidal waters: no geographic location within the state is more than 8 miles from tidal waters. The moderating influences of the Atlantic Ocean and the Delaware Bay tend to lessen temperature extremes. Slight variations in average (1991–2020) temperatures across this small, relatively flat state range from 53°F in the north to 58°F along the coast in the south. The statewide annual average (1991–2020) precipitation is 45.9 inches, with large interannual variability ranging from 27.4 inches in 1930 to 60.1 inches in 1948. Annual average snowfall ranges from 9 to 20 inches.

Temperatures in Delaware have risen more than 3°F since the beginning of the 20th century (Figure 1). The number of very hot days at Dover has been highly variable, with no long-term trend since 1910 (Figure 2a). By contrast, the number of very warm nights at Dover has been increasing since the early 1960s, reaching a peak during the 2015–2019 period (Figure 3). The number of freezing days has been generally below the long-term average since the early 1990s (Figure 2b).

Observed and Projected Temperature Change

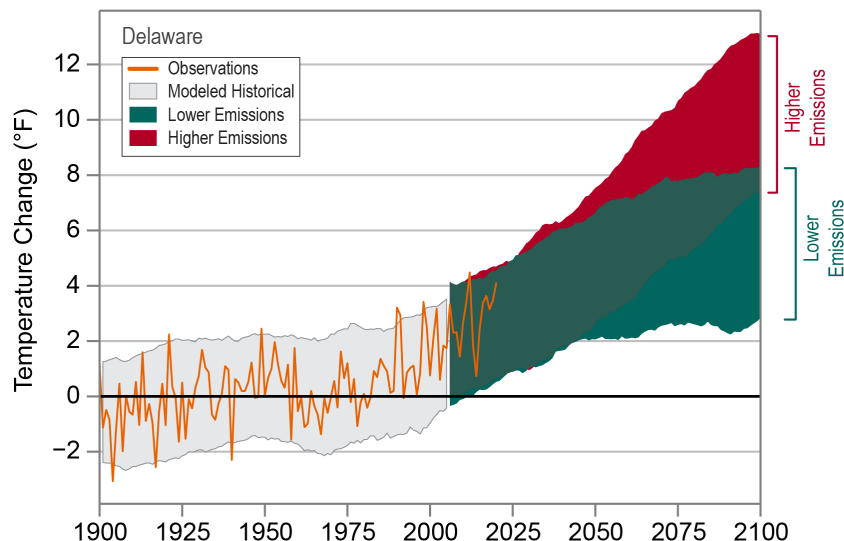


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Delaware. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Delaware (orange line) have risen more than 3°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 2°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 9°F warmer than the hottest year in the historical record; red shading). Sources: CISS and NOAA NCEI.

being about 9°F warmer than the hottest year in the historical record; red shading). Sources: CISS and NOAA NCEI.

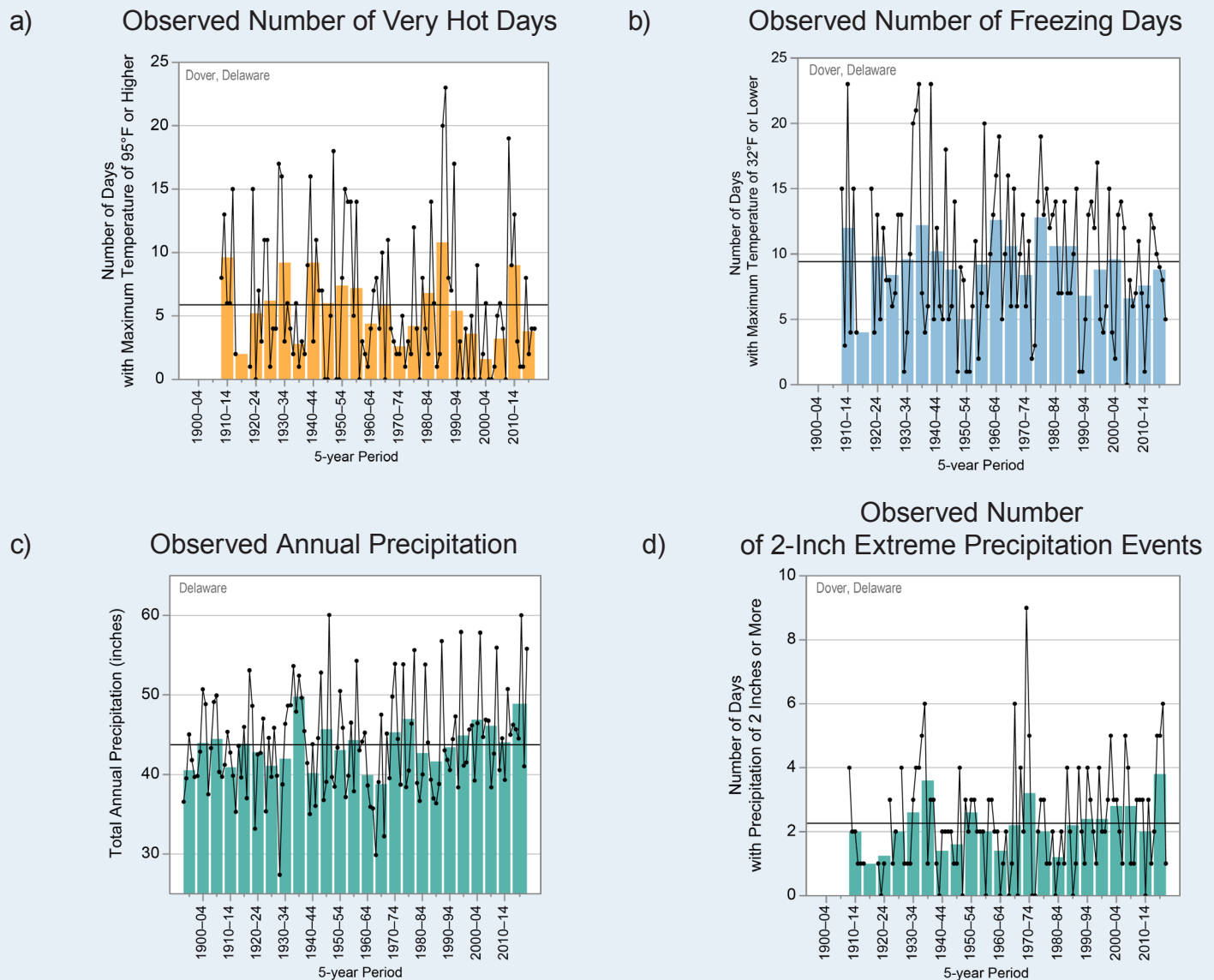


Figure 2: Observed (a) annual number of very hot days (maximum temperature of 95°F or higher) at Dover from 1910 to 2019, (b) annual number of freezing days (maximum temperature of 32°F or lower) at Dover from 1910 to 2019, (c) total annual precipitation for Delaware from 1895 to 2020, and (d) annual number of 2-inch extreme precipitation events (days with precipitation of 2 inches or more) at Dover from 1910 to 2019. Dots show annual values. Bars show averages over 5-year periods (last bar in Figure 2c is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 5.9 days, (b) 9.4 days, (c) 43.7 inches, (d) 2.3 days. (For Figures 2a, 2b, and 2d, data were not recorded for 1916 to 1919.) At Dover, there is no overall trend in the number of very hot days; however, the number of freezing days has been generally below average since the early 1990s. Statewide, total annual precipitation has been above average since the mid-1990s. The number of 2-inch extreme precipitation events at Dover has been mostly above average since the early 1990s; a typical reporting station experiences between 2 and 3 events per year. Sources: CISESS and NOAA NCEI. Data: (a, b, d) GHCN-Daily from 1 long-term station, (c) nClimDiv.

Statewide, total annual precipitation has shown a slight upward trend since 1895 and has been above average since the mid-1990s (Figure 2c). The number of 2-inch extreme precipitation events at Dover has generally been above average since the early 1990s (Figure 2d).

The state's coastline is highly vulnerable to damage from coastal and tropical storms. Nor'easters, the most common coastal storms, bring strong winds,

heavy precipitation, and coastal flooding. They are most active from mid-winter through spring, with peak activity during March. The Ash Wednesday nor'easter of March 6–8, 1962, was the worst in Delaware history and illustrates the potential danger of such storms. The strong northeast winds, broad fetch (upwind distance traveled), and high angle of wave approach caused record flooding and beach erosion in Delaware and along the eastern seaboard

from New England to Florida. Most houses near the beach that were not protected by a wide beach and dunes were destroyed. February 2010 brought multiple snowstorms to Delaware, which closed schools, disrupted transportation, and contributed to several snowfall records (greatest daily snow depth, greatest monthly snowfall, and greatest seasonal snowfall). During a blizzard in January 2016, gusts up to 75 mph caused dangerous storm surge and flooding. Tropical storms and hurricanes occasionally affect Delaware in the late summer and fall. In New Castle County, densely populated areas along major streams are at significant risk of flooding due to heavy precipitation and possible surges up Delaware Bay. Hurricanes Irene (2011) and Sandy (2012) caused significant economic and infrastructure damage to the state. Hurricane Sandy, which made landfall in New Jersey as a post-tropical storm, caused record flooding along the Atlantic and Delaware Bay coasts. Tornadoes and heavy rains trailing Hurricane Irene resulted in power outages for at least 119,000 residents and damages in the millions of dollars for the state.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical records by the middle of this century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. According to the Delaware Climate Change Impact Assessment, annual maximum (daytime) temperature is projected to increase by an average of 2°–2.5°F and annual minimum (nighttime) temperature by an average of 1.5°–2.5°F by 2039. In the near term (2020–2039), extreme heat waves are projected to occur 3 out of every 5 years. Projections for midcentury show an average of 1 extreme heat wave per year under the lower scenario and up to 10 extreme heat waves per year by the end of the century under the higher scenario. Higher temperatures and extreme heat events in the future may result in decreased air quality and related health risks for Delaware residents. However, future cold waves are projected to be not as cold.

Total annual precipitation is projected to increase for Delaware (Figure 4), **with the greatest increases occurring in winter and spring.** This change is characteristic of a large area of the Northern

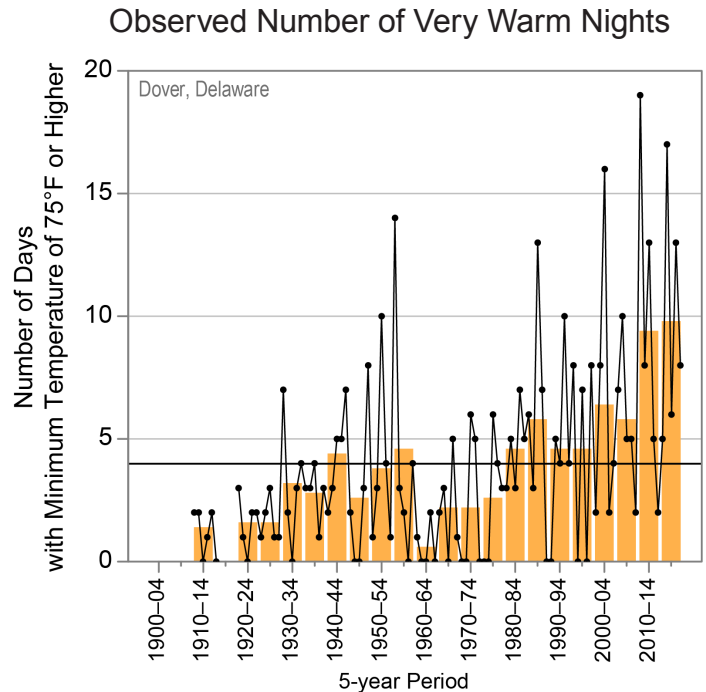


Figure 3: Observed annual number of very warm nights (minimum temperature of 75°F or higher) at Dover from 1910 to 2019. Dots show annual values. Bars show averages over 5-year periods. The horizontal black line shows the long-term (entire period) average of 4.0 nights. (Data were not recorded for 1916 to 1919.) The number of very warm nights at Dover has consistently been above average since 1980, with the highest multiyear average occurring during the 2015–2019 period. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 1 long-term station.

Hemisphere in the higher mid-latitudes that is projected to see increases in both total precipitation and extreme precipitation events. On average, the state experiences about 2 days each year with 2 or more inches of rain. State-level projections show an increase of 0.5 to 1 day each year with 2 inches of rainfall by the end of the century. These precipitation projections may also result in increased flooding risks throughout the state.

Since 1900, global average sea level has risen by about 7–8 inches. It is projected to rise another 1–8 feet, with a likely range of 1–4 feet, by 2100 as a result of both past and future emissions from human activities (Figure 5). The rise on Delaware's coasts has been greater due to land subsidence. Findings from the 2012 Sea Level Rise Vulnerability Assessment for the state project increases in sea level rise based on three levels of global warming: (1) 1.6 feet rise for low levels of global warming, (2) 3.3 feet for moderate levels, and (3) 4.9 feet for high levels (see the Delaware Climate Change Impact Assessment [http://www.dnrec.delaware.gov/energy/Documents/Climate%20Change%202013-2014/DCCIA%20interior_full_dated.pdf] for more sea level rise

resources). Sea level rise has important future cross-sector implications for public health, water resources, coastal ecosystems and wildlife, agriculture, and transportation infrastructure. Demographic trends may increase the risks of coastal flooding. Due to the relocation of retirees, coastal communities show increases in their vulnerable elderly populations. Sea level rise has also caused an increase in tidal floods associated with nuisance-level impacts. Nuisance floods are events in which water levels exceed the local threshold (set by NOAA's National Weather Service) for minor impacts. These events can damage infrastructure, cause road closures, and overwhelm storm drains. As sea level has risen along the Delaware coastline, the number of tidal flood days (all days exceeding the nuisance-level threshold) has also increased, with the greatest number (15) occurring at Lewes in 2009 and 2017 (Figure 6).

Observed Change in Annual Precipitation

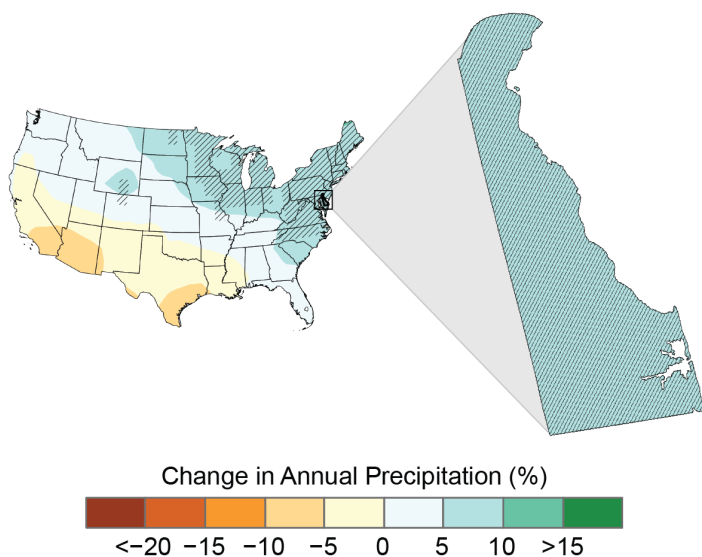


Figure 4: Projected changes in total annual precipitation (%) by the middle of the 21st century relative to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. Delaware is part of a large area of projected increases in the Northeast. Sources: CISESS and NEMAC. Data: CMIP5.

Observed and Projected Change in Global Sea Level

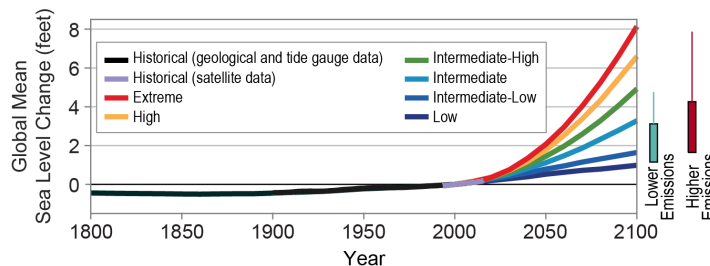


Figure 5: Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate-Low, royal blue; Intermediate, cyan; Intermediate-High, green; High, orange; and Extreme, red curves) relative to historical geological, tide gauge, and satellite altimeter GMSL reconstructions from 1800–2015 (black and magenta lines) and the very likely ranges in 2100 under both lower and higher emissions futures (teal and dark red boxes). Global sea level rise projections range from 1 to 8 feet by 2100, with a likely range of 1 to 4 feet. Source: adapted from Sweet et al. 2017.

Observed and Projected Annual Number of Tidal Floods for Lewes, DE

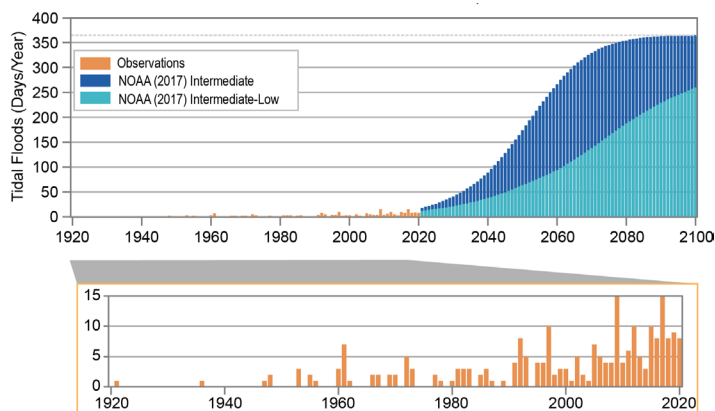


Figure 6: Number of tidal flood days per year for Lewes, Delaware, for the observed record (1921–2020; orange bars) and projections for two NOAA (2017) sea level rise scenarios (2021–2100): Intermediate (dark blue bars) and Intermediate-Low (light blue bars). The NOAA (2017) scenarios are based on local projections of the GMSL scenarios shown in Figure 5. Sea level rise has caused a gradual increase in tidal floods associated with nuisance-level impacts. The greatest number of tidal flood days (all days exceeding the nuisance-level threshold) occurred in 2009 and 2017 at Lewes. Projected increases are large even under the Intermediate-Low scenario. Under the Intermediate scenario, tidal flooding is projected to occur every day of the year by the end of the century. Additional information on tidal flooding observations and scenarios is available at <https://statesummaries.ncics.org/technicaldetails>. Sources: CISESS and NOAA NOS.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

FLORIDA

Key Messages

Temperatures in Florida have risen more than 2°F since the beginning of the 20th century. Under a higher emissions pathway, historically unprecedented warming is projected during this century. Increases in the rate of soil moisture loss due to rising temperatures will likely increase the intensity of naturally occurring droughts.

The number of landfalling hurricanes in Florida is highly variable from year to year. Hurricane rainfall rates are projected to increase as the climate continues to warm.

Global sea level is projected to rise, with a likely range of 1–4 feet by 2100, and will likely increase the frequency of nuisance-level coastal flooding and contribute to saltwater contamination of coastal groundwater reservoirs.

Due to its location at subtropical latitudes and adjacent to the warm waters of the Gulf of Mexico and western Atlantic, Florida has a climate characterized by hot, humid summers and mild winters. The Bermuda High, a semipermanent high-pressure system off the Atlantic coast, plays an important role in the climate of the state, particularly in the summer. Typically, the Bermuda High draws moisture northward or westward from the Atlantic Ocean, causing warm and moist summers with frequent thunderstorms in the afternoons and evenings. Average (1991–2020 normals) temperatures in January range from the lower 50s (°F) in the northern portion of the state to the upper 60s (°F) in the south. During July, typically the hottest month of the year, average temperatures in the low 80s (°F) are prevalent throughout the state. Statewide annual average (1895–2020) precipitation is 53.7 inches, with more precipitation falling during the warmer months of June through September.

Temperatures in Florida have risen more than 2°F since the beginning of the 20th century (Figure 1). Although there has been a general lack of daytime warming (Figure 2a), nighttime warmth has increased dramatically since 1995 (Figure 3); the number of very warm nights during the 2015 to 2020 period was more than double the numbers of the mid-20th century (1930–1944). While Florida typically experiences far fewer days with temperatures exceeding 100°F than most other southern states, it is the most humid state in the Nation. Extended periods of extreme heat, especially when combined with high humidity, can result in heat-related illness among vulnerable populations and place excess stress on agricultural production, water supplies, and energy generation.

Observed and Projected Temperature Change

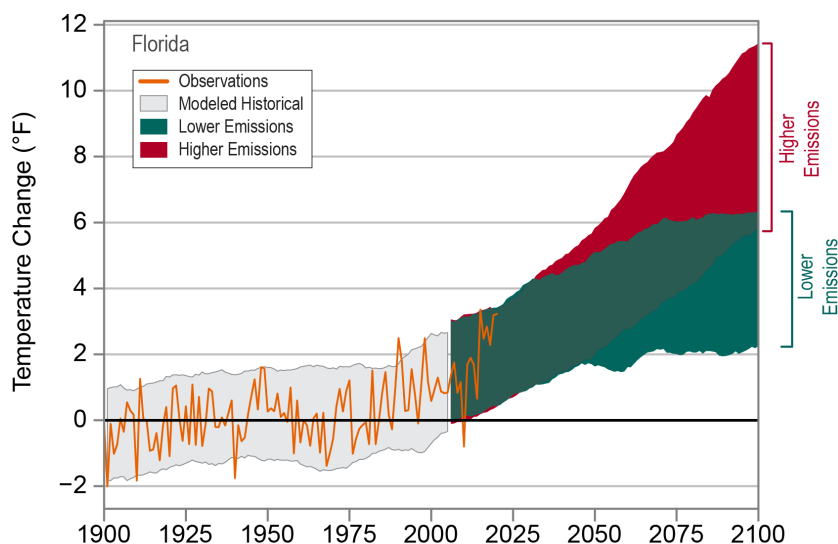
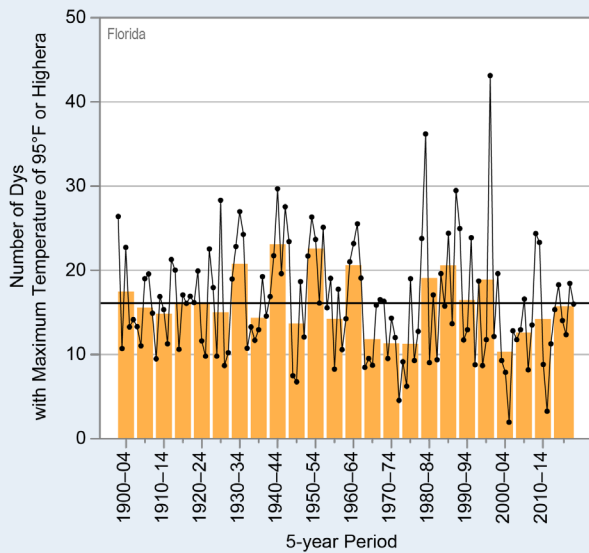


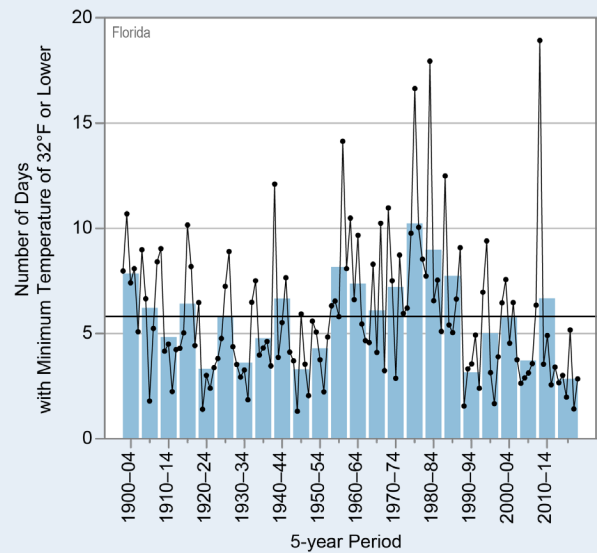
Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Florida. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Florida (orange line) have risen more than 2°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 2°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 8°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

century projections being about 8°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

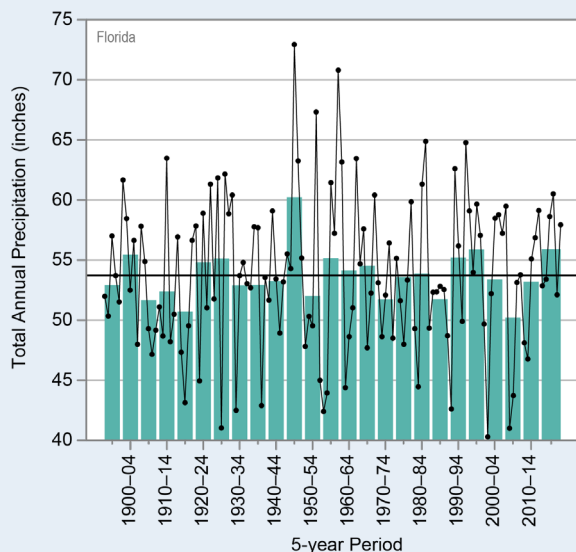
a) Observed Number of Very Hot Days



b) Observed Numbers of Freezing Nights



c) Observed Annual Precipitation



d) Total Hurricane Events in Florida

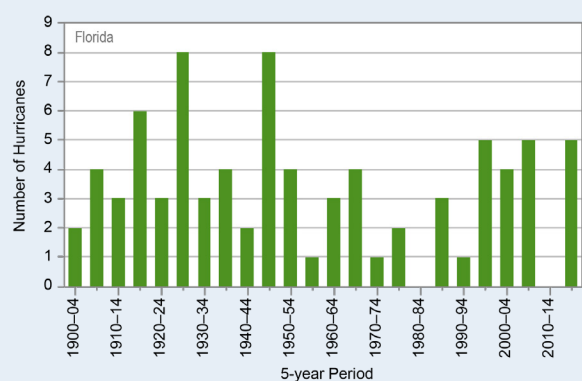


Figure 2: Observed (a) annual number of very hot days (maximum temperature of 95°F or higher), (b) annual number of freezing nights (minimum temperature of 32°F or lower), (c) total annual precipitation, and (d) total number of hurricane events (wind speeds reaching hurricane strength somewhere in the state) for Florida from (a, b, d) 1900 to 2020 and (c) 1895 to 2020. In

Figures 2a, 2b, and 2c, dots show annual values, bars show averages over 5-year periods (last bar is a 6-year average), and the horizontal black lines show the long-term (entire period) averages: (a) 16 days, (b) 5.8 nights, (c) 53.7 inches. In Figure 2d, bars show totals over 5-year periods (last bar is a 6-year total). Since 2000, the number of very hot days has been below average. The number of freezing nights has generally been below average since 1990. Total annual precipitation reached its lowest level during the 2005–2009 period, coinciding with an increase in drought and wildfires. Hurricane strikes occur frequently along the Florida coast, with most multiyear periods experiencing at least 3 hurricanes. Some years are more active than others. For example, following a very active 2004 (4 events) and 2005 (5 events), there were no landfalling hurricanes in Florida from 2006 to 2015. Sources: (a, b, c) CISESS and NOAA NCEI; (d) NOAA Hurricane Research Division. Data: (a, b) GHCN-Daily from 13 long-term stations; (c) nClimDiv.

During the cold season, extratropical cyclones and associated fronts are responsible for significant day-to-day variability in the weather. While the temperatures associated with cold waves are warmer than in areas to the north, they can have major impacts on those sectors adapted to the generally mild climate, such as agriculture. For example, several strong freezes since

the beginning of the 19th century have gradually forced the citrus and other industries (e.g., winter vegetables and sugarcane) to migrate from North Florida into South Florida. The annual average (1991–2020) number of freezing nights varies from greater than 20 in the far northern part of the state to 0 in the south (Figure 4). Throughout 80 years of record keeping, Miami

International Airport has dropped below freezing only 7 times and not once since 1989. Subfreezing air sometimes reaches as far south as Central Florida, causing major damage to citrus crops. A severe cold outbreak lasting more than a week in January 2010 resulted in more than \$200 million in losses to the Florida citrus industry. There is no long-term trend in the number of freezing nights, but there has been a decrease from the high numbers of the late 1970s (Figure 2b).

Total annual precipitation varies widely from year to year (Figure 2c). The driest year on record was 2000, with 40.3 inches of precipitation, and the wettest was 1947, with 72.9 inches. The driest consecutive 5-year interval was 2006–2010, with an average of 47.9 inches per year, and the wettest was 1945–1949, with an average of 60.2 inches per year. Historically, the number of 4-inch extreme precipitation events has been highly variable but has been near or above average since 1995 (Figure 5). Two notable extreme precipitation events occurred in 2014. During January 9–10, torrential rain fell in the West Palm Beach area, with more than 10 inches at Fort Pierce and more than 14 inches at Sun Valley. On April 29 in the Panhandle, more than 15 inches fell in Pensacola and about 20 inches in Milton.

Observed Number of Very Warm Nights

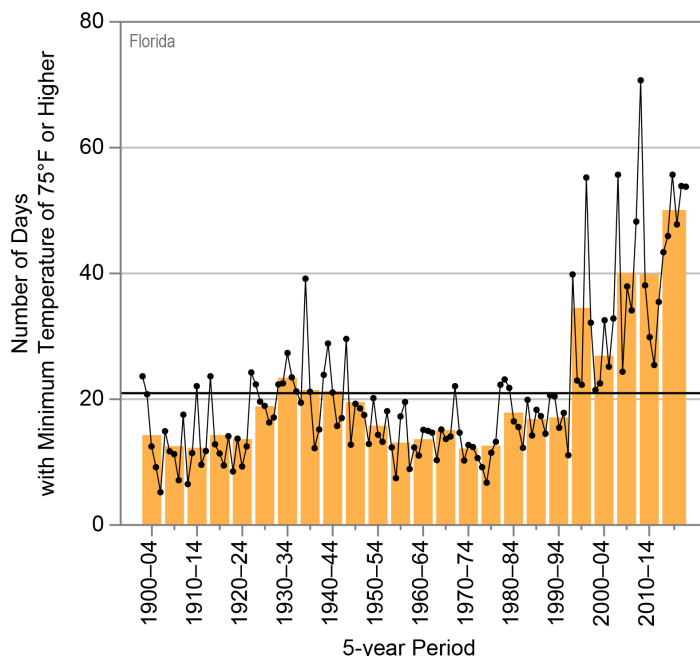


Figure 3: Observed annual number of very warm nights (minimum temperature of 75°F or higher) for Florida from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 21 nights. The number of very warm nights has risen substantially since 1995. The 2015 to 2020 multiyear average is more than double the 1930–1934 multiyear average. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 13 long-term stations.

Observed Number of Freezing Nights for the Southeast and Florida (1991–2020)

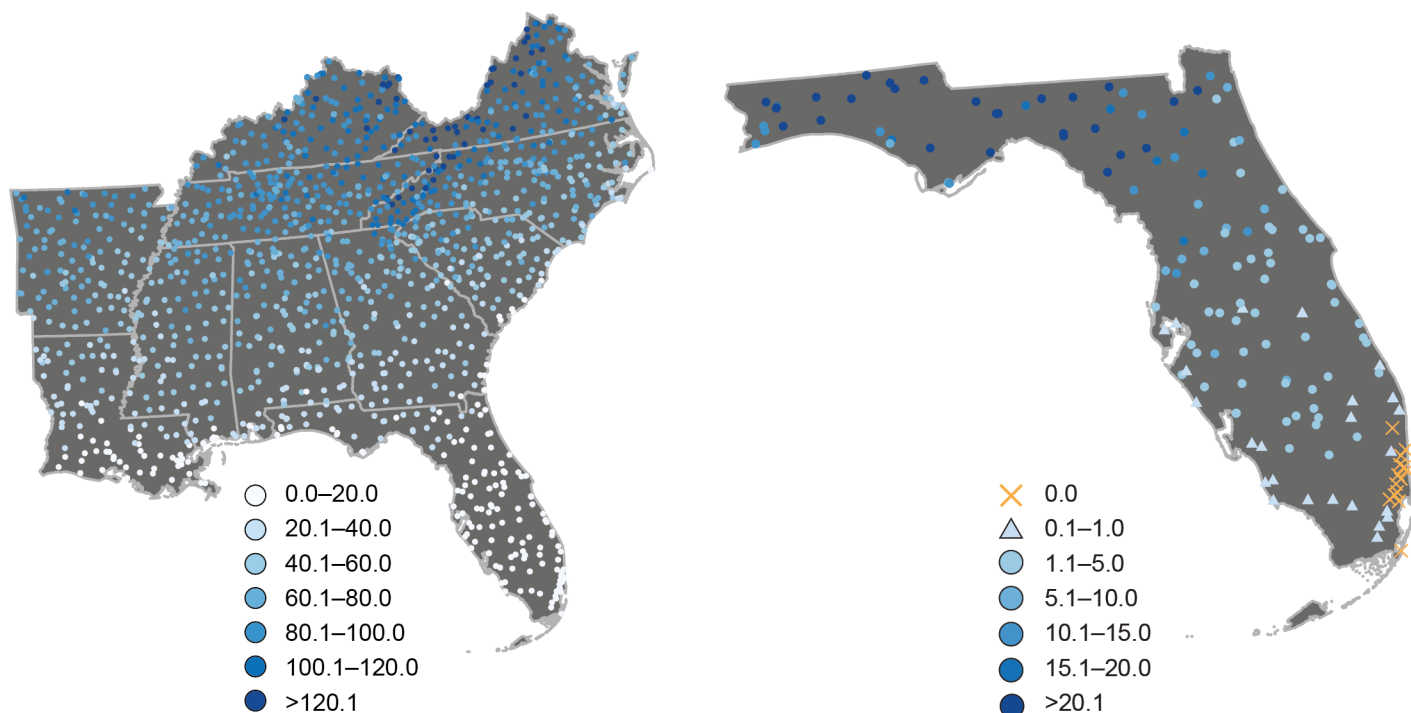


Figure 4: Observed annual average (1991–2020) number of freezing nights (minimum temperature of 32°F or lower) for the Southeast region (left) and Florida (right, with a different scale). Source: CISESS.

Drought is a persistent climate threat for Florida, resulting in water supply reductions, disruptions to agriculture, and increased risk of wildfires. In every decade since 1900, the state has been impacted by at least one severe and widespread drought.

Thunderstorms are ubiquitous during the summer. Florida experiences the highest annual number of thunderstorms in the United States. Hurricanes and intense coastal storms are the most serious weather threats. Hurricane strikes occur frequently along the Florida coast, with hurricane-force winds impacting the state an average of 3 times every 5 years (Figure 2d). In 2018, Hurricane Michael (Category 5) struck the Panhandle, nearly destroying Mexico Beach and causing extensive damage to Panama City and Tyndall Air Force Base and more than \$20 billion in damages. Michael was the strongest hurricane on record to make landfall along the Florida Panhandle. In 2017, Hurricane Irma (Category 4) made landfall at Cudjoe Key, then crossed over the Gulf of Mexico and made landfall again in the Florida Panhandle. The Florida Keys were heavily impacted, and near-historic levels of storm surge caused significant coastal flooding in Jacksonville.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of the century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. By 2050, most of the state is projected to see an increase of more than 50 days with temperatures of 95°F or higher. The summer heat index is projected to increase by 8° to 15°F, the largest escalation in the Nation.

Increases in the frequency and intensity of extreme precipitation and drought are projected. Projected changes in summer precipitation are uncertain (Figure 6); however, even if precipitation remains constant, higher temperatures will increase the rate of soil moisture loss and likely lead to more intense droughts. Decreased water availability, exacerbated by population growth and land-use change, will continue to increase competition for water and affect the region's economy and unique ecosystems. Increasing drought intensity

Observed Number of 4-Inch Extreme Precipitation Events

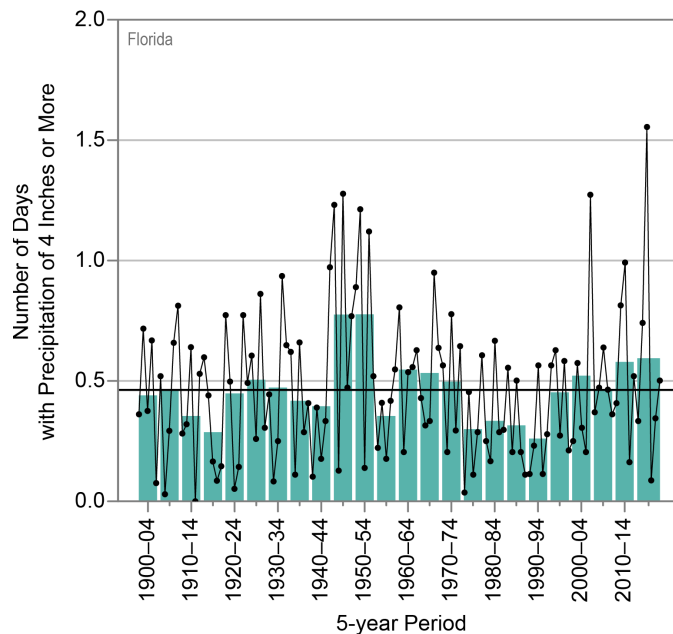


Figure 5: Observed annual number of 4-inch extreme precipitation events (days with precipitation of 4 inches or more) for Florida from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 0.5 days. A typical station experiences an event about once every 2 years. The number of 4-inch extreme precipitation events shows wide variability but has been near or above average since 1995. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 15 long-term stations.

Projected Change in Summer Precipitation

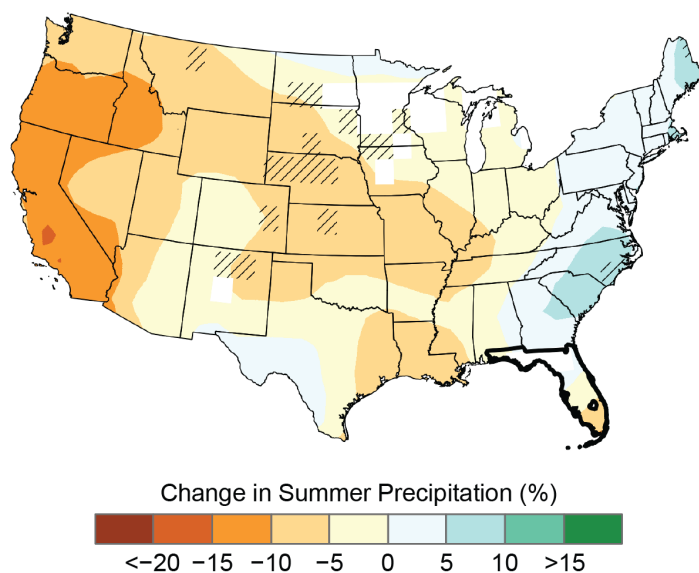


Figure 6: Projected changes in total summer (June–August) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Whited-out areas indicate that the climate models are uncertain about the direction of change. Hatching represents areas where the majority of climate models indicate a statistically significant change. Summer precipitation projections are uncertain for Florida, as well as for a larger part of the Southeast. Sources: CISESS and NEMAC. Data: CMIP5.

will likely trigger more frequent wildfire events. Typically, the state exhibits a peak in wildfire activity from January to mid-June, a period when tropical moisture is reduced and occasional cold fronts usher in dry, windy conditions. In 2020, Florida experienced 2,381 wildfires, ranking fifth in the Nation for number of wildfires; a total of 99,413 acres burned. While the annual frequency of hurricanes has remained relatively stable throughout the 20th and early 21st centuries (Figure 2d), **hurricane rainfall is expected to increase for Florida as the climate continues to warm.**

Since 1900, global average sea level has risen by about 7–8 inches. It is projected to rise another 1–8 feet, with a likely range of 1–4 feet, by 2100 as a result of both past and future emissions from human activities (Figure 7). Sea level rise has caused an increase in tidal floods associated with nuisance-level impacts. Nuisance floods are events in which water levels exceed the local threshold (set by NOAA’s National Weather Service) for minor impacts. These events can damage infrastructure, cause road closures, and overwhelm storm drains. Tidal flood days (all days exceeding the nuisance-level threshold) remain rare at Key West, but as global sea level rises, they are projected to become a common occurrence (Figure 8). Increased inland flooding during heavy precipitation events in low-lying coastal areas is a threat, because mere inches of sea level rise have the potential to impair the capacity of stormwater drainage systems to empty into the ocean. Sea level rise presents major challenges to South Florida’s existing coastal water management system due to a combination of increasingly urbanized areas, aging flood control facilities, flat topography, and permeable limestone aquifers. Increases in nuisance-level coastal flooding and saltwater contamination of coastal groundwater reservoirs are likely consequences of sea level rise.

Observed and Projected Change in Global Sea Level

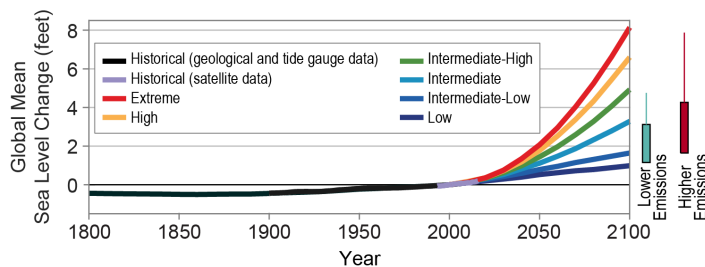


Figure 7: Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate-Low, royal blue; Intermediate, cyan; Intermediate-High, green; High, orange; and Extreme, red curves) relative to historical geological, tide gauge, and satellite altimeter GMSL reconstructions from 1800–2015 (black and magenta lines) and the very likely ranges in 2100 under both lower and higher emissions futures (teal and dark red boxes). Global sea level rise projections range from 1 to 8 feet by 2100, with a likely range of 1 to 4 feet. Source: adapted from Sweet et al. 2017.

Observed and Projected Annual Number of Tidal Floods for Key West, FL

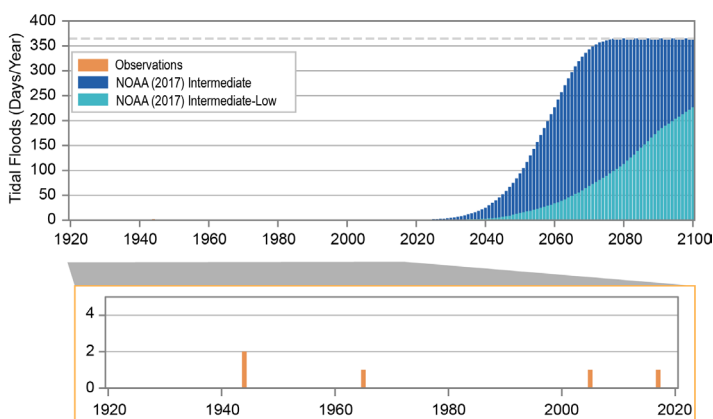


Figure 8: Number of tidal flood days per year at Key West, Florida, for the observed record (1920–2020; orange bars) and projections for two NOAA (2017) sea level rise scenarios (2021–2100): Intermediate (dark blue bars) and Intermediate-Low (light blue bars). The NOAA (2017) scenarios are based on local projections of the GMSL scenarios shown in Figure 7. Sea level rise has caused a gradual increase in tidal floods associated with nuisance-level impacts. The greatest number of tidal flood days (all days exceeding the nuisance-level threshold) occurred in 1944 at Key West. Projected increases are large even under the Intermediate-Low scenario. Under the Intermediate scenario, tidal flooding is projected to occur every day of the year by the end of the century. Additional information on tidal flooding observations and scenarios is available online at <https://statesummaries.ncics.org/technicaldetails>. Sources: CISESS and NOAA NOS.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

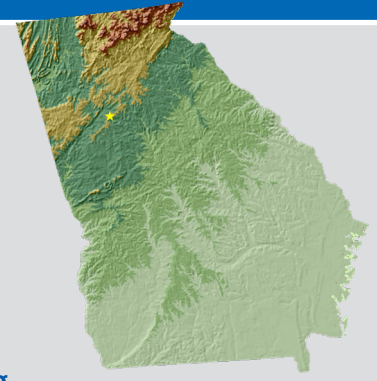
GEORGIA

Key Messages

Temperatures in Georgia have risen by 0.8°F, about half of the warming for the contiguous United States, since the beginning of the 20th century, but the warmest consecutive 5-year interval was 2016–2020. However, under a higher emissions pathway, historically unprecedented warming is projected during this century, including increases in heat wave intensity and decreases in cold wave intensity.

Higher temperatures will increase the rate of soil moisture loss during dry spells, which could lead to more intense droughts and increased competition for the state's water resources.

Global sea level has risen by about 7 to 8 inches since 1900 and is projected to rise another 1 to 4 feet by 2100. Sea level rise will increase the frequency, extent, and severity of coastal flooding, posing a grave risk to developments along Georgia's coastline.



Due to its location at subtropical latitudes and proximity to the warm waters of the Gulf of Mexico and the Atlantic Ocean, Georgia has a climate characterized by long, hot and humid summers and short, usually mild winters. Georgia is the largest U.S. state in land area east of the Mississippi River and encompasses diverse geographic features. Elevation ranges from sea level along the coast to higher than 4,700 feet in the Blue Ridge Mountains in the northeast. Temperatures vary substantially across the state. Inland cities, such as Macon and Columbus, experience very high summertime temperatures, with an average of around 20 days per year exceeding 95°F, while Atlanta averages only 7 such days and areas in the Appalachian Mountains less than 1. The number of very warm nights also varies across Georgia. Locations in the Appalachian Mountains rarely experience such nights, while Atlanta averages 4 per year and Brunswick, located along the southeastern coast, more than 30.

Temperatures in Georgia have risen by 0.8°F, about half of the warming for the contiguous United States, since the beginning of the 20th century, but the warmest consecutive 5-year interval was 2016–2020 (Figure 1). During the last century, temperatures in Georgia were highest in the 1920s and 1930s, followed by a cooling of almost 2°F by the

Observed and Projected Temperature Change

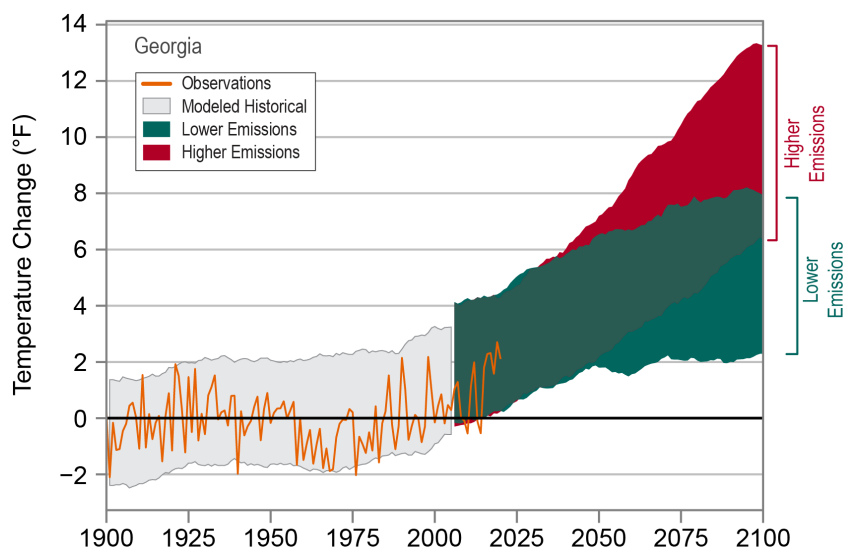


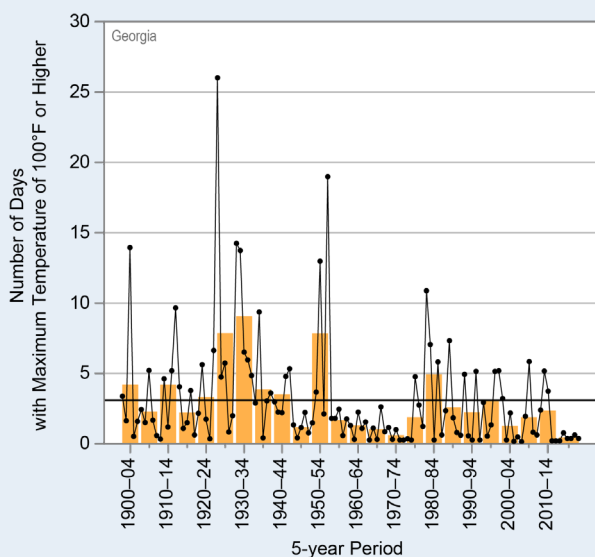
Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Georgia. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Georgia (orange line) have risen by 0.8°F, about half of the warming for the contiguous United States, since the beginning of the 20th century, but the warmest consecutive 5-year interval was 2016–2020. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about as warm as the hottest year in the historical

record; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 11°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

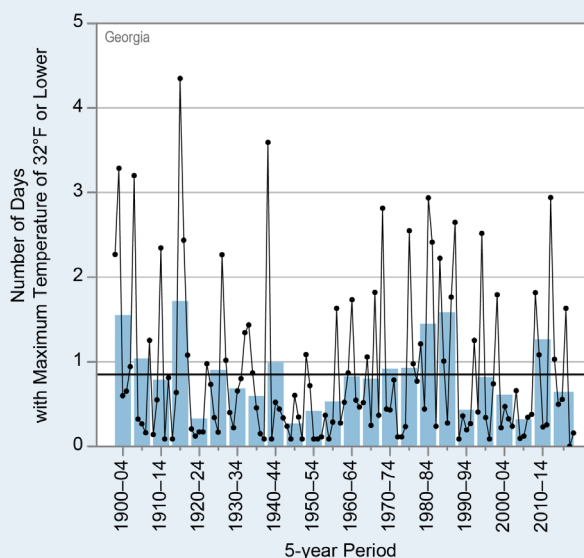
1960s. Temperatures have risen since that cool period by about 3°F, such that the temperatures of the 1990s and 2000s approximated the levels of the 1930s; however, the 2015–2020 period reached a record-high level that far exceeded the one set during the 1930–1934 period. The contiguous United States as a whole has warmed by about 1.8°F since 1900, although it also cooled from the

1930s into the 1960s but not by nearly as much as Georgia. Hypothesized causes for this difference in warming rates include increased cloud cover and precipitation, increased small particles from coal burning, natural factors related to forest regrowth, decreased heat flux due to irrigation, and multidecadal variability in North Atlantic and tropical Pacific sea surface temperatures.

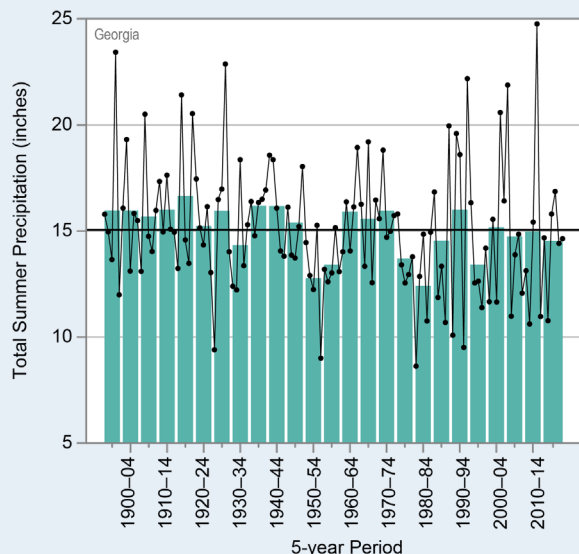
a) Observed Number of Extremely Hot Days



b) Observed Number of Freezing Days



c) Observed Summer Precipitation



d) Observed Number of 3-Inch Extreme Precipitation Events

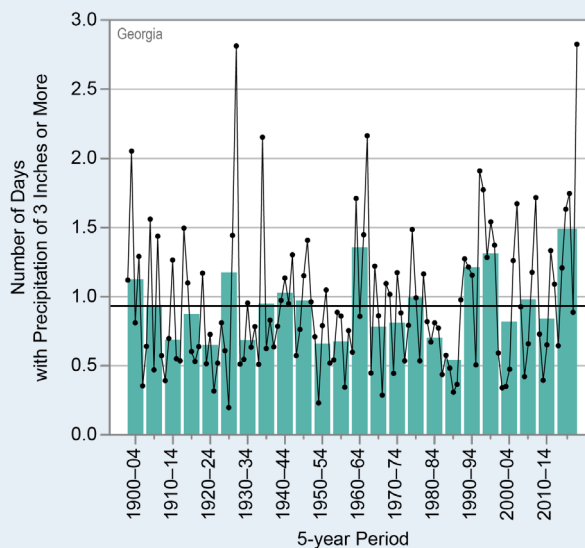


Figure 2: Observed (a) annual number of extremely hot days (maximum temperature of 100°F or higher), (b) annual number of freezing days (maximum temperature of 32°F or lower), (c) total summer (June–August) precipitation, and (d) annual number of 3-inch extreme precipitation events (days with precipitation of 3 inches or more) for Georgia from (a, b, d) 1900 to 2020 and (c) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 3.1 days, (b) 0.9 days, (c) 15.1 inches, (d) 0.9 days. The number of extremely hot days and freezing days has generally been below average since 1955 and 1990, respectively. Summer precipitation has been near or below average since 1995. The number of 3-inch extreme precipitation events is variable but reached its highest level during the 2015 to 2020 period. A typical reporting station experiences about 1 event per year. Sources: CISESS and NOAA NCEI. Data: (a, b) GHCN-Daily from 11 long-term stations; (c) nClimDiv; (d) GHCN-Daily from 19 long-term stations.

Extreme high temperatures in Georgia have shown wide variability over the period of record (1895–2020). The highest number of extremely hot days occurred during the late 1920s, early 1930s, and early 1950s; however, since 1955, the number of these days has generally been near or below average (Figure 2a). The number of very warm nights has shown similar variability and, with the exception of the interval between 2005 and 2014, has been below average since 1955 (Figure 3). The number of freezing days has generally been below average since 1990 (Figure 2b). Georgia has recently experienced several warm years: 2016, 2017, and 2019 were the three hottest on record. On June 29, 2012, Athens set a record-high temperature of 109°F, and on the following day, Atlanta set a record of 106°F.

The state's climate is favorable for a wide variety of agricultural crops; however, untimely cold spells can have devastating consequences. After a very warm winter, freezing temperatures from March 14 to 16, 2017, had severe impacts on blueberry and peach crops in particular, with overall industry losses of about \$1 billion.

Georgia receives abundant precipitation throughout the year, with totals ranging from more than 70 inches in the mountainous northeastern corner of the state to around 45 inches in the southeastern and central portions. Statewide annual total precipitation has ranged from a low of 31.1 inches in 1954 to a high of 70.5 inches in 1964. The driest multiyear periods were in the early 1930s, early 1950s, and late 1980s and the wettest in the late 1940s, early 1960s, and early 1990s (Figure 4). The driest consecutive 5-year interval was 1954–1958, averaging 43.8 inches per year, and the wettest was 1944–1948, averaging 56.7 inches per year. The year 2013 was the fifth wettest, with a statewide average of 63.5 inches, while 2018 and 2020 were the tenth and eleventh wettest, respectively. Snowfall is generally light in the state. Even in the northern mountains, total annual snowfall averages only 5 inches.

The Bermuda High, a semipermanent high-pressure system off the Atlantic Coast, plays an important role in Georgia's summer climate. Typically, the Bermuda High draws moisture northward or westward from the Atlantic Ocean and the Gulf of Mexico, causing warm and moist summers with frequent thunderstorms in the

Observed Number of Very Warm Nights

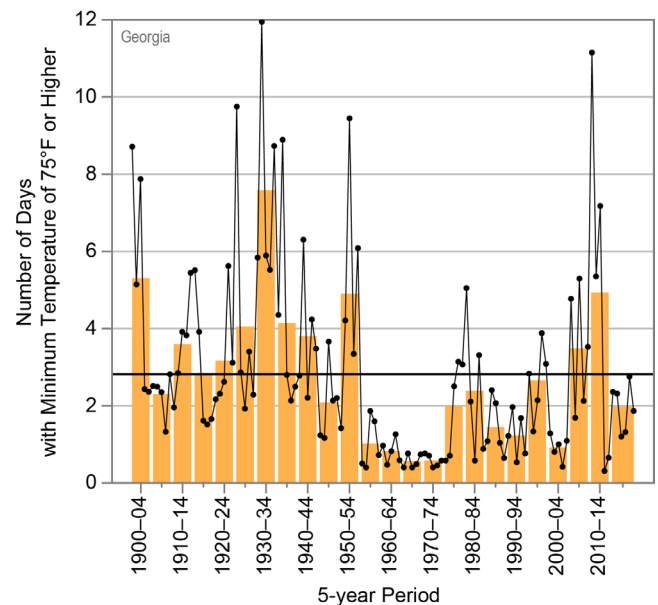


Figure 3: Observed annual number of very warm nights (minimum temperature of 75°F or higher) for Georgia from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 2.8 nights. During the first half of the 20th century, Georgia experienced a high frequency of very warm nights. With the exception of the interval between 2005 and 2014, the number of these nights has been below average since 1955. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 11 long-term stations.

Observed Annual Precipitation

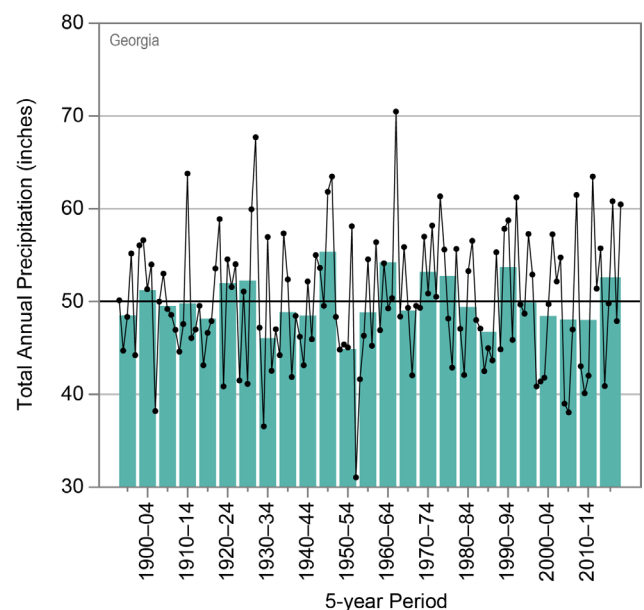


Figure 4: Observed total annual precipitation for Georgia from 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 50.0 inches. Georgia receives abundant precipitation throughout the year. There is no long-term trend in annual precipitation. Sources: CISESS and NOAA NCEI. Data: nClimDiv.

afternoons and evenings. Daily and weekly variations in the positioning of the Bermuda High can strongly influence precipitation patterns. When it extends westward into the southeastern United States, hot and dry weather occurs, which can result in heat waves and drought. In 2007, as a result of a strong Bermuda High over the Southeast and a strengthening La Niña, Georgia experienced its third-driest year on record. This very dry year, compounded by low precipitation in 2006 (the state's fifth-driest year), led to one of Georgia's worst droughts. By the end of August, most of the state was in severe or extreme drought.

Thunderstorms are common in Georgia, particularly in the spring and summer months, and often bring heavy rains that can cause severe flooding (Figure 2d). During September 16–22, 2009, torrential rains caused severe flooding in North Georgia and the Atlanta area. Over this 1-week period, some portions of the state received more than 15 inches of rain, with the Chattahoochee River reaching 100-year flood levels and the Sweetwater Creek basin reaching 500-year flood levels. Seventeen counties were declared federal disaster areas, and damages from the flooding exceeded \$500 million. Tornadoes are another hazard of these thunderstorms. On March 14, 2008, a tornado struck downtown Atlanta, causing 1 death and more than \$150 million in damages. The following day, the same storm system spawned multiple tornadoes across the state, including an EF3 tornado in northwestern Georgia, which killed 2 people. Only ten EF4 tornadoes have occurred in Georgia since 1950. One such tornado hit Catoosa County on the evening of April 27, 2011, as part of the historic 2011 Super Outbreak. Another EF4 tornado occurred more recently, on March 26, 2021, in Newnan, causing widespread damage and 1 fatality.

Although Georgia rarely experiences direct landfall of hurricanes, tropical storm system remnants can bring heavy rains and strong winds to the state. In 1994, Tropical Storm Alberto passed over the state, resulting in significant rain totals. More than 27 inches of precipitation fell on Americus in the southwestern part of the state—21 of those inches fell within 24 hours, setting a new state record. Alberto caused significant flooding, particularly along the Flint and Ocmulgee Rivers, which resulted in 33 deaths and extensive agricultural losses. In September 2004, precipitation from the remnants of three hurricanes—Frances, Ivan,

and Jeanne—resulted in Georgia's wettest September on record and significant flooding across the state. In 2018, Hurricane Michael was the first major hurricane (Category 3+) to directly impact Georgia since the 1890s. Wind gusts as high as 115 mph were recorded in Donalsonville, in southwest Georgia. On the evening of October 10, winds exceeding 70 mph in portions of central Georgia led to widespread tree damage, power outages, and severe crop damage, especially to cotton and peach crops.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of the century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. Heat waves are projected to intensify in this region, which already experiences hot and humid conditions. Extreme heat is a particular concern for Atlanta and other urban areas where the urban heat island effect raises summer temperatures. High temperatures combined with high humidity can create dangerous heat index values.

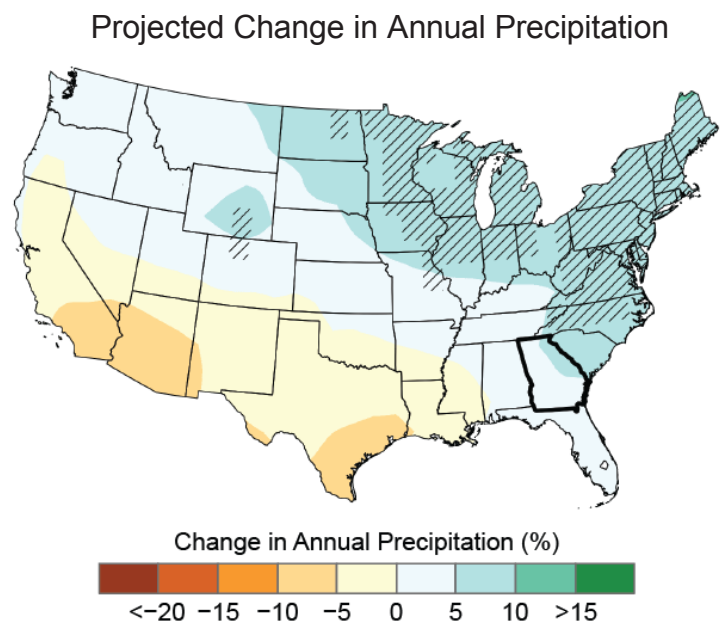


Figure 5: Projected changes in total annual precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. Precipitation is projected to increase throughout Georgia; however, these changes are small relative to the natural variability in this region. Sources: CISESS and NEMAC. Data: CMIP5.

Precipitation projections for Georgia are uncertain

(Figure 5). Even if annual precipitation remains constant, higher temperatures will increase evaporation rates and decrease soil moisture during dry spells, leading to greater drought intensity. This could increase competition for limited water resources, such as the Apalachicola–Chattahoochee–Flint River basin, which currently supports large population centers in multiple states.

Increasing temperatures raise concerns for sea level rise in coastal areas. Since 1900, global average sea level has risen by about 7–8 inches. It is projected to rise another 1–8 feet, with a likely range of 1–4 feet, by 2100 as a result of both past and future emissions from human activities (Figure 6). Sea level rise has caused an increase in tidal floods associated with nuisance-level impacts. Nuisance floods are events in which water levels exceed the local threshold (set by NOAA’s National Weather Service) for minor impacts.

Observed and Projected Change in Global Sea Level

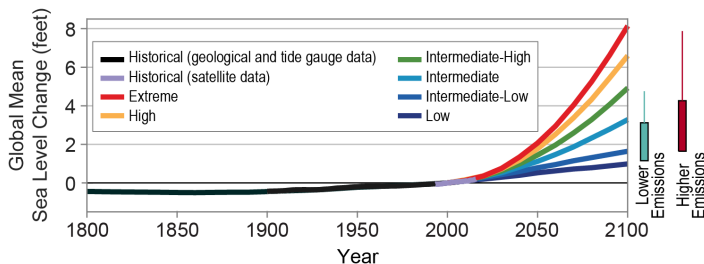


Figure 6: Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate-Low, royal blue; Intermediate, cyan; Intermediate-High, green; High, orange; and Extreme, red curves) relative to historical geological, tide gauge, and satellite altimeter GMSL reconstructions from 1800–2015 (black and magenta lines) and the very likely ranges in 2100 under both lower and higher emissions futures (teal and dark red boxes). Global sea level rise projections range from 1 to 8 feet by 2100, with a likely range of 1 to 4 feet. Source: adapted from Sweet et al. 2017.

These events can damage infrastructure, cause road closures, and overwhelm storm drains. As sea level has risen along the Georgia coastline, the number of tidal flood days (all days exceeding the nuisance-level threshold) has also increased, with the greatest number (13) occurring at Fort Pulaski in 2019 (Figure 7). **Georgia is at extreme risk for sea level rise due to its low elevation along the coast.** Continued sea level rise will present major challenges to Georgia’s existing coastal water management system and could cause extensive economic harm through ecosystem damage and losses in property, tourism, and agriculture.

Observed and Projected Annual Number of Tidal Floods for Fort Pulaski, GA

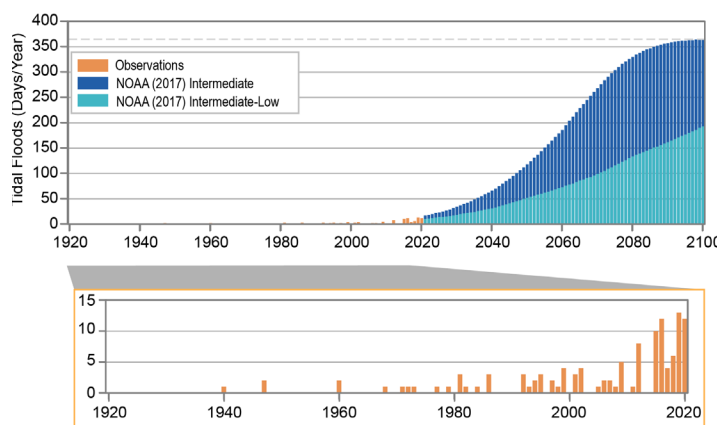


Figure 7: Number of tidal flood days per year at Fort Pulaski, Georgia, for the observed record (1935–2020; orange bars) and projections for two NOAA (2017) sea level rise scenarios (2021–2100): Intermediate (dark blue bars) and Intermediate-Low (light blue bars). The NOAA (2017) scenarios are based on local projections of the GMSL scenarios shown in Figure 6. Sea level rise has caused a gradual increase in tidal floods associated with nuisance-level impacts. The greatest number of tidal flood days (all days exceeding the nuisance-level threshold) occurred in 2019 at Fort Pulaski. Projected increases are large even under the Intermediate-Low scenario. Under the Intermediate scenario, tidal flooding is projected to occur nearly every day of the year by the end of the century. Additional information on tidal flooding observations and scenarios is available online at <https://statesummaries.ncics.org/technicaldetails>. Sources: CIESSE and NOAA NOS.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

HAWAII

Key Messages

Temperatures in Hawai'i have risen by about 2°F since 1950, with a sharp increase in warming over the last decade. Under a higher emissions pathway, historically unprecedented warming is projected during this century.

Annual rainfall has decreased throughout Hawai'i since the early 1980s, with uncertain projections for the future. The frequency and magnitude of extreme precipitation events have changed in recent years, but these changes are not uniform across the island chain. Extreme precipitation events have become less frequent for Kaua'i and O'ahu but more frequent for the Island of Hawai'i.

Sea level rise will continue to be a major threat to the state's coastline through inundation and erosion.

Hawai'i is the only U.S. state located in the tropics. Almost half of the state's land area is within 5 miles of the ocean, which provides a moderating effect on the climate. August is the warmest month, with an average (1950–2020) temperature of about 79°F, while the coldest month, February, averages about 72°F. Large geographical differences in temperature occur due to the state's varied elevations. At elevations of less than 1,000 feet, winter temperatures rarely fall below 50°F, whereas lows can reach less than 20°F at the peaks of Mauna Kea and Mauna Loa. Hawai'i, however, is the only state to have never recorded temperatures below 0°F.

Since 1950, temperatures across the Hawaiian Islands have risen by about 2°F, with a sharp increase in warming over the last decade (Figure 1). Temperatures in Honolulu have increased by 2.6°F since 1950 and have consistently been above the 1951–1980 average since 1975 (Figure 2). Statewide, the number of hot days and the number of very warm nights were well above average during the 2015–2020 period, with values more than double the respective long-term averages (Figures 3 and 4). The rate of temperature increase is greatest at high elevations, far exceeding the global average rate of change. The annual number of days below freezing is decreasing over time, as is the daily temperature range, largely due to nighttime warming. Historically, temperatures in Hawai'i have been tightly coupled with the decadal variability of the atmospheric circulation and sea surface temperature anomalies in the Pacific Basin (known as the Pacific Decadal Oscillation); however, since the 1970s, increasing temperatures are more consistent with an increase in the frequency of the trade wind inversion (a layer above the surface where temperature increases with height) and a decrease in the frequency of trade winds (steady, persistent northeasterly winds).

Observed and Projected Temperature Change

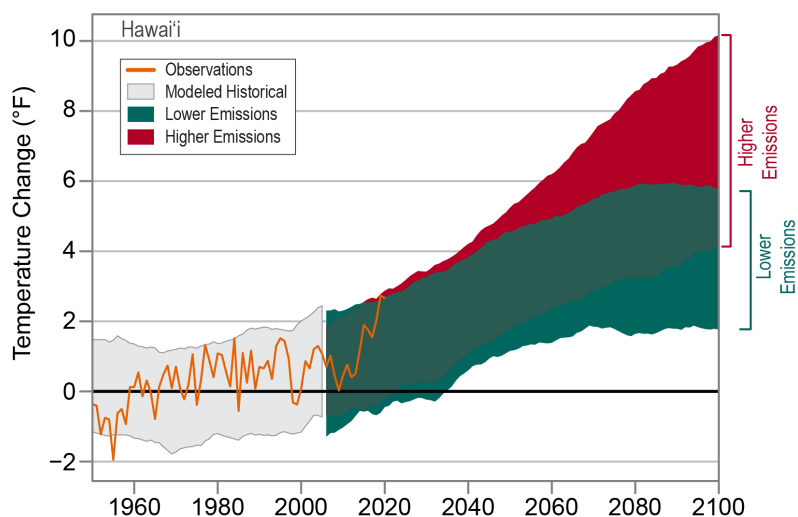


Figure 1: Observed and projected changes (compared to the 1951–1980 average) in near-surface air temperature for Hawai'i. Observed data are for 1950–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Hawai'i (orange line) have risen by about 2°F since 1950, with a sharp increase in warming over the last decade. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 2°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 10°F warmer than the hottest year in the historical record; red shading). Sources:

Precipitation varies greatly according to season and location. Hawai'i experiences a drier season from May through October, when warm, steady trade winds cause light to moderate showers. The wet season runs from November through April, with weaker and less frequent trade winds and a significant amount of rain from mid-latitude storms. The interaction of mountainous terrain, persistent trade winds, heating and cooling of the land, and other factors results in dramatic differences in average rainfall over short distances. Total annual rainfall sometimes exceeds 300 inches along the windward slopes of mountains, while it averages less than 20 inches in leeward coastal areas and on the highest mountain slopes. Hawai'i historically experienced drier than normal conditions during the El Niño wet season and greater than normal rainfall during the La Niña wet season. Since the early 1980s, Hawai'i has experienced drier conditions during the wet season of La Niña years. In fact, a drying trend in Hawaiian rainfall during La Niña years is evident since 1956. Moreover, El Niño events have occurred more frequently over the last two decades. Larger total acres burned by wildfires are more likely to occur in the year following an El Niño event.

Despite great spatial variability in precipitation amounts across the islands, annual rainfall has decreased throughout the island chain (Figures 5 and 6), particularly during recent years in the wet season. In 10 of the 15 years since 2007, wet-season precipitation was below average, with 4 of the remaining 5 years being very near average. All of the 17 substantially above average wet years (greater than 0.5 standardized anomalies) occurred prior to 2006 (Figure 5). The changing relationship between La Niña and Hawai'i rainfall and the increasing El Niño frequency seem to have contributed to the long-term drought since 1980. The Island of Hawai'i has experienced the largest significant long-term declines in annual and dry-season rainfall; among 5 major reporting stations, Hilo recorded the greatest decrease in annual precipitation of 14 inches since 1950 (Figure 6). An increase in the frequency of the trade wind inversion is also linked to a decrease in precipitation at high elevations. The number of consecutive dry days across the major Hawaiian Islands has increased since the 1950s. An increase in drought conditions has been seen in recent years, particularly at high elevations. In 2010, more than 40% of the Hawaiian Islands experienced severe, extreme,

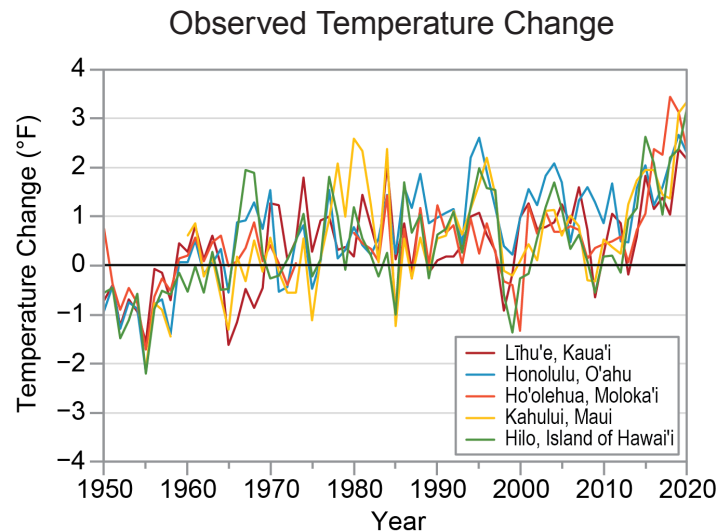


Figure 2: Observed changes (compared to the 1951–1980 average; horizontal black line) in annual near-surface air temperature for 5 long-term reporting stations in Hawai'i from 1950 to 2020: Līhu'e, Kaua'i (red line); Honolulu, O'ahu (blue line); Ho'olehua, Molokai'i (orange line); Kahului, Maui (yellow line); and Hilo, Island of Hawai'i (green line). Temperatures across the islands have increased since 1950 at rates ranging from 0.2°F to 0.4°F per decade. Temperatures in Honolulu have increased by 2.6°F over this period and have consistently been above the 1951–1980 average since 1975. Sources: CISESS and NOAA NCEI. Data: GHCN-Monthly.

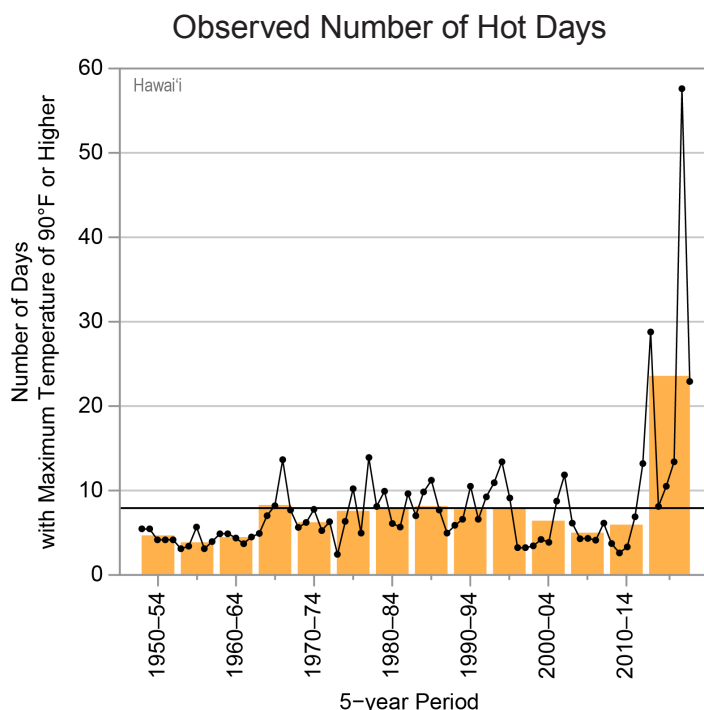


Figure 3: Observed annual number of hot days (maximum temperature of 90°F or higher) for Hawai'i from 1950 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 7.9 days. The number of hot days increased dramatically during the 2015–2020 period, with a multiyear average more than double the long-term average. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 6 long-term stations.

or exceptional drought conditions. Such conditions lead to a lack of usable water and an increased risk of fire. The number of 3-inch extreme precipitation events has been near or below average since 1990 (Figure 7), with areas at the highest elevations experiencing the largest downward trend. Regionally, extreme precipitation events have become less frequent for O‘ahu and Kaua‘i but more frequent for the Island of Hawai‘i.

The North Pacific High, a semipermanent area of high pressure, has a strong influence on Hawai‘i’s weather.

It is responsible for the trade winds, which dominate during the dry season. During the wet Hawaiian winter, however, the North Pacific High is weaker, and the mid-latitude jet stream shifts southward, providing an occasional opportunity for cool winter storms known as Kona storms. They usually affect the state for a week or less and occur, on average, 2 to 3 times per year. Kona storms often result in flash flooding (and associated landslides), a common occurrence due to the state’s steep terrain and the leading cause of direct weather-related deaths, far exceeding the toll due to high wind events and tropical cyclones. Kona storms can produce additional hazards such as hail, heavy mountain snows, waterspouts, and high surf events—the leading cause of indirect weather-related deaths.

Hawai‘i is also susceptible to tropical storms, most often occurring between June and November. Such storms bring heavy rains, high winds, and high waves to the islands. **Hurricanes rarely affect the state**, with many dissipating into tropical storms or tropical depressions as they approach the islands. Since 1950, 25 hurricanes have affected Hawai‘i (passing within 200 miles), with only 2 making landfall. The annual number of tropical cyclones observed in the Central North Pacific has varied over time, with a greater number forming during El Niño years. The most active hurricane season on record in the Central Pacific was 2015, with 8 hurricanes and 6 additional tropical storms. Due to storm tracks shifting northward in the Central North Pacific, Hawai‘i is projected to see an increase in the frequency of tropical cyclones.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of the century. However, a large range of temperature

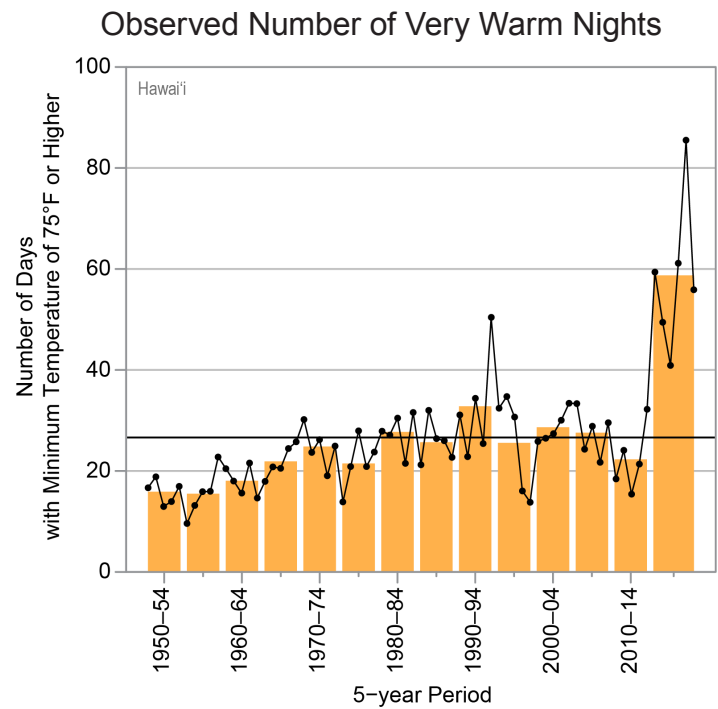


Figure 4: Observed annual number of very warm nights (minimum temperature of 75°F or higher) for Hawai‘i from 1950 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 27 nights. The number of very warm nights has increased since the 1950s and rose dramatically during the 2015 to 2020 period, with a multiyear average more than double the long-term average. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 6 long-term stations.

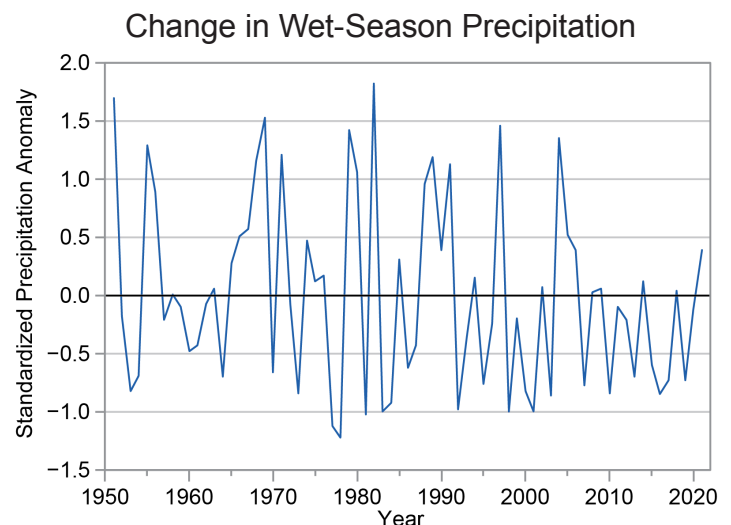


Figure 5: Time series of wet-season (November through March) Hawai‘i precipitation for 1950–2021 as derived from 25 long-term reporting stations. These values represent precipitation variations over different climate regions of the Hawaiian Islands. A normalization technique is applied to each individual station, and a regional value is then computed as the arithmetic average of all station values. The time series therefore represents the variations in the regional standardized precipitation anomalies. The year axis label indicates the ending year of the period (e.g., 1990 is November 1989 through March 1990). A persistent dry pattern has been in place since 2007. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily.

increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. Rising temperatures will cause future heat waves to be more intense. This warming, accompanied by reduced rainfall in some areas, will stress native Pacific Island plants and animals, especially in high-elevation ecosystems with increasing exposure to invasive species, and increase the risk of extinctions. Rising temperatures, combined with a growing human population and expanding invasive grass cover, are likely to increase the frequency of wildfires, which have been observed since the beginning of the 20th century.

Precipitation projections for Hawai'i are particularly challenging due to the state's high and steep topography, which leads to pronounced small-scale variations in climate. Projections of total annual precipitation are uncertain, with one likelihood that Hawai'i will straddle the transition between wetter conditions in the tropics and drier conditions in the subtropics (Figure 8). It is likely that the currently wet windward sides of the major islands will see an increase in rainfall, while the currently dry leeward sides will experience a decrease. Projected changes in the frequency and magnitude of extreme precipitation events are also uncertain, with some climate models indicating increases and others decreases. Even if average precipitation remains constant, higher temperatures will increase the rate of soil moisture loss during dry periods and potentially increase the intensity of naturally occurring droughts.

Increasing temperatures raise concerns for sea level rise in Hawai'i. Since 1900, global average sea level has risen by about 7–8 inches. It is projected to rise another 1–8 feet, with a likely range of 1–4 feet, by 2100 as a result of both past and future emissions due to human activities (Figure 9). Rates of sea level rise in Hawai'i vary between the islands, ranging from 0.6 inches per decade for Kaua'i, O'ahu, and Maui to 1.6 inches per decade for the Island of Hawai'i. There is evidence that a higher rate of relative sea level rise around Maui is driving higher rates of beach erosion on that island compared to O'ahu, although both islands are experiencing severe coastal erosion problems. Sea level rise is projected to cause an increase in tidal floods associated with nuisance-level impacts (Figure 10). Nuisance floods are events in which water levels exceed the local threshold (set by NOAA's

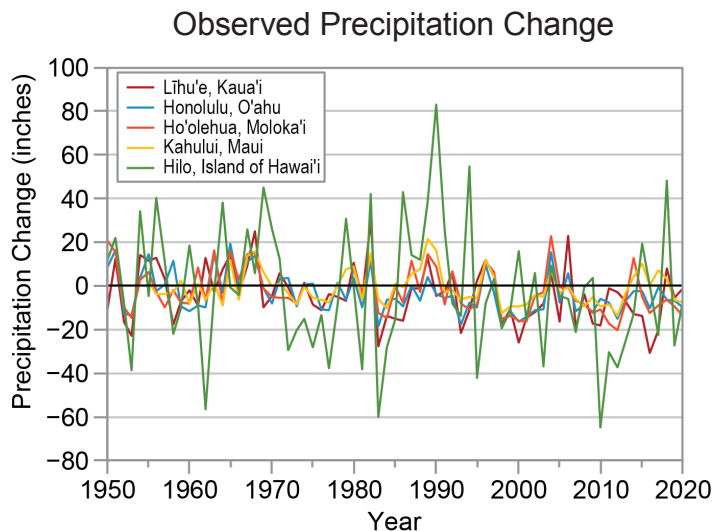


Figure 6: Observed changes (compared to the 1951–1980 average; horizontal black line) in annual precipitation for 5 long-term reporting stations in Hawai'i from 1950 to 2020: Līhu'e, Kaua'i (red line); Honolulu, O'ahu (blue line); Ho'olehua, Molokai (orange line); Kahului, Maui (yellow line); and Hilo, Island of Hawai'i (green line). Annual precipitation varies greatly from year to year; however, overall amounts have decreased since 1950 at all 5 stations. Hilo has seen the greatest decrease of 14 inches across the period of record. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily.

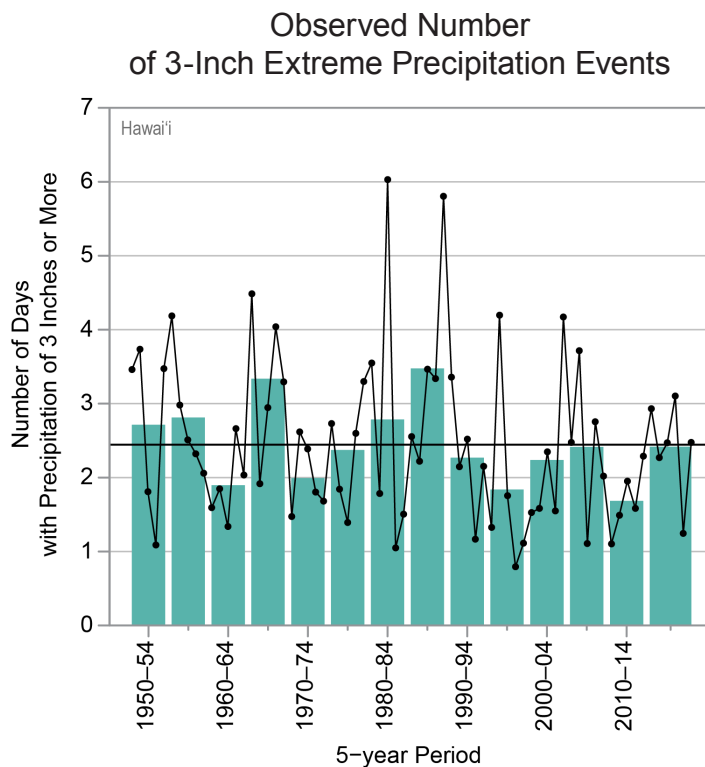


Figure 7: Observed annual number of 3-inch extreme precipitation events (days with precipitation of 3 inches or more) for Hawai'i from 1950 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 2.4 days. A typical reporting station experiences 2 to 3 events per year. The number of 3-inch extreme precipitation events has varied over time but has been near or below average since 1990. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 25 long-term stations.

National Weather Service) for minor impacts. These events can damage infrastructure, cause road closures, and overwhelm storm drains. Continued sea level rise will also present major challenges to Hawai'i's coastline through coastal inundation and erosion. Seventy percent of Hawai'i's beaches have already been eroded over the past 100 years, with more than 13 miles of beach completely lost. With increasing sea level rise, historical rates of shoreline recession are projected to double by 2050, and more than 90% of beaches are projected to be in retreat by that time. Sea level rise will also affect Hawai'i's coastal water management system and could cause extensive economic damage through ecosystem damage and losses in property, tourism, and agriculture.

Observed and Projected Change in Global Sea Level

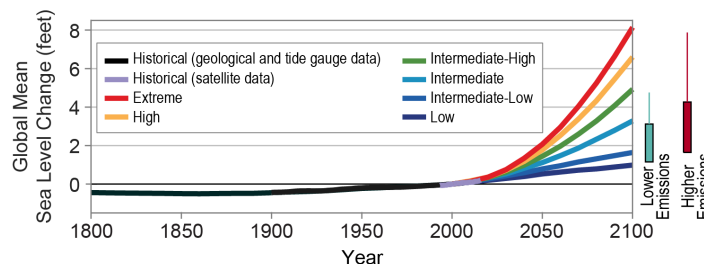


Figure 9: Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate-Low, royal blue; Intermediate, cyan; Intermediate-High, green; High, orange; and Extreme, red curves) relative to historical geological, tide gauge, and satellite altimeter GMSL reconstructions from 1800–2015 (black and magenta lines) and the very likely ranges in 2100 under both lower and higher emissions futures (teal and dark red boxes). Global sea level rise projections range from 1 to 8 feet by 2100, with a likely range of 1 to 4 feet. Source: adapted from Sweet et al. 2017.

Projected Change in Annual Precipitation

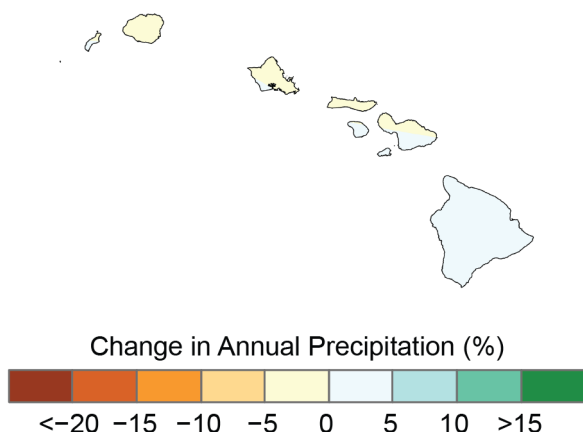


Figure 8: Projected changes in total annual precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Annual precipitation is projected to increase slightly across southern parts of the state and decrease across the northernmost islands. These changes are small, however, relative to natural variability in Hawai'i. Sources: CISESS and NEMAC. Data: CMIP5.

Observed and Projected Annual Number of Tidal Floods for Honolulu, HI

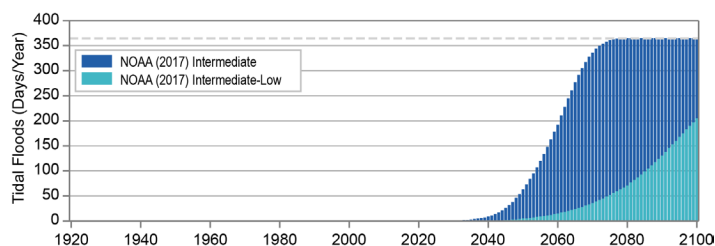


Figure 10: Number of tidal flood days per year at Honolulu, Hawai'i, for the observed record (no data) and projections for two NOAA (2017) sea level rise scenarios (2021–2100): Intermediate (dark blue bars) and Intermediate-Low (light blue bars). The NOAA (2017) scenarios are based on local projections of the GMSL scenarios shown in Figure 9. No tidal flood days have yet been observed for Honolulu; however, projected increases are large even under the Intermediate-Low scenario, with tidal flooding occurring from the 2040s onward. Under the Intermediate scenario, tidal flooding is projected to commence in the 2030s and occur every day of the year by the end of the century. Additional information on tidal flooding observations and scenarios is available at <https://statesummaries.ncics.org/technicaldetails>. Sources: CISESS and NOAA NOS.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

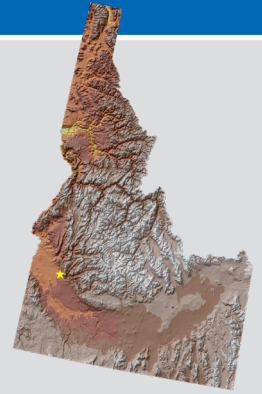
IDAHO

Key Messages

Temperatures in Idaho have risen almost 2°F since the beginning of the 20th century. Under a higher emissions pathway, historically unprecedented warming is projected during this century.

Winter and spring precipitation is projected to increase during this century. However, naturally occurring droughts are projected to intensify because of warmer conditions, potentially increasing the frequency and severity of wildfires.

Higher temperatures are projected to cause more of winter and spring precipitation to fall as rain instead of snow, which may increase flood risks.



Due to Idaho's northerly latitude and location in the interior of North America, its climate has large seasonal temperature differences, with cold winters and pleasantly warm summers. Wide ranges in elevation affect regional precipitation. The low-elevation regions of southern Idaho are shielded by mountains to the east and west, reducing the amount of moisture that can penetrate the area and resulting in generally low amounts of precipitation. By comparison, the higher elevations of northern and central Idaho receive up to four times the amount of rain and snow. The majority of precipitation falls during the cool season (November–May). Idaho is reliant on mountain snowpack for water storage.

Temperatures in Idaho have risen almost 2°F since the beginning of the 20th century (Figure 1). The year 2015 was the second-hottest (after 1934) since records began in 1895, with a statewide average temperature of 46.4°F. As with precipitation, Idaho's temperature climate exhibits regional variation. In the southwestern city of Boise, the average (1991–2020 normals) high temperature in July is 92.7°F, while in the northern town of Coeur D'Alene, it is 82.8°F. In January, average low temperature is colder in Boise (25.5°F) than in Coeur D'Alene (26.2°F). Statewide, the number of very hot days (Figure 2) has been highly variable since 2000 but shows no overall trend. The number of warm nights (Figure 3) has been above average since 2000, exceeding the previous highest values of the late 1920s and 1930s. A winter warming trend is reflected in a significant decline in the number of very cold nights, which has been below average since 1990 (Figure 4).

Observed and Projected Temperature Change

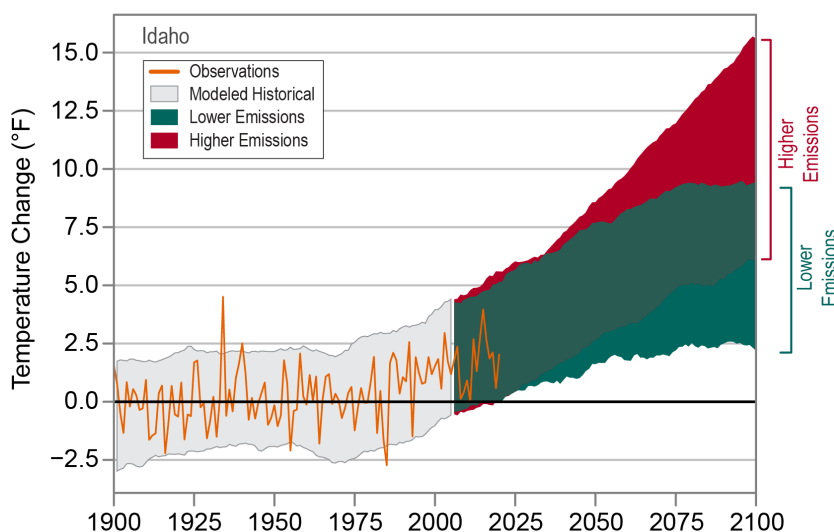


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Idaho. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Idaho (orange line) have risen almost 2°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 2°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 15°F warmer than the historical average; red shading). Sources: CISESS and NOAA NCEI.

being about 15°F warmer than the historical average; red shading). Sources: CISESS and NOAA NCEI.

Total annual precipitation at long-term monitoring stations ranges from more than 40 inches at some northern mountain sites to less than 10 inches at sites in the southwest. Statewide, there is substantial variability but no overall trend in total annual precipitation for the 126-year period of record (Figure 5). **However, the number of 1-inch extreme precipitation events has been above average for the past 16 years and has been trending upward since 2000** (Figure 6). A record-high number of events (more than 2 per year) occurred during the 1995–1999 period. The driest year on record for Idaho was 1935, with a total of 16.2 inches of precipitation, while the wettest was 1996, with 32.10 inches. The driest consecutive 5-year interval was 1928–1932, with an annual average of 20.1 inches, and the wettest was 1980–1984, with an annual average of 28.8 inches. Annual total snowfall ranges from about 10 to 20 inches in the southern lowlands to more than 100 inches in the higher mountains. Snowpack accumulation in the mountains is the state’s major source of water. It is highly variable from year to year and has generally declined since the mid-20th century (Figure 7).

Extreme weather and weather-related events in Idaho include severe winter storms, wildfires, floods, droughts, and heat and cold waves. Flooding occurs frequently in Idaho; an estimated 90% of damages from natural disasters each year is attributable to riverine flooding, flash floods, or floods caused by ice/debris jams. The winter of 1996–97 brought tremendous amounts of snow (80–100 inches) to some parts of the state. Heavy rains and unusually warm temperatures produced significant amounts of snowmelt, resulting in disaster declarations for one-third of the state’s counties due to severe flooding and mudslides. Flash flooding typically occurs after intense thunderstorm events in the spring and summer. In 2012, Idaho experienced one of its most active fire seasons to date, with more than 1.6 million acres burned. Additionally, 11 of the state’s 44 counties were designated as primary natural disaster areas due to damages and losses caused by drought, excessive heat, and high winds. Extreme weather cost the state more than \$400 million in property damages in 2012 alone.

Observed Number of Very Hot Days

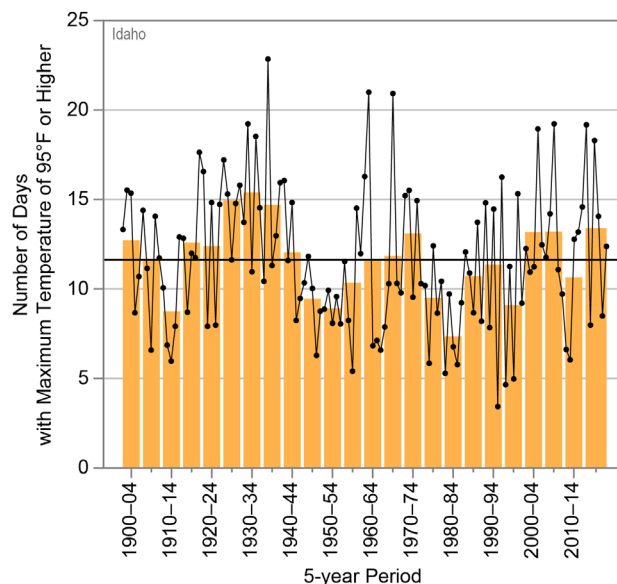


Figure 2: Observed annual number of very hot days (maximum temperature of 95°F or higher) for Idaho from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 12 days (note that the average for individual reporting stations varies greatly because of the state’s large elevation range). The number of very hot days has been highly variable since 2000 but with no overall trend. The highest number of these days occurred during the late 1920s and 1930s. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 10 long-term stations.

Observed Number of Warm Nights

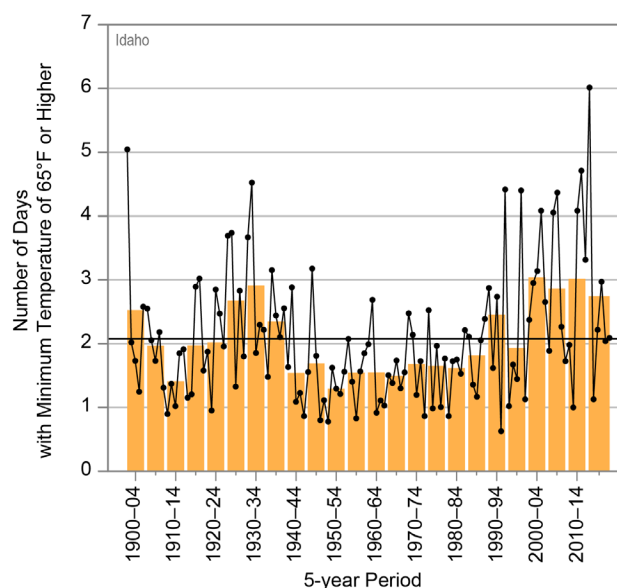


Figure 3: Observed annual number of warm nights (minimum temperature of 65°F or higher) for Idaho from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 2.1 nights (note that the average for individual reporting stations varies greatly because of the state’s large elevation range). The number of warm nights has been above average since 2000, exceeding the previous highest values of the late 1920s and 1930s. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 10 long-term stations.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of the century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. The intensity of heat waves is projected to increase, while cold wave intensity is projected to decrease.

Projected rising temperatures will raise the snow line—the average lowest elevation at which the snow falls. This will increase the likelihood that precipitation will fall as rain instead of snow, reducing water storage in the snowpack, particularly at lower mountain elevations that are now on the margins of reliable snowpack accumulation. **Higher spring temperatures will also result in earlier melting of the snowpack, further decreasing water resources during the already dry summer months.**

Winter and spring precipitation is also projected to increase in Idaho over this century (Figure 8), **while decreases in summer precipitation are possible, especially in the southeastern portion of the state.**

However, even if overall precipitation increases, naturally occurring droughts will likely be more intense because higher temperatures will increase the rate of soil moisture loss during dry spells. The earlier melting of mountain snowpack may also lead to a reduction in soil moisture during the summer months. As a result, the frequency and severity of wildfires are projected to increase.

Extreme precipitation events are projected to become more frequent. The combination of more extreme precipitation events and more winter and spring precipitation falling as rain rather than snow will increase the risk of flooding during the cold season.

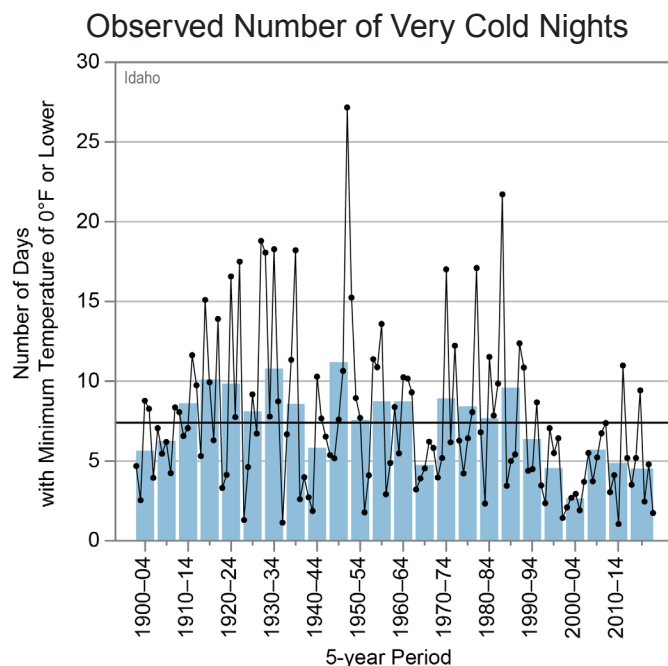


Figure 4: Observed annual number of very cold nights (minimum temperature of 0°F or lower) for Idaho from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 7.4 nights (note that the average for individual reporting stations varies greatly because of the state's large elevation range). The number of very cold nights has been below average since 1990. The greatest number of these nights occurred during the 1945–1949 period, with a multiyear average of 12 nights. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 10 long-term stations.

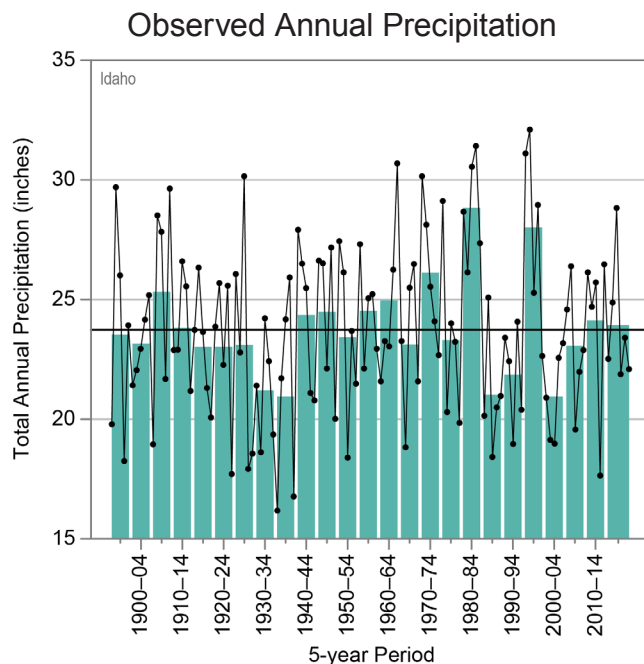


Figure 5: Observed total annual precipitation for Idaho from 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 23.7 inches. Annual precipitation varies widely and shows no overall trend. Sources: CISESS and NOAA NCEI. Data: nClimDiv.

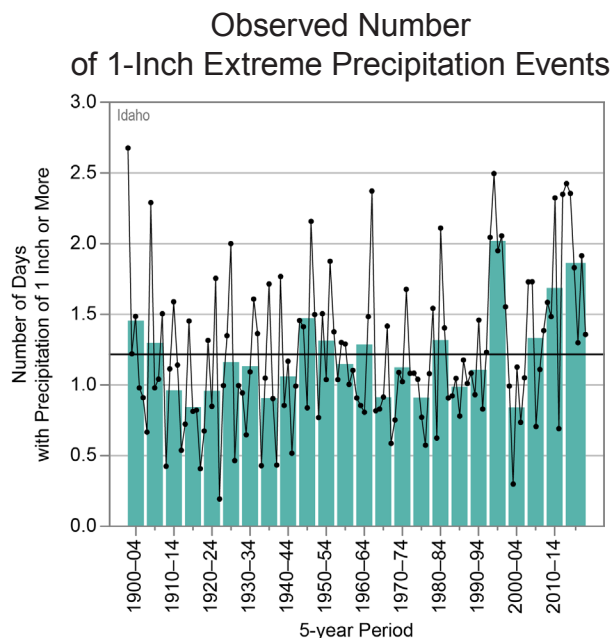


Figure 6: Observed annual number of 1-inch extreme precipitation events (days with precipitation of 1 inch or more) for Idaho from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 1.2 days (note that the average for individual reporting stations varies greatly because of the state's large elevation range). A typical station experiences 1 event per year. The number of 1-inch extreme precipitation events has been above average since 2005, with an overall upward trend since 1900. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 10 long-term stations.

Projected Change in Spring Precipitation

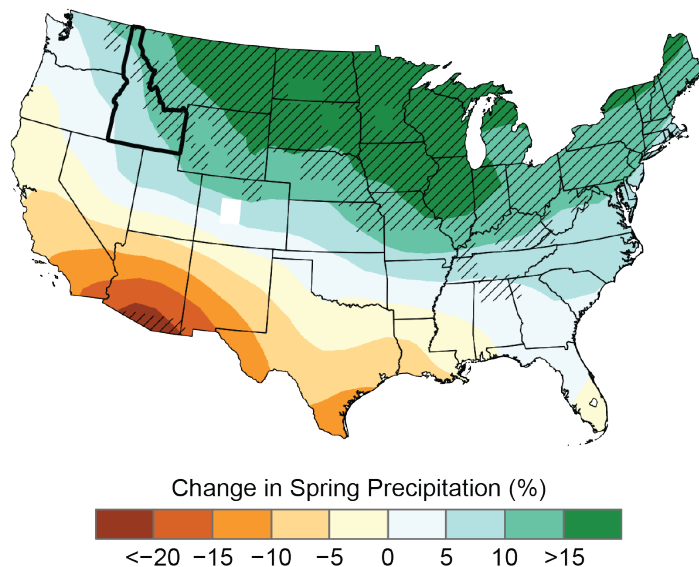


Figure 8: Projected changes in total spring (March–May) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. The white-out area indicates that the climate models are uncertain about the direction of change. Hatching represents areas where the majority of climate models indicate a statistically significant change. Idaho is part of a large area of projected increases across the northern United States. Sources: CISESS and NEMAC. Data: CMIP5.

April 1 Snow Water Equivalent (SWE) at Camp Creek, ID

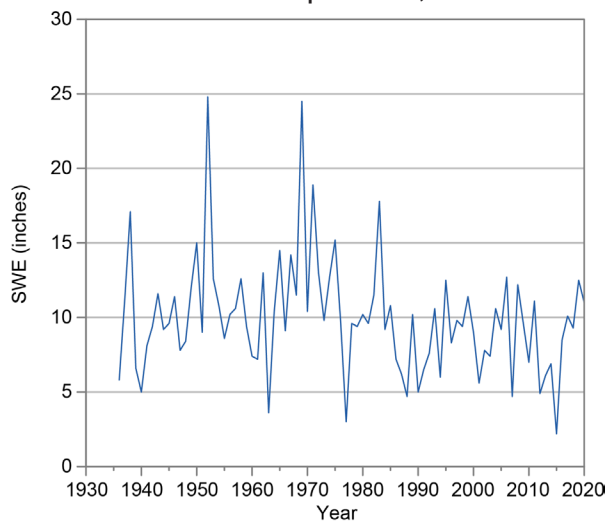


Figure 7: Variations in the April 1 snow water equivalent (SWE) at the Camp Creek, Idaho, snow course site from 1936 to 2020. SWE, the amount of water contained within the snowpack, is highly variable from year to year. There is an overall decline in SWE since high values in 1952 and 1969. The lowest value on record occurred in 2015. Source: NRCS NWCC.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

ILLINOIS

Key Messages

Temperatures in Illinois have risen about 1.5°F since the beginning of the 20th century. This warming shows seasonal variations, with spring average temperature increasing by about 2°F and summer average temperature increasing very little. Under a higher emissions pathway, historically unprecedented warming is projected during this century.

Precipitation in spring and summer has generally been above average since the mid-1990s, affecting agriculture both positively (adequate soil moisture) and negatively (delays in spring planting). Projected increases in winter and spring precipitation pose a continuing risk of spring planting delays.

Severe flooding and drought have occurred periodically in recent years. Future increases in the frequency and intensity of extreme precipitation events may increase the frequency and intensity of floods, while increases in evaporation rates due to rising temperatures may increase the intensity of naturally occurring droughts.



Illinois's location in the interior of North America and the lack of mountains to the north and south expose the state to incursions of bitterly cold air masses from the Arctic in the winter and warm, humid air masses from the Gulf of Mexico in the summer. Annual average temperature varies widely across the state, with a range of about 10°F from north to south. In northeastern Illinois, Lake Michigan moderates the temperature, causing cooler summers and warmer winters. Topography and urbanization also have local impacts on climate.

Temperatures in Illinois have risen about 1.5°F since the beginning of the 20th century (Figure 1). Temperatures in the 2000s have been higher than in any other historical period, with the exception of comparable temperatures during the early 1930s Dust Bowl era. Warming has been concentrated in winter and spring, while summers have not warmed substantially, a feature characteristic of much of the Midwest (Figures 2a and 2b). The lack of summer warming is reflected in a below average number of very hot days since the mid 1950s (Figure 3a) and no overall trend in very warm nights since the beginning of the 20th century (Figure 3b). The winter warming trend is reflected in a below average number of very cold nights since 1990 (Figure 3c).

Observed and Projected Temperature Change

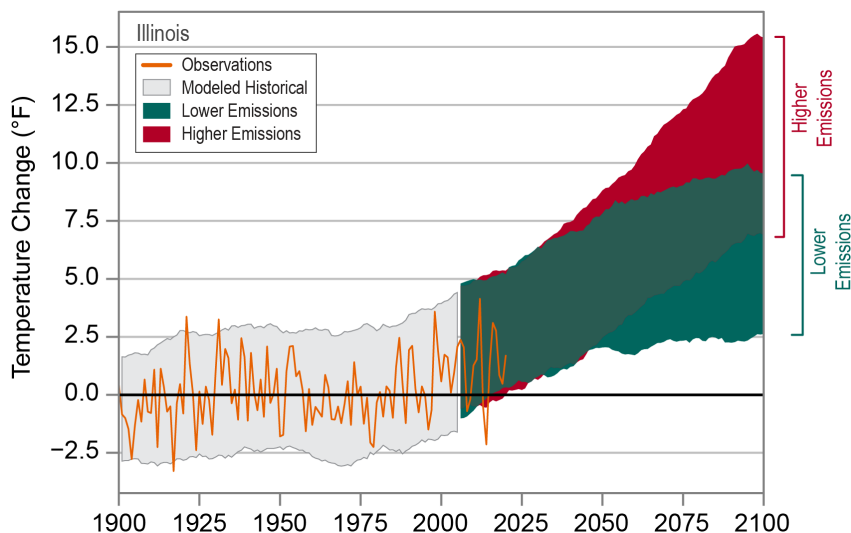


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Illinois. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Illinois (orange line) have risen about 1.5°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 2°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 11°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

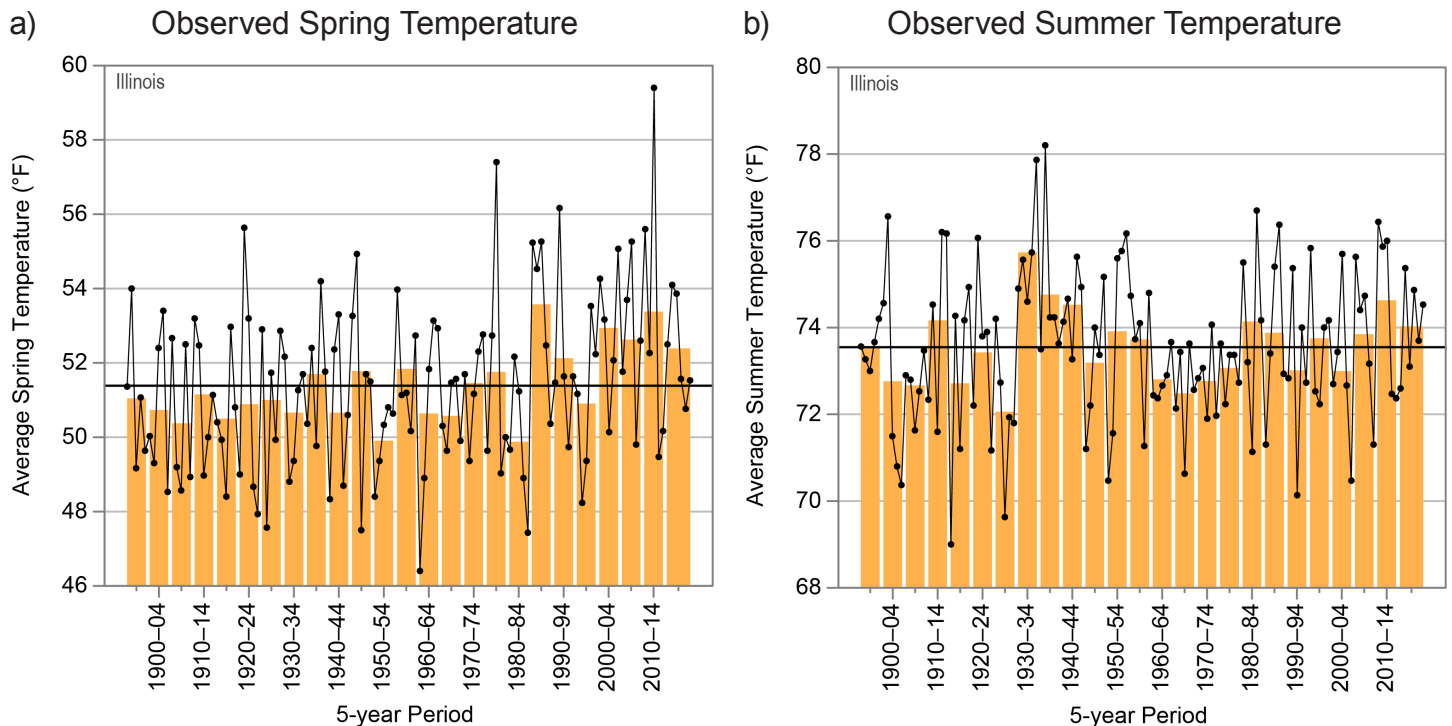


Figure 2: Observed (a) spring (March–May) and (b) summer (June–August) average temperature for Illinois from 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 51.4°F and (b) 73.6°F. Since 1985, Illinois has experienced the highest springtime temperatures in the historical record. Summer temperatures during the 2010–2014 period reached the highest level since the extreme heat of the 1930s Dust Bowl era. Sources: CISESS and NOAA NCEI. Data: nClimDiv.

Statewide annual precipitation has ranged from a low of 25.5 inches in 1901 to a high of 51.2 inches in 1993. The driest multiyear periods occurred in the first half of the 20th century, and the wettest have been observed since the 1970s (Figure 3d). The driest consecutive 5-year interval was 1952–1956, and the wettest was 2007–2011. **Annual precipitation varies widely across the state, ranging from more than 50 inches in the south to less than 35 inches in the north.** For annual snowfall, the pattern is reversed, with the northeastern part of the state averaging more than 40 inches compared to less than 10 inches in the southernmost section. Due to its proximity to Lake Michigan, the Chicago metropolitan area occasionally receives heavy winter precipitation from lake-effect snows.

Agriculture is an important sector of Illinois's economy and is particularly vulnerable to extreme weather conditions. On average, spring and summer precipitation has been above average since the mid-1990s (Figures 4a and 4b). While precipitation during these critical growth seasons is important for adequate soil moisture, it is also vital for proper planting and root development. Poor root development in important state crops, such as corn and soybeans, can lead to

reduced plant absorption of nutrients and water from the soil, increased soil erosion, and loss of nutrients from the fields into rivers and streams. Both flooding and droughts have resulted in billions of dollars in losses in recent years. In 2012, a large drought across the Midwest had severe impacts on Illinois. Rainfall totals for May, June, and July were several inches below average, resulting in the third-driest May–July period (after 1936 and 1988) in 126 years of record keeping. By early August, much of the state was in extreme drought. The drought caused major damage to crops, particularly in the southern third of the state.

Illinois has experienced a dramatic increase in the number of 2-inch extreme precipitation events, which can cause severe flooding (Figure 5). In the summer of 1993, persistent heavy rainfall over the upper Midwest caused severe flooding along the Mississippi River. The 1993 flood was one of the greatest natural disasters in U.S. history, causing billions of dollars in damages to homes, businesses, agriculture, and infrastructure. More recently, during April 16–19, 2013, heavy rainfall from a slow-moving storm system caused severe flooding across parts of northern and central Illinois, with some areas receiving up to 10 inches of rain. This event,

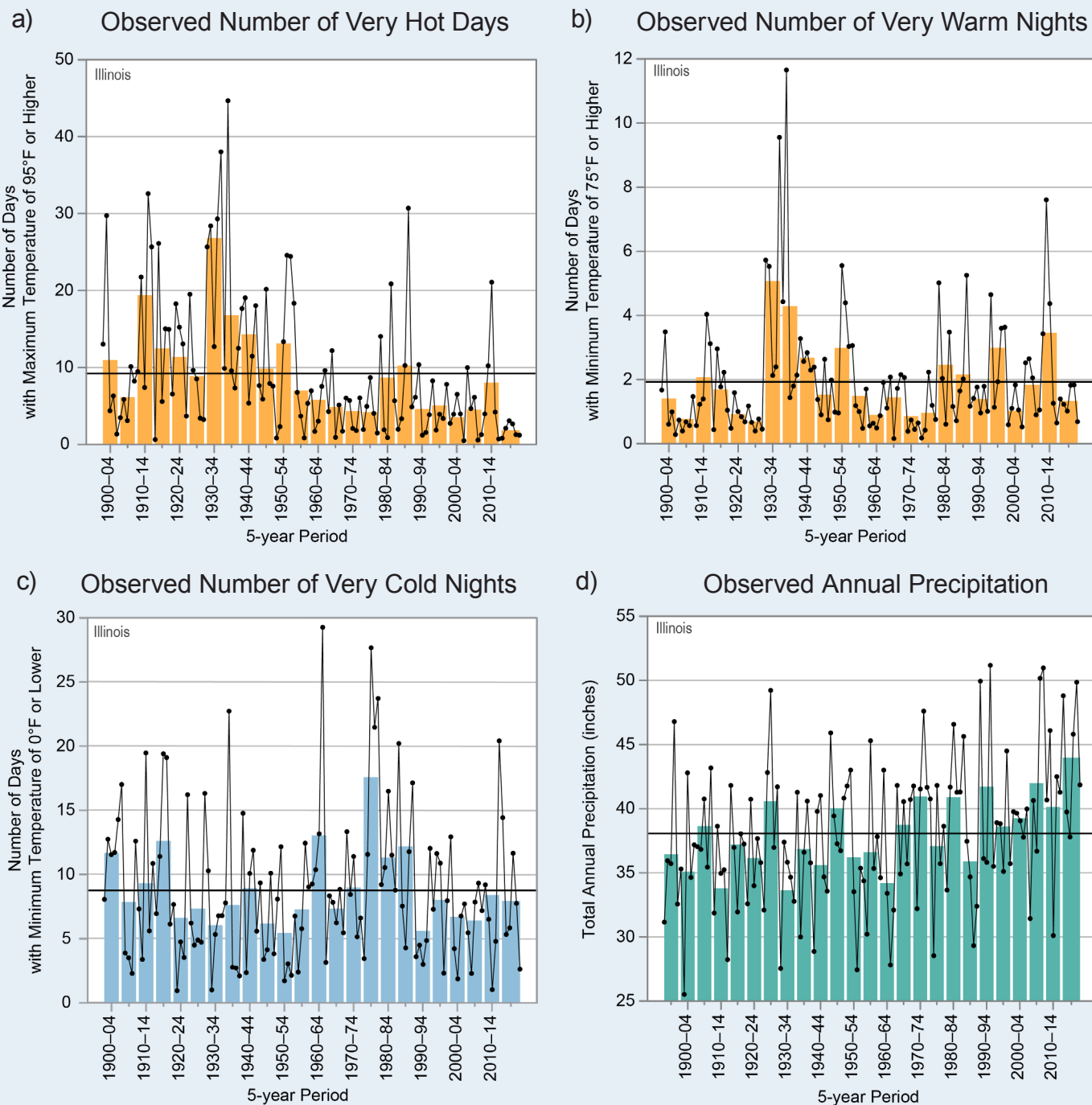


Figure 3: Observed (a) annual number of very hot days (maximum temperature of 95°F or higher), (b) annual number of very warm nights (minimum temperature of 75°F or higher), (c) annual number of very cold nights (minimum temperature of 0°F or lower), and (d) total annual precipitation for Illinois from (a, b, c) 1900 to 2020 and (d) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 9.2 days, (b) 1.9 nights, (c) 8.8 nights, (d) 38.1 inches. The number of very hot days has generally been below average since 1955. The number of very warm nights shows no clear trend; however, the number of very cold nights has been below average since 1990. Annual precipitation varies widely but has been above average since 1990. Sources: CISESS and NOAA NCEI. Data: (a, b, c) GHCN-Daily from 34 long-term stations, (d) nClimDiv.

which contributed to the second-wettest January–June on record in the state, caused planting delays and diminished revenue for many farmers. Illinois has also struggled with urban flooding caused by heavy rains falling on impervious surfaces (e.g., roads, sidewalks, and driveways) and inadequate infrastructure. A recent

report found that more than 90% of urban flooding damage claims from 2007 to 2014 were outside the mapped floodplain.

Illinois experiences storms during all seasons. During February 1–3, 2011, one of the most powerful winter

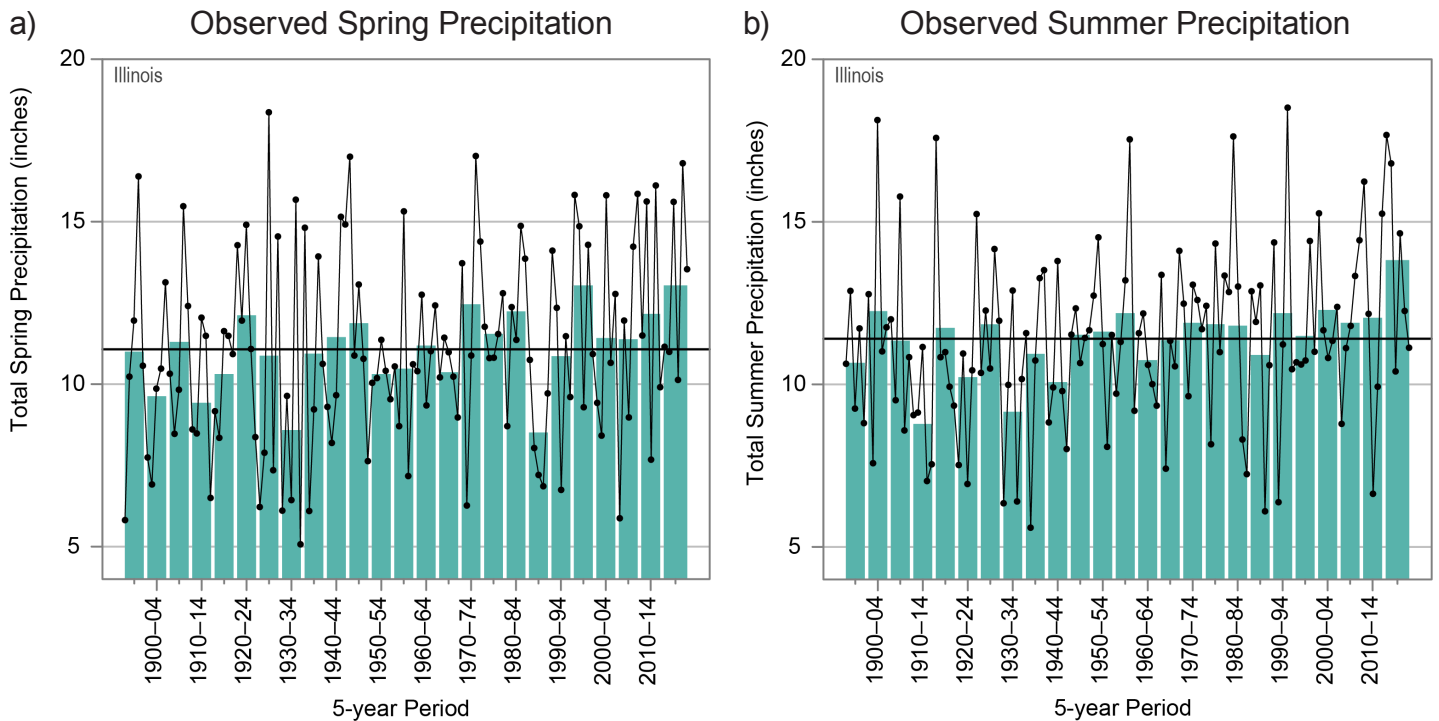


Figure 4: Observed (a) total spring (March–May) and (b) total summer (June–August) precipitation for Illinois from 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 11.1 inches and (b) 11.4 inches. Seasonal precipitation varies widely. Since 1995, Illinois has experienced above average spring and summer precipitation. Sources: CISESS and NOAA NCEI. Data: nClimDiv.

storms in history hit Illinois. Antioch, which normally averages only one snowfall greater than 6 inches per year, received the greatest accumulation of 27 inches. Chicago O’Hare International Airport recorded wind gusts of more than 60 mph and 20.2 inches of snow, the third-largest snowfall accumulation for the city in 120 years of record keeping. More than 9.8 million Illinois residents were in areas that received 12 or more inches of snow. Severe thunderstorms occur frequently during late spring and early summer. These storms can occasionally cause tornadoes, which sometimes cause major damage and loss of life. On August 10, 2020, a powerful derecho traveled through Illinois, producing widespread damaging winds. There were 15 tornadoes across northeastern Illinois, with several affecting the Chicago metropolitan area.

Water levels in the Great Lakes have fluctuated over a range of 3 to 6 feet since the late 19th century (Figure 6). Higher lake levels were generally noted in the late 19th century, the early 20th century, and the 1940s, 1950s, 1980s, and the late 2010s. Lower lake levels were observed in the 1920s and 1930s and again in the 1960s. For Lake Michigan–Huron, lower levels occurred during the first decade of this century. Lake levels have risen rapidly since 2013, with the highest levels since 1886 observed in 2020.

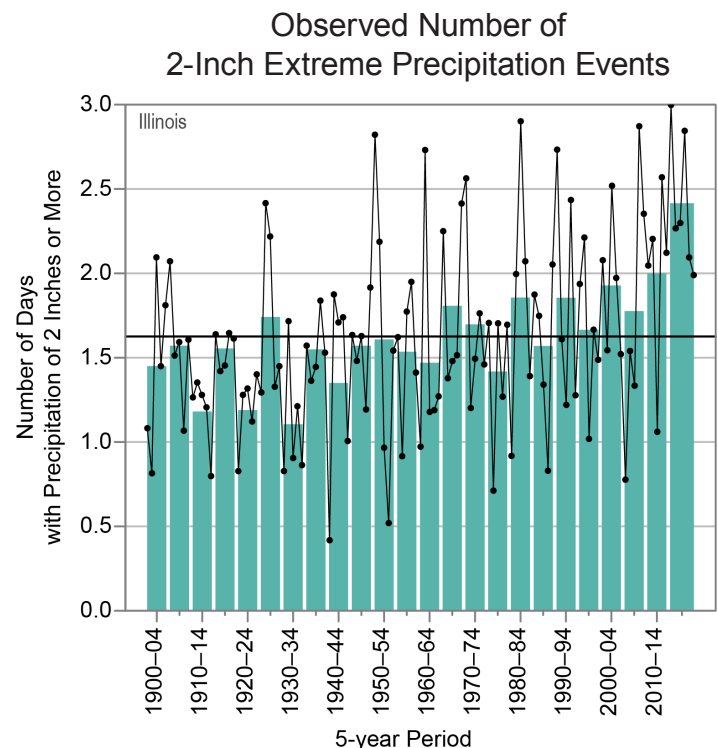


Figure 5: Observed annual number of 2-inch extreme precipitation events (days with precipitation of 2 inches or more) for Illinois from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 1.6 days. A typical reporting station experiences 1 to 2 events per year. The number of 2-inch extreme precipitation events has been above average since 1990. During the most recent 6-year period (2015–2020), Illinois experienced a record-high number of more than 2 events per station per year. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 41 long-term stations.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of the century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. During July 12–16, 1995, Chicago experienced a severe heat wave—the worst weather-related disaster in the city’s history. Over a 5-day period, more than 700 people died. In addition to daytime highs of 90°F or higher (including 2 days of 100°F or higher), nighttime temperatures dropped only into the 80s (°F). Furthermore, the heat index, which considers both temperature and humidity, reached values of 105°F or more for 42 hours during the event. Values of 105°F or higher are considered dangerous by the National Weather Service. An analysis shows that the number of hours above critical thresholds of the heat index were the highest on record (Figure 7). If temperatures continue rising, future heat waves are likely to be more intense. High temperatures combined with high humidity pose risks to human health, particularly for residents of Chicago and other urban areas. By contrast, the intensity of cold waves is projected to decrease.

Increases in precipitation are projected for Illinois, most likely during the winter and spring (Figure 8). The frequency and intensity of extreme precipitation events are also projected to increase, potentially increasing the frequency and intensity of floods. Springtime flooding in particular could pose a threat to Illinois’s important agricultural economy by delaying planting and reducing yields.

The intensity of future droughts is projected to increase even if precipitation increases. Rising temperatures will increase evaporation rates and the rate of soil moisture loss. Thus, future summer droughts, a natural part of Illinois’s climate, are likely to be more intense.

Lake-Wide Water Levels for Lake Michigan-Huron

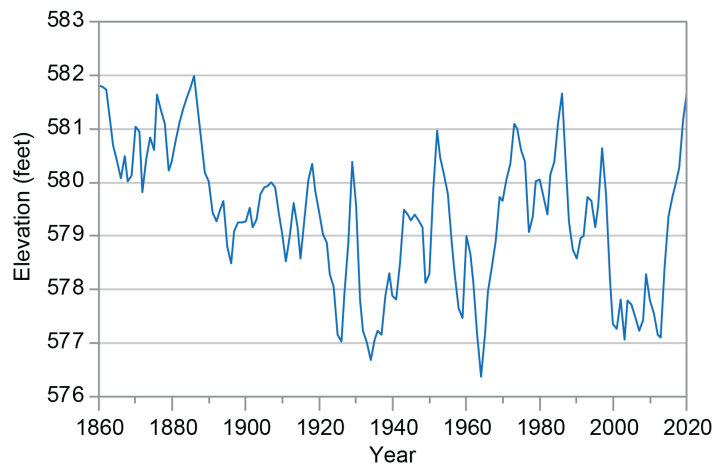


Figure 6: Annual time series of the average water levels for Lake Michigan–Huron from 1860 to 2020. Water levels in the Great Lakes have fluctuated widely over the years. Lake Michigan–Huron levels were very low during 2000–2013 but have since risen rapidly to the highest levels since 1886. Source: NOAA GLERL.

Hours of Heat Index at or above Threshold Value Chicago Midway Airport (June to September)

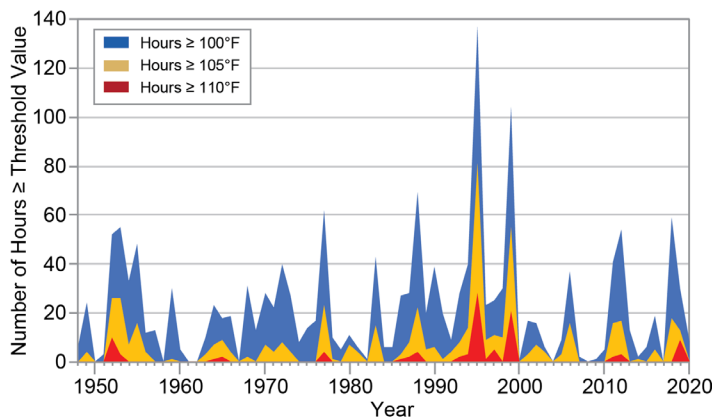


Figure 7: Observed annual number of hours with heat index values at or above selected thresholds (100°F, 105°F, and 110°F) for Chicago Midway International Airport from 1948 to 2020. The number of hours at or above the three thresholds reached record-high levels during the 1995 heat wave (137, 81, and 28 hours, respectively). Source: CISESS and NOAA NCEI. Data: Integrated Surface Database.

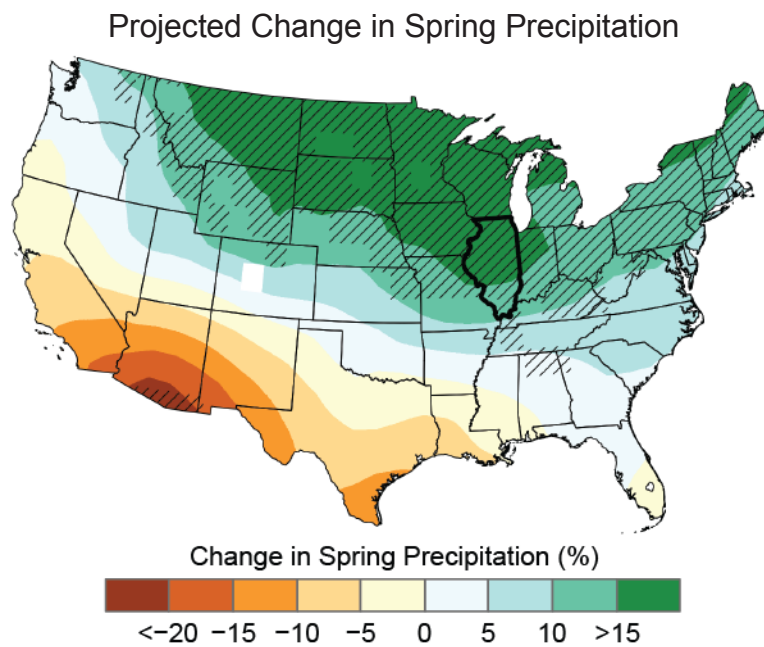


Figure 8: Projected changes in spring (March–May) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. The white-out area indicates that the climate models are uncertain about the direction of change. Hatching represents areas where the majority of climate models indicate a statistically significant change. Spring precipitation in Illinois is projected to increase in the range of 10% to greater than 15% by 2050. These increases are part of a large area of projected increases across the northern United States. Sources: CISESS and NEMAC. Data: CMIP5.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

INDIANA

Key Messages

Temperatures in Indiana have risen almost 1.5°F since the beginning of the 21st century. Warming has been concentrated in winter and spring, with a general lack of summer warming. Under a higher emissions pathway, historically unprecedented warming is projected during this century, with corresponding decreases in cold wave intensity and increases in heat wave intensity.

Spring and summer precipitation has generally been above average since the 1990s, affecting agriculture both positively (adequate soil moisture) and negatively (delays in spring planting). Projected increases in winter and spring precipitation pose a continuing risk of spring planting delays.

Severe flooding and drought have occurred periodically in recent years. Future increases in the frequency and intensity of extreme precipitation events may increase the frequency and intensity of floods, while increases in evaporation rates due to rising temperatures may increase the intensity of naturally occurring droughts.



Indiana's location in the interior of North America and the lack of mountains to the north and south expose the state to incursions of bitterly cold air masses from the Arctic in the winter and warm, humid air masses from the Gulf of Mexico in the summer. Annual average temperature varies widely across the state, with a range of about 10°F from north to south. In northwestern Indiana, Lake Michigan moderates the temperature, causing cooler summers and warmer winters. Lake Michigan is also the source of lake-effect snows, which can extend as far inland as Elkhart (north-central Indiana).

Temperatures in Indiana have risen almost 1.5°F since the beginning of the 20th century (Figure 1). Temperatures in the 2000s have been higher than in any other historical period with the exception of the early 1930s Dust Bowl era. Warming has been concentrated in winter and spring (Figure 2a), while summers have not warmed substantially (Figure 2b), a feature characteristic of much of the Midwest. The lack of summer warming is reflected by a below average number of very hot days (Figure 2c), although the number of very warm nights has generally been near average since the early 1980s (Figure 2d).

Observed and Projected Temperature Change

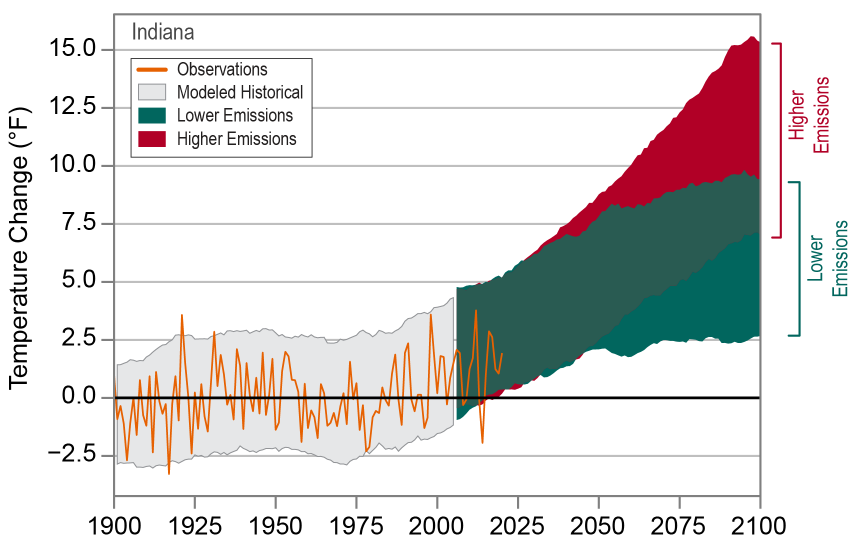


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Indiana. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Indiana (orange line) have risen almost 1.5°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 3°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 12°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

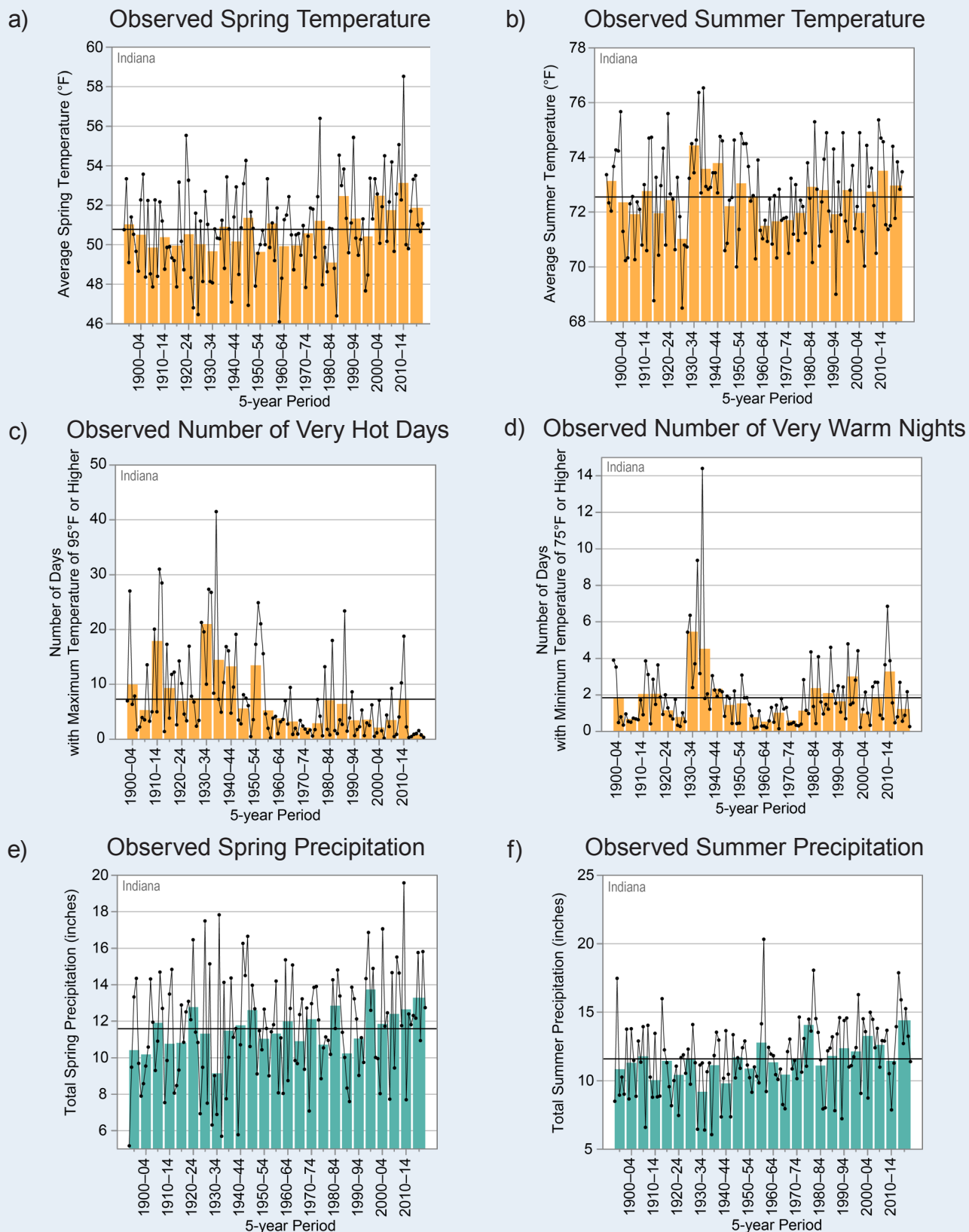


Figure 2: Observed (a) spring (March–May) average temperature, (b) summer (June–August) average temperature, (c) annual number of very hot days (maximum temperature of 95°F or higher), (d) annual number of very warm nights (minimum temperature of 75°F or higher), (e) total spring precipitation, and (f) total summer precipitation for Indiana from (a, b, e, f) 1895 to 2020 and (c, d) 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 50.8°F, (b) 72.6°F, (c) 7.3 days, (d) 1.9 nights, (e) 11.6 inches, (f) 11.6 inches. Spring temperatures have generally trended upward, while summer temperatures show little change. Since 1955, the number of very hot days has been below average, while the number of very warm nights has generally trended upward but has not reached the levels of the 1930s. Spring and summer precipitation has generally trended upward. Sources: CISESS and NOAA NCEI. Data: (a, b, e, f) nClimDiv, (c, d) GHCN-Daily from 17 long-term stations.

Due to extreme drought and poor land management practices, the summers of the 1930s and early 1940s remain the warmest on record. Winter warming is reflected in a below average number of very cold nights since the early 1990s (Figure 3).

Annual precipitation has varied from a low of 29.1 inches in 1963 to a high of 55.2 inches in 2011. The driest multiyear periods were in the 1930s, 1940s, and 1960s and the wettest in the 2010s (Figure 4). The driest consecutive 5-year interval was 1940–1944, averaging 35.2 inches per year, and the wettest was 2015–2019, averaging 47.2 inches per year. Annual precipitation also varies widely across the state, ranging from about 47 inches in the south to 37 inches in the north. For snowfall, the pattern is reversed, with the southwest averaging about 14 inches and some northern locations near Lake Michigan averaging more than 70 inches. Locations close to Lake Michigan occasionally receive heavy winter precipitation from lake effect snows. During January 21–22, 2014, a lake effect storm dropped 18 inches of snow in Gary over a 5-hour period.

Dangerous storms can occur in every season and can cause major impacts, including loss of life, property damage, and disruptions to economic activity. Winter can bring snow and ice storms, while thunderstorms capable of producing floods, hail, and tornadoes are common in the warmer months. One of the state's worst winter storms occurred during December 22–23, 2004. More than 20 inches of snow fell across the southern part of the state. Many locations reported record amounts, including the city of Washington, with 32 inches of snow. With temperatures below freezing, the snow lingered for several days, shutting down airports and interstates and stranding holiday travelers. The storm killed 5 people, and a state of emergency was declared for 50 counties. Heavy snowstorms during the first week of January 2014 dumped 1 to more than 2 feet of snow over central and northern Indiana.

Indiana has a long and deadly history of tornadic storms. On March 18, 1925, the deadliest tornado in U.S. history—the Tri-State Tornado—struck southwestern Indiana after tracking across Missouri and Illinois. The tornado destroyed parts of Griffin, Owensville, and Princeton and caused hundreds of

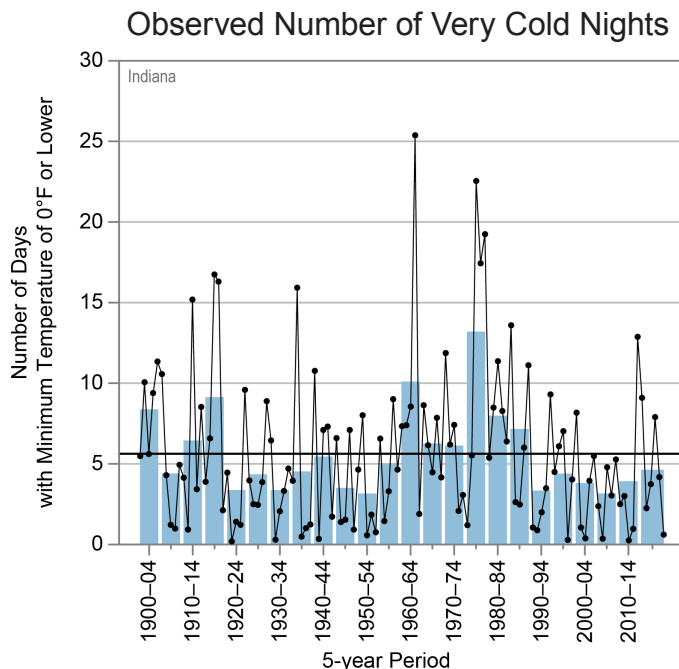


Figure 3: Observed annual number of very cold nights (minimum temperature of 0°F or lower) for Indiana from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 5.6 nights. The number of very cold nights has been below average since 1990 at an average of 3.9 nights per year, indicative of overall winter warming in the region. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 17 long-term stations.

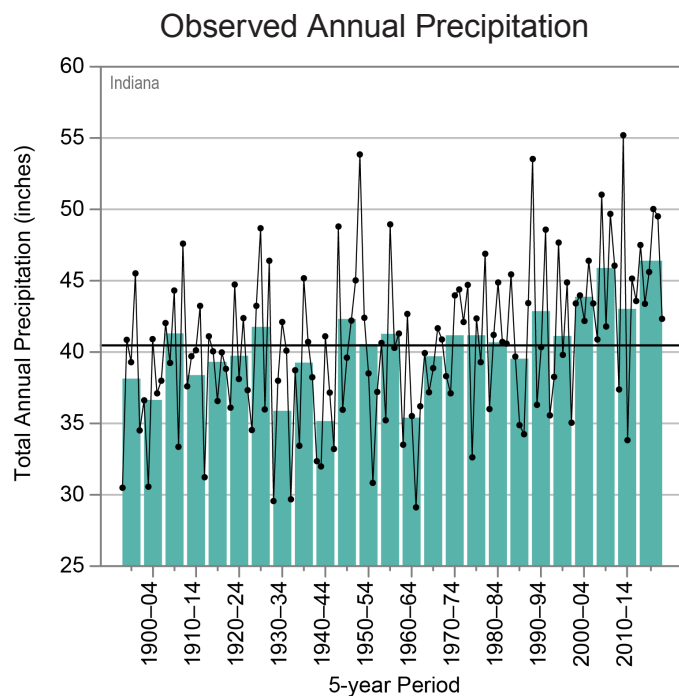


Figure 4: Observed total annual precipitation for Indiana from 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 40.5 inches. Annual precipitation varies widely but has been above average since 1990. The driest consecutive 5-year interval on record (1940–1944) averaged 35.2 inches, while the wettest (2015–2019) averaged 47.2 inches. Sources: CISESS and NOAA NCEI. Data: nClimDiv.

injuries and 76 deaths. The Palm Sunday Outbreak on April 11, 1965, included several tornadoes in Indiana, 8 of them at F4 intensity. The outbreak injured hundreds in the state and killed more than 130 people. Indiana's largest tornado outbreak occurred on June 2, 1990, and included 37 tornadoes, several of them at F4 intensity.

Agriculture is an important sector of Indiana's economy and is particularly vulnerable to a variety of extreme weather conditions. In 2007, unusually warm March temperatures followed by a hard freeze in April devastated much of the state's fruit crops, with total agricultural losses estimated at more than \$40 million. In 2012, a large drought across the Midwest severely impacted the state. Rainfall for May, June, and July totaled 6.6 inches, more than 5 inches below average, making this the fourth-driest May–July period (after 1936, 1930, and 1988) in 126 years of record keeping. By early August, almost 70% of the state was in extreme drought, with a quarter of the state experiencing exceptional drought. The drought caused major damage to crops, particularly in the southern third of the state.

On average, Indiana has experienced wet springs and summers since the 1990s (Figures 2e and 2f). While precipitation during these critical growth months is important for adequate soil moisture, it can also make it difficult for farmers to plant crops. **Indiana has also experienced an increase in the number of 2-inch extreme precipitation events** (Figure 5), which can cause severe flooding. The Great Flood of March 23–26, 1913, was the worst flood in Indiana history. Heavy rains caused many rivers across the state to reach flood stage. More than 100 people were killed, with damages estimated at more than \$20 million. Heavy rains on saturated ground were also responsible for severe flooding during June 6–7, 2008. Heavy rain fell across central and southern Indiana, with some stations reporting up to 10 inches. Many streams reached record flood levels. In total, 39 counties were declared disaster areas, and damages were estimated at hundreds of millions of dollars. In the summer of 2015, central Indiana experienced historic levels of rainfall; it was the wettest July on record at Indianapolis (8.7 inches above normal). Flooding in June and July exceeded flood control capacity in three reservoirs for the first time since they were built in the late 1960s. The magnitude

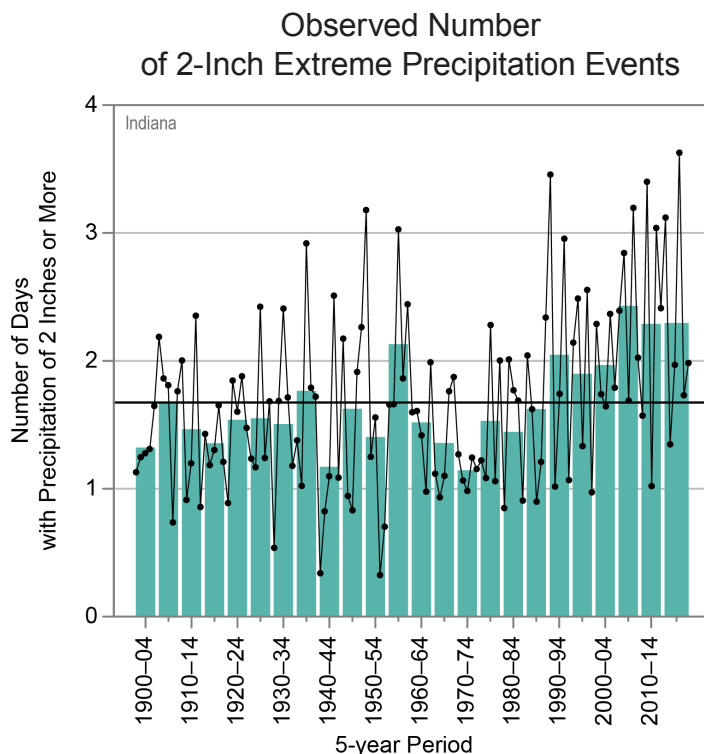


Figure 5: Observed annual number of 2-inch extreme precipitation events (days with precipitation of 2 inches or more) for Indiana from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 1.7 days. The number of 2-inch extreme precipitation events has been above average since 1990. The 2005–2009 period had the highest multiyear average on record of nearly 2.5 days. A typical station experiences about 2 events per year. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 21 long-term stations.

of this event rivaled that of the exceptional drought that impacted the state in 2012, highlighting the extremes in climate that Indiana has experienced in recent years.

Water levels in the Great Lakes have fluctuated over a range of 3 to 6 feet since the late 19th century (Figure 6). Higher lake levels were generally noted in the late 19th century, the early 20th century, and the 1940s, 1950s, 1980s, and late 2010s. Lower lake levels were observed in the 1920s and 1930s and again in the 1960s. For Lake Michigan–Huron, lower levels occurred during the first decade of this century. Lake levels have risen rapidly since 2013, reaching in 2020 the highest levels since 1886.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle

of the century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. If temperatures continue rising, future heat waves are likely to be more intense. Extreme heat is a particular concern for Indianapolis and other urban areas, where high temperatures combined with high humidity can cause dangerous heat index values, a phenomenon known as the urban heat island effect. By contrast, the intensity of cold waves is projected to decrease.

Increases in precipitation are projected for Indiana, most likely during the winter and spring (Figure 7).

The frequency and intensity of extreme precipitation events are also projected to increase, potentially increasing the frequency and intensity of floods. Springtime flooding in particular poses a threat to Indiana's important agricultural economy by delaying planting and reducing yields.

The intensity of future droughts is projected to increase even if precipitation increases. Rising temperatures will increase evaporation rates and the rate of soil moisture loss. Thus, future summer droughts, a natural part of Indiana's climate, are likely to be more intense.

Lake-Wide Water Levels for Lake Michigan-Huron

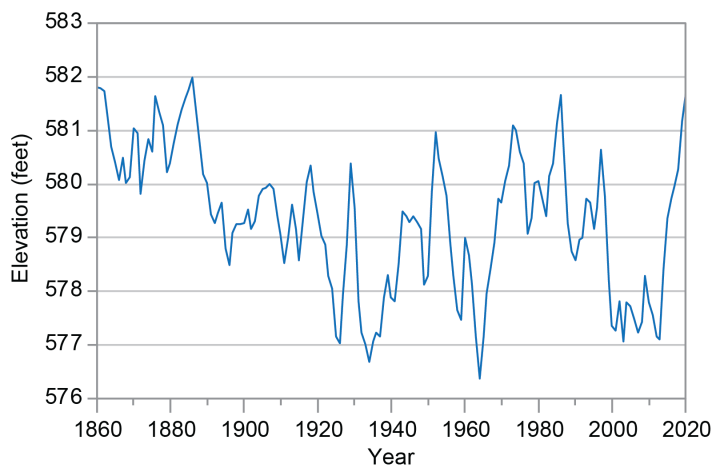


Figure 6: Annual time series of the average water levels for Lake Michigan–Huron from 1860 to 2020. Water levels in the Great Lakes have fluctuated widely over the years. Lake Michigan–Huron levels were very low during 2000–2013 but have since risen rapidly to the highest levels since 1886. Source: NOAA GLERL.

Projected Change in Spring Precipitation

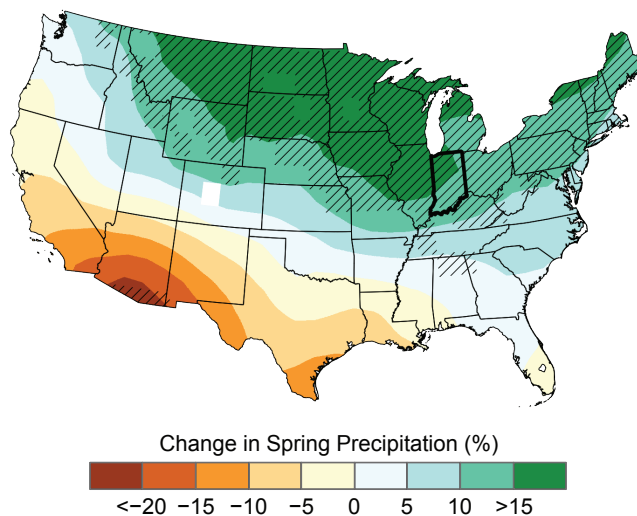


Figure 7: Projected changes in spring (March–May) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. The whited-out area indicates that the climate models are uncertain about the direction of change. Hatching represents areas where the majority of climate models indicate a statistically significant change. Spring precipitation in Indiana is projected to increase in the range of 10% to greater than 15% by 2050. Source: CISESS and NEMAC. Data: CMIP5.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

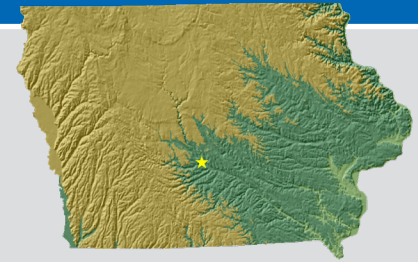
IOWA

Key Messages

Temperatures in Iowa have risen more than 1°F since the beginning of the 20th century. Warming has been concentrated in winter and fall, with a general lack of summer warming. Under a higher emissions pathway, historically unprecedented warming is projected during this century.

Spring precipitation has been above average since 1990, affecting agriculture both positively (adequate soil moisture) and negatively (delays in spring planting). Projected increases in winter and spring precipitation pose a continued risk of spring planting delays.

Severe flooding and drought have occurred periodically in recent years, with major impacts on several communities. Future increases in the frequency and intensity of extreme precipitation events may increase the frequency and intensity of floods, while increases in evaporation rates due to rising temperatures may increase the intensity of naturally occurring droughts.



Iowa's location in the interior of North America and the lack of mountains to the north and south expose the state to incursions of bitterly cold air masses from the Arctic in the winter and warm, humid air masses from the Gulf of Mexico in the summer. As a result, its climate is characterized by wide-ranging temperatures.

Temperatures in Iowa have risen more than 1°F since the beginning of the 20th century (Figure 1). Temperatures in the 2000s have been higher than in any other historical period, with the exception of the early 1930s Dust Bowl era. The warming is due to increases in nighttime minimum temperatures; daytime maximum temperatures, however, show no trend. Increases in humidity may be one cause of this asymmetric warming between night and day. The hottest year on record was 2012, with an annual average temperature of 52.1°, which is 4.5°F above the long-term (1895–2020) average. Warming has been concentrated in winter and fall, while summers have not warmed substantially (Figure 2a), a feature characteristic of much of the Midwest. This lack of summer warming is reflected in a below average number of very hot days (Figure 2b) and no overall trend in warm nights (Figure 2c). The winter warming trend is reflected in a below average number of very cold nights since 1990, with the exception of the 2010–2014 period (Figure 2d).

Observed and Projected Temperature Change

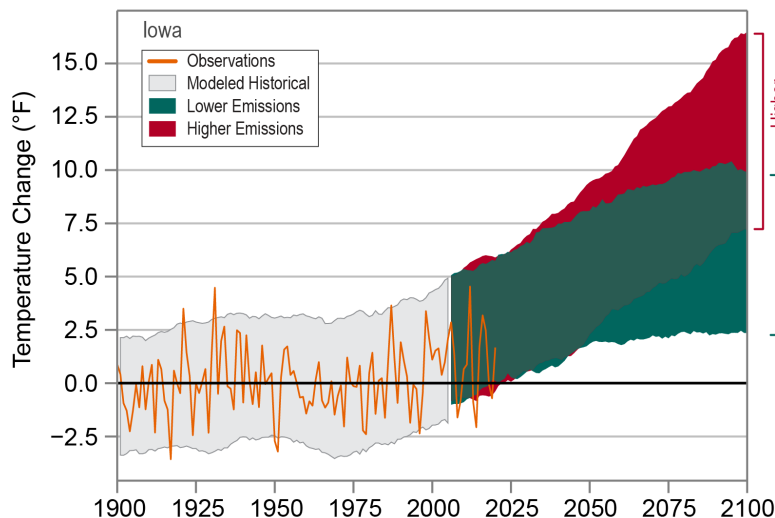


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Iowa. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Iowa (orange line) have risen more than 1°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 2°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 12°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

century projections being about 12°F warmer than the hottest year in the historical record). Sources: CISESS and NOAA NCEI.

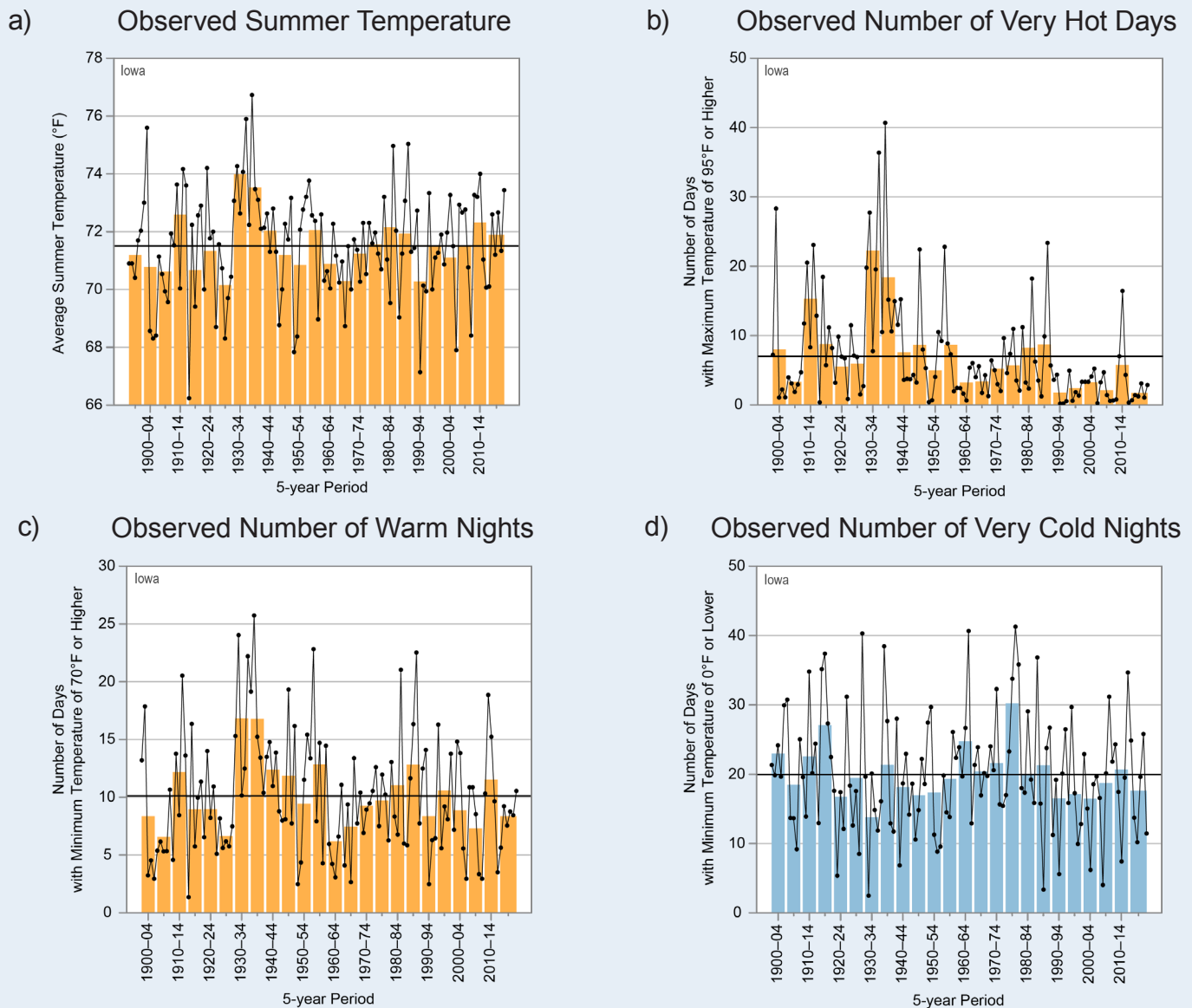


Figure 2: Observed (a) summer (June–August) average temperature, (b) annual number of very hot days (maximum temperature of 95°F or higher), (c) annual number of warm nights (minimum temperature of 70°F or higher), and (d) annual number of very cold nights (minimum temperature of 0°F or lower) for Iowa from (a) 1895 to 2020 and (b, c, d) 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 71.5°F, (b) 7 days, (c) 10 nights, (d) 20 nights. Summer temperatures have generally been near average since 1995. The number of very hot days has been below average since 1990, while the number of warm nights shows no clear trend. Due to extreme drought and poor land management practices, the summers of the 1930s remain the warmest on record. The number of very cold nights has been below average since 1990, except for the 2010–2014 period. Sources: CISESS and NOAA NCEI. Data: (a) nClimDiv, (b, c, d) GHCN-Daily from 49 long-term stations.

Precipitation varies widely across Iowa, with the southeastern portion of the state receiving around 38 inches annually compared to only 26 inches in the northwest. Much of Iowa's precipitation falls in summer, averaging about 14 inches in the central part of the state. Spring precipitation has been above average since 1990 (Figure 3a), which can make it difficult for farmers to plant crops. Summer and annual precipitation has also been above average since 2005 (Figures 3b and 4), which has benefited crop production but also increased

flooding. Iowa's planting season, which runs from April into June, has been particularly wet in recent years, averaging about 2.8 inches above the long-term average of 12 inches since 2008. Statewide annual precipitation has ranged from a low of 20.2 inches in 1910 to a high of 47.9 inches in 1993. Snowfall also varies across the state, ranging from more than 40 inches in the north to about 20 inches in the south. For most of the state, more than 40% of the annual precipitation occurs on the 10 wettest days of the year, a percentage that rises to

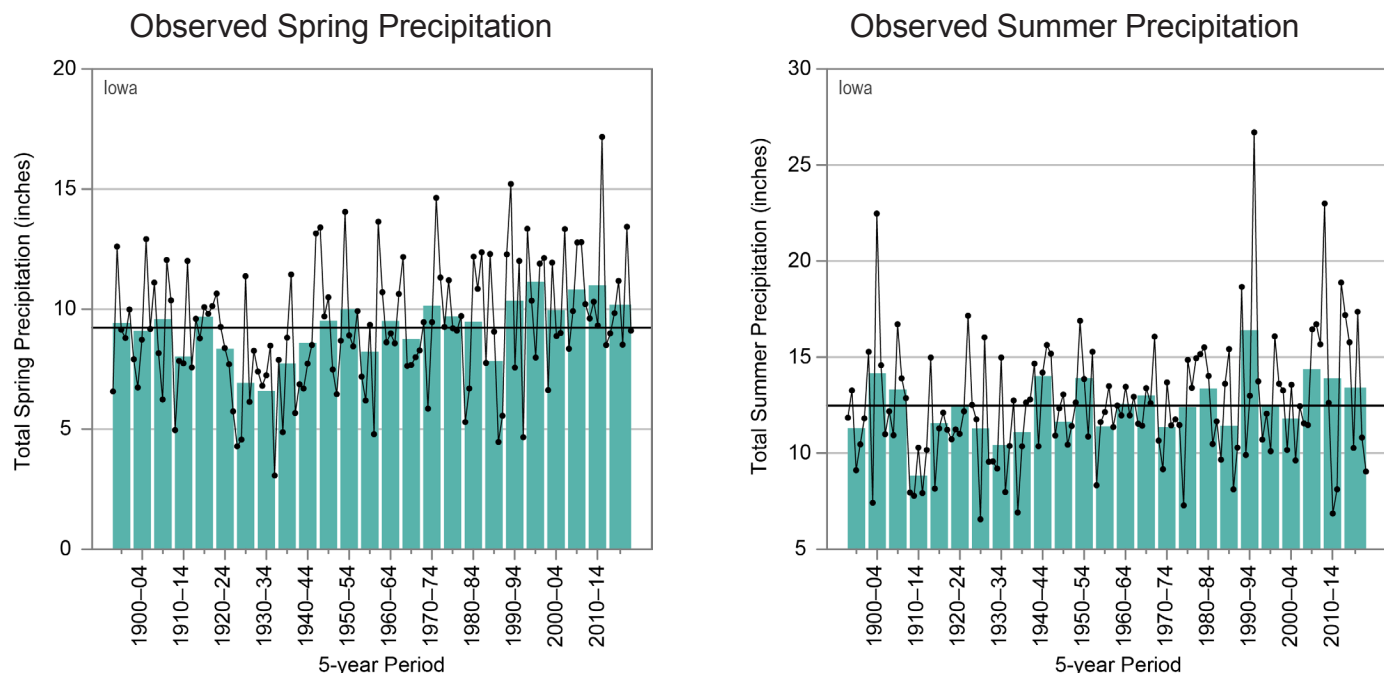


Figure 3: Observed (a) total spring (March–May) and (b) total summer (June–August) precipitation for Iowa from 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 9.2 inches and (b) 12.5 inches. Spring and summer precipitation has been above average since 1990 and 2005, respectively. Sources: CISESS and NOAA NCEI. Data: nClimDiv.

more than 48% in the western portion. **The frequency of 2-inch extreme precipitation events has increased**, with the highest number occurring during the past 16 years (Figure 5).

Agriculture is an important sector of Iowa's economy and is particularly vulnerable to extreme weather conditions. Both flooding and droughts have resulted in billions of dollars in losses in recent years. Following abnormally dry conditions in 2011, Iowa experienced severe drought conditions in 2012 and then very dry conditions again in 2013. Below average rainfall totals for the critical growth months of July and August were 6.4, 4.1, and 3.2 inches in 2011, 2012, and 2013, respectively (the long-term average for July–August rainfall is 7.8 inches). This 3-year period was unlike any other 3-year period dating back to 1895 and superseded the dry years of the Dust Bowl era. By the end of September 2012, much of the state was in extreme drought, with portions in the northwest experiencing exceptional drought conditions extending into 2013.

Thousands of miles of rivers flow through Iowa, which is bordered by the Mississippi River to the east and the Big Sioux and Missouri Rivers to the west. **With many of these waterways located alongside cities and farmland, flooding is a severe hazard.** From 1955

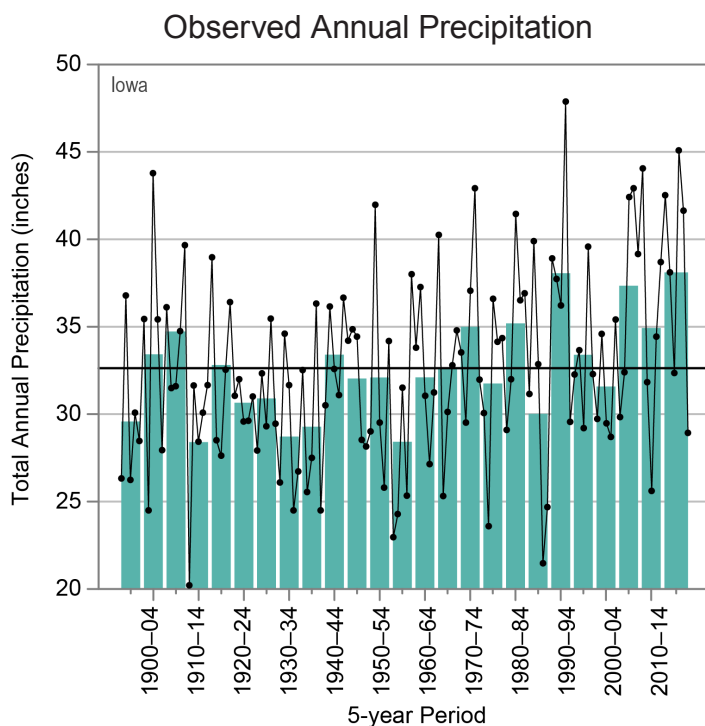


Figure 4: Observed total annual precipitation for Iowa from 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 32.6 inches. Annual precipitation over the past 16 years has generally been several inches above average. The wettest consecutive 5-year interval was 2006–2010, while the driest was 1952–1956. Sources: CISESS and NOAA NCEI. Data: nClimDiv.

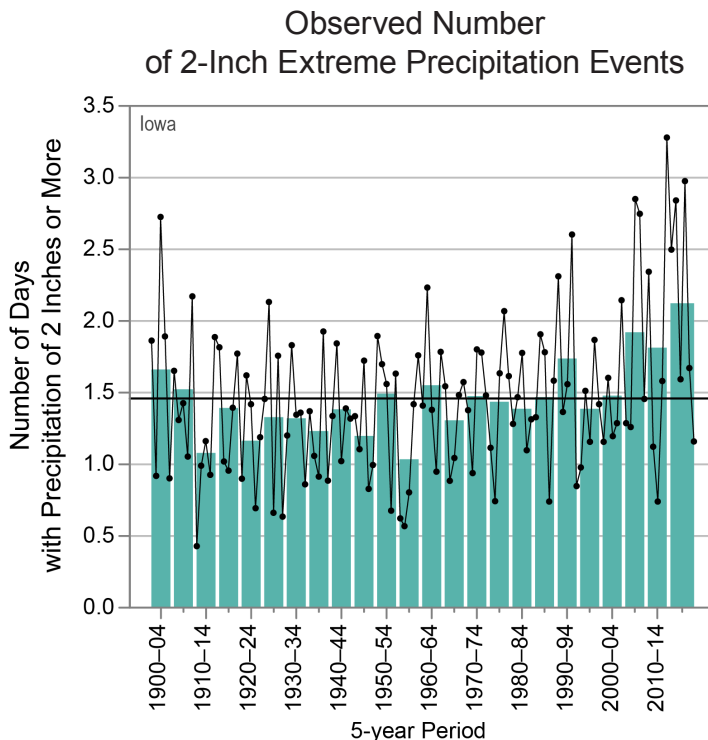


Figure 5: Observed annual number of 2-inch extreme precipitation events (days with precipitation of 2 inches or more) for Iowa from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 1.5 days. A typical station experiences 1 to 2 events per year. Multiyear averages since 2005 are the highest in the historical record. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 45 long-term stations.

to 1997, Iowa was ranked first in state losses due to flooding. During the first two weeks of June 2008, heavy rainfall on soil already saturated from unusually wet conditions caused record flooding along multiple rivers. Numerous long-term stations reported more than 10 inches during the 2-week period, and levels on the Cedar River exceeded the previous record by more than 11 feet. Of the state's 99 counties, 83 were declared disaster areas, and damages were estimated at almost \$10 billion. Snowmelt, as well as ice jams, can also cause flooding. In June 2011, runoff from a record winter snowpack in the Rocky Mountains accompanied by heavy rains caused major flooding along the entire length of the Missouri River. The region around Hamburg was particularly hard hit, where levee failures forced evacuation of the town and farmland flooding caused extensive agricultural losses.

Iowa experiences damaging storms during all seasons. During winter months, snowstorms and ice storms are a frequent hazard. During December 8–9, 2009, a strong

storm produced heavy snowfall across the state, with multiple long-term stations reporting more than 15 inches. Wind gusts of more than 50 mph produced large snow drifts and caused widespread whiteout conditions. The blizzard conditions were compounded by bitter cold on December 9, with temperatures below 10°F and wind chills below 0°F across large portions of the state. Thunderstorms capable of producing floods, hail, and tornadoes are common in the warmer months. On May 25, 2008, an EF-5 tornado killed 8 people and destroyed nearly 200 homes in Parkersburg. This was the strongest tornado to hit the state since June 13, 1976. One of the most destructive thunderstorms to ever affect the state occurred on August 10, 2020. A powerful derecho produced widespread winds greater than 100 mph, causing extensive damage to millions of acres of corn and soybean crops across central Iowa and severe damage to homes, businesses and vehicles, particularly in Cedar Rapids.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of this century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. Intense heat waves can occur in Iowa, often accompanied by high humidity. Heat waves are projected to become more intense, and impacts on human health could be significant. However, cold waves are projected to be less intense.

Increases in precipitation are projected for Iowa, most likely during the winter and spring (Figure 6). Increases in the frequency and intensity of extreme precipitation are also projected, potentially increasing the frequency and intensity of floods. Springtime flooding in particular could pose a threat to Iowa's important agricultural economy by delaying planting and reducing yields.

The intensity of future droughts is projected to increase even if precipitation increases. Rising temperatures will increase evaporation rates and the rate of soil moisture loss. Thus, periodic summer droughts, a natural part of Iowa's climate, are likely to be more intense in the future.

Projected Change in Spring Precipitation

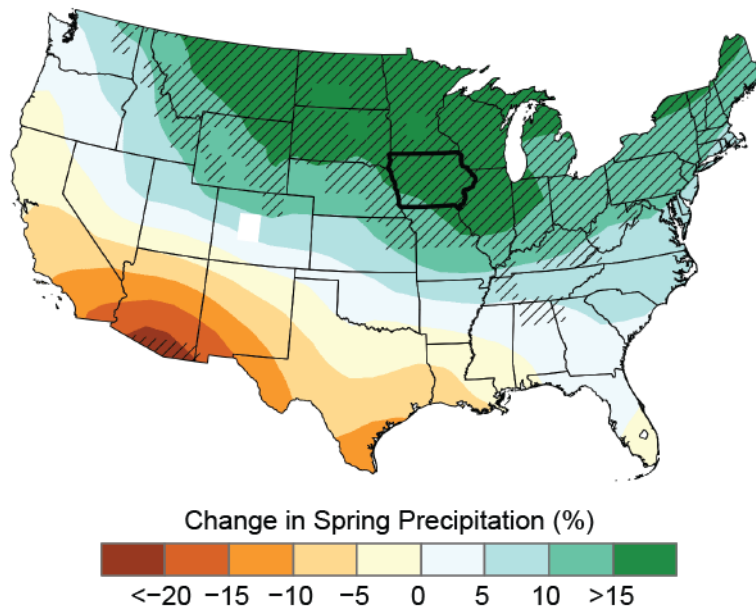


Figure 6: Projected changes in spring (March–May) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. The whited-out area indicates that the climate models are uncertain about the direction of change. Hatching represents areas where the majority of climate models indicate a statistically significant change. Iowa is part of a large area of projected increases in the Northeast and Midwest. Sources: CISESS and NEMAC. Data: CMIP5.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

KANSAS

Key Messages

Temperatures in Kansas have risen about 1.5°F since the beginning of the 20th century, with greater warming in the winter and spring than in the summer and fall. The number of very cold nights has been below average since 1990. Under a higher emissions pathway, historically unprecedented warming is projected during this century.

Kansas is a region of transition between the humid conditions to the east of the state and the semiarid conditions to the west, and as a result, precipitation in the state varies greatly from year to year. Projected increases in winter precipitation and decreases in summer precipitation may have both positive and negative impacts on the state.

Droughts and heat waves pose a particular risk to Kansas's agricultural economy. Such events occurred in the 1930s, 1950s, and in recent years. Projected increases in temperatures may increase the intensity of future droughts. The frequency and severity of wildfires are also projected to increase throughout the state.



Kansas lies in the central Great Plains, straddling the transition from relatively abundant precipitation (more than 45 inches annually; 1991–2020 normals) in the southeast, supporting forests and rain-fed agriculture, to semiarid conditions (less than 20 inches annually) in the west. The state is located far from the moderating effects of the oceans, and temperatures vary widely across seasons. The statewide average temperature is 33.0°F in the winter and 76.8°F in the summer.

Temperatures in Kansas have risen about 1.5°F since the beginning of the 20th century (Figure 1). Recent multiyear periods have been among some of the warmest on record for Kansas, comparable to the extreme heat of the Dust Bowl era of the 1930s, when intense drought and poor land management likely exacerbated the hot summer conditions. Many record-high temperatures were set during the summer of 2012, which was the hottest year on record with an average temperature of 58.2°F. Recent spring temperatures have been above average (Figure 2a), which may have implications for crop planting. Summer temperatures have been near or above average since 2000 (Figure 2b). There is no long-term trend in very warm nights or extremely hot days, although both were slightly above average during the 2010–2014 period (Figures 3a and 3b). The number of very cold nights has been mostly below average since 1990 (Figure 4). The freeze-free season has also lengthened, especially in eastern Kansas, averaging about 9 days longer in this century than the 20th century average.

Observed and Projected Temperature Change

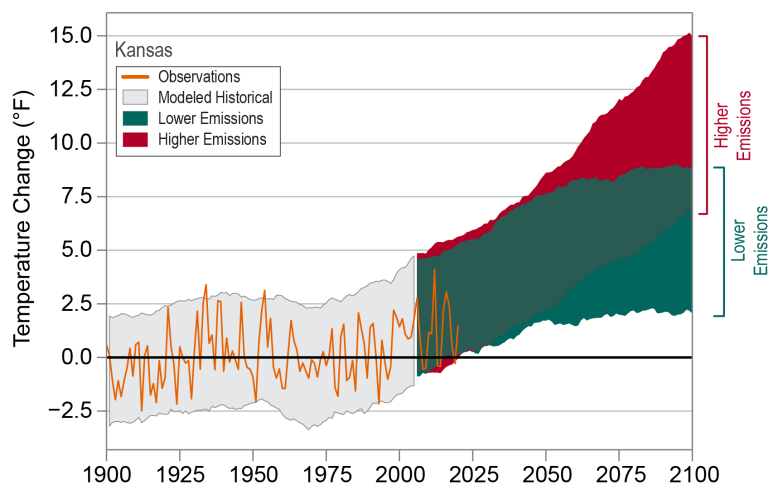


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Kansas. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Kansas (orange line) have risen about 1.5°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 2°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 11°F warmer than the hottest year in the historical record; red shading). Sources: CISS and NOAA NCEI.

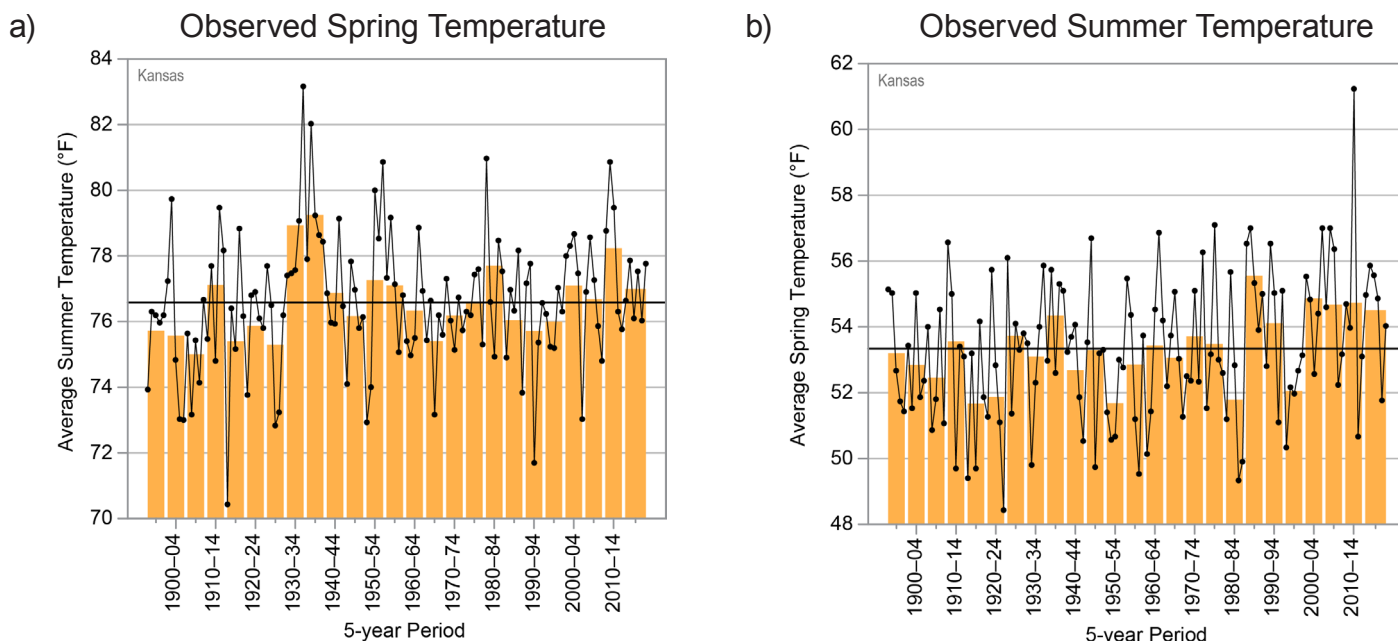


Figure 2: Observed (a) spring (March–May) average temperature and (b) summer (June–August) average temperature for Kansas from 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 53.3°F and (b) 76.6°F. Since 2000, Kansas has experienced some of the highest springtime temperatures on record, while summer temperatures have been near to above average. The warmest summers on record were 1934 and 1936. Sources: CISESS and NOAA NCEI. Data: nClimDiv.

Precipitation is highly variable from year to year, with the majority of precipitation falling during the warm-season months (Figures 3d and 3e). Throughout the period of record (1895–2020), total annual precipitation has ranged from a low of 15.3 inches in 1956 to a high of 40.6 inches in 1951 and has generally been above average since 1985 (Figure 3c). The driest multiyear periods occurred during the 1910s, 1930s, and 1950s and the wettest during the 1940s, 1990s, and since 2015. The driest consecutive 5-year interval was 1952–1956, and the wettest was 2015–2019.

The frequency of extreme precipitation events has been highly variable but shows a general increase; the number of 2-inch precipitation events was well above average during the 2015–2020 period (Figure 5). The increase in extreme precipitation events has been more pronounced in the eastern part of the state. Several major floods have occurred since the beginning of the 20th century. The Great Flood of 1951 extended over about half the state, with both rural and urban areas suffering severe losses, including more than \$2 billion in total damages and 19 fatalities.

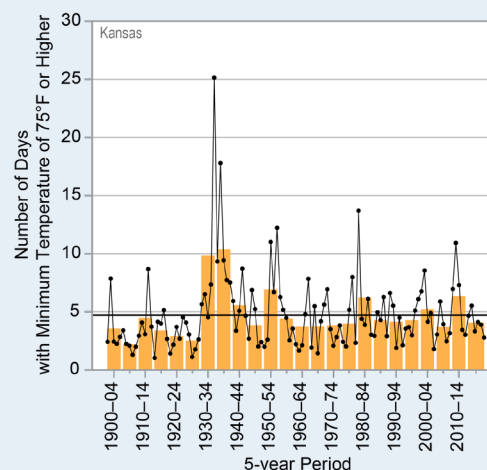
Due to the state’s geography, which allows cold, dry air from the north to combine with warm, moist air from the Gulf of Mexico, severe thunderstorms are common in Kansas. Some of these thunderstorms can produce large hail, high winds, and tornadoes. During 1991–2010, the state experienced an average of just

under 100 tornadoes each year, which occasionally caused major damage and loss of life. The Topeka tornado of June 8, 1966, one of the most destructive in Kansas’s history, killed 17 people, injured more than 500, and caused more than \$200 million in damages (at the time, it was the costliest tornado in U.S. history, and as of 2015, it was the fourth costliest). Since 1950, Kansas has had six F5/EF5 tornadoes, the third most of any state. The most recent EF5 tornado occurred on May 4, 2007, when nearly 95% of Greensburg was completely destroyed and 11 people were killed.

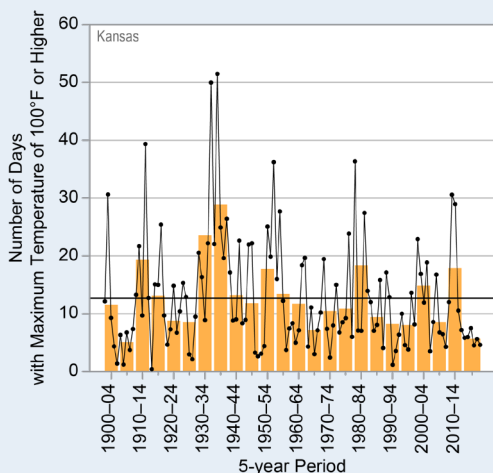
Droughts pose a particular risk to Kansas’s agricultural economy (Figure 6). A multiyear drought impacted the state from late 2010 through late 2015. The peak of the drought occurred in 2012, which was one of the state’s driest years on record. The critical growth months of May–July were the driest on record, with a statewide average of only 4.9 inches of rain. By August, nearly 90% of the state was in extreme or exceptional drought status. The drought, combined with the extreme summer heat, had significant negative impacts on crop yields, livestock production, and pasture conditions. Despite the occurrence of this very intense drought, the late 20th and early 21st centuries generally have been characterized by few droughts, either short-term or long-term.

Figure 3: Observed (a) annual number of very warm nights (minimum temperature of 75°F or higher), (b) annual number of extremely hot days (maximum temperature of 100°F or higher), (c) total annual precipitation, (d) total spring (March–May) precipitation, and (e) total summer (June–August) precipitation for Kansas from (a, b) 1900 to 2020 and (c, d, e) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 4.7 nights, (b) 13 days, (c) 27.3 inches, (d) 8.1 inches, (e) 10.6 inches. The frequency of very warm nights and extremely hot days peaked during the 1930s Dust Bowl era. All precipitation metrics were above average during the 2015–2020 period. Sources: CISESS and NOAA NCEI. Data: (a, b) GHCN-Daily from 32 long-term stations; (c, d, e) nClimDiv.

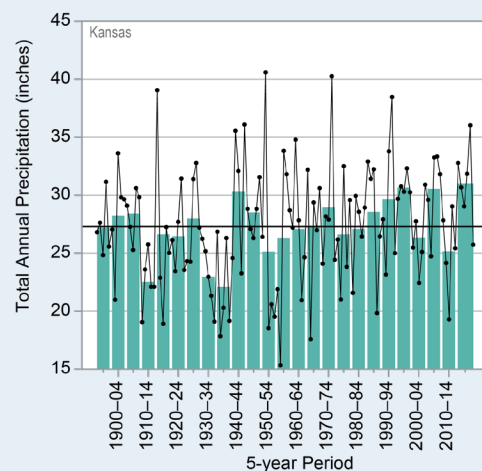
a) Observed Number of Very Warm Nights



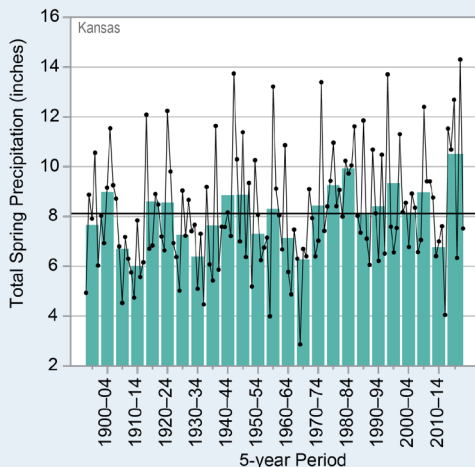
b) Observed Number of Extremely Hot Days



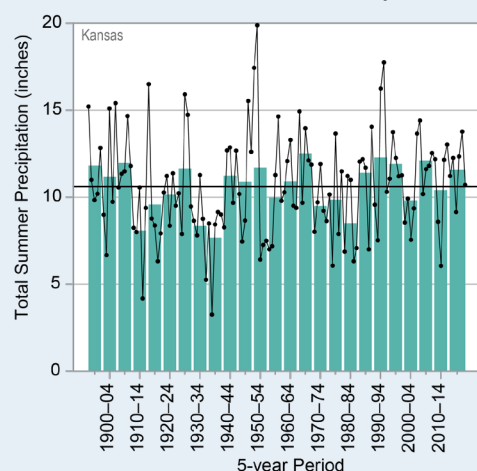
c) Observed Annual Precipitation



d) Observed Spring Precipitation



e) Observed Summer Precipitation



Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, temperatures are projected to most likely exceed record levels by the middle of this century. However, a large range of temperature increases is projected under both pathways,

and under the lower pathway, a few projections are only slightly warmer than historical records. Heat wave intensity is projected to increase, posing a risk to both livestock and human health, while cold wave intensity is projected to decrease. The freeze-free season is projected to lengthen.

Although projections of overall annual precipitation are uncertain, summer precipitation is projected to decrease across the state (Figure 7), while winter precipitation is projected to increase. Winter precipitation increases could benefit winter wheat production, but summer drying would have negative impacts on rain-fed summer crops and rangeland.

The intensity of future droughts is projected to increase. Droughts are a natural part of the climate system. Although projections of overall precipitation are uncertain, higher temperatures will increase the rate of soil moisture loss during dry spells, leading to more serious conditions during future naturally occurring droughts, including an increase in the occurrence and severity of wildfires.

Observed Number of Very Cold Nights

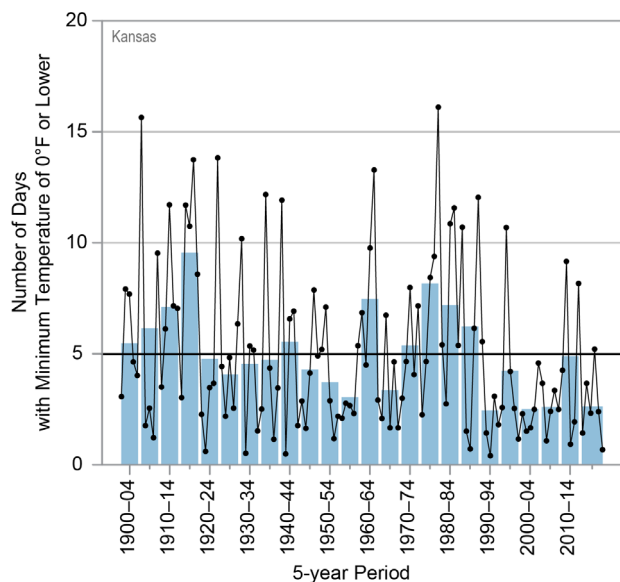


Figure 4: Observed annual number of very cold nights (minimum temperature of 0°F or lower) for Kansas from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 5.0 nights. Since 1990, Kansas has experienced a near to below average number of very cold nights, indicative of overall winter warming in the region. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 32 long-term stations.

Observed Number
of 2-Inch Extreme Precipitation Events

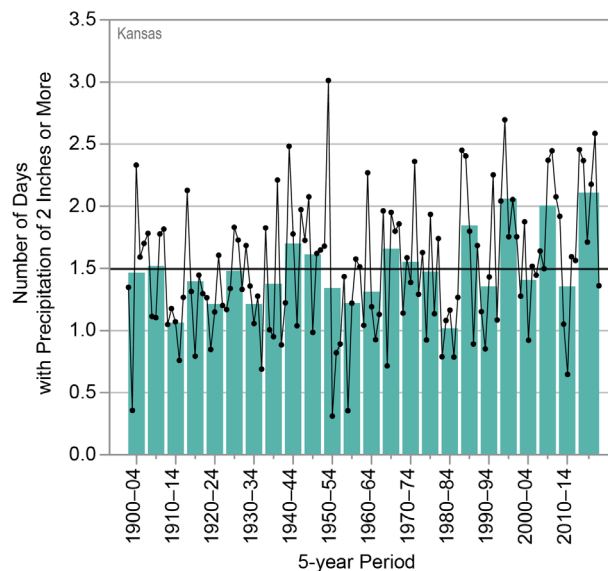


Figure 5: Observed annual number of 2-inch extreme precipitation events (days with precipitation of 2 inches or more) for Kansas from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 1.5 days. A typical reporting station experiences 1 to 2 events per year. The largest number of 2-inch extreme precipitation events occurred during the 2015–2020 period, with an average of 2.1 events per year, followed by the 1995–1999 period, with an average of 2.0 events annually. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 51 long-term stations.

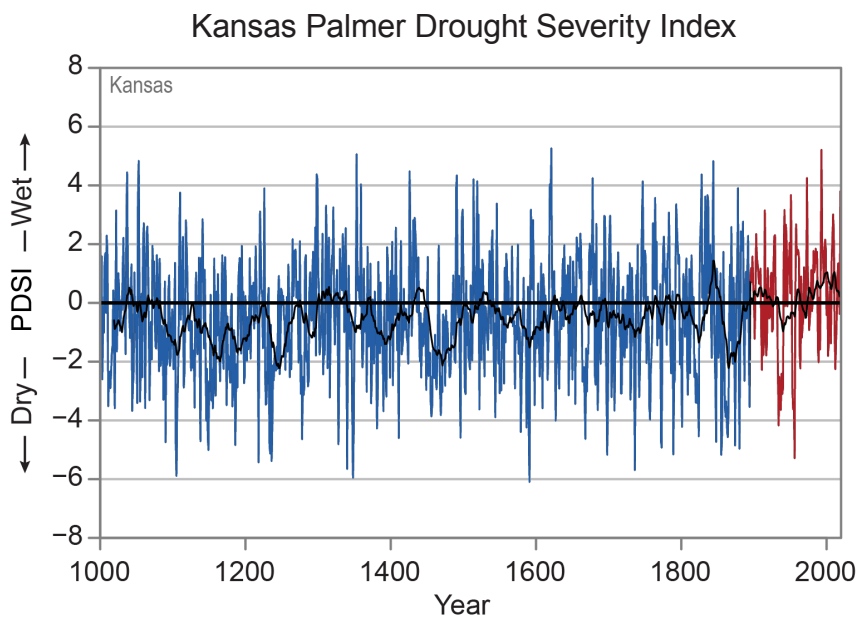


Figure 6: Time series of the Palmer Drought Severity Index for Kansas from the year 1000 to 2020. Values for 1895 to 2020 (red) are based on measured temperature and precipitation. Values prior to 1895 (blue) are estimated from indirect measures such as tree rings. The fluctuating black line is a running 20-year average. In the modern era, the wet periods of the early 1900s and the dry period of the 1930s to 1940s are evident. With the exception of the 2010–2015 drought, Kansas has experienced overall wet conditions since the 1980s. The extended record indicates periodic occurrences of similar extended wet and dry periods. Sources: CISESS and NOAA NCEI. Data: nClimDiv and NADAv2.

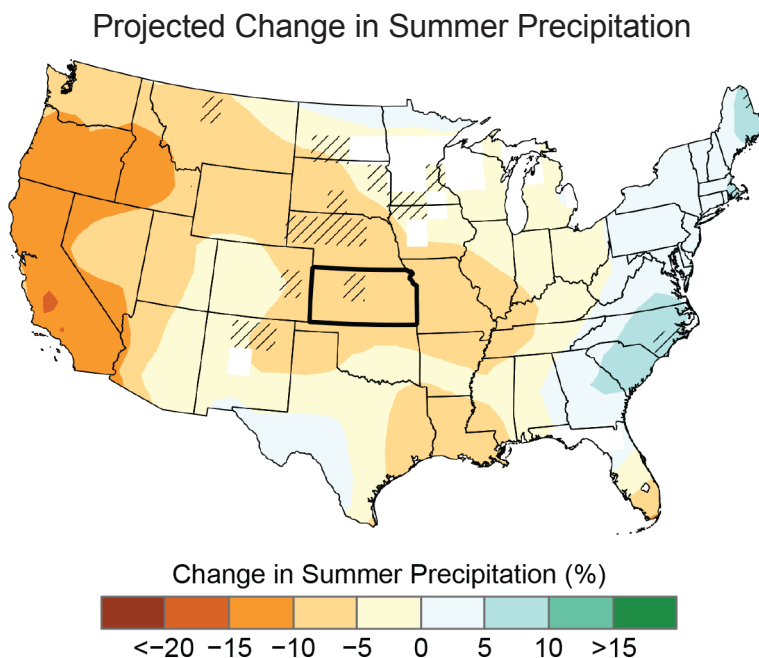


Figure 7: Projected changes in total summer (June–August) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Whited-out areas indicate that the climate models are uncertain about the direction of change. Hatching represents areas where the majority of climate models indicate a statistically significant change. In Kansas, summer precipitation is projected to decrease in the range of 5% to 10% by 2050, although the changes are statistically significant only in the central part of the state. Sources: CISESS and NEMAC. Data: CMIP5.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

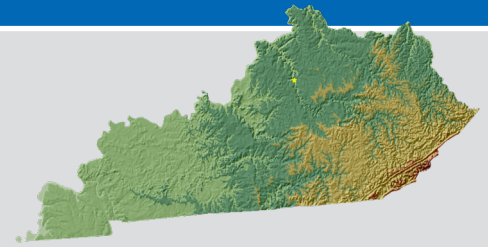
KENTUCKY

Key Messages

Temperatures in Kentucky have risen by 0.6°F, less than half of the warming for the contiguous United States, since the beginning of the 20th century, but the warmest consecutive 5-year interval was 2016–2020. Under a higher emissions pathway, historically unprecedented warming is projected during this century, with associated increases in heat wave intensity and decreases in cold wave intensity.

Total annual precipitation and the number of extreme precipitation events have generally been above average since 2000. Future increases in the frequency and intensity of extreme precipitation events are projected.

Increases in evaporation rates due to rising temperatures may increase the intensity of naturally occurring droughts.



Due to its central location in the eastern half of the United States and the lack of mountain barriers to the interior of the North American continent and south to the Gulf of Mexico, Kentucky's climate is characterized by moderately large variations in temperature and abundant precipitation. Summers vary from warm to hot and humid, while winters are cool with occasional episodes of very cold arctic air. Average (1991–2020 normals) daily high temperatures for July range from 82°F in the east to 91°F in the west, while January highs range from 40°F in the north to 47°F in the south. Temperatures fall below 0°F for more than 3 days per year in the north to less than 1 day in the south. Kentucky's elevation ranges from 400 feet above sea level along the Mississippi River in the west to more than 4,100 feet at the peak of Black Mountain in the southeast, although most of the state is below 1,000 feet. Annual average precipitation ranges from about 38 inches in the northeast to around 58 inches in the southeast. The wettest year on record was 2011, with 64 inches of precipitation, while the driest was 1930, with 29 inches.

Temperatures in Kentucky have risen by 0.6°F, less than half of the warming for the contiguous United States, since the beginning of the 20th century, but the warmest consecutive 5-year interval was 2016–2020 (Figure 1). Very warm temperatures occurred during the 1930s, followed by a substantial cooling of about 2°F in the 1960s. Since then, temperatures have risen about 3°F and have exceeded the highs of the 1930s. The hottest year on record was 1921, but two recent years, 2012 and 1998, rank second and third, respectively. Because of the cooling in the mid-20th century, the southeastern United States is one of the few regions globally that has experienced little to no overall warming since 1900. The contiguous United States as a whole has warmed by about 1.8°F since 1900, although it also cooled from the 1930s into the 1960s but not by nearly as much as Kentucky. Hypothesized causes for this difference in warming rates include increased cloud cover and precipitation, increased small particles from coal burning, natural factors related to forest regrowth, decreased heat flux due to irrigation, and multidecadal variability in North Atlantic and tropical Pacific sea surface temperatures.

Observed and Projected Temperature Change

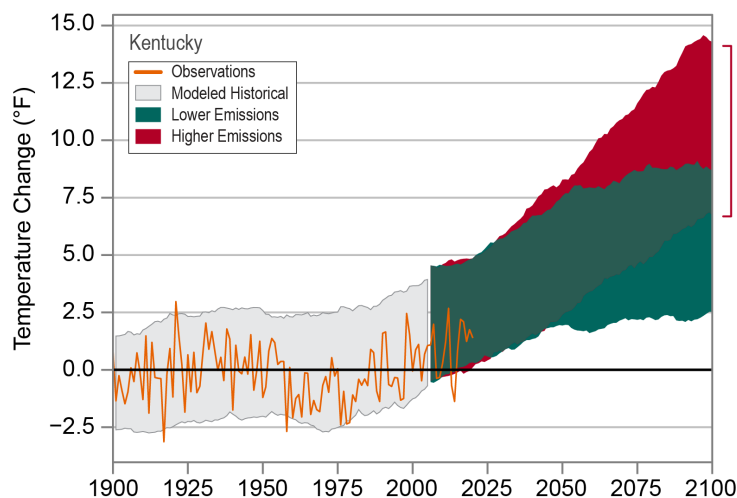
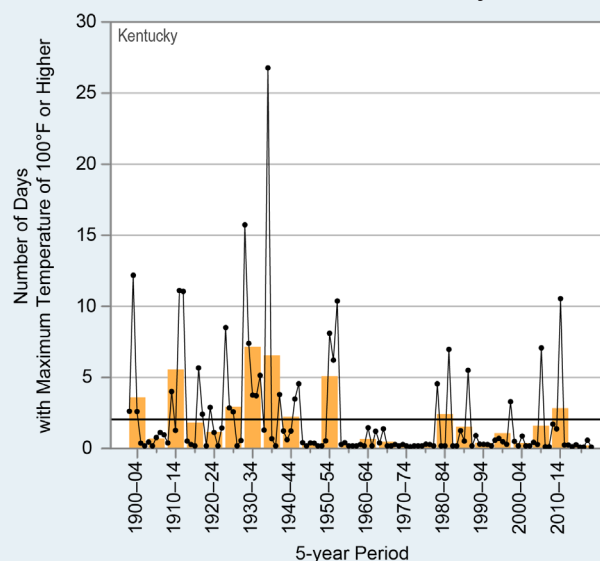


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Kentucky. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Kentucky (orange line) have risen by 0.6°F, less than half of the warming for the contiguous United States, since the beginning of the 20th century, but the warmest consecutive 5-year interval was 2016–2020. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within, but on the lower end of, the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about as warm as the hottest year in the historical record; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 11°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

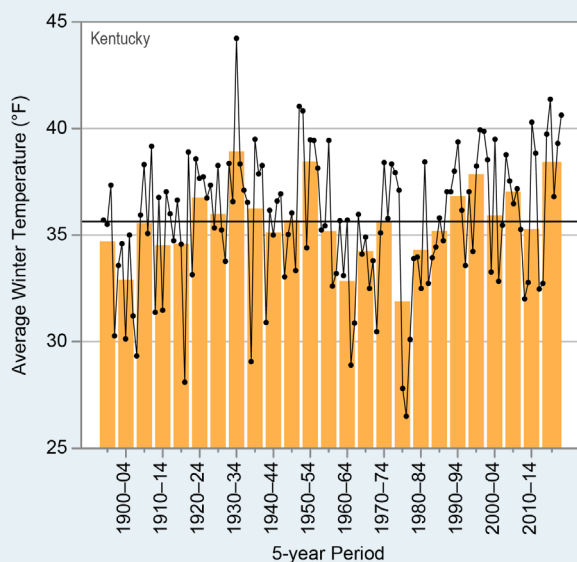
hottest end-of-century projections being about 11°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

Figure 2: Observed (a) annual number of extremely hot days (maximum temperature of 100°F or higher), (b) winter (December–February) average temperature, (c) summer (June–August) average temperature, (d) total annual precipitation, and (e) total summer precipitation for Kentucky from (a) 1900 to 2020 and (b, c, d, e) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 2.1 days, (b) 35.6°F, (c) 74.7°F, (d) 47.7 inches, (e) 12.5 inches. Since 1955, extremely hot days have been rare compared to their occurrence prior to 1955. Winter temperatures have generally been above average since 1990, while summer temperatures have been above average since 2005. Due to extreme drought and poor land management practices, the summers of the 1930s remain the warmest on record. Total annual precipitation shows an overall upward trend. The driest consecutive 5-year interval was 1940–1944, and the wettest was 2015–2019. Summer precipitation was at its highest level during the 2015 to 2020 period. Sources: CISESS and NOAA NCEI. Data: (a) GHCN-Daily from 7 long-term stations; (b, c, d, e) nClimDiv.

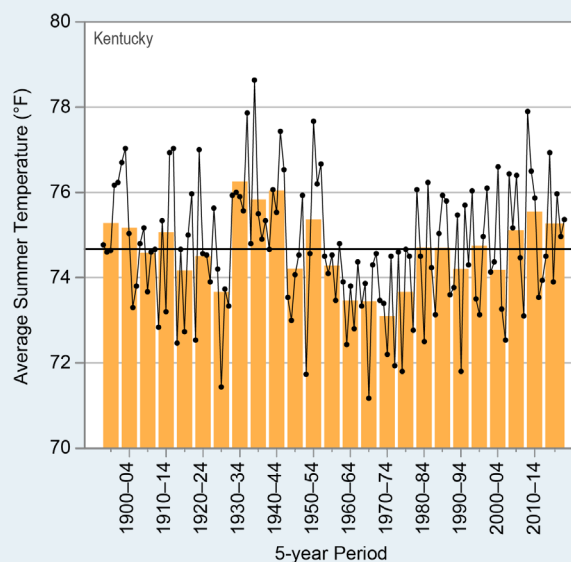
a) Observed Number of Extremely Hot Days



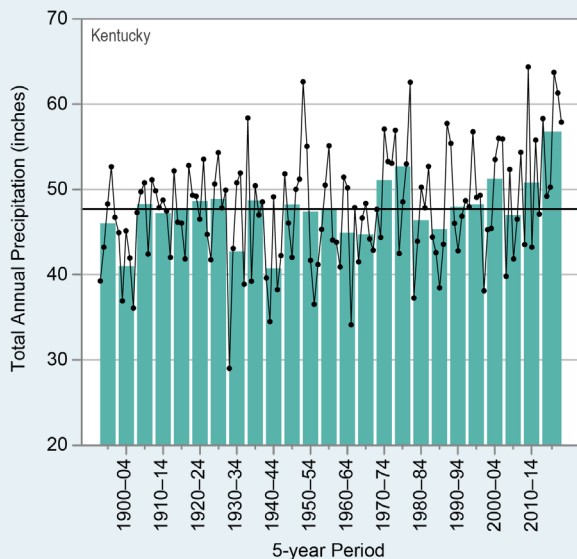
b) Observed Winter Temperature



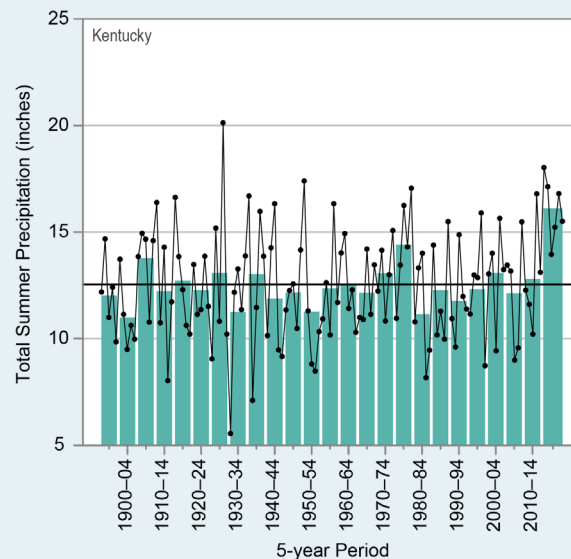
c) Observed Summer Temperature



d) Observed Annual Precipitation



e) Observed Summer Precipitation



The greatest number of extremely hot days occurred in the early 1910s and the Dust Bowl era of the 1930s, with a record high of 27 days in 1936 (Figure 2a). Since 1955, the number of extremely hot days has generally been below average. **The number of extremely cold events has also been below average in recent winters.** The top 10 coldest winters all occurred prior to 1980. Also, since 1990, the number of very cold nights has been below average (Figure 3), and winter average temperatures have generally been near to above average (Figure 2b). For the 2015–2020 period, multiyear averages for both the number of very warm nights (Figure 4) and summer average temperature (Figure 2c) were above average but not as high as the multiyear averages for the 1930s.

Total annual precipitation in Kentucky exhibits an overall upward trend (Figure 2d) and has averaged 7.4 inches above the long-term (1895–2020) average since 2011. The annual number of 2-inch extreme precipitation events has been highly variable (Figure 5). The two highest multiyear averages of more than 3 days occurred during the 1975–1979 and 2010–2014 periods. Summer precipitation was well above average during the 2015–2020 period (Figure 2e). Deficient precipitation coupled with hot temperatures during the summer months can result in drought. During the summer of 2012, extreme drought conditions in western Kentucky were exacerbated by a heat wave in late June and early July, when high temperatures rivaled those experienced in the 1930s.

Extreme weather events in Kentucky include ice and snowstorms in the winter and severe thunderstorms in the warmer months. Heavy rain from severe thunderstorms can often lead to flash flooding in low-lying areas and in urban areas where the prevalence of impermeable surfaces (such as roads, roofs, and parking lots) accelerates storm runoff to ditches and streams. High winds, hail, and tornadoes are also associated with severe thunderstorms. From 2010 to 2020, the Federal Emergency Management Agency granted 19 disaster declarations, mostly for severe storms, tornadoes, and flooding. **Kentucky experiences a relatively high number of tornadoes each year**, with an annual average of about 24 tornadoes between 1991 and 2019. On March 2, 2012, eighteen tornadoes touched down in Kentucky, including one of EF4 and four of EF3 intensity, resulting in 22 fatalities. In April 2011, 41 tornadoes were reported, superseding an earlier April record of 29 tornadoes during the Super Outbreak of 1974. The December 10–11, 2021, tornado outbreak is one of the deadliest in Kentucky history, resulting in 76 fatalities. Twenty tornadoes touched down, including one of EF4 and three of EF3 intensity. The EF4 tornado path extended from near Woodland Mills, TN (just across the border from Fulton County, KY), to Breckinridge County (near Falls of Rough, KY), a distance of 165.7 miles. The maximum estimated wind speed was 190 mph.

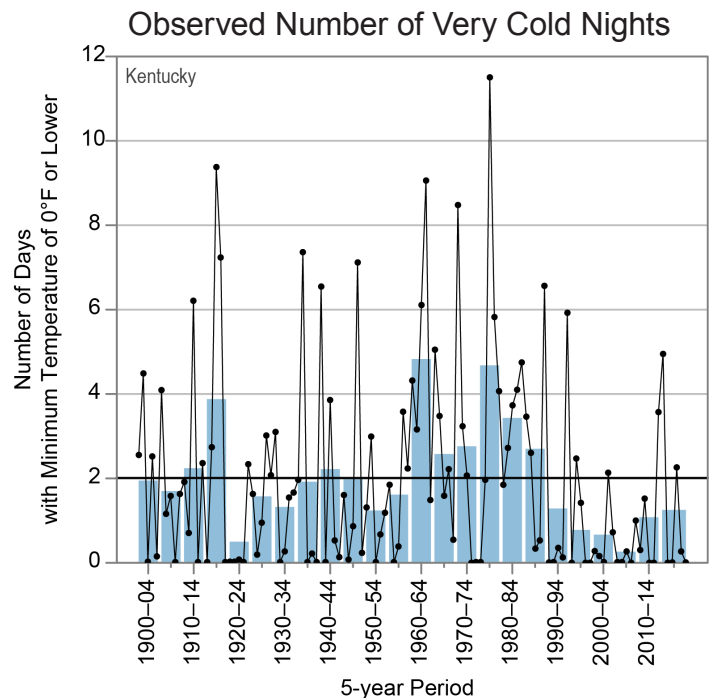


Figure 3: Observed annual number of very cold nights (minimum temperature of 0°F or lower) for Kentucky from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 2.0 nights. The number of very cold nights has been below average since 1990. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 7 long-term stations.

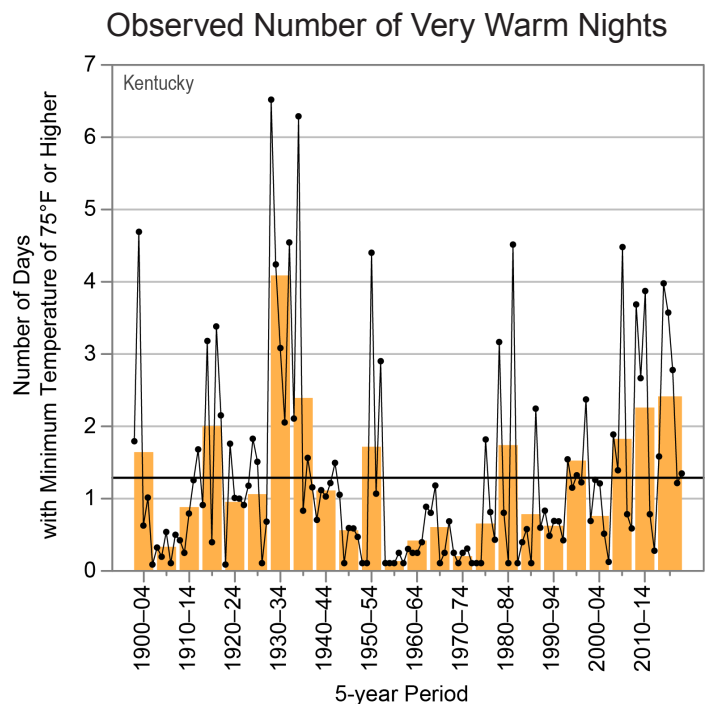


Figure 4: Observed annual number of very warm nights (minimum temperature of 75°F or higher) for Kentucky from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 1.3 nights. The number of very warm nights has been steadily increasing since 2000 but has not exceeded the values of the early 1930s. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 7 long-term stations.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, temperatures are projected to most likely exceed historical record levels by the middle of the century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records—if observed temperatures continue to follow the lower end of model projections. Heat waves are projected to be more intense in the future, posing increased risks of heat-related illness and deaths, especially for urban residents. Cold waves are projected to be less intense.

Increases in precipitation are projected for Kentucky, most likely during the winter and spring (Figure 6). Changes in summer and fall precipitation are uncertain, however. Continuing increases in the frequency and intensity of extreme precipitation events are also projected, potentially increasing the frequency and intensity of floods. At the same time, the intensity of future droughts is projected to increase because of increases in evaporation rates due to rising temperatures in combination with naturally occurring periods of below average rainfall. These potential increases in the intensity of both floods and droughts will have implications for important sectors of the state's economy, including agriculture, industry, tourism, and natural resource management.

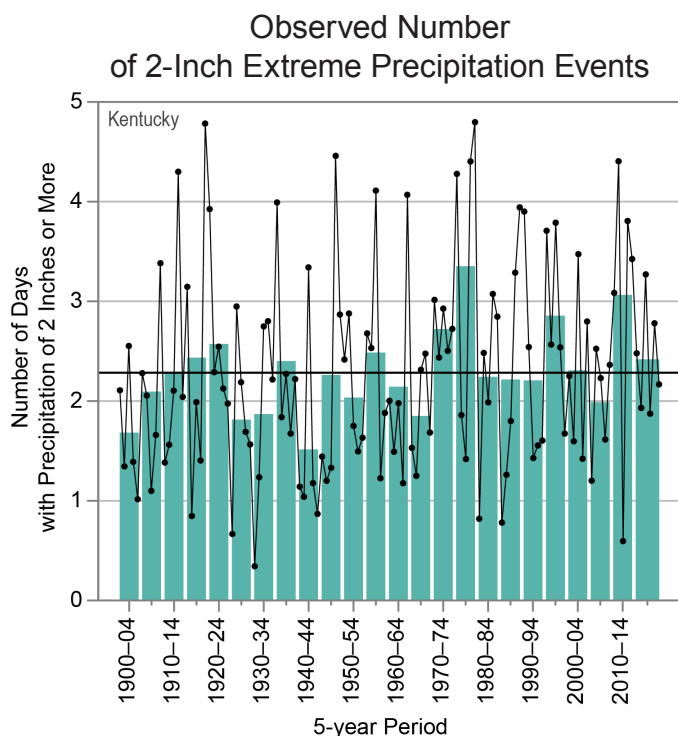


Figure 5: Observed annual number of 2-inch extreme precipitation events (days with precipitation of 2 inches or more) for Kentucky from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 2.3 days. A typical station experiences about 2 events per year. The number of 2-inch extreme precipitation events was mostly below average between 1900 and 1969 but mostly near or above average since then. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 7 long-term stations.

Projected Change in Spring Precipitation

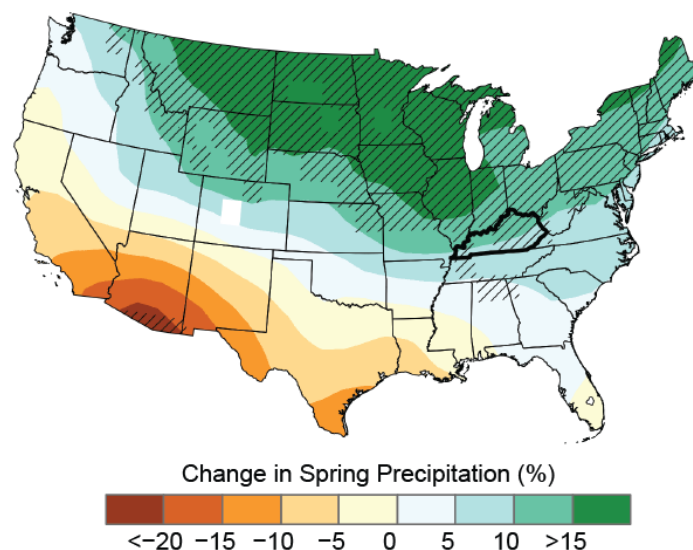


Figure 6: Projected changes in total spring (March–May) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. The white-out area indicates that the climate models are uncertain about the direction of change. Hatching represents areas where the majority of climate models indicate a statistically significant change. Kentucky is part of a large area of projected increases in the Northeast and Midwest. Sources: CICESS and NEMAC. Data: CMIP5.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

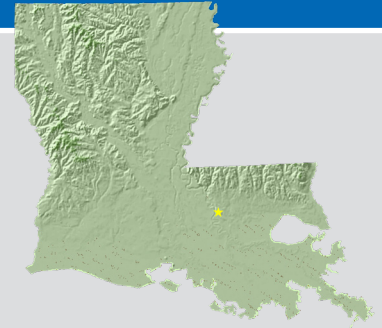
LOUISIANA

Key Messages

Temperatures in Louisiana have risen by 0.5°F since the beginning of the 20th century, less than a third of the warming for the contiguous United States, but the warmest consecutive 5-year interval was the most recent, 2016–2020. Historically unprecedented warming is projected during this century.

Hurricanes strike Louisiana an average of once every three years. As the climate continues to warm, hurricane-associated rainfall rates are projected to increase, and the resulting flooding is a particular concern for the state.

Global sea level is projected to rise, with a likely range of 1–4 feet by 2100. Louisiana's coastline is extremely vulnerable to sea level rise due to coastal subsidence, wetland loss, and low elevation in the southern portion of the state. Projected sea level rise poses widespread and continuing threats to coastal communities.



Louisiana is located between the Gulf of Mexico and the southern end of the vast, relatively flat plains of central North America, which extend from the Arctic Circle to the Gulf of Mexico. The state is therefore exposed to the influences of diverse air masses, including the warm, moist air over the Gulf of Mexico and the drier continental air masses, which are cold in the winter and warm in the summer. Additionally, clockwise circulation of air around a semipermanent high-pressure system in the North Atlantic (known as the Bermuda High) causes a persistent southerly flow of air off the gulf during the warmer half of the year. **Louisiana's climate is characterized by relatively short and mild winters, hot summers, and year-round precipitation.** The Gulf of Mexico helps moderate the climate in the southern portion of the state, while temperatures and precipitation are more variable in the north. Extreme temperatures range from a record high of 114°F at Plain Dealing (August 10, 1936) to a record low of –16°F at Minden (February 13, 1899).

Temperatures in Louisiana have risen by 0.5°F since the beginning of the 20th century, less than a third of the warming for the contiguous United States, but the warmest consecutive 5-year interval was the most recent, 2016–2020 (Figure 1). Temperatures during the 20th century were highest in the first half of the century, followed

Observed and Projected Temperature Change

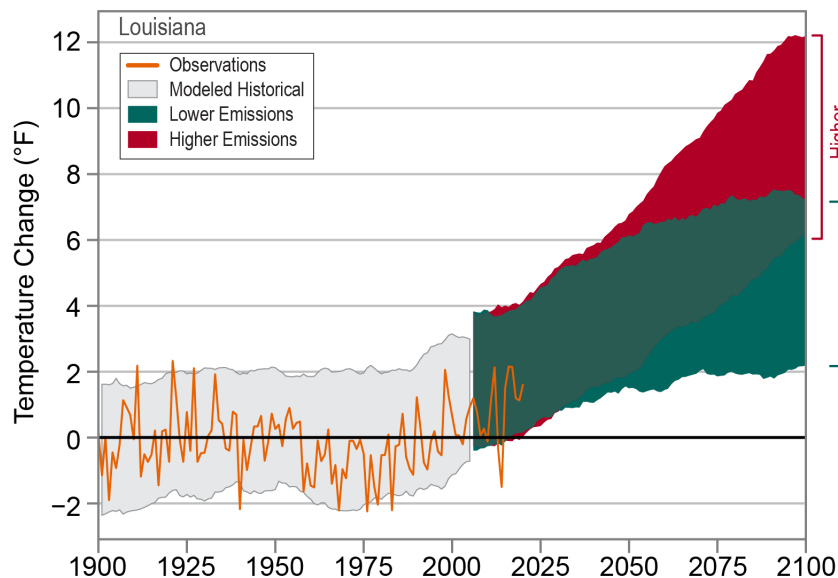
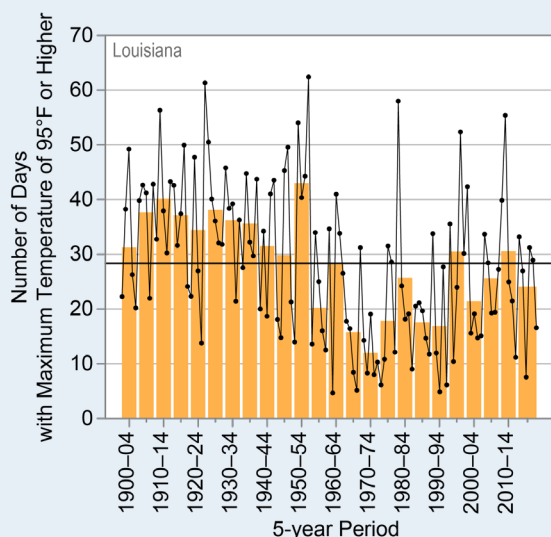


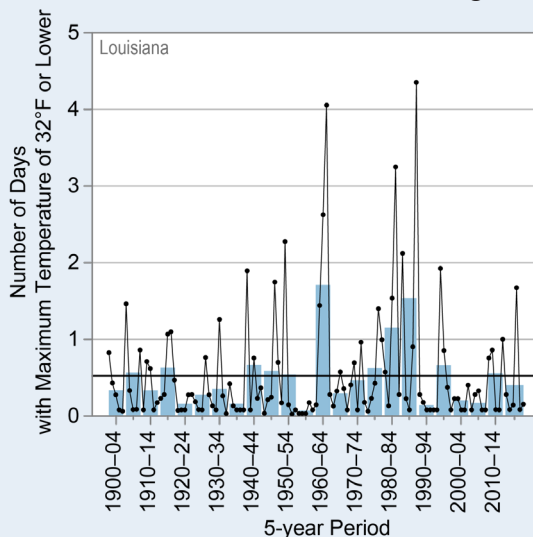
Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Louisiana. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Louisiana (orange line) have risen by 0.5°F since the beginning of the 20th century, less than a third of the warming for the contiguous United States, but the warmest consecutive 5-year interval was the most recent, 2016–2020. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projected years being about as warm as the hottest year in the historical record; green shading) and more warming under a higher emissions future (the hottest end-of-century projected years being about 10°F warmer than the hottest year in the historical record; red shading). Sources: CISS and NOAA NCEI.

projected years being about as warm as the hottest year in the historical record; green shading) and more warming under a higher emissions future (the hottest end-of-century projected years being about 10°F warmer than the hottest year in the historical record; red shading). Sources: CISS and NOAA NCEI.

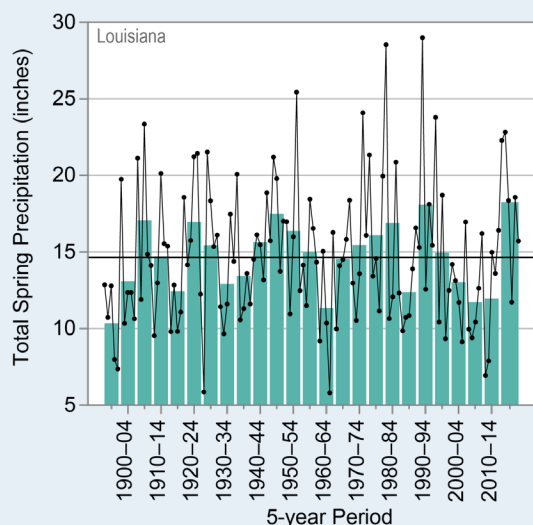
a) Observed Number of Very Hot Days



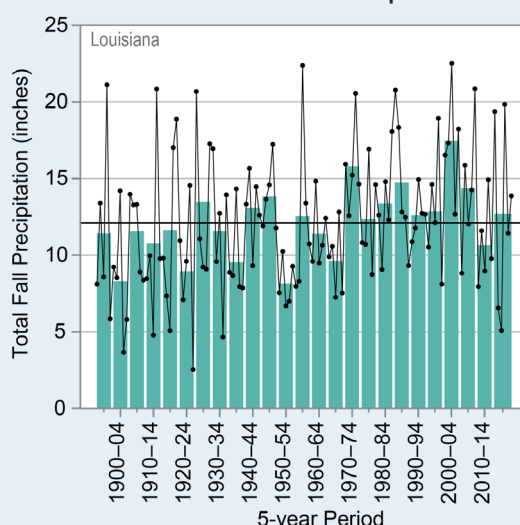
b) Observed Number of Freezing Days



c) Observed Spring Precipitation



d) Observed Fall Precipitation



e) Observed Number of 4-Inch Extreme Precipitation Events

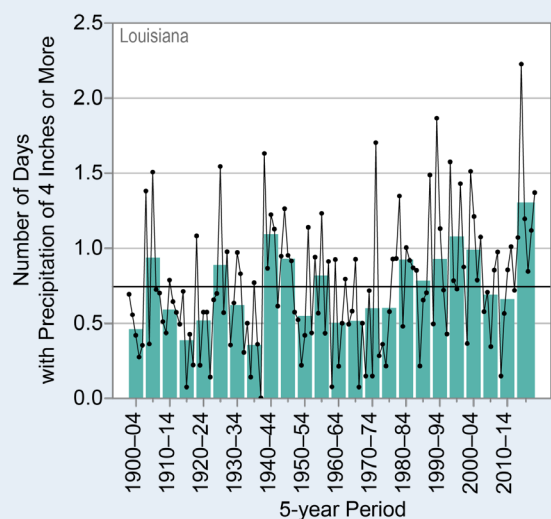


Figure 2: Observed (a) annual number of very hot days (maximum temperature of 95°F or higher), (b) annual number of freezing days (maximum temperature of 32°F or lower), (c) total spring (March–May) precipitation, (d) total fall (September–November) precipitation, and (e) annual number of 4-inch extreme precipitation events (days with precipitation of 4 inches or more) for Louisiana from (a, b, e) 1900 to 2020 and (c, d) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 28 days, (b) 0.5 days, (c) 14.7 inches, (d) 12.1 inches, (e) 0.7 days. Since 1965, the number of very hot days has generally been below average. The number of freezing days has generally been below average since 1990. Seasonal precipitation is highly variable from year to year and between seasons. Spring precipitation shows no long-term trend, while fall precipitation has been mostly near or above average since 1970. The number of 4-inch extreme precipitation events has been generally above average since 1980 and was well above average during the 2015–2020 period; a typical reporting station experiences an event every one to two years. Sources: CISESS and NOAA NCEI. Data: (a, b) GHCN-Daily from 10 long-term stations; (c, d) nClimDiv; (e) GHCN-Daily from 12 long-term stations.

by a substantial cooling of almost 2°F from the 1950s to the 1970s. Temperatures have risen since that cool period by more than 2°F, such that the first 21 years of this century have been about as warm as or warmer than early 20th-century levels, with 17 of the 21 years since 2000 being above average. Because of the cooling in the mid-20th century, the southeastern United States is one of the few locations globally that has experienced little to no warming since 1900. The contiguous United States as a whole has warmed by about 1.8°F since 1900, although it also cooled from the 1930s into the 1960s but not by nearly as much as Louisiana. Hypothesized causes for this difference in warming rates include increased cloud cover and precipitation, increased small particles from coal burning, natural factors related to forest regrowth, decreased heat flux due to irrigation, and multidecadal variability in North Atlantic and tropical Pacific sea surface temperatures.

In Louisiana, the number of very hot days was above average in the early 20th century but was well below average during the late 1960s and 1970s. Since 1995, the number of very hot days has begun to increase but has generally remained below average (Figure 2a). By contrast, the number of very warm nights has increased steadily since 2000, reaching a record-high level during the 2015–2020 period (Figure 3). The number of freezing days showed wide variability over the 20th century but has generally been below average since 1990 (Figure 2b). While the recent trend is toward fewer extremely cold events, a historic cold wave affected the state during February 11–20, 2021. In the northwest, temperatures remained below freezing for 5 consecutive days and fell into the 0°–10°F range. Severe icing caused widespread damage.

Louisiana receives abundant precipitation throughout the year. Annual precipitation ranges from around 50 inches in the north to around 70 inches at some locations in the southeast. Statewide annual precipitation has ranged from a low of 36.6 inches in 1924 to a high of 79.5 inches in 1991. The driest multiyear periods occurred in the early 1900s and late 1930s and the wettest in the early 1990s and late 2010s (Figure 4). The driest consecutive 5-year interval was 1914–1918, with an annual average of 49.2 inches, and the wettest was 1989–1993, with an annual average of 65.6 inches. Total annual precipitation has generally been above average since 1970. While 2010 and 2011

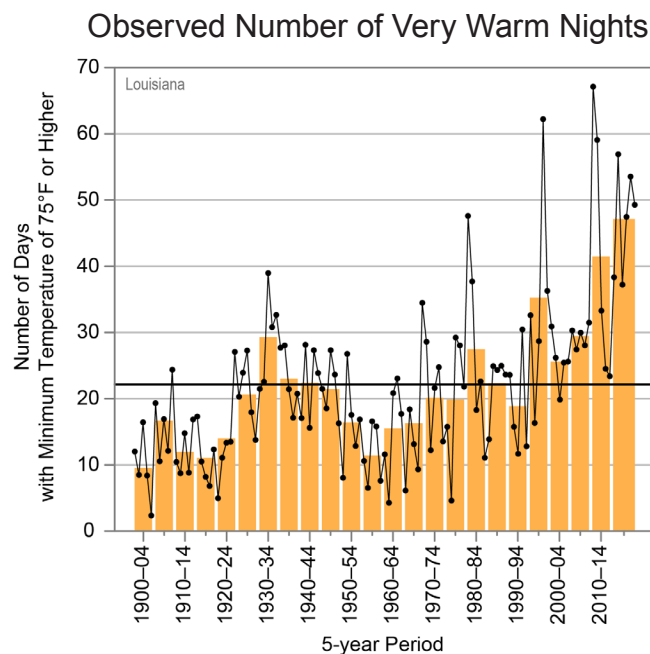


Figure 3: Observed annual number of very warm nights (minimum temperature of 75°F or higher) for Louisiana from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 22 nights. The number of very warm nights has increased steadily since 2000. The multiyear average for the 2015–2020 period is more than double the long-term average. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 10 long-term stations.

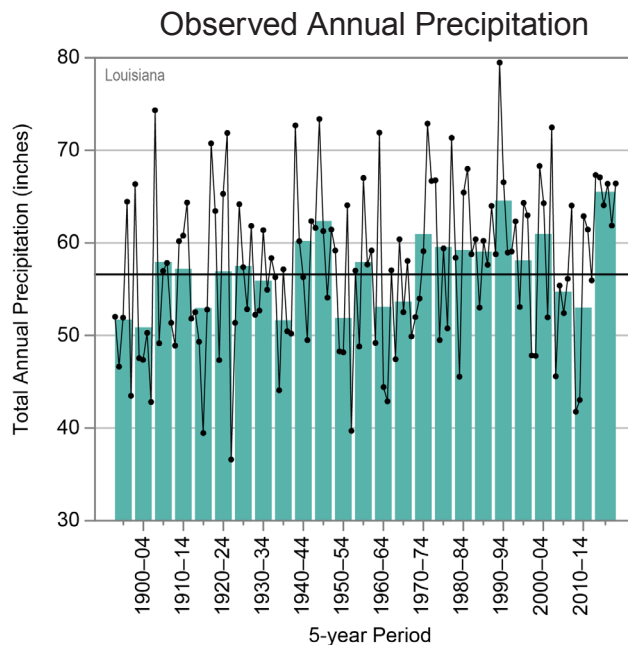


Figure 4: Observed total annual precipitation for Louisiana from 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 57.2 inches. Louisiana receives abundant precipitation throughout the year. The most recent 6-year period (2015–2020) was wetter than average. Sources: CISESS and NOAA NCEI. Data: nClimDiv.

were very dry, 8 of the 9 years since then have been above average. Spring and fall precipitation has been highly variable, with very wet springs in 1991 and 2016 interspersed by very dry springs in 2010 and 2011 and very wet falls in 2009 and 2018 interspersed by very dry falls in 2016 and 2017 (Figures 2c and 2d). The number of 4-inch extreme precipitation events has generally been above average since 1980, reaching a record high during the 2015–2020 period (Figure 2e). After Florida, Louisiana has, on average, the second-highest annual number of thunderstorms in the contiguous United States, with a typical location in the state averaging more than 60 thunderstorms per year. Severe thunderstorms capable of producing tornadoes occur throughout the year but less frequently in the summer months. Snowfall is rare near the Gulf of Mexico but can occur occasionally in the northern part of the state during incursions of polar air masses.

The Louisiana coast is particularly vulnerable to severe flooding from a direct hurricane strike, which occurs about once every three years (Figure 5). In August 2005, Hurricane Katrina (a Category 3 storm at landfall) caused massive damage from storm surge flooding in the eastern part of the state. New Orleans was particularly hard hit, with more than 80% of the city flooded and some areas under as much as 15 feet of water. Hurricane Katrina caused more than 1,500 fatalities in the state and immense property damage. Three hurricanes made landfall in Louisiana in 2020, the strongest being Hurricane Laura (Category 4). Laura was the strongest hurricane making landfall in Louisiana since 1856, with wind speeds of 150 mph and a 15-foot storm surge, causing massive property damage in southwestern Louisiana. The average return period (estimated average time between events) of a 10-foot storm surge is 25 to 50 years along the southwestern coast of Louisiana (Figure 6, top panel). Along the southeastern coast, the geography relative to the general path of tropical cyclones through the central Gulf of Mexico causes a funneling effect of water, leading to greater surge heights, with a 10-foot storm surge having a 10- to 25-year return period (Figure 6, bottom panel).

Flooding is also a hazard, particularly for regions along the Mississippi River. In May 2011, one of the worst floods in Louisiana history affected the Lower Mississippi valley. To control the massive flooding,

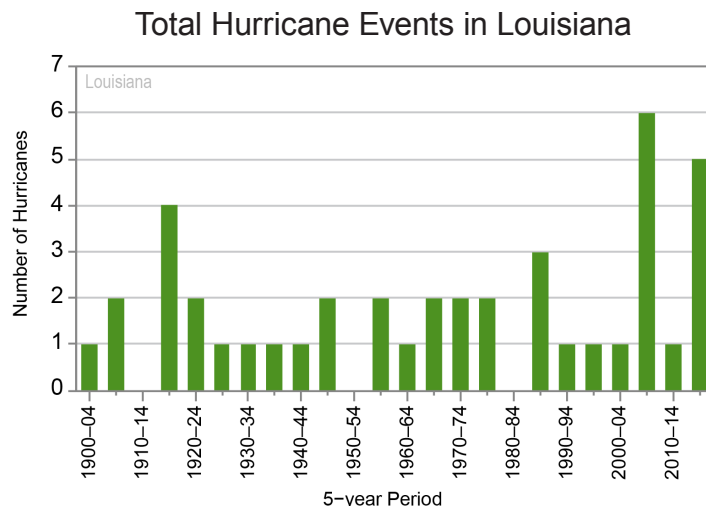


Figure 5: Total number of hurricane events (wind speeds reaching hurricane strength somewhere in the state) for Louisiana from 1900 to 2020. Bars show 5-year totals (last bar is a 6-year total). On average, Louisiana is struck by a hurricane about once every three years. From 2005 to 2009, Louisiana was struck by 6 hurricanes, the largest number during a 5-year period since the beginning of the 20th century. Source: NOAA Hurricane Research Division.

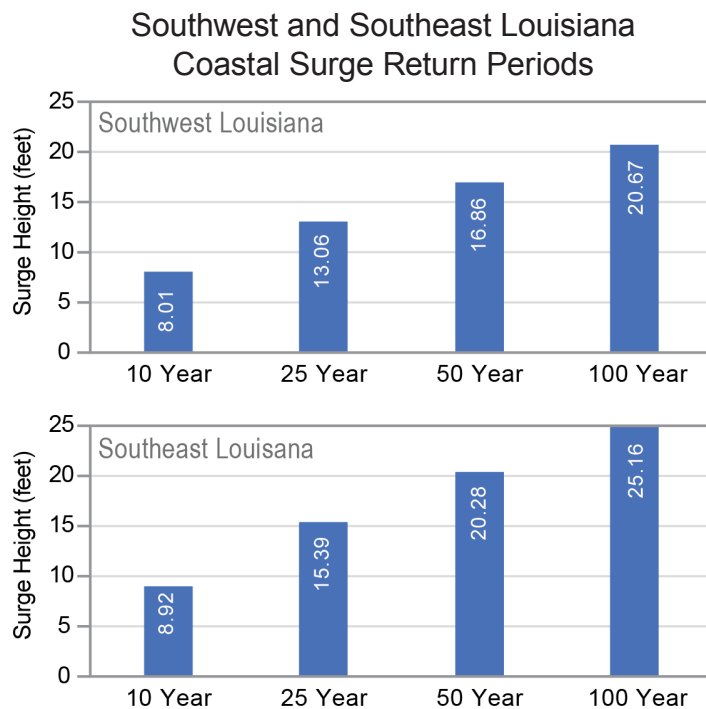


Figure 6: Storm surge heights occurring at selected average return intervals (10, 25, 50, and 100 years) along the Louisiana southwestern (top) and southeastern (bottom) coasts. Sources: CISESS and NOAA NCEI. Data: Needham et al. 2012.

the Morganza Spillway was opened for only the second time (the first was in 1973) to protect levees and prevent flooding downstream in Baton Rouge and New Orleans. Yet despite the massive floodwaters, southern Louisiana was experiencing an extreme drought at the

same time. Both the flood and drought were tied to La Niña conditions in the equatorial Pacific Ocean, which caused storm tracks to shift to the north across the Ohio River valley, bypassing Louisiana and producing drought conditions. At the same time, the storm tracks caused the excessive rainfall in the Midwest that then produced the flood wave, which moved downstream along the Mississippi River into the drought-stricken area. Most recently, in August 2016, a historic flooding event produced 20 to more than 30 inches of rainfall over several days and exceeded 500-year flood amounts in some locations. More than 30,000 people were rescued from floodwaters that damaged or destroyed more than 50,000 homes, 100,000 vehicles, and 20,000 businesses. With damages estimated at \$10 billion dollars, this was one of the most costly U.S. flood events in history.

Despite the lack of a distinct dry season, Louisiana is vulnerable to drought. Since the creation of the United States Drought Monitor map in 2000, Louisiana has been

completely drought-free for approximately 47% of the time (2000–2020), and at least half of the state has been in drought conditions approximately 17% of that time.

Historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to exceed historical record levels in most years by the middle of the century. Since the 1970s, Louisiana temperatures have generally been within the range, but on the low end, of model-simulated temperatures. Under a lower emissions pathway, a continuation of the post-1980 warming trend would lead to an additional warming of about 1.5°F by 2050 and 3°F by 2100. In this case, the future warming would be on the low end of the model-simulated increases. However, a higher emissions pathway would potentially lead to considerably larger temperature increases. Any overall warming will lead to increasing heat wave intensity but decreasing cold wave intensity.

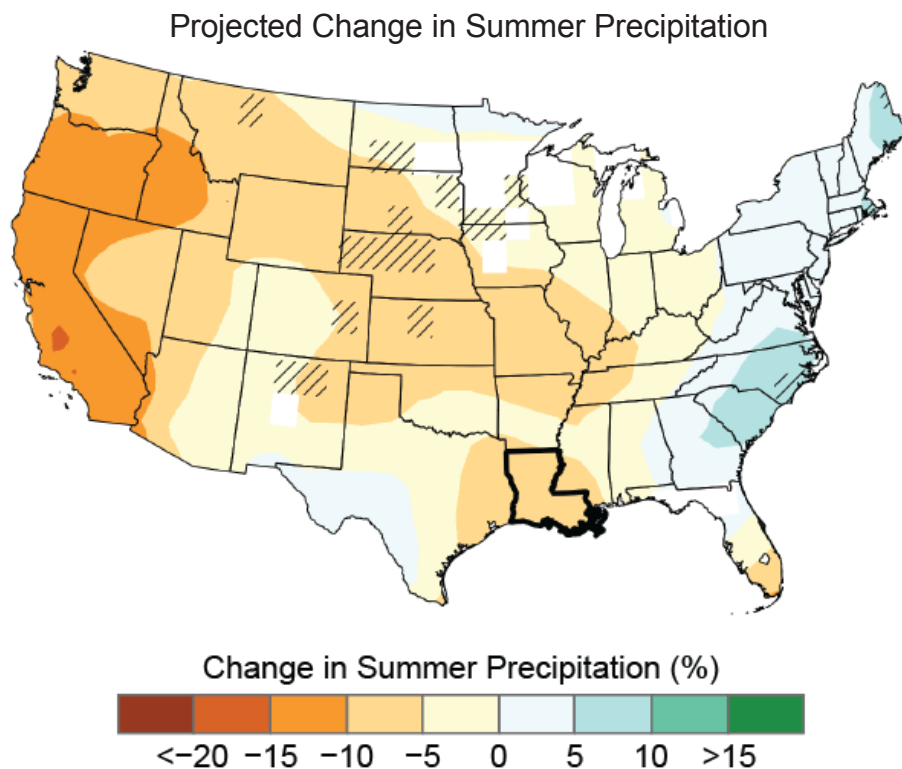


Figure 7: Projected changes in total summer (June–August) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Whited-out areas indicate that the climate models are uncertain about the direction of change. Hatching represents areas where the majority of climate models indicate a statistically significant change. Summer precipitation is projected to decrease throughout Louisiana; however, these changes are small relative to the natural variability in this region. Sources: CISESS and NEMAC. Data: CMIP5.

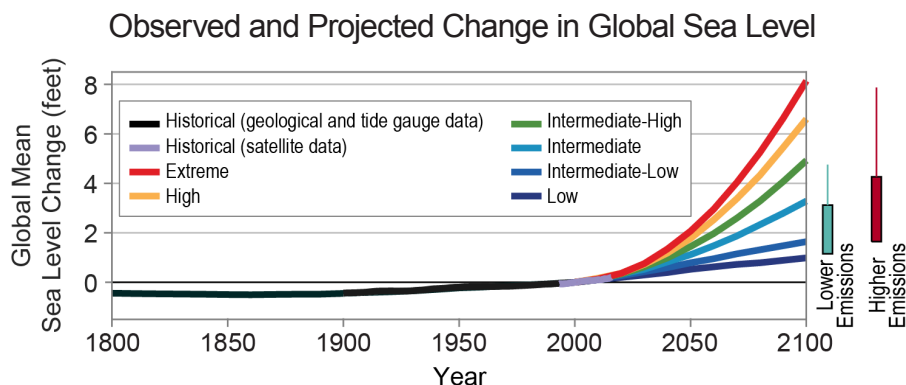


Figure 8: Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate–Low, royal blue; Intermediate, cyan; Intermediate High, green; High, orange; and Extreme, red curves) relative to historical geological, tide gauge, and satellite altimeter GMSL reconstructions from 1800–2015 (black and magenta lines) and the very likely ranges in 2100 under both lower and higher emissions futures (teal and dark red boxes). Global sea level rise projections range from 1 to 8 feet by 2100, with a likely range of 1 to 4 feet. Source: Adapted from Sweet et al. 2017.

Summer precipitation is projected to decrease in Louisiana, although the projected decreases are smaller than natural variations (Figure 7).

Even if average precipitation remains the same, higher temperatures will increase the rate of soil moisture loss during dry spells, which could increase the intensity of naturally occurring droughts.

Increasing global temperatures raise concerns for sea level rise in coastal areas. Since 1900, global average sea level has risen by about 7–8 inches. It is projected to rise another 1–8 feet, with a likely range of 1–4 feet, by 2100 as a result of both past and future emissions from human activities (Figure 8). Sea level rise has caused an increase in tidal floods associated with nuisance-level impacts. Nuisance floods are events in which water levels exceed the local threshold (set by NOAA’s National Weather Service) for minor impacts. These events can damage infrastructure, cause road closures, and overwhelm storm drains. Nuisance

flooding has increased in all U.S. coastal areas, with more rapid increases along the East and Gulf Coasts. Nuisance flooding events in Louisiana are likely to occur more frequently as global and local sea levels continue to rise. **Much of Louisiana is at extreme risk for sea level rise due to its low elevation, which averages only 3 feet in the southeastern part of the state.** Additionally, the coastline is rapidly sinking due to subsidence (settling of the soil over time), which has already caused the state to lose almost 2,000 square miles of land since the 1930s. Due to subsidence, relative sea level rise at some locations is more than 4 times the global rate. The New Orleans metropolitan area, the most populous in the state, is at particular risk for sea level rise impacts. Sea level rise will present major challenges to Louisiana’s existing coastal water management system and could cause extensive economic damage through ecosystem degradation and losses in property, tourism, and agriculture.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

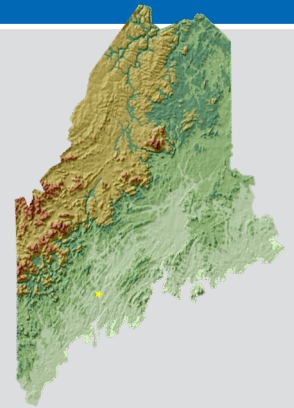
MAINE

Key Messages

Temperatures in Maine have risen almost 3.5°F since the beginning of the 20th century. Winter temperatures have been increasing about twice as fast as summer temperatures. Under a higher emissions pathway, historically unprecedented warming is projected during this century.

Precipitation since 2005 has averaged 6.6 inches more than during 1895–2004. The number of extreme precipitation events has been near to well above average since 2005 and is projected to increase during this century.

Global sea level is projected to rise, with a likely range of 1–4 feet by 2100. Sea level at Portland has risen by about 7.4 inches since 1912 and is projected to rise another 1–4 feet by 2100.



Maine is located on the eastern margin of the North American continent. Its northerly latitude and geographic location expose the state to both the moderating and moistening influence of the Atlantic Ocean and the effects of hot and cold air masses from the interior of the continent. Maine is also located within the primary storm track of the mid-latitudes. **Maine's climate is characterized by cold, snowy winters and mild summers.** Winter average temperatures range from 25°F in the far south to less than 15°F in the northern and interior portions of the state. Summer average temperatures range from near 60°F in the far north to near 70°F in the south. Maine is approximately 90% forested and has more than 3,500 miles of coastline, making forestry, fishery, hunting and fishing, tourism, and ecosystem services all sensitive to a changing climate.

Temperatures in Maine have risen almost 3.5°F since the beginning of the 20th century (Figure 1). Since the mid-1990s, the amount of winter warming (Figure 2a) has been approximately twice that of summer warming (Figure 2b), with persistently above average temperatures occurring since the 1990s. Winter warming is reflected in the number of very cold nights, which has been below average since the late 1990s (Figure 3). However, the number of hot days has not increased (Figure 2c). Winter warming has resulted in earlier lake ice-out dates. On Damariscotta Lake, the average ice-out date during the mid-20th century was mid- to late April; it is now early April. The growing season has also lengthened.

Observed and Projected Temperature Change

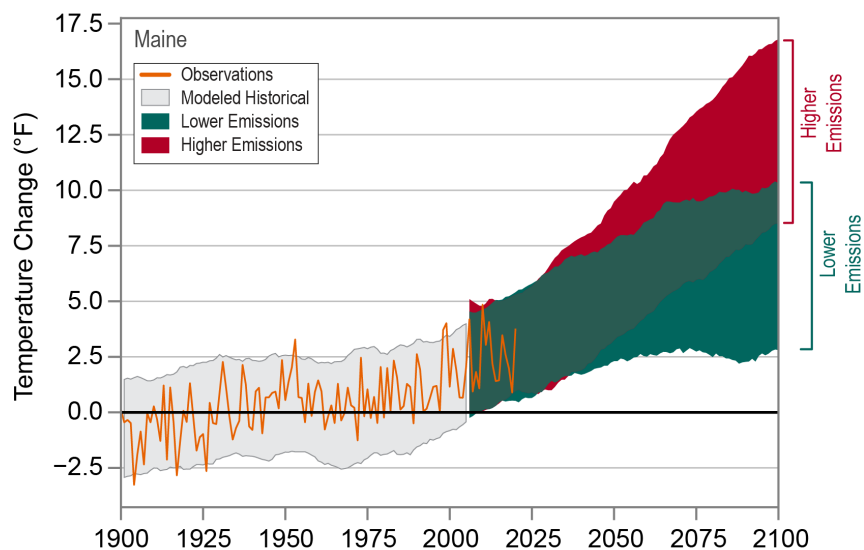


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Maine. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Maine (orange line) have risen almost 3.5°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-year projections being about 2°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 12°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

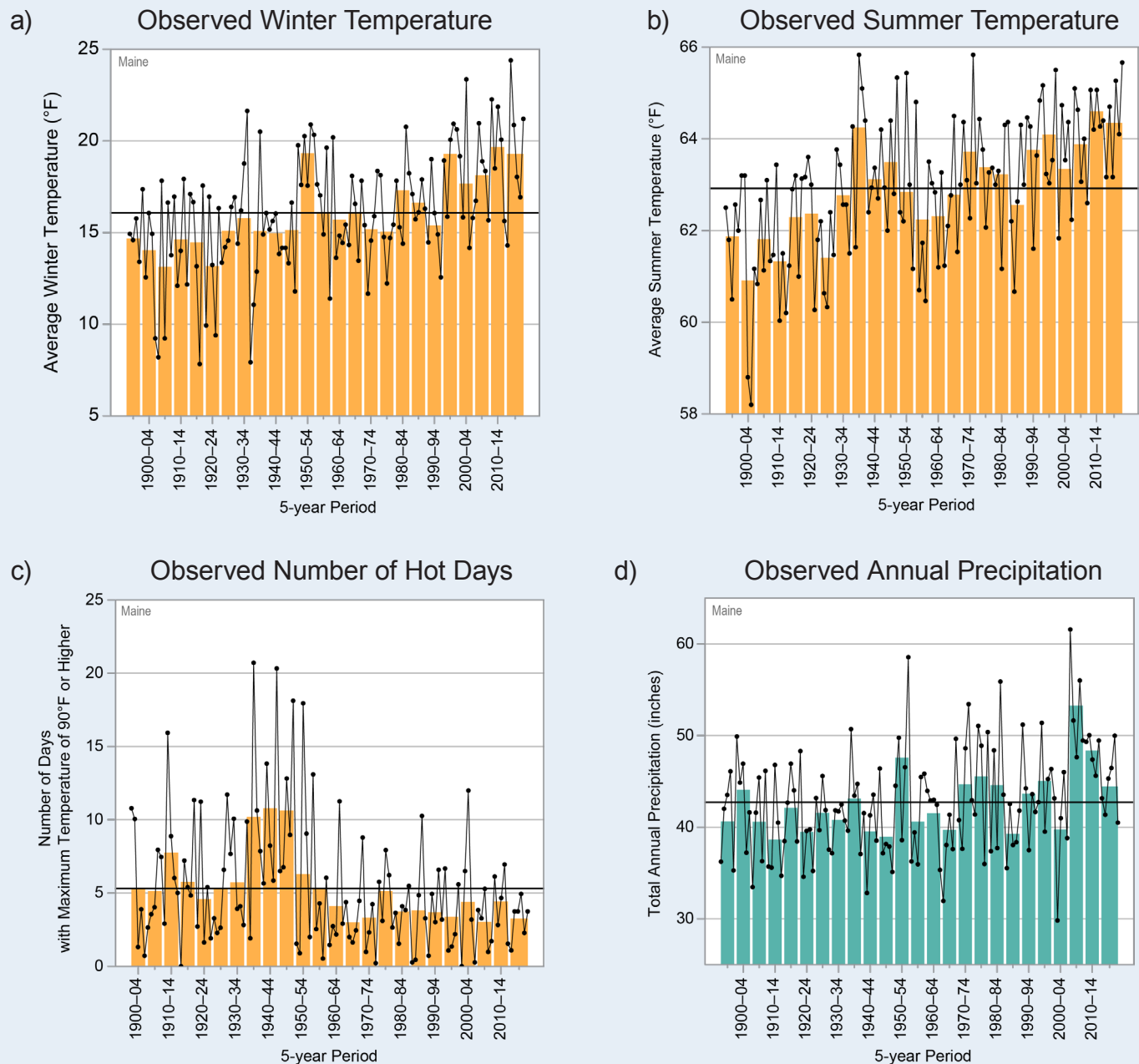


Figure 2: Observed (a) winter (December–February) average temperature, (b) summer (June–August) average temperature, (c) annual number of hot days (maximum temperature of 90°F or higher), and (d) total annual precipitation for Maine from (a, b, d) 1895 to 2020 and (c) 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages for Maine: (a) 16.1°F (b) 62.9°F, (c) 5.3 days, (d) 42.7 inches. Summer and winter temperatures have been above average since the mid-1990s, with the highest multiyear averages for both occurring during the 2010–2014 period. Annual precipitation has been above average for the past 16 years (2005–2020). Sources: (a–d) CISESS and NOAA NCEI. Data: (a, b, d) nClimDiv, (c) GHCN-Daily from 3 long-term stations.

Total annual precipitation in Maine reached a historically high multiyear average during the 2005–2020 period (Figure 2d). In the harsh winter months, average accumulated snowfall ranges from 40 to 80 inches across the Southern Interior and Northern Interior climate divisions, with the northern tip of the state receiving up to 100 inches. The annual number of 2-inch extreme precipitation events has varied over the period of record,

but the 10-year interval from 2005 to 2014 had a record number (nearly double the long-term average; Figure 4), similar to the rest of the northeastern United States.

Maine has also been experiencing more short-term dry periods, with extreme drought occurring in 2002, 2016, and 2020. Drought conditions in 2020 contributed to more than 900 wildfires, the most Maine has seen in a decade.

Heat and cold waves, droughts, severe rainstorms, nor'easters, ice storms, and tornadoes are all part of Maine's normal climate. In general, nor'easters cause more disruption than any other type of extreme weather. Nor'easters are cold-season coastal storms that can generate a tremendous amount of precipitation (in the form of snow, sleet, or freezing rain), strong winds, coastal flooding, and damage to infrastructure. Observed wind speeds from nor'easters are commonly equal to or greater than those from hurricanes that have reached Maine. Nor'easters are prevalent in most years in winter, spring, and fall, while landfalling hurricanes are very rare. Since 1861, only 3 hurricanes have reached Maine with hurricane-force winds, the last being Gloria in 1985. Since 2007, weather-related disasters have been declared in every county in Maine.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, temperatures are generally projected to exceed historical record levels by the middle of this century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. The intensity of cold waves is projected to decrease, while heat waves are projected to increase in intensity, potentially raising the importance of such events in this normally moderate summer climate.

Precipitation is projected to increase. Maine is part of a large area in the higher mid-latitudes that is projected to see increases in winter (Figure 5) and spring precipitation. The frequency of extreme precipitation events is also projected to increase, potentially resulting in increased flooding risks and the degradation of surface water quality as greater runoff from more intense storms carries pollutants into freshwater resources.

Since 1900, global average sea level has risen by about 7–8 inches. It is projected to rise another 1–8 feet, with a likely range of 1–4 feet, by 2100 as a result of both past and future emissions from human activities (Figure 6). **Greater rises along the Maine coast are possible.** Sea surface temperatures in the coastal waters of Maine have increased by almost 2°F since 1970. The Gulf of Maine has warmed faster than 99% of the global

Observed Number of Very Cold Nights

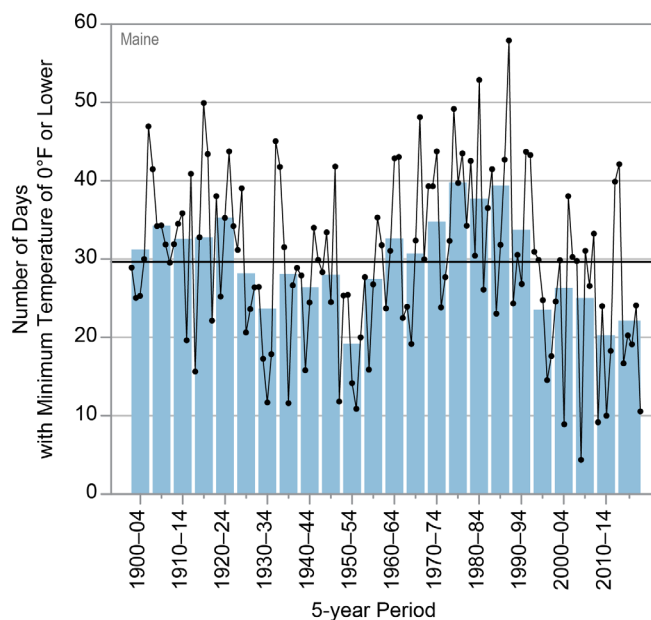


Figure 3: Observed annual number of very cold nights (minimum temperature of 0°F or lower) for Maine from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 29.6 nights. Periods of very cold nighttime temperatures have occurred episodically throughout the period of record, notably in the 1970s and 1980s. Since the mid-1990s, the number of very cold nights has been below average, reflecting winter warming. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 3 long-term stations.

Observed Number of 2-Inch Extreme Precipitation Events

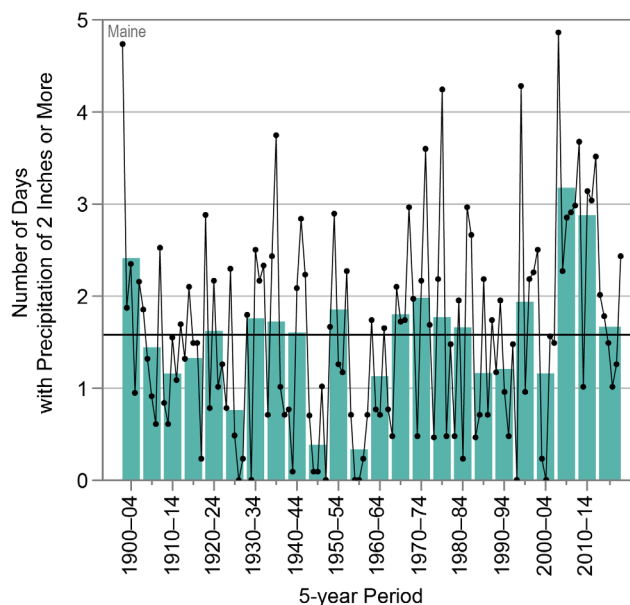


Figure 4: Observed annual number of 2-inch extreme precipitation events (days with precipitation of 2 inches or more) for Maine from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 1.6 days. A typical reporting station experiences 1 to 2 events per year. Maine experienced a record number of 2-inch extreme precipitation events during the 2005–2009 and 2010–2014 periods. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 3 long-term stations.

ocean. Tide-gauge records in Portland show a sea level rise of approximately 7.4 inches since 1912. Changes in ocean and atmospheric circulation have caused temporary, destructive increases in sea level, such as the 5-inch rise along the Maine coast in 2010. Future projections of sea level rise show that some coastal cities and towns could lose up to 30% of their land area.

Sea level rise has caused an increase in tidal floods associated with nuisance-level impacts. Nuisance

floods are events in which water levels exceed the local threshold (set by NOAA's National Weather Service) for minor impacts. These events can damage infrastructure, cause road closures, and overwhelm storm drains. Nuisance flooding has increased in all U.S. coastal areas, with more rapid increases along the East and Gulf Coasts. Nuisance flooding events in Maine are likely to occur more frequently as global and local sea levels continue to rise.

Projected Change in Winter Precipitation

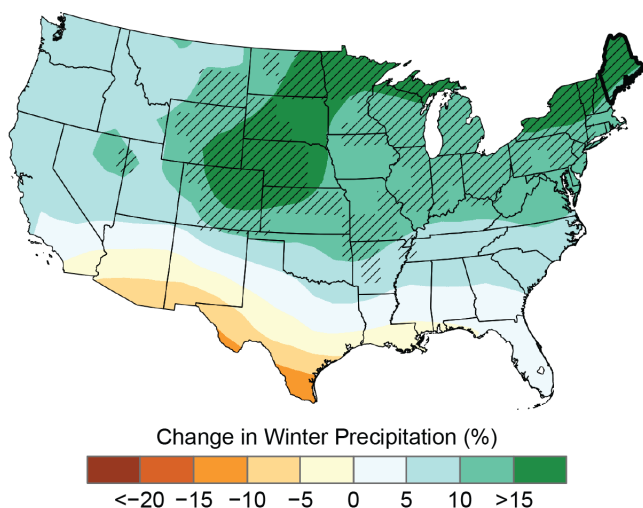


Figure 5: Projected changes in total winter (December–February) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. Maine is part of a large area in the northeastern and central United States with projected increases in winter precipitation. Sources: CISESS and NEMAC. Data: CMIP5.

Past and Projected Changes in Global Sea Level

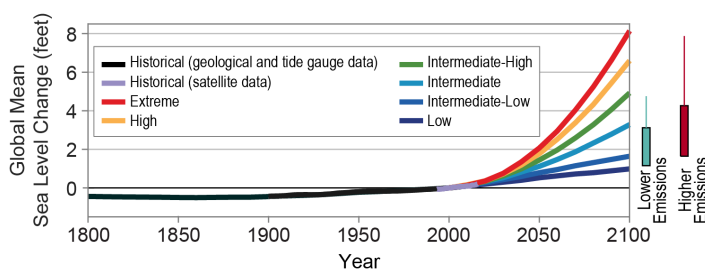
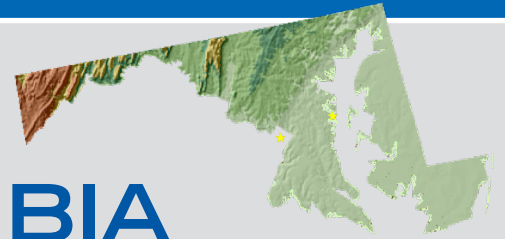


Figure 6: Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate-Low, royal blue; Intermediate, cyan; Intermediate-High, green; High, orange; and Extreme, red curves) relative to historical geological, tide gauge, and satellite altimeter GMSL reconstructions from 1800–2015 (black and magenta lines) and the very likely ranges in 2100 under both lower and higher emissions futures (teal and dark red boxes). Global sea level rise projections range from 1 to 8 feet by 2100, with a likely range of 1 to 4 feet. Source: adapted from Sweet et al. 2017.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

MARYLAND AND THE DISTRICT OF COLUMBIA



Key Messages

Temperatures in Maryland have risen about 2.5°F since the beginning of the 20th century. Historically unprecedented warming is projected during this century under a higher emissions pathway. Heat waves are projected to be more intense, while cold waves are projected to be less intense.

Precipitation is projected to increase, particularly in the winter and spring. The frequency and intensity of extreme precipitation events are also projected to increase, which could increase the risk of flooding.

Global sea level is projected to rise, with a likely range of 1 to 4 feet by 2100. Sea level has been rising along the Maryland coastline, and large additional increases (in the likely range of 1 to 4 feet by 2100) are projected, with potential significant environmental and economic impacts, including more low-lying coastal flooding, shoreline erosion, and property and infrastructure damage.

Maryland and the District of Columbia (DC) are located on the eastern coast of the North American continent. Their geographic location exposes them to both the cold winter and warm summer air masses from the continental interior and the moderate and moist air masses from the Atlantic Ocean. Maryland and DC's climates are characterized by moderately cold and occasionally snowy winters and warm, humid summers. Due to their mid-latitude location, the jet stream is often located near the state and city, particularly in the late fall, winter, and spring. Precipitation is frequent because of low-pressure storms associated with the jet stream. In winter, the contrasting influences of cold air masses from the interior and moist air masses from the Atlantic provide the energy for occasional intense storms commonly known as nor'easters. Maryland has a west-to-east contrast in temperature. Larger seasonal variations occur in the highland west in the Appalachian Mountains, while temperatures in the east are moderated by the Chesapeake Bay and the Atlantic Ocean. The annual number of nights below freezing ranges from more than 100 nights in the northwest to fewer than 20 nights in the southeast. Similar gradients exist for the annual number of very hot days, which varies from 0 to 1 days in the

Observed and Projected Temperature Change

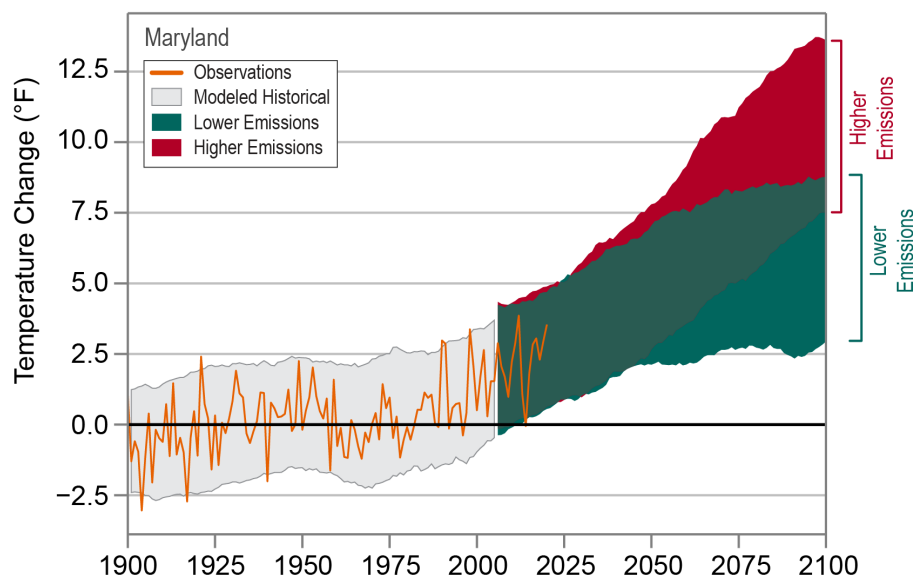
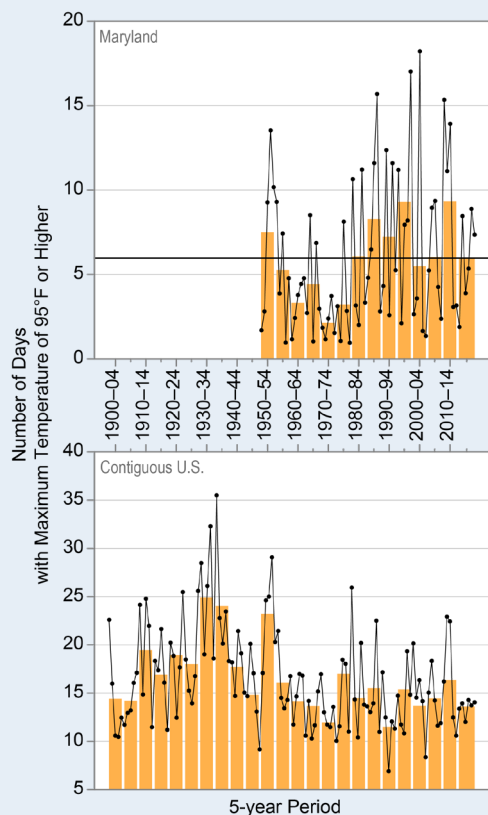


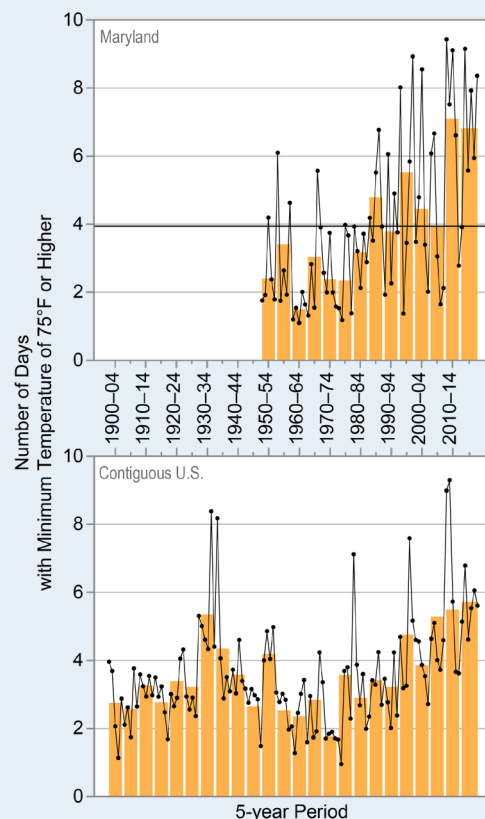
Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Maryland. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Maryland (orange line) have risen about 2.5°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 2.5°F warmer than the historical average; green shading) and

more warming under a higher emissions future (the hottest end-of-century projections being about 10°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

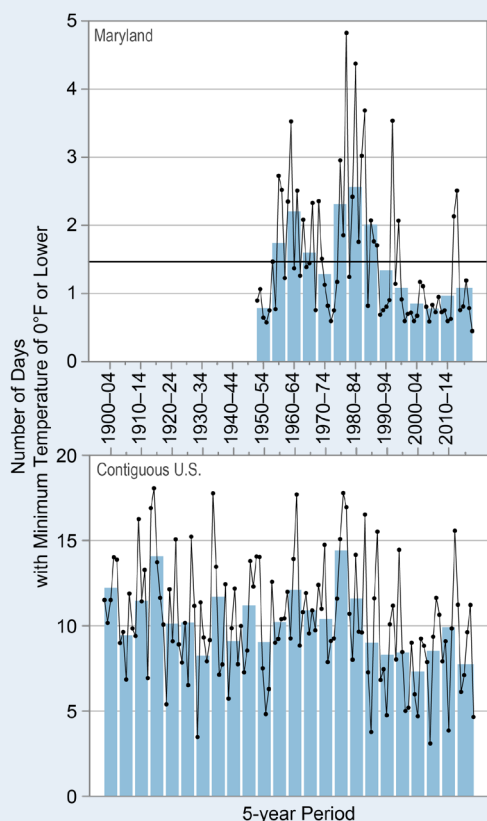
a) Observed Number of Very Hot Days



b) Observed Number of Very Warm Nights



c) Observed Number of Very Cold Nights



d) Observed Annual Precipitation

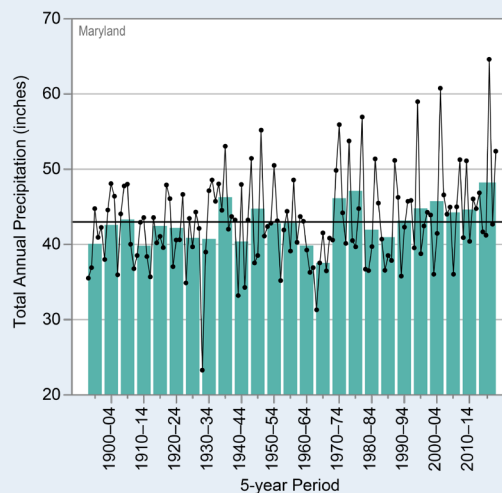


Figure 2: Observed (a) annual number of very hot days (maximum temperature of 95°F or higher), (b) annual number of very warm nights (minimum temperature of 75°F or higher), (c) annual number of very cold nights (minimum temperature of 0°F or lower), and (d) total annual precipitation for Maryland from (a, b, c) 1950 to 2020 and (d) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages for Maryland: (a) 6.0 days, (b) 3.9 nights, (c) 1.5 nights, (d) 43.0 inches. Values for the contiguous United States (CONUS) from 1900 to 2020 are included for Figures 2a, 2b, and 2c to provide a longer and larger context. Long-term stations dating back to 1900 were not available for Maryland. The annual

number of very hot days has varied over the period of record; however, the number of very warm nights has generally been rising since 1950, with the highest multiyear averages occurring during the last two periods (2010–2014 and 2015–2020). The number of very cold nights has been below average since 1990. Annual precipitation has been variable but shows a slight upward trend. Sources: CISESS and NOAA NCEI. Data (a, b, c) GHCN-Daily from 10 (MD) and 655 (CONUS) long-term stations, (d) nClimDiv.

Allegheny Plateau to 2 to 11 days in north-central Maryland and 3 to 8 days in the Lower Eastern Shore.

The Chesapeake Bay, which divides Maryland in the east, is the largest estuary in North America and one of the most productive in the world, with more than 64,000 square miles of watershed. This area is particularly vulnerable to climate change in several ways: through sea level rise, changes in river discharge from precipitation extremes, increased water temperatures, and potential acidification (ocean and biological). Increasing urban development, excessive pollution levels, and changes in water temperature and salinity have impacted some plant and animal species, affecting Chesapeake Bay area ecosystems.

Temperatures in Maryland have risen about 2.5°F since the beginning of the 20th century (Figure 1), and temperatures in this century have been warmer than in any other period. The warmest year on record was 2012, and 7 of the 10 warmest years have occurred since 2000. The second-warmest year was 2020, and July 2020 was the all-time hottest month for both the city of Baltimore and the state as a whole. The annual number of very hot days and annual number of very warm nights have averaged 7 days and 5 nights since 1985, compared to 6 days and 3 nights for the 1950–1984 interval (Figures 2a and 2b).

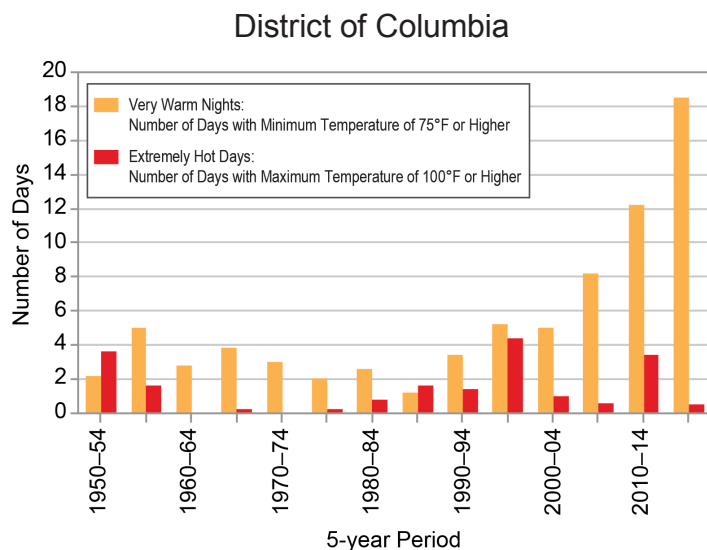


Figure 3: Observed annual number of very warm nights (minimum temperature of 75°F or higher) and extremely hot days (maximum temperature of 100°F or higher) for the District of Columbia from 1950 to 2020. Bars show averages over 5-year periods (last bar is a 6-year average). Since 1950, there has been no trend in extremely hot days. By contrast, the number of very warm nights has been steadily increasing since 1985, with the highest multiyear averages occurring during the 2005–2020 interval. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 1 long-term station (National Arboretum).

A winter warming trend is reflected in a below average number of very cold nights since the mid-1990s (Figure 2c). Since 1950, there has been no trend in extremely hot days in the District of Columbia (Figure 3). However, from 2015 to 2020, DC averaged more than 18 very warm nights per year, compared to the 1950–2009 average of 3.7 nights per year.

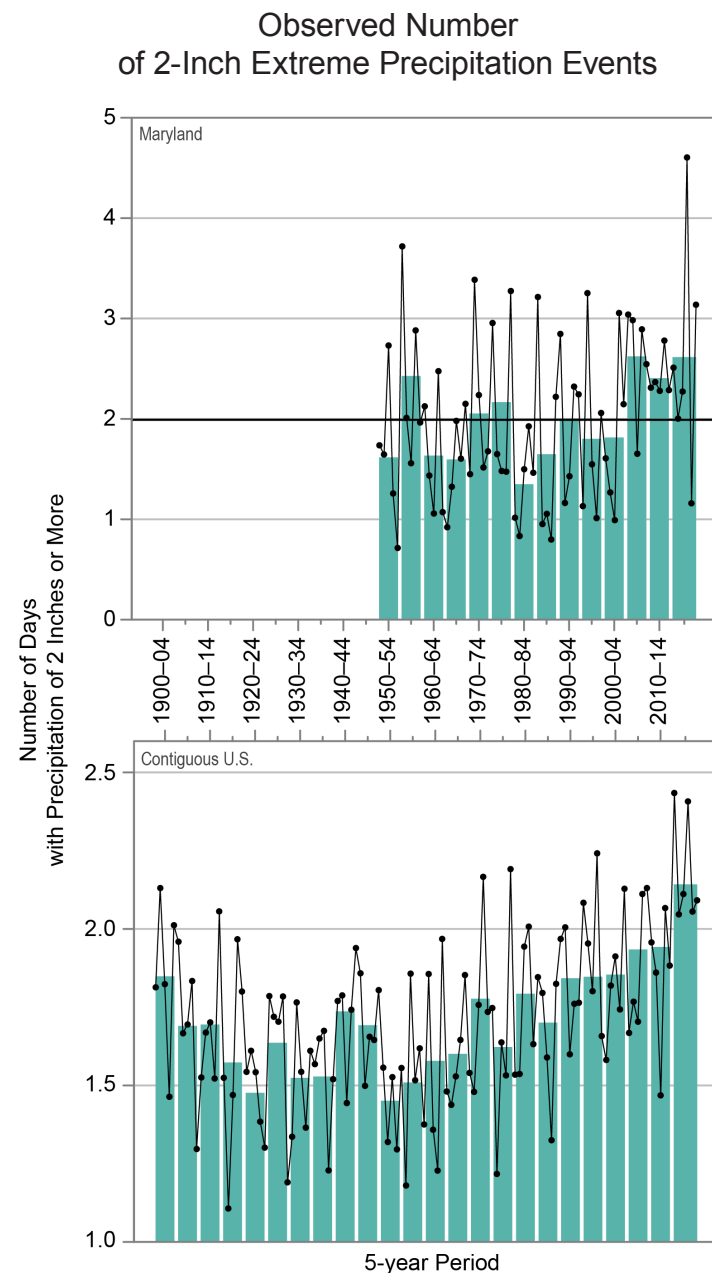


Figure 4: Observed annual number of 2-inch extreme precipitation events (days with precipitation of 2 inches or more) for Maryland from 1950 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average for Maryland of 2.0 days. A typical reporting station experiences about 2 events per year. Values for the contiguous United States (CONUS) are included to provide a longer and larger context. Long-term stations dating back to 1900 were not available for Maryland. The number of extreme precipitation events has been above average since 2005. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 11 long-term stations.

Annual average precipitation in Maryland varies from about 40 inches in the Appalachian Mountain region to about 50 inches in the western and eastern areas of the state. The wettest decade was the 1970s, with the wettest consecutive 5-year interval (1971–1975); the driest decade was the 1960s, with the driest consecutive five-year interval (1962–1966). **Total annual precipitation has been above the long-term average for the last 26 years (1995–2020; Figure 2d).** The annual number of 2-inch extreme precipitation events averaged 2.5 days per year during the 2005–2020 interval, compared to 1.8 days per year during the 1950–2004 interval (Figure 4).

Maryland and the District of Columbia are susceptible to several extreme weather types, including tropical storms and hurricanes, severe thunderstorms, tornadoes, nor'easters, blizzards and ice storms, flooding, drought, and heat and cold waves. Multiple snowstorms impacted the Mid-Atlantic in February 2010, bringing heavy snowfall and shutting down the federal government for 4 and a half days. Hurricane Irene, in 2011, caused considerable wind damage along the coast. In 2012, Superstorm Sandy (a post-tropical storm) caused damage from wind and a storm surge of 4 to 5 feet, which destroyed a large portion of Ocean City's fishing pier and caused widespread flooding in Crisfield and other low-lying areas of Maryland's Lower Eastern Shore. On June 29, 2012, a derecho (a widespread, long-lived line of thunderstorms with very strong winds) moved through the Ohio Valley and the Mid-Atlantic states; Maryland and the District of Columbia were two of the hardest hit areas. One-third of Maryland residents and one-quarter of DC residents were left without power after the storm, with some outages lasting longer than a week. Both mountainous terrain in the narrow, western portion of Maryland and dense urbanized areas are highly vulnerable to flash flooding. During August 12–13, 2014, torrential rainfall of up to 6 to 10 inches resulted in flooding along the coastal plain from Baltimore into New Jersey. An extreme precipitation event occurred on July 30, 2016, impacting Ellicott City, MD, with 6 inches of rain in several hours and causing two fatalities. Less than 2 years later, on May 27, 2018, another extreme precipitation event impacted the Ellicott City and Catonsville area; 6–12 inches of rain caused catastrophic damage and one fatality. Catonsville recorded 84.6 inches of precipitation that year, the state record.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of this century. However, a large range of temperature increases is projected under both pathways, and under the lower

pathway, a few projections are only slightly warmer than historical records. In addition, the intensity of summer heat waves is projected to increase, with important implications for human health, while cold wave intensity is projected to decrease.

Annual average precipitation is projected to increase in Maryland over this century, particularly during winter and spring (Figure 5). This is part of a large-scale pattern of projected increases in precipitation over northern and central portions of North America. An increase in the frequency and intensity of extreme precipitation events is projected, potentially increasing flooding events in urban areas and likely expanding flood hazard areas (areas inundated by a flood event). The 100-year storm

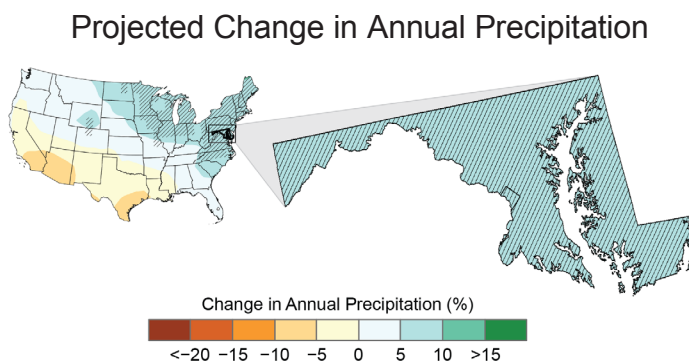


Figure 5: Projected changes in total annual precipitation (%) for the middle of the 21st century relative to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. Annual precipitation is projected to increase in Maryland. Sources: CISESS and NEMAC. Data: CMIP5.

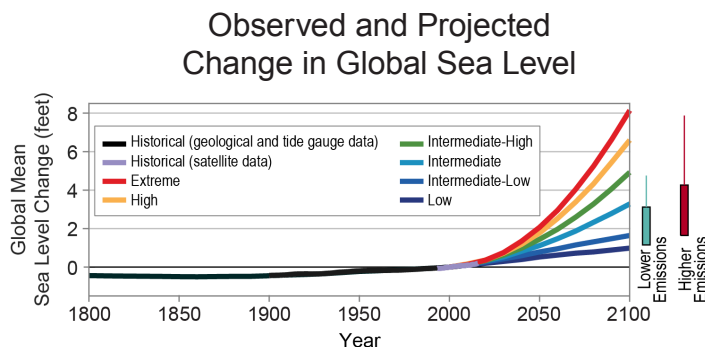


Figure 6: Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate-Low, royal blue; Intermediate, cyan; Intermediate-High, green; High, orange; and Extreme, red curves) relative to historical geological, tide gauge, and satellite altimeter GMSL reconstructions from 1800–2015 (black and magenta lines) and the very likely ranges in 2100 under both lower and higher emissions futures (teal and dark red boxes). Global sea level rise projections range from 1 to 8 feet by 2100, with a likely range of 1 to 4 feet. Source: adapted from Sweet et al. 2017.

event, as defined by historical data, is expected to occur every 20 to 50 years by the end of the century. Naturally occurring droughts will also continue to be a part of the climate, even if precipitation increases. Such droughts are projected to be more intense because higher temperatures will increase the rate of soil moisture loss during dry spells.

Since 1900, global average sea level has risen by about 7–8 inches. It is projected to rise another 1–8 feet, with a likely range of 1–4 feet, by 2100 as a result of both past and future emissions from human activities (Figure 6).

The Chesapeake Bay area is the third most vulnerable area of the United States to sea level rise (SLR), behind Louisiana and South Florida. The foremost impacts of SLR on the state include more frequent and severe coastal flood events, increased shore erosion, inundation of wetlands and low-lying lands, and saltwater intrusion into groundwater. Tide-gauge records show that sea level in the Chesapeake Bay has been increasing at an average rate of 1.3 to 1.5 inches per decade over the past 100 years, 50% more than the global historical average

observed over the same time period. For the Chesapeake Bay, global SLR is compounded by substantial rates of land subsidence (sinking; an average rate of 3.1 mm per year was found between 2006 and 2011 due to a combination of groundwater withdrawal and natural geologic effects associated with post-glaciation adjustments). A recent study specific to Maryland states that the likely range (66% probability) of SLR between 2000 and 2050 is 0.8 to 1.6 feet; if emissions continue to increase, the likely range of SLR is 2.0 to 4.2 feet over this century.

Sea level rise has caused an increase in tidal floods associated with nuisance-level impacts. Nuisance floods are events in which water levels exceed the local threshold (set by NOAA's National Weather Service) for minor impacts. These events can damage infrastructure, cause road closures, and overwhelm storm drains. As sea level has risen along the Maryland coastline, the number of tidal flood days (all days exceeding the nuisance-level threshold) has also increased, with the greatest number occurring in 2018 (Figure 7).

Observed and Projected Annual Number of Tidal Floods for Baltimore, MD

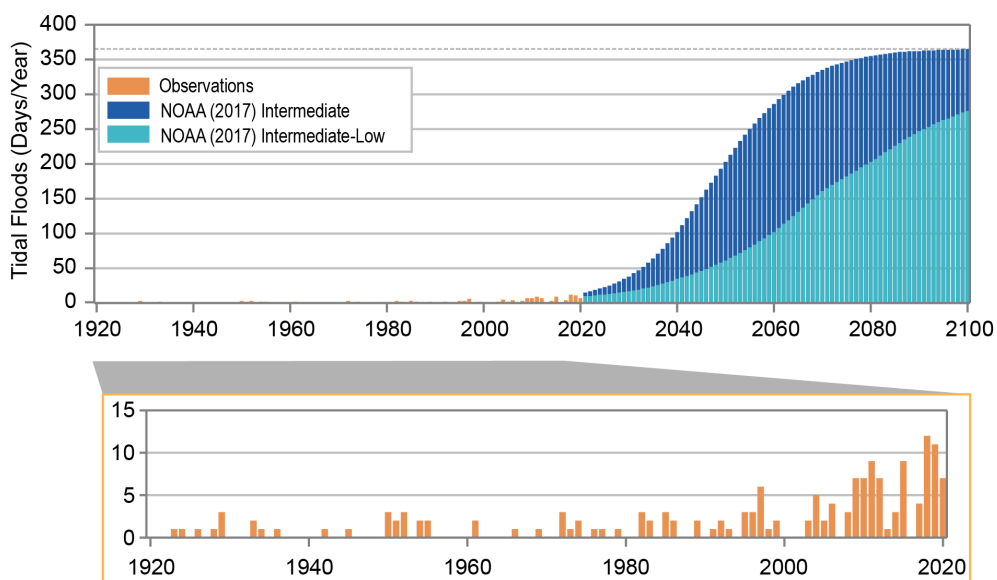
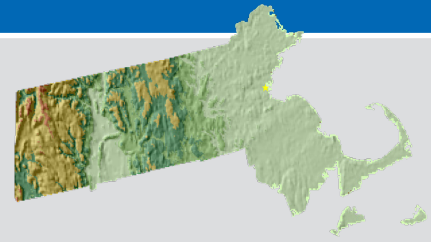


Figure 7: Number of tidal flood days per year at Baltimore, MD, for the observed record (1920–2020; orange bars) and projections for 2 NOAA (2017) sea level rise scenarios (2021–2100): Intermediate (dark blue bars) and Intermediate-Low (light blue bars). The NOAA (2017) scenarios are based on local projections of the GMSL scenarios shown in Figure 6. Sea level rise has caused a gradual increase in tidal floods associated with nuisance-level impacts. The greatest number of tidal flood days (all days exceeding the nuisance-level threshold) occurred in 2018 at Baltimore. Projected increases are large even under the Intermediate-Low scenario. Under the Intermediate scenario, tidal flooding is projected to occur every day of the year by the end of the century. Additional information on tidal flooding observations and scenarios is available at <https://statesummaries.ncics.org/technicaldetails>. Sources: CISESS and NOAA NOS.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

MASSACHUSETTS



Key Messages

Temperatures in Massachusetts have risen almost 3.5°F since the beginning of the 20th century. Under a higher emissions pathway, historically unprecedented warming is projected during this century, with associated increases in heat wave intensity and decreases in cold wave intensity.

Precipitation since 1970 has averaged about 4.7 inches more than during 1895–1969, and a record-setting number of extreme precipitation events occurred during 2005–2014. Winter and spring precipitation is projected to increase, as is the frequency of extreme precipitation events.

Global sea level is projected to rise, with a likely range of 1–4 feet by 2100. Sea level rise poses significant risks, including inundation, erosion-induced land loss, and greater flood vulnerability due to higher storm surge.

Massachusetts is located on the eastern edge of the North American continent. Its northerly latitude and geographic location expose the state to both the moderating and moistening influence of the Atlantic Ocean and the effects of hot and cold air masses from the interior of the continent. Its climate is characterized by cold, snowy winters and warm summers. The jet stream, often located near the state, gives it highly variable weather patterns, wide-ranging daily and annual temperatures, and generally abundant precipitation throughout the year. Massachusetts comprises approximately one-eighth of New England's total land area (8,257 square miles). Although small in size and with forestland covering more than half of the state, Massachusetts is home to more than 6 million residents. The topography, varying from the flat coastal plains in the east to hillier and higher terrain in the west, provides some regional variations in climate. For the most part, summer temperatures are comfortably warm and relatively uniform across the state. Average (1991–2020 normals) temperatures in July range from the upper 60s (°F) to mid-70s (°F), with western portions of the state being cooler and eastern portions being warmer. January temperatures are more variable than summer temperatures, ranging from the low 20s (°F) in the west to around 30°F near the coast. Annual average precipitation varies from 45 to 55 inches across the state.

Observed and Projected Temperature Change

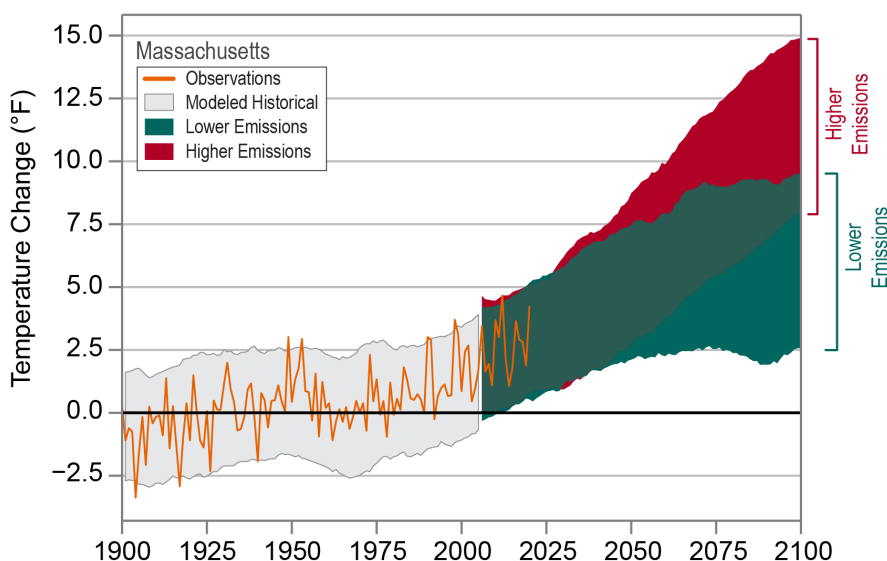


Figure 1. Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Massachusetts. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Massachusetts (orange line) have risen almost 3.5°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-year projections being about 2°F warmer than the

historical average; green shading) and more warming under a higher emissions future (the hottest end-of-year projections being about 10°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

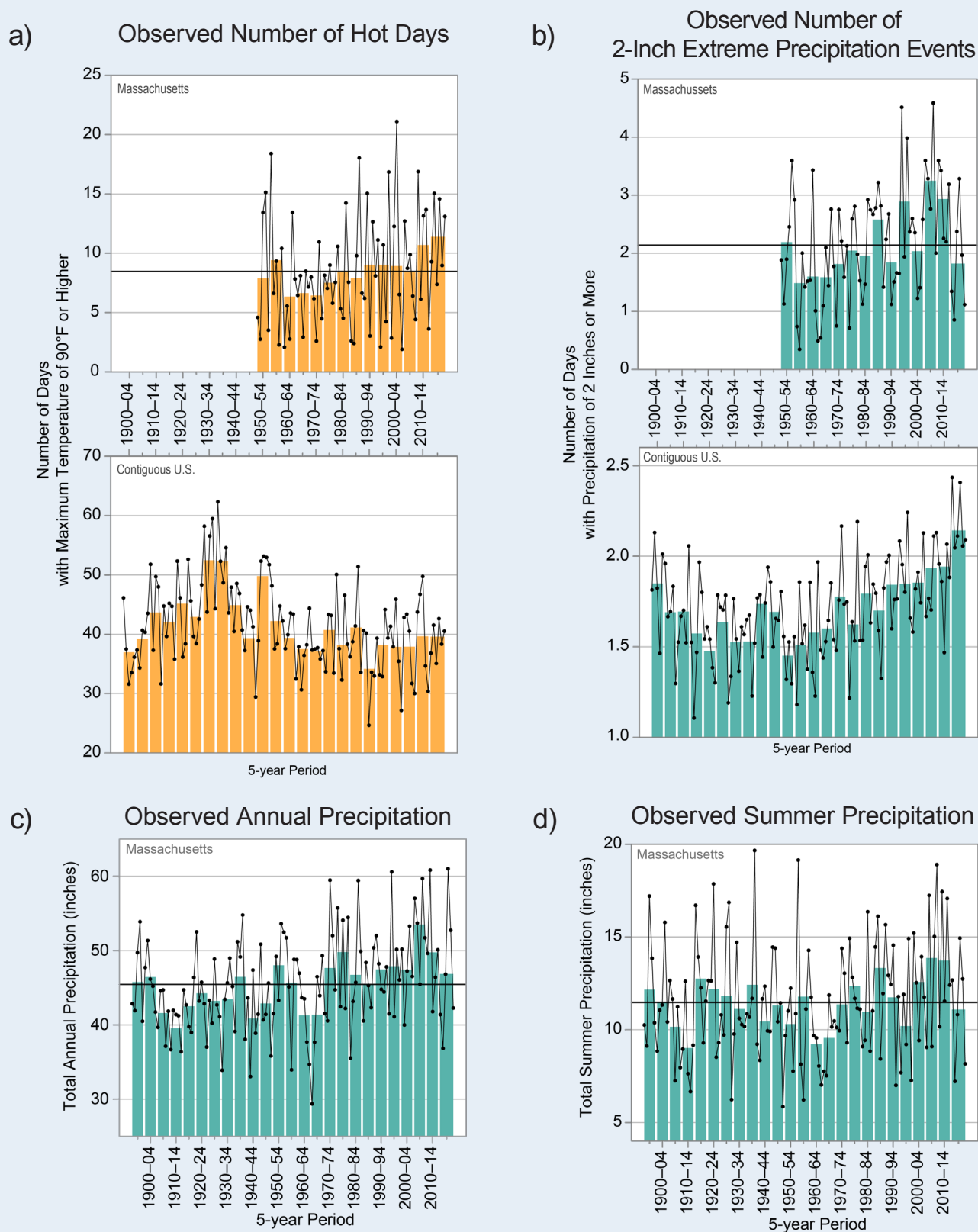


Figure 2. Observed (a) annual number of hot days (maximum temperature of 90°F or higher), (b) annual number of 2-inch extreme precipitation events (days with precipitation of 2 inches or more), (c) total annual precipitation, and (d) total summer (June–August) precipitation for Massachusetts from (a, b) 1950 to 2020 and (c, d) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages for Massachusetts: (a) 8.5 days, (b) 2.1 days, (c) 45.4 inches, (d) 11.5 inches. Values for the contiguous United States (CONUS) from 1900 to 2020 are included for Figures 2a and 2b to provide a longer and larger context. Long-term stations dating back to 1900 were not available for Massachusetts. The number of hot days in Massachusetts has consistently remained above average since 2010, with the 2015–2020 multiyear average setting a record high. All precipitation metrics were highest during the 2005–2014 interval. Sources: CISESS and NOAA NCEI. Data: (a) GHCN-Daily from 15 (MA) and 655 (CONUS) long-term stations, (b) GHCN-Daily from 23 (MA) and 832 (CONUS) long-term stations, (c, d) nClimDiv.

Temperatures in Massachusetts have risen almost 3.5°F since the beginning of the 20th century (Figure 1). The number of hot days has been considerably above the long-term (1950–2020) average since 2010 (Figure 2a); the highest multiyear average since 1950 (11.5 days per year) occurred during the 2015–2020 period. **The number of warm nights has been steadily increasing since 1995**, with the highest multiyear average occurring during the 2015–2020 period (Figure 3). In 2012, Boston experienced the warmest January to July in 85 years. During that span, Boston’s average temperature was 53.5°F—almost 4°F warmer than the historical average temperature. Changes in extreme low temperatures also reflect this warming trend. The number of very cold nights has been below average since the early 1990s (Figure 4). Despite this overall trend, the recent winter of 2014–15 was rather severe, when the eastern United States was one of few places globally with colder than normal temperatures. Heavy snowfall was the most prominent feature of that winter, with Boston setting several records for snowfall, including 110 inches for seasonal snowfall and the snowiest month on record; the Massachusetts Bay Transportation Authority rail service also shut down for several days. The winter average temperature was the 30th coldest for Massachusetts.

Precipitation is abundant but highly variable from year to year. The driest conditions were observed in the early 1910s and again in the 1960s, with wetter conditions occurring since the 1970s (Figures 2c and 2d). The wettest consecutive 10-year interval on record was 2005–2014, averaging about 51 inches per year, well above the long-term (1895–2020) annual average of 45.4 inches (Figure 2c). The driest consecutive 5-year interval was 1962–1966, and the wettest was 2005–2009. Massachusetts experienced extreme drought during 2016–2017 and again in 2020, straining water supplies. During 2005–2014, Massachusetts experienced the largest number of 2-inch extreme precipitation events (Figure 2b), about 30% above the long-term average. In March 2010 alone, three intense rainstorms led to extensive flooding throughout the state and southern New England, with estimated damages exceeding \$2 billion. The heaviest rain fell in eastern Massachusetts, with more than 19 inches recorded near Jamaica Plain, Middleton, and Winchester.

Periodic weather events include extreme precipitation and flooding, severe storms (coastal, winter, and thunder), drought, and, on occasion, tropical storms and hurricanes. **The state’s coastline is highly vulnerable**

Observed Number of Warm Nights

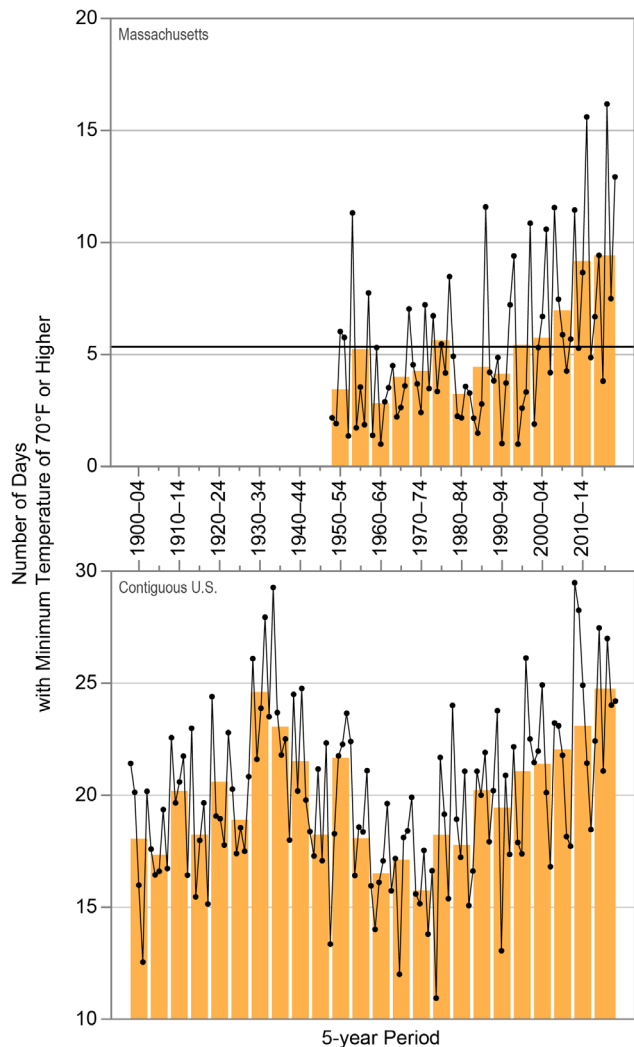


Figure 3. Observed annual number of warm nights (minimum temperature of 70°F or higher) for Massachusetts from 1950 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average for Massachusetts of 5.3 nights. Values for the contiguous United States (CONUS) from 1900 to 2020 are included to provide a longer and larger context. Long-term stations dating back to 1900 were not available for Massachusetts. The number of warm nights in Massachusetts has steadily increased since the mid-1990s, with the highest multiyear average (since 1950) occurring during the 2015–2020 period. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 15 (MA) and 655 (CONUS) long-term stations.

to damage from powerful nor’easters and tropical storms and hurricanes. Landfalling hurricanes have produced hurricane-force winds in Massachusetts 7 times between 1900 and 2020. In 2012, Superstorm Sandy (a post-tropical storm) was the most extreme and destructive event to affect the northeastern United States in 40 years and the fourth costliest in the Nation’s history. Massachusetts was one of more than a dozen northeastern states impacted by Sandy. Storm impacts included strong winds, record high storm

tides, flooding of some coastal areas, and loss of power for 385,000 residents. The state suffered more than \$300 million in property losses alone. A year earlier, Hurricane Irene, dubbed the “costliest Category 1 storm” (with more than \$15 billion in damages), swept through northern New England. Irene’s most severe impact was catastrophic inland flooding in New Jersey, Massachusetts, and Vermont. A number of weather stations in central and western Massachusetts recorded more than 4 inches of rainfall during August 27–29, 2011, with a few locations exceeding 7 inches, including Granville Dam and Westhampton.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of this century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. Heat waves are projected to increase in intensity, while cold waves are projected to become less intense. Massachusetts is vulnerable to extreme heat because of its densely populated urban areas. Excessive heat exposure is projected to contribute to more heat-related illnesses and, in severe cases, deaths. The annual number of days above 90°F is projected to increase by up to 40 days for parts of Massachusetts by midcentury under a higher emissions pathway.

Winter and spring precipitation is projected to continue to increase for Massachusetts over this century (Figure 5). In response to winter warming, projections indicate that more precipitation (12%–30%) will fall as rain rather than snow, and there will be earlier lake ice-out dates and a reduction in winter snowpack. As winters become warmer, the number of snow events is expected to decline from an average of 5 each month of winter to 1 to 3. The number of extreme precipitation events is also projected to more than double by the end of this century. Projections of above average precipitation totals and more frequent extreme precipitation events may also result in increased coastal and inland flooding, including substantial increases in riverine flooding in Boston by 2050. Increased evaporation from warmer temperatures, alterations in the timing and amount of streamflow following reductions in snowpack, and changes in the amount, timing, and type of precipitation may intensify naturally occurring droughts.

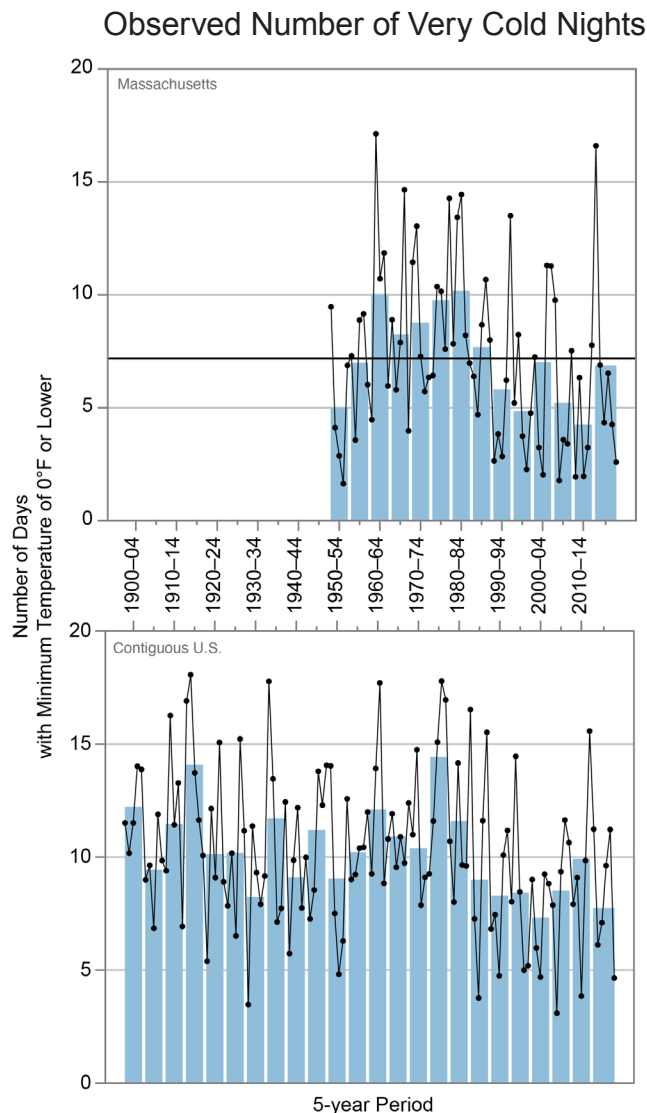


Figure 4. Observed annual number of very cold nights (minimum temperature of 0°F or lower) for Massachusetts from 1950 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average for Massachusetts of 7.2 nights. Values for the contiguous United States (CONUS) from 1900 to 2020 are included to provide a longer and larger context. Long-term stations dating back to 1900 were not available for Massachusetts. The number of very cold nights has been consistently below average since the early 1990s. The lowest number of cold nights occurred during the 2010–2014 period. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 15 (MA) and 655 (CONUS) long-term stations.

Coastal communities are particularly vulnerable to sea level rise and coastal storm surge. **Since 1900, global average sea level has risen by about 7–8 inches. It is projected to rise another 1–8 feet, with a likely range of 1–4 feet by 2100 as a result of both past and future emissions from human activities** (Figure 6). From 1921 to 2020, relative sea level increased 0.11 inches per year in Massachusetts, or approximately 11 inches per century, greater than the global rate. Land in the state

is naturally subsiding (sinking); thus, sea level rise has and will continue to contribute to increases in coastal flooding frequency, shoreline erosion, and saltwater intrusion. While local elevation conditions and trends (e.g., subsidence and sediment compaction) need to be accounted for in the adjustment of global sea level rise scenarios to derive relative sea level rise, thermal expansion and melting glacial ice sheets are projected to dominate any local changes in land movement by 2050. State-level findings indicate that sea level rise by 2100 could range from 4 feet (Intermediate scenario) to 10 feet (Extreme scenario), given a high emissions pathway. Sea level rise–induced coastal flooding of densely populated, low-lying coastal communities has important future implications for the state’s economy, public health, natural resources, and infrastructure.

Sea level rise has caused an increase in tidal floods associated with nuisance-level impacts. Nuisance floods are events in which water levels exceed the local threshold (set by NOAA’s National Weather Service) for minor impacts. These events can damage infrastructure, cause road closures, and overwhelm storm drains. As sea level has risen along the Massachusetts coastline, the number of tidal flood days (all days exceeding the nuisance-level threshold) has also increased, with the greatest number (22 days) occurring at Boston in both 2009 and 2017 (Figure 7).

Projected Change in Spring Precipitation

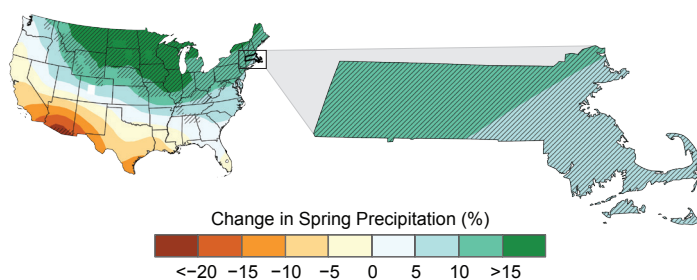


Figure 5. Projected changes in total spring (March–May) precipitation (%) for the middle of the 21st century relative to the late 20th century under a higher emissions pathway. The white-out area indicates that the climate models are uncertain about the direction of change. Hatching represents areas where the majority of climate models indicate a statistically significant change. Spring precipitation is projected to increase in Massachusetts by midcentury. Sources: CISESS and NEMAC. Data: CMIP5.

Observed and Projected Change in Global Sea Level

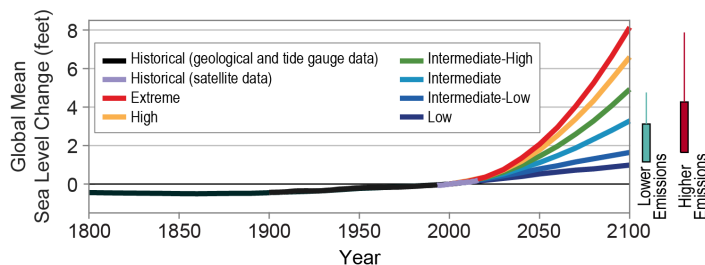


Figure 6. Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate-Low, royal blue; Intermediate, cyan; Intermediate-High, green; High, orange; and Extreme, red curves) relative to historical geological, tide gauge, and satellite altimeter GMSL reconstructions from 1800–2015 (black and magenta lines) and the very likely ranges in 2100 under both lower and higher emissions futures (teal and dark red boxes). Global sea level rise projections range from 1 to 8 feet by 2100, with a likely range of 1 to 4 feet. Source: adapted from Sweet et al. 2017.

Observed and Projected Annual Number of Tidal Floods for Boston, MA

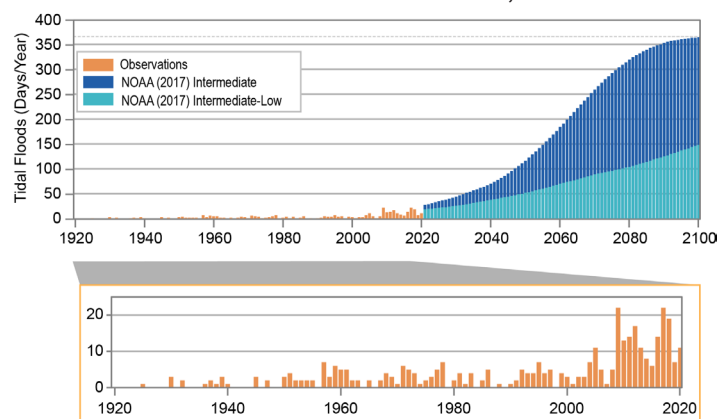


Figure 7. Number of tidal flood days per year at Boston, Massachusetts, for the observed record (1921–2020; orange bars) and projections for two NOAA (2017) sea level rise scenarios (2021–2100): Intermediate (dark blue bars) and Intermediate-Low (light blue bars). The NOAA (2017) scenarios are based on local projections of the GMSL scenarios shown in Figure 6. Sea level rise has caused a gradual increase in tidal floods associated with nuisance-level impacts. The greatest number of tidal flood days (all days exceeding the nuisance-level threshold) occurred in 2009 and 2017 at Boston. Projected increases are large even under the Intermediate-Low scenario. Under the Intermediate scenario, tidal flooding is projected to occur nearly every day of the year by the end of the century. Additional information on tidal flooding observations and scenarios is available at <https://statesummaries.ncics.org/technicaldetails>. Sources: CISESS and NOAA NOS.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

MICHIGAN

Key Messages

Temperatures in Michigan have risen almost 3°F since the beginning of the 20th century. Historically unprecedented warming is projected during this century. Extreme heat is a particular concern for densely populated urban areas such as Detroit, where high temperatures and high humidity can cause dangerous conditions.

Projected increases in winter and spring precipitation raise the risk of springtime flooding, which could delay planting and reduce yields.

Changes in seasonal and multiyear precipitation and increased evaporation rates due to rising temperatures can affect water levels in the Great Lakes, causing serious environmental and socioeconomic impacts.



Michigan experiences large seasonal changes in temperature, with warm, humid summers and cold winters. The Great Lakes play an important role in moderating the state's climate, causing it to be more temperate and moist than other north-central states. The Lower Peninsula is bordered by Lake Michigan to the west and by Lakes Huron and Erie to the east; the Upper Peninsula, by Lake Superior to the north and Lakes Michigan and Huron to the east and south. The moderating effect is most evident along the shores, which are considerably warmer during the winter and cooler in the summer than more inland locations. For example, Lansing and Muskegon have similar latitudes but experience very different frequencies of hot and cold days. Lansing, located in the center of the state, averages 9.0 hot days and 6.9 very cold nights per year. In contrast, Muskegon, located along the western shore of Lake Michigan, averages only 3.4 hot days and 2.5 very cold nights. The moderating effects are even more striking along the shores of the colder waters of Lake Superior in the Upper Peninsula. Sault Ste. Marie averages only 1.4 hot days per year, and there have been only 11 warm nights since 1888.

Temperatures in Michigan have risen almost 3°F since the beginning of the 20th century (Figure 1). Temperatures in the 2000s have been higher than in any other historical period. The year 2012 was the hottest on record, with a statewide annual average temperature of 48.4°F, 4.6°F above the long-term (1895–2020) average.

Observed and Projected Temperature Change

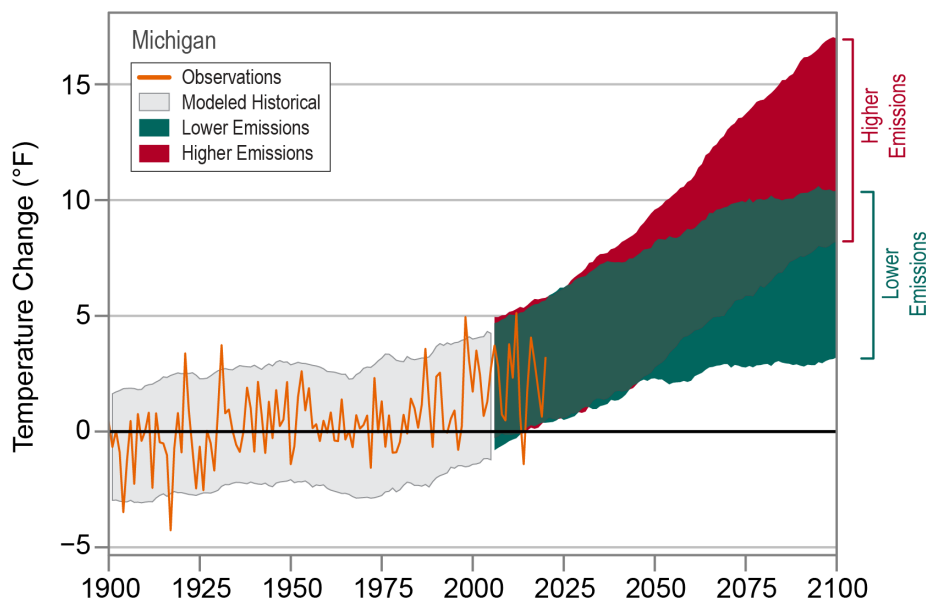


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Michigan. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Michigan (orange line) have risen almost 3°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 3°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 12°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

century projections being about 12°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

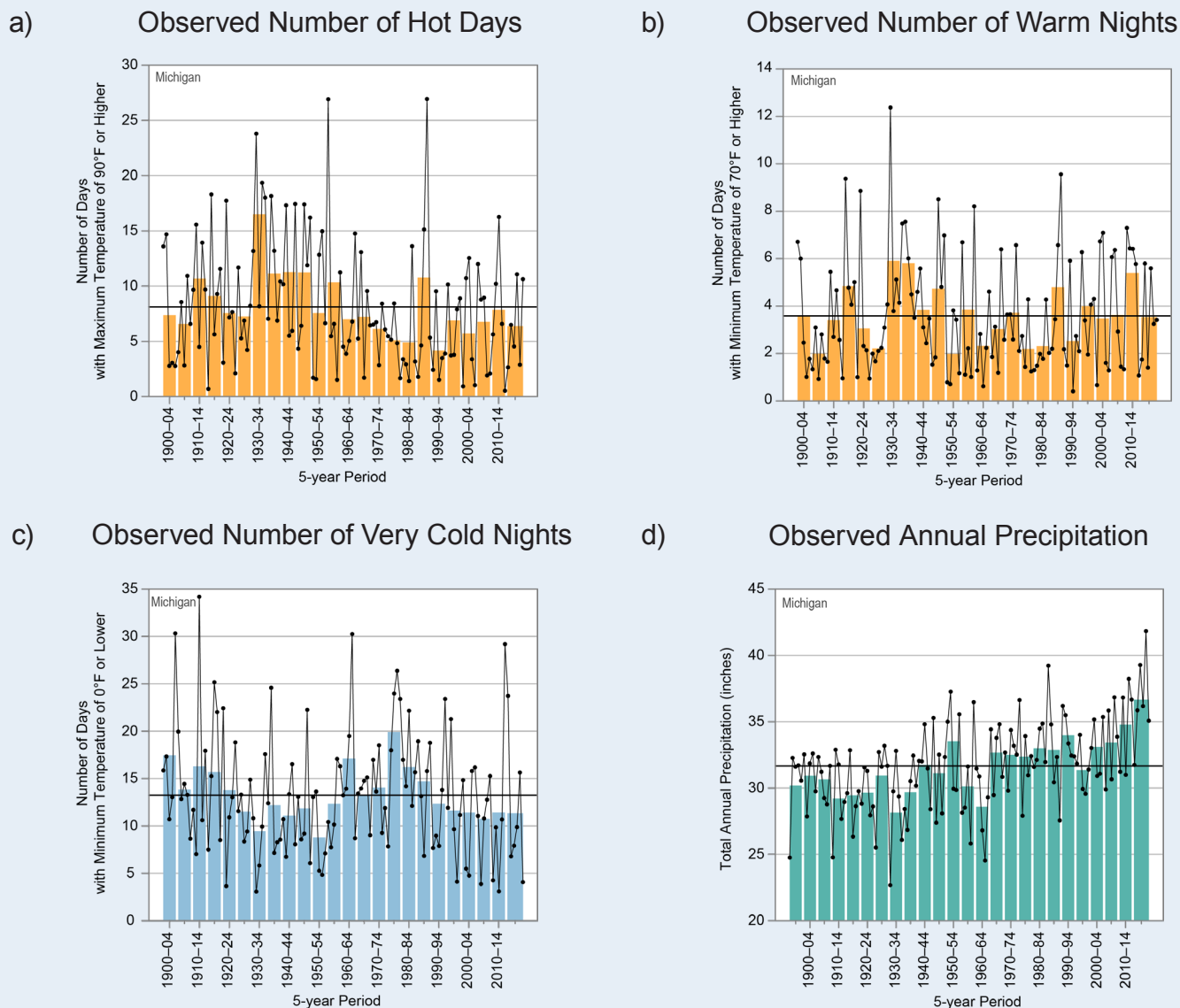


Figure 2: Observed (a) annual number of hot days (maximum temperature of 90°F or higher), (b) annual number of warm nights (minimum temperature of 70°F or higher), (c) annual number of very cold nights (minimum temperature of 0°F or lower), and (d) total annual precipitation for Michigan from (a, b, c) 1900 to 2020 and (d) 1895 to 2020. Dots show annual values. Bars show averages over five-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 8.1 days, (b) 3.6 nights, (c) 13 nights, (d) 31.7 inches. The number of hot days has been below average since 1990, while the number of warm nights shows no clear trend. Due to extreme drought and poor land management practices, the summers of the 1930s remain the warmest on record. The number of very cold nights has been below average since 1990. Annual precipitation shows an upward trend since 1995, with the highest multiyear average recorded for the 2015 to 2020 period. Sources: CICESS and NOAA NCEI. Data: (a, b, c) GHCN-Daily from 21 long-term stations, (d) nClimDiv.

Warming has been concentrated in winter and spring, while summers have not warmed substantially, a feature characteristic of much of the Midwest. A lack of summer warming is reflected in a below average number of hot days since 1990 (Figure 2a) and no overall trend in warm nights (Figure 2b). The winter warming trend is reflected in a below average number of very cold nights since 1990 (Figure 2c) and reduced ice cover in the Great Lakes. The 2000–2021 annual average maximum ice coverage was about 47%, compared to the 1973–1999 average of 58%.

Statewide annual precipitation has ranged from a low of 22.7 inches in 1930 to a high of 41.8 inches in 2019. The driest multiyear periods were in the 1930s and early 1960s and the wettest in the early 1950s, early 1990s, and 2010s (Figure 2d). The driest consecutive 5-year interval was 1930–1934, and the wettest was 2016–2020.

The frequency of extreme precipitation events has increased. Multiyear averages for 2-inch extreme precipitation events for the 2010–2014 and 2015–2020 periods are the highest on record (Figure 3). Snowfall is common in the state but varies regionally. Due to their proximity to the Great Lakes, the south shore of Lake Superior in the Upper Peninsula and the eastern shore of Lake Michigan in the Lower Peninsula receive much more snowfall than the rest of the state. Parts of the Upper Peninsula receive more than 180 inches annually.

Water levels in the Great Lakes have fluctuated over a range of 3 to 6 feet since the late 19th century (Figure 4). Higher lake levels were generally noted in the late 19th century, the early 20th century, and the 1940s, 1950s, 1980s, and late 2010s. Lower lake levels were observed in the 1920s and 1930s and again in the 1960s. For Lake Michigan–Huron, lower levels occurred during the first decade of this century. Lake levels have risen rapidly since 2013, with the highest levels since 1886 observed in 2020.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of this century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. Extreme heat is a particular concern for Detroit and other urban areas, where high temperatures combined with high humidity can cause dangerous heat index values, a phenomenon known as the urban heat island effect. Higher spring temperatures will lengthen the growing season but also potentially increase the risk of spring freeze damage. In 2012, record-high March temperatures caused Michigan’s fruit trees to bloom early. When temperatures dropped back down to below freezing in April, the budding fruit crop was destroyed, causing exceptionally large monetary losses in the hundreds of millions of dollars.

Observed Number of 2-Inch Extreme Precipitation Events

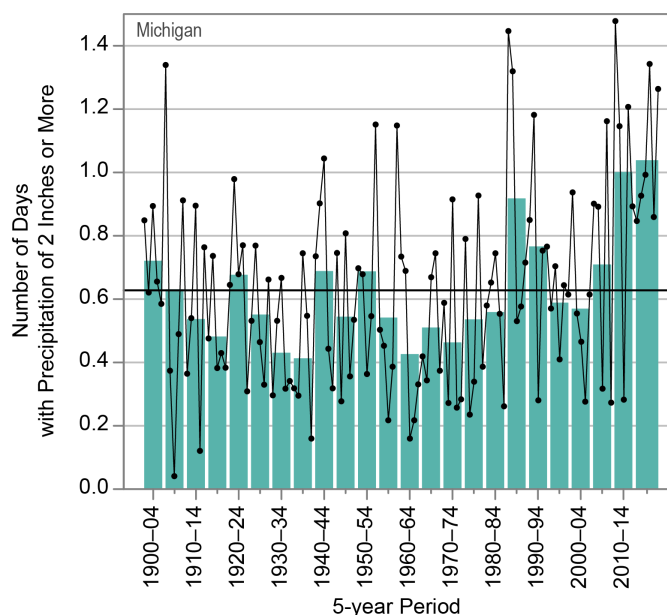


Figure 3: Observed annual number of 2-inch extreme precipitation events (days with precipitation of 2 inches or more) for Michigan from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 0.6 days. A typical reporting station experiences about 1 event every 2 years. The number of 2-inch extreme precipitation events has been increasing since 2000, with record-high multiyear values for the last two periods. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 20 long-term stations.

Lake-Wide Water Levels for Lake Michigan-Huron

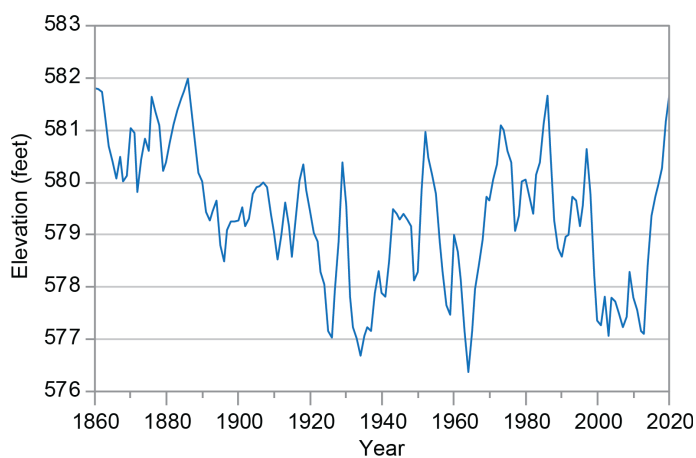


Figure 4: Annual time series of the average water levels for Lake Michigan–Huron from 1860 to 2020. Water levels in the Great Lakes have fluctuated widely over the years. Lake Michigan–Huron levels were very low during 2000–2013 but have since risen rapidly to the highest levels since 1886. Source: NOAA GLERL.

Increases in precipitation are projected for Michigan, most likely during the winter and spring (Figure 5).

The frequency and intensity of extreme precipitation are also projected to increase, potentially increasing the frequency and intensity of floods. Springtime flooding, in particular, could pose a threat to Michigan's important agricultural industry by delaying planting and threatening yield losses.

The intensity of future droughts is projected to increase even if precipitation increases. Rising temperatures will increase evaporation rates and the rate of soil moisture loss. Thus, summer droughts, a natural part of Michigan's climate, are likely to be more intense in the future.

Changes in seasonal and multiyear precipitation and increases in evaporation rates due to rising temperatures can affect water levels in the Great Lakes, causing serious environmental and socioeconomic impacts. During the 1980s, high lake levels resulted in the destruction of beaches, erosion of shorelines, and the flooding and destruction of near-shore structures. Low lake levels can affect the supply and quality of water, restrict shipping, and result in the loss of wetlands. Future changes in lake levels are uncertain and the subject of research. Reduced winter ice cover from warmer temperatures also leaves shores vulnerable to erosion and flooding.

Projected Change in Winter Precipitation

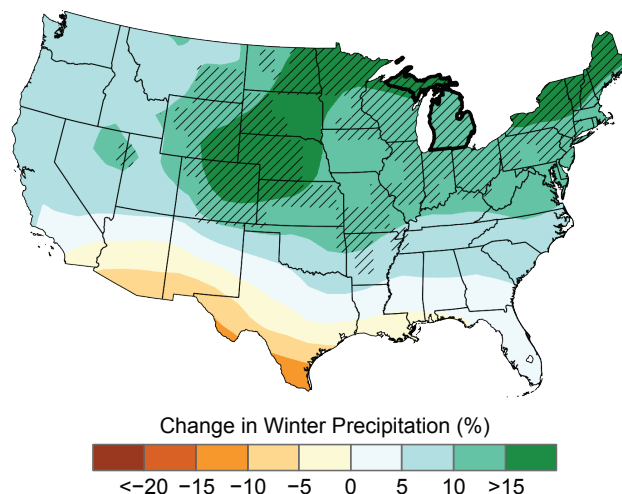


Figure 5: Projected changes in total winter (December–February) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. Precipitation is projected to increase in Michigan, with the largest increases projected for winter and spring. Sources: CISESS and NEMAC. Data: CMIP5.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

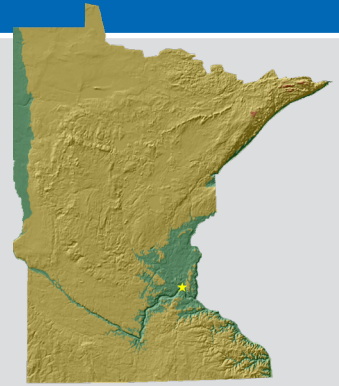
MINNESOTA

Key Messages

Temperatures in Minnesota have risen more than 2.5°F since the beginning of the 20th century. Under a higher emissions pathway, historically unprecedented warming is projected during this century. While warmer temperatures will reduce heating energy demand and lengthen the growing season, they will also increase the intensity of naturally occurring droughts.

Precipitation has increased over the last 100 years. Spring precipitation is projected to increase by about 15% to 20% by midcentury.

Extreme precipitation events are projected to increase in frequency and intensity, resulting in increased flooding and associated impacts, such as increased erosion, infrastructure damage, and agricultural losses.



Minnesota's location in the interior of North America and the lack of mountains to the north and south expose the state to incursions of bitterly cold air masses from the Arctic in the winter and warm, humid air masses from the Gulf of Mexico in the summer, resulting in large temperature variations across the seasons. Winters are cold in the south and frigid in the north, and summers are mild to occasionally hot in the south and pleasantly cool in the north. The summer is characterized by frequent warm air masses, either hot and dry continental air masses from the arid west and southwest or warm and moist air that pushes northward from the Gulf of Mexico. The summer is also punctuated by periodic intrusions of cooler air from Canada, providing breaks from the heat. Temperature extremes have ranged from as low as -60°F (February 2, 1996, at Tower) to as high as 115°F (July 29, 1917, at Beardsley). Among the non-mountainous U.S. states, Minnesota has the third-largest range of highest to lowest temperatures. The state's location on the eastern edge of the transition zone between the humid climate of the eastern United States and the semiarid climate of the Great Plains also creates large differences in average precipitation across the state. Snowstorms are a normal part of the winter and early spring climate, with annual average snowfall ranging from 30 to 70 inches over most of the state, with higher values near 90 inches along the shores of Lake Superior.

Observed and Projected Temperature Change

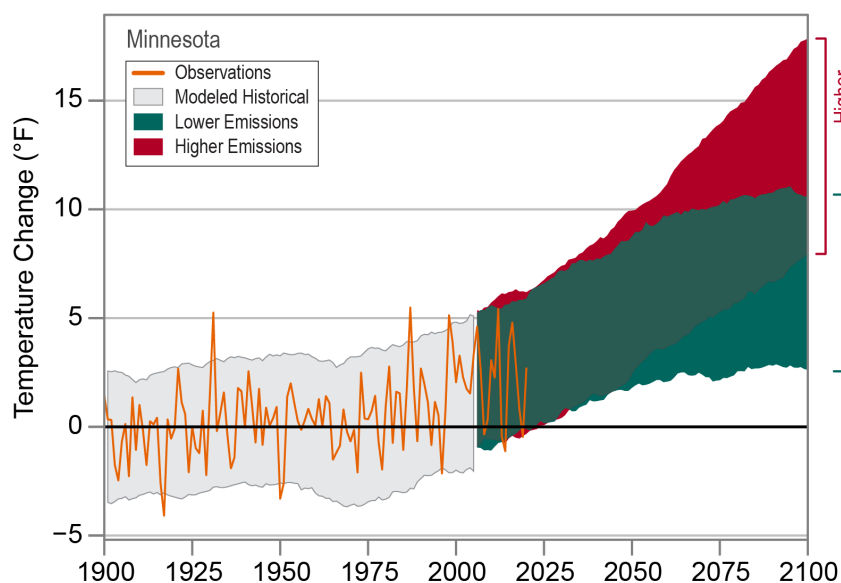


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Minnesota. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Minnesota (orange line) have risen more than 2.5°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 2°F warmer than the historical average; green shading) and more warming under

a higher emissions future (the hottest end-of-century projections being about 10°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

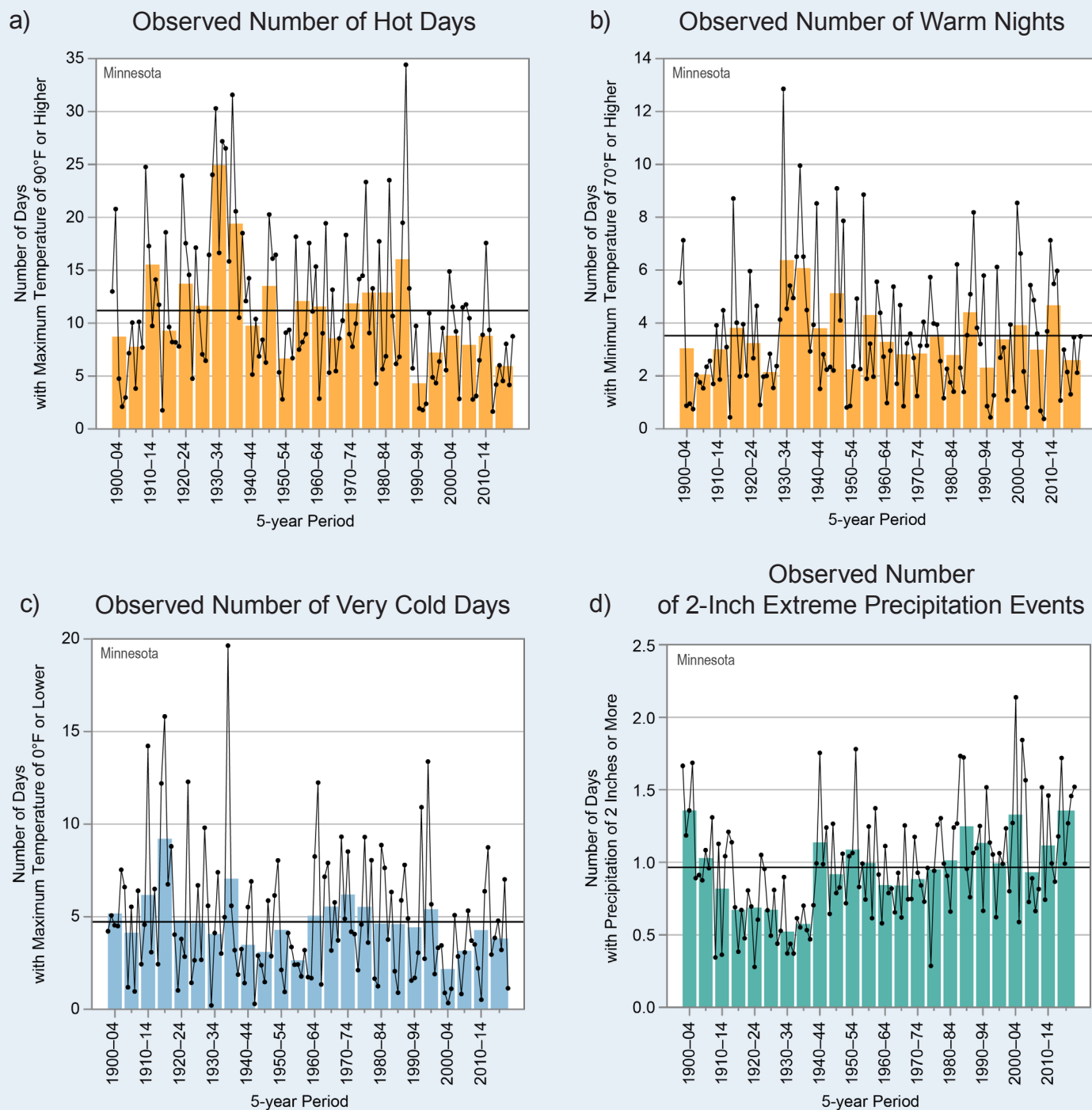


Figure 2: Observed annual number of (a) hot days (maximum temperature of 90°F or higher), (b) warm nights (minimum temperature of 70°F or higher), (c) very cold days (maximum temperature of 0°F or lower), and (d) 2-inch extreme precipitation events (days with precipitation of 2 inches or more) for Minnesota from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 11 days, (b) 3.5 nights, (c) 4.7 days, (d) 1.0 days. Since 1990, Minnesota has experienced a below average number of hot days. The number of warm nights peaked during the 1930s and shows no long-term trend. Since 1980, the number of very cold days has been near or below average. The number of 2-inch extreme precipitation events was above the long-term average during the most recent 6-year period (2015–2020); a typical station experiences about 1 event per year. Sources: CISESS and NOAA NCEI. Data: (a, b, c) GHCN-Daily from 21 long-term stations; (d) GHCN-Daily from 25 long-term stations.

Temperatures in Minnesota have risen more than 2.5°F since the beginning of the 20th century (Figure 1). Since 1998, Minnesota has experienced 8 of its 10 warmest years on record. This warming has been concentrated in the winter, while summers have not warmed as much. Summer warming has been mostly due to an increase in nighttime temperatures, with the coolest nights of summer becoming warmer. By contrast, summer daytime high temperatures have increased very little, which is reflected in a below average occurrence of hot days (Figure 2a). There is no overall trend in warm nights (Figure 2b). The winter warming trend is reflected in a below average number of very cold days since 2000, with a historic low occurring during the 2000–2004 period (Figure 2c). In addition, the ice-out date for Lake Osakis has been earlier than April 16 for 11 years since 2000 (Figure 3).

Total annual precipitation in Minnesota has been above the long-term (1895–2020) average since 1990 (Figure 4). The number of 2-inch extreme precipitation events has been mostly above average since 1985, with the 2015–2020 period having the highest recorded multiyear average (Figure 2d). Annual average precipitation, including rainfall and the water equivalent found in snowfall, ranges from 23 inches in the far northwest to more than 35 inches in the southeast. Nearly two-thirds of annual precipitation falls during the growing season (May through September). However, occasional drought is a natural feature of the climate, occurring when anomalous circulation patterns bring in dry air from the interior of North America.

Between 2000 and 2012, extreme weather events (including extreme drought, summer heat waves, severe storms, heavy rain and flooding, and tornadoes) caused more than \$4 billion in property damages. In general, thunderstorms cause more property damage in Minnesota than any other type of extreme event. The annual frequency of thunderstorm days is roughly 45 days in the southern part of the state and 30 days along the northern border. Due to Minnesota's northern location, heat waves are infrequent but can have severe consequences for populations less acclimatized to these events. Between 1995 and 2012, excessive heat events occurred most frequently in the central and southern counties (Figure 5). Since 2000, the number of very heavy rains (6 inches or more in a day) has been 2 to 3 times higher than in the 20th century.

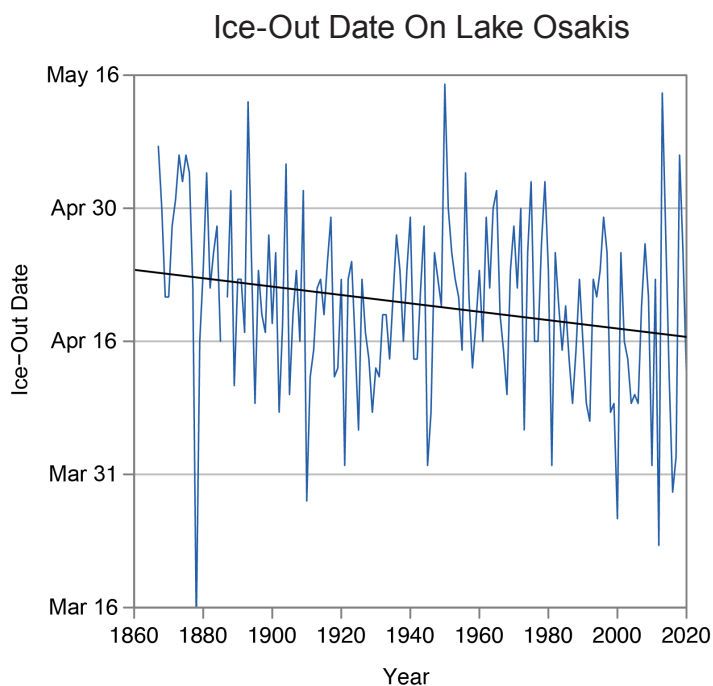


Figure 3: Annual changes in ice-out dates for Lake Osakis (blue line) from 1867 to 2020. The black line shows the long-term trend. Lake Osakis ice-out dates have been getting earlier over the last few decades, with 3 of the 5 earliest dates occurring since 2000. Source: Minnesota Department of Natural Resources.

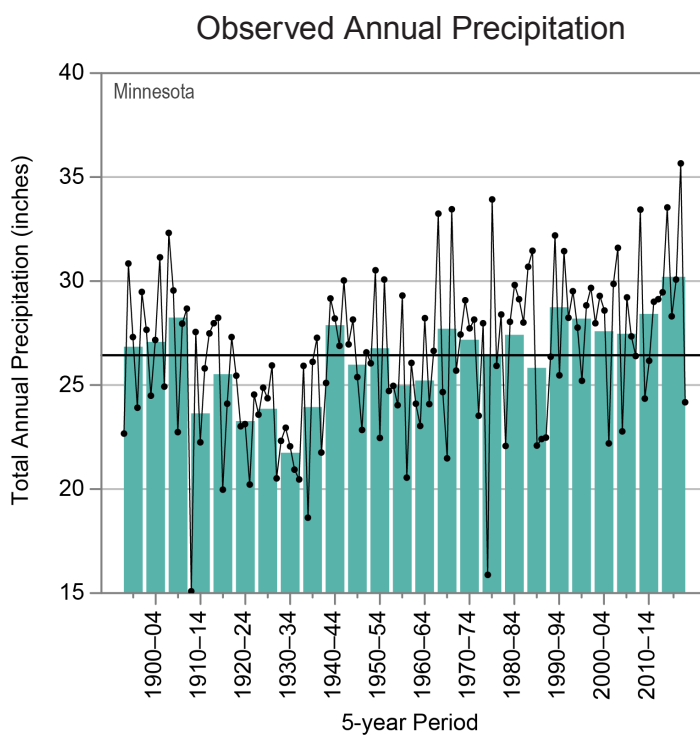
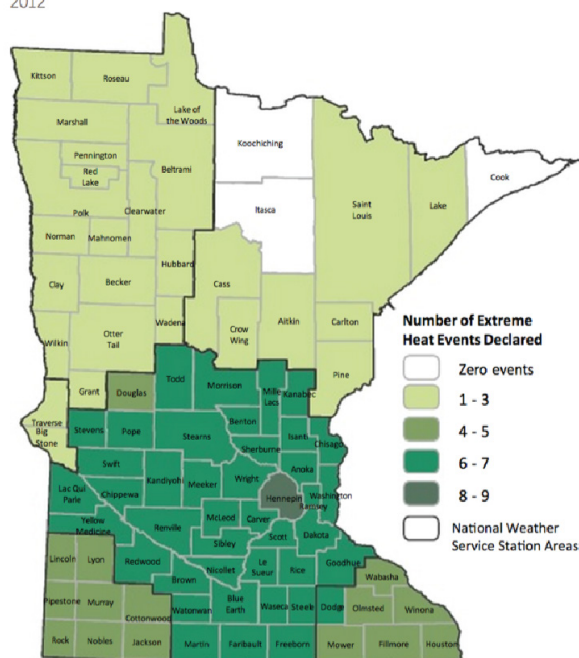


Figure 4: Observed total annual precipitation for Minnesota from 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 26.4 inches. The driest multiyear periods were in the 1910s through the 1930s, and the wettest were from the 1990s to the present. The driest consecutive 5-year interval was 1932–1936, and the wettest was 2015–2019. Sources: CISESS and NOAA NCEI. Data: nClimDiv.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of this century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. Increases in the number of extremely hot days and decreases in the number of extremely cold days are projected to accompany the overall warming.

Number of Extreme Heat Events by County 1995-2012

FIGURE IV-3: NUMBER OF EXTREME HEAT EVENTS BY COUNTY 1995-2012



Data source: NOAA National Climatic Data Center (NCDC, 2013).

Figure 5: Total number of extreme heat events by county for Minnesota from 1995 to 2012. Excessive heat events occurred more frequently in counties located in central and southern Minnesota. Source: Minnesota Climate Change Vulnerability Assessment. Data: NCEI Storm Events Database. Used with permission of Minnesota Department of Health.

Annual average precipitation is projected to increase, with increases most likely occurring in winter and spring (Figure 6). Minnesota is part of a large area of the Northern Hemisphere in the higher mid-latitudes projected to see increases. Increases in intense rainfall are also expected. Despite these increases in precipitation, it is possible that future droughts will be more intense because of higher temperatures, which will increase the rate of soil moisture loss. In 2007, 24 counties in Minnesota received federal drought designations, while 7 counties were declared flood disasters. And in 2012, 55 counties received drought designations, while 11 counties were declared flood emergencies. Recent events demonstrate the likelihood of simultaneous increases in both flooding and drought severity within the state.

Projected Change in Spring Precipitation

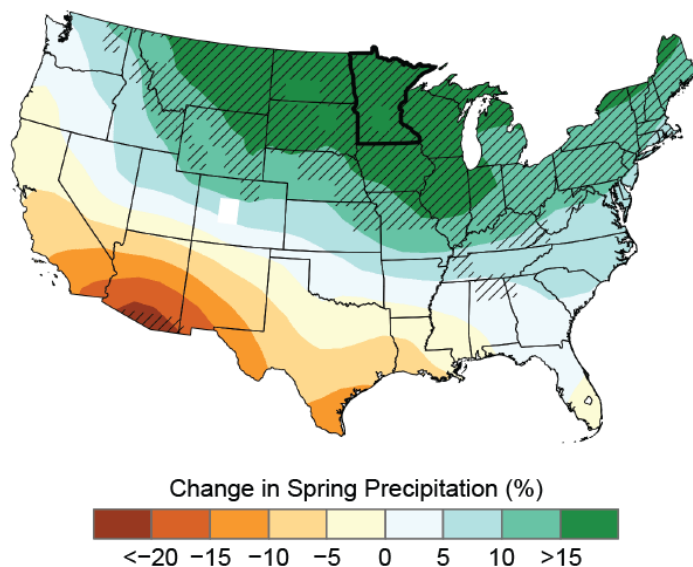


Figure 6: Projected changes in total spring (March–May) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. The white-out area indicates that the climate models are uncertain about the direction of change. Hatching represents areas where the majority of climate models indicate a statistically significant change. Minnesota is part of a large area of projected increases across the northern United States. Sources: CIESSE and NEMAC. Data: CMIP5.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

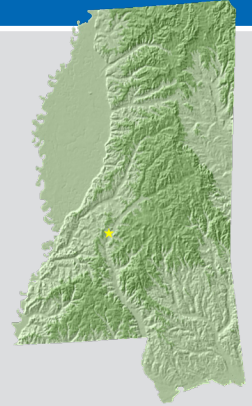
MISSISSIPPI

Key Messages

Temperatures in Mississippi have risen by a miniscule 0.1°F since the beginning of the 20th century, but recent years have been very warm. The warmest consecutive 5-year interval was the most recent, 2016–2020. Mississippi is one of the few areas globally to experience little net warming. However, historically unprecedented warming is projected during this century.

Increases in the frequency and intensity of extreme precipitation events are projected. Higher temperatures will increase the rate of soil moisture loss during dry spells, which could increase the intensity of naturally occurring droughts.

Sea level rise poses an increasing threat to Mississippi's coastal communities. Potential impacts of sea level rise include higher storm surge and disappearing barrier islands.



Mississippi is located between the Gulf of Mexico and the southern end of the vast, relatively flat plains of central North America, which extend from the Arctic Circle to the Gulf of Mexico. The state is therefore exposed to diverse air masses, including the warm, moist air from the Gulf of Mexico and drier continental air masses, which are cold in the winter and warm in the summer. Clockwise circulation of air around a semipermanent high-pressure system in the North Atlantic (the Bermuda High) causes a quite persistent southerly flow of air off the Gulf during the warmer half of the year. Thus, **Mississippi's climate is characterized by relatively mild winters, hot summers, and year-round precipitation.** In addition to serving as a predominant source of moisture, the warm waters of the Gulf of Mexico help moderate temperatures along Mississippi's coast. This mild climate is an important economic driver for agricultural production and tourism. Statewide annual average (1991–2020 normals) precipitation is 55.9 inches and ranges from 50 inches in the north to about 65 inches along the coast. Extreme temperatures range from a record low of −19°F at Corinth (January 30, 1966) to a record high of 115°F at Holly Springs (July 29, 1930).

Observed and Projected Temperature Change

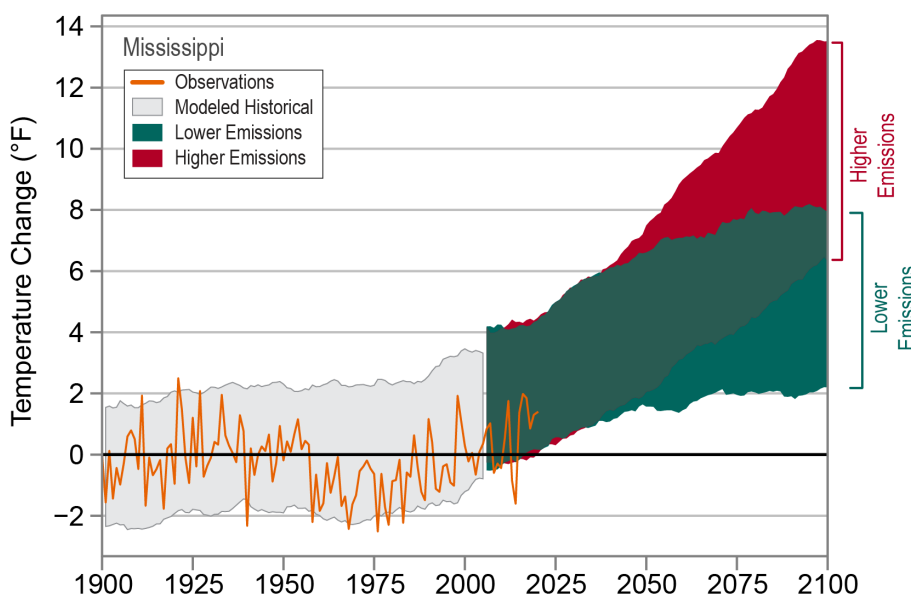


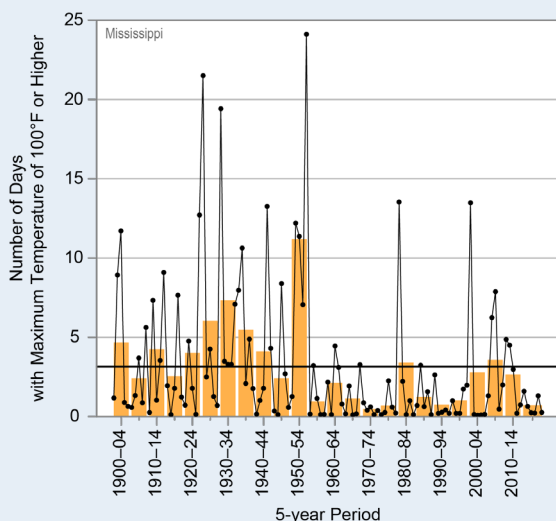
Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Mississippi. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Mississippi (orange line) have risen by a miniscule 0.1°F since the beginning of the 20th century, but recent years have been very warm. The warmest consecutive 5-year interval was the most recent, 2016–2020. Mississippi is one of the few areas globally to experience little net warming. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within, but on the low end of, the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming

is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projected years being about as warm as the hottest year in the historical record; green shading) and more warming under a higher emissions future (the hottest end-of-century projected years being about 11°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

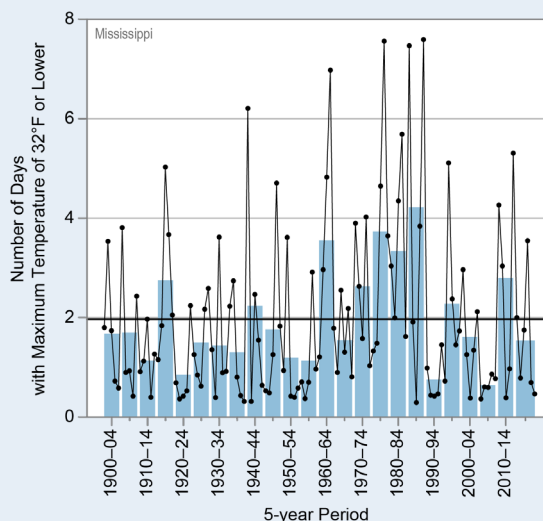
Temperatures in Mississippi have risen by a miniscule 0.1°F since the beginning of the 20th century, but recent years have been very warm. The warmest consecutive 5-year interval was the most recent, 2016–2020. Mississippi is one of the few areas globally to experience little net warming (Figure 1). Temperatures in Mississippi were above average in the 1920s, 1930s, and 1950s, followed by a substantial cooling of almost 2°F throughout the 1960s and 1970s. Temperatures have risen since that cool period by

more than 2°F. The contiguous United States as a whole has warmed by about 1.8°F since 1900, with only slight cooling from the 1930s into the 1960s. Hypothesized causes for this difference in warming rates include increased cloud cover and precipitation, increased small particles from coal burning, natural factors related to forest regrowth, decreased heat flux due to irrigation, and multidecadal variability in North Atlantic and tropical Pacific sea surface temperatures.

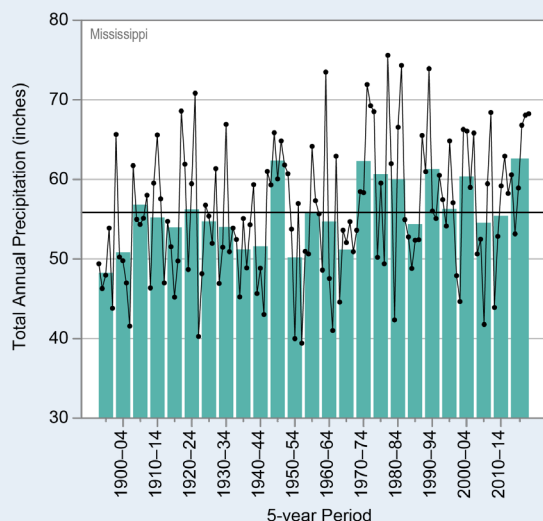
a) Observed Number of Extremely Hot Days



b) Observed Number of Freezing Days



c) Observed Annual Precipitation



d) Observed Summer Precipitation

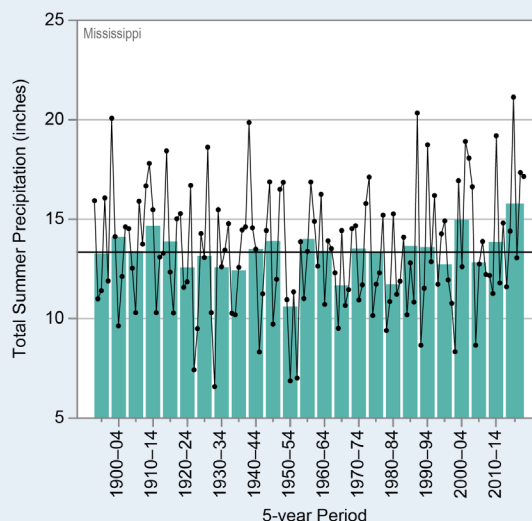


Figure 2: Observed (a) annual number of extremely hot days (maximum temperature of 100°F or higher), (b) annual number of freezing days (maximum temperature of 32°F or lower), (c) total annual precipitation, and (d) total summer (June–August) precipitation for Mississippi from (a, b) 1900 to 2020 and (c, d) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 3.2 days, (b) 2.0 days, (c) 55.9 inches, (d) 13.3 inches. Since 1955, the number of extremely hot days has generally been below average. The number of freezing days shows wide variability but has generally been below average since 1990. Annual precipitation has generally been above average since 1970, while summer precipitation shows no long-term trend. Sources: CISESS and NOAA NCEI. Data: (a, b) GHCN-Daily from 17 long-term stations; (c, d) nClimDiv.

The number of extremely hot days was generally above average in the first half of the 20th century, but since 1955, the number of these days has generally been below average (Figure 2a). During the last 11 years, the number of very warm nights has been above average, with the 2010–2014 multiyear average exceeding that of previous multiyear-year periods (Figure 3). Since 2005, summer temperatures have been above average, but the highest multiyear average occurred during the 1950–1954 period (Figure 4). The number of freezing days was mostly well above average between 1960 and 1989 but has been highly variable since then (Figure 2b). While the recent trend is toward fewer extremely cold events, a historic cold wave affected the state during February 11–20, 2021. In the northwest, temperatures remained below freezing for 8 consecutive days and fell to around 0°F. Heavy snow (more than 10 inches in some locations) and severe icing caused widespread damage. Drinking water supplies in the state capital, Jackson, were not fully restored for weeks.

Total annual precipitation in Mississippi has generally been above average since 1970 (Figure 2c). The driest consecutive 5-year interval was 1895–1899, averaging 48.3 inches per year, while the wettest was 2016–2020, averaging 63.1 inches. Total summer precipitation shows no long-term trend; however, the highest multiyear average occurred during the 2015–2020 period (Figure 2d). The number of 3-inch extreme precipitation events has generally been above average since 1970 (Figure 5). Agricultural droughts (inadequate soil moisture levels to meet crop water demands) occur frequently during the summer. Since the creation of the United States Drought Monitor map in 2000, Mississippi has been completely drought-free approximately 48% of that time (2000–2020), and at least half of the state has been in drought conditions approximately 12% of that time.

Extreme weather events in Mississippi include severe thunderstorms, flooding, extreme heat, tornadoes, winter storms, and tropical cyclones (hurricanes and tropical storms). Between 2005 and 2020, the Federal Emergency Management Agency granted 29 disaster declarations to the state; 23 were for severe storms, tornadoes, and flooding events, and the other 6 were for hurricanes. The typical flood season is November through June, when the Mississippi River's flow is at its peak. Tropical cyclone flooding on smaller rivers occurs in the late summer and fall. Flooding of historic proportions occurred along the

Observed Number of Very Warm Nights

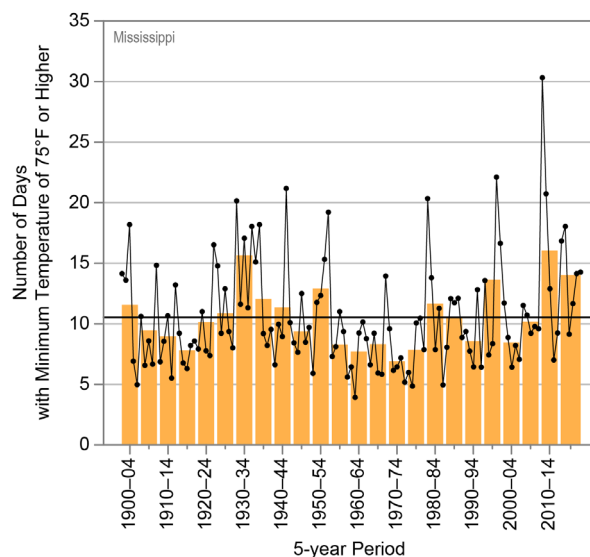


Figure 3: Observed annual number of very warm nights (minimum temperature of 75°F or higher) for Mississippi from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 11 nights. The number of very warm nights has generally been above average since 2010. The multiyear average for the 2010–2014 period exceeded that of the previous highest multiyear period (1930–1934). Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 17 long-term stations.

Observed Summer Temperature

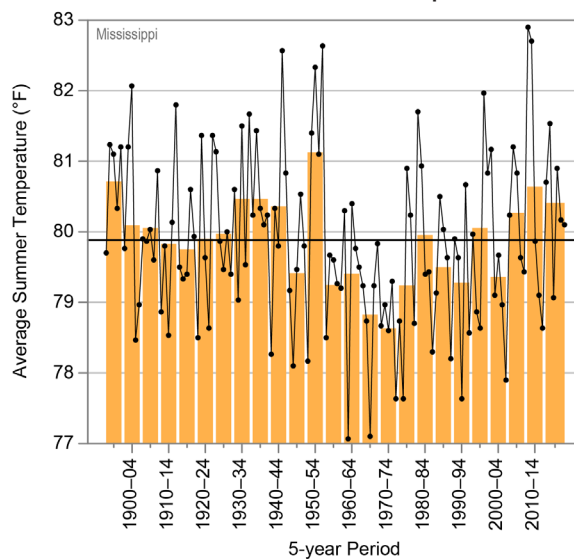


Figure 4: Observed summer (June–August) average temperature for Mississippi from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-summer average). The horizontal black line shows the long-term (entire period) average of 79.9°F. Summer temperatures have been above average since 2005, including the two warmest summers on record, 2010 and 2011. Sources: CISESS and NOAA NCEI. Data: nClimDiv

Mississippi River in the spring of 2011, following record snowmelt and unprecedented rainfall upstream of the state. Agricultural production damages exceeded \$500 million in Mississippi alone.

Mississippi is at risk for catastrophic damage from hurricanes. In 1969, Hurricane Camille devastated parts of the state as either the strongest (peak wind speed) or the second strongest (minimum pressure) Category 5 storm to strike the United States in the 20th century. Mississippi alone incurred damages of more than \$900 million. In 2005, Hurricane Katrina caused extensive damage along the Mississippi coast and inland, resulting in 238 fatalities and billions of dollars in damages. The storm surge at Pass Christian was 22.6 feet for Camille and 27.8 feet for Katrina. Along the Mississippi coast, surges of approximately 15 feet or greater have an average return period (estimated average time between events) of 25 years, and surges of 20 feet or greater have an average return period of 50 to 100 years (Figure 6).

Tornadoes are another important weather hazard for Mississippi. **Between 1985 and 2019, Mississippi averaged 46 tornadoes annually, with 4 fatalities per year.** The state ranks twelfth nationally for the total number of reported tornadoes but first for the number of tornado deaths per million people. Since 2005, the state has experienced its four highest annual number of tornadoes: 2005 (105 tornadoes), 2008 (109 tornadoes), 2011 (94 tornadoes), and 2019 (113 tornadoes). Tornadoes occur year-round, but there is a distinct tornado season with a high peak of events in April and a second, smaller peak in November.

Historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to exceed historical record levels in most years by the middle of this century. Since the 1970s, Mississippi temperatures have generally been within the range, but on the low end, of model-simulated temperatures. The projected rate of warming over the next several decades is similar to the observed warming rate since the 1970s.

Summer precipitation is projected to decrease in Mississippi, although the projected decreases are smaller than natural variations (Figure 7). Little change is projected for spring precipitation. Increases are

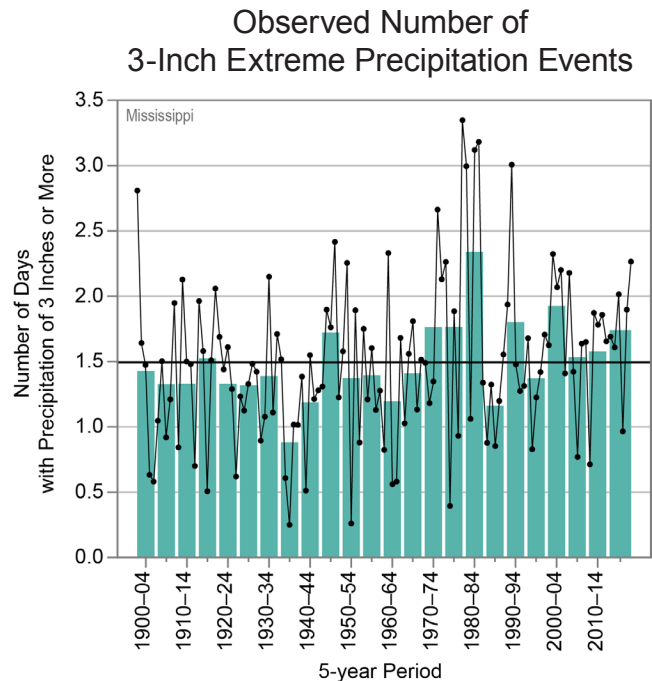


Figure 5: Observed annual number of 3-inch extreme precipitation events (days with precipitation of 3 inches or more) for Mississippi from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 1.5 days. A typical station experiences 1 to 2 events per year. The number of 3-inch extreme precipitation events has generally been above average since 1970, with the highest number occurring during the 1980–1984 period. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 20 long-term stations.

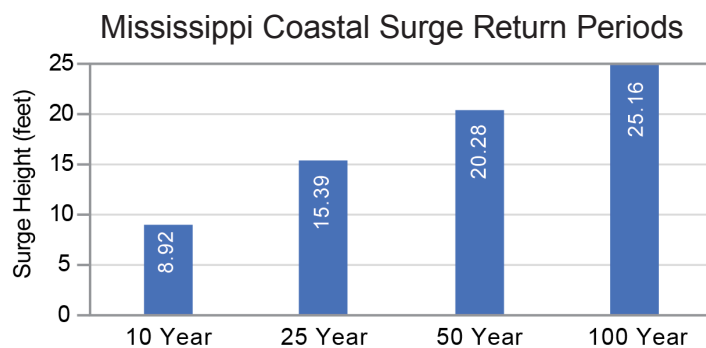


Figure 6: Storm surge heights occurring at selected average return intervals (10, 25, 50, and 100 years) along the Mississippi Gulf Coast. Storm surges of 22.6 feet (recorded for Camille) and 27.8 feet (recorded for Katrina) are expected to occur less than once every 50 years and 100 years, respectively. Sources: CISESS and NOAA NCEI. Data: Needham et al. 2012.

projected for fall and winter, but the increases are smaller than natural variations. Increases in evaporation rates due to rising temperatures may increase the rate of soil moisture loss and the intensity of naturally occurring droughts. During such droughts, decreased water availability will likely have important implications for the region's and the state's agricultural economy.

Since 1900, global average sea level has risen by about 7–8 inches. It is projected to rise another 1–8 feet, with a likely range of 1–4 feet, by 2100 as a result of both past and future emissions from human activities (Figure 8). Sea level rise along the Mississippi coast may be even higher. The closest tide gauge with long-term data (at Alabama’s Dauphin Island) reports a rise of more than 11 inches over the past century. Sea level rise has caused an increase in tidal floods associated with nuisance-level impacts. Nuisance floods are events in which water levels exceed the local threshold (set by NOAA’s National Weather Service) for minor impacts. These events can damage infrastructure, cause road closures, and overwhelm storm drains. Nuisance flooding has increased in all U.S. coastal areas, with more

rapid increases along the East and Gulf Coasts. Nuisance flooding events in Mississippi are likely to occur more frequently as global and local sea levels continue to rise.

Sea level rise has the potential to significantly damage critical transportation assets and negatively impact coastal resort communities along the Gulf Coast of Mississippi. Increasing erosion of the barrier islands may exacerbate the potential impacts of sea level rise, as these islands can shield the densely populated coastal areas, such as Gulfport and Biloxi, from storm surge. Horn Island, for example, is losing sediment faster than it can be replenished.

Projected Change in Summer Precipitation

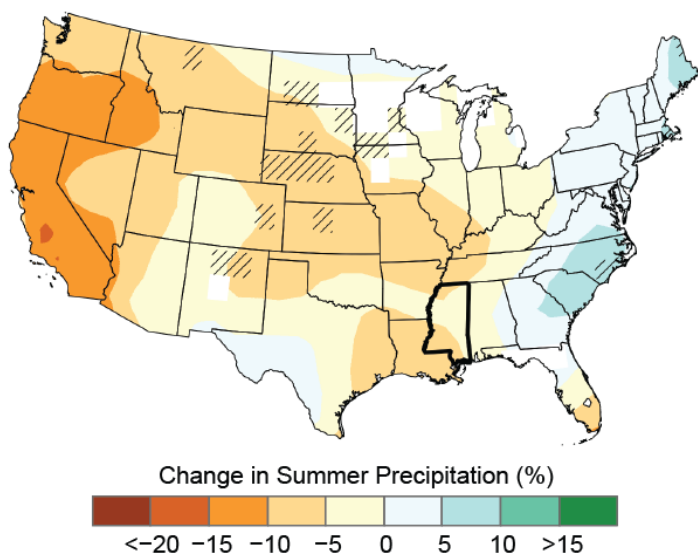


Figure 7: Projected changes in total summer (June–August) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Whited-out areas indicate that the climate models are uncertain about the direction of change. Hatching represents areas where the majority of climate models indicate a statistically significant change. While the map indicates slight decreases for Mississippi, these changes are minimal compared to natural variations and are not statistically significant. Mississippi is part of a large area of the Southeast where projected summer precipitation changes are small compared to natural variations. Sources: CISESS and NEMAC. Data: CMIP5.

Observed and Projected Change in Global Sea Level

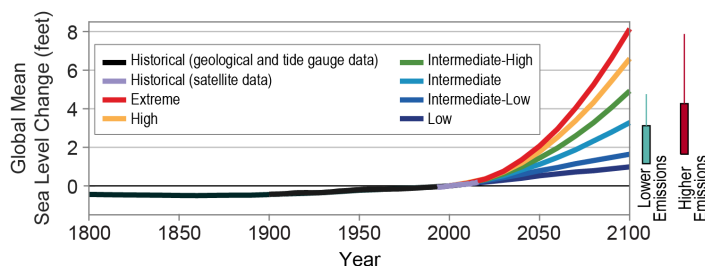


Figure 8: Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate-Low, royal blue; Intermediate, cyan; Intermediate-High, green; High, orange; and Extreme, red curves) relative to historical geological, tide gauge, and satellite altimeter GMSL reconstructions from 1800–2015 (black and magenta lines) and the very likely ranges in 2100 under both lower and higher emissions futures (teal and dark red boxes). Global sea level rise projections range from 1 to 8 feet by 2100, with a likely range of 1 to 4 feet. Source: adapted from Sweet et al. 2017.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

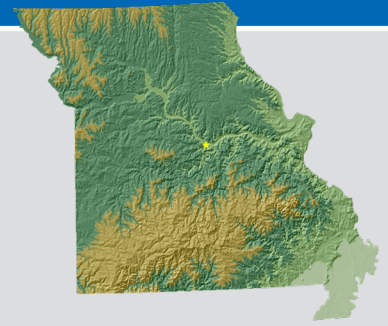
MISSOURI

Key Messages

Temperatures in Missouri have risen almost 1°F since the beginning of the 20th century. Winter warming is reflected in a below average occurrence of very cold nights since 1990. Under a higher emissions pathway, historically unprecedented warming is projected during this century.

Missouri has experienced an increase in extreme precipitation events, a trend that is projected to continue. Future increases in winter precipitation will pose a continued risk of spring planting delays and increased flooding along rivers and streams.

Severe drought, a natural part of Missouri's climate, is a risk to this agriculture-dependent state. Future increases in evaporation rates due to higher temperatures may increase the intensity of naturally occurring droughts.



Missouri's location in the interior of North America and the lack of mountain barriers to the north and south expose the state to incursions of cold arctic air masses in the winter and warm, moist air masses from the Gulf of Mexico in the summer. Annual average temperatures across the state vary by about 10°F from north to south. The hottest year on record was 2012, with an annual average temperature of 58.5°F, which is 3.9°F higher than the long-term (1895–2020) average.

Since the beginning of the 20th century, temperatures in Missouri have risen almost 1°F (Figure 1), and temperatures in the 2000s have been higher than in any other historical period with the exception of comparable temperatures in the early 1930s Dust Bowl era. This warming has been concentrated in the winter and spring. Summer temperatures have recently been slightly above the long-term average but below levels experienced during the 1930s, a feature characteristic of much of the Midwest (Figure 2a). Due to extreme drought and poor land management practices, the summers of the 1930s remain the warmest on record. Recent summer temperatures have been characterized by much higher nighttime minimum temperatures (slightly above Dust Bowl levels; Figure 2c), while daytime maximum temperatures have been near the long-term average (Figure 2b). The

Observed and Projected Temperature Change

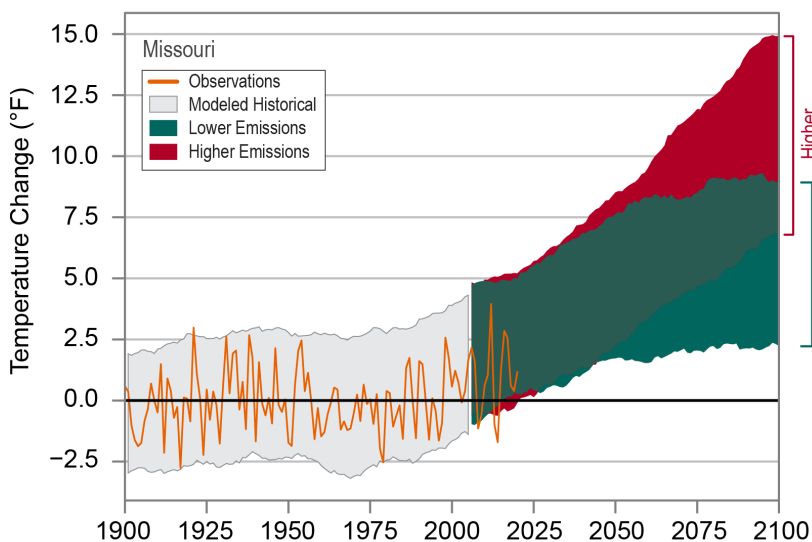
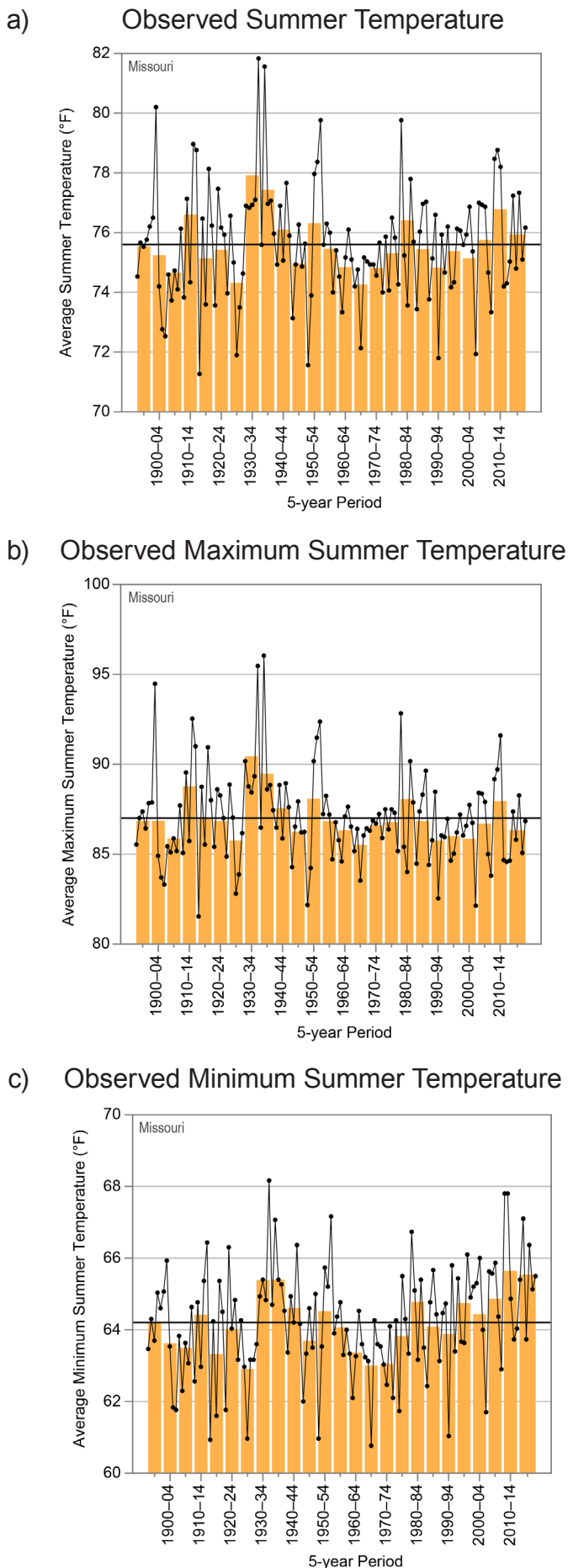


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Missouri. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Missouri (orange line) have risen almost 1°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 2°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 11°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

century projections being about 11°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.



state has also experienced a below average number of extremely hot days (Figure 3a). In addition to the overall trend of higher average temperatures, the state has seen an above average number of very warm nights (Figure 4). At St. Louis Lambert International Airport, the number of very warm nights has increased from 13 per year during 1961–1990 to 20 per year during 1991–2020. There is also an upward trend in summer humidity since the mid-20th century. The winter warming trend is reflected in a below average number of very cold nights since 1990 (Figure 3b).

Annual average precipitation varies widely across the state, from a low of 35 inches in the northwest to a high of 55 inches in the southeast. The northern part of the state receives more snowfall, with an annual average of more than 20 inches compared to less than 5 inches in the south. Statewide, total annual precipitation has ranged from a low of 25.1 inches in 1953 to a high of 57.1 inches in 1973. The driest consecutive 5-year interval was 1952–1956, and the wettest was 2007–2011 (Figure 3c). Summer precipitation exhibits no overall trend (Figure 3d). For large portions of the state, more than 40% of the total annual precipitation occurs on the 10 wettest days of the year.

Because agriculture is an important sector of Missouri's economy, **the state is particularly vulnerable to extreme precipitation conditions**. Both floods and droughts can result in billions of dollars in losses. In 2012, a severe drought across the Midwest had large impacts on Missouri. Rainfall for the critical growth period of May–July totaled only 5.8 inches, several inches below average, resulting in the third-driest growth period (after 1901 and 1936) in 126 years of record keeping. The drought was the worst Missouri had seen in 30 years. By the end of July, all 114 counties had been declared disaster areas.

Figure 2: Observed (a) summer (June–August) average temperature, (b) summer average maximum temperature, and (c) summer average minimum temperature for Missouri from 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 75.6°F, (b) 87.0, (c) 64.2°F. Missouri experienced its highest summertime temperatures during the extreme heat of the 1930s Dust Bowl era. Since 2010, summer temperatures have been above average because average nighttime lows have been the highest on record, even higher than the 1930s. Sources: CISESS and NOAA NCEI. Data: nClimDiv.

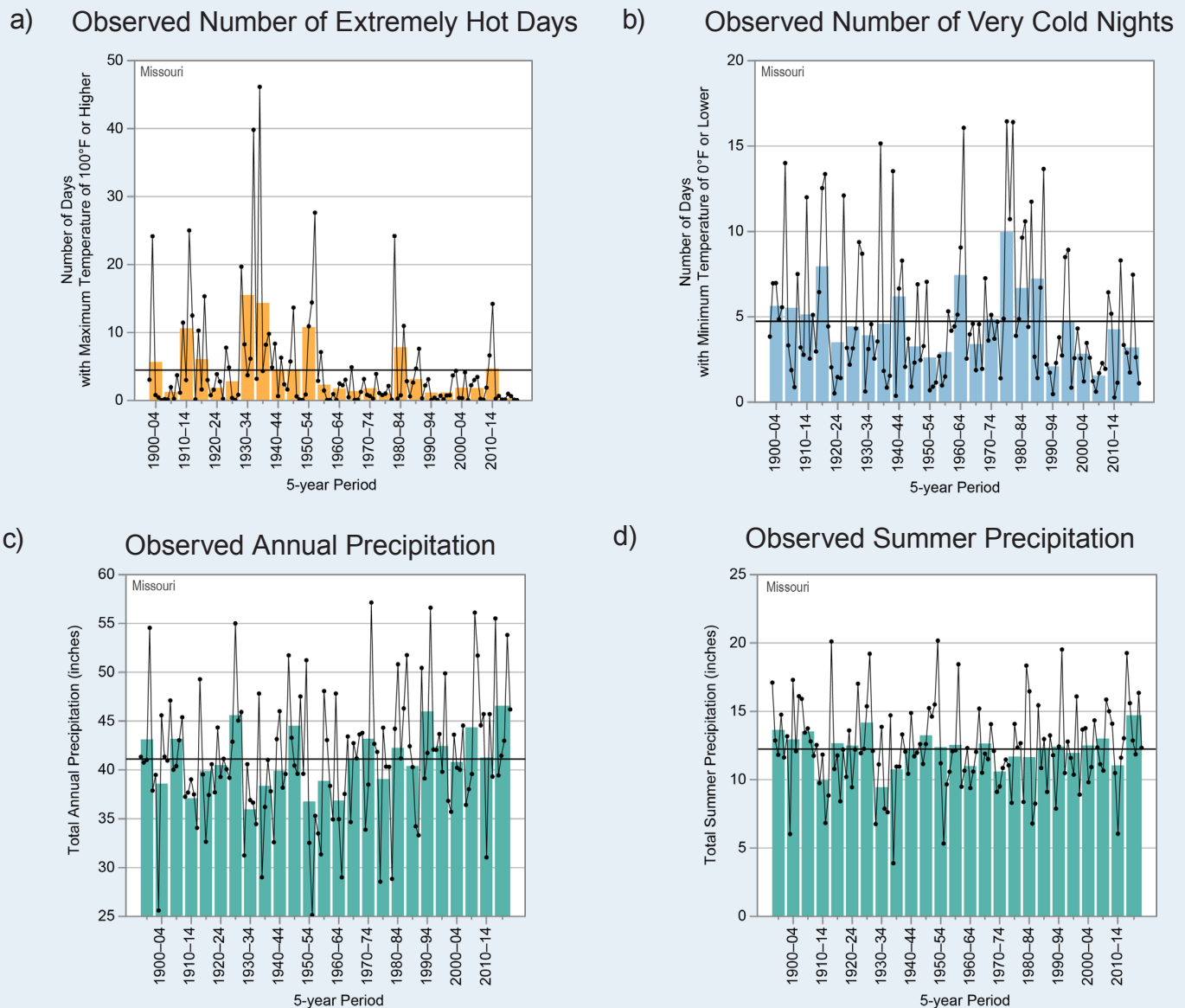


Figure 3: Observed (a) annual number of extremely hot days (maximum temperature of 100°F or higher), (b) annual number of very cold nights (minimum temperature of 0°F or lower), (c) total annual precipitation, and (d) total summer (June–August) precipitation for Missouri from (a, b) 1900 to 2020 and (c, d) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 4.5 days, (b) 4.7 nights, (c) 41.0 inches, (d) 12.2 inches. The number of extremely hot days and very cold nights has been mostly below average since 1990. Due to extreme drought and poor land management practices, the summers of the 1930s remain the warmest on record. Annual precipitation has been generally above average since 1990, while summer precipitation has been variable, with no extended periods of above or below average levels. The driest consecutive 5-year interval was 1952–1956, and the wettest was 2007–2011. Sources: CISESS and NOAA NCEI. Data: (a, b) GHCN-Daily from 19 long-term stations; (c, d) nClimDiv.

Missouri has experienced an increase in the number of extreme precipitation events (Figure 5), and the state's position in the lower river basins of several large midwestern rivers makes downstream flooding an extreme hazard. Missouri ranked fourth in state losses due to flooding during 1955–1997. One of the most severe climate events in the state's history was the 1993 Mississippi River flood. Near St. Louis, the Mississippi River crested at 49.6 feet, almost 20 feet above flood stage and 6 feet higher than the previous peak in

April 1973. The flooding resulted in billions of dollars in damages to homes, businesses, agriculture, and infrastructure. In 2011, the state experienced flooding along both the Mississippi and Missouri Rivers. A wet April along the Ohio River valley and record snowmelt in the upper Mississippi River basin caused record swelling along both the Ohio and Mississippi Rivers. To save the town of Cairo, Illinois, a levee was destroyed near Birds Point, flooding hundreds of thousands of acres of Missouri farmland. Property and crop damages

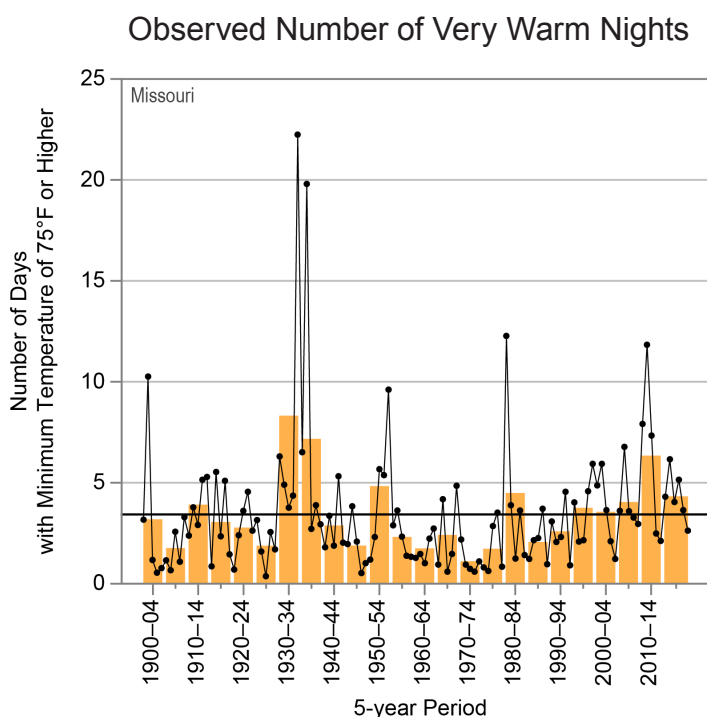


Figure 4: Observed annual number of very warm nights (minimum temperature of 75°F or higher) for Missouri from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 3.4 nights. During the 1930s, Missouri experienced a high frequency of very warm nights. This was followed by a cool period during the 1960s and 1970s. The 2010–2014 period had the highest number of very warm nights since the extreme heat of the 1930s. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 19 long-term stations.

were estimated to be more than \$300 million. In June of that year, runoff from a record winter snowpack in the northern Rockies, combined with heavy rains, caused major flooding along the entire length of the Missouri River. In mid-March 2019, a major storm and associated snowmelt resulted in historic Midwest flooding, the worst since 1993, inundating millions of acres of farmland and numerous cities and towns and causing widespread damage to roads, bridges, levees, and dams. Additional persistent, heavy rainfall pushed rivers to similar levels in early June 2019.

Severe thunderstorms are common in Missouri. During the summer, the state's lack of geographic barriers allows cold, dry air from the north to collide with warm, moist air from the Gulf of Mexico, triggering severe thunderstorms that can produce high winds, heavy rain, tornadoes, and hail. On April 10, 2001, a strong thunderstorm produced catastrophic hail damage across the I-70 corridor. The storm produced hail as

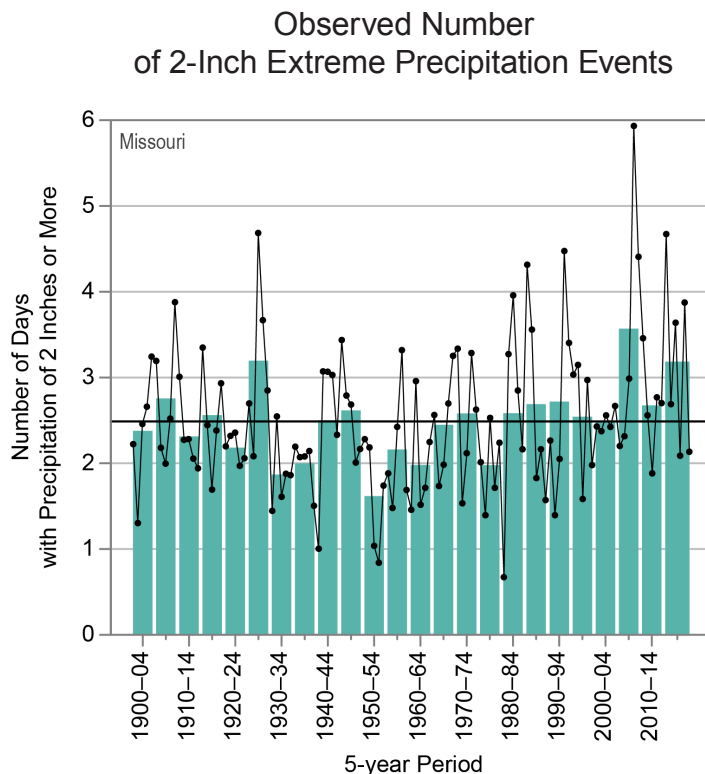


Figure 5: Observed annual number of 2-inch extreme precipitation events (days with precipitation of 2 inches or more) for Missouri from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 2.5 days. A typical reporting station experiences 2 to 3 events per year. Since 2005, Missouri has experienced an above average number of 2-inch extreme precipitation events, with the highest number occurring during the 2005–2009 period, when a typical station experienced 3 to 4 events per year. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 25 long-term stations.

large as 3 inches in diameter, and damages in the Kansas City and St. Louis areas were estimated at more than \$1 billion. **Missouri has a long and deadly history of tornadic storms.** On May 22, 2011, an EF5 tornado with winds exceeding 200 mph hit the city of Joplin, killing more than 150 people and causing billions of dollars in damages. This was the deadliest tornado in Missouri history. On March 18, 1925, the Tri-State Tornado, the deadliest tornado in U.S. history, tracked more than 200 miles from southeastern Missouri, across southern Illinois, and into Indiana. In Missouri, the storm killed at least 11 people and caused extensive property damage, including the near complete destruction of the town of Annapolis.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle

of this century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. In southern Missouri, the annual number of consecutive days with temperatures exceeding 95°F is projected to increase by up to 20 days. Temperature increases will cause future heat waves to be more intense, a concern for this region, which already experiences hot and humid conditions. Extreme heat is a particular concern for urban areas, such as St. Louis and Kansas City, where the urban heat island effect raises summer temperatures. During July 9–14, 1966, St. Louis experienced a severe heat wave that caused many deaths. In addition to daytime highs between 101°F and 106°F at St. Louis Lambert International Airport, nighttime temperatures never dropped below 77°F, and on July 12, the low was only 84°F. If the warming trend continues, future heat waves are likely to be more intense, and cold wave intensity is projected to decrease.

Although projections of overall annual precipitation are uncertain, winter and spring precipitation is projected to increase (Figure 6), while summer precipitation may decrease. Additionally, the frequency and intensity of extreme precipitation events are projected to increase, potentially increasing the frequency and intensity of floods. Springtime flooding in particular could pose a threat to Missouri's important agricultural economy by delaying planting and resulting in yield losses.

The intensity of droughts is projected to increase.

Even if precipitation increases in the future, rising temperatures will increase evaporation rates, resulting in more rapid loss of soil moisture. Thus, future summer droughts, a natural part of Missouri's climate, are likely to become more intense.

Projected Change in Spring Precipitation

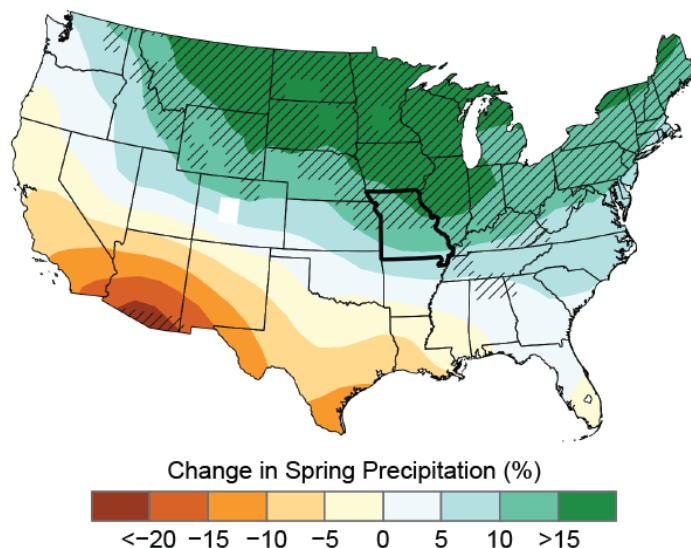


Figure 6: Projected changes in total spring (March–May) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. The white-out area indicates that the climate models are uncertain about the direction of change. Hatching represents areas where the majority of climate models indicate a statistically significant change. Missouri is part of a large area of projected increases in spring precipitation in the Northeast and Midwest. Sources: CISESS and NEMAC. Data: CMIP5.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

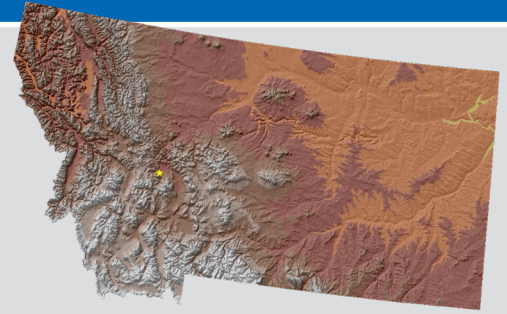
MONTANA

Key Messages

Temperatures in Montana have risen almost 2.5°F since the beginning of the 20th century, higher than the warming for the contiguous United States as a whole. This increase is most evident in winter warming, characterized by fewer very cold days since 1990. Under a higher emissions pathway, historically unprecedented warming is projected during this century.

Montana's mountains and river systems provide critical water resources for the state, as well as other downstream states. Projected increases in spring precipitation may have both positive (increased water supplies) and negative (increased flooding) impacts.

Higher temperatures, and possible decreased summer precipitation, will increase the rate of soil moisture loss during dry spells, leading to an increase in the intensity of naturally occurring droughts. The frequency and severity of wildfires are projected to increase in Montana.



Montana, the fourth largest U.S. state in land area, has large climatic variations due to its geographic diversity and altitudinal range. The central and eastern portions of the state are part of the Northern Great Plains, which experience warm summers and cold winters. The western part of the state is mountainous, with snowy winters and cool summers. Elevations across the state range from about 1,800 to 12,800 feet, leading to large variations in temperature. Average (1991–2020 normals) January temperatures at valley and plains locations range from less than 12°F in the northeast to greater than 25°F in some south-central and far western portions of the state, while average July temperatures range from less than 64°F in the western mountains to greater than 72°F in the southeastern plains.

Temperatures in Montana have risen almost 2.5°F since the beginning of the 20th century, higher than the warming for the contiguous United States as a whole. The first 21 years of this century represent the warmest period on record for Montana (Figure 1). Temperatures have warmed in all seasons and in most areas of the state.

Observed and Projected Temperature Change

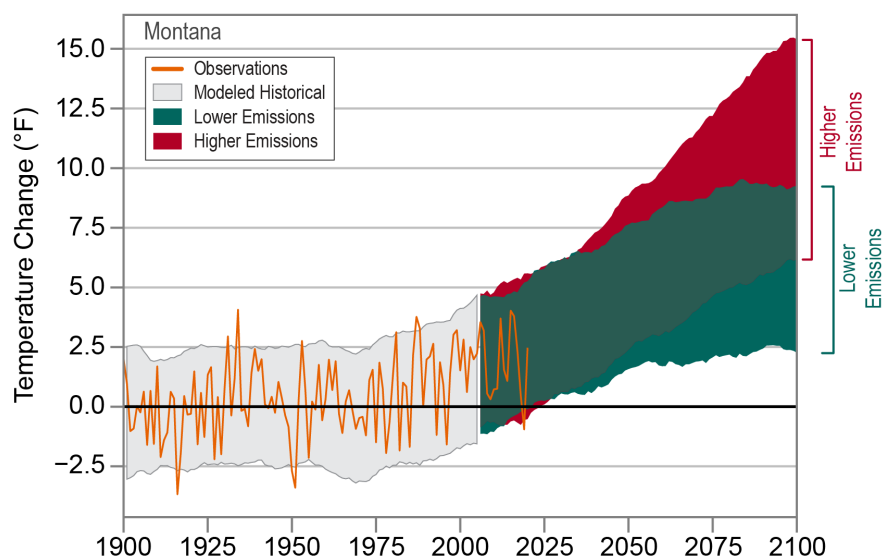


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Montana. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Montana (orange line) have risen almost 2.5°F since the beginning of the 20th century, higher than the warming for the contiguous United States as a whole. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about

2°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 11°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

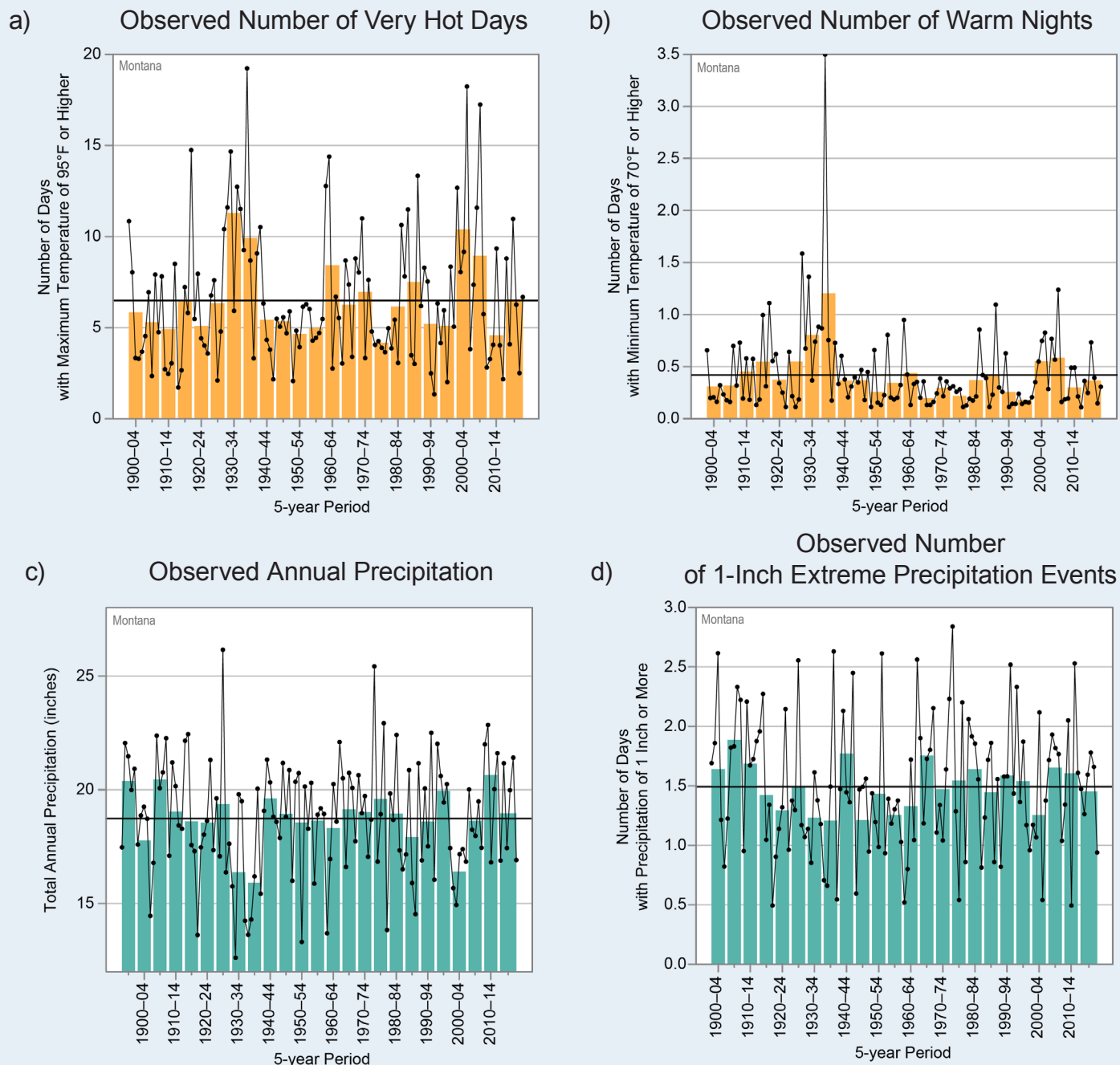


Figure 2: Observed (a) annual number of very hot days (maximum temperature of 95°F or higher), (b) annual number of warm nights (minimum temperature of 70°F or higher), (c) total annual precipitation, and (d) annual number of 1-inch extreme precipitation (days with precipitation of 1 inch or more) for Montana from (a, b, d) 1900 to 2020 and (c) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 6.5 days, (b) 0.4 nights, (c) 18.7 inches, (d) 1.5 days. (Note that for Figures 2a, 2b, and 2d, the average for individual reporting stations varies greatly because of the state's large elevation range.) The highest number of very hot days and warm nights occurred during the 1930s and early 2000s. Annual precipitation varies widely and shows no overall trend. The number of 1-inch extreme precipitation events has generally been near average since 1970; a typical station experiences 1 to 2 events per year. Sources: CISESS and NOAA NCEI. Data: (a, b) GHCN-Daily from 16 long-term stations; (c) nClimDiv; (d) GHCN-Daily from 20 long-term stations.

During 2000–2007, the state experienced its highest number of very hot days since the extreme summer heat of the 1930s Dust Bowl era (Figure 2a). With an annual average temperature of 44.9°F (3.6°F above the long-term [1895–2020] average), 2015 tied with 1934 for the hottest year on record. Montana rarely

experiences warm nights due to its dry air and high average elevation. The number of warm nights during the 2000s averaged about 50% higher than during the 1940s through the 1990s; the highest values on record occurred during the Dust Bowl era (Figure 2b). In addition to the overall trend of higher average

Observed Number of Very Cold Days

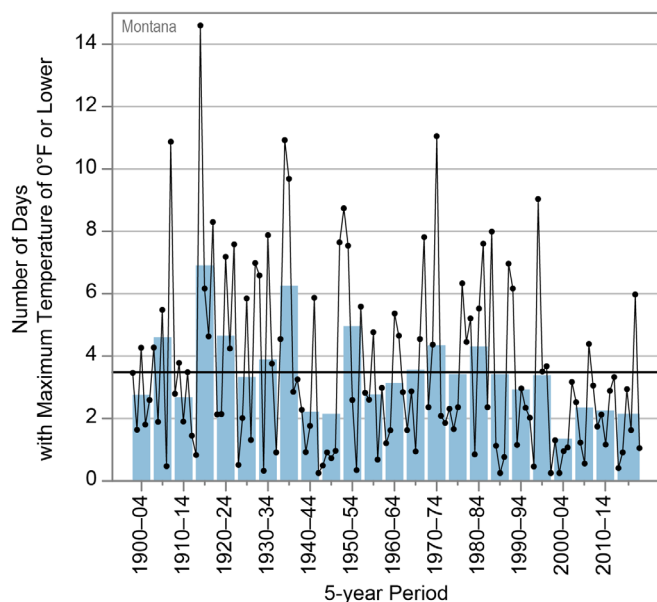


Figure 3: Observed annual number of very cold days (maximum temperature of 0°F or lower) for Montana from 1900–2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 3.5 days (note that the average for individual reporting stations varies greatly because of the state's large elevation range). The number of very cold days has been below average since 2000, indicative of winter warming in the state. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 16 long-term stations.

temperatures, the state has experienced a below average number of very cold days since 1985 (Figure 3). Additionally, the rise in winter and summer average temperatures has been quite pronounced (Figures 4a and 4b).

Montana's topographic variability causes large regional variations in precipitation, with annual totals ranging from less than 7 inches in lowland and valley locations across the southern portion of the state to more than 35 inches in the mountainous northwest. Some of the higher mountain locations can receive much more, with late-season snow depths averaging more than 40 inches of water content (Figure 5). Most of the state's precipitation falls during the summer months, although some areas in the mountains experience a peak during the winter and spring months due to abundant snowfall induced by airflow over the mountains. Statewide average precipitation has varied from a low of 12.6 inches in 1931 to a high of 26.2 inches in 1927. The wettest multiyear periods were in the late 1890s, early 1910s, and early 2010s, and the driest were in the 1930s and the early 2000s (Figure 2c). The wettest consecutive

5-year interval was 2010–2014, with an annual average of 20.7 inches, and the driest was 1933–1937, with an annual average of 15.6 inches. Annual snowfall varies across the state, with some areas in the mountains receiving more than 300 inches. The number of 1-inch extreme precipitation events has generally been near average since 1970 (Figure 2d).

During the summer months, the state experiences frequent thunderstorms, which can produce hail, lightning, and strong winds. Tornadoes are infrequent and occur almost entirely in the eastern third of the state. Montana's northern location and lack of mountain barriers to the north makes it highly susceptible to the impacts of winter storm systems, including heavy snows, high winds, and low wind chill temperatures. Blizzards are most common in the northeastern part of the state, occurring about five times per year. The eastern part of the state can experience bitterly cold temperatures, occasionally lower than –30°F. The state's record low of –70°F, observed at Rogers Pass (1954), is the lowest of the contiguous 48 states. Alternatively, the state is prone to summer hot spells, with an all-time high temperature of 117°F, observed at Medicine Lake and Glendive (1937 and 1893, respectively). This record bests those of more obvious states, such as Florida, and is a result of the dry air and downslope winds in the lower elevations of the eastern plains.

Chinook winds—warm and dry winds common along the eastern slopes of the Rocky Mountains—are a hazard to Montana during the winter months and often bring large temperature increases. Over January 14–15, 1972, chinook winds caused the temperature in Loma to increase from –54°F to 49°F (a 103°F change), the largest 24-hour temperature change in U.S. history. Although these winds can bring pleasant warmer temperatures during the winter months, they can be accompanied by strong gusts and dangerous crosswinds, resulting in property damage and quickly melting snow cover, even in mid-winter.

Because Montana serves as a major water source for other states, changes in precipitation can have broad impacts beyond its boundaries. Water from the state's rivers flows into the Atlantic Ocean via the Gulf of Mexico (Missouri River system), the Arctic Ocean via Hudson Bay (Belly, Saint Mary, and Waterton Rivers), and the Pacific Ocean (Columbia River system), making Montana one of

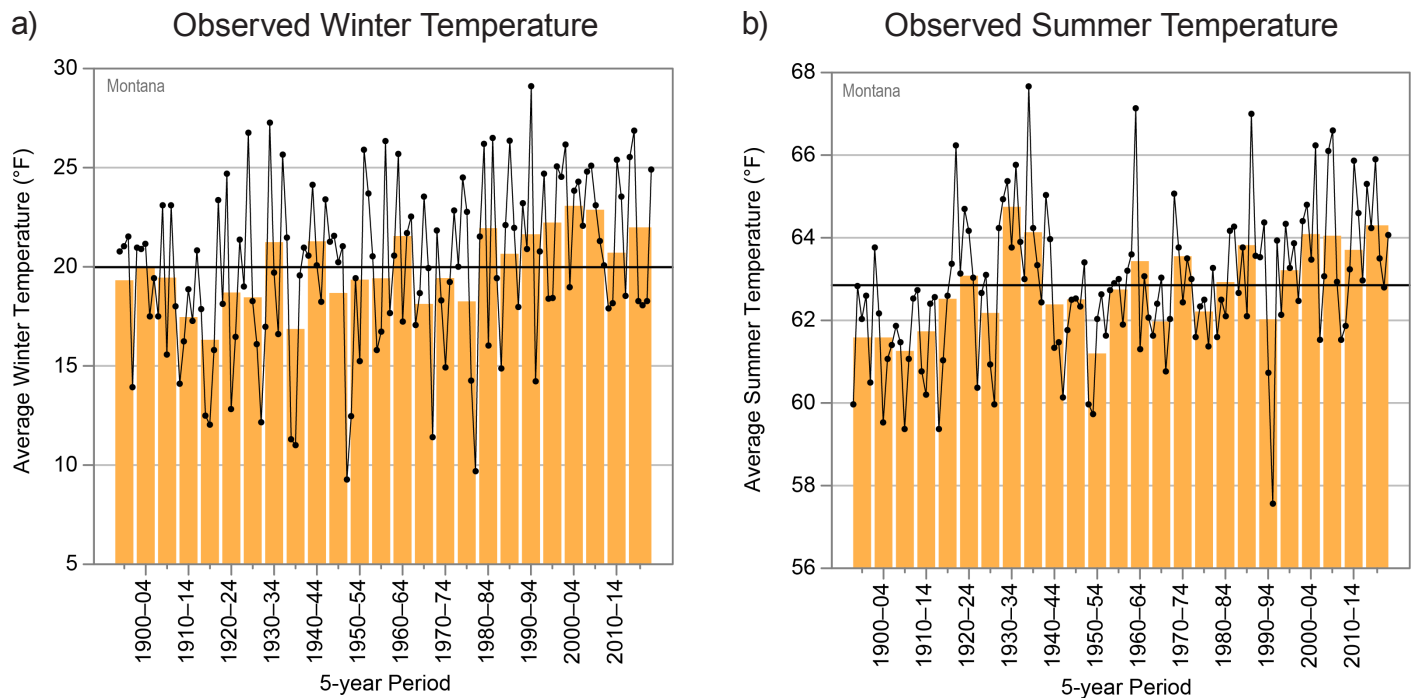


Figure 4: Observed (a) winter (December–February) and (b) summer (June–August) average temperature for Montana from (a) 1895–96 to 2019–20 and (b) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (first bar in Figure 4a is a 4-winter average, last bar in Figures 4a and 4b is a 6-winter and 6-summer average, respectively). The horizontal black lines show the long-term (entire period) averages of (a) 20.0°F and (b) 62.9°F. Since 1980, Montana has experienced above average winter temperatures. Since 1995, summer temperatures have been above average but have not surpassed the record high of the 1930 to 1934 period. Sources: CISESS and NOAA NCEI. Data: nClimDiv.

the few regions globally whose waters feed three oceans. Streamflow in these rivers relies on meltwater from the snowpack in the late spring and summer.

Extreme precipitation events during the spring thaw can cause severe flooding. In 1964, a cool spring delayed melting of the snowpack. From June 8 to 9, heavy rains fell on the above average snowpack, with some areas receiving more than 10 inches in 36 hours. This was one of the worst flash floods in the state’s history, causing at least 28 deaths and damages of more than \$50 million. In 2011, heavy spring rains, along with an extremely heavy snowpack, caused significant flooding across the state. Multiple stations reported more than 10 inches of rain during the month of May, making it the second-wettest May in Montana’s history, with many rivers hitting record levels. Below normal temperatures in the area caused pieces of floating ice to accumulate in some streams and rivers, leading to ice jams that obstructed streamflow and resulted in additional flooding. By mid-June, 31 of the state’s 56 counties and 4 of the state’s 7 reservations were declared disaster areas. Total damages across the state were estimated at more than \$50 million. Ice jam flooding can also occur during rapid spring warming.

As an agriculturally dependent state, Montana is particularly vulnerable to drought. The Dust Bowl is by far the most famous drought of the past 100 years, but recent severe droughts are also noteworthy. In 2012, the state experienced the driest July–September period in the historical record, dating back to 1895. By October 2012, much of the southern half of the state was in severe drought. The drought provided ideal conditions for wildfires and resulted in more than 2,000 fires burning more than 1.2 million acres. Warmer temperatures are increasing the risk of flash droughts, such as a severe event that occurred during the 2017 summer.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of the century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. Increases in heat wave intensity are projected, but the intensity of cold waves is projected to decrease. **Projected rising temperatures**

will also raise the snow line—the average lowest elevation at which snow falls. This will increase the likelihood that precipitation will fall as rain instead of snow, reducing water storage in the snowpack, particularly at those lower mountain elevations that are now on the margins of reliable snowpack accumulation. **Higher spring temperatures will also result in earlier melting of the snowpack, further decreasing water availability during the summer months.**

Although projections of overall annual precipitation are uncertain, winter and spring precipitation is projected to increase (Figure 6). Rising temperatures will affect snowmelt patterns, shifting runoff to earlier in the year. Heavy spring precipitation could increase the potential for flooding. Increased spring precipitation can have both positive and negative impacts on Montana's agricultural economy, improving soil moisture but potentially delaying planting and resulting in yield losses. Changes in snowmelt patterns could also affect other water-reliant industries, such as mining and tourism.

The intensity of future droughts is projected to increase. Even if overall precipitation increases, rising temperatures will increase the rate of soil moisture loss during dry spells. In addition, while fall, winter, and spring precipitation is projected to increase, a majority of climate models project summer decreases. Thus, summer droughts are likely to become more intense, potentially leading to increases in the frequency and severity of wildfires.

April 1 Snow Water Equivalent (SWE)
at Noisy Basin

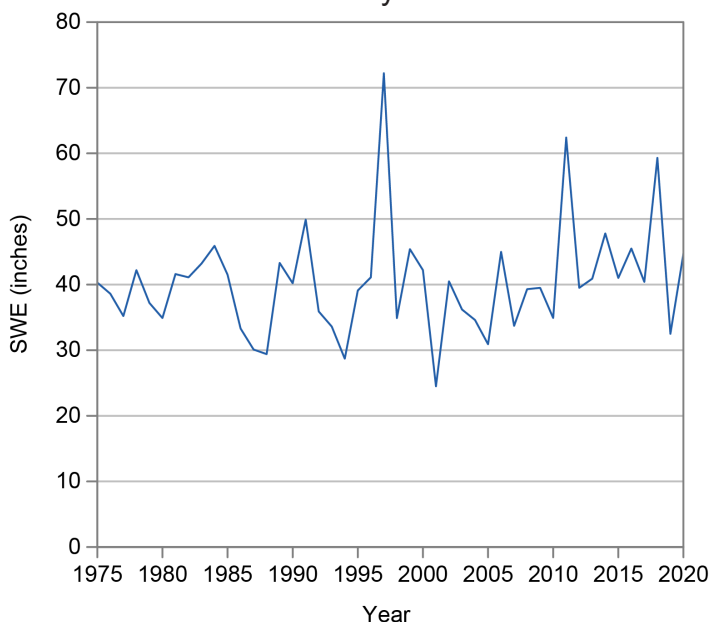


Figure 5: Variations in the April 1 snow water equivalent (SWE) at the Noisy Basin, Montana, SNOTEL site from 1975 to 2020. SWE, the amount of water contained within the snowpack, varies widely from year to year. In 2011, the April 1 snowpack reached the greatest depths since 1997. Melting of this snowpack led to severe flooding across the Northern Great Plains in the summer of 2011. Source: NRCS NWCC.

Projected Change in Spring Precipitation

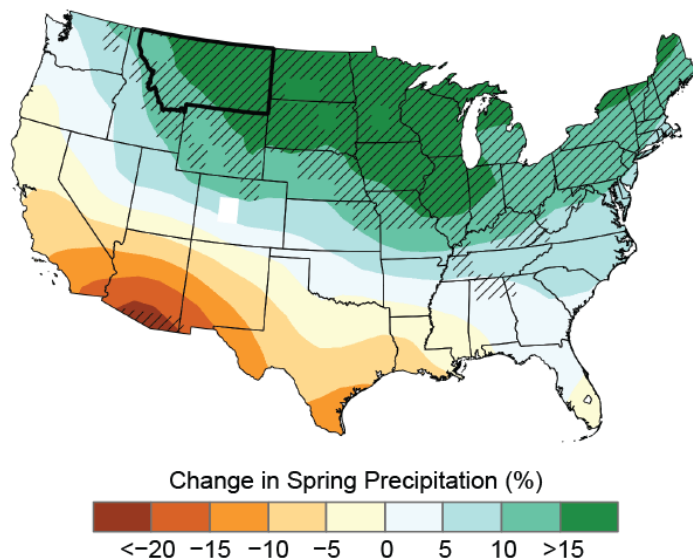


Figure 6: Projected changes in total spring (March–May) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. The white-out area indicates that the climate models are uncertain about the direction of change. Hatching represents areas where the majority of climate models indicate a statistically significant change. Sources: CISESS and NEMAC. Data: CMIP5.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

NEBRASKA

Key Messages

Temperatures in Nebraska have risen more than 1.6°F since the beginning of the 20th century, with warming concentrated in the winter and spring. Winter warming is evident in the below average occurrence of very cold nights since 1990. Under a higher emissions pathway, historically unprecedented warming is projected during this century.

Nebraska is a region of transition between the humid conditions to the east of the state and the semiarid conditions to the west, and as a result, precipitation in the state varies greatly from year to year. Projected increases in winter precipitation may have both positive and negative impacts on the state.

Droughts pose a particular risk to Nebraska's agricultural economy, although the impacts can be mitigated where irrigation is possible. Several droughts have occurred in recent years. Projected increases in temperature and evaporation rates may increase the intensity of future naturally occurring droughts.

Nebraska lies in the central Great Plains, straddling the transition from relatively abundant precipitation (averaging more than 34 inches annually; 1991–2020 normals) in the far southeast to semiarid conditions (averaging just over 17 inches) in the panhandle. The state is located far from the moderating effects of the oceans, and temperatures vary widely across seasons, averaging 25.1°F in January and 74.4°F in July. The hottest year on record was 2012, with an average temperature of 52.7°F, which was 4.1°F higher than the long-term (1895–2020) average.

Since the beginning of the 20th century, temperatures in Nebraska have risen more than 1.6°F (Figure 1). Since 2000, annual average temperatures have been higher than the long-term average and generally comparable to the 1930s Dust Bowl era. The warmest summers on record occurred in the 1930s, when drought and poor land management likely exacerbated the hot summer conditions (Figure 2b). Recent warming has been concentrated in the winter and spring, while summers have not warmed substantially, a characteristic of much of the Great Plains and Midwest. This lack of summer warming is reflected in a below average occurrence of extremely hot days (Figure 3a) and no overall trend in the number of warm nights (Figure 3b) since the 1960s. The winter warming trend is reflected in a below average number of very cold nights since 1990 (Figure 4). Winter temperatures peaked around 2000. The warmest consecutive 5-winter interval was 1998–2002. Winter temperatures have been slightly lower since then but have remained above the long-term (1895–2020) average.

Observed and Projected Temperature Change

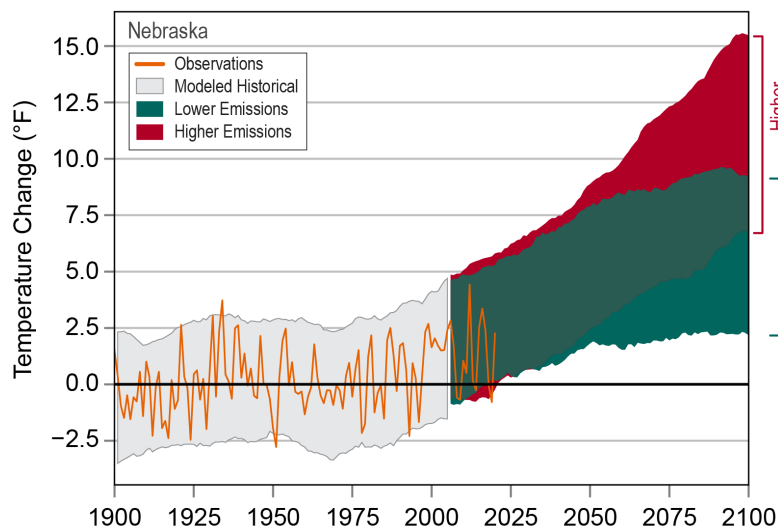


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Nebraska. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Nebraska (orange line) have risen more than 1.6°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 2°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 11°F warmer than

the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

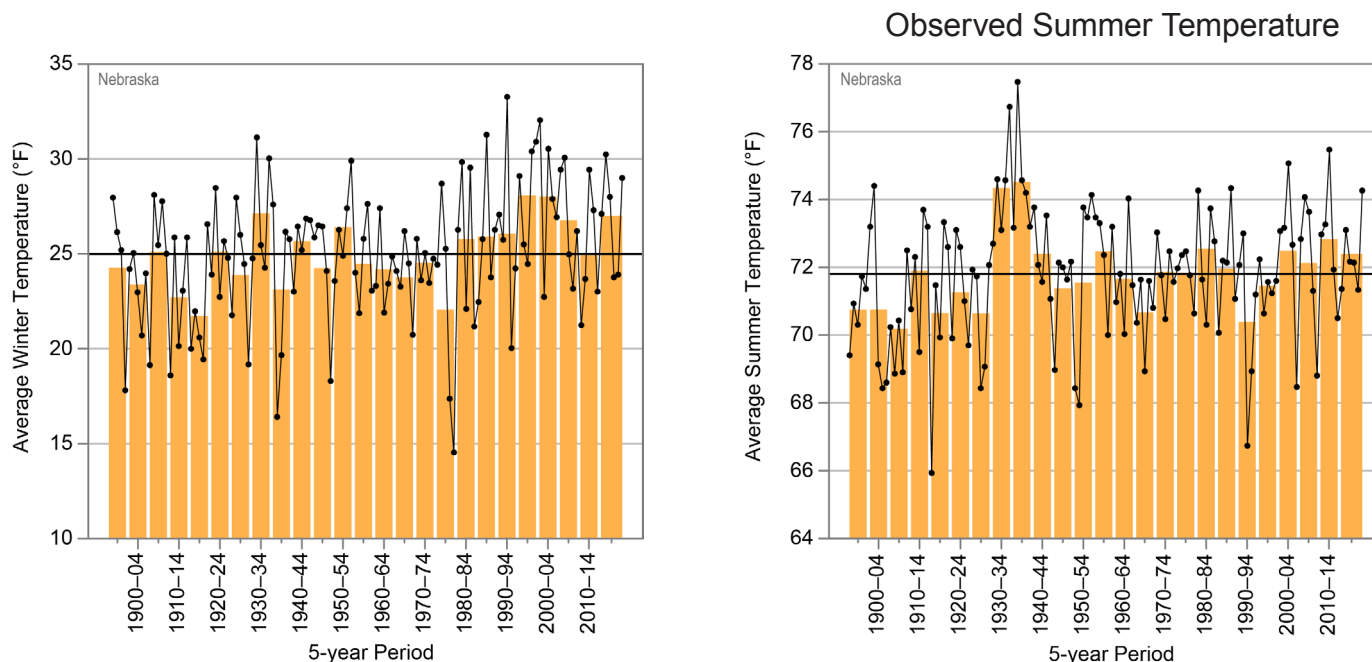


Figure 2: Observed (a) winter (December–February) average temperature and (b) summer (June–August) average temperature for Nebraska from (a) 1895–96 to 2019–20 and (b) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (first bar in Figure 2a is a 4-winter average, last bar in Figures 2a and 2b is a 6-winter and a 6-summer average, respectively). The horizontal black lines show the long-term (entire period) averages: (a) 25.0°F and (b) 71.8°F. From 1995 to 2004, Nebraska experienced the warmest winter temperatures on record. Since 2000, summer temperatures have been above average, although they have remained below the extreme heat of the 1930s Dust Bowl era. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 38 long-term stations.

Precipitation is highly variable from year to year, with the statewide annual average ranging from a low of 13.4 inches in 2012 to a high of 35.5 inches in 1915. The driest multiyear period was 1935–1939, and the wettest was 2015–2020 (Figure 3c). The driest consecutive 5-year interval was 1936–1940, and the wettest was 2015–2019. The majority of precipitation falls during the spring and summer months (Figure 3d), but seasonal precipitation varies widely.

Because agriculture is a vital sector of Nebraska’s economy, the state is particularly vulnerable to both high and low amounts of precipitation. The frequency of extreme precipitation events has increased in recent years, with the state experiencing an above average number of 2-inch precipitation events since 2005 (Figure 5). Nebraska also experiences periodic intense droughts, which can sometimes last for several years. One of the worst in the state’s history was the 1930s drought of the Dust Bowl era, when the impacts of the dry conditions were exacerbated by extreme heat. Nebraska’s hottest summers on record occurred in 1934 and 1936; they were also among the top 4 driest summers (1934 is fourth and 1936 is second). Conditions in July 1936 were particularly extreme, with Omaha experiencing 16 days with temperatures above 100°F and 1 day with

temperatures exceeding 110°F. This combination of heat and dryness, exacerbated by poor land management practices and the close temporal proximity of these two extreme summers, is unique in the record and contributed to the severe impacts of the Dust Bowl era. However, Nebraska’s driest year on record was 2012, when statewide precipitation averaged only 3.7 inches during the summer months, well below the historical average of 9.4 inches. By the end of September, more than 75% of the state was experiencing exceptional drought conditions, the U.S. Drought Monitor’s highest category of drought severity. The drought, combined with the extreme summer heat, had significant negative impacts on nonirrigated crop yields and pasture conditions, and the state did not see substantial relief from drought conditions for months.

Thousands of miles of rivers flow through Nebraska, and the state is bordered by the Missouri River to the east. Many cities and farmlands located along these waterways are at risk for flooding from extreme precipitation events and snowmelt. In the summer of 1993, heavy rains throughout the central United States caused record flooding along the Missouri (and Mississippi) River. This was Nebraska’s wettest summer, with statewide average precipitation totaling

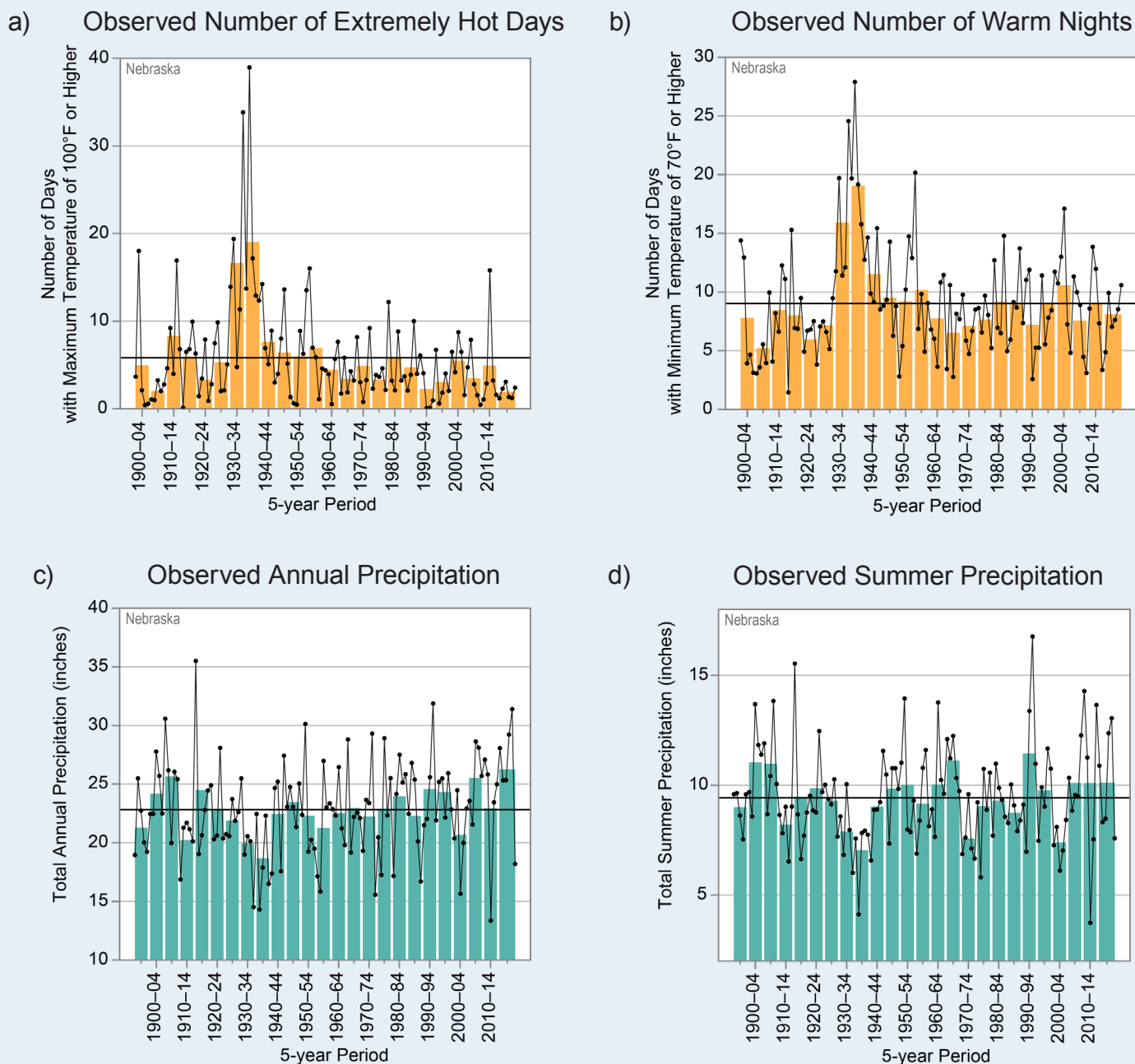


Figure 3: Observed (a) annual number of extremely hot days (maximum temperature of 100°F or higher), (b) annual number of warm nights (minimum temperature of 70°F or higher), (c) total annual precipitation, and (d) total summer (June–August) precipitation for Nebraska from (a, b) 1900 to 1920 and (c, d) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 5.8 days, (b) 9.0 nights, (c) 22.8 inches, (d) 9.4 inches. The state has consistently experienced a near or below average number of extremely hot days since 1960. Annual and seasonal precipitation varies widely. Since 2005, precipitation during the summer months has been above average. Sources: CISESS and NOAA NCEI. Data: (a, b) GHCN-Daily from 38 long-term stations; (c, d) nClimDiv.

16.8 inches, more than 7 inches above the long-term summer average. The flooding caused millions of dollars in damages to crops and infrastructure. In June 2011, runoff from the record winter snowpack in the Rocky Mountains combined with heavy rains, particularly in the upper Missouri River basin, to cause major flooding along the entire length of the Missouri River. In Omaha, the river crested at 36.29 feet on July 2, 2011, the

second highest crest on record. Historic flooding also occurred in March 2019, triggered by a “bomb cyclone” event. The stage was set for major flooding to occur, due to a combination of wet antecedent conditions, numerous winter storms, and bitter February cold that caused thick river ice to form. Warm temperatures accompanying the bomb cyclone caused rapid melting of snow and river ice (and subsequent ice jams), and

with soils already saturated from the previous autumn season, rivers were overwhelmed. Multiple dams and levees were breached as record crests occurred on the Big Blue, Elkhorn, Loup, Missouri, and Platte Rivers. Many towns were flooded, state highways and bridges were damaged or washed out, agricultural fields were inundated, and both humans and livestock perished. The entire event, which impacted several surrounding states, cost an estimated \$11 billion and was one of the costliest U.S. inland flooding events on record. The year 2019 became Nebraska's third-wettest year on record.

Nebraska experiences damaging storms during all seasons. During the winter months, snowstorms and ice storms are a frequent hazard. Western Nebraska, along with the Dakotas, has the highest probability of blizzards in the Nation, with a greater than 50% probability of a blizzard occurring in any given year. Convective storms are common in the warmer months, including flash flood-producing rainstorms and severe thunderstorms capable of producing hail, damaging winds, and tornadoes. The southwestern part of the Nebraska Panhandle lies in Hail Alley, the most hail-prone area in the entire country, and averages 7–9 hail days each year. A hailstone that fell in Aurora on June 22, 2003, holds the record for the largest hailstone by circumference (18.75 inches). Nebraska averages 57 tornadoes annually—the fifth-highest number of any state—and these tornadoes can be violent. On May 6, 1975, an F4 tornado struck Omaha, killing 3 people and causing more than \$1 billion in damages. On June 16, 2014, a supercell thunderstorm produced four EF4 tornadoes (including a set of rare “twin tornadoes”) in the northeastern part of the state, killing 2 and destroying large portions of the town of Pilger.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of this century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. Increases in heat wave intensity are projected, but the intensity of cold waves is projected to decrease.

Observed Number of Very Cold Nights

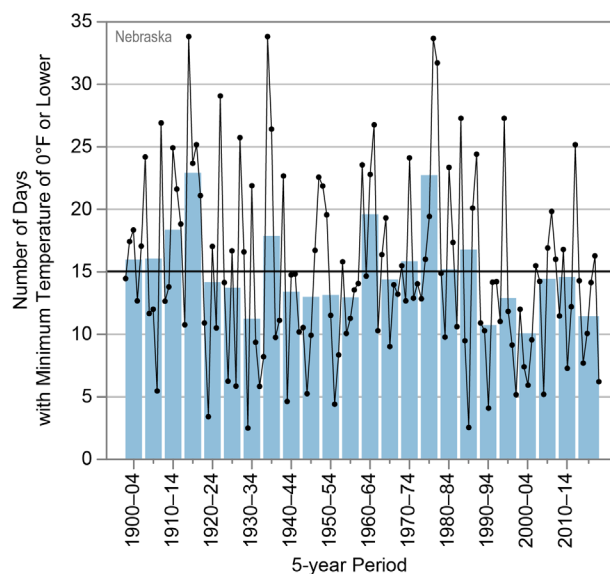


Figure 4: Observed annual number of very cold nights (minimum temperature of 0°F or lower) for Nebraska from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 15 nights. The number of very cold nights was highest in the late 1910s but has been below average since 1990, indicative of overall winter warming. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 38 long-term stations.

Observed Number of 2-Inch Extreme Precipitation Events

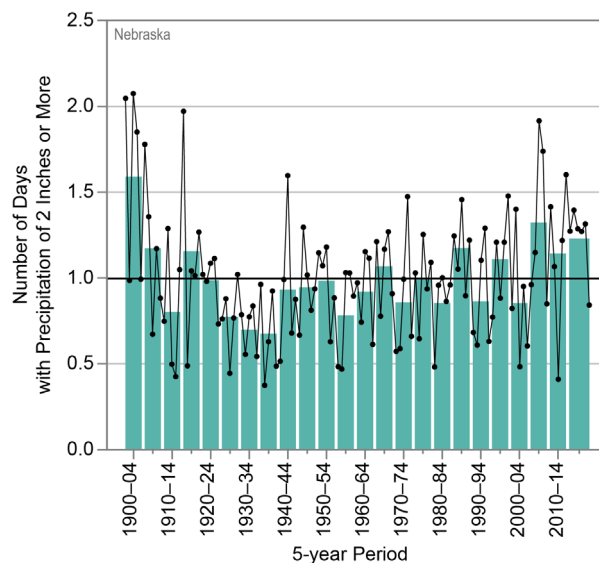


Figure 5: Observed number of 2-inch extreme precipitation events (days with precipitation of 2 inches or more) for Nebraska from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 1.0 days. A typical reporting station experiences 1 event per year. In the historical record, the highest number of extreme precipitation events occurred during the 1900–1904 period, with an average of 1.6 events per year, followed by the 2005–2009 period, with an average of 1.3 events per year. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 54 long-term stations.

Although projections of overall annual precipitation are uncertain, winter and spring precipitation are projected to increase across the state (Figure 6). Heavier winter precipitation could have both positive and negative effects on Nebraska's important agricultural economy, improving soil moisture for winter wheat but potentially delaying planting for summer crops. **Extreme precipitation events are also projected to increase**, leading to increased runoff and flooding, which can reduce water quality and erode soils.

The intensity of droughts is projected to increase.

Although projections of overall precipitation are uncertain, and droughts are a natural part of the climate system, higher temperatures will increase evaporation rates and decrease soil moisture, leading to more intense future droughts. This would have negative impacts on dryland farming, although the impacts could be mitigated where irrigation is possible.

Projected Change in Winter Precipitation

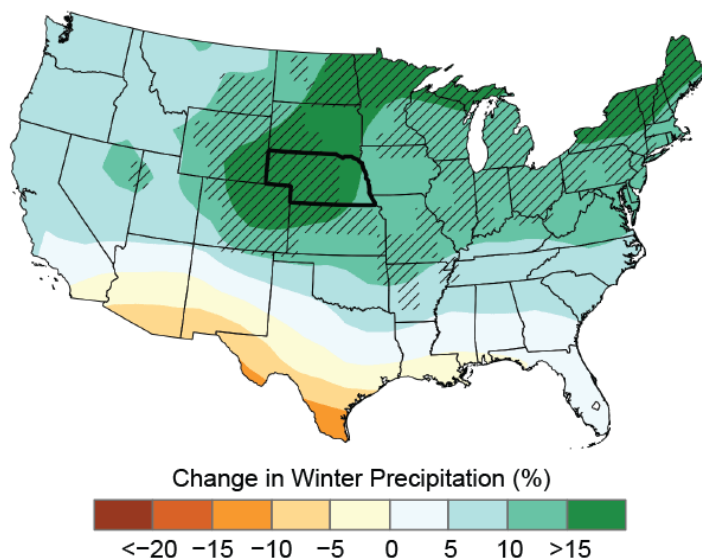


Figure 6: Projected changes in total winter (December–February) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. Nebraska is part of a large area across the northern and central United States with projected increases in winter precipitation. Sources: CISESS and NEMAC. Data: CMIP5.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

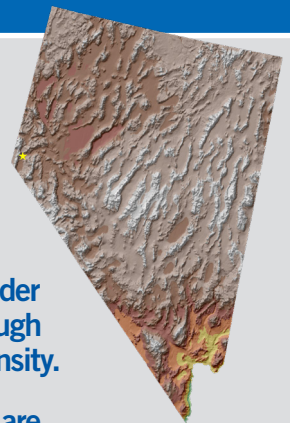
NEVADA

Key Messages

Temperatures in Nevada have risen almost 2.4°F since the beginning of the 20th century. Under a higher emissions pathway, historically unprecedented warming is projected to continue through this century, with associated increases in heat wave intensity and decreases in cold wave intensity.

Nevada is the driest state in the United States, and future projections of annual precipitation are uncertain. Increases in temperature are projected to lead to reductions in late winter and spring snowpack, with potential negative impacts to water supplies.

Drought has been common since the beginning of this century. Higher temperatures will increase the rate of soil moisture loss during dry spells, increasing the intensity of future naturally occurring droughts. The frequency and severity of wildfires are projected to increase in Nevada and surrounding states.



Nevada is largely a dry state with a highly diverse climate due its large range of elevations: from less than 500 feet in the scorching lowland desert in the south to more than 13,000 feet in the cool mountain forests in the north. Las Vegas is one of the hottest cities in the United States, with summer high temperatures averaging 102°F and regularly exceeding 110°F (an average of about 9 days per year reach 110°F or higher). Much of the state lies within the Great Basin, a region between the Rockies and the Sierra Nevada, encompassing numerous small mountain ranges and high-elevation desert valleys. Nevada is located on the eastern side of the Sierra Nevada, which blocks much of the moisture from the Pacific Ocean from reaching the state. Due to the climate and rugged mountainous terrain, much of the land is sparsely populated. The majority of residents live in two concentrated urban areas, the Las Vegas and Reno-Sparks metro areas, which are supported by water from Lake Tahoe and the Colorado River, respectively. Nevada is the Nation's driest state, with statewide annual average (1895–2020) precipitation only 10.2 inches. Regionally, annual average (1991–2020 normals) precipitation varies from 4 inches in some low elevation locations in the southwest to more than 50 inches on high mountain peaks of the Sierra Nevada.

Temperatures in Nevada have risen almost 2.4°F since the beginning of the 20th century (Figure 1). Over the last 26 years, the annual number of very hot days has been above average, with the highest 5-year average occurring during the 2015–2020 period (Figure 2), partly because of very high annual values in 2017, 2018, and 2020. In

Observed and Projected Temperature Change

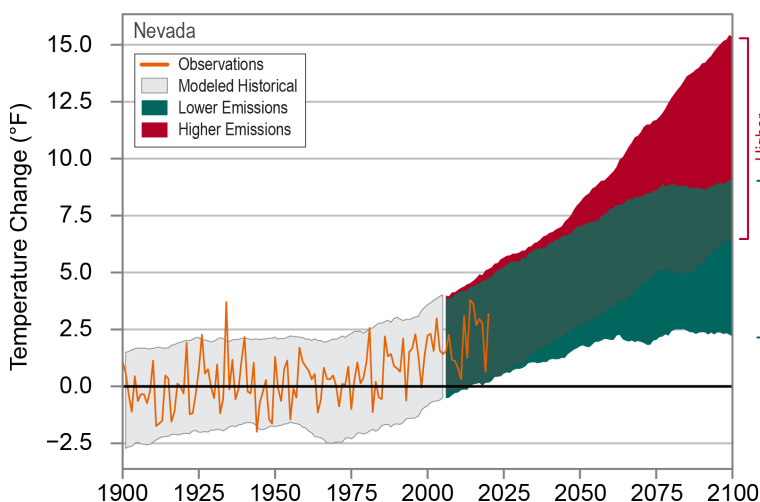


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Nevada. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Nevada (orange line) have risen almost 2.4°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected to continue through this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 2°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 12°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

emissions future (the hottest end-of-century projections being about 12°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

addition to a general daytime warming, Nevada has experienced an above average number of warm nights since 2000 (Figure 3). The state is one of the most urbanized in the Nation, with 94% of the population living in areas defined as urban. The urban heat island effect has likely exacerbated these warming trends in Las Vegas in particular, where explosive growth has taken place.

After wet conditions in the late 1990s, total annual precipitation has been near or below average since 2000 but shows no overall trend across the 126-year

period of record (Figure 4). Seasonal precipitation patterns vary across the state, with most locations receiving the majority of their precipitation during the winter months. However, eastern and southern areas, including Las Vegas, can experience intense summer rainfall from the North American Monsoon system.

Drought is a critical climate threat for this arid state (Figure 5). Since 2000, the Colorado River basin, the source of water for the southern part of the state, has experienced drought conditions, with impacts on Lake Mead. In addition, winter precipitation was well

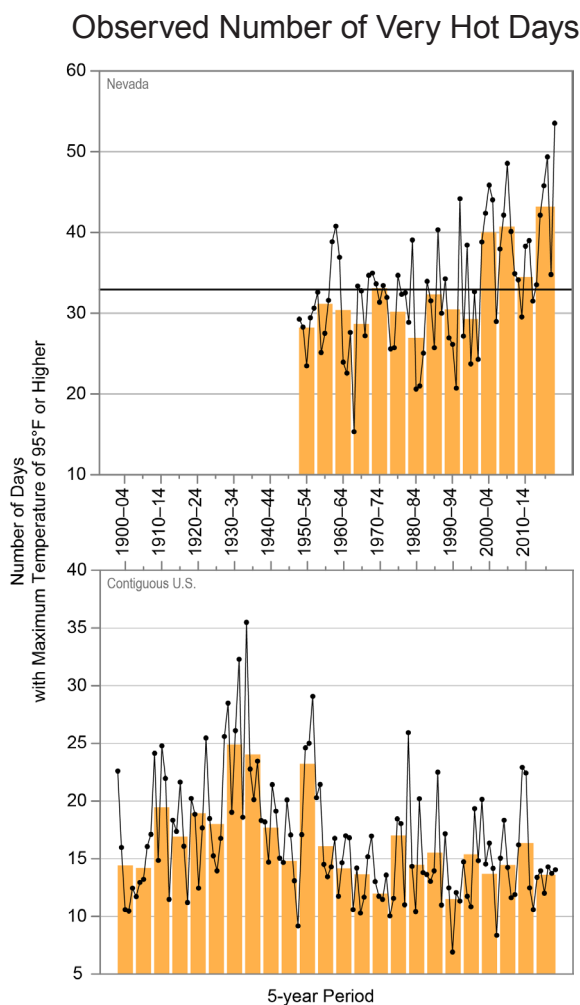


Figure 2: Observed annual number of very hot days (maximum temperature of 95°F or higher) for Nevada from 1950 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 33 days (note that the average for individual reporting stations varies greatly because of the state's large elevation range). Values for the contiguous United States (CONUS) from 1900 to 2020 are included to provide a longer and larger context. Long-term stations back to 1900 were not available for Nevada. Since 2000, the number of very hot days has been well above average, and the highest number occurred during the 2015 to 2020 period. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 19 long-term stations.

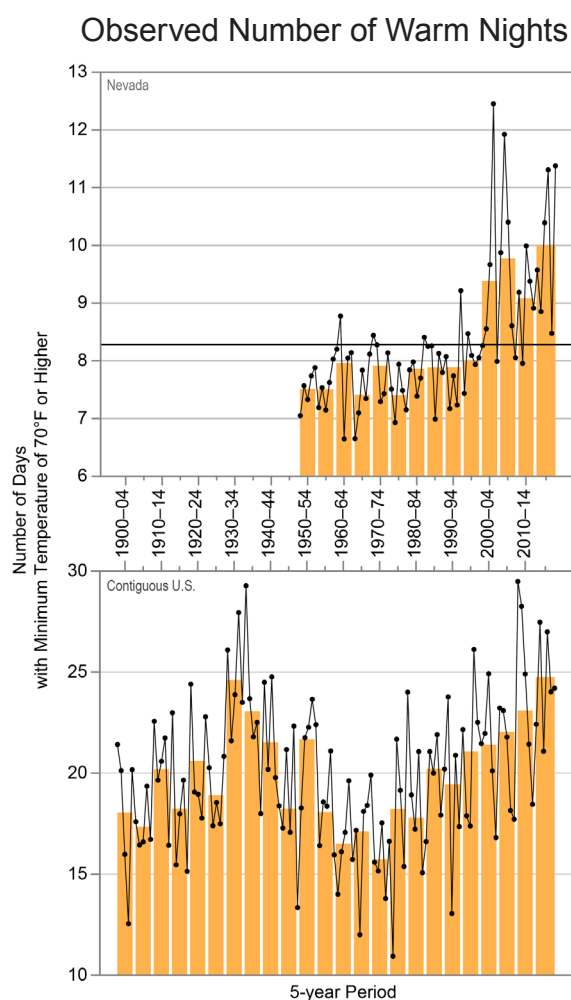


Figure 3: Observed annual number of warm nights (minimum temperature of 70°F or higher) for Nevada from 1950 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 8.3 nights (note that the average for individual reporting stations varies greatly because of the state's large elevation range). Values for the contiguous United States (CONUS) from 1900 to 2020 are included to provide a longer and larger context. Long-term stations back to 1900 were not available for Nevada. The number of warm nights has been above average since 2000, and the highest number occurred during the 2015 to 2020 period. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 19 long-term stations.

below average from the 2011–12 through the 2014–15 water years (October–September), and all of those years were abnormally warm. This led to a strain on water supplies in agricultural areas that rely on surface water. The majority of the counties in the state have been designated as natural disaster areas due to extreme drought conditions. Lake Mead, the largest man-made reservoir in the United States, provides water for southern Nevada, as well as Arizona, southern California, and northern Mexico. As of October 25, 2021, water storage in Lake Mead was at 34% capacity, and water levels have been dropping since 2000 (Figure 6). Due to aggressive conservation policies, metropolitan areas have been able to manage the reductions in water supplies. Parallel declines in snowpack have been observed over this same time period (Figure 7). Snowpack refills Lake Tahoe every spring, and lake levels slowly decrease throughout the year. Warm and/or dry years lead to low snowpack and associated decreases in the lake's water levels. Since 1900, the lake has fallen below the natural rim 21 times (Figure 8).

Since 2004, the state has received multiple federal disaster declarations for wildfire events. Following the national drought of 2012, western wildfires burned an estimated 9 million acres across 8 states, including Nevada, causing more than \$1 billion in damages. In 1997 and 2005, severe flooding along the Truckee River caused extensive damages in Reno and the surrounding area. Summer monsoon rains frequently lead to disruptive flooding in the Las Vegas Valley.

Under a higher emissions pathway, historically unprecedented warming is projected to continue through this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of this century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. Extreme high temperatures are projected to increase substantially, with potentially large impacts in the very hot southern deserts, particularly the Las Vegas metro area, where 70% of the state's population resides. Extreme heat, combined with the urban heat island effect, will result in poor air quality and an increased risk of chronic respiratory conditions and heat stress.

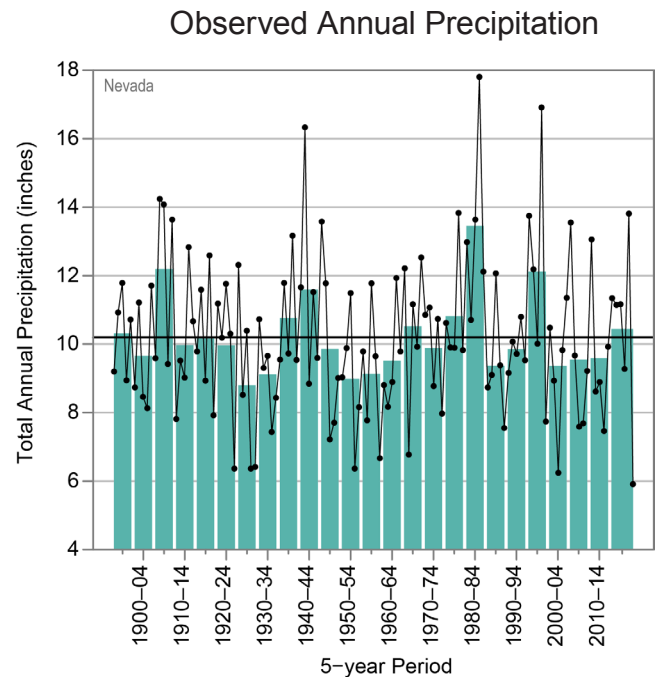


Figure 4: Observed total annual precipitation for Nevada from 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 10.2 inches. Five-year average total precipitation has ranged from 8.4 inches per year during 1958–1962 to 13.5 inches per year during 1980–1984. The early part of this century was below average, but the 2015 to 2020 period was near average. Sources: CISESS and NOAA NCEI. Data: nClimDiv.

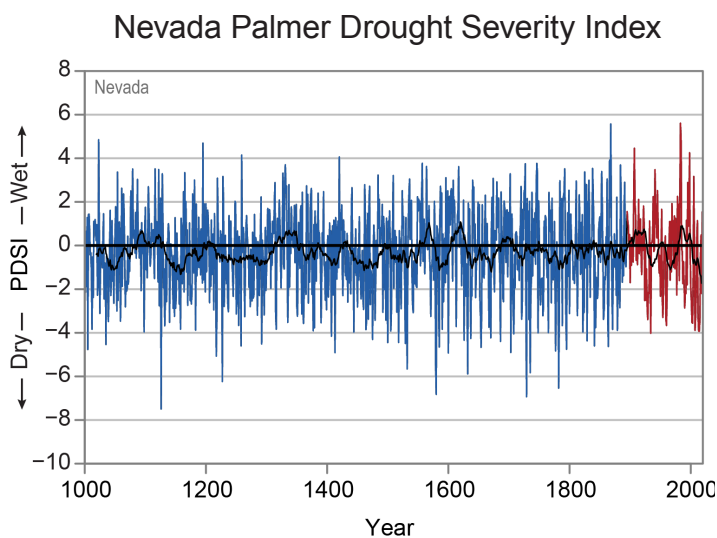


Figure 5: Time series of the Palmer Drought Severity Index for Nevada from the year 1000 to 2020. Values for 1895–2020 (red) are based on measured temperature and precipitation. Values prior to 1895 (blue) are estimated from indirect measures such as tree rings. The fluctuating black line is a running 20-year average. In the modern era, the wet periods of the early 1900s and the 1980s–1990s and the dry period of the 1950s are evident. The extended record indicates periodic occurrences of similar extended wet and dry periods. Sources: CISESS and NOAA NCEI. Data: nClimDiv and NADAv2.

Projected rising temperatures in Nevada will raise the snow line—the average lowest elevation at which snow falls. This will increase the likelihood that precipitation will fall as rain rather than snow, reducing water storage in the snowpack, particularly at those lower mountain elevations that are now on the margins of reliable snowpack accumulation. Higher spring temperatures will also result in earlier melting of the snowpack, further decreasing water availability during the already dry summer months.

Projections of annual precipitation for Nevada are uncertain throughout this century (Figure 9), but warmer temperatures are likely to decrease the amount of water in the mountain snowpack and increase the demand for water. Higher temperatures will also increase the evaporation rate, which will reduce streamflow and soil moisture. Thus, the intensity of future droughts is likely to increase, as will the risk of wildfires in some ecosystems. Increases in population and potentially decreased water flow from the Colorado River may lead to future water security issues across the state.

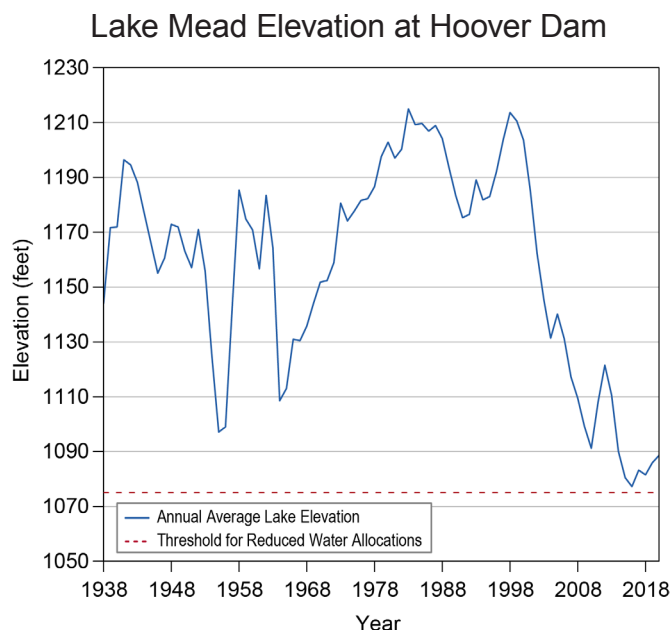


Figure 6: Time series of the annual average water level (blue line) of Lake Mead at Hoover Dam from 1938 to December 2020. Water levels in Lake Mead have varied widely over the years. Low levels in the 1950s and 1960s were due to drought and the filling of Lake Powell, respectively. Recent years have seen the lowest recorded levels since the original filling of Lake Mead. The red-dashed line indicates the threshold (1,075 feet) below which a federal shortage will be declared, resulting in reduced water allocations for Nevada and Arizona. Source: USBR.

April 1 Snow Water Equivalent (SWE) at Mt. Rose, NV

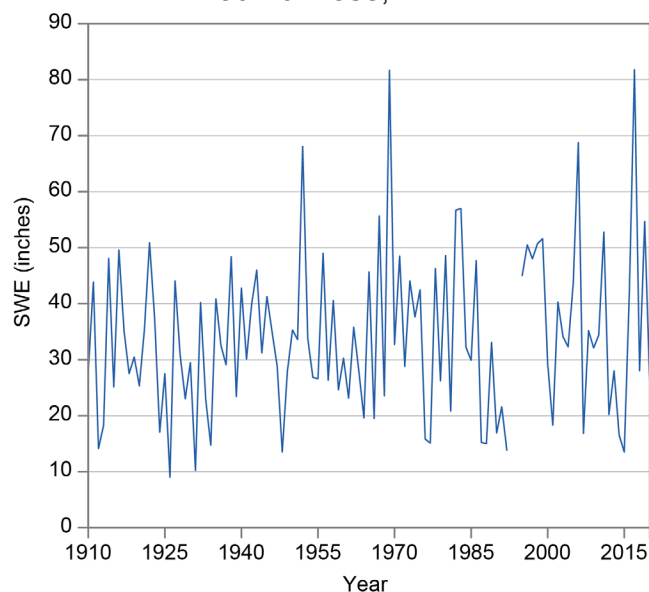


Figure 7: Variations in the April 1 snow water equivalent (SWE) at the Mt. Rose, Nevada, snow survey site from 1910 to 2020. SWE, the amount of water contained within the snowpack, varies widely from year to year. Data is not available for 1993 and 1994. Recent years have seen some of the lowest and highest levels in snowpack depth. Source: NRCS NWCC.

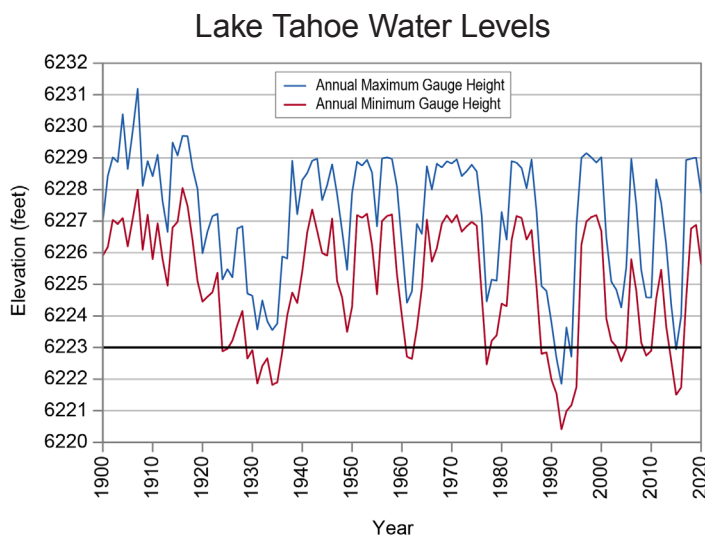


Figure 8: Time series of the annual maximum (blue line) and minimum (red line) water levels for Lake Tahoe (1900–2020). Ground-level lake elevation is 6,220 feet. The horizontal black line shows the natural rim elevation of 6,223 feet. A dam controlling outflow from the lake is 10 feet higher than the natural rim but by law spills at about 6,229 feet. Since 1900, the lake has fallen below the natural rim 21 times. Lake elevation in the early 1990s reached historically low levels. Source: USGS.

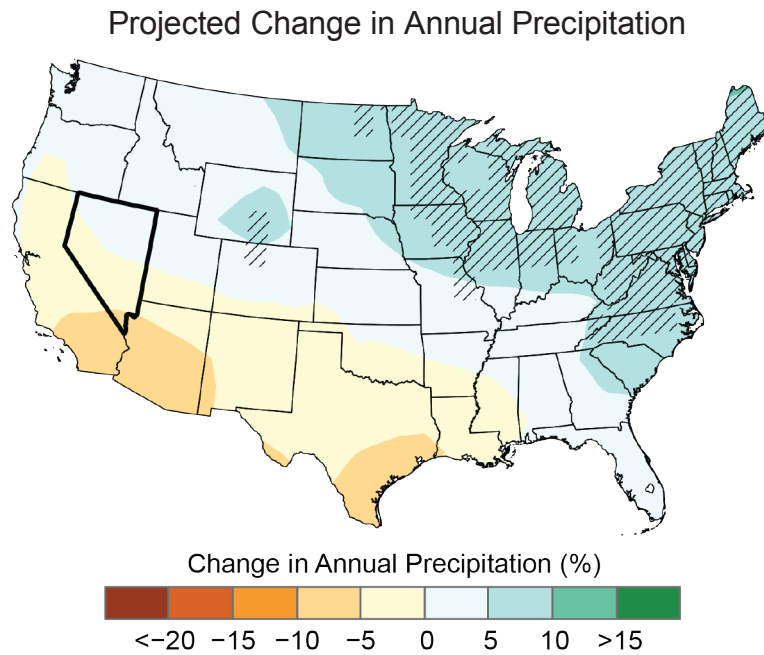


Figure 9: Projected changes in total annual precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. The projected changes in annual precipitation for Nevada are uncertain, similar to that across much of the Southwest. Sources: CISESS and NEMAC. Data: CMIP5.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

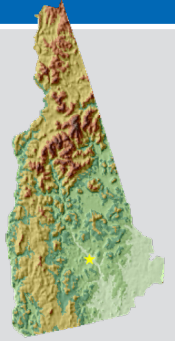
NEW HAMPSHIRE

Key Messages

Temperatures in New Hampshire have risen more than 3°F since the beginning of the 20th century. Under a higher emissions pathway, historically unprecedented warming is projected during this century. Warming has increased more in the winter than in any other season. Future winter warming will have large effects on snowfall and snow cover.

Precipitation since 2005 has averaged 6.8 inches more than the 1895–2004 average, and the highest number of extreme precipitation events occurred during 2005–2014. Annual average precipitation and the frequency and intensity of extreme precipitation events are projected to increase, with associated increases in flooding.

Global sea level is projected to rise, with a likely range of 1–4 feet by 2100. Rising sea levels pose significant risks to coastal communities and structures, such as inundation, erosion-induced land loss, and greater flood vulnerability due to higher storm surge.



New Hampshire is located on the eastern margin of the North American continent. Its northerly latitude and geographic location expose the state to both the moderating and moistening influence of the Atlantic Ocean and the effects of hot and cold air masses from the interior of the continent. **Its climate is characterized by cold, snowy winters and mild summers.** The jet stream is often located near the state, particularly in the late fall, winter, and spring, and gives it highly variable weather patterns. Precipitation is frequent because several preferred storm tracks associated with the jet stream cross the state. The extreme northern and western portions of the state are the least influenced by the moderating effects of the Gulf of Maine and thus experience more extreme cold temperatures. The southeast, with its lower elevations and proximity to the Atlantic Ocean, is somewhat warmer. Average minimum temperatures in January are colder in the north (Lancaster: 2°F to 7°F) and at higher elevations (Mount Washington: –5°F to –1°F) than in the south (Concord: 12°F to 15°F). Coastal communities, such as the Portsmouth area, are even warmer, with average minimum temperatures ranging from 15°F to 18°F. Average maximum temperatures in July range from 75°F to 80°F in the north and from 80°F to 85°F in the south. The statewide annual average (1991–2020 normals period) precipitation is 48.8 inches, with higher amounts occurring in the south and along the eastern border of the state and lower amounts in the west and north.

Observed and Projected Temperature Change

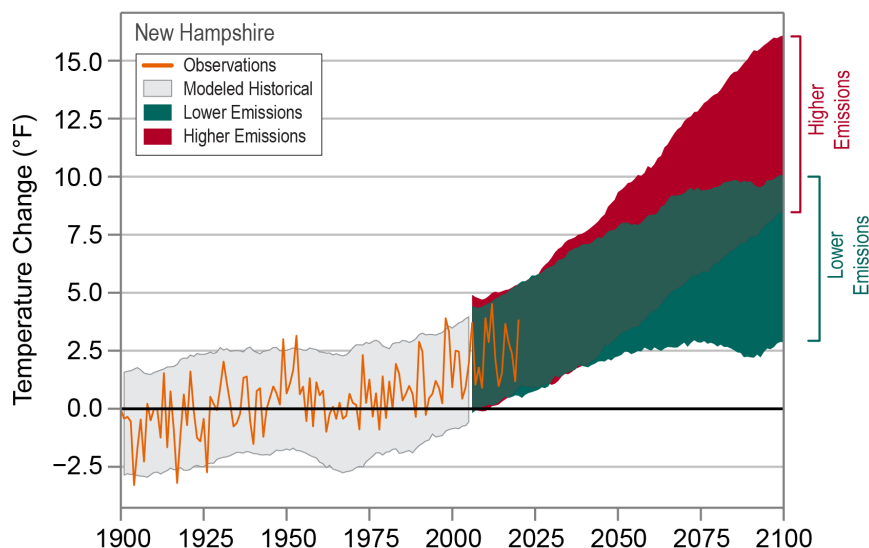


Figure 1. Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for New Hampshire. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in New Hampshire (orange line) have risen more than 3°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-year projections being about 2°F warmer than the

historical average; green shading) and more warming under a higher emissions future (the hottest end-of-year projections being about 12°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

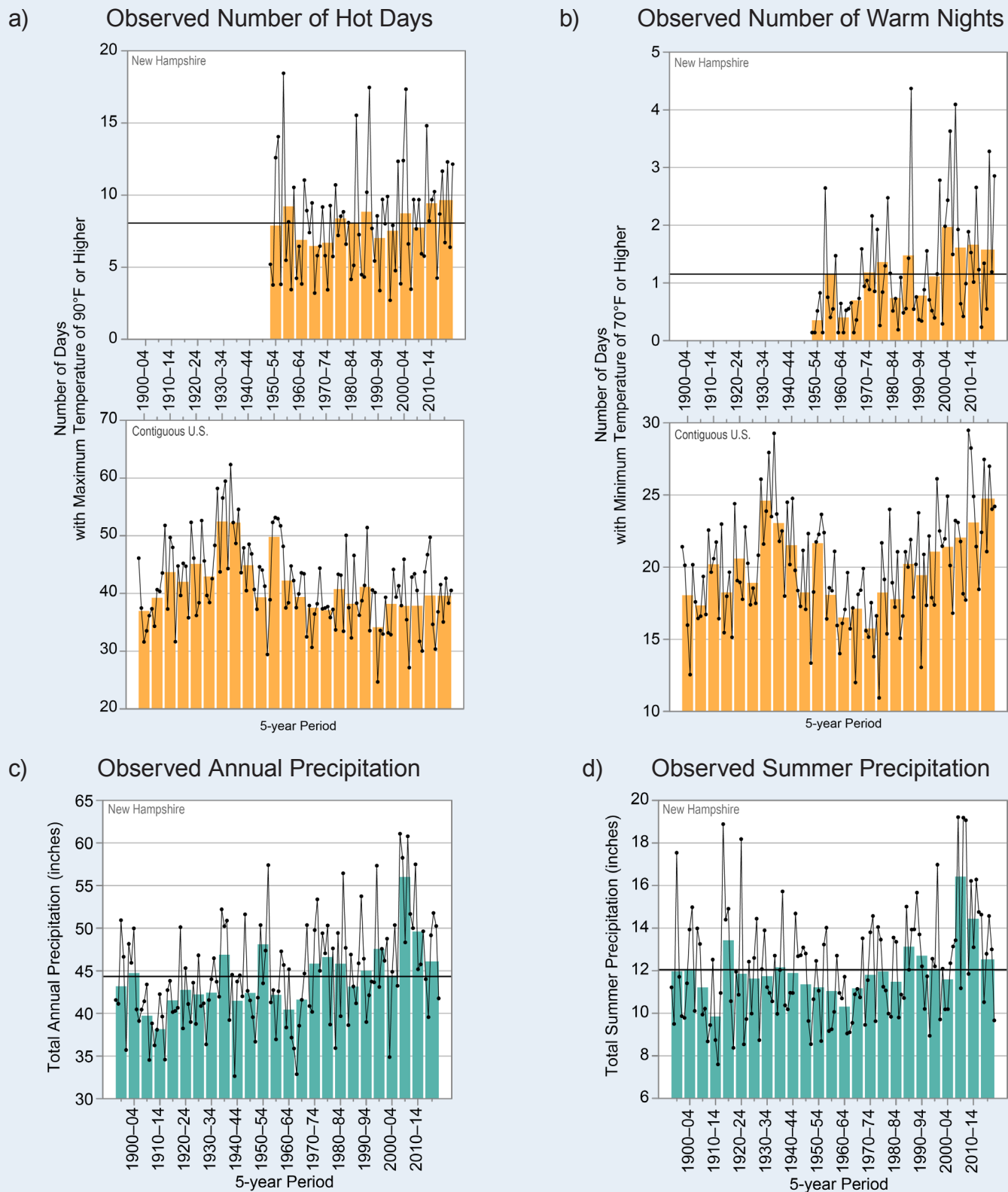


Figure 2. Observed (a) annual number of hot days (maximum temperature of 90°F or higher), (b) annual number of warm nights (minimum temperature of 70°F or higher), (c) total annual precipitation, and (d) total summer (June–August) precipitation for New Hampshire from (a, b) 1950 to 1920 and (c, d) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages for New Hampshire: (a) 8.1 days, (b) 1.2 nights, (c) 44.3 inches, (d) 12.1 inches. Values for the contiguous United States (CONUS) from 1900 to 2020 are included for Figures 2a and 2b to provide a longer and larger context. Long-term stations dating back to 1900 were not available for New Hampshire. There is no overall trend in the number of hot days; however, the number of warm nights has been above average since 2000. A significantly larger amount of both annual and summer precipitation occurred between 2005 and 2014 than in any previous consecutive 10-year interval. Sources: CISESS and NOAA NCEI. Data: (a, b) GHCN-Daily from 10 (NH) and 655 (CONUS) long-term stations; (c, d) nClimDiv.

Temperatures in New Hampshire have risen more than 3°F since the beginning of the 20th century (Figure 1). The number of hot days has varied across the period of record (1950–2020; Figure 2a); however, the most recent period (2015–2020) had the highest multiyear average of about 9 days. Since 2000, the number of warm nights has been above average, with the 2000–2004 period having the highest multiyear average of about 2 nights per year (Figure 2b). The greatest warming has occurred in the winter, with an increase of more than 4°F since 1900. This is reflected in the number of very cold nights, which has been below average since the early 1990s (Figure 3). The 2010–2014 period had the lowest multiyear average of about 18 nights per year. Warmer winters are also reflected in a trend toward earlier ice-out dates on lakes and fewer nights below freezing.

Total annual precipitation for New Hampshire has been above to well above average over the last 16 years (2005–2020; Figure 2c). The wettest multiyear periods were in the early 1950s, late 2000s, and early 2010s. The wettest consecutive 5-year interval was 2005–2009, averaging 56.0 inches per year. The driest multiyear periods were in the late 1900s, early 1910s, and 1960s. The driest consecutive 5-year interval was 1963–1967, averaging 37.2 inches per year. A state-level analysis for southern New Hampshire found that the rate of increase in annual precipitation from 1970 to 2012 was double to triple the long-term (1895–2012) average because of the high values occurring from 2005 to 2011. Similar trends in total summer precipitation have been observed over the last 16 years, with a record multiyear average of 16.4 inches during the 2005–2009 period (Figure 2d). The state experienced the highest annual number of 2-inch extreme precipitation events during the 2005–2009 period (2.4 days) and an above average number during the 2010–2014 period (1.9 days; Figure 4), although the 2015–2020 period had a below average number of such days (1.1 days). New Hampshire has also been experiencing more short-term dry periods, with extreme drought occurring in 2016 and again in 2020.

Extreme weather events common to New Hampshire include severe coastal storms, winter storms, cold waves, thunderstorms, floods, and tropical cyclones. The Federal Emergency Management Agency made 15 major disaster declarations for New Hampshire over the last 10 years (2011–2020); almost half (7) were related to severe storms and flooding. **The state's coastline**

Observed Number of Very Cold Nights

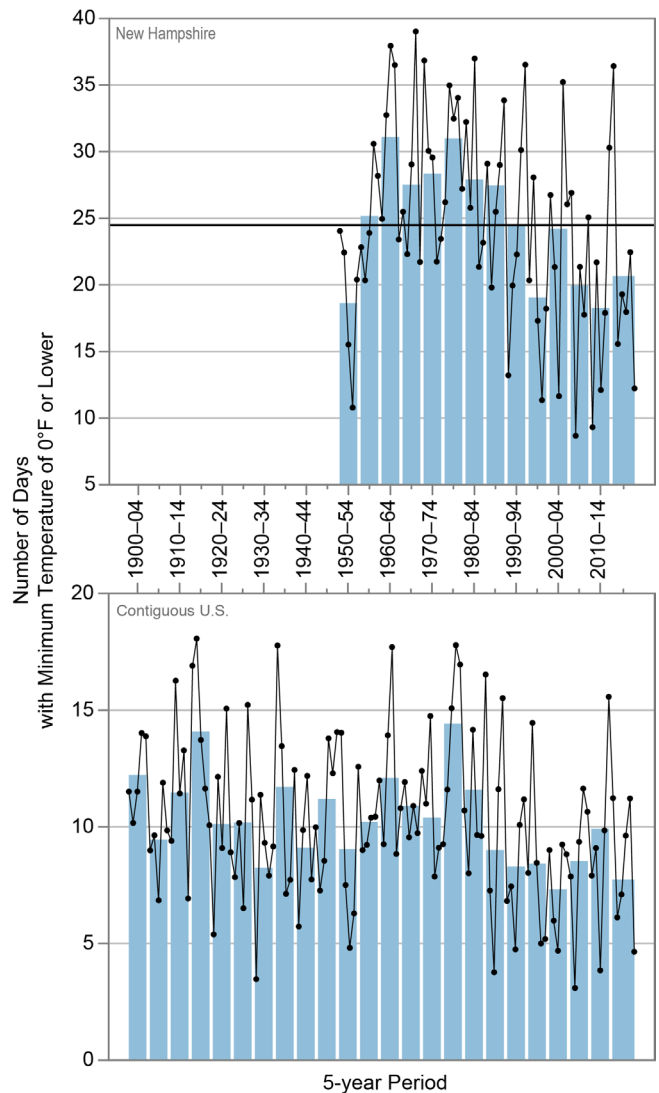


Figure 3. Observed annual number of very cold nights (minimum temperature of 0°F or lower) for New Hampshire from 1950 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average for New Hampshire of 25 nights. Values for the contiguous United States (CONUS) from 1900 to 2020 are included to provide a longer and larger context. Long-term stations dating back to 1900 were not available for New Hampshire. Since the mid-1990s, the number of very cold nights has been below average. The 2010–2014 period had the lowest multiyear average. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 10 (NH) and 655 (CONUS) long-term stations.

is highly vulnerable to damage from winter coastal storms (known as nor'easters) and tropical cyclone events (hurricanes and tropical storms). These cyclonic storms often result in wide-scale flooding, property damage, and coastal erosion. Superstorm Sandy, in 2012, was the most extreme and destructive event to affect the northeastern United States in 45 years and the fourth costliest in the Nation's history. The most

destructive element of Sandy was storm surge, with heights reaching 3.2 feet above normal tide levels in New Hampshire. The state suffered more than \$75 million in economic losses.

Winter storms are an important feature of New Hampshire's climate. In most years, several storms depositing 5 or more inches of snow will affect the state. Seasonal snowfall totals for 2014–15 were well above the long-term average of about 60 inches across southern portions of the state; for example, Concord received more than 90 inches. Concord also received more than 85 inches during 2016–17 and 2017–18. However, the 2007–08 season holds the record for the highest seasonal snowfall in Concord (118 inches). **Although these recent winters were snowy, overall snowfall has been declining at a majority of stations. During the 2015–16 season, Concord received about half of its normal snowfall.** The number of snow-covered days is also decreasing throughout the state.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of this century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. Heat waves are projected to increase in intensity, while cold waves are projected to become less intense. In response to cold season warming, the state can expect more precipitation falling as rain rather than snow, earlier lake ice-out dates, and a decline in days with snow cover. This has implications for winter tourism. By midcentury (under a higher emissions pathway), the annual number of days above 90°F is projected to increase by up to 30 days in southern New Hampshire and up to 10 days in the north.

Annual average precipitation is projected to continue to increase for New Hampshire over this century, particularly during the winter (Figure 5). This trend is characteristic of a large area of the Northern Hemisphere in the higher mid-latitudes that is projected to see increases in precipitation totals. The frequency of extreme precipitation events is also expected to more

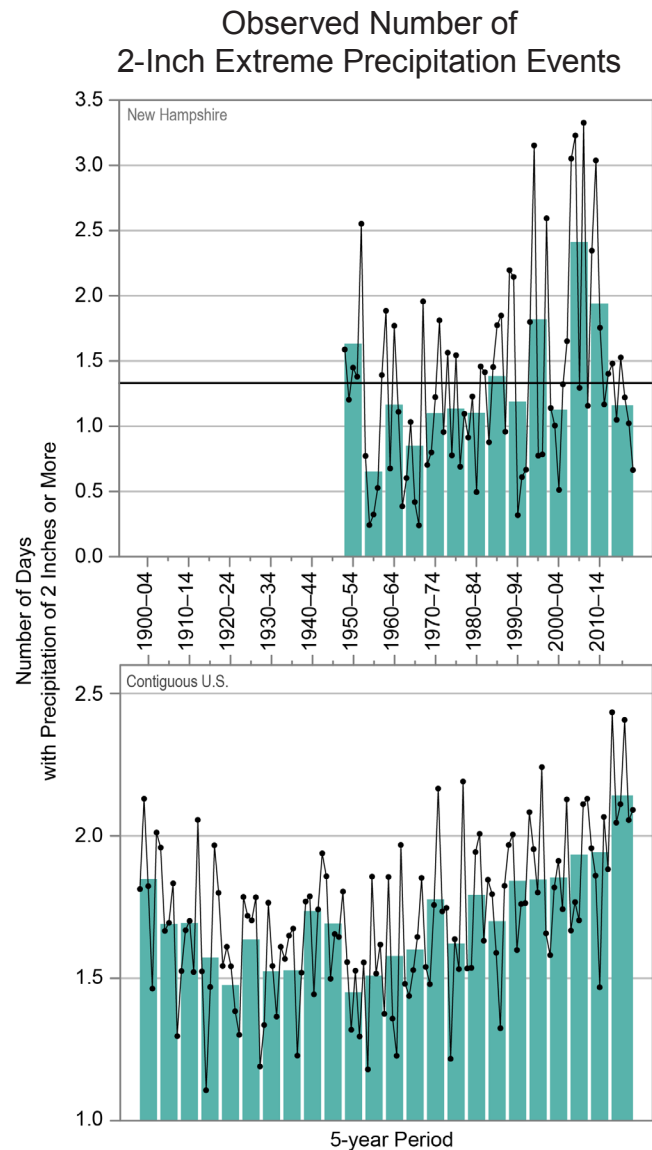


Figure 4. Observed annual number of 2-inch extreme precipitation events (days with precipitation of 2 inches or more) for New Hampshire from 1950 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average for New Hampshire of 1.3 days. A typical reporting station experiences 1 to 2 events per year. Values for the contiguous United States (CONUS) from 1900 to 2020 are included to provide a longer and larger context. Long-term stations dating back to 1900 were not available for New Hampshire. The highest number of 2-inch extreme precipitation events occurred during the 2005 to 2014 interval. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 13 (NH) and 832 (CONUS) long-term stations.

than double in the region by the end of this century under a higher emissions pathway. These precipitation projections may also result in increased flooding risks. The intensity of naturally occurring droughts is also projected to increase because of an increased rate of soil moisture depletion from higher temperatures during dry spells.

Since 1900, global average sea level has risen by about 7–8 inches. It is projected to rise another 1–8 feet, with a likely range of 1–4 feet, by 2100 as a result of both past and future emissions from human activities (Figure 6). Coastal communities in Portsmouth are particularly vulnerable to sea level rise and coastal storm surge. From 1926 to 2019, tidal-gauge records showed that sea level in Portsmouth Harbor had risen more than half a foot (8.04 inches), nearly the same as the global average. Sea level rise contributes to increases in coastal erosion and saltwater intrusion and has also caused an increase in tidal floods associated with nuisance-level impacts. Nuisance floods are events in which water levels exceed the local threshold (set by NOAA’s National Weather Service) for minor impacts. These events can damage infrastructure, cause road closures, and overwhelm storm drains. Nuisance flooding has increased in all U.S. coastal areas, with more rapid increases along the East and Gulf Coasts. Nuisance flooding events in New Hampshire are likely to occur more frequently as global and local sea levels continue to rise.

Projected Change in Winter Precipitation

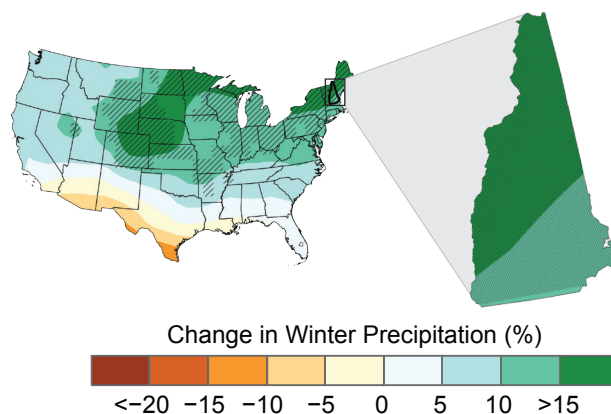


Figure 5. Projected changes in total winter (December–February) precipitation (%) for the middle of the 21st century relative to the late 20th century under a higher emissions future. Hatching represents areas where the majority of climate models indicate a statistically significant change. Winter precipitation is projected to increase in New Hampshire. Sources: CISESS and NEMAC. Data: CMIP5.

Observed and Projected Change in Global Sea Level

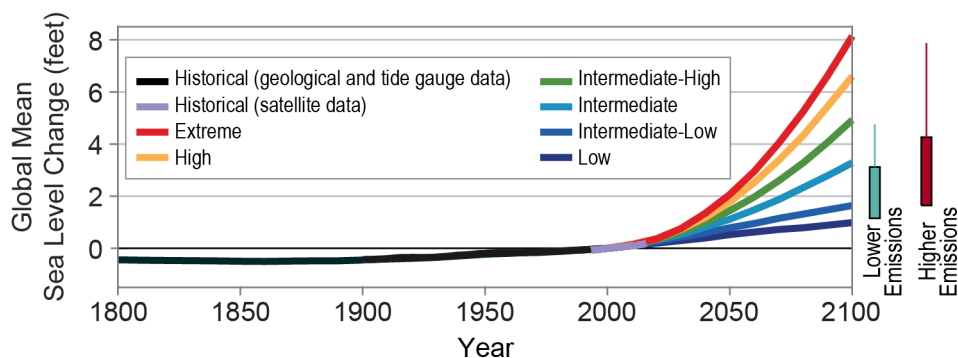


Figure 6. Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate-Low, royal blue; Intermediate, cyan; Intermediate-High, green; High, orange; and Extreme, red curves) relative to historical geological, tide gauge, and satellite altimeter GMSL reconstructions from 1800–2015 (black and magenta lines) and the very likely ranges in 2100 under both lower and higher emissions futures (teal and dark red boxes). Global sea level rise projections range from 1 to 8 feet by 2100, with a likely range of 1 to 4 feet. Source: adapted from Sweet et al. 2017.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

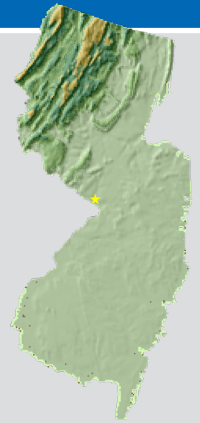
NEW JERSEY

Key Messages

Annual average temperatures have risen more than 3.5°F in New Jersey since the beginning of the 20th century. Under a higher emissions pathway, historically unprecedented warming is projected during this century. Heat waves are projected to be more intense, while cold waves are projected to be less intense.

Precipitation has been highly variable, with wetter than average conditions over the last decade, and the highest number of extreme events occurred during 2005–2014. Winter and spring precipitation and extreme precipitation events are projected to increase in the future.

Sea level along the New Jersey coast has risen by more than 16 inches, double the global average, since 1911. Global average sea level is projected to rise another 1 to 4 feet by 2100. Sea level rise poses substantial risks, including greater vulnerability to severe coastal flooding.



New Jersey's geographic position in the mid-latitudes often places it near the jet stream, particularly in the late fall, winter, and spring, giving the state its characteristic varied weather. Precipitation is frequent because low-pressure storms associated with the jet stream commonly affect the state. In addition, New Jersey's location on the eastern coast of North America exposes it to the cold winter and warm summer air masses of the continental interior and the moderate and moist air masses of the western Atlantic Ocean. In winter, the contrast between the frigid air masses of the continental interior and the relatively warm Atlantic provides the energy for occasional intense storms known as nor'easters. As a result of these influences, **New Jersey's climate is characterized by moderately cold and occasionally snowy winters and warm, humid summers.** There is a west-to-east contrast of temperatures, with cooler temperatures in the higher elevations of the northwest and warmer temperatures in the east near the coast. Temperature differences from the northwest to southeast are most noticeable in the winter. The northern elevated highlands and valleys experience colder temperatures and more annual average precipitation than the rest of the state. Average minimum temperatures in January range from 15° to 20°F in the northwest to 25° to 30°F along the coast. A similar temperature gradient exists for average maximum temperatures in July—cooler summertime

Observed and Projected Temperature Change

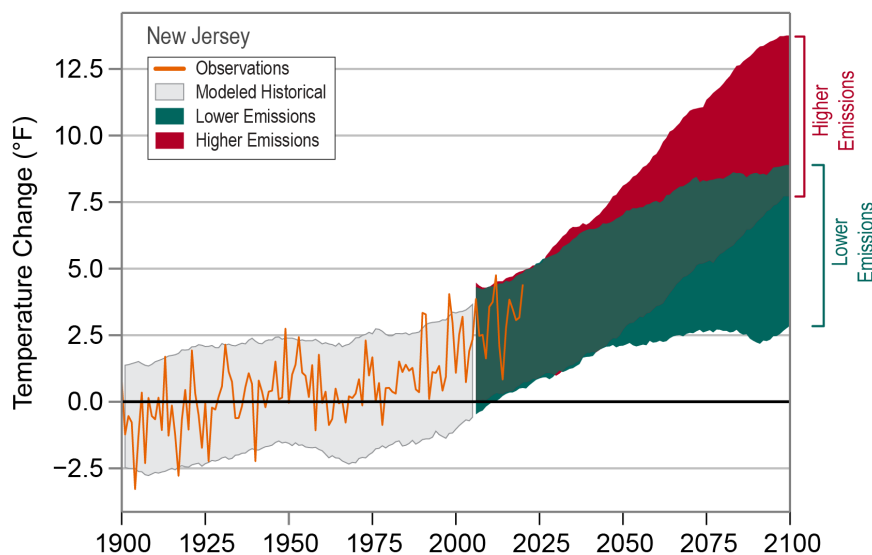


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for New Jersey. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in New Jersey (orange line) have risen more than 3.5°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 2°F warmer than the historical average; green shading)

and more warming under a higher emissions future (the hottest end-of-century projections being about 9°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

temperatures of 80° to 85°F occur in the northwestern corner and temperatures between 85° and 90°F occur in the rest of the state. The statewide annual average precipitation is 47.6 inches. There is a north-south

precipitation gradient as well, with the north-central portion of the state averaging around 50 inches of precipitation and the coastal region averaging 40–45 inches.

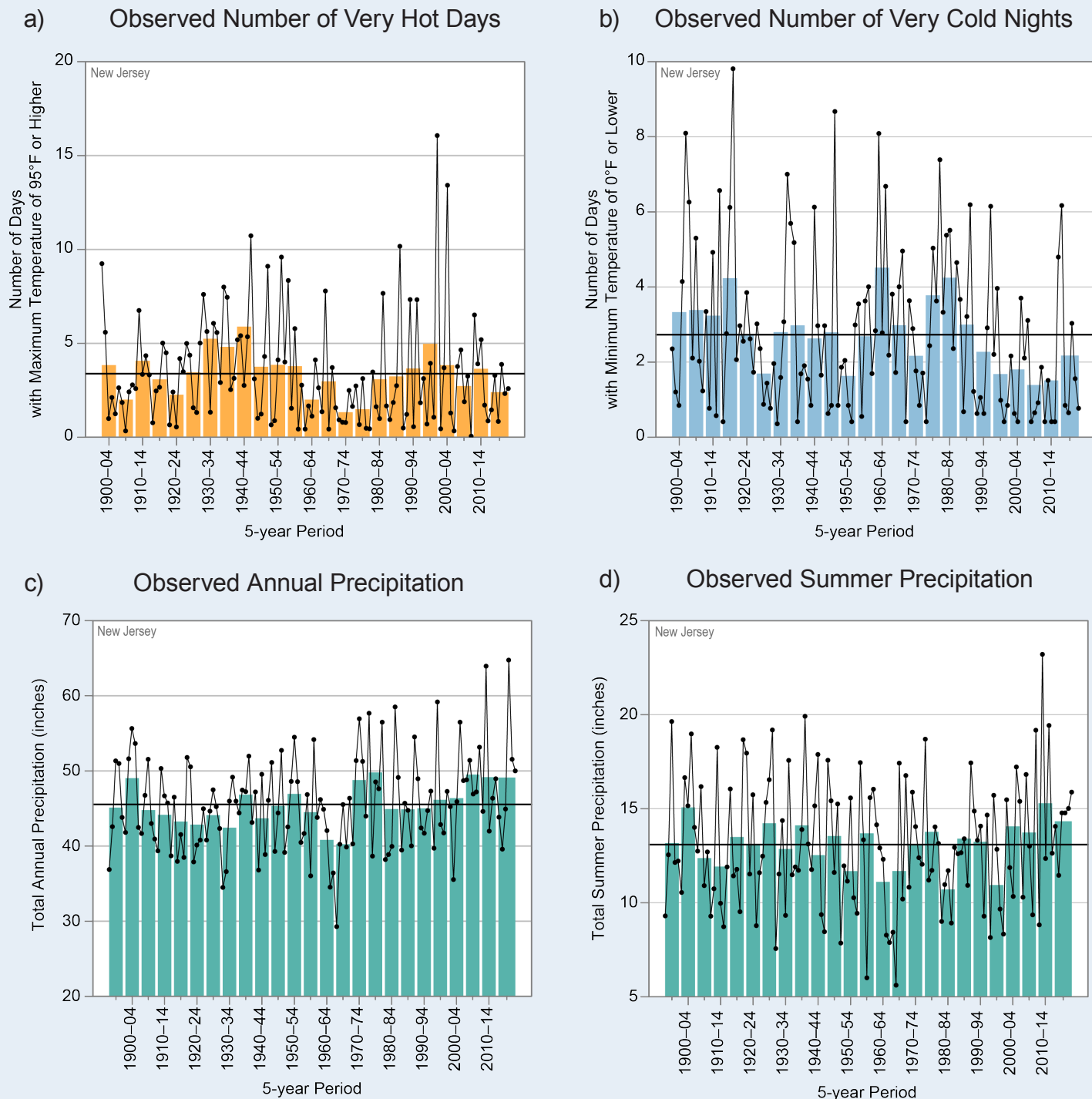


Figure 2: Observed (a) annual number of very hot days (maximum temperature of 95°F or higher); (b) annual number of very cold nights (minimum temperature of 0°F or lower); (c) total annual precipitation; and (d) total summer (June–August) precipitation for New Jersey from (a, b) 1900 to 2020 and (c, d) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 3.4 days, (b) 2.7 nights, (c) 45.5 inches, (d) 13.1 inches. Since the late 1980s the number of very hot days has been near to above the long-term average. Very cold nights have been an increasingly rare occurrence since the early 1990s, and this downward trend has extended into this century. Annual and summer precipitation has been above average during the most recent 16 years (2005–2020), with record amounts of summer precipitation occurring between 2010 and 2014. Sources: CISESS and NOAA NCEI. Data: (a, b) GHCN-Daily from 5 long-term stations; (c, d) nClimDiv.

Temperatures in New Jersey have risen more than 3.5°F since the beginning of the 20th century (Figure 1). All of the 10 hottest calendar years on record for the state have occurred since 1990, and six have occurred since 2010. The year 2012 was the warmest on record at 3.0°F above average, and 2020 was the second warmest on record at 2.6°F above average. The number of very hot days has been varied (Figure 2a). The number of warm nights in New Jersey has consistently been above the long-term average since the early 2000s, with the highest 5-year average occurring during the 2010–2014 period (Figure 3). The number of very cold nights has been below average since the early 1990s (Figure 2b). Over the past 25 years, there have been many more unusually warm months than unusually cold months in New Jersey. During the 2000–2020 interval, there were no top 5 coldest months, but there were 38 top 5 warmest months.

Total annual precipitation for New Jersey has been about 3.7 inches above average over the last 16 years (Figure 2c). The driest conditions were in the 1960s, and near normal to wet conditions have occurred since the 1970s. The wettest consecutive 5 years was the 1971–1975 interval, and the driest was the 1962–1966 interval. The number of 2-inch extreme precipitation events was well above average during 2005–2014 but has been slightly below average since then (Figure 4). During 2010–2014, the state experienced the greatest number of 2-inch extreme precipitation events, about 50% above the long-term average. Summer precipitation has been above the long-term average during this century, with the highest 5-year average occurring during the 2010–2014 period (Figure 2d). The state can also experience short-term droughts, such as in 2002, 2010, and 2016–2017.

Extreme weather events typically experienced in the state include coastal nor'easters, snowstorms, spring and summer thunderstorms, flooding rains, heat and cold waves, tropical storms, and on rare occasions, hurricanes. The state's coastline is highly vulnerable to damage from coastal storms, which include nor'easters, tropical storms, and hurricanes. Damaging nor'easters are most common between October and April, and those tracking over or near the coast can bring strong winds and heavy precipitation. **Annually, the state experiences at least one coastal storm, but some years have seen as many as 5 to 10 storm events.** The most

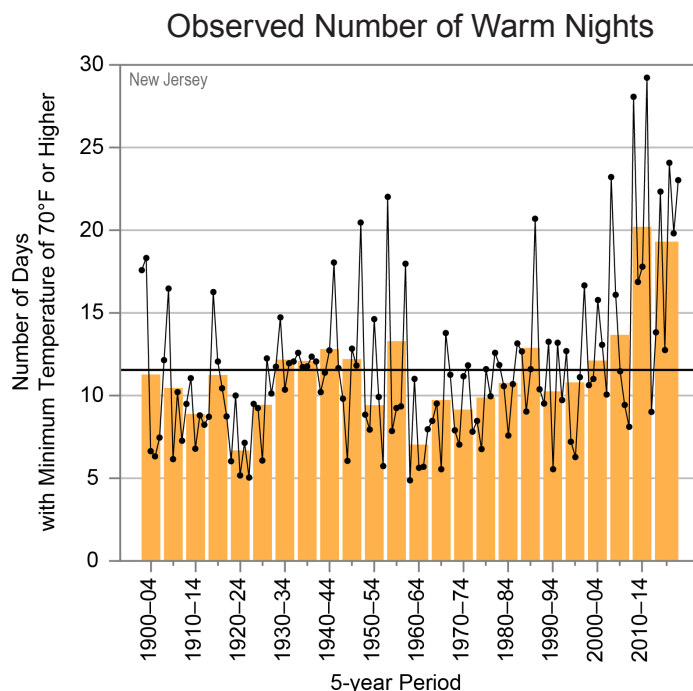


Figure 3: Observed annual number of warm nights (minimum temperature of 70°F or higher) for New Jersey from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 12 days. The number of warm nights in New Jersey has been above average since 2000, with the highest 5-year average being the 2010–2014 period. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 5 long-term stations.

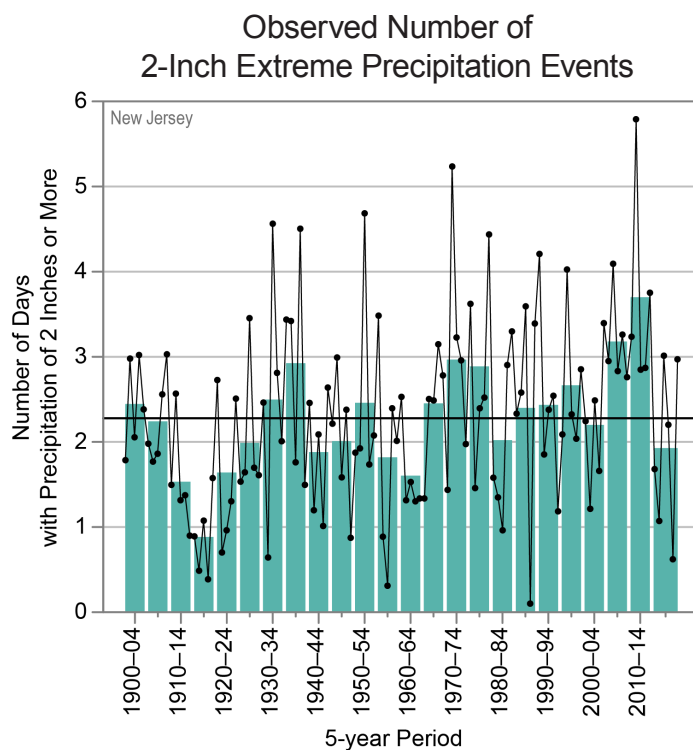


Figure 4: Observed annual number of 2-inch extreme precipitation events for New Jersey from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 2.3 days. A typical reporting station experiences 2–3 events per year. The number of extreme precipitation events was highest during the 2005–2014 interval. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 5 long-term stations.

extreme and destructive event to affect New Jersey in recent years was Superstorm Sandy in 2012. The powerful storm surge, the most destructive element of Sandy, reached 9–10 feet above normal in some areas along the coast. This was caused by strong winds and an unusual west-northwestward track. New Jersey experienced extensive damage from severe winds and coastal flooding, with an estimated \$29.4 billion in repair, response, and restoration costs. February 2010 brought three winter storms to the state, causing Atlantic City to have their snowiest month on record. The blizzard of 2016 brought high winds and heavy snow; Bayville, NJ, had gusts of 72 mph and many beaches experienced moderate to major erosion.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, temperatures are projected to most likely exceed historical record levels by the middle of this century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records (Figure 1). Increases in the number of extremely hot days and decreases in the number of extremely cold days are projected to accompany the overall warming. According to a state-level analysis, by the middle of this century an estimated 70% of summers in this region are anticipated to be hotter than what we now recognize as the warmest summer on record.

Winter and spring precipitation and extreme precipitation events are projected to increase in this century (Figure 5). The projections of increasing precipitation and heavy precipitation events are true for a large area of the Northern Hemisphere in the northern middle latitudes. This may result in increased coastal and inland flooding risks throughout the state.

Since 1900, global average sea level has risen by about 7–8 inches. It is projected to rise another 1–8 feet, with a likely range of 1–4 feet, by 2100 as a result of both past and future emissions from human activities (Figure 6). Even greater rises are projected along the

New Jersey coast because of land subsidence. Sea level along the coast of New Jersey has also risen faster than the global average. Observations beginning in 1911 show sea level has risen at an average rate of 1.6 inches per decade, about double the global rate, over the period of record at Atlantic City. Sea level rise has caused an increase in tidal floods associated with nuisance-level impacts. Nuisance floods are events in which water levels exceed the local threshold (set by NOAA's National Weather Service) for minor impacts. These events can damage infrastructure, cause road closures, and overwhelm storm drains. As sea level has risen along the New Jersey coastline, the number of tidal flood days (all days exceeding the nuisance-level threshold) has also increased, with the greatest number occurring in 2017 (Figure 7). Coastal flooding caused by sea level rise has important future cross-sector implications for public health, water resources, and coastal ecosystems.

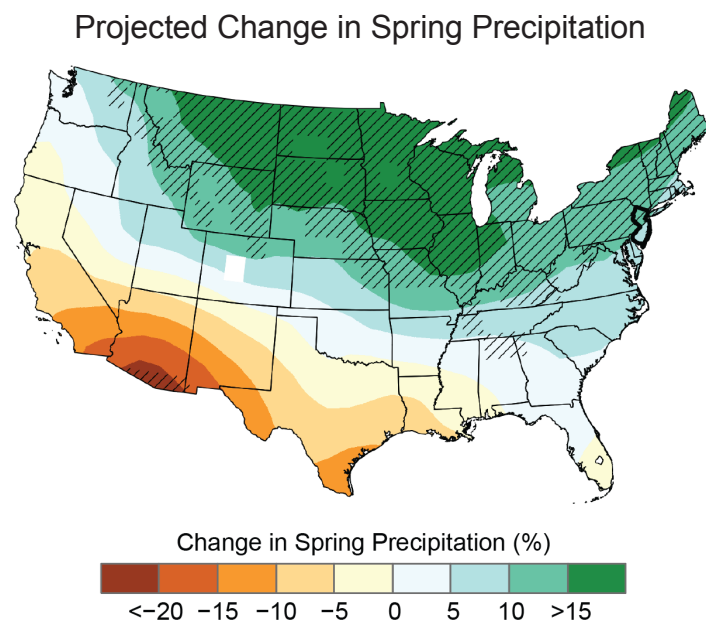


Figure 5: Projected changes in total spring (March–May) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. The white-out area indicates that the climate models are uncertain about the direction of change. Hatching represents areas where the majority of climate models indicate a statistically significant change. New Jersey is part of a large area of projected increases in spring precipitation in the northeastern and central United States. Source: CISESS and NEMAC. Data: CMIP5.

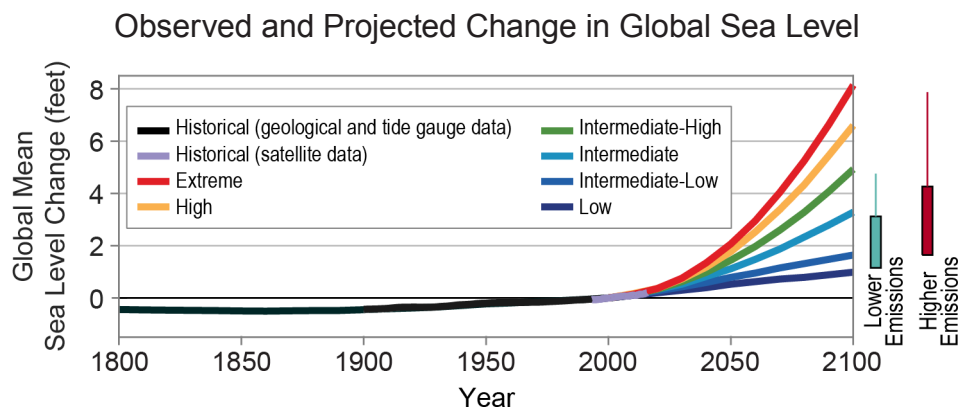


Figure 6: Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate-Low, royal blue; Intermediate, cyan; Intermediate-High, green; High, orange; and Extreme, red curves) relative to historical geological, tide gauge, and satellite altimeter GMSL reconstructions from 1800–2015 (black and magenta lines) and the very likely ranges in 2100 under both lower and higher emissions futures (teal and dark red boxes). Global sea level rise projections range from 1 to 8 feet by 2100, with a likely range of 1 to 4 feet. Source: adapted from Sweet et al. 2017.

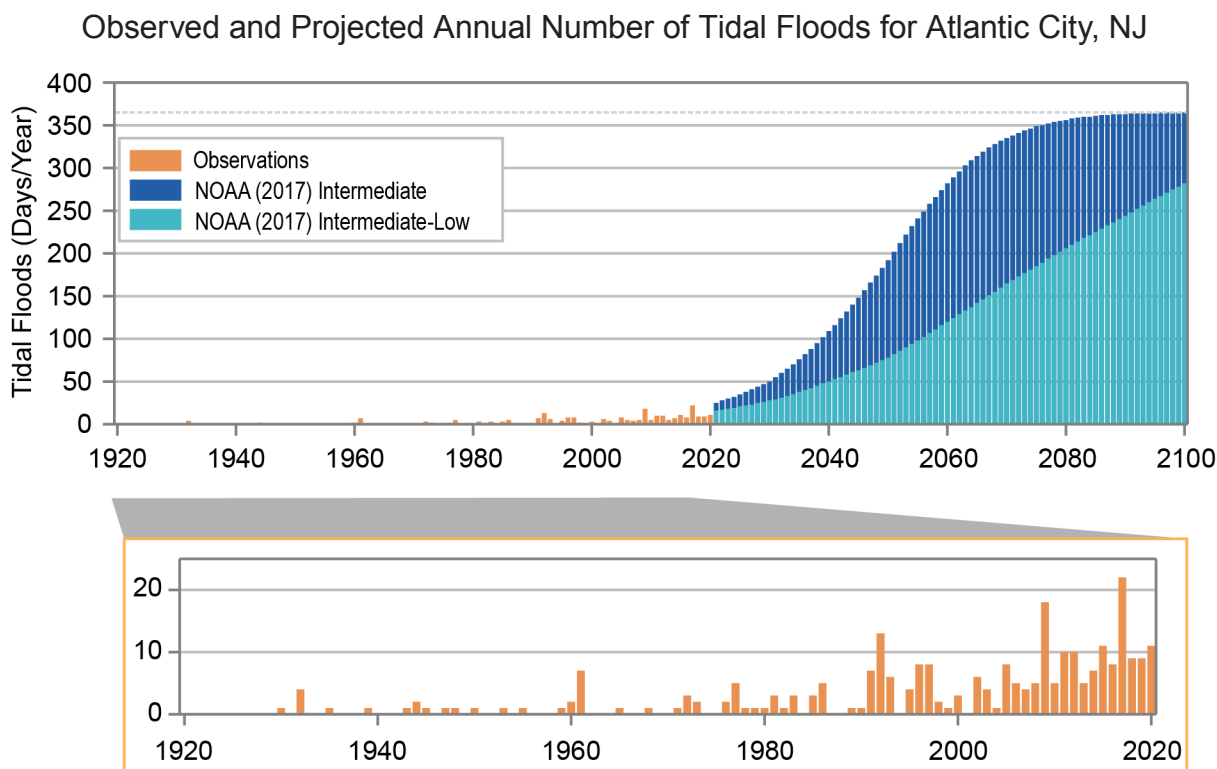


Figure 7: Number of tidal flood days per year at Atlantic City, NJ, for the observed record (1923–2020; orange bars) and projections for 2 NOAA (2017) sea level rise scenarios (2021–2100): Intermediate (dark blue bars) and Intermediate-Low (light blue bars). The NOAA (2017) scenarios are based on local projections of the GMSL scenarios shown in Figure 6. Sea level rise has caused a gradual increase in tidal floods associated with nuisance-level impacts. The greatest number of tidal flood days (all days exceeding the nuisance-level threshold) occurred in 2017 at Atlantic City. Projected increases are large even under a the Intermediate-Low scenario. Under the Intermediate scenario, tidal flooding is projected to occur nearly every day of the year by the end of the century. Additional information on tidal flooding observations and scenarios is available at <https://statesummaries.ncics.org/technicaldetails>. Sources: CISESS and NOAA NOS.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

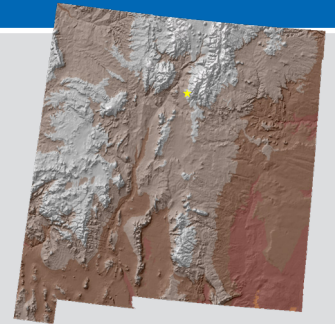
NEW MEXICO

Key Messages

Temperatures in New Mexico have risen more than 2°F since the beginning of the 20th century. The number of extremely hot days and warm nights have also increased. Historically unprecedented warming is projected during this century.

The summer monsoon rainfall, which provides much needed water for agricultural and ecological systems, varies greatly from year to year, and future trends in such precipitation are highly uncertain.

Droughts are a serious threat in this water-scarce state. Drought intensity is projected to increase, and snowpack accumulation is projected to decrease, posing a major challenge to New Mexico's environmental, agricultural, and human systems. Wildfire frequency and severity are also projected to increase throughout the state.



New Mexico encompasses a large geographic area of diverse interior-continental environments, including mountain ranges, forests, grasslands, and deserts. Temperatures vary widely across the state. Monthly average (1991–2020 normals) temperatures in the northern mountainous regions range from the low 20s in January to around 60 in July, and in the lower elevations in the south, temperatures range from the middle 40s in January to the low 80s in July. Much of the state is characterized as arid to semiarid, with most areas in the central and west receiving less than 15 inches of precipitation annually.

Temperatures in New Mexico have risen more than 2°F since the beginning of the 20th century (Figure 1). The last decade has been the warmest on record for the state, with increasing trends in both extremely hot days and warm nights. Over the past several decades, much of the state has seen increases in the number of extremely hot days (Figure 2), most significantly in the eastern plains. A similar warming trend is apparent in the number of warm nights (Figure 3), which has increased since the mid-1970s, and in winter temperatures, as the number of very cold nights was below average during the 1990–2009 and 2015–2020 periods (Figure 4a). While the recent trend is toward fewer very cold nights, a historic cold wave affected the state during February 9–18, 2021. In the eastern plains, temperatures remained below freezing for 7 consecutive days and fell below -10°F in a few locations, with the coldest temperature being -17°F at Lake Maloya. The extreme cold temperatures, heavy snow (more than 10 inches in numerous locations), severe icing, and accompanying power outages caused catastrophic damage.

Observed and Projected Temperature Change

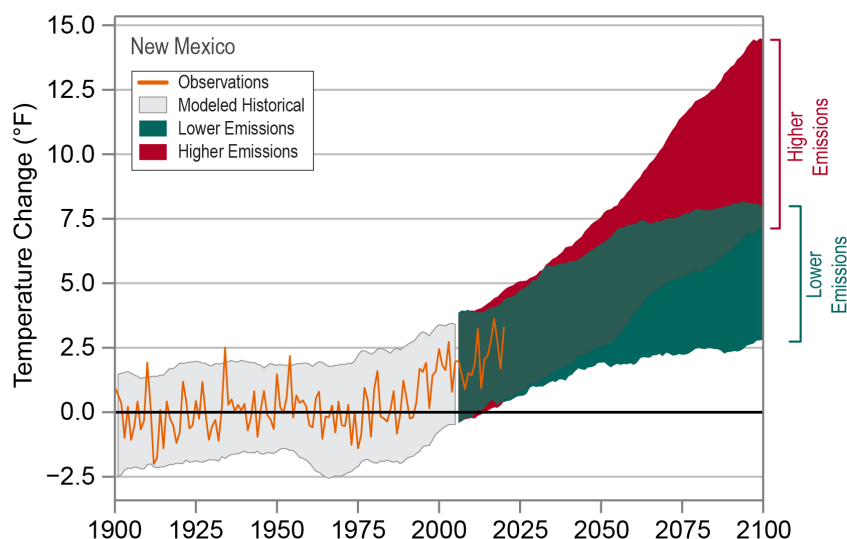


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for New Mexico. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in New Mexico (orange line) have risen more than 2°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 2°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 11°F warmer than the hottest year in the historical record; red shading). Sources: CISS and NOAA NCEI.

Precipitation is highly variable from year to year and decade to decade. Statewide total annual precipitation has ranged from a high of 26.6 inches in 1941 to a low of 6.6 inches in 1956 (Figure 4b). The wettest multiyear periods were in the early 1940s and mid-1980s, and the wettest consecutive 5 years was the 1984–1988 interval. The driest multiyear periods were in the early 1950s and early 2010s, and the driest consecutive 5 years was the 1952–1956 interval. Multiyear periods of high and low precipitation have resulted in very large swings in reservoir supplies for agriculture. Levels in the Elephant Butte Reservoir were high from the 1920s to the 1940s before dropping until the 1980s, when they increased again. High levels remained throughout the 1980s and 1990s until falling again in the first part of this century (Figure 5). This illustrates that there have been extended (decades-long) periods of unusual wet or dry conditions. **The most recent multiyear drought (2011–2014; the second-worst statewide drought since the early 1950s) resulted in near record low levels of water in the reservoir.** Although a wet 2015 and near normal precipitation during 2016–2019 caused some rebound in water levels, they remain well below normal.

Unlike many areas of the United States, New Mexico has not experienced an upward trend in the frequency of extreme precipitation events (Figure 4c). The annual number of 1-inch extreme precipitation events has been variable since 1985, fluctuating in a similar fashion to the pronounced variations in total annual precipitation. Since drought conditions began in the 2000s, the occurrence of these events was near or below average until the 2015–2020 period.

An important feature of New Mexico's summer climate is the North American Monsoon, which can start in late June and extend into September (Figure 4d). July and August are the wettest months across much of the state. In some regions of the state, monsoon rainfall accounts for half of the annual precipitation and plays an important role in supporting the agricultural economy. **The monsoon rains are highly beneficial but occasionally can be destructive.** In 2006, a remarkably persistent monsoon regime was in place from late July through most of August and caused significant damage and flooding in southern New Mexico. This was seen again in the summer of 2013, when a single, very wet week in September caused major flooding across the central and western portions of the state. These events

Observed Number of Extremely Hot Days

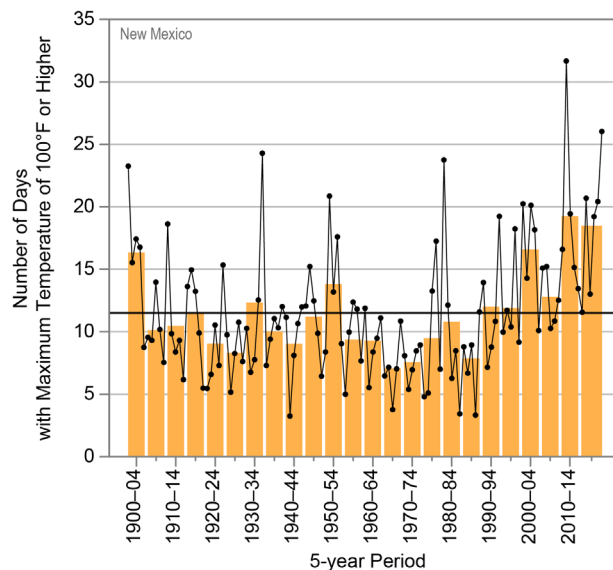


Figure 2: Observed annual number of extremely hot days (maximum temperature of 100°F or higher) for New Mexico from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 12.0 days (note that the average for individual stations varies greatly because of the state's large elevation range). Since 1990, the number of extremely hot days has risen on average in New Mexico although not all locations have experienced increases. The greatest number of days was recorded in the 2010–2014 period, with the 5 long-term stations averaging 19 days per year with temperatures higher than 100°F. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 5 long-term stations.

Observed Number of Warm Nights

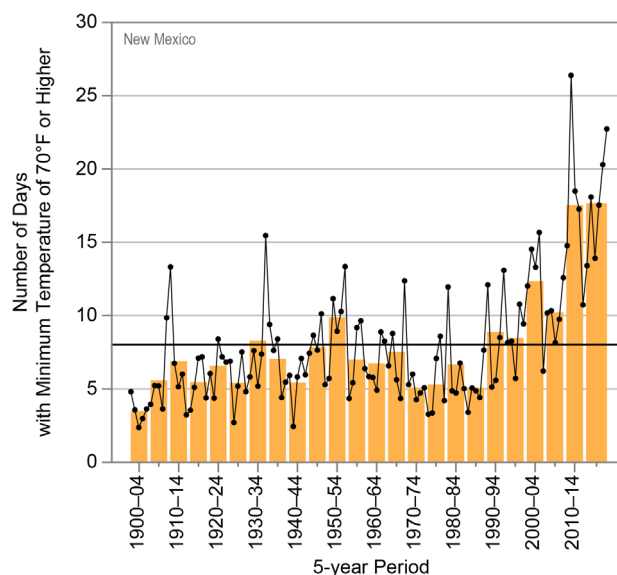


Figure 3: Observed annual number of warm nights (minimum temperature of 70°F or higher) for New Mexico from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 8.0 nights (note that the average for individual stations varies greatly because of the state's large elevation range). The frequency of warm nights has risen dramatically since 2000, with the 2010–2014 period and the 2015–2020 period experiencing about double the long-term average. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 5 long-term stations.

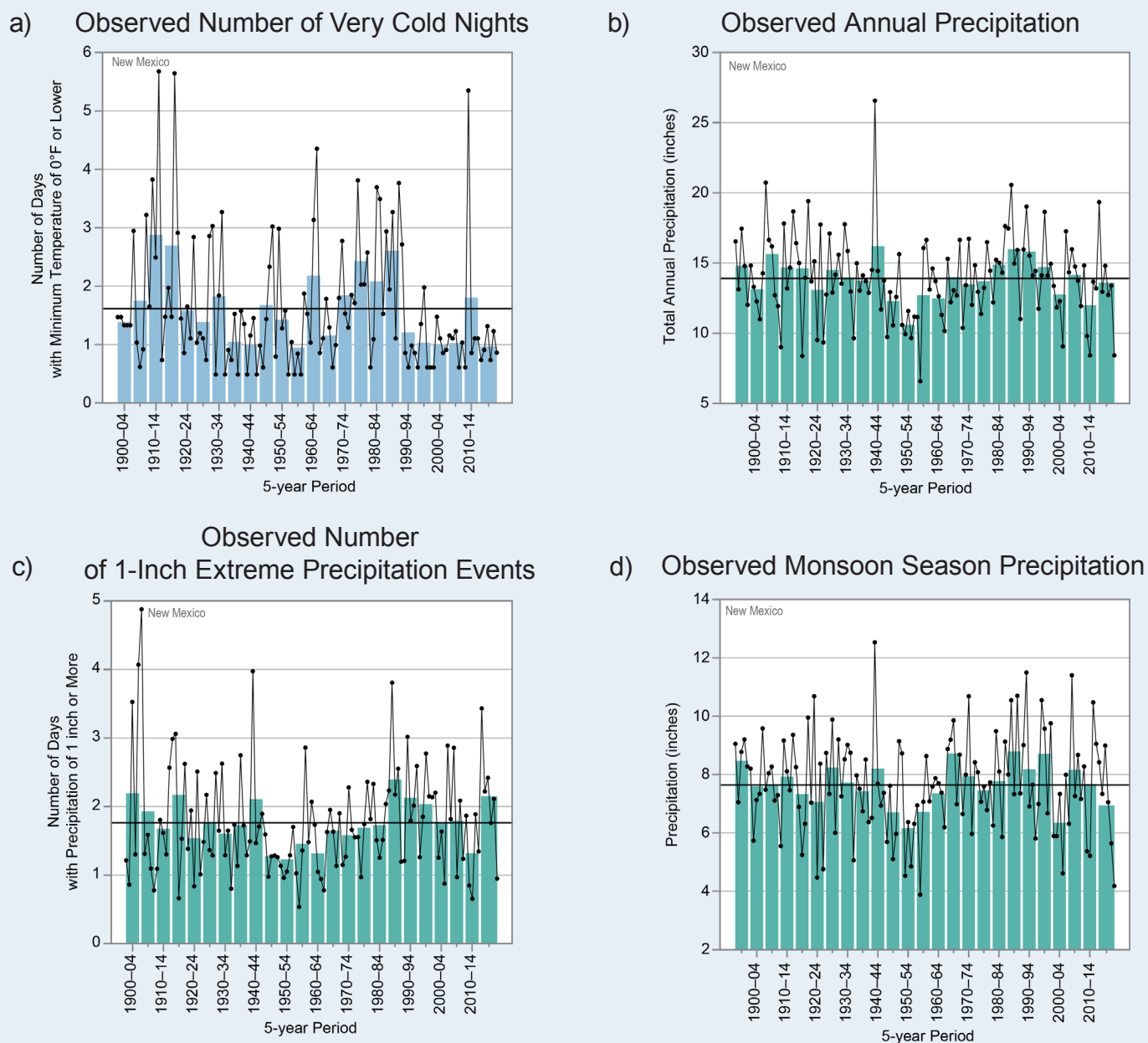


Figure 4: Observed (a) annual number of very cold nights (minimum temperature of 0°F or lower), (b) total annual precipitation, (c) annual number of 1-inch extreme precipitation events (days with precipitation of 1 inch or more), and (d) monsoon season (June–September) precipitation for New Mexico from (a, c) 1900 to 2020 and (b, d) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 1.6 nights, (b) 13.9 inches, (c) 1.8 days, (d) 7.6 inches. (Note that for Figures 4a and 4c, the average for individual reporting stations varies greatly because of the state's large elevation range.) The number of very cold nights has been below average since 1990, with the exception of the 2010–2014 period. Precipitation is highly variable from year to year. A typical station experiences about two 1-inch extreme precipitation events per year. Sources: CISESS and NOAA NCEI. Data: (a) GHCN-Daily from 5 long-term stations; (b) nClimDiv; (c) GHCN-Daily from 12 long-term stations; (d) nClimDiv.

provided much-needed water for the reservoirs but also caused widespread damage. In contrast, the 2020 monsoon season was the second driest on record, after 1956.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed

historical record levels by the middle of this century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. Heat waves are projected to increase in intensity, posing a risk to human health, while cold wave intensity is projected to decrease.

Although projections of annual precipitation are uncertain, precipitation in spring, which is already the dry season in New Mexico, is projected to decrease across most of the state (Figure 6). The combination of decreased spring precipitation and warmer temperatures would have profoundly negative impacts on the mountain snowpack that feeds water supply reservoirs, reducing water flow to the river basins that rely on the snowpack for summer water supplies. Even if snowpack accumulation does not decrease, the projected higher temperatures will lead to an earlier start and end to the snowmelt season, potentially necessitating changes in water management.

The extended record indicates that droughts are a frequent occurrence in New Mexico and that episodes more severe than any in the recent historical record have occurred in the more distant past (Figure 7).

Droughts are projected to become more intense.

Recent drought conditions have negatively impacted ecosystems across the state. For example, extreme drought in the Chihuahuan Desert has caused grasslands to die, decreasing grazing resources for livestock. While projections of changes in precipitation are uncertain, higher temperatures will increase water evaporation from moist and vegetated surfaces, which will reduce streamflow and soil moisture and increase the intensity of naturally occurring droughts. Drought will not only further challenge limited agricultural resources but also increase the occurrence and severity of wildfires and the frequency of dust storms.

Storage Levels in the Elephant Butte Reservoir

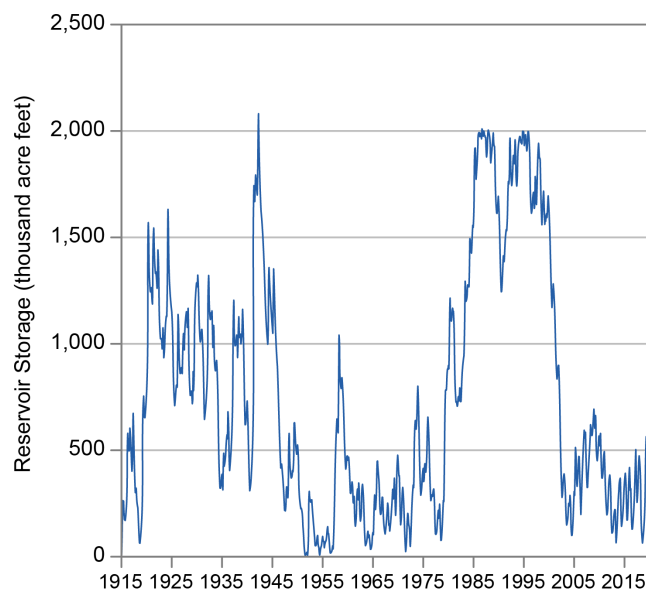


Figure 5: Monthly time series of the average water storage levels in the Elephant Butte Reservoir from March 1915 to January 2021. Water storage levels in the reservoir have varied widely over the years. They were generally low, and in some cases nearly zero, from the late 1940s to early 1980s. Following high levels during the 1980s and 1990s, a large decline occurred in the early 21st century in response to severe drought conditions. In 2004, 2013, and 2018, storage levels approached record lows due to the extended drought. Source: USBR.

Projected Change in Spring Precipitation

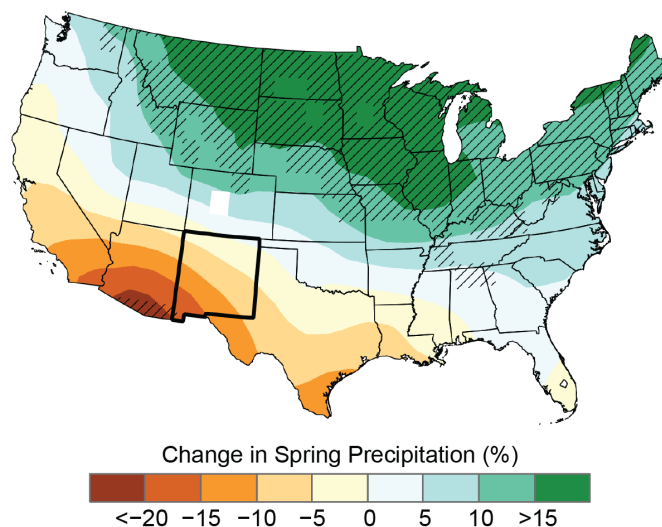


Figure 6: Projected changes in total spring (March–May) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. The white-out area indicates that the climate models are uncertain about the direction of change. Hatching represents areas where the majority of climate models indicate a statistically significant change. New Mexico is south of the transition zone from wetter conditions in the north to drier conditions in the south. Southwestern New Mexico is part of a large area of projected decreases that includes Central America, Mexico, and the southwestern United States. Sources: CISESS and NEMAC. Data: CMIP5.

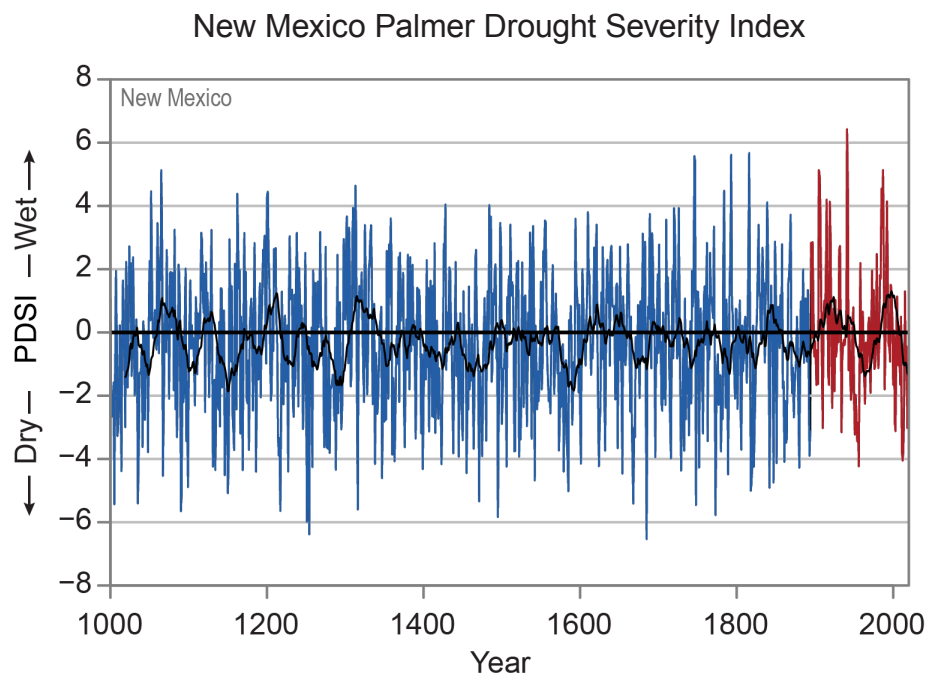


Figure 7: Time series of the Palmer Drought Severity Index for New Mexico from the year 1000 to 2020. Values for 1895–2020 (red) are based on measured temperature and precipitation. Values prior to 1895 (blue) are estimated from indirect measures such as tree rings. The fluctuating black line is a running 20-year average. In the modern era, the wet periods of the early 1900s and the 1980s to 1990s and the dry period of the 1950s are evident. The extended record indicates periodic occurrences of similar extended wet and dry periods. Sources: CISESS and NOAA NCEI. Data: nClimDiv and NADAv2.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

WWW.NCEI.NOAA.GOV | [HTTPS://STATESUMMARIES.NCICS.ORG/CHAPTER/NM/](https://statesummaries.ncics.org/CHAPTER/NM/) | LEAD AUTHORS: REBEKAH FRANKSON, KENNETH E. KUNKEL
CONTRIBUTORS: LAURA E. STEVENS, DAVID R. EASTERLING

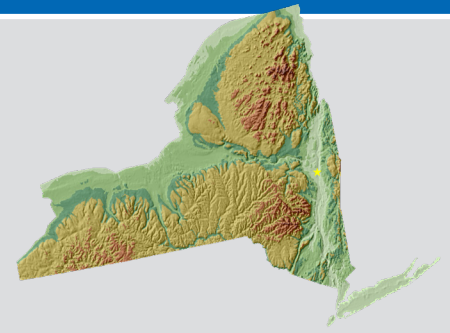
NEW YORK

Key Messages

Temperatures in New York have risen almost 2.5°F since the beginning of the 20th century. Under a higher emissions pathway, historically unprecedented warming is projected during this century. Extreme heat is a particular concern for densely populated urban areas such as New York City, where high temperatures and high humidity can cause dangerous conditions.

Since 1880, sea level has risen by about 13 inches along the coast of New York, more than the global average rise of 7–8 inches. Global average sea level is projected to rise another 1–4 feet by 2100, but levels along the coast of New York will likely be higher due to local and regional factors. Sea level rise will increase the frequency, extent, and severity of coastal flooding, which is a grave risk to dense, high-value development along New York's coastline.

New York has experienced a large increase in the frequency and intensity of extreme precipitation events, and further increases are projected. Increases in winter and spring precipitation are projected, raising the risk of springtime flooding, which could cause delayed planting and reduced yields.



New York is regionally diverse, encompassing the Nation's most populous metropolitan area, as well as large expanses of sparsely populated but ecologically and agriculturally important areas. The state's climate is heavily influenced by several geographic features. The Atlantic Ocean has a moderating effect on coastal areas, while the Great Lakes and Lake Champlain moderate the northwestern and northeastern parts of the state, respectively. During much of the year, the prevailing westerly flow brings air masses from the North American interior across the entire region, with occasional episodes of bitter cold during winter. The jet stream, which is often located near or over the region during winter, brings frequent storm systems that cause cloudy skies, windy conditions, and precipitation. New York is often affected by extreme events, such as floods, droughts, heat waves, hurricanes, nor'easters, and snow and ice storms.

Observed and Projected Temperature Change

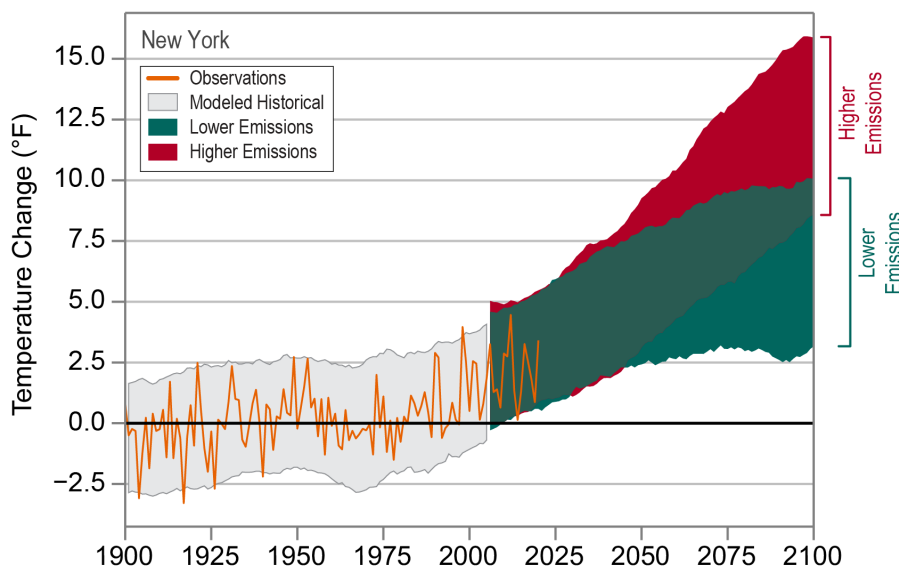
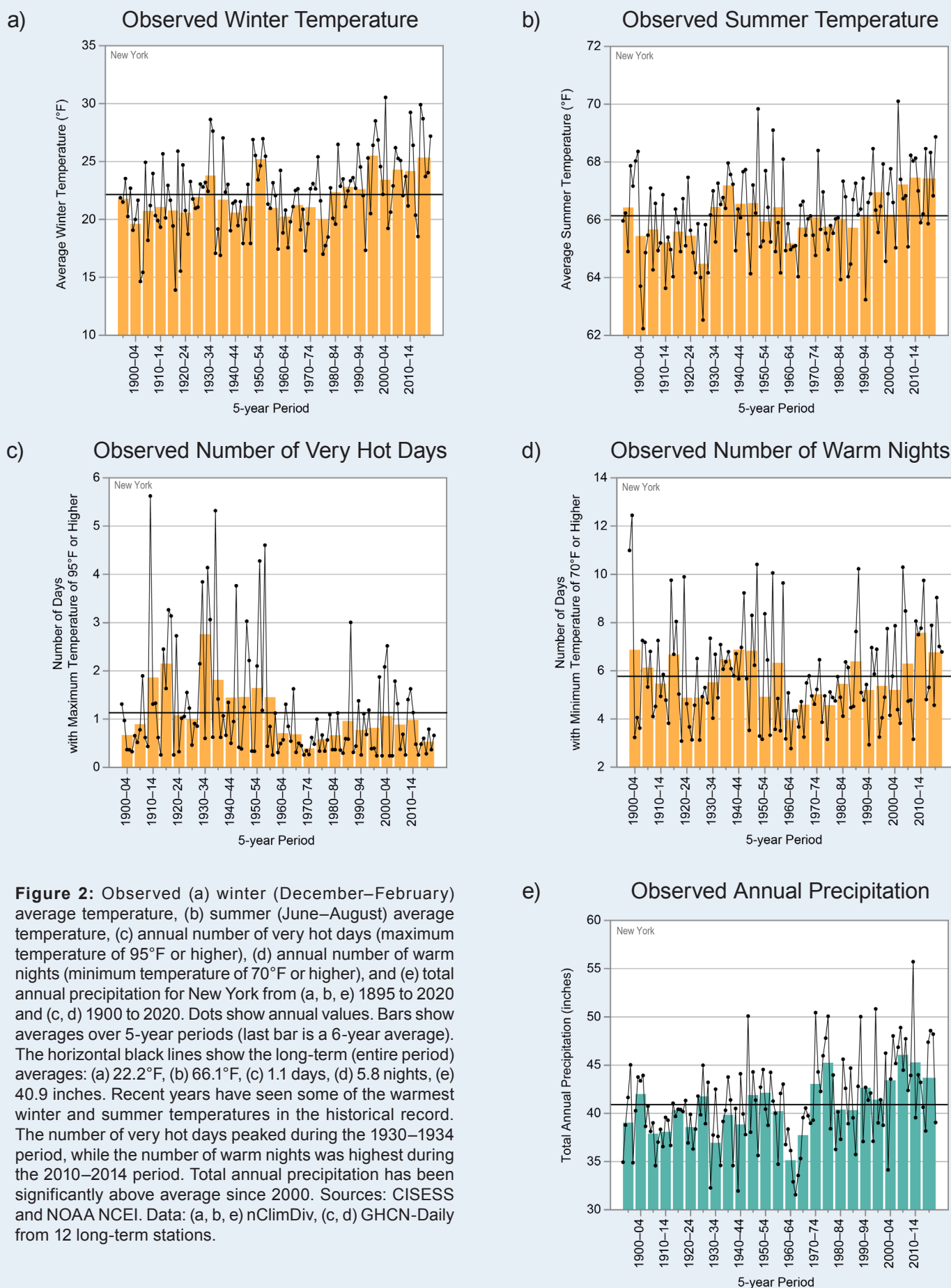


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for New York. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in New York (orange line) have risen almost 2.5°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 3°F warmer than the historical average; green shading) and more

warming under a higher emissions future (the hottest end-of-century projections being about 11°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.



Since the beginning of the 20th century, temperatures in New York have risen almost 2.5°F, and temperatures in the 2000s have been higher than in any other historical period (Figure 1). As of 2020, the hottest year on record for New York was 2012, with a statewide average temperature of 48.8°F, more than 4°F above the long-term average (44.5°F). This warming has been concentrated in the winter and spring, while summers have not warmed as much (Figures 2a and 2b). Summer warming is more influenced by the number of warm nights than by the occurrence of very hot days (Figures 2c and 2d). The state has experienced an increase in the number of warm nights and a decrease in the number of very cold nights (Figure 3). The increase in winter temperatures has had an identifiable effect on Great Lakes ice cover. Since 1998, there have been several years when Lakes Erie and Ontario were mostly ice-free (Figure 4).

Annual average precipitation is slightly more than 40 inches statewide but varies regionally, with mountainous areas receiving near 50 inches per year. Statewide annual precipitation has ranged from a low of 31.6 inches in 1964 to a high of 55.7 inches in 2011. The driest multiyear periods were in the early 1930s and

early 1960s and the wettest in the late 1970s and since 2000 (Figure 2e). The driest consecutive 5-year interval was 1962–1966, with an annual average of 33.9 inches, and the wettest was 2007–2011, with an annual average of 46.8 inches. **New York has recently experienced a large increase in the number of 2-inch extreme precipitation events** (Figure 5), which peaked during the 2010–2014 period. The annual precipitation record, set in 2011, was partially due to extreme precipitation events caused by Hurricane Irene and Tropical Storm Lee in late August and early September, respectively. Many areas of eastern New York received more than 7 inches of rain from Hurricane Irene, with more than 18 inches in some locations in the Catskill Mountains. Less than two weeks later, Tropical Storm Lee brought additional heavy rainfall, with more than 12 inches falling in the Susquehanna River basin. The extreme rainfall from these two events caused devastating flooding and damage. Nontropical systems can also bring extreme rainfall, such as during August 12–13, 2014, when the state 24-hour precipitation record was broken (13.57 inches) at Islip. New York experienced extreme drought during 2016 and severe drought during 2020, which had major impacts on agriculture in some parts of the state.

Observed Number of Very Cold Nights

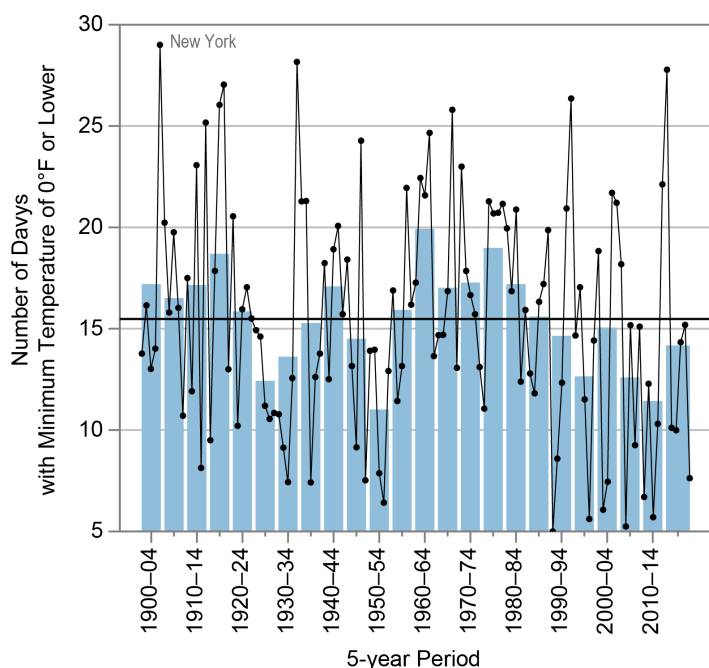


Figure 3: Observed annual number of very cold nights (minimum temperature of 0°F or lower) for New York from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 16 nights. The number of very cold nights has been below average since 1990, reflecting a long-term winter warming trend. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 12 long-term stations.

In addition to causing heavy flooding inland, hurricanes and tropical storms can cause coastal damage from storm surge and flooding. In late October 2012, Superstorm Sandy (a post-tropical storm) caused massive storm surge in New York City. The extensive

Annual Maximum Ice Cover for Lake Erie and Lake Ontario

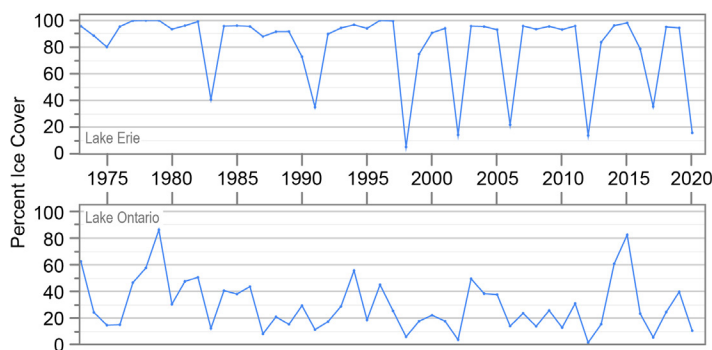


Figure 4: Annual maximum ice cover extent (%) for Lake Erie (top) and Lake Ontario (bottom) from 1973 to 2020. During most years, Lake Erie was nearly frozen over, while Lake Ontario was mostly ice-free. There were 6 years when Lake Erie was mostly ice-free, and all of those occurred since 1998. Since 2006, Lake Ontario's ice cover extent has remained below 40%, except for higher values during the cold 2013–14 and 2014–15 winters. Source: NOAA GLERL.

flooding from the storm surge inundated subway tunnels, damaged the electrical grid, overwhelmed sewage treatment plants, and destroyed thousands of homes. Superstorm Sandy caused tens of billions of dollars in damages in the state, with an estimated \$19 billion in damages to New York City.

Winter storms occur frequently across the state due to the large temperature contrast between the cold interior of the North American continent and the warm moist air of the western Atlantic. **These storms, popularly known as nor'easters, can produce crippling snowfall, flood-producing rainfall, hurricane-force winds, and dangerous cold.** The Blizzard of 1996, January 6–8, was a classic nor'easter, dropping more than 20 inches of snow in New York City and causing an estimated \$70 million in damages across the state. During the Blizzard of 2016, January 22–24, more than 30 inches of snow fell in some areas, such as Kennedy Airport, where near-blizzard conditions persisted for 9 hours; travel bans were also enacted in New York City. The northern part of the state frequently experiences heavy lake-effect snows due to the warming and moistening of arctic air masses as they pass over the Great Lakes. This results in intense bands of heavy snowfall over areas downwind of Lakes Ontario and Erie. During November 17–19, 2014, a lake-effect snowstorm delivered more than 5 feet of snow just east of Buffalo. A second lake-effect event immediately followed during November 19–20, dropping as much as an additional 4 feet of snow; snowfall rates as high as 6 inches per hour were reported, with some areas receiving more than 3 feet of snow in less than 12 hours. These two storms were considered unprecedented events but were characteristic of lake-effect snows that affect the state. The Great Lakes can also experience flooding and erosion due to high water levels. Wet spring conditions contributed to record-high water levels and flooding in 2017 and 2019. Cleanup costs, infrastructure damages, and agricultural losses were in the millions of dollars.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of this century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than

Observed Number of 2-Inch Extreme Precipitation Events

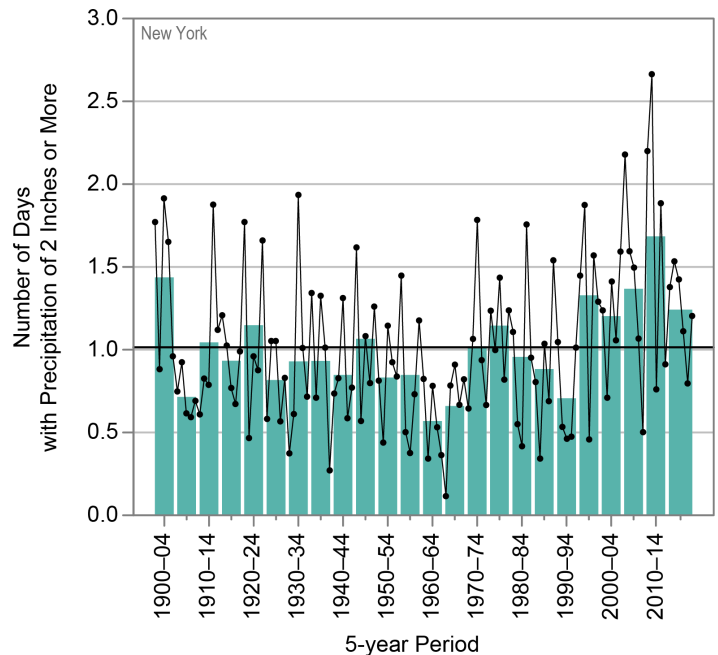


Figure 5: Observed annual number of 2-inch extreme precipitation events (days with precipitation of 2 inches or more) for New York from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 1.0 days. A typical station experiences 1 event each year. Since 1995, New York has experienced an above average number of 2-inch extreme precipitation events, with the highest frequency occurring during the 2010–2014 period. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 16 long-term stations.

Observed and Projected Change in Global Sea Level

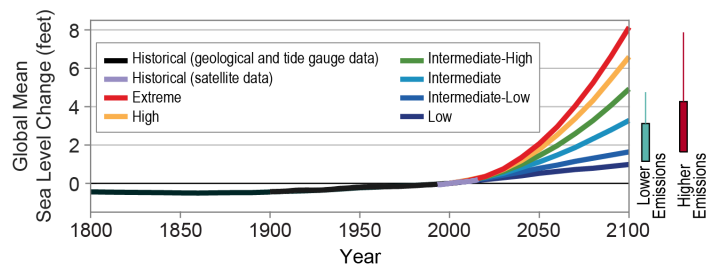


Figure 6: Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate-Low, royal blue; Intermediate, cyan; Intermediate-High, green; High, orange; and Extreme, red curves) relative to historical geological, tide gauge, and satellite altimeter GMSL reconstructions from 1800–2015 (black and magenta lines) and the very likely ranges in 2100 under both lower and higher emissions futures (teal and dark red boxes). Global sea level rise projections range from 1 to 8 feet by 2100, with a likely range of 1 to 4 feet. Source: adapted from Sweet et al. 2017.

historical records. Heat waves are projected to be more intense. Extreme heat is a particular concern for New York City and other urban areas, where the urban heat island effect raises summer temperatures. High temperatures

combined with high humidity can create dangerous heat index values. By contrast, cold waves are projected to become less intense.

Increasing temperatures raise concerns for sea level rise in coastal areas. Since 1880, sea level has risen by about 13 inches along the coast of New York, more than the global average rise of about 7–8 inches since 1900. Global sea level is projected to rise another 1–4 feet by 2100 as a result of both past and future emissions from human activities (Figure 6), but local and regional factors are expected to cause New York’s sea level to rise more than the global projection. Even if storm patterns remain the same, sea level rise will increase the frequency, extent, and severity of coastal flooding. Sea level rise has caused an increase in tidal floods associated with nuisance-level impacts. Nuisance floods are events in which water levels exceed the local threshold (set by NOAA’s National Weather Service) for minor impacts.

Observed and Projected Annual Number of Tidal Floods for The Battery, NY

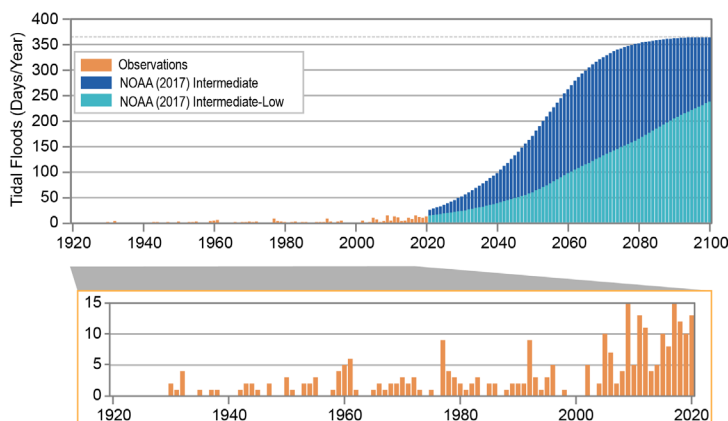


Figure 7: Number of tidal flood days per year at The Battery, NY, for the observed record (1920–2020; orange bars) and projections for two NOAA (2017) sea level rise scenarios (2021–2100): Intermediate (dark blue bars) and Intermediate-Low (light blue bars). The NOAA (2017) scenarios are based on local projections of the GMSL scenarios shown in Figure 6. Sea level rise has caused a gradual increase in tidal floods associated with nuisance-level impacts. The greatest number of tidal flood days (all days exceeding the nuisance-level threshold) occurred in 2009 and 2017 at The Battery. Projected increases are large even under the Intermediate-Low scenario. Under the Intermediate scenario, tidal flooding is projected to occur nearly every day of the year by the end of the century. Additional information on tidal flooding observations and scenarios is available at <https://statesummaries.ncics.org/technicaldetails>. Sources: CISESS and NOAA NOS.

These events can damage infrastructure, cause road closures, and overwhelm storm drains. As sea level has risen along the New York coastline, the number of tidal flood days (all days exceeding the nuisance-level threshold) has also increased, with the greatest number occurring in 2009 and 2017 (Figure 7). This is a particular concern for New York because of dense, high-value development along the coastline.

Winter and spring precipitation is projected to increase in New York (Figure 8). This could result in enhanced snowpack at higher elevations, but with warmer temperatures, more of the precipitation will fall as rain, particularly at lower elevations. In addition, the frequency and intensity of extreme precipitation events are projected to increase, potentially increasing the frequency and intensity of floods. Heavier precipitation increases the risk of springtime flooding, which could pose a particular threat to New York’s agricultural industry by delaying planting and resulting in yield losses.

Projected Change in Winter Precipitation

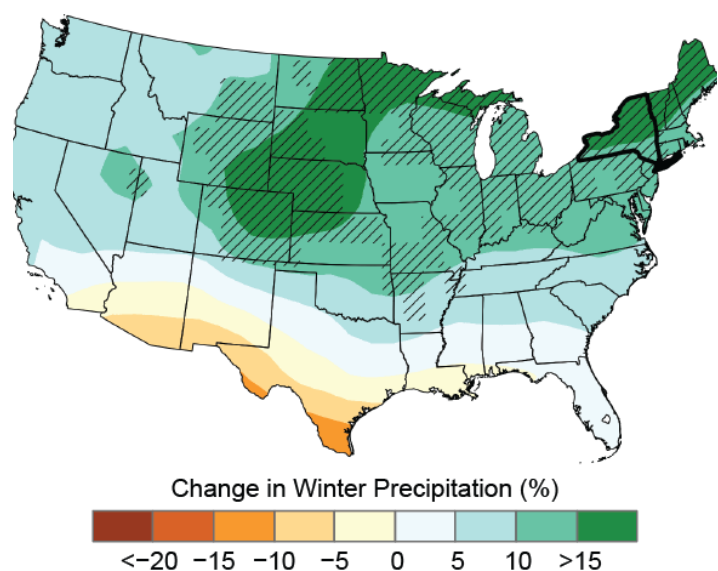
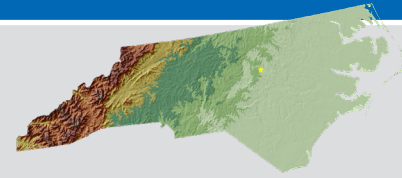


Figure 8: Projected change in winter (December–February) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. By the middle of this century, if greenhouse gas emissions continue to rise rapidly, winter precipitation is projected to increase by 10%–15% in southern New York and 15%–20% in northern New York. Sources: CISESS and NEMAC. Data: CMIP5.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

NORTH CAROLINA



Key Messages

Temperatures in North Carolina have risen more than 1°F since the beginning of the 20th century. Under a higher emissions pathway, historically unprecedented warming is projected during this century.

The number of landfalling hurricanes in North Carolina is highly variable from year to year. Hurricane-associated storm intensity and rainfall rates are projected to increase as the climate warms.

Global sea level is projected to rise, with a likely range of 1–4 feet by 2100. A large portion of North Carolina's coastline is extremely vulnerable to projected sea level rise due to its low elevation and subsidence (sinking) of land in the northern Coastal Plain.

North Carolina has a humid climate with very warm summers and moderately cold winters. Its climate exhibits substantial regional variation due to its diverse geographic elements, including the Appalachian Mountains in the west, the Piedmont plateau in the central region, and the Coastal Plain to the east. Elevations range from sea level along the Atlantic coast to more than 6,000 feet in the western mountains (the largest elevation range of any state east of the Mississippi River). Annual average (1991–2020 normals) temperatures vary more than 20°F from the highest elevations to the lowest points on the coast. Winter temperatures are moderated somewhat by the Appalachian Mountains, which partially block cold air coming from the Midwest.

Temperatures in North Carolina have risen more than 1°F since the beginning of the 20th century (Figure 1). North Carolina is part of a larger region of the southeastern United States that exhibited little overall warming in surface temperatures over the 20th century. Temperatures were highest during the first half of the 20th century, followed by a cool period in the 1960s and 1970s. Since that time, temperatures have increased steadily and have consistently been above average since the late 1990s. Winter average temperatures have generally been above average since 1990, with the 2015–2020 period exceeding the levels of the early 1930s and early 1950s (Figure 2a). Summer average temperatures have been the warmest on record for the last 16 years (2005–2020; Figure 2b). Although North Carolina has not experienced an increase in the frequency of very hot days (Figure 3a), the last 11 years (2010–2020) have seen the largest number of very warm nights (Figure 4).

Observed and Projected Temperature Change

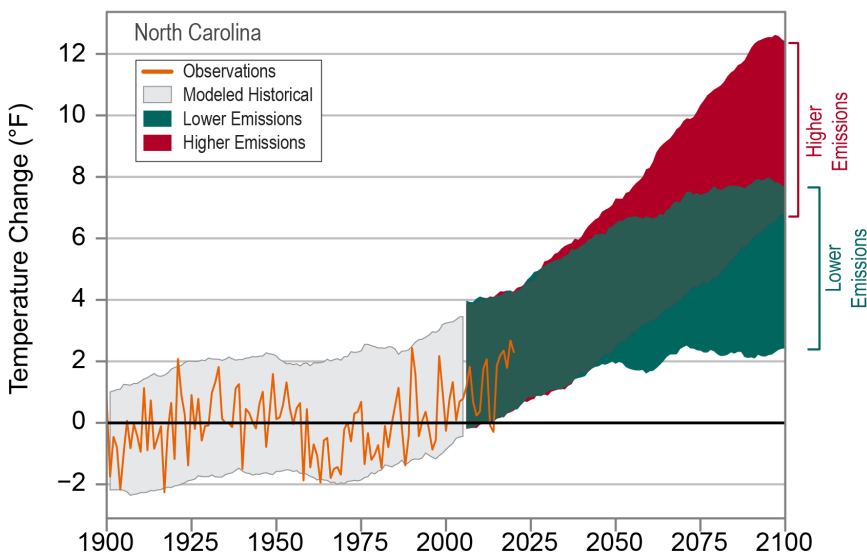


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for North Carolina. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in North Carolina (orange line) have risen more than 1°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about as warm as the hottest year in the historical record; green shading) and more warming under a higher

emissions future (the hottest end-of-century projections being about 10°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

Statewide total annual precipitation has ranged from a low of 34.8 inches in 2007 to a high of 68.4 inches in 2018. The driest multiyear periods were in the early 1930s and early 1950s and the wettest in the late 1900s and late 2010s (Figure 3b). The driest consecutive 5-year interval was 1930–1934, averaging 44.4 inches per year, and the wettest was 2016–2020, averaging 56.9 inches per year. There is no overall trend in annual precipitation. Precipitation totals are generally highest in the summer, with a peak in July. Southwestern North Carolina is one of the wettest locations in the Southeast, receiving more than 90 inches of precipitation annually in a few locations. The number of 3-inch extreme precipitation events was highest during the 2015–2020 period (Figure 3c) but shows no overall trend. The state averages around 5 inches of snowfall annually, although the higher elevations of the Appalachian Mountains can receive up to 100 inches. **Snow and ice storms have the potential to cause significant damage.** Some of these storms are the result of “cold-air damming,” which occurs when cold air becomes trapped against the Appalachian Mountains by a layer of less dense warm air above it. A strong cold-air damming event took place during February 12–13, 2014, causing a severe winter storm. Large portions of the state received between 5 and 10 inches of snow, and some areas received as much as a half inch of freezing rain.

The Bermuda High, a semipermanent high-pressure system off the Atlantic coast, plays an important role in the summer climate of the state. Typically, the Bermuda High draws moisture northward or westward from the Atlantic Ocean and Gulf of Mexico, causing warm and moist summers with frequent thunderstorms in the afternoons and evenings. Daily and weekly variations in the positioning of the Bermuda High can strongly influence precipitation patterns. **When the Bermuda High extends westward into the southeastern United States, hot and dry weather occurs, which can result in heat waves and drought.** In 2007, as a result of a strong Bermuda High over the Southeast and a strengthening La Niña, North Carolina experienced its driest year in history. By the end of August, most of the state was in severe drought.

North Carolina’s location along the Atlantic coast makes the state vulnerable to tropical storms and hurricanes. A storm at hurricane intensity reaches the state about once every 3 years; however, storms

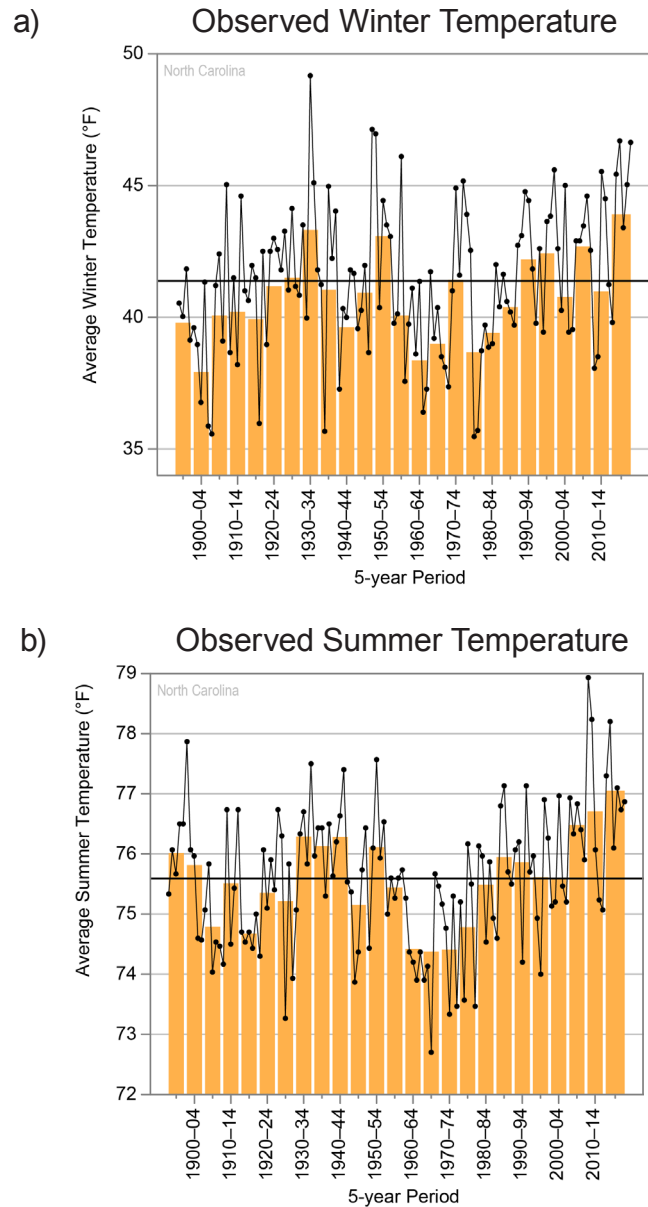


Figure 2: Observed (a) winter (December–February) and (b) summer (June–August) average temperature for North Carolina from (a) 1895–96 to 2019–20 and (b) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (first bar in Figure 2a is a 4-winter average, last bar in Figures 2a and 2b is a 6-winter and a 6-summer average, respectively). The horizontal black lines show the long-term (entire period) averages of (a) 41.4°F and (b) 75.6°F. Winter and summer temperatures have been trending upward since the cool period of the 1960s and 1970s and have exceeded the record highs of the early 1930s and early 1950s. Sources: CISESS and NOAA NCEI. Data: nClimDiv.

at less than hurricane intensity can also have major impacts. The late 1990s through the early 2000s and the late 2010s through 2020 were notably active hurricane periods (Figure 3d). In addition to damaging winds and coastal flooding from storm surges, **extreme precipitation from these storms is a great hazard to the state.** In 1999, Hurricane Floyd dropped 15 to 20 inches of rain in the eastern part of the state, which

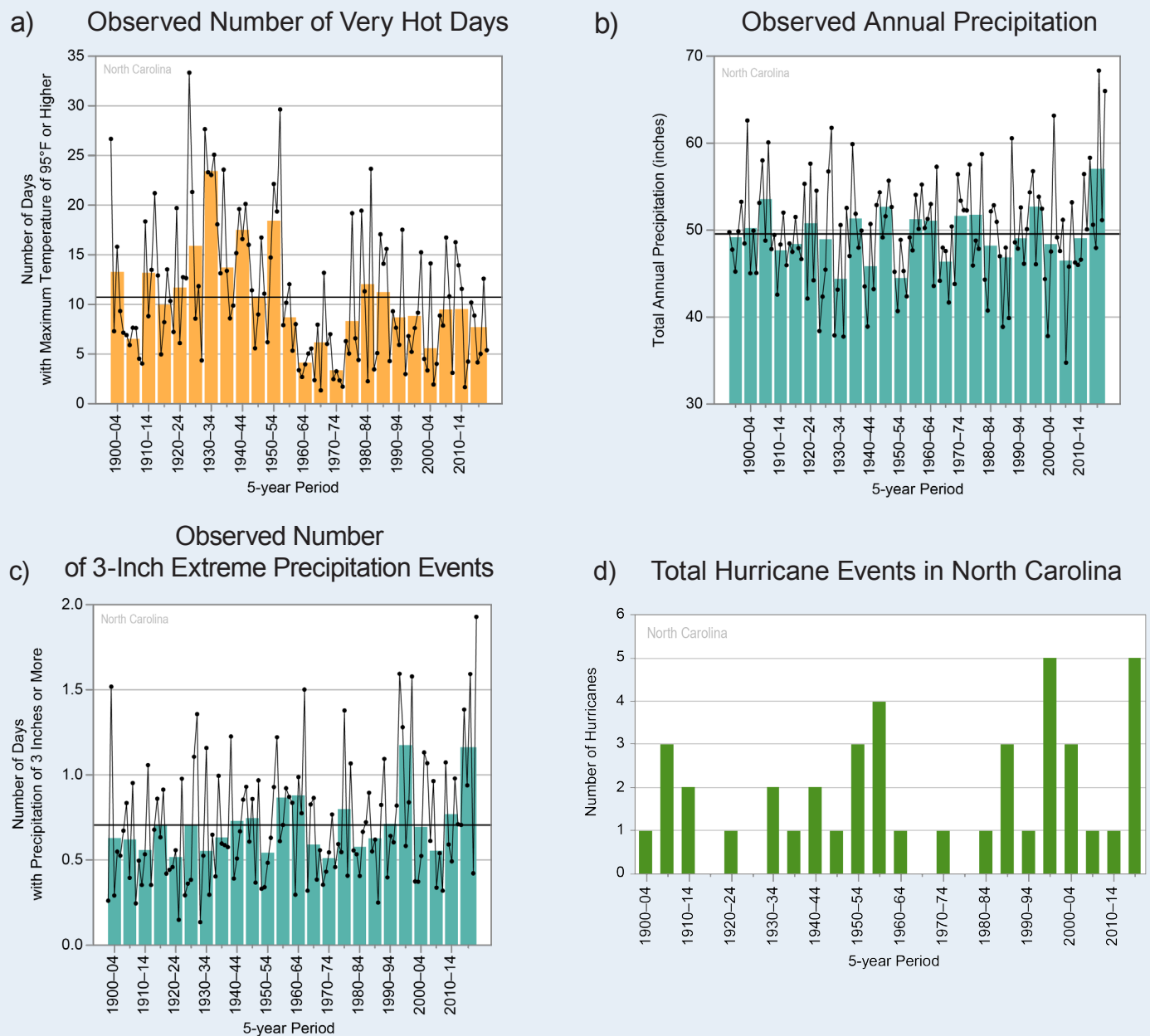


Figure 3: Observed (a) annual number of very hot days (maximum temperature of 95°F or higher), (b) total annual precipitation, (c) annual number of 3-inch extreme precipitation events (days with precipitation of 3 inches or more), and (d) total number of hurricane events (wind speeds reaching hurricane strength somewhere in the state) for North Carolina from (a, c, d) 1900 to 2020 and (b) 1895 to 2020. In Figures 3a, 3b, and 3c, dots show annual values, bars show averages over 5-year periods (last bar is a 6-year average), and the horizontal black lines show the long-term (entire period) averages: (a) 11 days, (b) 49.6 inches, (c) 0.7 days. In Figure 3d, bars show totals over 5-year periods (last bar is a 6-year total). The number of very hot days has declined compared to mid-20th century levels, which coincided with periods of exceptionally dry weather. Annual precipitation and the number of 3-inch extreme precipitation events show variability but were well above average during the 2015–2020 period. A typical reporting station experiences a 3-inch precipitation event about once every 1 to 2 years. Hurricanes reach the North Carolina coast with hurricane-force winds about once every 3 years. Sources: (a, b, c) CISESS and NOAA NCEI; (d) NOAA Hurricane Research Division. Data: (a) GHCN-Daily from 20 long-term stations; (b) nClimDiv; (c) GHCN-Daily from 12 long-term stations.

was still recovering from flooding caused by Hurricane Dennis several weeks earlier. Beginning on September 6, 2004, the remnants of Hurricane Frances dropped 6 to 10 inches of rain across much of western North Carolina over a 3-day period. Less than 2 weeks later, the remnants of Hurricane Ivan struck the same area,

dropping 10 inches of rain and causing hundreds of landslides in the mountains. During October 7–9, 2016, Hurricane Matthew dumped torrential rain that caused major flooding in eastern North Carolina, with many locations receiving more than 10 inches and a few locations more than 18 inches. In September 2018,

the most intense rainfall event on record occurred as Hurricane Florence dropped 20 to 36 inches in eastern North Carolina, causing widespread destruction and losses exceeding \$20 billion, more than the combined losses from Floyd and Matthew. **In addition to damage from high winds and flooding, hurricane strikes can produce tornadoes.** Rainbands associated with Hurricane Frances spawned multiple tornadoes in the central and eastern portions of the state.

Severe thunderstorms, another hazard commonly experienced in the state, occasionally produce tornadoes. The largest tornado outbreak occurred on April 16, 2011, with 30 confirmed tornadoes and 24 deaths.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of the century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. Future heat waves are likely to be more intense, but cold wave intensity is projected to decrease.

Although there is no historical trend, total annual precipitation is projected to increase in North Carolina (Figure 5), primarily in the winter and spring. Naturally occurring droughts are projected to be more intense because higher temperatures will increase the rate of soil moisture loss during dry periods. Additionally, hurricane-associated storm intensity and rainfall rates are projected to increase as the climate warms.

Increasing temperatures raise concerns for sea level rise in coastal areas. Since 1900, global average sea level has risen by about 7–8 inches. It is projected to rise another 1–8 feet, with a likely range of 1–4 feet, by 2100 as a result of both past and future emissions from human activities (Figure 6). Sea level rise has caused an increase in tidal floods associated with nuisance-level impacts. Nuisance floods are events in which water levels exceed the local threshold (set by NOAA's National Weather Service) for minor impacts. These events can damage infrastructure, cause road closures, and overwhelm storm drains. As sea level has risen along the North

Observed Number of Very Warm Nights

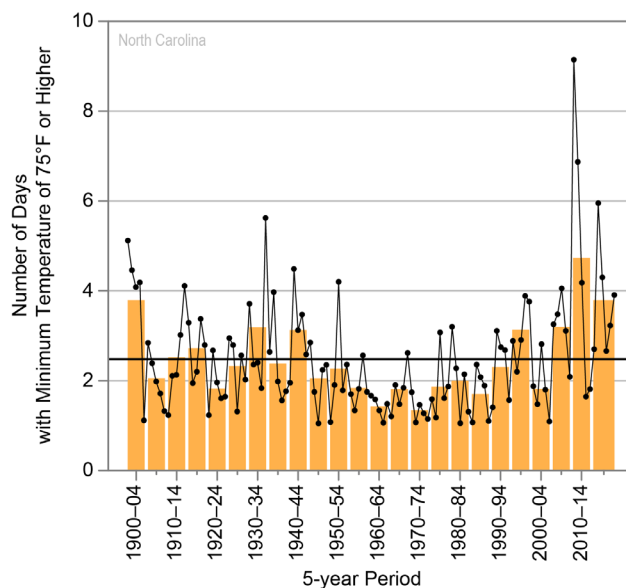


Figure 4: Observed annual number of very warm nights (minimum temperature of 75°F or higher) for North Carolina from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term average of 2.5 nights. Since the cool period of the second half of the 20th century, the number of very warm nights has increased and reached its highest level, more than double the long-term average, during the 2010–2014 period. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 20 long-term stations.

Projected Change in Annual Precipitation

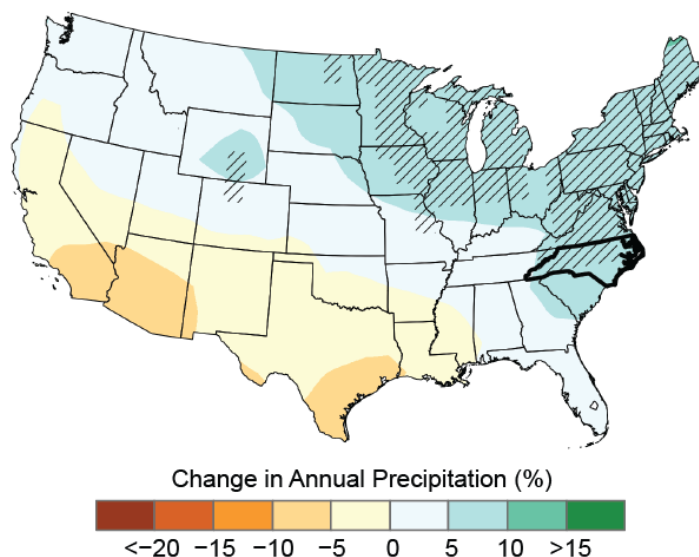


Figure 5: Projected changes in total annual precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. North Carolina is on the southern end of a large area of projected increases in annual precipitation over the northeastern United States. Sources: CISESS and NEMAC. Data: CMIP5.

Carolina coastline, the number of tidal flood days (all days exceeding the nuisance-level threshold) has also increased, with the greatest number (14) occurring at Wilmington in 2018 (Figure 7). Large increases in nuisance flooding at Wilmington are projected. **A large portion of North Carolina's coastline is extremely vulnerable to sea level rise due to its low elevation and to geological factors that are causing the land to sink in the northern Coastal Plain.** Sea level rise will present major challenges to North Carolina's existing coastal water management system and may cause extensive economic damage through losses in property, tourism, and agriculture.

Observed and Projected Change in Global Sea Level

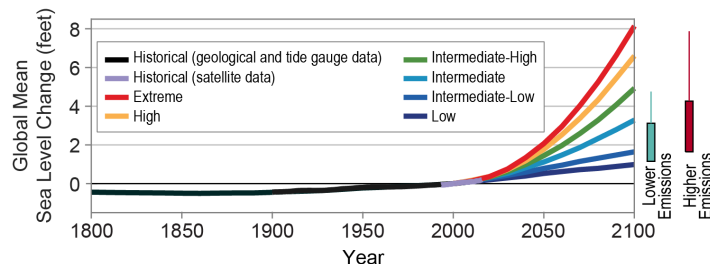


Figure 6: Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate-Low, royal blue; Intermediate, cyan; Intermediate-High, green; High, orange; and Extreme, red curves) relative to historical geological, tide gauge, and satellite altimeter GMSL reconstructions from 1800–2015 (black and magenta lines) and the very likely ranges in 2100 under both lower and higher emissions futures (teal and dark red boxes). Global sea level rise projections range from 1 to 8 feet by 2100, with a likely range of 1 to 4 feet. Source: adapted from Sweet et al. 2017.

Observed and Projected Annual Number of Tidal Floods for Wilmington, NC

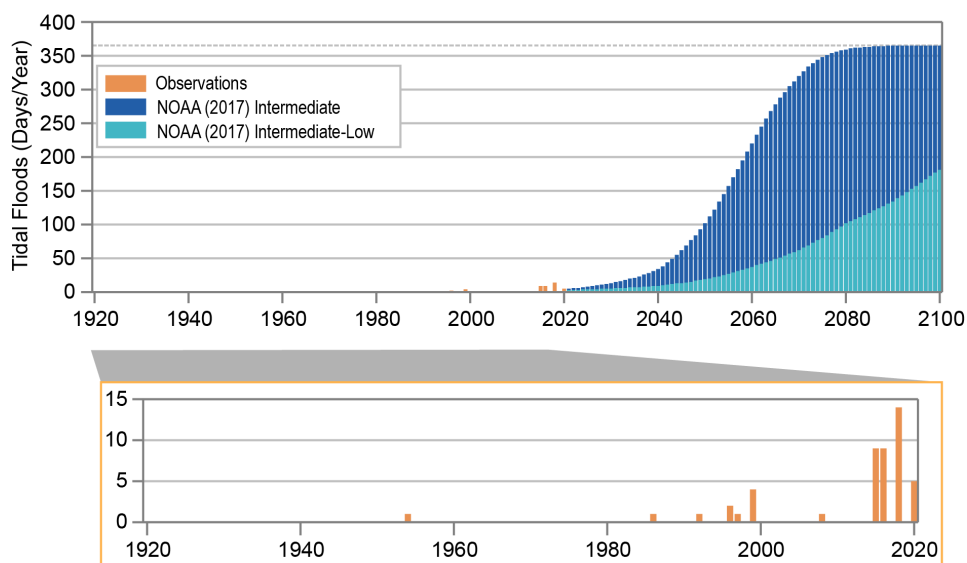


Figure 7: Number of tidal flood days per year at Wilmington, North Carolina, for the observed record (1936–2020; orange bars) and projections for two NOAA (2017) sea level rise scenarios (2021–2100): Intermediate (dark blue bars) and Intermediate-Low (light blue bars). The NOAA (2017) scenarios are based on local projections of the GMSL scenarios shown in Figure 6. Sea level rise has caused a gradual increase in tidal floods associated with nuisance-level impacts. The greatest number of tidal flood days (all days exceeding the nuisance-level threshold) occurred in 2018 at Wilmington. Projected increases are large even under the Intermediate-Low scenario. Under the Intermediate scenario, tidal flooding is projected to occur every day of the year by the end of the century. Additional information on tidal flooding observations and scenarios is available online at <https://statesummaries.ncics.org/technicaldetails>. Sources: CISESS and NOAA NOS.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

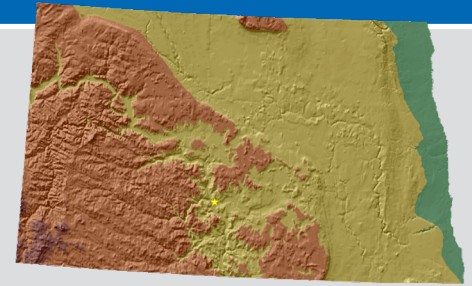
NORTH DAKOTA

Key Messages

Temperatures in North Dakota have risen more than 2.6°F since the beginning of the 20th century. The annual average temperature has increased at a rate of 0.2°F per decade. This warming is most evident in winter and is reflected in a below average number of very cold days since 2000. Under a higher emissions pathway, historically unprecedented warming is projected during this century.

Increases in evaporation rates due to rising temperatures may increase the rate of soil moisture loss and the intensity of naturally occurring droughts.

Precipitation is projected to increase during the colder months. Increases in the frequency and intensity of extreme precipitation events are also projected.



North Dakota lies in the northern Great Plains, straddling the transition from the moist eastern United States to the semiarid West. Due to its location in the center of the North American continent, far from the moderating effects of the oceans, the state experiences large temperature extremes. Average (1991–2020 normals) January temperatures range from about 4°F in the northeast to 18°F in the southwest, while average July temperatures range from 65°F in the northeast to 72°F in the south. Temperatures of 100°F or higher occur nearly every year and are most prevalent in the drier southwestern and south-central regions. The lack of mountain ranges to the north exposes the state to bitterly cold arctic air masses in the winter.

Temperatures in North Dakota have risen more than 2.6°F since the beginning of the 20th century (Figure 1). The first two decades of this century represent one of the warmest periods on record for North Dakota, with several years (2006, 2012, 2015, and 2016) meeting or exceeding the extreme heat of many of the 1930s Dust Bowl years, when intense drought and poor land management likely exacerbated the hot summer temperatures. Over the last 126 years, North Dakota’s annual average temperature has increased 0.2°F per decade. Warming has occurred in all four seasons but has been largest in the winter, with warming rates more than double the other seasons and

Observed and Projected Temperature Change

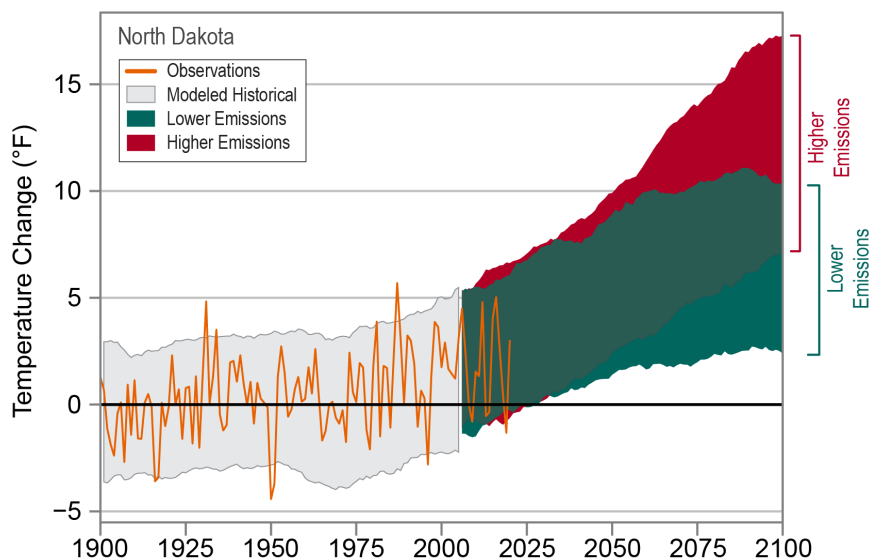


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for North Dakota. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in North Dakota (orange line) have risen more than 2.6°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 2°F warmer than the historical average; green shading) and more warming

under a higher emissions future (the hottest end-of-century projections being about 12°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

greater than those for any other state. The relatively small summer warming is reflected in a below average number of very hot days since 1990 (Figure 2) and no overall trend in the number of warm nights since the beginning of the 20th century (Figure 3). Winter warming is reflected in a below average number of very cold days since 2000 (Figure 4). Additionally, over the past 126 years, winter temperatures have increased by 4.5°F per century, more than three times the summer trend of 1.5°F per century.

Annual precipitation ranges from less than 16 inches in the northwest to about 24 inches in the southeast. Statewide total annual precipitation varies from year to year, ranging from a low of 8.8 inches in 1936 to a high of 24.4 inches in 2019 (Figure 5). The wettest multiyear periods were in the early 1940s, 1990s, and early 2010s and the driest in the 1930s. The wettest consecutive 5-year interval was 2007–2011, and the driest was 1933–1937. Most of the state’s precipitation falls during the late spring and early summer months, when thunderstorm activity is highest. The most severe thunderstorms can produce hail, tornadoes, or damaging straight-line winds exceeding 75 mph. **The frequency of 2-inch extreme precipitation events has increased** (Figure 6). Since 1990, the number of these events has been above average, peaking during the most recent 6-year period (2015–2020).

Compared to other northern states, North Dakota receives less snowfall, averaging 30 to 55 inches annually. However, due to the state’s northern location, winter storm systems can be accompanied by exceptionally severe conditions, including heavy snows, high winds, and low wind chill temperatures. The probability of a blizzard occurring in any given year in North Dakota—greater than 50%—is one of the highest in the Nation. During the winter of 1996–97, North Dakota experienced multiple blizzards and winter storms, which contributed to seasonal snowfalls of more than 100 inches in some parts of the state.

North Dakota is highly prone to both flooding and drought. The Red River Valley is one of the most flood-prone areas in the United States due to the river’s low gradient and northward flow. The spring thaw causes snow and river ice in the south to melt prior to the downstream river channel to the north, creating

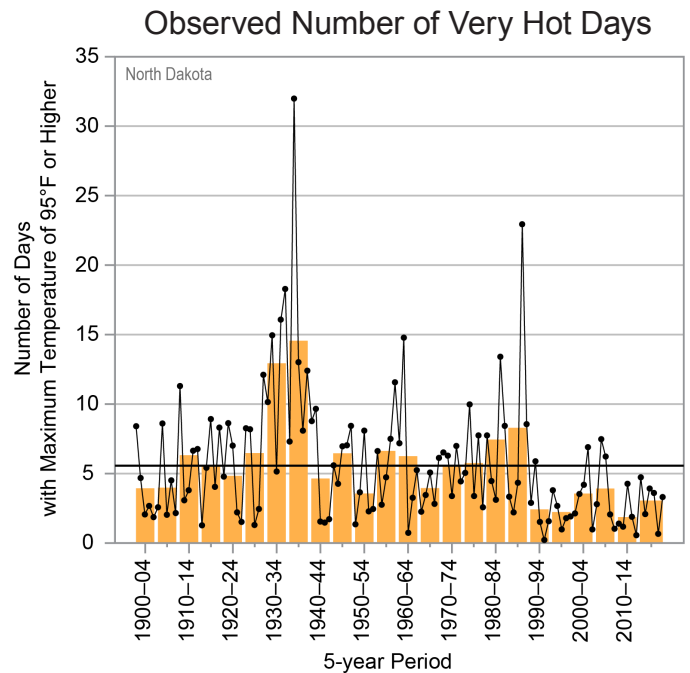


Figure 2: Observed annual number of very hot days (maximum temperature of 95°F or higher) for North Dakota from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 5.6 days. Multiyear averages for the 1930s were the highest on record and more than double the long-term average. Since 1990, however, the number of very hot days has been below average. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 12 long-term stations.

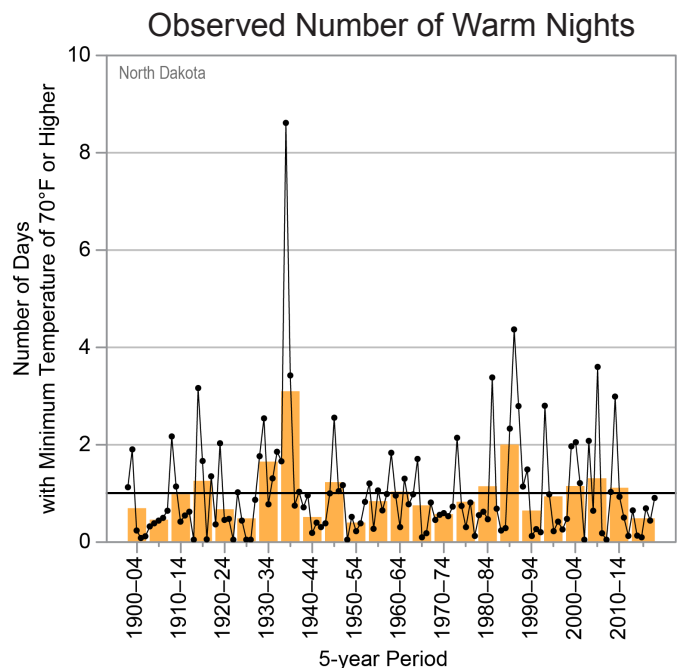


Figure 3: Observed annual number of warm nights (minimum temperature of 70°F or higher) for North Dakota from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 1.0 nights. The late 1930s had the highest number of warm nights, more than three times the long-term average. Since 1990, the number of warm nights has been near or below average. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 12 long-term stations.

natural ice jams, flooding of the upstream river, and backfill of runoff into the river's tributaries. In addition to snowmelt, recharge of soil moisture due to fall precipitation and direct runoff of spring rainfall from saturated soils contribute to spring floods. Based on more than 100 years of river-stage data collected in Fargo, the Red River has exceeded major flood stages 18 times. In the spring of 1997, the melting of record snowfall caused record floods along the river. These records were exceeded by the 2009 floods, when the river at Fargo reached its highest level in recorded history. In June 2011, record-breaking flood levels on the Souris River caused major property damage, including the flooding of 4,000 homes in Minot. Another flood-prone area is Devils Lake, where rapidly rising waters since the early 1990s have destroyed hundreds of homes and businesses and inundated thousands of acres of productive farmland. Since 1993, state and federal funds totaling more than \$1 billion have been spent on flood-mitigation efforts in the region. If lake levels were to rise substantially from current levels, an uncontrolled natural spill to the Sheyenne River could occur, potentially causing extensive downstream flooding, channel erosion, and water quality degradation (Figure 7). Drought has been a regular occurrence in the state. The 2017 Northern Plains drought, which primarily impacted North Dakota, South Dakota, and Montana, as well as adjacent Canadian Prairies, was devastating for livestock and agricultural production. The drought emerged in the spring and rapidly spread and intensified throughout the summer, leading to crop failure, the culling of livestock herds, widespread wildfires, low water supplies, and losses exceeding \$2.5 billion.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of the century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. Although the frequency of hot summer temperatures has not increased, continued overall warming is expected to intensify heat waves, while cold waves are projected to decrease in intensity.

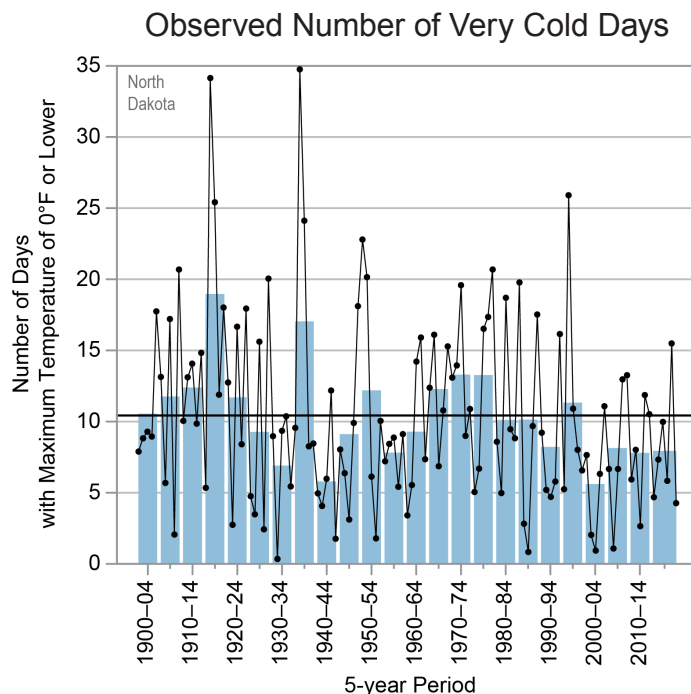


Figure 4: Observed annual number of very cold days (maximum temperature of 0°F or lower) for North Dakota from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 10 days. The number of very cold days has been below average since 2000 and is indicative of overall winter warming in the region. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 12 long-term stations.

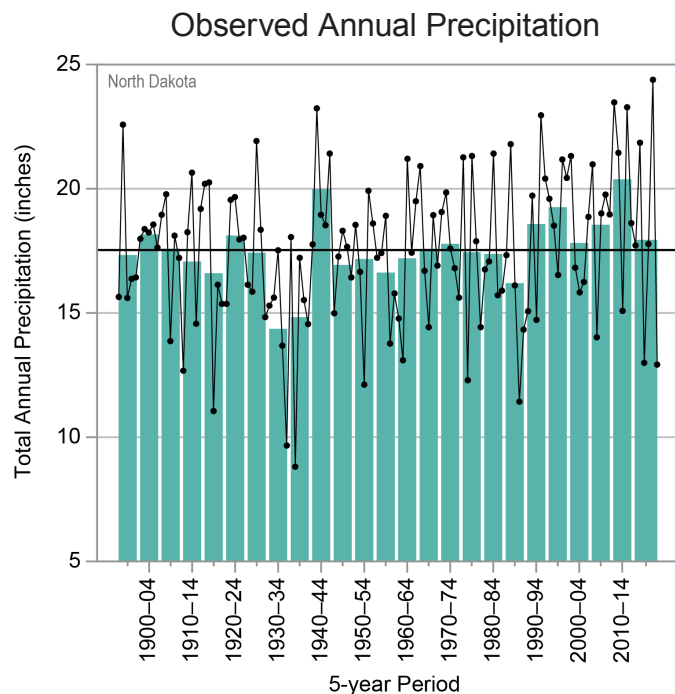


Figure 5: Observed total annual precipitation for North Dakota from 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 17.5 inches. Total annual precipitation varies widely but has been near or above average since 1990. The wettest consecutive 5-year interval on record was 2007–2011, averaging 20.5 inches, while the driest was 1933–1937, averaging 13.5 inches. Sources: CISESS and NOAA NCEI. Data: nClimDiv.

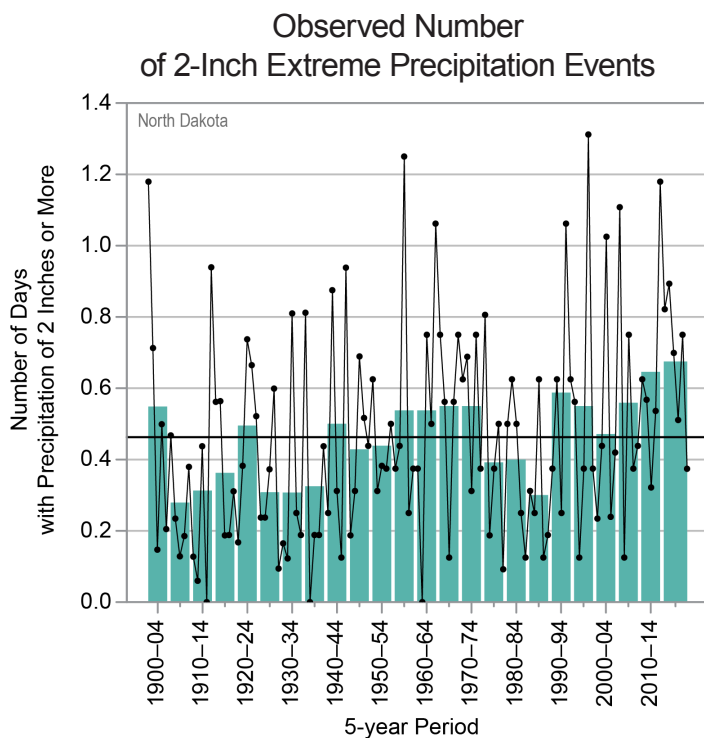


Figure 6: Observed annual number of 2-inch extreme precipitation events (days with precipitation of 2 inches or more) for North Dakota from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 0.5 days. A typical reporting station experiences an event about once every 2 years. The number of 2-inch extreme precipitation events has been near to above average since 1990. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 12 long-term stations.

Although current observations do not show a positive trend in cold-season precipitation, projections suggest that winter precipitation will increase (Figure 8), even under a lower emissions pathway. Increased cold-season precipitation can impact North Dakota's agricultural economy both positively (increased soil moisture) and negatively (loss of soil nutrients, planting delays, and yield losses). Extreme precipitation events are also projected to increase in frequency and intensity, potentially leading to increased runoff and flooding, which can reduce water quality and erode soils.

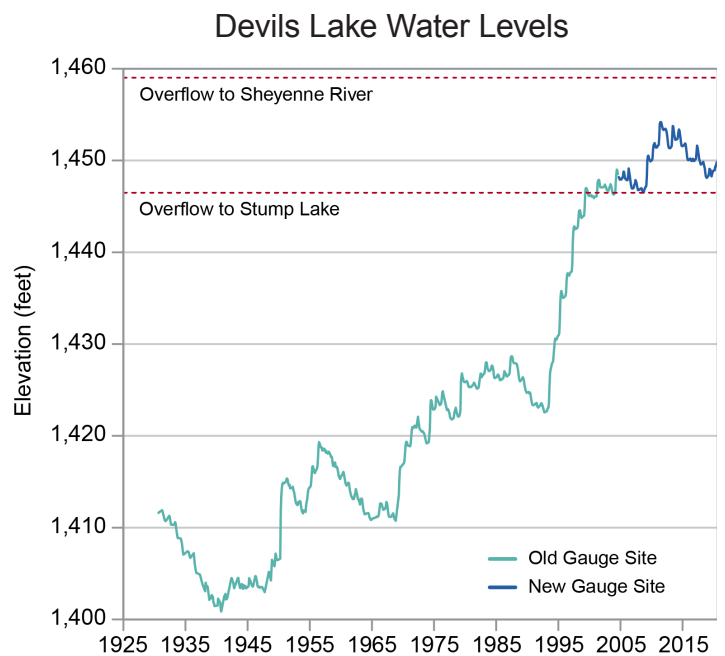


Figure 7: Annual time series of the average water level of Devils Lake at Creel Bay from 1930 to 2020. Lake levels have fluctuated over time but have been steadily rising overall since the 1940s. Water began spilling from Devils Lake to Stump Lake in 1999, and in 2007, Devils Lake and Stump Lake essentially became one continuous body of water. If lake levels were to rise substantially from current levels, an uncontrolled natural spill to the Sheyenne River could occur. Source: USGS NWIS.

The intensity of droughts is projected to increase.

Droughts are a natural part of the climate system, and because precipitation increases are projected to occur during the cooler months, North Dakota will remain vulnerable to periodic drought. Increases in evaporation rates due to rising temperatures may increase the rate of soil moisture loss and the intensity of naturally occurring droughts. Wildfires may also become more common from mid-summer through early fall.

Projected Change in Winter Precipitation

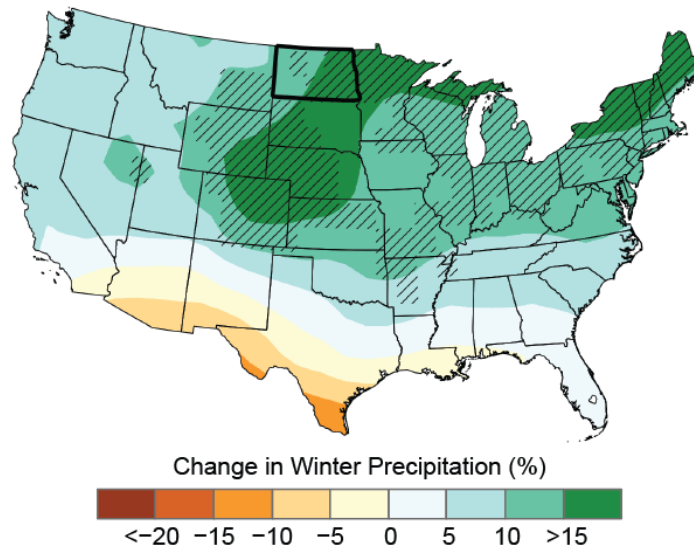


Figure 8: Projected changes in total annual precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. Winter precipitation for North Dakota is projected to increase in the range of 10% to more than 15% by 2050. Spring precipitation is also projected to increase. North Dakota is part of a large area in the northern and central United States with projected increases. Sources: CISESS and NEMAC. Data: CMIP5.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

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OHIO

Key Messages

Annual average temperature in Ohio has risen more than 1.5°F since the beginning of the 20th century. Under a higher emissions pathway, historically unprecedented warming is projected to continue through this century. Extreme heat is a particular concern for the state's urban areas, where high temperatures and high humidity can cause dangerous health conditions.

Ohio has experienced a significant increase in heavy rain events. Increases in winter and spring precipitation are projected and will enhance the risk of springtime flooding.

Severe drought is a risk to this agriculture-dependent state. Projected temperature increases may increase the intensity of naturally occurring droughts.



Ohio's mid-latitude, interior location and the lack of mountains to the north or south expose the state to incursions of very cold air masses from the Arctic in the winter and warm, humid air masses from the Gulf of Mexico in the summer. Lake Erie also has a significant influence on the local climate. Near-shore locations are considerably warmer during the winter and cooler during the summer than locations farther away from the shores. Lake-effect snow, caused by the warming and moistening of arctic air masses over the Great Lakes, is a hazard along the southeastern shoreline of Lake Erie.

Since the beginning of the 20th century, temperatures in Ohio have risen more than 1.5°F, and temperatures in the 2000s and 2010s were warmer than in any other historical period (Figure 1). The warming has not been steady. The 1930s through the mid-1950s were generally above the long-term average but were followed by the coldest period on record: the 1960s and 1970s. Since the 1970s, annual average temperature has risen more than 2°F. Based on observations through 2020, 1998 was the hottest year on record, with an annual average temperature for the state of 54.1°F. The second hottest year was 2012, with an average temperature of 54.0°F. This warming has been concentrated in the winter and spring. Summer days have not warmed substantially in the state, a feature characteristic of much of the Midwest. This lack of summer warming is reflected in a below average occurrence of very hot days (Figure 2a). However, in addition to the overall higher summer average nighttime temperatures,

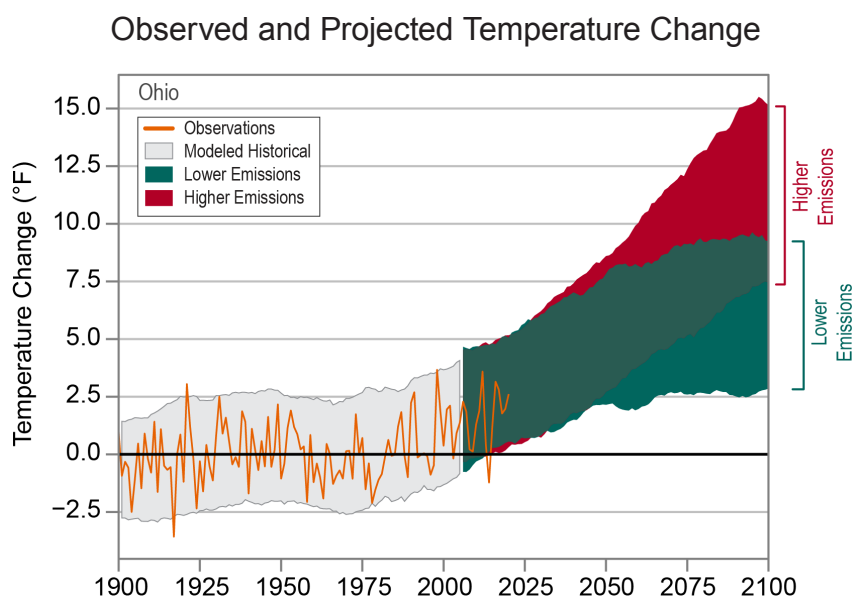
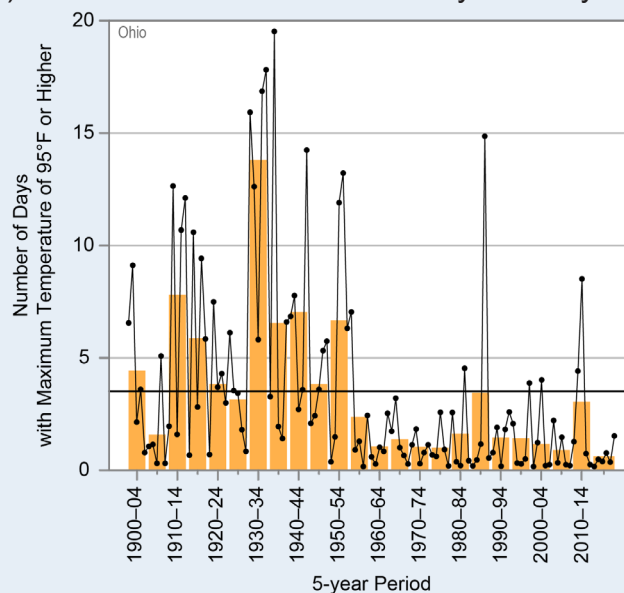


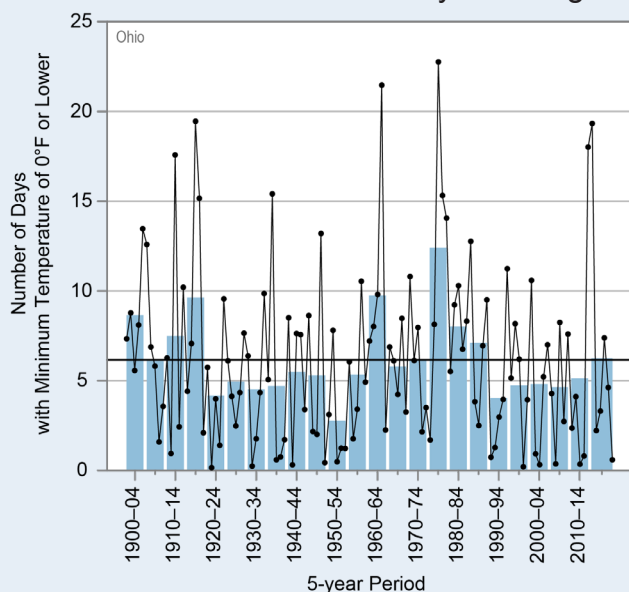
Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Ohio. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Ohio (orange line) have risen more than 1.5°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected to continue through this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 3°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 11°F warmer than the hottest year in the historical record; red shading). Source: CISESS and NOAA NCEI.

Figure 2: Observed (a) annual number of very hot days (maximum temperature of 95°F or higher), (b) annual number of very cold nights (minimum temperature of 0°F or lower), (c) total annual precipitation, (d) total winter (December–February) precipitation, and (e) total summer (June–August) precipitation for Ohio from (a, b) 1900 to 2020 and (c, d, e) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 3.5 days, (b) 6.2 nights, (c) 38.9 inches, (d) 8.0 inches, (e) 11.6 inches. The number of very hot days has been below the long-term average since the mid-1950s. The number of very cold nights has generally been near to below average since 1990, following overall winter warming, except for very high values in 2014 and 2015. Both annual and seasonal (winter and summer) precipitation amounts have been above the long-term average since 1990. Sources: CISESS and NOAA NCEI. Data: (a, b) GHCN-Daily from 20 long-term stations; (c, d, e) nClimDiv.

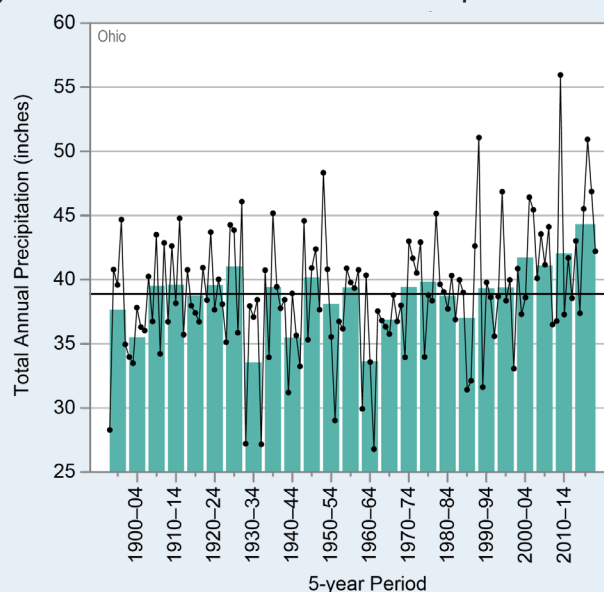
a) Observed Number of Very Hot Days



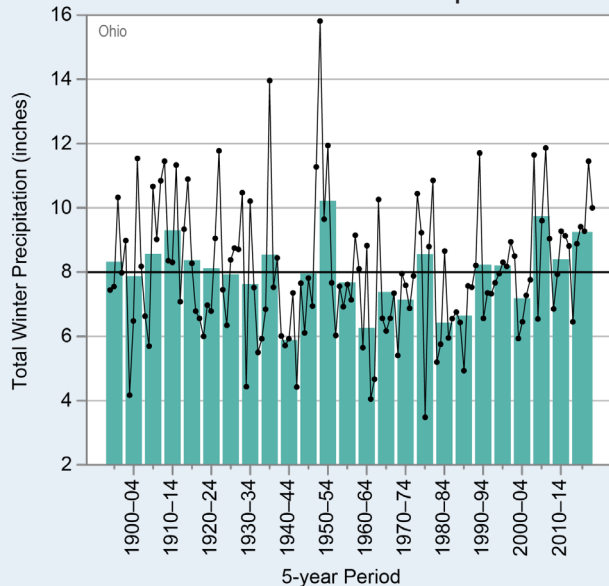
b) Observed Number of Very Cold Nights



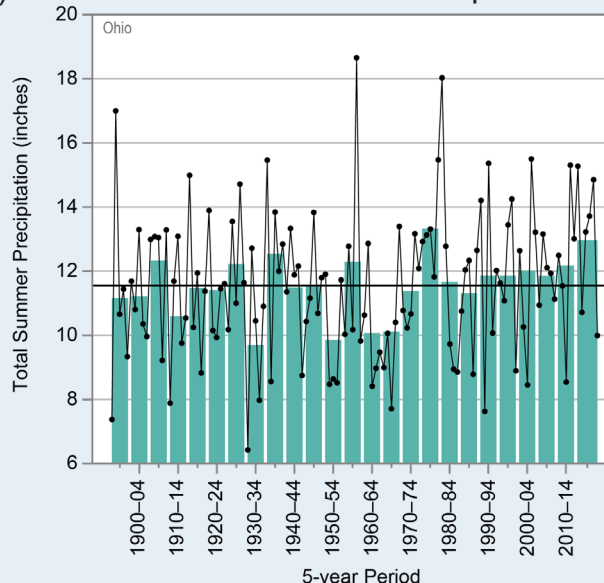
c) Observed Annual Precipitation



d) Observed Winter Precipitation



e) Observed Summer Precipitation



the state has experienced an increase in the number of warm nights (Figure 3). Both Cleveland and Columbus have experienced statistically significant increases in the number of warm nights since 1950. Since 2000, Cleveland and Columbus have averaged 17 and 22 warm nights, respectively, per year, compared to an average of 8 and 9 nights, respectively, in the 1950s through 1970s. Although both cities also experienced a higher frequency of warm nights in the 1930s, this was mostly due to extreme high daytime temperatures. While Ohio generally experienced a near to below average number of very cold nights between 1990 and 2020, very high values occurred in 2014 and 2015, when the so-called “polar vortex” pattern dominated winter weather in the eastern U.S. (Figure 2b).

Annual precipitation varies regionally, with the northwestern part of the state averaging 32 inches each year and the southern part of the state averaging 42 inches each year. Statewide total annual precipitation has ranged from a low of 26.8 inches in 1963 to a high of 56.0 inches in 2011. The driest multiyear periods were 1930–1934 and 1960–1964, and the wettest multiyear periods have occurred since 2000 (Figure 2c). Annual average precipitation during the driest and wettest consecutive 5 years has ranged from a low of 33.6 inches for the 1930–1934 period to a high of 43.3 inches for the 2015–2019 interval. Snowfall also varies across the state. The northern portion of the state along the southern shores of Lake Erie receives 60 inches or more annually, and the southern portion of the state receives less than 16 inches annually.

Ohio has experienced a significant increase in the number of 2-inch extreme precipitation events since the mid-1990s (Figure 4). Past episodes of heavy rains have caused severe flooding in the state. The Great Flood of 1913 was one of the deadliest floods in U.S. history and Ohio’s greatest weather disaster. From March 23 to 26, heavy rains caused extreme runoff from soils saturated from winter storms. Levees along the Great Miami River failed, flooding the entire Great Miami River watershed. Downtown Dayton was hit particularly hard, with floodwaters reaching depths of 20 feet. The flooding caused more than \$2 billion in damages, and more than 400 people died. One of the worst floods in recent decades occurred in March 1997.

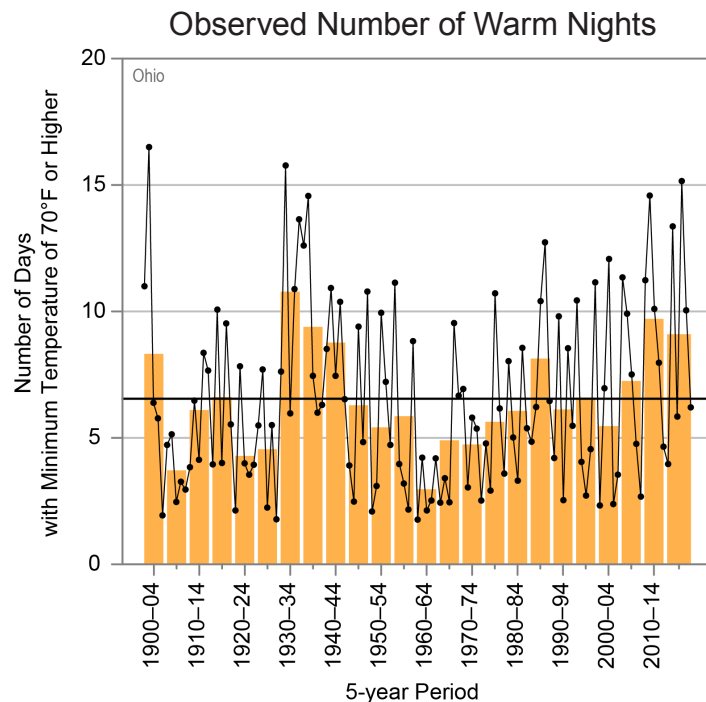


Figure 3: Observed annual number of warm nights (minimum temperature of 70°F or higher) for Ohio from 1900 to 2020. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 6.6 nights. Ohio experienced the highest and second-highest number of warm nights during the 1930–1934 period and the 2010–2014 period, respectively. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 20 long-term stations.

Between March 1 and 3, 6–12 inches of rain fell in parts of southern Ohio, causing serious flooding, particularly along Brush Creek and the Scioto and Great Miami Rivers. Levels on the main stem of the Ohio River were the highest in more than 30 years. Seventeen counties were declared federal disaster areas, and more than 5,000 homes were damaged or destroyed, resulting in almost \$300 million in damages.

Dangerous storms can occur in every season and can cause major impacts, including loss of life, property damage, and disruptions to economic activity. Winter can bring snowstorms and ice storms, while convective storms (including thunderstorms, flood-producing rainstorms, hail, and tornadoes) are common in the warmer months. Although Ohio does not experience as many tornadoes as other states in the Midwest and Great Plains, the state has experienced several deadly tornado outbreaks. On June 28, 1924, Ohio’s deadliest tornado struck the towns of Sandusky and Lorain, killing 85 people and causing more than a billion dollars in damages. Other notable storms include the Palm

Sunday Outbreak on April 11, 1965, which produced 10 tornadoes in the state (4 of which were F4 intensity) and caused 60 deaths; the Xenia tornado (F5 intensity) in the Super Outbreak of 1974 that killed 34 people; and the outbreak of April 8–9, 1999, which produced 54 tornadoes, including an F4 intensity tornado in Blue Ash and Montgomery that killed 4 people.

Agriculture is an important component of Ohio's economy, and this sector is particularly vulnerable to extreme weather conditions. In 2007, unusually warm March temperatures were followed by a hard freeze in April, which devastated much of the state's apple crop. This scenario was again observed in 2012, when March temperatures were 9° to 15°F above average for the state but a cool April followed, with hard freezes. Seasonal precipitation can vary, with no real trend in winter or summer precipitation (Figures 2d and 2e). In 2012, an intense drought throughout the Midwest had severe impacts on Ohio. Rainfall totals for the summer were several inches below average. In addition to low precipitation, the period from January to June was the warmest in 120 years of record, with the warm temperatures compounding the dry conditions. By the end of the year, 86 of Ohio's 88 counties had been declared drought disaster areas.

Under a higher emissions pathway, historically unprecedented warming is projected to continue through this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of this century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. Increases in extreme heat are a particular concern for Cincinnati, Columbus, and other urban areas, where the urban heat island effect raises summer temperatures. High temperatures combined with high humidity can create dangerous heat index values. From July 17 to 24, 2011, the Ohio River Valley experienced a prolonged heat wave. With temperatures above 90°F for several days in a row and dewpoints in the mid to upper 70s (°F), heat index values rose to between 100° and 110°F during the day. These occurrences are likely to become more common as temperatures continue

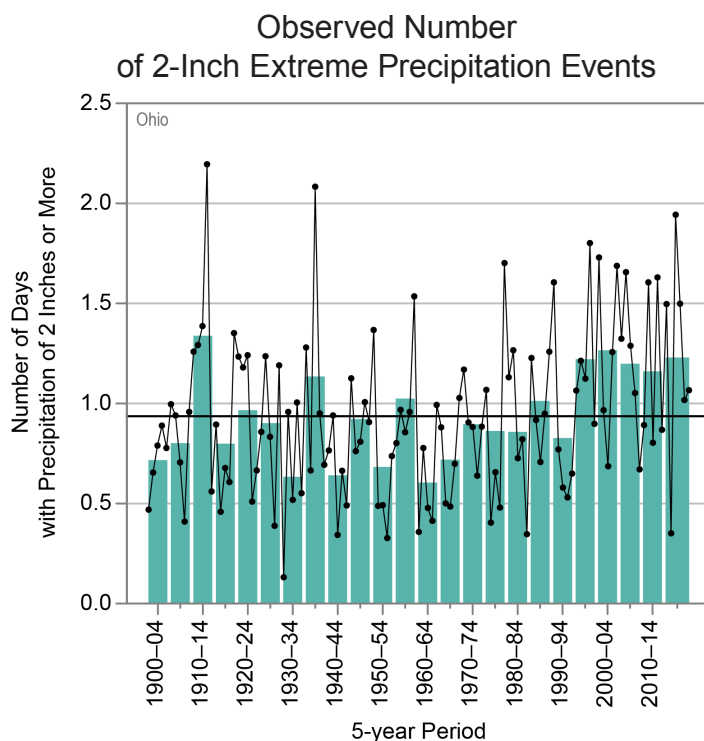


Figure 4: Observed annual number of 2-inch extreme precipitation events for Ohio from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 0.9 days. A typical reporting station experiences 1 event per year. Ohio has experienced a substantial increase in the number of heavy rain events, with the past 26 years having the some of the highest levels on record since the historic peak from 1910 to 1914. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 25 long-term stations.

to rise. However, there have been exceptionally cold winters in recent years. During the winters of 2013–2014 and 2014–2015, persistent weather patterns brought frigid air southward from the Arctic, causing temperatures from December to February to be more than 3°F below average. Although the state averages approximately 6 very cold nights annually, these two winters averaged 18 very cold nights. The intensity of such events is projected to decrease in the future.

Although annual precipitation projections are uncertain, winter and spring precipitation is projected to increase (Figure 5). In addition, extreme precipitation is projected to increase, potentially causing more frequent and intense floods. Heavier precipitation and higher temperatures increase the risk of springtime flooding, posing a threat to Ohio's agricultural industry by delaying planting and resulting in a loss of yield.

The intensity of future droughts is projected to increase. Even if precipitation increases in the future, rising temperatures will increase the rate of loss of soil moisture during dry spells. Thus, future summer droughts, a natural part of the Ohio climate, are likely to be more intense.

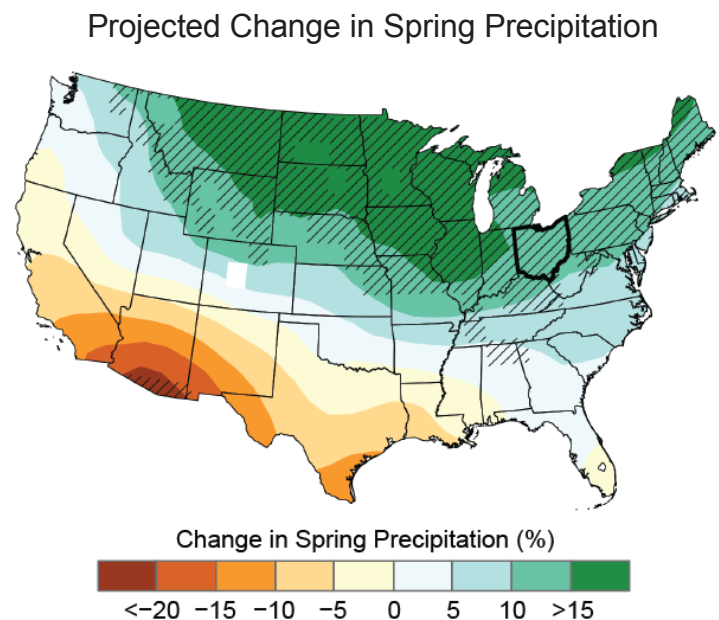


Figure 5: Projected changes in total spring (March–May) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. The white-out area indicates that the climate models are uncertain about the direction of change. Hatching represents areas where the majority of climate models indicate a statistically significant change. Ohio is part of a large area of projected increases in spring precipitation in the Northeast and Midwest. Source: CISESS and NEMAC. Data: CMIP5.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

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CONTRIBUTORS: SARAH M. CHAMPION, DAVID R. EASTERLING

OKLAHOMA

Key Messages

Temperatures in Oklahoma have risen by about 0.6°F since the beginning of the 20th century. Winter warming is evident in the less frequent occurrence of very cold nights since 1990. Historically unprecedented warming is projected during this century.

Oklahoma is in a region of transition from humid to semiarid conditions, and as a result, precipitation can vary greatly from year to year. Extreme precipitation events are projected to increase, which may increase the risk of flooding and the associated soil erosion and nonpoint source runoff into streams and lakes.

Droughts pose a particular risk to the agricultural economy of Oklahoma. Several such events have occurred in recent years. Higher temperatures will increase the rate of soil moisture loss, leading to an increase in the intensity of future naturally occurring droughts.

Oklahoma lies in the central Great Plains, straddling the transition from relatively abundant precipitation (more than 50 inches per year) in the southeast to semiarid conditions (less than 20 inches per year) in the west. Due to its location in the interior of the United States and its distance from the moderating effects of any oceans, the state experiences a wide range of average (1991–2020 normals) daily temperatures, averaging from the upper 30s to low 40s in the winter and the upper 70s to low 80s in the summer. The hottest year on record was 2012, with an average temperature of 63.2°F, which was 3.4°F degrees warmer than the long-term (1895–2020) average. Extreme temperatures for the state range from 120°F, observed at several locations in the summer of 1936, to –31°F, observed in northeastern Oklahoma during the winter of 2011.

Since the beginning of the 20th century, temperatures in Oklahoma have risen by about 0.6°F (Figure 1). Since 2010, temperatures have been higher than they were during the previous 40 years and have approached the levels seen during the 1950s and the 1930s Dust Bowl era, when poor land management likely exacerbated the hot summer temperatures. The recent warming has been concentrated in the winter and spring. While summer average

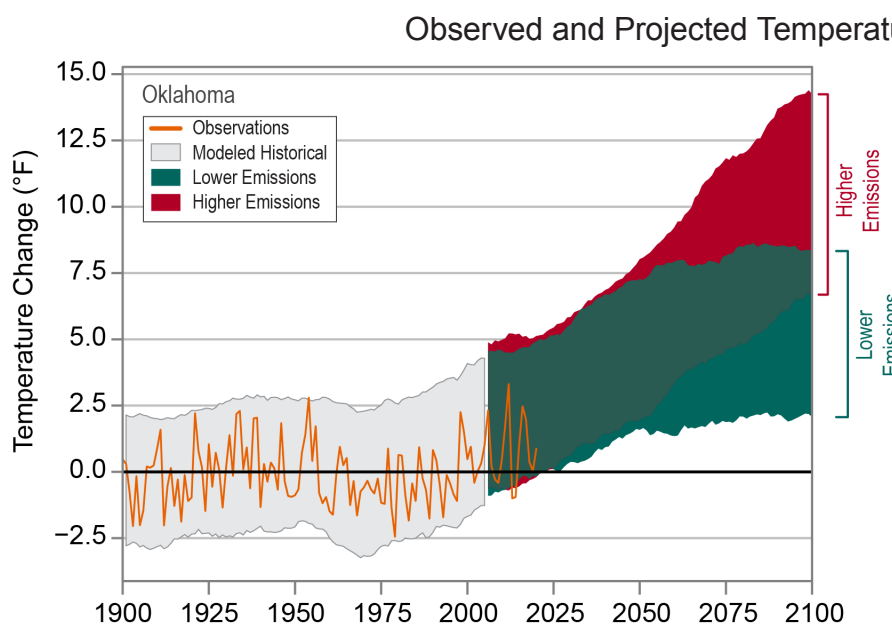


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Oklahoma. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Oklahoma (orange line) have risen about 0.6°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during the 21st century. Less warming is expected under a lower emissions future (the coldest end-of-century projected years being about 2°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest end-of-century projected years being about 11°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

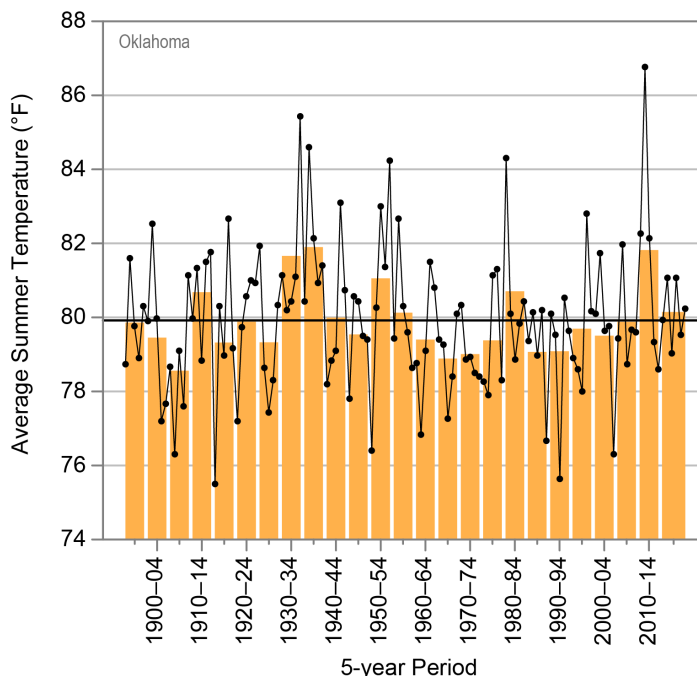
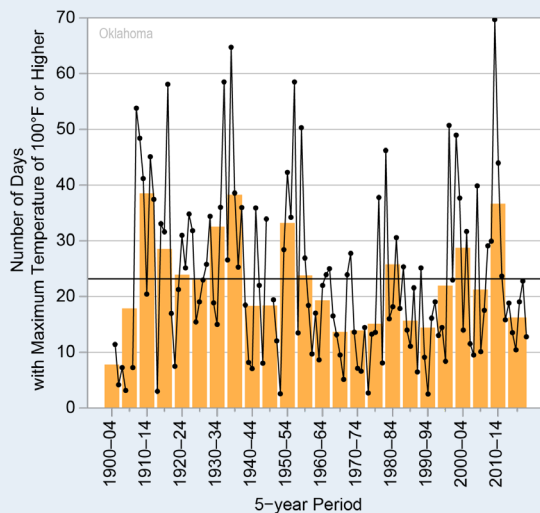


Figure 2: Observed summer (June–August) average temperature for Oklahoma from 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 79.9°F. Summer temperatures during the 2010–2014 period reached about the same level as the record extreme heat of the 1930s Dust Bowl era. Due to extreme drought and poor land management practices, the summers of the 1930s remain the warmest decade-long period on record. Sources: CISESS and NOAA NCEI. Data: nClimDiv.

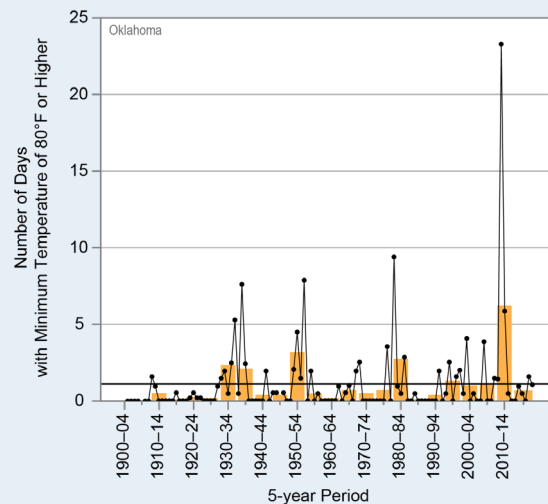
temperatures were above the long-term average in the 2010s, which included the all-time hottest summer in 2011, they have not reached the levels experienced consistently during the 1930s, a feature characteristic of much of the Great Plains and Midwest (Figure 2). The lack of summer warming is reflected in the mostly below average number of extremely hot days in recent years (Figure 3a) and the lack of a clear trend in extremely warm nights (Figure 3b). The winter warming trend is reflected in a below average number of very cold nights since 1990 (Figure 4). While the recent trend is toward fewer extremely cold nights, a historic cold wave affected the state during February 9–20, 2021. Temperatures remained below freezing for 10 consecutive days and fell to around -20°F in a few locations with the coldest temperature being -21°F at Ralston. The extreme cold temperatures, heavy snow (of more than 10 inches in many locations), severe icing, and accompanying power outages caused considerable damage.

Precipitation is highly variable from year to year, with the statewide annual total ranging from a low of 20.3 inches in 1910 to a high of 53.7 inches in 2015. The driest multiyear periods were in the 1910s, 1950s, and 1960s, and the wettest were the 1990s and late 2010s (Figure 3c). The driest consecutive 5 years was the 1952–1956 interval and the wettest was the 2015–2019 period. The majority of precipitation falls during the spring and summer months. Summer precipitation was well below average during 2011 and 2012 (Figure 3d). Annual snowfall ranges from less than 2 inches in the extreme southeast to almost 30 inches in the Panhandle. Oklahoma regularly experiences freezing rain, particularly in the southeastern part of the state. **The frequency of 2-inch extreme precipitation events has increased since 1985, with the highest number of events occurring in 2015** (Figure 5).

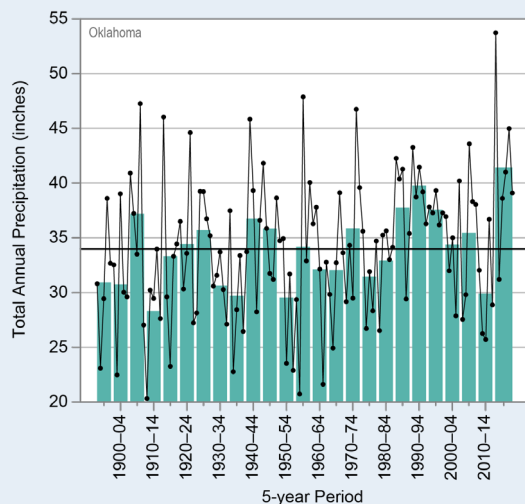
a) Observed Number of Extremely Hot Days



b)



c) Observed Annual Precipitation



d) Observed Summer Precipitation

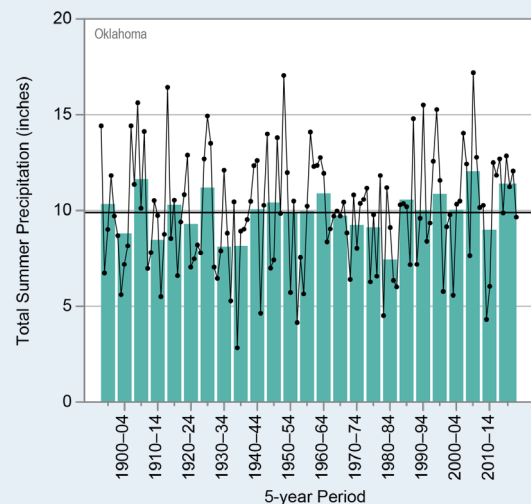


Figure 3: Observed (a) annual number of extremely hot days (maximum temperature of 100°F or higher), (b) annual number of extremely warm nights (minimum temperature of 80°F or higher), (c) total annual precipitation, and (d) total summer (June–August) precipitation for Oklahoma from (a, b) 1903–2020 and (c, d) 1895–2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 23 days, (b) 1.1 nights, (c) 34.0 inches, (d) 9.9 inches. The number of extremely hot days and extremely warm nights have been primarily below the long-term average, although the 2010 to 2014 period was above average in both categories. Annual and summer precipitation have been above average in recent decades, except for the 2010 to 2014 period, which was drier than normal, reflecting the severe multiyear drought in the state. Sources: CISESS and NOAA NCEI. Data: (a, b) GHCN-Daily from 2 long-term stations; (c, d) nClimDiv.

Severe thunderstorms are common in Oklahoma due to the state's geographical location, which allows cold, dry air from the north and west to clash frequently with warm, moist air from the Gulf of Mexico. Oklahoma locations experience approximately 45 to 60 thunderstorm days each year. These storms frequently produce tornadoes. From 1985 to 2019, Oklahoma averaged 60 tornadoes and 4 fatalities per year. Tornadoes are most frequent during April and May. The state's deadliest tornado occurred on April 9, 1947, killing more than 100 people and injuring more than 700. On May 3, 1999, a supercell thunderstorm spawned

more than 60 tornadoes, the largest outbreak ever recorded in the state. One of these tornadoes caused F4–F5 damage in Bridge Creek, Newcastle, Moore, and Oklahoma City, destroying 1,800 homes and causing 36 direct fatalities. On May 20, 2013, the same area was struck by yet another EF5 tornado, which killed 24 people and caused more than \$2 billion in damages.

Droughts are a frequent and severe hazard in Oklahoma (Figure 6). In 2011, a severe drought occurred when the state experienced its third driest January–October on record, receiving only 19.4 inches of

precipitation—more than 10 inches below the long-term average. Although winter precipitation brought some relief, extremely dry and hot conditions in 2012 once again brought widespread drought conditions to the area. By the end of September 2012, more than 95% of the state was experiencing extreme drought conditions. Since the creation of the United States Drought Monitor Map in 2000, Oklahoma has been completely drought-free for approximately 21% of the time and has had at least 50% or more drought coverage for approximately 28% of the time. **In addition to devastating impacts on the agricultural economy, severe droughts also increase the risk of wildfires.** In 2011, wildfires burned more than 132,000 acres in the state.

Historically unprecedented warming is projected during this century (Figure 1). Even under a lower

emissions pathway, annual average temperatures are projected to exceed historical record levels in most years by the middle of this century. If large increases in temperature occur, future heat waves are likely to be more intense, while cold waves are projected to become less intense.

Projections of overall annual precipitation do not indicate a clear trend. **Although summer precipitation is projected to decrease slightly across the state** (Figure 7), **the decreases are smaller than natural variations.** Even if summer precipitation remains the same, higher temperatures will increase evaporation rates and decrease soil moisture, leading to increased intensity of future droughts and increased risk of severe wildfires.

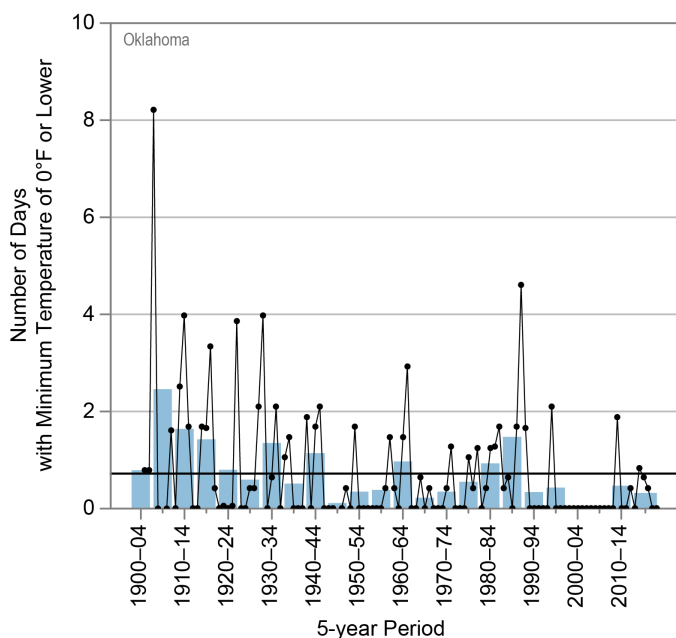


Figure 4: Observed annual number of very cold nights (minimum temperature of 0°F or lower) for Oklahoma from 1903 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 0.7 nights. Since 1990, Oklahoma has consistently experienced a below average number of very cold nights, indicative of winter warming in the region. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 2 long-term stations.

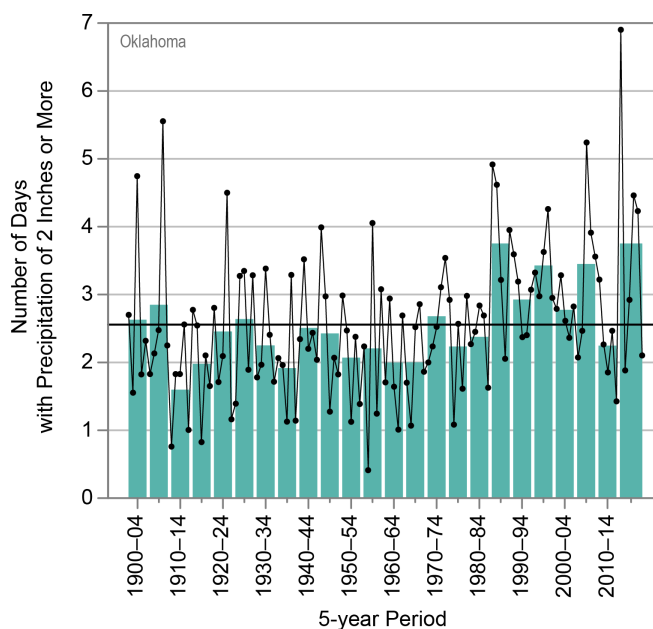


Figure 5: Observed annual number of 2-inch extreme precipitation events (days with precipitation of 2 inches or more) for Oklahoma from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 2.6 days. A typical reporting station experiences 2 to 3 events per year. Oklahoma has experienced an above average number of extreme precipitation events since 1985, with the exception of the 2010–2014 period. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 18 long-term stations.

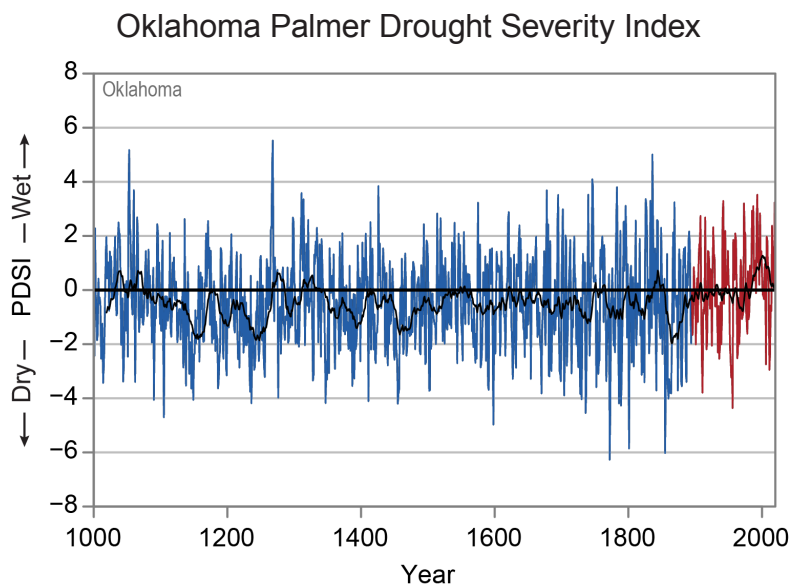


Figure 6: Time series of the Palmer Drought Severity Index for Oklahoma from the year 1000 to 2020. Values for 1895–2020 (red) are based on measured temperature and precipitation. Values prior to 1895 (blue) are estimated from indirect measures such as tree rings. The fluctuating black line is a running 20-year average. In the modern era, the wet periods of the 1980s and 1990s and the dry periods of the 1930s and 1950s are evident. The extended record indicates periodic occurrences of similar extended wet and dry periods. Sources: CISESS and NOAA NCEI. Data: nClimDiv and NADAv2.

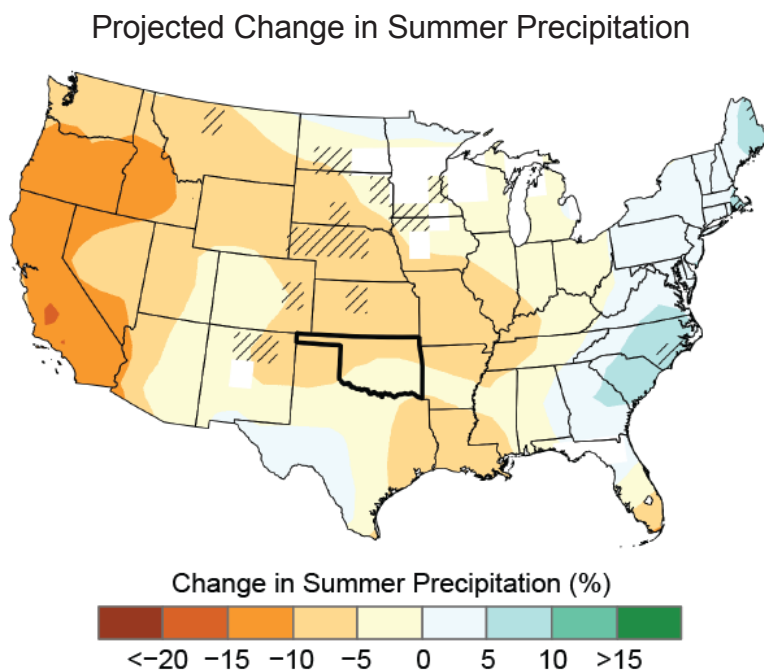


Figure 7: Projected changes in total summer (June–August) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Whited-out areas indicate that the climate models are uncertain about the direction of change. Hatching represents areas where the majority of climate models indicate a statistically significant change. Precipitation in the summer is projected to decrease slightly in Oklahoma, but the changes are smaller than natural variations. Sources: CISESS and NEMAC. Data: CMIP5.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

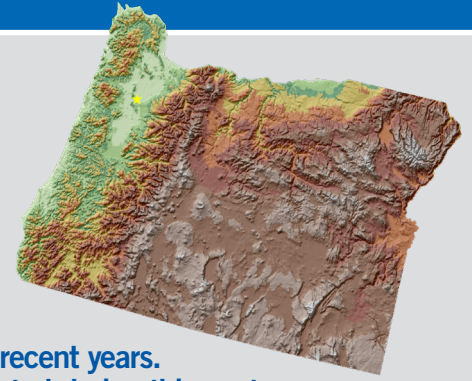
OREGON

Key Messages

Temperatures in Oregon have risen about 2.5°F since the beginning of the 20th century. Winter warming has been characterized by rising nighttime temperatures, with the number of very cold nights falling below average during recent years. Under a higher emissions pathway, historically unprecedented warming is projected during this century.

Snowpack plays a critical role in spring and summer water supplies. Projected rising temperatures will lead to more precipitation falling as rain instead of snow and earlier melting of the snowpack, both of which could have negative impacts on critical sectors.

Precipitation in Oregon varies greatly both across the state and throughout the year. Projected increases in winter precipitation and decreases in summer precipitation will change the dry season availability of water, leading to challenges for water management. Both the frequency and severity of wildfires are projected to increase in Oregon.



Oregon's climate varies widely from the eastern to western regions of the state. On the western side, temperatures are generally mild due to the Pacific Ocean's moderating effect. The Pacific Ocean also provides abundant moisture, causing frequent precipitation west of the Cascade Mountains from October to May. Temperatures in the central and eastern portions of the state exhibit a greater annual and diurnal range, and since the Cascades block the flow of moisture, it is much drier in the eastern part of the state. Oregon seldom experiences severe thunderstorms, compared to other states in the nation.

Temperatures in Oregon have risen about 2.5°F since the beginning of the 20th century, and temperatures in the 1990s and 2000s were higher than any other historical period (Figure 1). The year 2015 was the warmest year since records began in 1895 and 2014 was the 3rd warmest (1934 was the 2nd warmest). During the 2005–2009 and 2015–2020 periods, the state experienced the highest number of extremely hot days in the historical record (Figure 2). In addition to the overall trend of higher average temperatures, the state has experienced below average numbers of very cold nights since 1990 (Figure 3). The number of freezing days has been near or below average since 1995, and the 2000–2004 period had the lowest multiyear value (Figure 4a). The state rarely experiences warm nights due to the moderating effects of the Pacific Ocean in the west and low humidity east of the Cascades (Figure 4b).

Observed and Projected Temperature Change

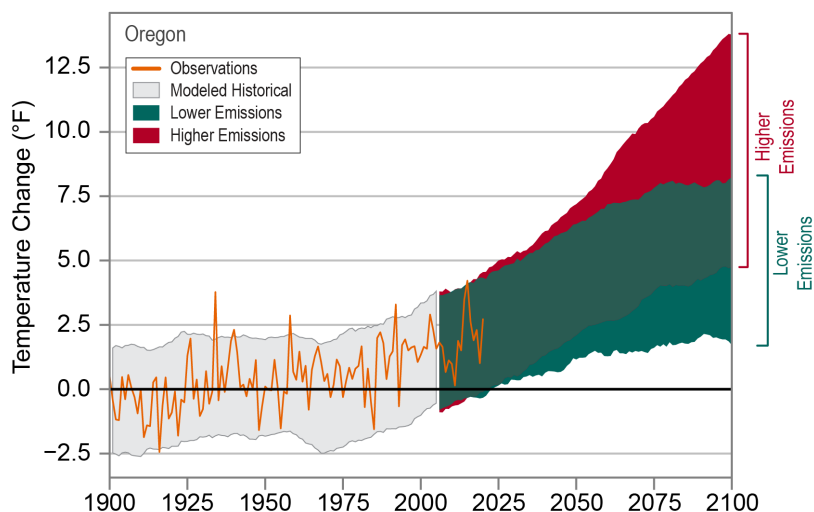


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Oregon. Observed data are for 1900–2020. Projected changes for 2006–2100 are from a suite of global climate model simulations for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). The shading indicates the range of projected temperature increases from all model simulations and provides a measure of uncertainty in projections. Temperatures in Oregon (orange line) have risen about 2.5°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 1°F warmer than the historical average; green shading)

and more warming under a higher emissions future (the hottest end-of-century projections being about 10°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

Precipitation varies widely across the state and from year to year, with areas west of the Cascades also experiencing a large variation in rainfall amounts across the seasons.

Portions of the Coast Range receive more than 100 inches of precipitation annually, while some of the desert areas in the eastern part of the state receive less than 10 inches. Statewide total annual precipitation has ranged from a low of about 22 inches in 1930 to a high of about 49 inches in 1996, and precipitation can fluctuate greatly between years. The driest consecutive 5-year interval was 1928–1932, with an annual average of 26.2 inches, and the wettest was 1995–1999, with an annual average of 39.5 inches (Figure 4c). Long-term periods of wet and dry spells can have critical impacts on water supplies.

Unlike many areas of the United States, Oregon has not experienced an upward trend in the frequency of extreme precipitation events (Figure 4d). The number of 2-inch extreme precipitation events has been highly variable over the historical record (since 1900) and mostly below normal since 2000. Since 1990, the 5-year periods with the highest and lowest frequency of extreme precipitation events (1995–1999 and 2000–2004, respectively) have occurred.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even with the lower emissions pathway, statewide annual average temperatures are projected to most likely exceed historical record levels by the middle of this century. However, a large range of temperature increases is projected in both emission scenarios. In the lower emissions pathway, only a few projections are warmer than historical records (Figure 1).

Projected rising temperatures will raise the snow line—the average lowest elevation at which snow falls. **This will increase the likelihood that precipitation will fall as rain instead of snow, reducing water storage in the snowpack, particularly at lower elevations that are now on the margins of reliable snowpack accumulation.** While a few areas in eastern Oregon experience a primary or secondary peak in precipitation in May, most areas of Oregon receive the bulk of their annual precipitation during the winter months; thus, the snowpack at higher elevations is an important source of water during the drier summer months (Figure 5). Higher spring temperatures will also result in earlier melting of the snowpack, further decreasing water availability for critical sectors such as agriculture and recreation.

Observed Number of Extremely Hot Days

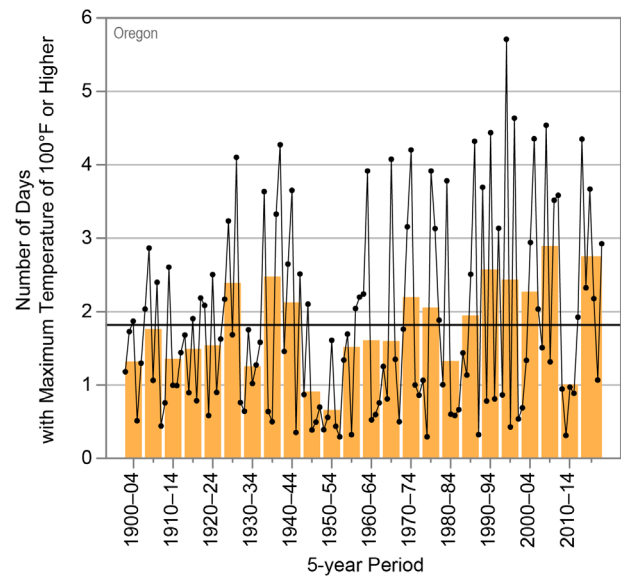


Figure 2: Observed annual number of extremely hot days (maximum temperature of 100°F or higher) for Oregon from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 1.8 days (note that the average for individual stations varies greatly because of the state's large elevation range). The number of extremely hot days has been mostly above the long-term average since the late 1980s, reaching historic peaks in 2005–2009 and 2015–2020. However, the number was well below average during the 2010–2014 period. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 14 long-term stations.

Observed Number of Very Cold Nights

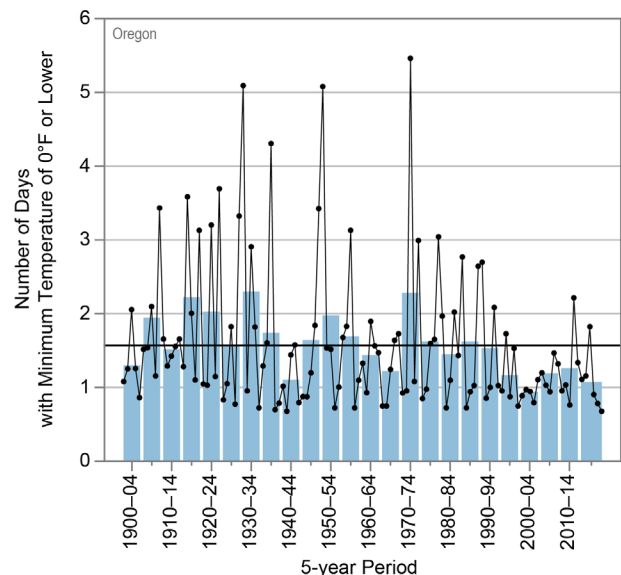


Figure 3: Observed annual number of very cold nights (minimum temperature of 0°F or lower) for Oregon from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year period). The horizontal black line shows the long-term (entire period) average of 1.6 nights (note that the average for individual stations varies greatly because of the state's large elevation range). Since 1995, Oregon has experienced a below average number of very cold nights, indicative of the winter warming occurring in the region. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 14 long-term stations.

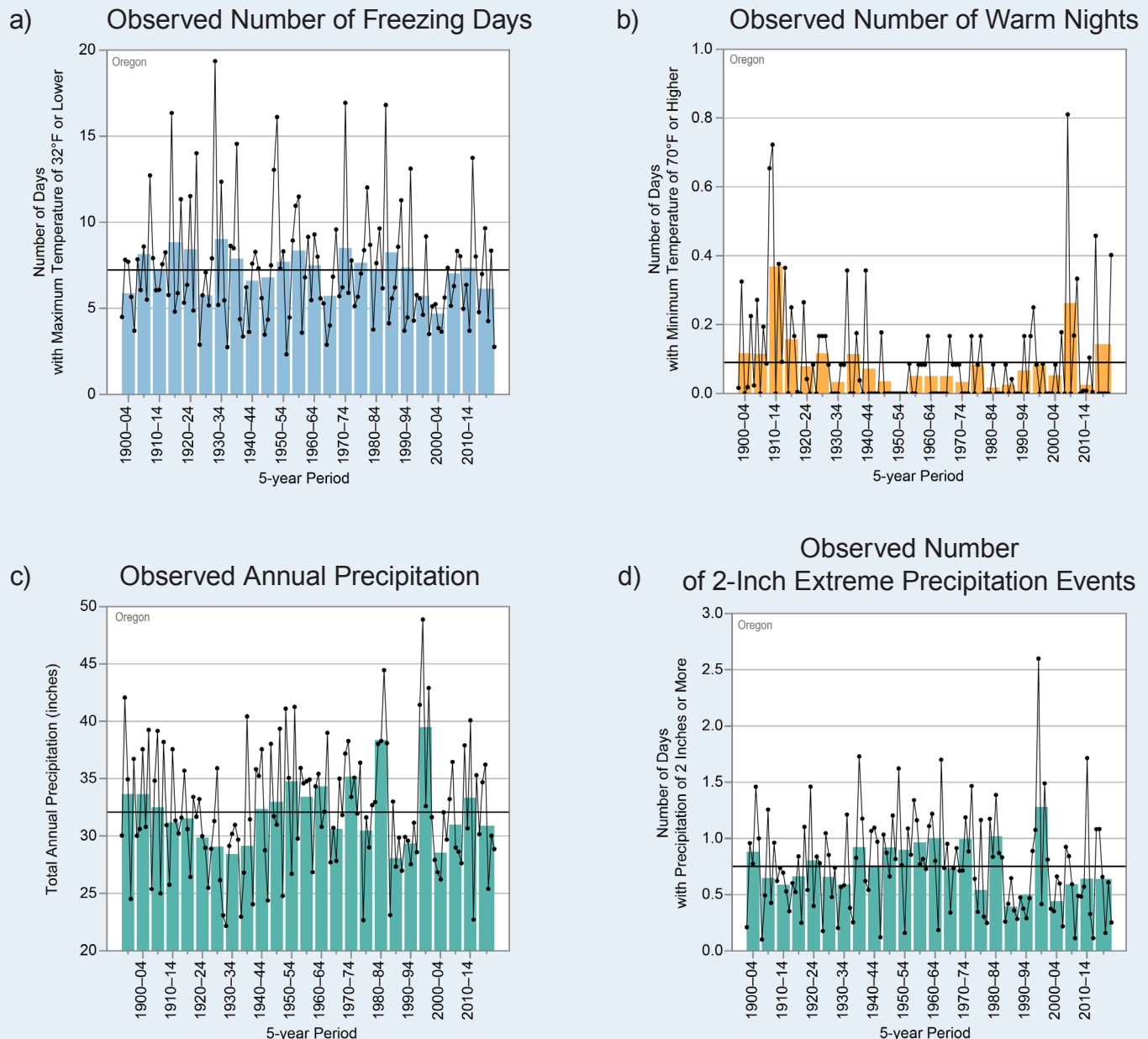


Figure 4: Observed (a) annual number of freezing days (maximum temperature of 32°F or lower), (b) annual number of warm nights (minimum temperature of 70°F or higher), (c) total annual precipitation, and (d) 2-inch extreme precipitation events (days with precipitation of 2 inches or more) for Oregon from (a, b, d) 1900 to 2020 and (c) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 7.2 days, (b) 0.1 days, (c) 32.1 inches, (d) 0.8 days. (Note that for Figures 4a, 4b, and 4d, the average for individual reporting stations varies greatly because of the state's large elevation range.) Since 1995, the number of freezing days has been mostly below average. The observed number of warm nights does not exhibit a trend, although the 2005–2009 period experienced the second highest number on record. Annual precipitation varies widely and was below average during the 2015–2020 period. A typical reporting station experiences a 2-inch extreme precipitation event every 1 to 2 years on average. The last three decades have seen 5-year periods with both the highest (1995–1999) and lowest (2000–2004) frequency of extreme precipitation events. Sources: CISESS and NOAA NCEI. Data: (a, b) GHCN-Daily from 14 long-term stations; (c) nClimDiv; (d) GHCN-Daily from 16 long-term stations.

Although projections of overall annual precipitation are uncertain, winter precipitation is projected to increase (Figure 6) and summer precipitation is projected to decrease. More precipitation is expected to fall as rain instead of snow, which will decrease the amount of water from snowmelt available during the dry season and pose

challenges for water management. These changes are of particular concern for areas that rely on hydroelectric power and regions that depend on the availability of irrigation water from snowmelt-fed basins. For example, the 2015 snow drought caused hundreds of millions of dollars in crop losses and negatively impacted local fish populations.

Wildfires are also of particular concern for the state and have become more severe and costly in recent years. The Long Draw fire in 2012 was the state's largest wildfire since the 1860s, burning more than half a million acres in southeastern Oregon. The combined Labor Day fires of 2020 were even larger, resulting in historic levels of wildfire damage with more than 2,000 structures burned. **The combination of drier summers, higher temperatures, and earlier melting of the snowpack is projected to increase the frequency and severity of wildfires.**

Increasing temperatures raise concerns for sea level rise in coastal areas. Since 1900, global average sea level has risen by about 7–8 inches. It is projected to rise another 1–8 feet, with a likely range of 1–4 feet, by 2100 as a result of both past and future emissions from human activities (Figure 7). Due to the movement of tectonic plates on the ocean floors, the Oregon coast is rising, a phenomenon known as “uplift.” In some parts of the Oregon coast, the uplift is exceeding the rate of sea level rise; consequently, sea level has dropped in these locations. However, by the middle of this century, the rate of sea level rise is projected to exceed the rate of uplift along the entire Oregon coast, resulting in sea level rise for all locations. Nuisance floods are events in which water levels exceed the local threshold (set by NOAA's National Weather Service) for minor impacts. These events can damage infrastructure, cause road closures, and overwhelm storm drains. Nuisance flooding events in Oregon are likely to occur more frequently as global and local sea levels continue to rise.

April 1 Snow Water Equivalent (SWE) at Tangent, OR

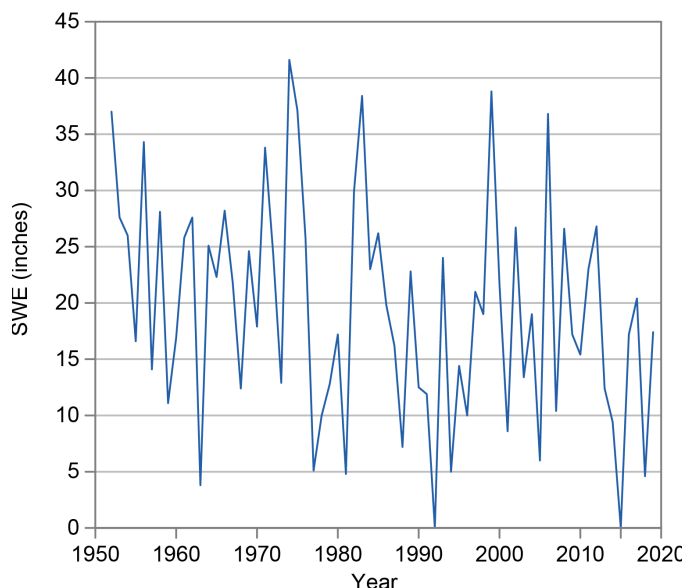


Figure 5: Variations in the annual April 1 snow water equivalent (SWE) at the Tangent snow course site, located near Bend, Oregon, from 1952 to 2020. SWE, the amount of water contained within the snowpack, is highly variable from year to year and there is an overall downward trend. There was no snowpack in 2015 due to unusually low precipitation and warm temperatures during the first three months of the year. Source: NRCS NWCC.

Projected Change in Winter Precipitation

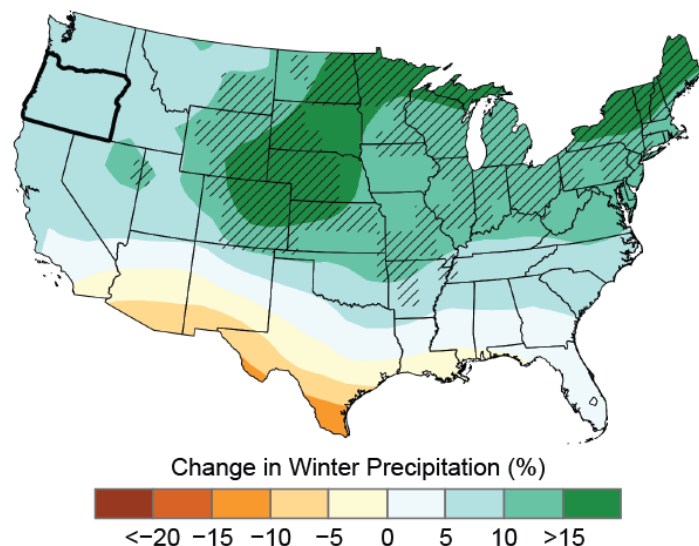


Figure 6: Projected changes in total winter (December–February) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. Precipitation in the winter is projected to increase across the entire state of Oregon. Sources: CISESS and NEMAC. Data: CMIP5.

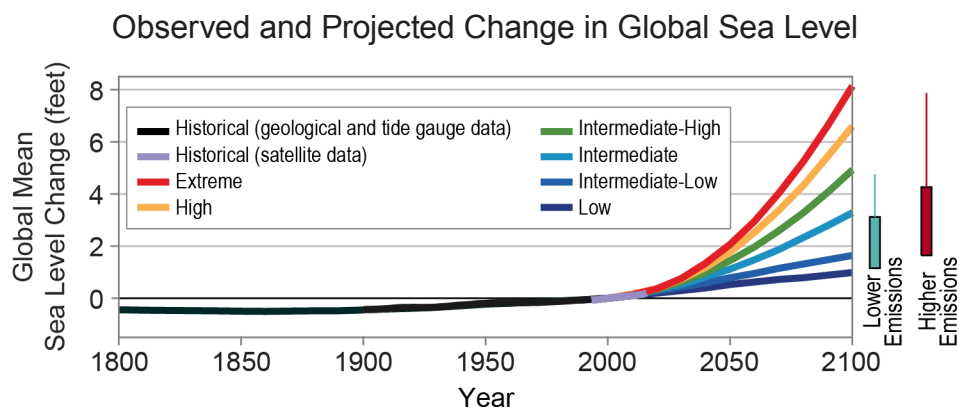


Figure 7: Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate-Low, royal blue; Intermediate, cyan; Intermediate-High, green; High, orange; and Extreme, red curves) relative to historical geological, tide gauge, and satellite altimeter GMSL reconstructions from 1800–2015 (black and magenta lines) and the very likely ranges in 2100 under both lower and higher emissions futures (teal and dark red boxes). Global sea level rise projections range from 1 to 8 feet by 2100, with a likely range of 1 to 4 feet. Source: adapted from Sweet et al. 2017.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

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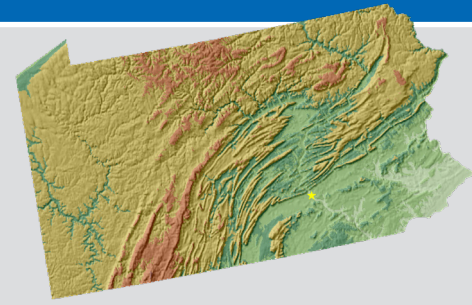
PENNSYLVANIA

Key Messages

Temperatures in Pennsylvania have risen almost 2°F since the beginning of the 20th century. Under a higher emissions pathway, historically unprecedented warming is projected during this century. Extreme heat is a particular concern for densely populated urban areas (such as Philadelphia), where high temperatures and high humidity can cause dangerous heat index values.

Pennsylvania has experienced a large increase in extreme precipitation events. Future increases in winter and spring precipitation expand the risk of springtime flooding along rivers and streams.

Since 1900, global average sea level has risen by about 7–8 inches. It is projected to rise another 1–8 feet, with a likely range of 1–4 feet, by 2100. Sea level rise will increase the frequency, extent, and severity of coastal flooding along the Philadelphia riverfront, where the observed sea level rise over the past century has exceeded the global average.



Pennsylvania has a diverse landscape of mountains, agricultural regions, and large metropolitan areas. The Appalachian Mountains cut across the center of the state, with the Piedmont and Coastal Plain to the east and the Allegheny Plateau and Lake Erie lowlands to the west. The state is bordered by Lake Erie to the northwest and the Delaware River and Delaware Estuary to the east. The state's climate is heavily influenced by several geographic features. The Atlantic Ocean has a moderating effect on coastal areas, while Lake Erie moderates the northwestern part of the state. During much of the year, the prevailing westerly flow brings air masses from the North American interior across the entire region, with occasional episodes of bitter cold during winter. The jet stream, which is often located near or over the region during winter, brings frequent storm systems, causing cloudy skies, windy conditions, and precipitation. Pennsylvania is affected by a number of extreme weather events, including floods, tropical cyclones, heat and cold waves, severe thunderstorms, snow and ice storms, and nor'easters.

Observed and Projected Temperature Change

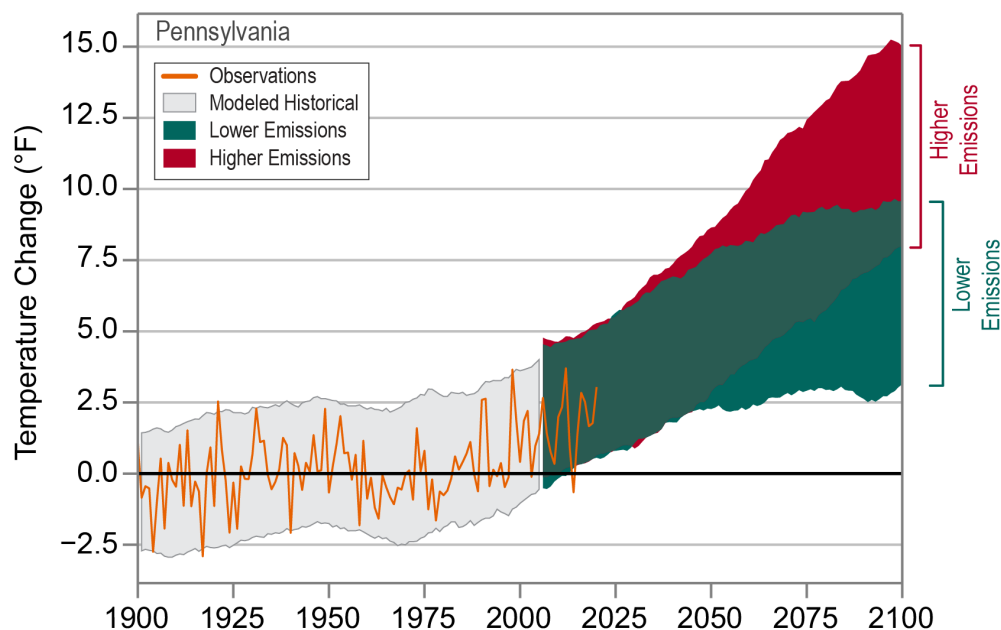


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Pennsylvania. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Pennsylvania (orange line) have risen almost 2°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future

(the coldest end-of-century projections being about 3°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 11°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

Since the beginning of the 20th century, temperatures in Pennsylvania have risen almost 2°F, and temperatures in the 2000s have been higher than in any other historical period (Figure 1). This warming has occurred mostly in the winter and spring, while summer and fall have not warmed as much. The small amount of summer warming is evident in the near average occurrence of hot days during the last 11 years (2010–2020; Figure 2a). However, there has been an increase in the number of warm nights and a decrease in the number of very cold nights (Figures 3 and 2b, respectively). Since record keeping began in 1895, the highest annual average temperature for the state was 51.8°F, set in 1998 and tied again in 2012.

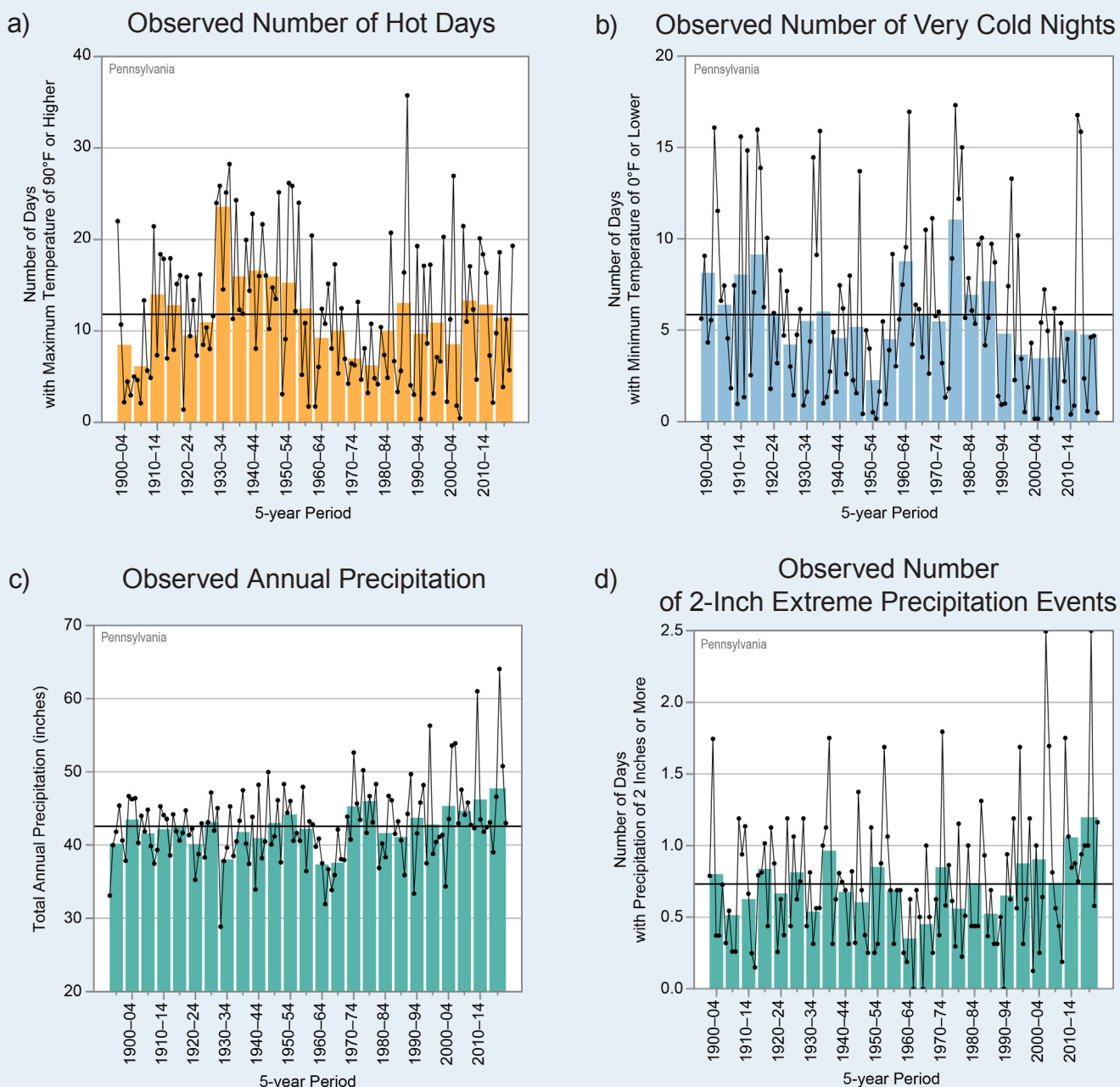


Figure 2: Observed (a) annual number of hot days (maximum temperature of 90°F or higher), (b) annual number of very cold nights (minimum temperature of 0°F or lower), (c) total annual precipitation, and (d) annual number of 2-inch extreme precipitation events (days with precipitation of 2 inches or more) for Pennsylvania from (a, b, d) 1900 to 2020 and (c) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 12 days; (b) 5.9 nights; (c) 42.6 inches; (d) 0.7 days. The number of hot days has been near the long-term average since the mid-2000s, and the number of very cold nights has been below average since the 1990s, indicative of a long-term winter warming trend. During the most recent 6-year period (2015–2020), both annual precipitation and the number of 2-inch extreme precipitation events were the highest on record. A typical reporting station experiences a 2-inch event about once every 1 to 2 years. Sources: CISESS and NOAA NCEI. Data: (a, b) GHCN-Daily from 6 long-term stations; (c) nClimDiv; (d) GHCN-Daily from 10 long-term stations.

Pennsylvania experiences abundant precipitation.

Statewide annual precipitation has ranged from a low of 28.9 inches in 1930 to a high of 64.0 inches in 2018. The driest multiyear periods were in the 1960s and the wettest in the 1970s and 2010s (Figure 2c). The driest consecutive 5-year interval was 1962–1966, and the wettest was 2016–2020. The above average precipitation the state has recently experienced is primarily due to increases in summer and fall precipitation. **Winter storms are a common occurrence.** Lake effect snows, caused by the warming and moistening of arctic air masses passing over the Great Lakes, are a hazard for the northwestern part of the state, which can receive more than 100 inches of snow annually. The Great Lakes can also experience flooding and erosion due to high water levels. Wet spring conditions contributed to record high water levels and flooding in 2017 and 2019. Cleanup costs, infrastructure damages, and agricultural losses were in the millions of dollars. The area to the east of the Appalachian Mountains is at risk for nor'easters, which are fueled by the large temperature contrast between the cold interior of the eastern United States and the warm moist air over the western Atlantic. The Blizzard of 1996, a classic nor'easter, dropped more than 30 inches of snow in several parts of the state; Philadelphia received 30.7 inches, and 27.6 inches of that fell in 24 hours, a record for the city. February 2010 brought three winter storms to the state, causing Philadelphia, Pittsburgh, and Harrisburg to have their snowiest month on record. The blizzard of 2016 brought high winds and heavy snow; Allentown recorded more than 30 inches.

The number of extreme precipitation events has increased (Figure 2d). These rains can cause devastating flooding, particularly in the state's smaller streams and tributaries. One of the worst natural disasters in the history of the United States was the Great Flood of 1889, which was caused by intense, heavy rains and a catastrophic failure of the South Fork Dam upstream of Johnstown. The flood and subsequent fires killed more than 2,000 people and caused millions of dollars in damages. **Heavy rains can cause particularly damaging floods when they combine with spring snowmelt.** In 1936, runoff from rain falling on snow caused a record flood on the Monongahela River. The state can also experience short-term droughts, such as in 2002, 2016–2017, and 2020, which have an effect on agriculture.

Observed Number of Warm Nights

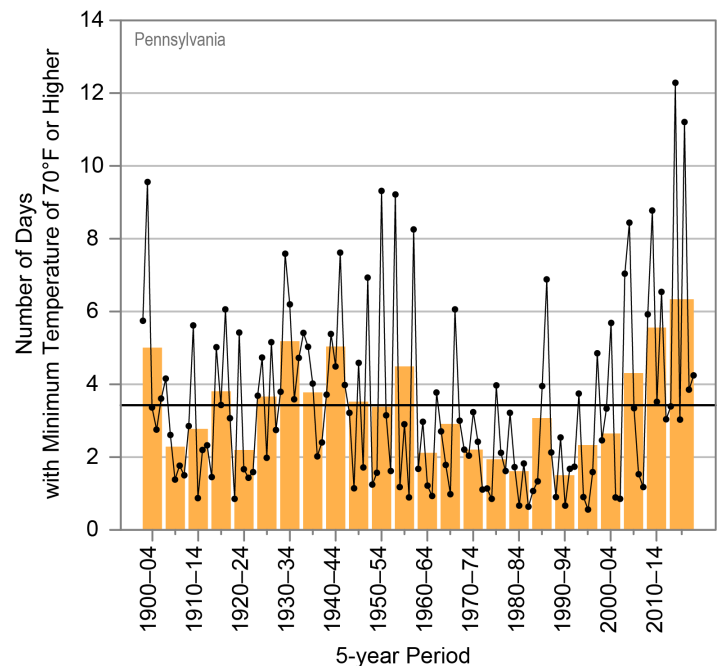


Figure 3: Observed annual number of warm nights (minimum temperature of 70°F or higher) for Pennsylvania from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 3.4 nights. During the most recent 6-year period (2015–2020), Pennsylvania experienced its highest frequency of warm nights, nearly double the long-term average. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 6 long-term stations.

Tropical cyclones occasionally pass through the state and are yet another cause of heavy rainfall and widespread flooding. Over a 2-week period in 2011, the remnants of both Hurricane Irene and Tropical Storm Lee drenched Pennsylvania in heavy rains and caused historic flooding. Several rivers and creeks reached record-high levels, including the Swatara Creek, which crested at 27.2 feet near Hershey (flood stage is 7 feet), and the Susquehanna River, which hit 42.6 feet in Wilkes-Barre (flood stage is 22 feet). Damages across the state were estimated to exceed \$100 million. One of the worst storms to hit the state was Tropical Storm Agnes in 1972. Agnes caused torrential rainfall, dropping more than 10 inches in parts of the state and causing catastrophic flooding, with statewide damages estimated at almost \$3 billion.

Thunderstorms are a common occurrence during the warmer months, and the most severe of these can occasionally cause extensive damages and loss of life. On June 30, 2012, a severe derecho (an organized thunderstorm complex with high winds) passed through

the state, causing extensive wind damage and power outages. Although Pennsylvania experiences only a few tornadoes each year, these events have the potential to cause widespread destruction. On May 31, 1985, a storm caused 21 tornadoes across the northern and western counties, killing more than 60 people and destroying more than 1,000 homes. One of these tornadoes destroyed much of the town of Wheatland and is the only F5 tornado in the state's history.

Large temperature increases are possible for the future if greenhouse gas concentrations continue to increase (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of this century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. **Extreme heat is a particular concern for Philadelphia and other urban areas, where the urban heat island effect raises summer temperatures.** High temperatures combined with high humidity can create dangerous heat index values. Pennsylvania has experienced several heat waves in recent years. One of the worst peaked on July 22, 2011, when most of the state experienced high temperatures above 95°F and many locations experienced temperatures above 100°F. On that date, Reading reported an all-time high of 106°F, while Scranton reported its highest minimum temperature of 80°F. July 2020 was the all-time hottest month for Scranton and Harrisburg; Philadelphia and Scranton recorded their greatest number of 90°F days for any month (21 and 16, respectively). July 2020 also tied for the all-time hottest month for the state. While heat

waves are projected to become more intense, cold waves are projected to become less intense.

Pennsylvania's coastline runs along the Delaware Estuary, and increasing temperatures raise concerns for sea level rise in these coastal areas. Since 1900, global average sea level has risen by about 7–8 inches. It is projected to rise another 1–8 feet, with a likely range of 1–4 feet, by 2100 as a result of both past and future emissions from human activities (Figure 4). Even if storm patterns remain the same, sea level rise will increase the frequency, extent, and severity of coastal flooding. This is a particularly serious risk for Philadelphia, where the observed sea level rise over the past century has exceeded the global average. Sea level rise has caused an increase in tidal floods associated with nuisance-level impacts. Nuisance floods are events in which water levels exceed the local threshold (set by NOAA's National Weather Service) for minor impacts. These events can damage infrastructure, cause road closures, and overwhelm storm drains. As sea level has risen along the Pennsylvania coastline, the number of tidal flooding days (all days exceeding the nuisance level threshold) has also increased, with the greatest number occurring in 2011 (Figure 5).

Winter and spring precipitation is projected to increase for Pennsylvania (Figure 6). In addition, extreme precipitation is projected to increase, expanding the risk for more frequent and intense floods. Heavier precipitation and higher temperatures causing earlier snowmelt increase the risk of springtime flooding, which could pose a threat to Pennsylvania's agricultural industry by delaying planting and reducing yields.

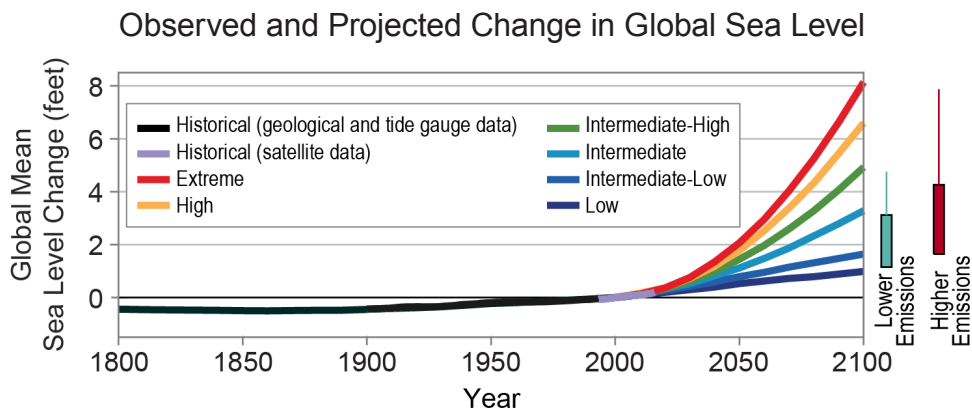


Figure 4: Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate-Low, royal blue; Intermediate, cyan; Intermediate-High, green; High, orange; and Extreme, red curves) relative to historical geological, tide gauge, and satellite altimeter GMSL reconstructions from 1800–2015 (black and magenta lines) and the very likely ranges in 2100 under both lower and higher emissions futures (teal and dark red boxes). Global sea level rise projections range from 1 to 8 feet by 2100, with a likely range of 1 to 4 feet. Source: adapted from Sweet et al. 2017.

Observed and Projected Annual Number of Tidal Floods for Philadelphia, PA

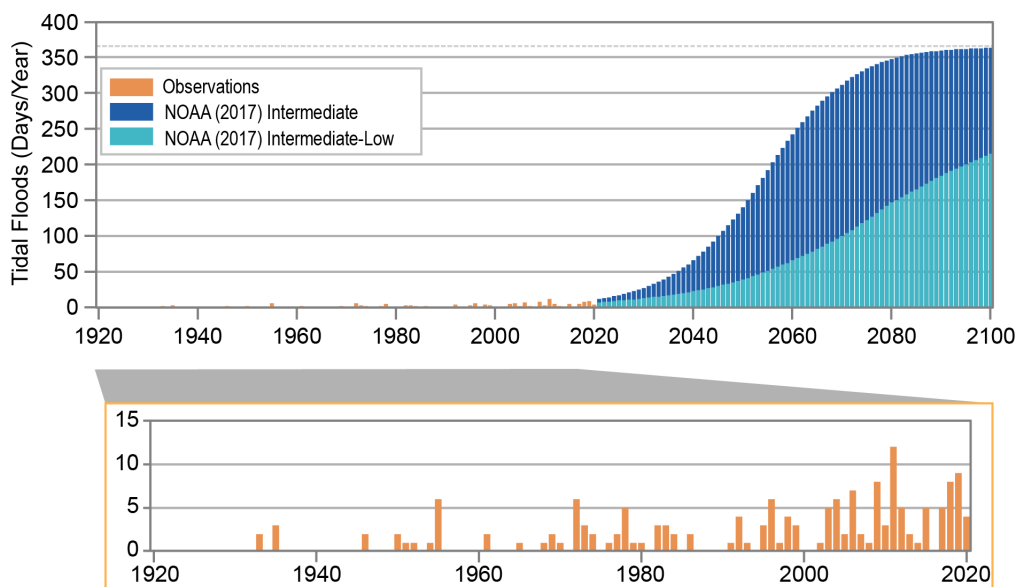


Figure 5: Number of tidal flood days per year at Philadelphia, PA, for the observed record (1920–2020; orange bars) and projections for 2 NOAA (2017) sea level rise scenarios (2021–2100): Intermediate (dark blue bars) and Intermediate-Low (light blue bars). The NOAA (2017) scenarios are based on local projections of the GMSL scenarios shown in Figure 4. Sea level rise has caused a gradual increase in tidal floods associated with nuisance-level impacts. The greatest number of tidal flood days (all days exceeding the nuisance-level threshold) occurred in 2011 at Philadelphia. Projected increases are large even under an Intermediate-Low scenario. Under the Intermediate scenario, tidal flooding is projected to occur nearly every day of the year by the end of the century. Additional information on tidal flooding observations and scenarios is available at <https://statesummaries.ncics.org/technicaldetails>. Sources: CISESS and NOAA NOS.

Projected Change in Winter Precipitation

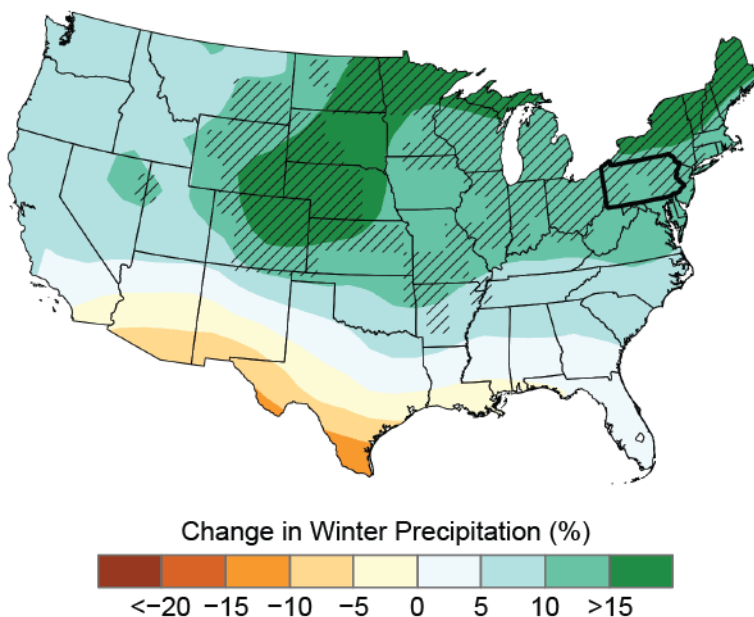


Figure 6: Projected changes in total winter (December–February) precipitation (%) for the middle of the 21st century relative to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. Winter precipitation is projected to increase in Pennsylvania. Sources: CISESS and NEMAC. Data: CMIP5.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

PUERTO RICO AND THE U.S. VIRGIN ISLANDS

Key Messages

Temperatures in Puerto Rico and the U.S. Virgin Islands have risen almost 2°F since 1950. Under a higher emissions pathway, historically unprecedented warming is projected during this century, including increases in extreme heat events.

Future changes in total precipitation are uncertain, but extreme precipitation is projected to increase, with associated increases in the intensity and frequency of flooding.

Since 1961, sea level has risen by 0.7 inches per decade at San Juan, Puerto Rico—a rate equal to the global sea level rise rate during the second half of the 20th century. Global sea level is projected to rise another 1–8 feet, and similar rises are projected for Puerto Rico and the U.S. Virgin Islands. Rising sea levels pose widespread and continuing threats to both natural and built environments in coastal communities.

Hurricanes are a major threat to both Puerto Rico and the U.S. Virgin Islands. Hurricane rainfall rates, storm surge heights due to sea level rise, and the number of the strongest (Category 3, 4, and 5) hurricanes are all projected to increase in a warming climate.

Puerto Rico and the U.S. Virgin Islands are located in the subtropical Caribbean region. Puerto Rico comprises the main island and several smaller nearby islands, including Vieques, Culebra, Isla de Mona, Caja de Muertos, and Isla Desecheo. The major islands of the U.S. Virgin Islands are St. Thomas, St. Croix, and St. John. Surrounded by ocean on all sides, the islands experience warm and humid tropical conditions with minimal temperature variations between seasons. The temperate climate of San Juan, Puerto Rico, illustrates the tropical conditions of these islands. The annual average (1991–2020 normals) temperature is 81.0°F. Temperatures are generally cooler in January, with an average minimum temperature of 72.0°F and an average maximum temperature of 83.2°F, and warmer in August, with an average minimum temperature of 77.8°F and an average maximum temperature of 89.1°F.

Observed and Projected Temperature Change

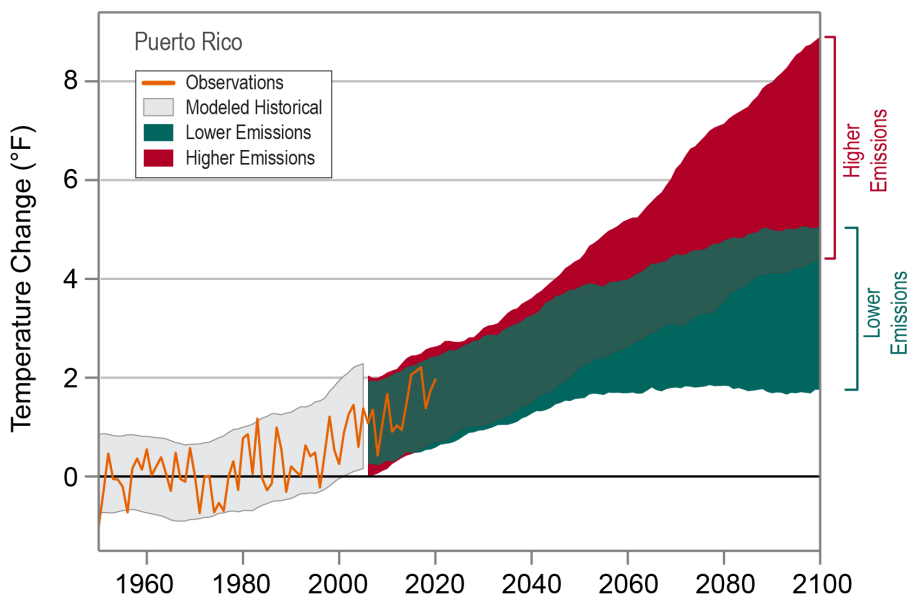


Figure 1: Observed and projected changes (compared to the 1951–1980 average) in near-surface air temperature for Puerto Rico. Observed data are for 1950–2020, based on data from six long-term reporting sites. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Puerto Rico (orange line) have risen almost 2°F since 1950. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 2°F warmer than the historical average; green shading), and more warming is expected under

a higher emissions future (the hottest end-of-century projections being about 7°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI. Data: GHCN-Monthly (observations) and CMIP5 (projections).

Precipitation across Puerto Rico and the U.S. Virgin Islands varies seasonally, with wetter summers and relatively drier winters. The predominant synoptic influence on the islands' climate is the North Atlantic subtropical high, which causes prevailing trade winds predominantly from the east and northeast. The east to west positioning of the Cordillera Central, where the highest elevation is 4,390 feet, provides a natural divide that separates Puerto Rico into two climatologically distinct regions. The northern two-thirds of Puerto Rico has a mostly humid climate, and the southern portion has a drier, semiarid climate. The northeast trade winds provide water vapor for precipitation along the northern coast and outlying islands, but passage over this mountain range removes moisture through precipitation, and the resulting downslope flow is drier. The U.S. Virgin Islands are not as high in elevation (the highest point is 1,555 feet on St. Thomas), but topographic effects on precipitation still occur, with the west (upwind) sides being wetter than the east (downwind) sides.

The islands warmed throughout the 20th and early 21st centuries. For example, **temperatures in Puerto Rico have risen almost 2°F since 1950** (Figure 1). The number of very hot days does not exhibit any trend (Figure 2). By contrast, extremely warm nights have generally been above average since 2000, with the highest number occurring since 2015 (Figure 3). The urban heat island effect has caused temperatures to rise faster in San Juan than across the rest of the islands. The surface temperatures of the surrounding ocean area, which provide an essential regulator on temperatures in Puerto Rico and the U.S. Virgin Islands, have risen by almost 2°F since the start of the 20th century (Figure 4).

Annual precipitation for Puerto Rico ranges from more than 200 inches in the high elevation regions of the El Yunque National Forest (located in the Sierra de Luquillo mountains) in the northeastern part of the island to less than 40 inches at Ponce on the southern coast. Annual rainfall in the U.S. Virgin Islands is less than 60 inches across all the islands. Much of the rainfall in the wet season (May through October) derives from tropical cyclones (hurricanes and tropical storms) and easterly waves, which move from east to west, but high sea surface temperatures can also trigger local thunderstorm activity. In the dry season (November through April),

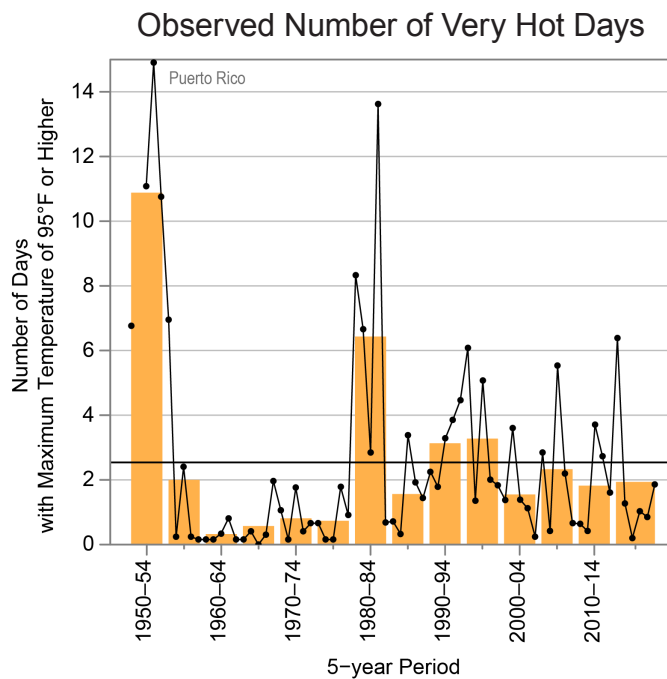


Figure 2: Observed annual number of very hot days (maximum temperature of 95°F or higher) for Puerto Rico from 1950 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year period). The horizontal black line shows the long-term (entire period) average of 2.5 days. (Data were not recorded for 1951.) There is no overall trend. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 4 long-term stations.

Observed Number of Extremely Warm Nights

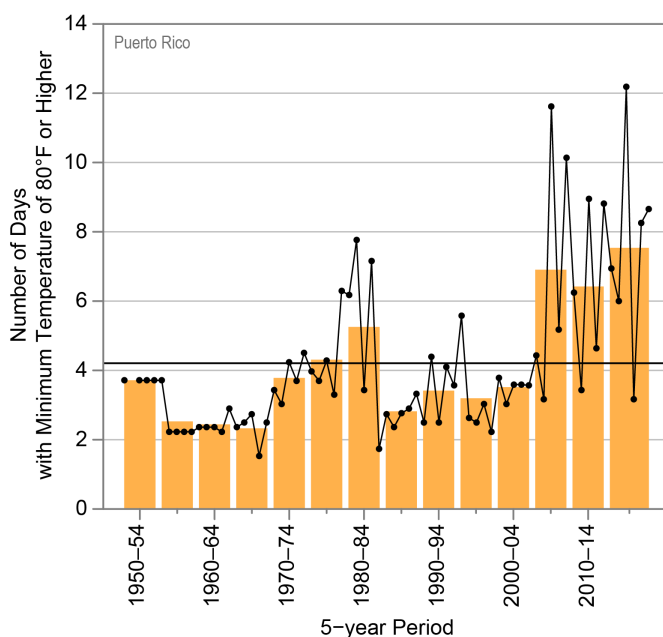


Figure 3: Observed annual number of extremely warm nights (minimum temperature of 80°F or higher) for Puerto Rico from 1950 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 4.2 nights. (Data were not recorded for 1951.) Since 2005, the islands have experienced an above-average number of such events, with the largest number occurring since 2015. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 4 long-term stations.

rainfall is caused by cold fronts moving from west to east.

Total annual precipitation in Puerto Rico varies from year to year but has been near to above average since 2003 (Figure 5).

Extreme precipitation in Puerto Rico has shown no overall trend since the 1950s. The highest number of 3-inch extreme precipitation events (Figure 6) occurred in the early 2010s. In 2011, Puerto Rico and the U.S. Virgin Islands experienced an extended period of heavy rainfall and flooding (not associated with a tropical cyclone) from mid-May through mid-June. Several locations recorded 2–4 times their normal rainfall during this period. Significant flooding occurred across Puerto Rico, with the exception of the southwest region of the island. Major flooding was also reported in Saint Croix, U.S. Virgin Islands, where weekly rainfall totals were on the order of 6 to 7 inches.

Tropical cyclone events (hurricanes, tropical storms, and tropical depressions) are an important concern for the islands due to their position in the Caribbean hurricane belt. While such weather systems occur near the islands only once every 1 to 2 years (Figure 7), they can have devastating impacts. The tropical cyclones that affected Puerto Rico and the U.S. Virgin Islands in this century include, but are not limited to, Tropical Storm Jeanne in 2004, Hurricane Irene (Category 1) in 2011, and Hurricane Irma (Category 5) in 2017. Hurricane Irene produced very heavy rainfall that resulted in major flooding in northeast Puerto Rico. In the late 20th century, Hurricane Hugo (Category 4) in 1989, Hurricane Marilyn (Category 2) in 1995, and Hurricane Georges (Category 3) in 1998 all caused catastrophic damage to the islands. Hurricane Lenny (Category 4) in 1999, the 2nd most powerful November hurricane of the satellite era, passed just to the south of the U.S. Virgin Islands while at peak intensity, causing more than \$300 million in damages in Puerto Rico and the U.S. Virgin Islands; it was characterized by an unusual west to east track through the Caribbean. Earlier hurricanes of note are the San Felipe Segundo storm (Category 5) of 1928 and the San Ciprián storm (Category 4) of 1932. The two most devastating hurricanes occurred in 1899 and 2017. The 1899 San Ciriaco hurricane (Category 4), the most severe natural disaster recorded in the islands' history, resulted in 3,300 deaths. In addition, a quarter of residents were left homeless, and more than \$200 million in coffee production was destroyed. In September 2017, Hurricane Maria (Category 4) made

Change in Annual Sea Surface Temperature

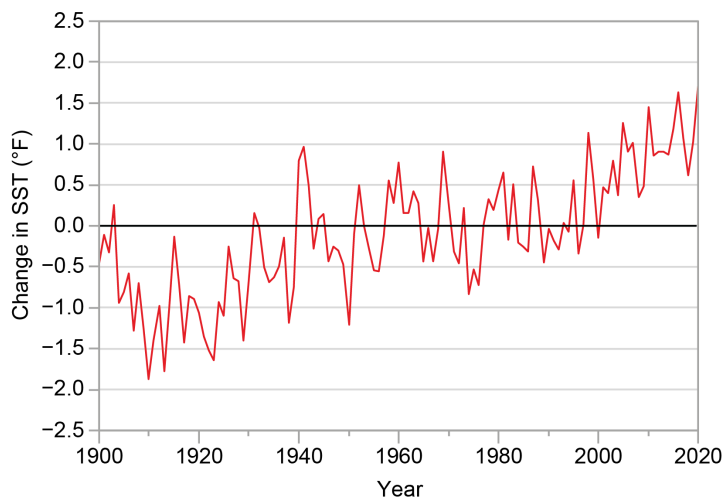


Figure 4: Observed changes for 1900–2020 (compared to the 1951–1980 average) in annual average sea surface temperature (SST) for the region surrounding Puerto Rico and the U.S. Virgin Islands (62°W–68°W, 17°N–19°N). SSTs have increased steadily since the mid-1900s. Sources: CISESS and NOAA NCEI. Data: NOAA ERSST v5.

Observed Annual Precipitation

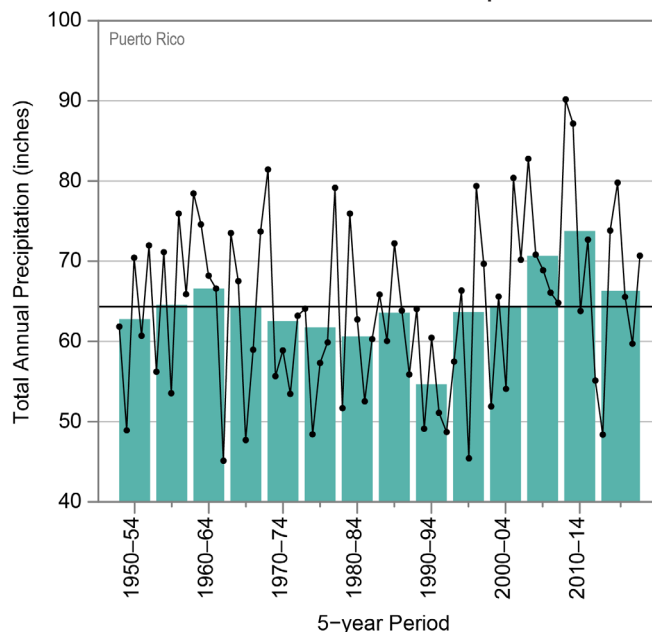


Figure 5: Observed total annual precipitation for Puerto Rico from 1950 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 64.3 inches. Annual precipitation in Puerto Rico varies from year to year. Precipitation totals have been near to above average since 1950, with only one period experiencing much below average conditions. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 8 long-term stations.

landfall in Puerto Rico, causing devastating destruction across the islands. Winds that locally reached Category 5 intensity, combined with extremely heavy rainfall and the destructive power of wave action and storm surge, led to

extensive damage to buildings and infrastructure. Severe flooding and mudslides affected much of Puerto Rico and the U.S. Virgin Islands, and most residents lost power for months in what is still the most severe power outage in American history. Maria is the third costliest hurricane in U.S. history, with an estimated \$90 billion in total damages across the islands.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of this century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. Increases in the number of extremely hot days and warm nights are projected to accompany the overall warming.

A decrease in annual average precipitation in Puerto Rico and the U.S. Virgin Islands is projected over the 21st century (Figure 8). Model projections indicate a decrease in precipitation averaging around 10%, however, there is significant uncertainty in the magnitude of precipitation changes in the Southern Caribbean region. Puerto Rico and the U.S. Virgin Islands may face an increased risk of drought, potentially affecting water supplies, agriculture, and the economy.

Although overall precipitation is projected to decrease, extreme precipitation events are projected to increase due to increased water vapor available in response to climate change–related warming of ocean temperatures. While it is uncertain whether the total number of hurricanes will increase or decrease in the future, hurricane rainfall rates, storm surge heights due to sea level rise, and the number of major (Category 3, 4, and 5) hurricanes are all projected to increase.

Since 1962, the sea level at San Juan has risen by 0.7 inches per decade (equal to the global sea level rise rate). Sea level rise is an important concern due to Puerto Rico's extensive coastline. Approximately 60% of the population lives within the islands' 44 coastal cities, and these areas are also home to a significant share of the islands' critical coastal infrastructure. Since 2010, sea level rise, as well as tropical cyclones and other extreme events, has increased

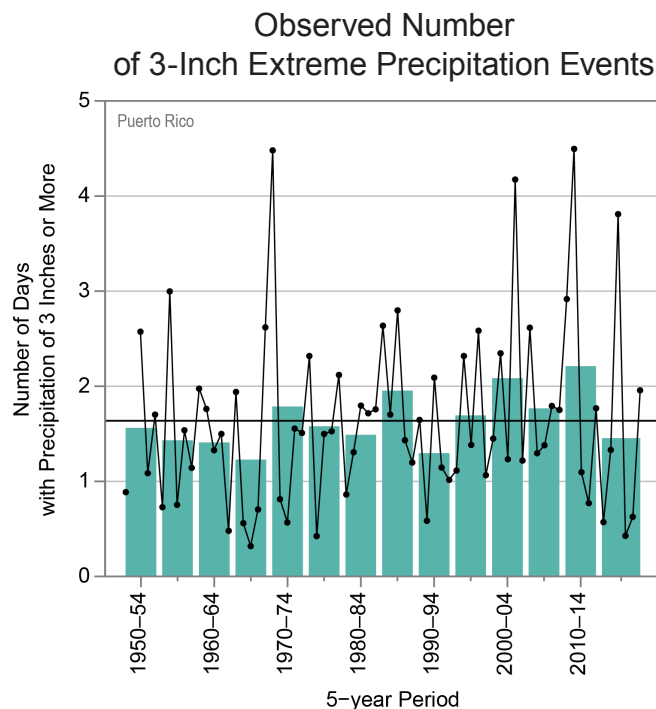


Figure 6: Observed annual number of 3-inch extreme precipitation events (days with precipitation of 3 inches or more) for Puerto Rico from 1950 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 1.6 days. (Data were not recorded for 1951.) A typical reporting station experiences 1 to 2 events per year. There is no overall trend. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 8 long-term stations.

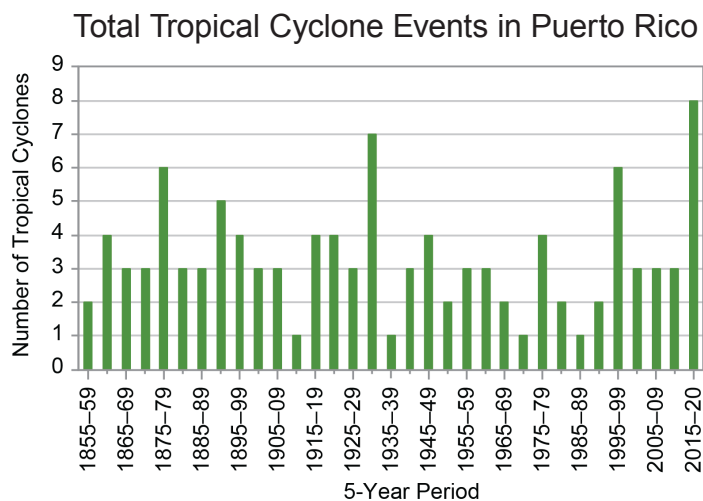


Figure 7: Number of tropical cyclone events (including hurricanes and tropical storms) within 60 nautical miles of Puerto Rico, totaled over 5-year periods (last bar is a 6-year total). Such events occur every 1 to 2 years; however, the 2015–2020 period saw 8 events. Source: CISESS and NOAA NCEI.

the rate of erosion at many sites along the Puerto Rican coastline. By amplifying tidal and storm surge, even marginal amounts of sea level rise increase the likelihood of previously less common flooding events. Most of the

U.S. Virgin Islands are well above sea level; however, waterfront property in the capital, Charlotte Amalie, is generally within a few feet of sea level.

Global sea level is projected to rise another 1–8 feet, with a likely range of 1–4 feet, by 2100 as a result of both past and future emissions from human activities (Figure 9), and similar rises are likely for Puerto Rico and the U.S. Virgin Islands. Some island-level estimates for Puerto Rico project a rise of up to 2.1 feet by 2060 and 4.9 feet by 2100 (Figure 10). Rising sea levels will likely result in increased coastal flooding, coastal erosion, and disruptions to coastal ecosystems and critical infrastructures.

Projected Change in Annual Precipitation

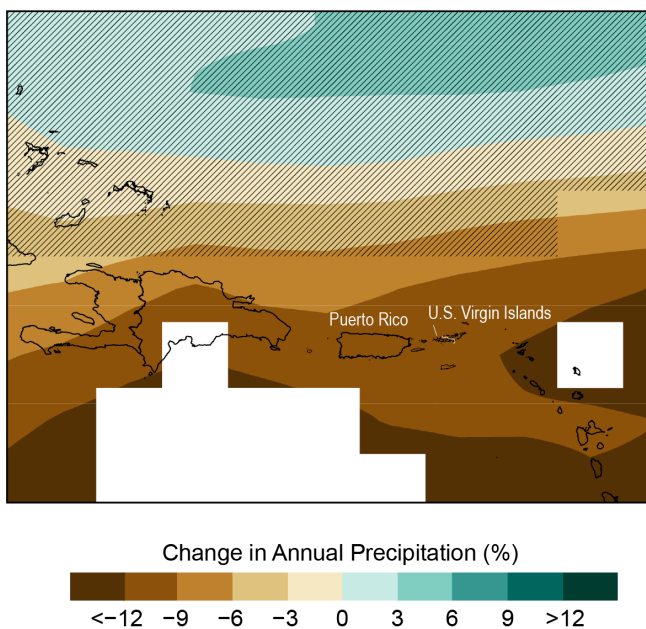


Figure 8: Projected changes in annual precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Total annual precipitation is projected to decrease in both Puerto Rico and the U.S. Virgin Islands. Hatching indicates areas where the changes are less than the standard deviation of the 20-year means from control simulations. The areas that are just shaded are where the changes are between one and two standard deviations of the 20-year means. Whited-out areas indicate that less than 90% of the models agree on the direction (increasing or decreasing) of the change. Sources: CISESS and NEMAC.

Observed and Projected Change in Global Sea Level

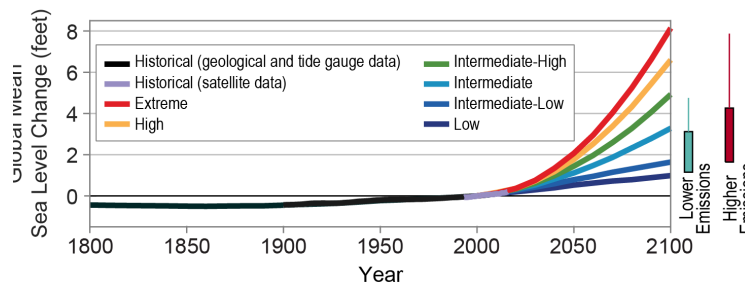


Figure 9: Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate-Low, royal blue; Intermediate, cyan; Intermediate-High, green; High, orange; and Extreme, red curves) relative to historical geological, tide gauge, and satellite altimeter GMSL reconstructions from 1800–2015 (black and magenta lines) and the very likely ranges in 2100 under both lower and higher emissions futures (teal and dark red boxes). Global sea level rise projections range from 1 to 8 feet by 2100, with a likely range of 1 to 4 feet. Source: adapted from Sweet et al. 2017.

Projected Change in Sea Level for San Juan, PR

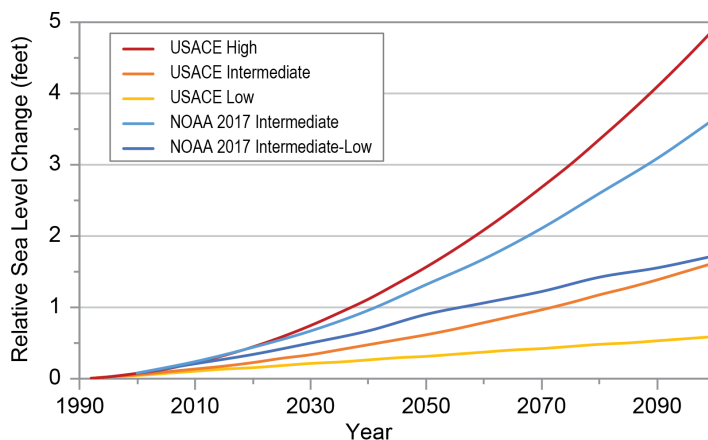
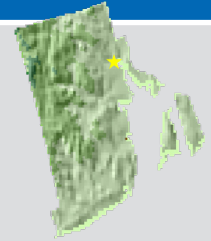


Figure 10: Relative sea level change for San Juan, Puerto Rico, from 1992 to 2100. Projected changes are shown for three U.S. Army Corps of Engineers' (USACE) Sea Level Change Curves (Low: yellow, Intermediate: orange, and High: red) and two NOAA (2017) Sea Level Rise scenarios (Intermediate-Low: dark blue and Intermediate: light blue). All scenarios start in 1992 which corresponds to the midpoint of the current National Tidal Datum Epoch of 1983–2001. These island-level estimates of sea level for Puerto Rico project a rise of up to 2.1 feet by 2060 and 4.9 feet by 2100. Source: Adapted from PRCCC 2013.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

RHODE ISLAND



Key Messages

Temperatures in Rhode Island have risen almost 4°F since the beginning of the 20th century. Under a higher emissions pathway, historically unprecedented warming is projected to continue through this century. Increased intensity of heat waves is also projected, while cold waves are projected to decrease in intensity.

Annual precipitation in Rhode Island has increased since 1895. Extreme precipitation has increased since 1950, with the highest number of extreme events occurring during the 2005–2014 interval. Continued increases in frequency and intensity of extreme precipitation events are projected.

Since 1930, sea level has risen more than 9 inches at Newport, faster than the global average. Global average sea level is projected to rise another 1 to 4 feet by 2100. Increases in sea level will likely increase coastal flooding and erosion during winter storms (nor'easters) and hurricanes.

Rhode Island's geographic position in the mid-latitudes often places it near the jet stream, particularly in the late fall, winter, and spring. The state's frequently changing weather is a result of the regular passing of low-pressure storms associated with the jet stream. In addition, Rhode Island's location on the East Coast of North America exposes it to the cold winter and warm summer air masses of the continental interior and the moderate and moist air masses of the western Atlantic Ocean. In winter, the contrast between the frigid air masses of the continental interior and the relatively warm Atlantic Ocean provides the energy for occasional intense storms known as nor'easters. In Providence, average temperatures in July are around 74°F and in January about 29°F. Statewide annual average precipitation is about 46 inches. The driest year on record (28 inches of precipitation) was 1965, while the wettest year on record (63 inches of precipitation) was 1972. Average accumulated snowfall ranges from 20 inches on Block Island and along the southeastern shores of Narragansett Bay to between 40 and 55 inches in the western portion of the state.

Temperatures in Rhode Island have risen almost 4°F since the beginning of the 20th century (Figure 1). The number of hot days has been above the long-term average since the 1990s with the greatest number occurring

Observed and Projected Temperature Change

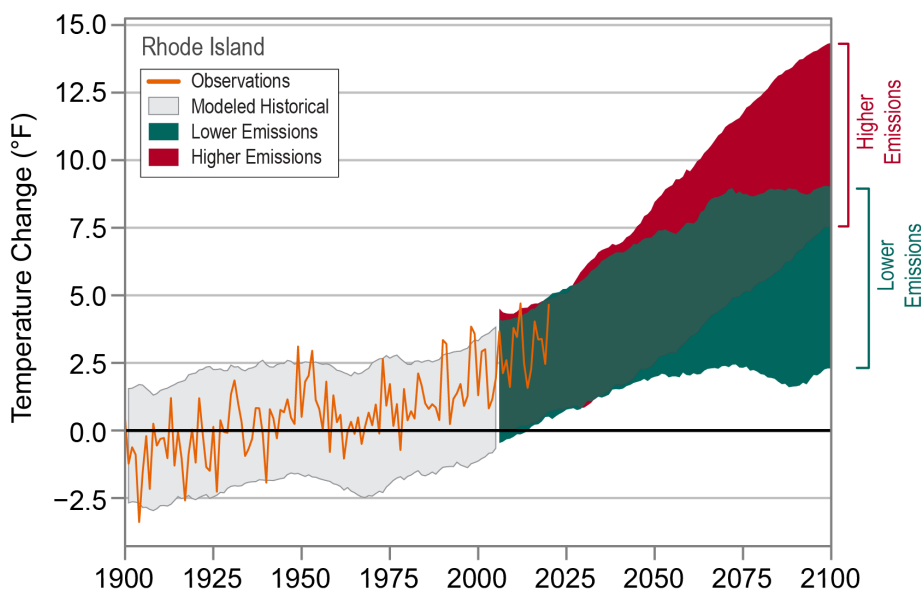


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Rhode Island. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Rhode Island (orange line) have risen almost 4°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected to continue through this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 1°F warmer than the historical

average; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 10°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

during the most recent 6-year period of 2015–2020 (Figure 2). The greatest number of warm nights also occurred during the 2015–2020 period (Figure 3a). Very cold nights have been mostly below average since the mid-1980s, and the most recent 6-year period (2015–2020) was about average (Figure 4).

Total annual precipitation for Rhode Island has generally been above average in recent decades. The driest multiyear periods were the 1940s and the latter half of the 1960s and the wettest period was the 2000s, although precipitation has been predominantly above average since the 1970s. The driest consecutive 5 years was the 1962–1966 interval, and the wettest 5-year period was 2005–2009, with an annual average of 54 inches of precipitation, which was about 8 inches more than the long-term average (Figure 3c). Since 2000, summer precipitation was above average until the most recent 6-year period (2015–2020), which was below average (Figure 3d). Rhode Island experienced the largest number of 2-inch extreme precipitation events in the 10-year period of 2005–2014 (Figure 3b). In 2010, major rainfall from a nor'easter in late March caused the worst flooding in the state's history. This event set an all-time monthly precipitation record in Providence of 16.34 inches, superseding the previous record of 15.38 inches, which was recorded in October 2005. The flooding of 2010 resulted in an estimated \$43 million in national flood insurance claims in the state. Rhode Island experienced severe drought in 2016 and extreme drought in 2020, straining water supplies.

Extreme weather events common to Rhode Island include severe storms (coastal, winter, and thunderstorms), often accompanied by flooding, and on occasion, tropical storms and hurricanes. The state's coastline is highly vulnerable to flood damage from winter and hurricane events. FEMA disaster declarations were sought 4 out of the last 10 years. Landfalling hurricanes produced hurricane-force winds in Rhode Island 6 times from 1900 to 2019. The Great New England Hurricane (Category 3) of 1938 was one of the most destructive and powerful storms ever to impact southern New England. Storm tides of 12 to 15 feet were recorded for Narragansett Bay, and downtown Providence was submerged under a storm tide of 20 feet. In October 2012, Superstorm Sandy (a post-tropical storm) caused a storm surge 9.4 feet above normal high tide in Providence, resulting in

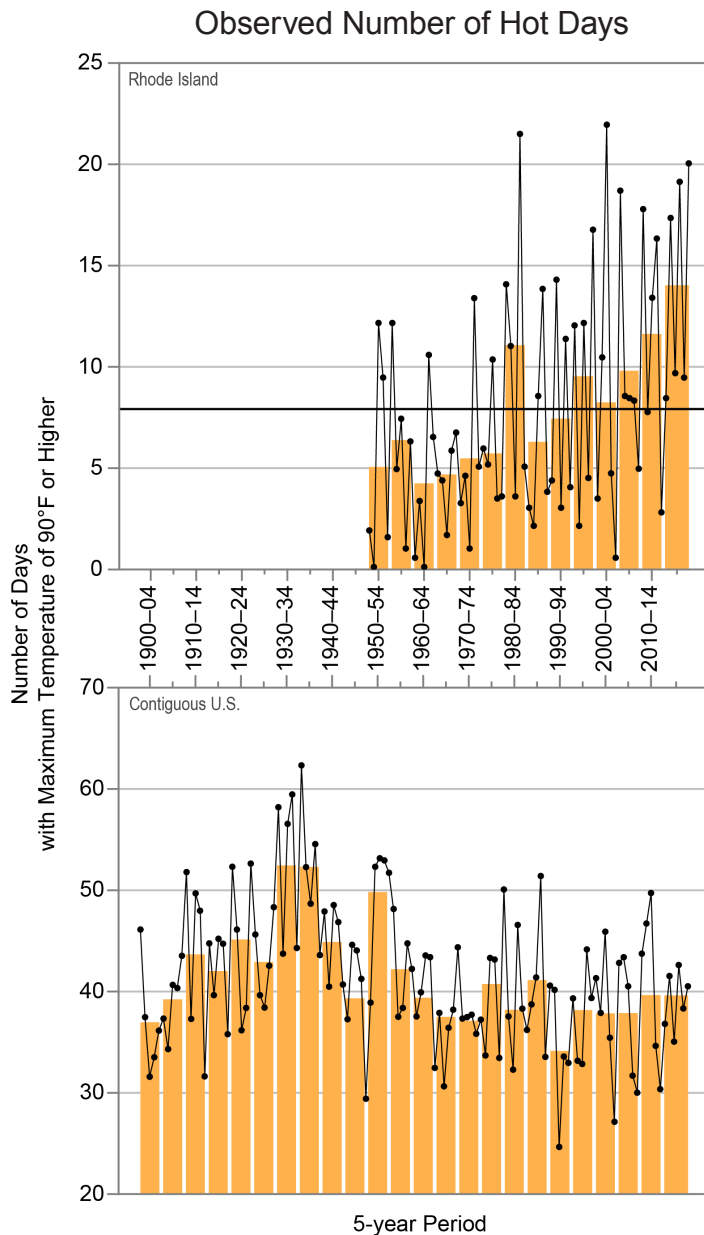


Figure 2: Observed annual number of hot days (maximum temperature of 90°F or higher) for Rhode Island from 1950 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 7.9 days. Long-term stations dating back to 1900 were not available for Rhode Island. Values for the contiguous United States (CONUS) from 1900 to 2020 are included to provide a longer and larger context. The number of hot days has been above average since the mid-1990s. The highest number of such days occurred in the most recent 6-year period (2015–2020), with an average of 14 hot days occurring each year. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 2 long-term stations.

extensive coastal flooding. One year earlier, Hurricane Irene brought heavy rainfall and strong southeast winds of up to 70 mph, knocking down power lines and leaving half of Rhode Island's one million residents without power. Both hurricanes demonstrated the region's vulnerability to extreme weather events.

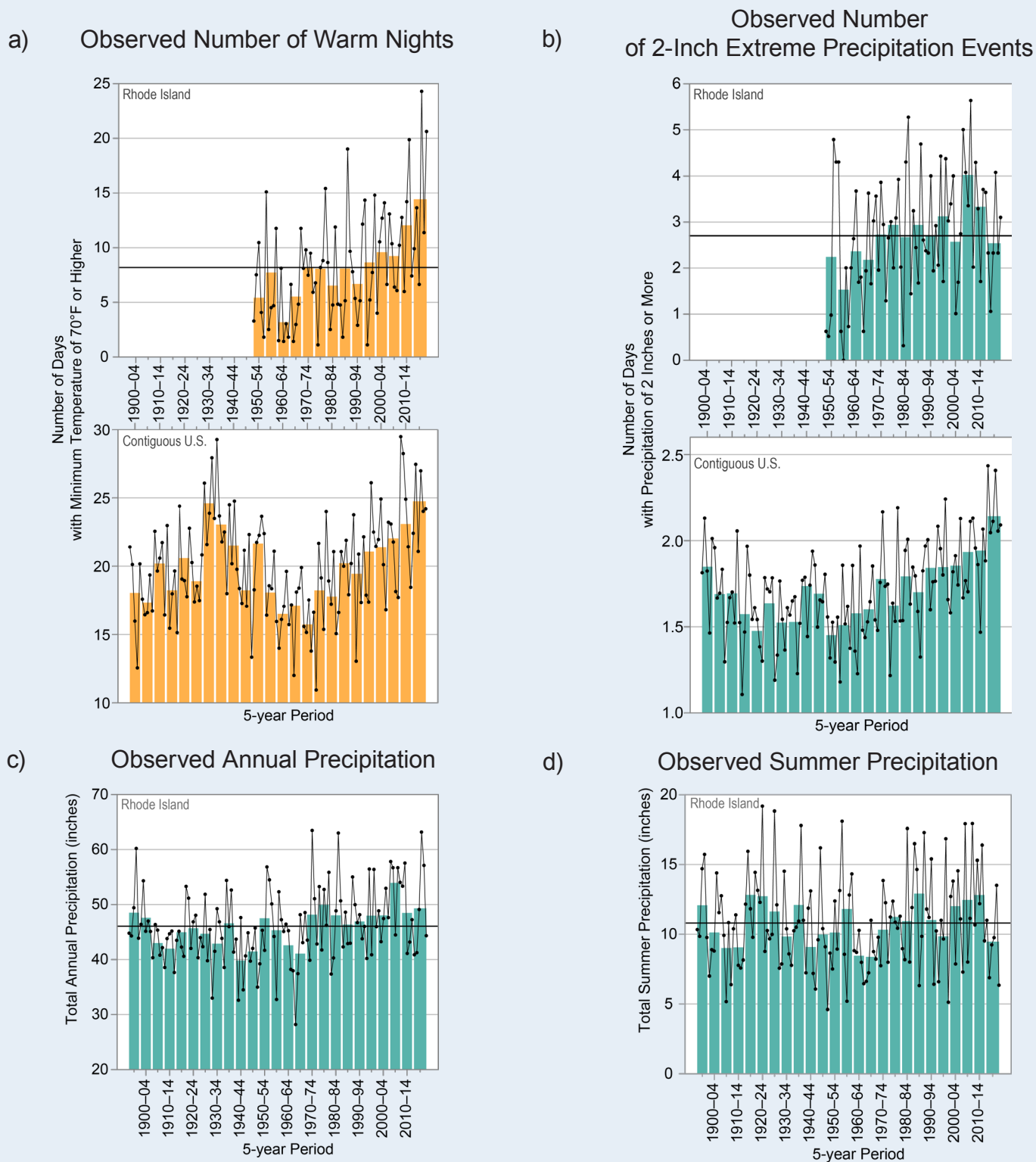


Figure 3: Observed (a) annual number of warm nights (minimum temperature of 70°F or higher), (b) annual number of 2-inch extreme precipitation events, (c) total annual precipitation, and (d) total summer (June–August) precipitation for Rhode Island from (a, b) 1950 to 2020 and (c, d) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages for Rhode Island: (a) 8.2 days, (b) 2.7 days, (c) 46.1 inches, (d) 10.8 inches. Long-term stations dating back to 1900 were not available for Rhode Island. Values for the contiguous United States (CONUS) from 1900 to 2020 are included for Figures 2a and 2b to provide a longer and larger context. The number of warm nights has been above average since 1995, with the highest number occurring in the most recent 6-year period of 2015–2020. Since 1970, annual precipitation has remained above the long-term average, while summer precipitation has varied. Extreme precipitation events have shown an increasing trend overall, but the number of events was below average during the last 6-year period. The wettest 5-year period on record was 2005–2009, with an estimated 54 inches of annual precipitation. Sources: CISESS and NOAA NCEI. Data: (a) GHCN-Daily from 2 (RI) and 655 (CONUS) long-term stations; (b) GHCN-Daily from 3 (RI) and 832 (CONUS) long-term stations; (c, d) nClimDiv.

Under a higher emissions pathway, historically unprecedented warming is projected to continue through this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of this century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. Heat waves are projected to increase in intensity while cold waves are projected to become less intense. Rhode Islanders may experience more heat-related deaths, and due to the heat island effect, hotter conditions will be most dangerous in urban areas.

Annual average precipitation is projected to increase for Rhode Island, with those increases coming in the winter and spring. Rhode Island is part of a large area of the Northern Hemisphere in the higher middle latitudes that is projected to see increases in precipitation (Figure 5), as well as increases in extreme precipitation events. More precipitation and a greater number of extreme precipitation events may also result in increased flooding risks. Although increased precipitation is projected, naturally occurring droughts are projected to be more intense because higher temperatures will increase evaporation rates.

Since 1900, global average sea level has risen by about 7–8 inches. Tide gauge recordings in Newport between 1930 and 2020 show an average rate of sea level rise of 0.11 inches (2.83 mm) per year, equivalent to about 11 inches over a century. Global average sea level is projected to rise another 1–8 feet, with a likely range of 1–4 feet, by 2100 as a result of both past and future emissions from human activities (Figure 6) and will be accompanied by large increases in tidal flood events with nuisance-level impacts. Nuisance floods are events in which water levels exceed the local threshold (set by NOAA's National Weather Service) for minor impacts. These events can damage infrastructure, cause road closures, and overwhelm storm drains. As sea level has risen along the Rhode Island coastline, the number of tidal flood days (all days exceeding the nuisance level threshold) has also increased, with the greatest number occurring in 2017 (Figure 7).

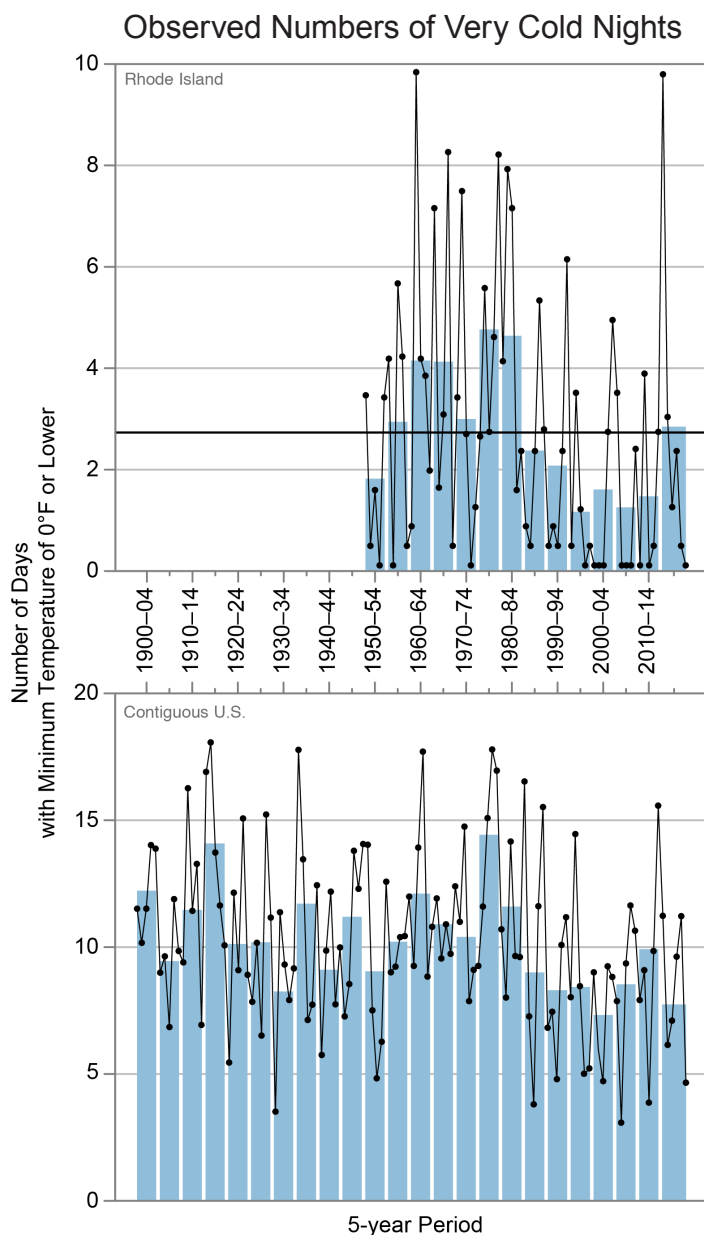


Figure 4: Observed annual number of very cold nights (minimum temperature of 0°F or lower) for Rhode Island from 1950 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 2.7 days. Long-term stations dating back to 1900 were not available for Rhode Island. Values for the contiguous United States (CONUS) from 1900 to 2020 are included to provide a longer and larger context. The average number of very cold nights was highest in the late 1970s and early 1980s. Beginning in the mid-1980s, the observed number of such days was mostly below average, and the most recent 6-year period was about average. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 2 long-term stations.

Higher sea levels will likely increase the probability for major flooding events. According to the National Flood Insurance Program, “the increase in the expected annual flood damage by the year 2100 for a representative National Flood Insurance Program (NFIP) insured property subject to sea level rise is estimated to increase by 36 to 58 percent for a one-foot rise” in sea level. Due to local land subsidence, sea level rise along most of the coastal Northeast is expected to exceed the global average rise. A sea level rise of two feet, without any changes in storms, would more than triple the frequency of dangerous coastal flooding throughout most of the Northeast.

Projected Change in Annual Precipitation

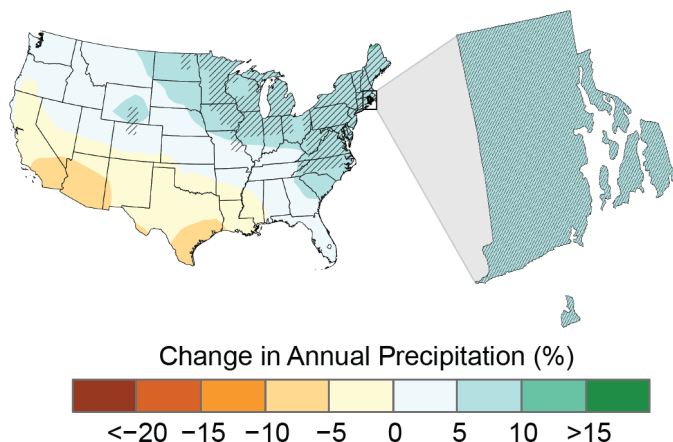


Figure 5: Projected changes in total annual precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. Rhode Island is part of a large area of projected increases that includes the Northeast region. Sources: CISESS and NEMAC. Data: CMIP5.

Observed and Projected Changes in Global Sea Level

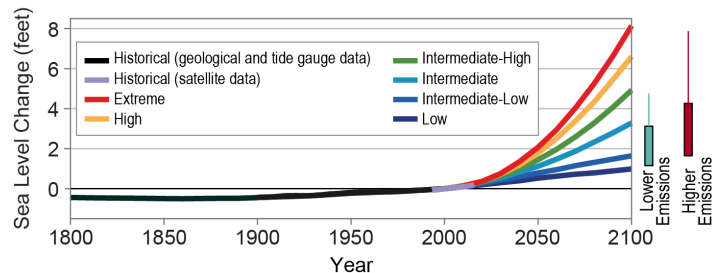


Figure 6: Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate-Low, royal blue; Intermediate, cyan; Intermediate-High, green; High, orange; and Extreme, red curves) relative to historical geological, tide gauge, and satellite altimeter GMSL reconstructions from 1800–2015 (black and magenta lines) and the very likely ranges in 2100 under both lower and higher emissions futures (teal and dark red boxes). Global sea level rise projections range from 1 to 8 feet by 2100, with a likely range of 1 to 4 feet. Source: adapted from Sweet et al. 2017.

Observed and Projected Annual Number of Tidal Floods for Providence, RI

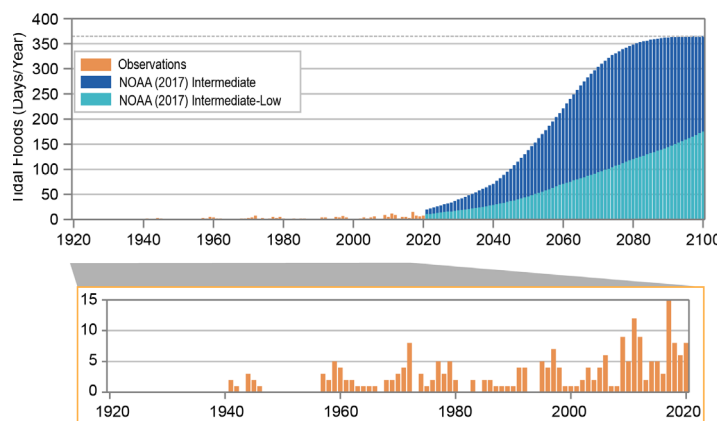
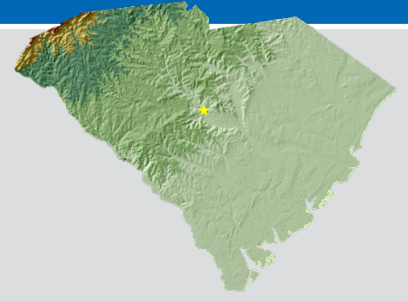


Figure 7: Number of tidal flood days per year at Providence, Rhode Island, for the observed record (1939–2020; orange bars) and projections for 2 NOAA (2017) sea level rise scenarios (2021–2100): Intermediate (dark blue bars) and Intermediate-Low (light blue bars). The NOAA (2017) scenarios are based on local projections of the GMSL scenarios shown in Figure 6. Sea level rise has caused a gradual increase in tidal floods associated with nuisance-level impacts. The greatest number of tidal flood days (all days exceeding the nuisance-level threshold) occurred in 2017 at Providence. Projected increases are large even under the Intermediate-Low scenario. Under the Intermediate scenario, tidal flooding is projected to occur nearly every day of the year by the end of the century. Additional information on tidal flooding observations and scenarios is available at <https://statesummaries.ncics.org/technicaldetails>. Sources: CISESS and NOAA NOS.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

SOUTH CAROLINA



Key Messages

Temperatures in South Carolina have risen more than 1°F since the beginning of the 20th century, less than the warming for the contiguous United States. Under a higher emissions pathway, historically unprecedented warming is projected during this century, including increases in extreme heat events.

Future changes in precipitation are uncertain, but extreme precipitation is projected to increase. In addition, projected increases in temperature will likely increase the intensity of naturally occurring droughts.

Sea level at Charleston has risen by 1.3 inches per decade, nearly double the global sea level rise, since reliable record keeping began in 1921. Global sea level is projected to rise another 1 to 4 feet by 2100, with greater rises projected for South Carolina. Rising sea levels pose widespread and continuing threats to both natural and built environments in coastal South Carolina.

South Carolina's geographic position at subtropical latitudes and adjacent to the Atlantic Ocean gives it a humid climate with hot summers and mild winters. The Appalachian Mountains to the north and west tend to partially shield the state from cold air masses approaching from the northwest, making winters milder than those in locations to the west of the mountains. However, the mountains are not high enough to fully block these air masses, so occasional periods of very cold conditions occur. Clockwise circulation of air around the Bermuda High, a semipermanent high-pressure system in the North Atlantic Ocean, provides a persistent flow of warm, moist air from the Atlantic during the warmer half of the year. The annual average (1991–2020 normals) temperature varies across the state from the mid-50s (°F) in the mountains to the mid-60s (°F) along the coast. During January, average temperatures range from 40°F in the north to around 47°F in the Lowcountry. Similar northwest to southeast temperature gradients also occur in the summer, with average temperatures in July ranging from 76°F in the northwest to 82°F in the Midlands and coastal Lowcountry.

Temperatures in South Carolina have risen more than 1°F since the beginning of the 20th century (Figure 1). The state warmed during the early part of the 20th century and then cooled substantially during the middle of the century. Warming has occurred since then, but only recently have temperatures reached the levels of the 1930s.

Observed and Projected Temperature Change

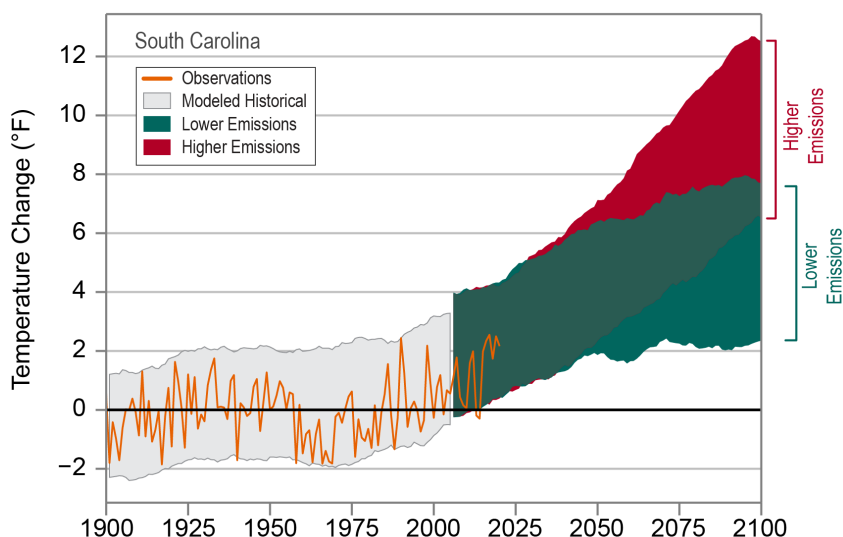
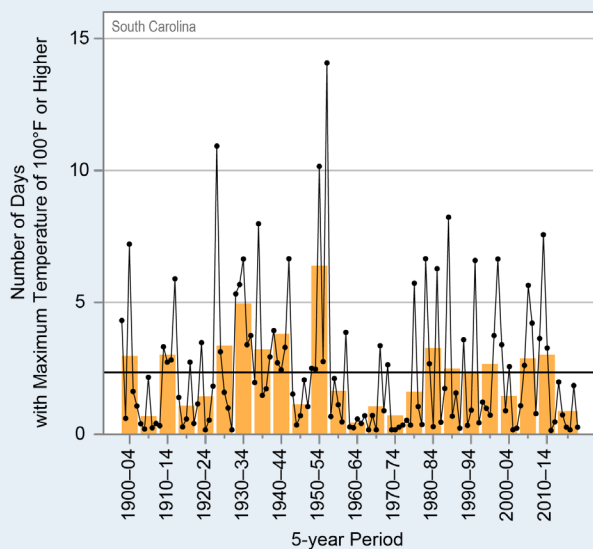


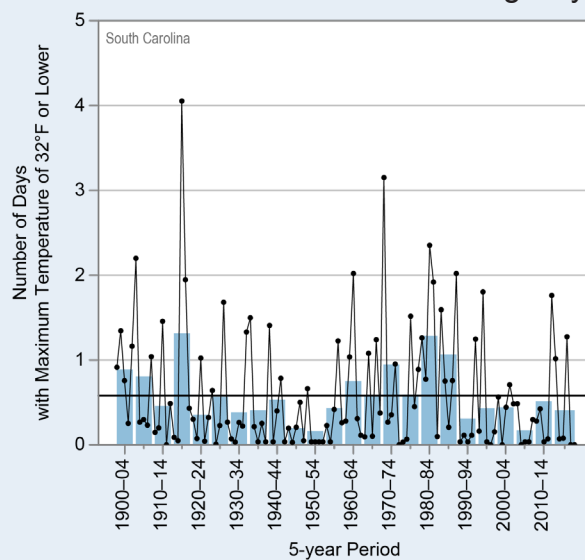
Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for South Carolina. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in South Carolina (orange line) have risen more than 1°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about as warm as the hottest year in the historical record; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 10°F

warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

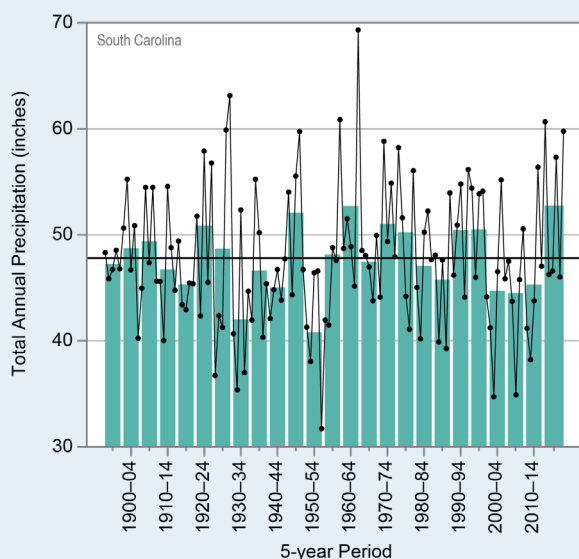
a) Observed Number of Extremely Hot Days



b) Observed Number of Freezing Days



c) Observed Annual Precipitation



d) Observed Number of 3-Inch Extreme Precipitation Events

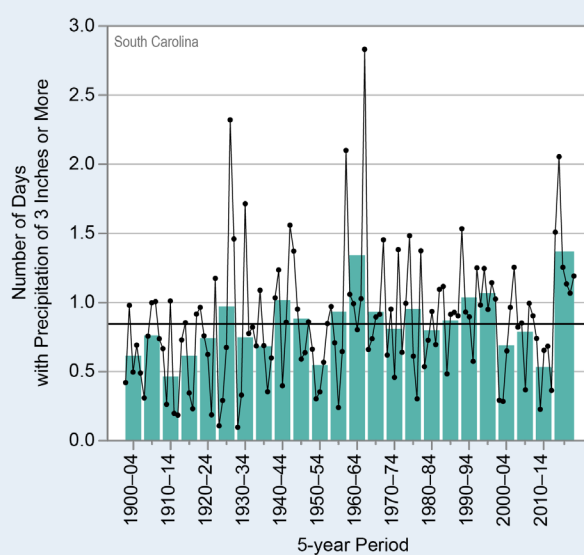


Figure 2: Observed (a) annual number of extremely hot days (maximum temperature of 100°F or higher), (b) annual number of freezing days (maximum temperature of 32°F or lower), (c) total annual precipitation, and (d) annual number of 3-inch extreme precipitation events (days with precipitation of 3 inches or more) for South Carolina from (a, b, d) 1900 to 2020 and (c) 1895 to 2020. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 2.3 days, (b) 0.6 days, (c) 47.8 inches, (d) 0.8 days. There is no overall trend in the number of extremely hot days, but they have been rare since 2014. The number of freezing days has been below average since 1990. Annual precipitation and the number of 3-inch extreme precipitation days has generally been above average since 2015. A typical reporting station experiences a 3-inch event about once every year. Sources: CISESS and NOAA NCEI. Data: (a, b) GHCN-Daily from 11 long-term stations; (c) nClimDiv; (d) GHCN-Daily from 17 long-term stations.

The number of extremely hot days has been generally near average since 1980 (Figure 2a), following very high numbers in the early 1930s and early 1950s and a period of below average numbers from the late 1950s to the late 1970s; however, such days have been rare since 2014. Between 1991 and 2020, the state capital of Columbia had an average of 3.5 days per year with temperatures of 100°F or higher, compared to a yearly

average of 2.4 days between 1961 and 1990. In the very hot summers of 2015 and 2016, the city experienced 10 and 16 extremely hot days, respectively, well above average. Statewide, very warm nights have generally been above average since 1980, with the highest 5-year average occurring during the 2010–2014 period (Figure 3). The number of freezing days has been below average since 1990 (Figure 2b).

Annual average precipitation ranges from 80 inches near Lake Jocassee in the mountains of the far northwest to less than 39 inches at Wateree in the Midlands, the driest part of the state. While isolated mountain areas receive large precipitation amounts, average precipitation for most of the Upstate is 45 to 55 inches. Average precipitation in the rest of the state is about 45 to 50 inches in the Midlands and 45 to 55 inches in the coastal Lowcountry. The high amounts of precipitation in the far northwest are due to moist air being forced up the mountains to higher elevations, while the slightly higher amounts along the Coastal Plain are due to sea-breeze-front thunderstorms, which occur during the summer months.

Total annual precipitation has been below average during most years since 2000 but was above average during the 2015–2020 period (Figure 2c). There is no overall trend in annual precipitation since the beginning of the 20th century; however, a few recent years (notably 2015, 2018, and 2020) have been very wet. **Between 2000 and 2015, the state experienced a below average number of 3-inch extreme precipitation events, but during the 2015–2020 period, the number was well above average** (Figure 2d). Of the last 21 years in South Carolina, 15 have been characterized by warm-season drought conditions.

Major storm threats for South Carolina include hurricanes, which occur in the summer and fall, and severe thunderstorms, which occur in the late winter and spring and are capable of producing tornadoes. The state ranks 23rd in the Nation for annual tornado frequency, with an average of about 23 tornadoes confirmed each year between 2000 and 2019 (compared to Texas, ranked 1st, with an estimated 132 tornadoes each year). Strong and destructive tornadoes occur 2 to 4 times each year. **Over the last decade, the state has experienced numerous billion-dollar disaster events involving severe storms, tornado outbreaks, hurricanes, and droughts.** One notable event was the April 13, 2020, tornado outbreak, which consisted of multiple category EF3 tornadoes and the first EF4 tornado to hit the state since 1995. This outbreak resulted in more than \$15 million in damages to the state.

In early October 2015, torrential rainfall caused catastrophic flooding in the central and coastal regions of South Carolina. While relieving the moderate to severe drought conditions of that year's summer, the rainfall shattered numerous 24-hour and 5-day total records. The state's previous 24-hour rainfall record of 14.8 inches (Myrtle Beach, September 16,

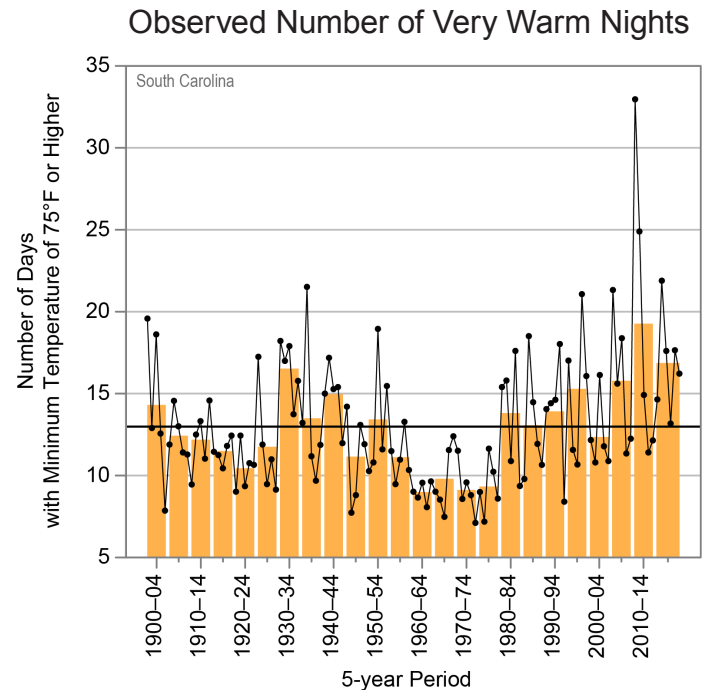


Figure 3: Observed annual number of very warm nights (minimum temperature of 75°F or higher) for South Carolina from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 13 nights. The number of very warm nights has been mostly above average since 1980. The highest number occurred during the 2010–2014 period, with an average of 19 nights per year. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 11 long-term stations.

1999, during Hurricane Floyd) was broken at White Birch Circle in Columbia, which recorded a total of 17.7 inches on October 4, with 15.1 inches falling in less than 10 hours. The previous 5-day rainfall record of 17.4 inches (Greenville, August 22–26, 1908) was broken at more than 40 locations: 27.2 inches at Mount Pleasant (Park West, October 2–6), 23.8 inches at Charleston (Clark Sound, October 1–5); 23.5 inches at Georgetown County Airport (October 1–5); 22.0 inches at Charleston (James Island, October 2–6); and 21.5 inches at Folly Beach (October 2–6).

Tropical cyclones and hurricanes occur less frequently than severe thunderstorms and tornadoes, but they have more destructive potential. Hurricane Hugo in 1989 was one of the strongest hurricanes (Category 4) in the state's history and, at that time, was one of the costliest Atlantic hurricanes (ranked 9th). Wind speeds of up to 120 mph were observed 200 miles inland, and the storm tide reached 20 feet, resulting in extensive damage, including loss of life, severe residential and commercial flooding, power outages, and other essential infrastructure loss. Damages were estimated at more than \$8 billion. Between 1901 and 2020, a total

of 19 hurricanes made landfall along the coast of South Carolina. Although hurricanes are rare in coastal South Carolina, Hurricane Hugo demonstrated the state's vulnerability to these events. Climate models project not only an increase in the number of Category 4 and 5 hurricanes but also an increase of 20% more rainfall associated with these storms by the end of this century.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of this century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. Increases in the number of extremely hot days and decreases in the number of extremely cold days are projected to accompany the overall warming.

Little change in total annual precipitation is projected over this century (Figure 4). However, any increases in temperature will cause more rapid loss of soil moisture during dry spells, increasing the intensity of naturally occurring droughts in the future. The resulting decreases in water availability, exacerbated by population growth, will continue to increase competition for water.

Global sea level is projected to rise another 1–8 feet, with a likely range of 1–4 feet, by 2100 as a result of both past and future emissions from human activities (Figure 5). Since 1921, sea level at Charleston has risen by 1.3 inches per decade, nearly double the global sea level rise of 0.7 inches per decade. Sea level rise is an important concern in South Carolina due to the state's extensive coastline, which includes an abundance of salt marshes and estuaries, as well as natural seaports such as Georgetown and Charleston. Today, more than 800 square miles of coastal land near the Charleston area lies less than 4 feet above the high tide line. Sea level rise has caused an increase in tidal floods associated with nuisance-level impacts. Nuisance floods are events in which water levels exceed the local threshold (set by NOAA's National Weather Service) for minor impacts. These events can damage infrastructure, cause road closures, and overwhelm storm drains. As sea level has risen along the South Carolina coastline, the number of tidal flood days (all days exceeding the nuisance level threshold) has also increased, with the greatest number

Projected Change in Annual Precipitation

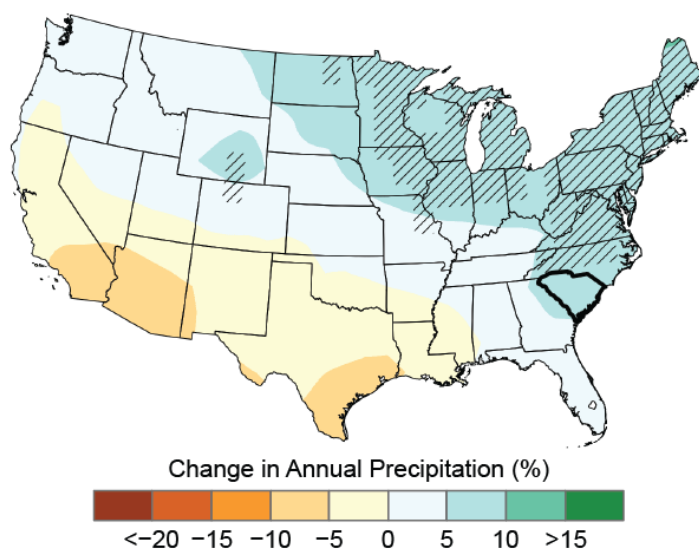


Figure 4: Projected changes in total annual precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. Sources: CISESS and NEMAC. Data: CMIP5.

Observed and Projected Change in Global Sea Level

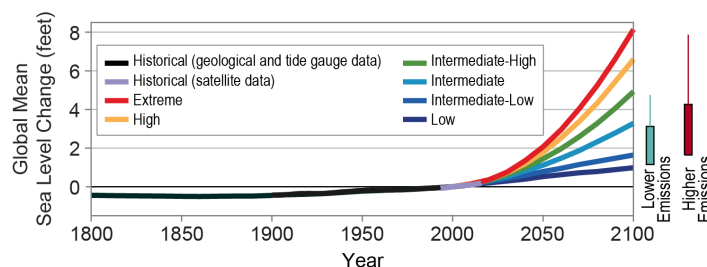


Figure 5: Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate-Low, royal blue; Intermediate, cyan; Intermediate-High, green; High, orange; and Extreme, red curves) relative to historical geological, tide gauge, and satellite altimeter GMSL reconstructions from 1800–2015 (black and magenta lines) and the very likely ranges in 2100 under both lower and higher emissions futures (teal and dark red boxes). Global sea level rise projections range from 1 to 8 feet by 2100, with a likely range of 1 to 4 feet. Source: adapted from Sweet et al. 2017.

(14 days) occurring in 2020 (Figure 6). Even marginal amounts of sea level rise increase the likelihood of less common flooding events by amplifying tide and storm surge. Greater rises are likely for South Carolina, following historical trends. Some state-level estimates project a rise of 3.9 feet by 2100 as compared to 2012, after accounting for local effects of land subsidence. Projected sea level rise will likely result in increased coastal flooding, coastal erosion, and disruptions to coastal and estuarine ecosystems.

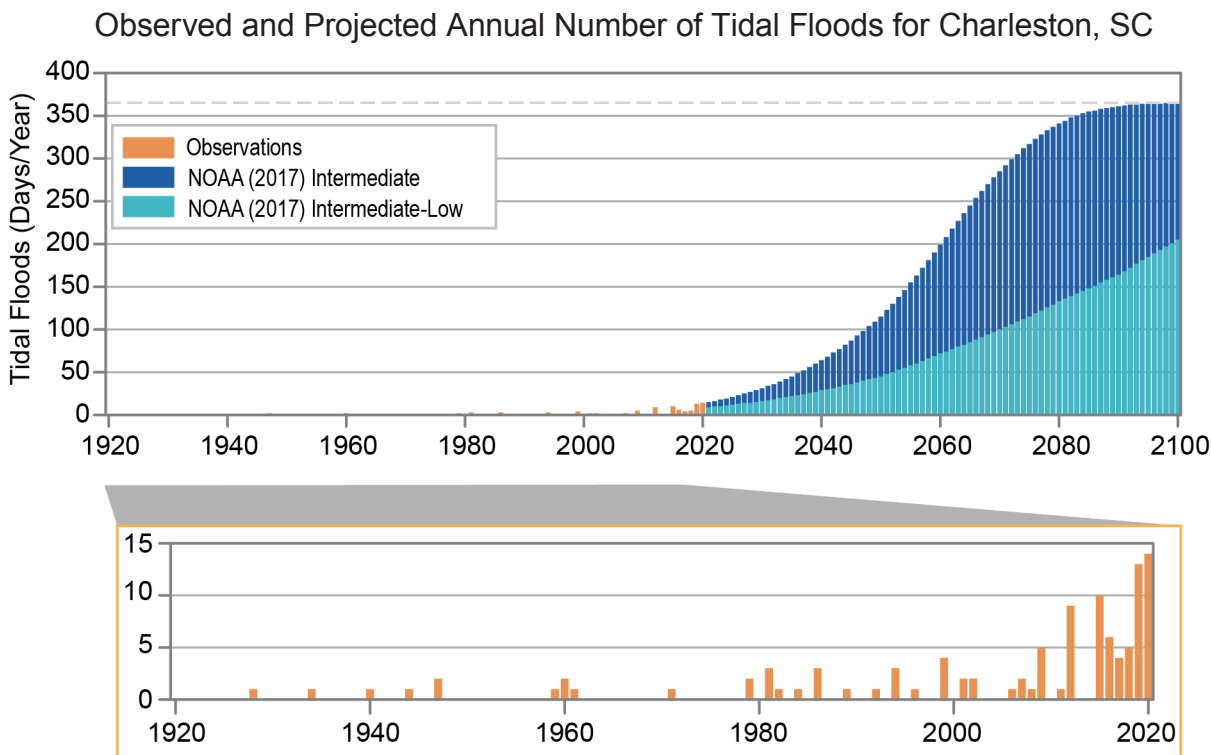
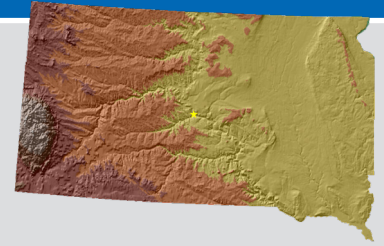


Figure 6: Number of tidal flood days per year at Charleston, SC, for the observed record (1922–2020; orange bars) and projections for two NOAA (2017) sea level rise scenarios (2021–2100): Intermediate (dark blue bars) and Intermediate-Low (light blue bars). The NOAA (2017) scenarios are based on local projections of the GMSL scenarios shown in Figure 5. Sea level rise has caused a gradual increase in tidal floods associated with nuisance-level impacts. The greatest number of tidal flood days (all days exceeding the nuisance-level threshold) occurred in 2020 at Charleston. Projected increases are large even under the Intermediate-Low scenario. Under the Intermediate scenario, tidal flooding is projected to occur every day of the year by the end of the century. Additional information on tidal flooding observations and scenarios is available at <https://statesummaries.ncics.org/technicaldetails>. Sources: CISESS and NOAA NOS.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

SOUTH DAKOTA



Key Messages

Temperatures in South Dakota have risen almost 2°F since the beginning of the 20th century, with warming concentrated in the winter and nighttime minimum temperatures increasing about twice as much as daytime maximums. Under a higher emissions pathway, historically unprecedented warming is projected during this century.

Increases in evaporation rates due to rising temperatures may increase the rate of warm-season soil moisture loss and the intensity of naturally occurring droughts.

Winter and spring precipitation is projected to increase, with associated increases in total seasonal snowfall. Extreme precipitation events are also projected to increase in frequency and intensity, raising the risk of springtime flooding.

South Dakota lies in the Northern Great Plains, straddling the transition from the moist eastern United States to the semiarid West. Due to its location in the center of the North American continent, far from the moderating effects of the oceans, the state experiences large temperature extremes. Average January temperatures range from less than 10°F–15°F in the northeast to more than 25°F in the southwest, while average July temperatures range from about 65°F in Black Hills National Forest to more than 75°F in the south-central region. Temperatures of 100°F or more occur nearly every year. The warmest year on record was 2012, with a statewide average temperature of 49.3°F (4.6°F above the long-term [1895–2020] average). The lack of mountain ranges to the north exposes the state to bitterly cold arctic air masses in winter.

Temperatures in South Dakota have risen almost 2°F since the beginning of the 20th century (Figure 1).

Temperatures in the first two decades of this century have been higher than in any other historical period, with the exception of the early 1930s Dust Bowl era, when poor land management likely exacerbated hot summer temperatures. Warming has occurred in all four seasons but has been largest in the winter (Figure 2a). Summers have

Observed and Projected Temperature Change

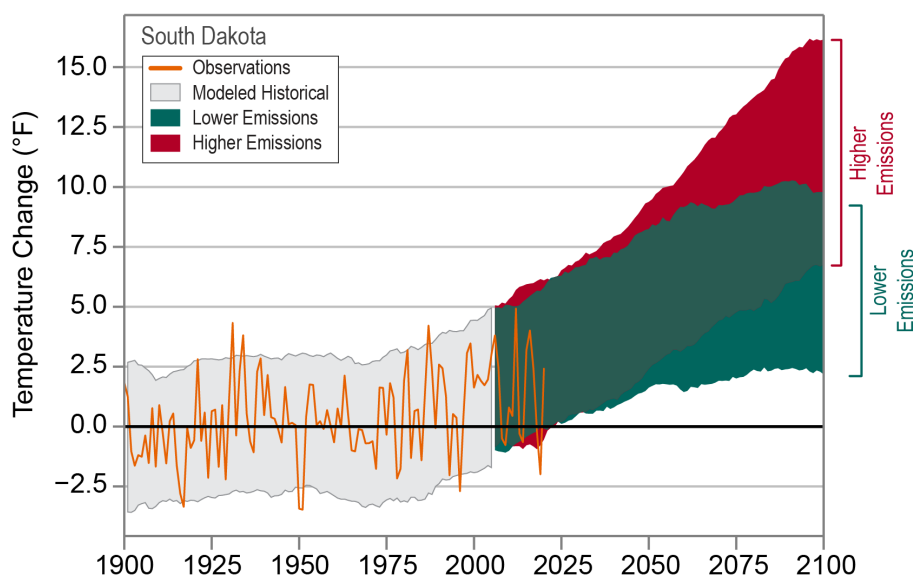


Figure 1. Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for South Dakota. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in South Dakota (orange line) have risen almost 2°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during the 21st century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 2°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 11°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 11°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

warmed very little (Figure 2b), which is characteristic of most states in the Great Plains and Midwest. The lack of summer warming is reflected in a below average number of extremely hot days since 1990 (Figure 3a) and no overall trend in warm nights (Figure 3b). In addition, nighttime minimum temperatures have risen at about twice the rate of daytime maximum temperatures, which might be attributed to an increase in absolute humidity. Winter warming is reflected in a below average number of very cold days since 2000 (Figure 4).

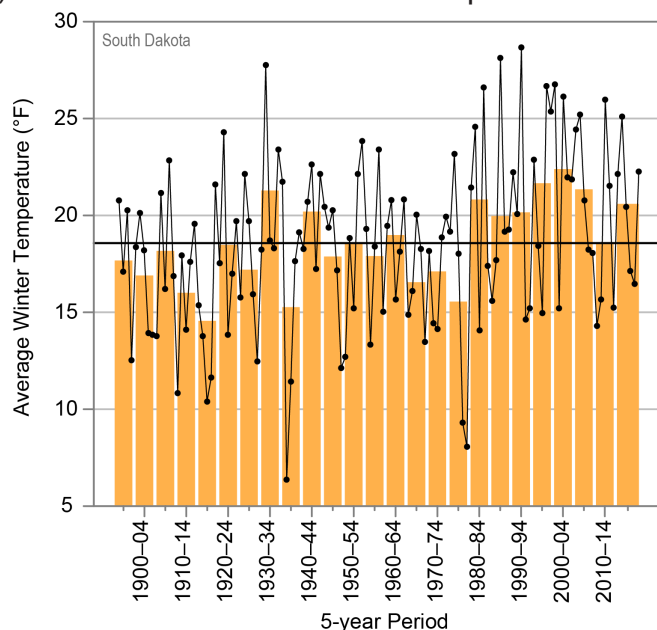
Annual average precipitation ranges from around 16 inches in the northwest to about 28 inches in the southeast. Statewide total precipitation has varied widely from year to year, ranging from a low of 10.9 inches in 1936 to a high of 31.4 inches in 2019 (Figure 3c). The driest multiyear periods occurred in the 1930s and the wettest in the late 1990s and from 2008 onward. Annual precipitation has ranged from an average of 14.3 inches per year during the driest consecutive 5-year interval (1933–1937) to an average of 23.2 inches per year during the wettest consecutive 5-year interval (2007–2011). Summer precipitation has generally been above average since 2008 (Figure 3d). Most of the state's precipitation falls between April and September, when thunderstorm activity is highest. The most severe thunderstorms can produce hail,

high winds, and tornadoes. A hailstone from a severe thunderstorm that fell on July 23, 2010, in Vivian holds the national record for hail weight (1.938 pounds) and diameter (8.00 inches). While most of the state averages at least 30 inches of snow annually, portions of Black Hills National Forest can receive upwards of 70 inches annually. South Dakota has generally experienced an increase in snowfall.

Like other Great Plains states, South Dakota

experiences periodic episodes of severe drought, which can last for several years. The 1930s drought of the Dust Bowl era was one of the worst in the state's history, when extreme heat exacerbated dry conditions. Not only was 1936 the driest summer on record, with only 3.5 inches of precipitation (4.6 inches below the long-term average), it was also the hottest summer, with an average temperature of 76.4°F (6.7°F above the long-term average). Recent drought years include 2012 and 2017. The 2017 Northern Plains drought, which primarily impacted North Dakota, South Dakota, and Montana, as well as adjacent Canadian Prairies, was devastating for livestock and agricultural production. Emerging in the spring, the drought rapidly spread and intensified throughout the summer, leading to crop failure, the culling of livestock herds, widespread wildfires, low water supplies, and losses exceeding \$2.5 billion.

a) Observed Winter Temperature



b) Observed Summer Temperature

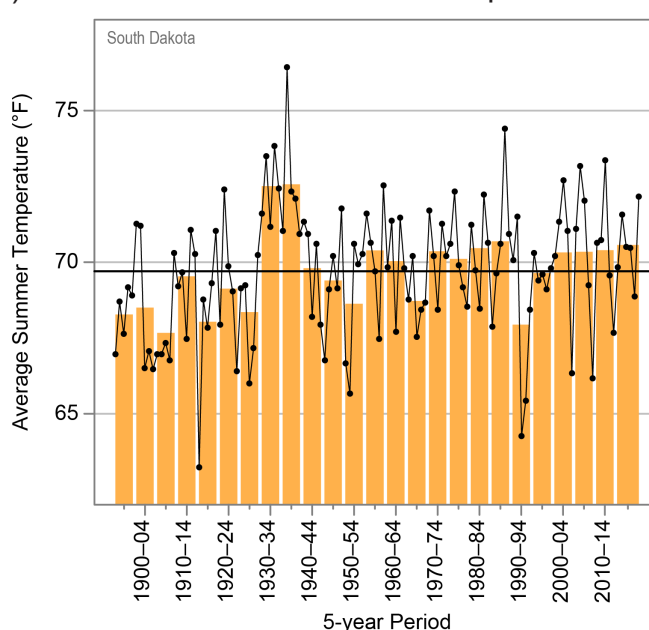
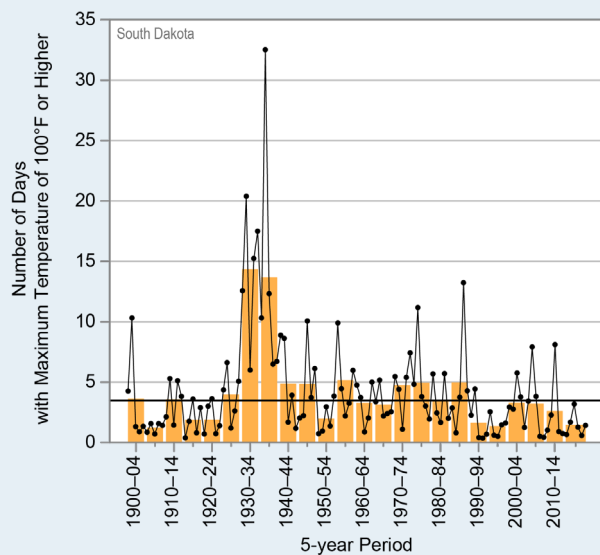
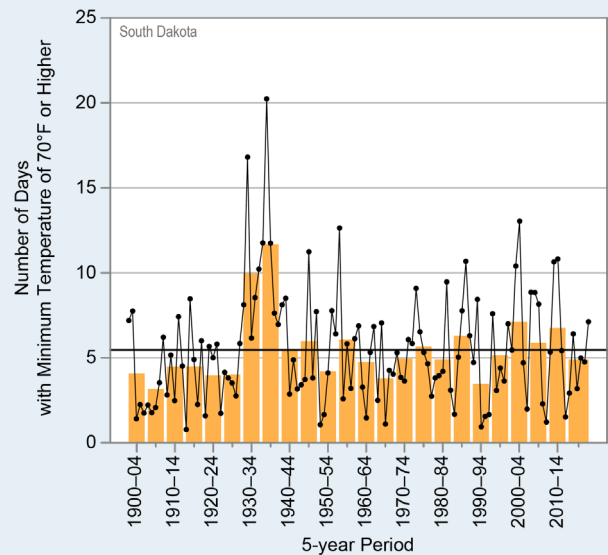


Figure 2. Observed (a) winter (December–February) and (b) summer (June–August) average temperature for South Dakota from (a) 1895–96 to 2019–20 and (b) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (first bar in Figure 2a is a 4-winter average, last bar in Figures 2a and 2b is a 6-winter and 6-summer average, respectively). The horizontal black lines show the long-term (entire period) averages: (a) 18.6°F and (b) 69.7°F. The multiyear periods between 1995 and 2009 had the highest winter temperatures on record. Since 2000, summer temperatures have been above average, although they have remained well below the extreme heat of the 1930s Dust Bowl era. Sources: CISESS and NOAA NCEI. Data: nClimDiv.

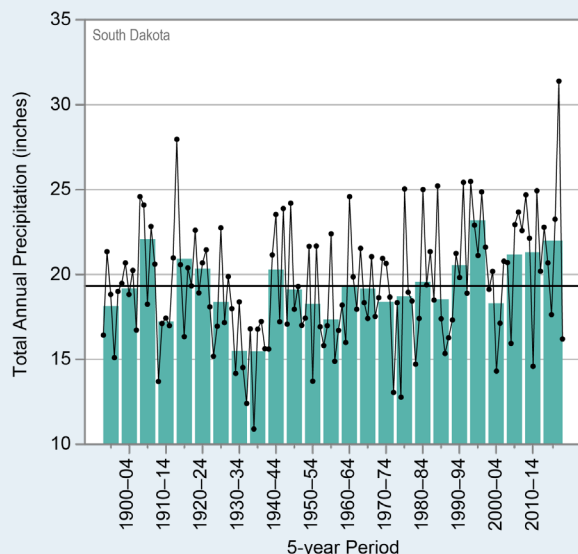
a) Observed Number of Extremely Hot Days



b) Observed Number of Warm Nights



c) Observed Annual Precipitation



d) Observed Summer Precipitation

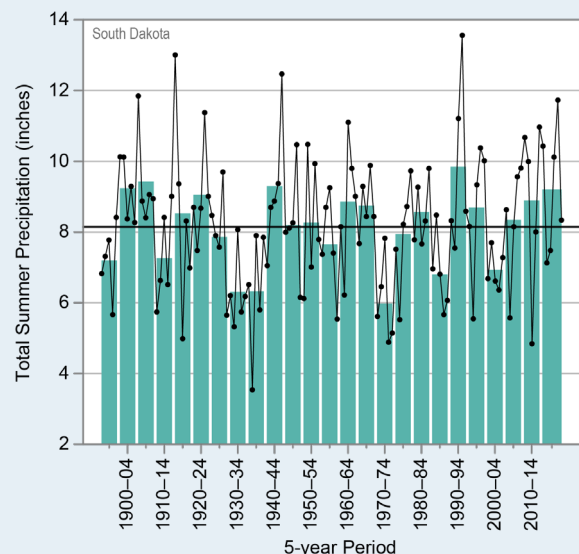


Figure 3. Observed (a) annual number of extremely hot days (maximum temperature of 100°F or higher), (b) annual number of warm nights (minimum temperature of 70°F or higher), (c) total annual precipitation, and (d) total summer (June–August) precipitation for South Dakota from (a, b) 1900 to 2020 and (c, d) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 4.1 days, (b) 5.5 nights, (c) 19.3 inches, (d) 8.1 inches. Since 1990, the number of extremely hot days has been near or below average, while the number of warm nights shows no overall trend. Total annual and summer precipitation varies widely but has been trending upward since 2000. Sources: CISESS and NOAA NCEI. Data: (a, b) GHCN-Daily from 25 long-term stations, (c, d) nClimDiv.

Snowfall is highly variable from year to year. For example, 20th-century annual snowfall totals at Menno varied from around 10 inches (in 1986–87 and 1999–2000) to almost 70 inches (1959–60 and 1983–84), and totals in this century have varied from less than 20 inches (2004–05 and 2011–12) to about 65 inches (2017–18; Figure 5). The year-to-year variations at this station are typical across South Dakota.

South Dakota's northern location and proximity to the typical U.S. winter storm track make it highly susceptible to heavy snows, high winds, and low wind chill temperatures. In any given year, the probability of a blizzard occurring somewhere in the state is greater than 50%. During October 3–5, 2013, western South Dakota was hit by a devastating early-season blizzard, with reported wind gusts as high as 70 mph

and widespread snowfall amounts of more than 20 inches. Among long-term weather observation stations, Lead reported one of the highest snowfall amounts of 55 inches over the 3-day period, 42 of which fell on October 4. Rapid City reported 23.1 inches, the city's second-highest 3-day snowfall total on record. Tens of thousands of livestock died from the event in South Dakota alone, with some herds losing more than 90% of their total populations.

With several large rivers running through the state, including the Missouri River, flooding is a great hazard.

The frequency of extreme precipitation events has increased. Since 1990, South Dakota has averaged 22% more 2-inch rain events compared to the long-term average (Figure 6). Some historic rain and flooding events have occurred in recent years. The daily rainfall record (at official reporting sites) was set at Groton on May 6, 2007, with 8.74 inches. In June 2011, runoff from a record winter snowpack in the Rocky Mountains, along with heavy May rains in Montana, caused major flooding along the entire length of the Missouri River. Several towns (including Pierre) had to be evacuated and required rapid flood control measures. The extreme volume of water caused long-duration flooding; below the Oahe Dam, the Missouri River at Pierre was above flood stage from May 24 to September 7. South Dakota experienced extreme flooding in 2019 due to a combination of wet antecedent conditions, numerous winter storms, and unrelenting precipitation throughout the spring, late summer, and early autumn. Many flood records were set, particularly along the Missouri and James Rivers. The James River at Columbia was above flood stage for 518 days, which was unprecedented for the Missouri River basin. The 2019 growing season was greatly impacted. Planting delays were widespread, and South Dakota led the Nation in unplanted acres (3.9 million). The persistent wetness and below average summer maximum temperatures slowed the progress of crops, as well as the fall harvest. As of June 2020, U.S. Department of Agriculture crop indemnities exceeded \$10 million for most counties in the eastern half of the state. One of the most devastating flash flooding events occurred during June 9–10, 1972, when torrential rainfall (unofficially, as much as 15 inches) fell overnight in the Black Hills area, causing the Canyon Lake Dam to fail. The resulting flooding in Rapid City killed more than 200 people, injured more than 3,000, destroyed 1,300 structures, and resulted in damages of more than \$1 billion.

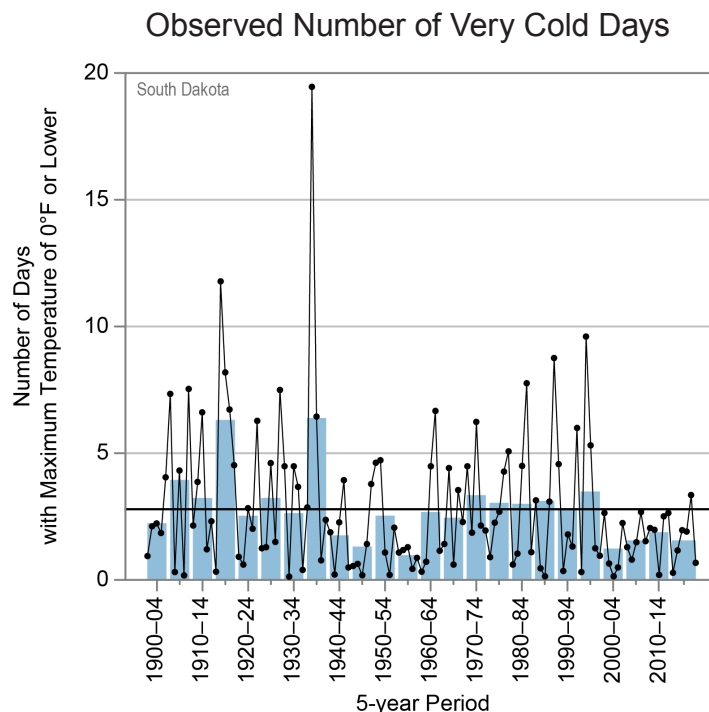


Figure 4. Observed annual number of very cold days (maximum temperature of 0°F or lower) for South Dakota from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 2.8 days. The number of very cold days has been below average since 2000, indicative of overall winter warming in the region. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 25 long-term stations.

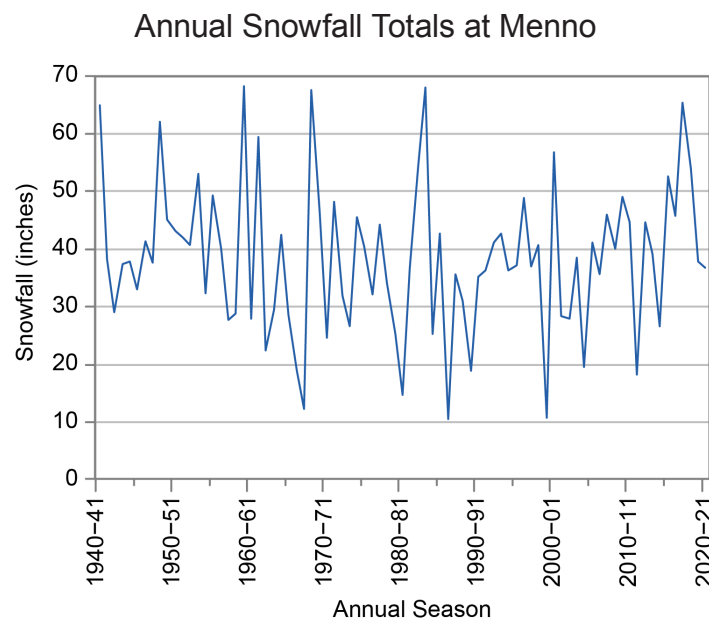


Figure 5. Annual snowfall totals at Menno, South Dakota, from 1940–41 to 2020–21. Snowfall totals at Menno, in the eastern part of the state, vary widely from year to year. Since 2000, snowfall has ranged from less than 20 inches to around 65 inches. Source: MRCC.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of the century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. Increases in heat wave intensity are projected, but the intensity of cold waves is projected to decrease.

Annual precipitation is projected to increase, with the largest increases occurring during spring and winter (Figure 7). Increased winter and spring precipitation can impact South Dakota's agricultural economy both positively (increased soil moisture) and negatively (loss

of soil nutrients, planting delays, and yield losses). **Increases in the frequency and intensity of extreme precipitation events are also projected**, potentially leading to increased runoff and flooding, which can reduce water quality and erode soils. Increased winter snowfall, rapid spring warming, and intense rainfall can combine to produce devastating floods.

The intensity of droughts is projected to increase. Droughts are a natural part of the climate system, and because the projected precipitation increases are expected to occur during the cooler months, South Dakota will remain vulnerable to periodic drought. Increases in evaporation rates due to rising temperatures may increase the rate of soil moisture loss and the intensity of naturally occurring droughts.

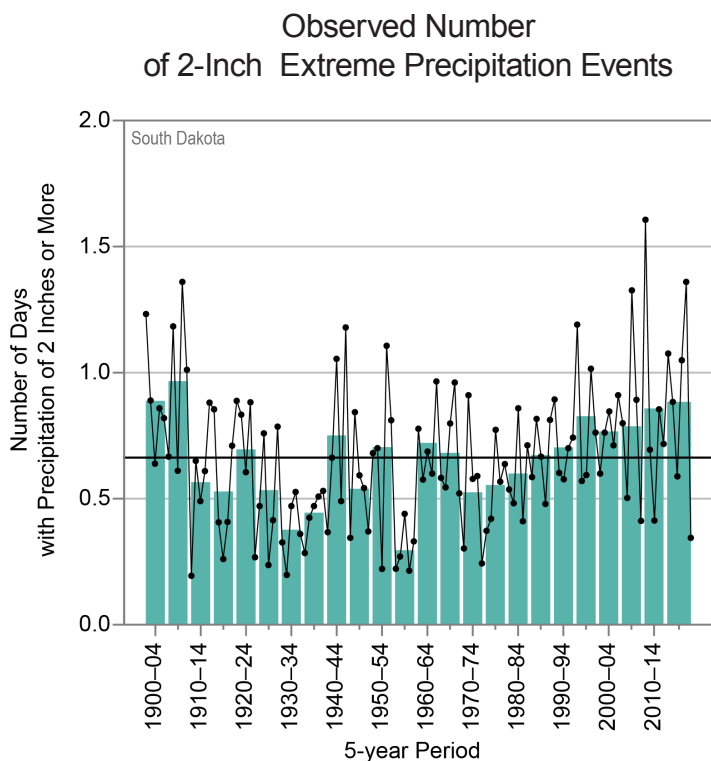


Figure 6. Observed annual number of 2-inch extreme precipitation events (days with precipitation of 2 inches or more) for South Dakota from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 0.7 days. A typical reporting station experiences an event about once every 1 to 2 years. Since 1970, the number of 2-inch extreme precipitation events has been trending upward. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 30 long-term stations.

Projected Change in Winter Precipitation

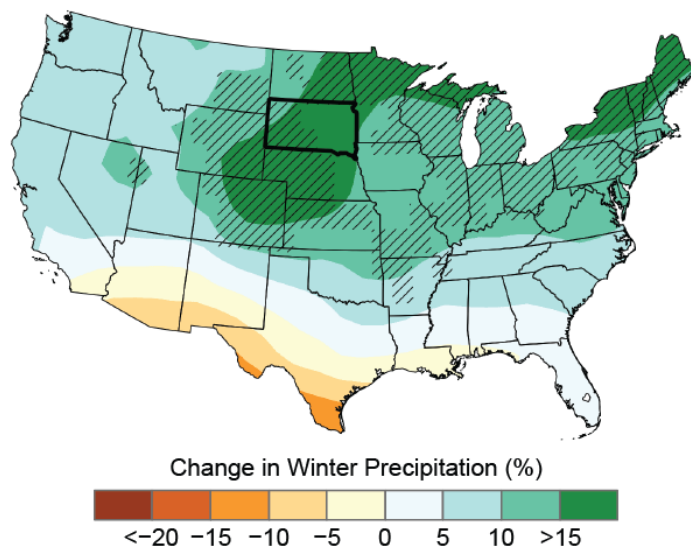
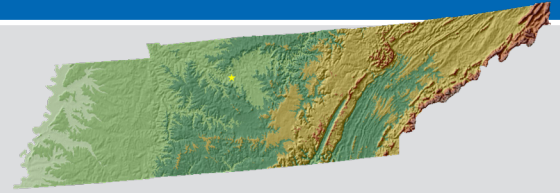


Figure 7. Projected changes in total winter (December–February) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. Sources: CISESS and NEMAC. Data: CMIP5.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

TENNESSEE



Key Messages

Tennessee, like much of the southeastern United States, has experienced little overall warming since the beginning of the 20th century. However, historically unprecedented warming is projected during this century.

Future naturally occurring droughts are projected to be more intense because higher temperatures will lead to more rapid depletion of soil moisture during dry spells.

The number and intensity of extreme heat and precipitation events are projected to increase in the future, while the intensity of cold waves is projected to decrease.

Tennessee's central location in the southeast exposes it to warm and humid air from the Gulf of Mexico and hot and cold air masses from the interior of North America. Its climate is characterized by moderately large variations in temperature and abundant precipitation. For most of the state, summers are warm and humid, while winters are cool with occasional episodes of very cold arctic air. Temperatures decrease across the state as elevation increases, averaging a 3°F decline per 1,000 feet increase in elevation. The higher elevations of the state, such as the Cumberland Plateau (average elevation of 2,000 feet) and the Smoky Mountains (peaks up to 6,000 feet), have noticeably lower average temperatures compared to the Great Valley of East Tennessee (slopes from 1,500 feet in the north to 700 feet in the south). Average (1991–2020 normals) minimum temperatures in January range from 22°F in Mountain City to 33°F in Memphis. Average high temperatures in the summer vary between 85°F and 90°F in western and central Tennessee and between 80°F and 85°F in the eastern portion of the state. Historical observed extreme temperatures for the state range from –32°F in Mountain City in the winter of 1917 to 113°F in Perryville in the summer of 1930.

Observed and Projected Temperature Change

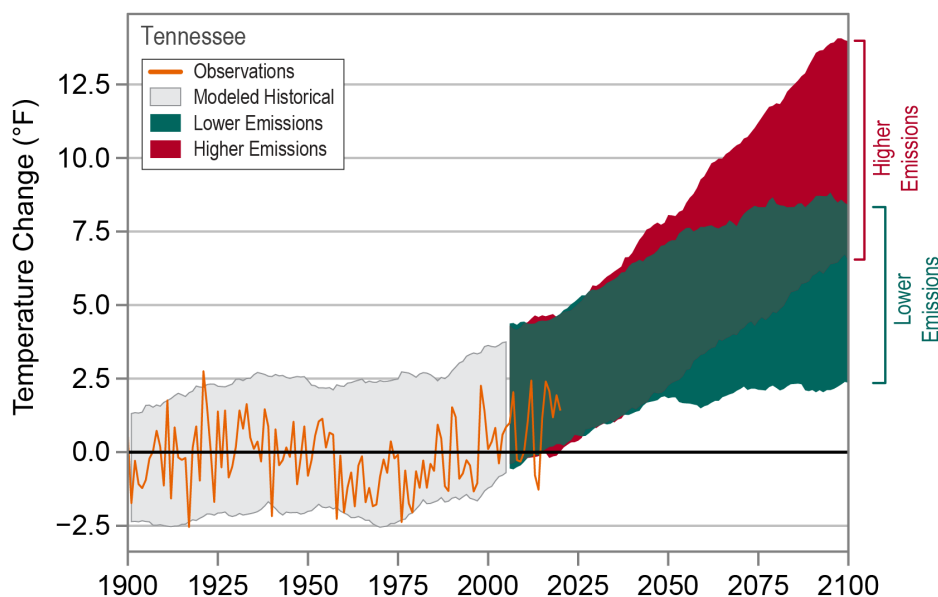


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Tennessee. Observed data are for 1900–2020. Projected changes for 2015–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Tennessee (orange line) have risen by 0.5°F since the beginning of the 20th century, less than a third of the warming for the contiguous United States, but the warmest consecutive 5-year interval was the most recent, 2016–2020. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under

a lower emissions future (the coldest end-of-century projected years being about as warm as the hottest year in the historical record; green shading) and more warming under a higher emissions future (the hottest end-of-century projected years being about 11°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

Temperatures in Tennessee have risen by 0.5°F since the beginning of the 20th century, less than a third of the warming for the contiguous United States.

Temperatures were highest in the 1920s and 1930s, followed by a substantial cooling of about 2°F by the 1960s (Figure 1). Since that cool period, temperatures have risen by more than 2°F, and since 2010, they have been near the highs of the 1920s and 1930s. Because of the significant cooling that occurred in the middle of the 20th century, the southeastern United States is one of the few locations globally that has experienced little to no overall warming since 1900, while the United States as a whole has warmed by about 1.8°F. The United States also cooled from the 1930s into the 1960s, but not by nearly as much as Tennessee. Hypothesized causes for this difference in warming rates include increased cloud cover and precipitation, increased small particles from coal burning, natural factors related to forest regrowth, decreased heat flux due to irrigation, and multidecadal variability in North Atlantic and tropical Pacific sea surface temperatures. However, some recent years have been very warm, including 2012 (2nd warmest), 2016 (3rd warmest), 2017 (5th warmest), and 2019 (7th warmest). The number of extremely hot days was highest in the 1930s and early 1950s.

Since then, the number has been mostly near to below average (Figure 2). The number of very warm nights has fluctuated around the long-term average over the last two decades (Figure 3). While the recent trend is toward warmer winters (see Tennessee Supplemental Figures), a historic cold wave affected the state during February 11–20, 2021. In the west, temperatures remained below freezing for 9 consecutive days and fell to around 0°F or below, with the coldest temperature being -5°F at Germantown.

Total annual precipitation has been mostly above average since 1990 (Figure 4). The number of 3-inch extreme precipitation events has also been generally above the long-term average over the same period. The highest 5-year average number of such events occurred during the 2000–2004 period (Figure 5). Total summer precipitation averages 12.6 inches and exhibits no long-term trend, although it has been consistently above average since 2013 (Figure 6). Over the entire historical period (1895–2020), the driest year on record occurred in 1941, with a statewide total of 36.4 inches of precipitation for the year. The wettest year recorded was 2018, with an annual total of 67.1 inches. The driest

Observed Number of Extremely Hot Days

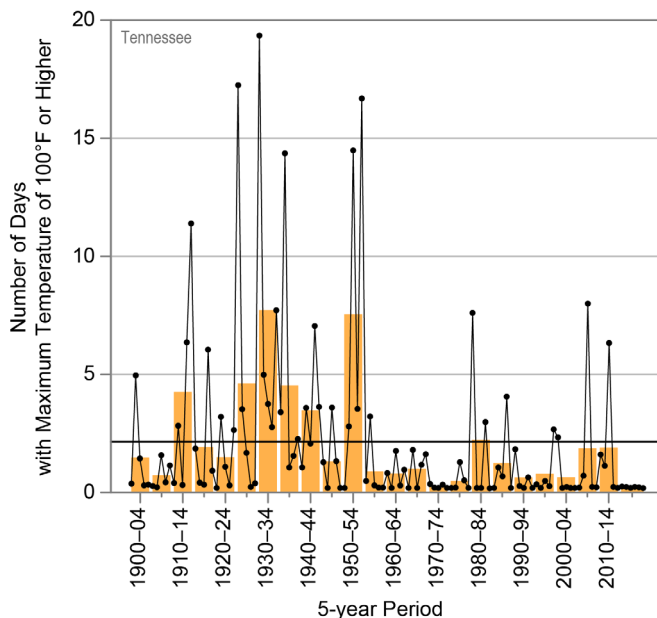


Figure 2: Observed annual number of extremely hot days (maximum temperature of 100°F or higher) for Tennessee from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 2.2 days. These values are averages from 19 long-term reporting stations. The number of extremely hot days has not changed much over the last 70 years. Record high numbers occurred during the droughts of the 1930s and early 1950s. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily.

Observed Number of Very Warm Nights

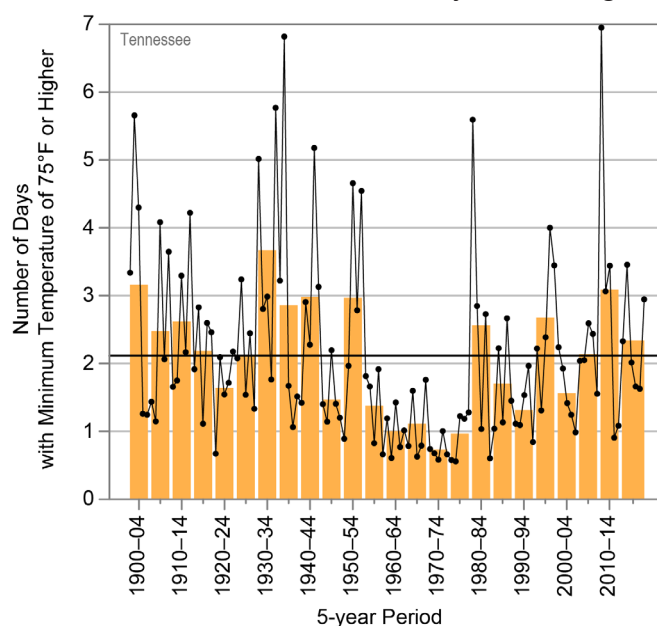


Figure 3: Observed annual number of very warm nights (minimum temperatures of 75°F or higher) for Tennessee from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 2.1 days. These values are averages from 19 long-term reporting stations. The number of very warm nights has generally been near the long-term average since 1980, with slightly above average levels for the last 5 years. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily.

consecutive 5 years was the 1939–1943 interval, with annual average precipitation of about 44 inches, and the wettest was 2016–2020, with an annual average of more than 60 inches per year.

Extreme weather events that frequently occur in Tennessee include severe thunderstorms, flooding, tornadoes, droughts, heat and cold waves, and winter storms. The remnants of hurricanes occasionally track across the state. **Since 2000, the state has received 33 major disaster declarations involving severe storms and flooding.** The Flood of 2010 was caused by record-breaking amounts of rainfall in early May. The National Weather Service reported a new 2-day rainfall record for Nashville on May 1–2, 2010, when 13.6 inches fell, shattering the previous record of 6.7 inches, which was set on September 13–14, 1979. An even more extreme rainfall event occurred in August 2021, when 20.73 inches of rain fell in less than 24 hours in the McEwen area of Middle Tennessee—by far a new state record. Multiple weather stations experienced more than 3 inches of rainfall over 3 consecutive hours. This resulted in deadly flash flooding downstream along the Trace Creek in Waverly. An area of 800–1,000 square miles experienced rainfall totals that would be expected to occur less than once every 1,000 years.

Tennessee experiences a relatively high number of tornadoes, averaging approximately 21 tornadoes and 5 fatalities per year over the period 1985–2019. While tornadoes can occur in any month, they tend to peak in the spring. One of the most active and destructive tornado months on record for the entire United States occurred in April 2011, with a total of 542 tornadoes recorded. Tennessee reported 93 tornadoes for that month, surpassing a historical record of 42 tornadoes in April 1974.

Droughts are a regular occurrence in Tennessee's climate. In about half of the weeks since 2000, at least some portion of the state has been in drought status; in 15% of those weeks, at least half of the state experienced some degree of drought conditions.

Annual average snowfall ranges from a modest 1–4 inches in southern sections to nearly a foot in the northeast, with higher amounts in the Great Smoky Mountains. **Winter weather includes occasional damaging snow and ice storms.** During February

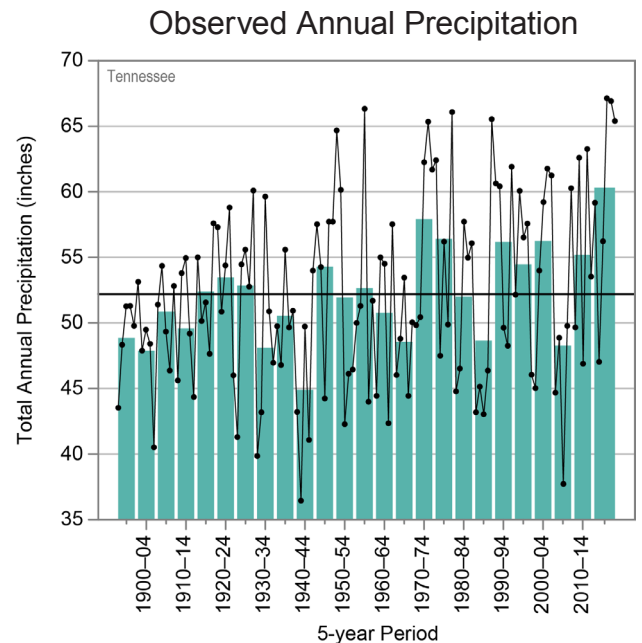


Figure 4: Observed total annual precipitation for Tennessee from 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 52.2 inches. Annual precipitation varies widely from year to year. Since 2010, precipitation has been above the long-term average. Sources: CISESS and NOAA NCEI. Data: nClimDiv.

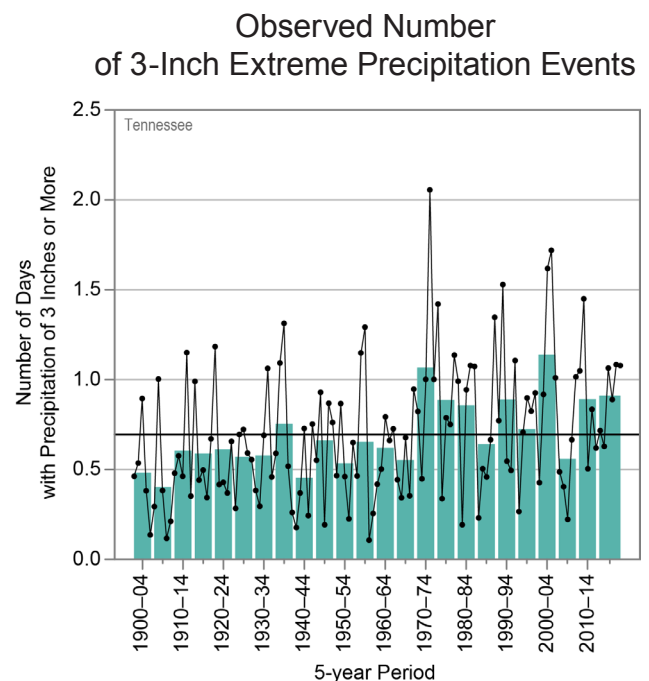


Figure 5: Observed annual number of 3-inch extreme precipitation events (days with precipitation of 3 inches or more) for Tennessee from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 0.7 days. These values are averages from 21 long-term reporting stations. A typical station experiences about 2 events every 3 years. Tennessee has experienced an above average number of extreme precipitation events since 1990, except for the period from 2005 to 2009. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily.

9–13, 1994, a devastating ice storm struck much of the southern United States. In Tennessee, 5–8 inches of rain (much of it freezing) fell in some locations. About 770,000 utility customers lost power (some for up to a month) and damages totaled about \$500 million (second behind Mississippi). During January 22–24, 2016, some parts of eastern Tennessee received 6–12 inches of snow, with more than a foot falling in the Great Smoky Mountains. In February 2021, heavy snow (around 10 inches in some locations) and severe icing caused widespread damage.

Historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to exceed historical record levels in most years by the middle of this century. However, a large range of temperature increases is projected under

both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. Continuation of the post-1980 warming trend would lead to an approximate additional warming of 1°F by 2050 and 3°F by 2100. In this case, the future warming would be on the low end of the model-simulated increases. However, under a high emissions scenario, considerably larger temperature increases are projected. Any substantial increase in temperature will lead to increased heat wave intensity but decreased cold wave intensity.

Winter and spring precipitation is projected to increase by midcentury (Figure 7), while changes in summer and fall precipitation are less distinct. **The intensity of naturally occurring droughts is likely to increase because higher temperatures will increase the rate of loss of soil moisture during dry spells.**

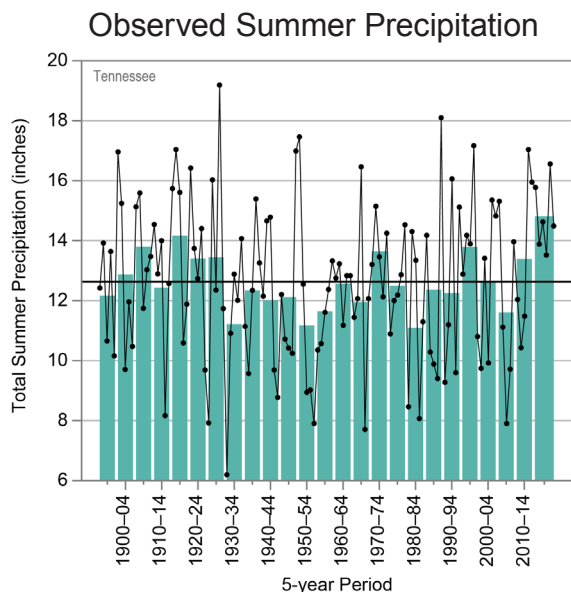


Figure 6: Observed total summer (June–August) precipitation for Tennessee from 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-summer average). The horizontal black line shows the long-term (entire period) average of 12.6 inches. Summer precipitation has been above average since 2010. Sources: CISESS and NOAA NCEI. Data: nClimDiv.

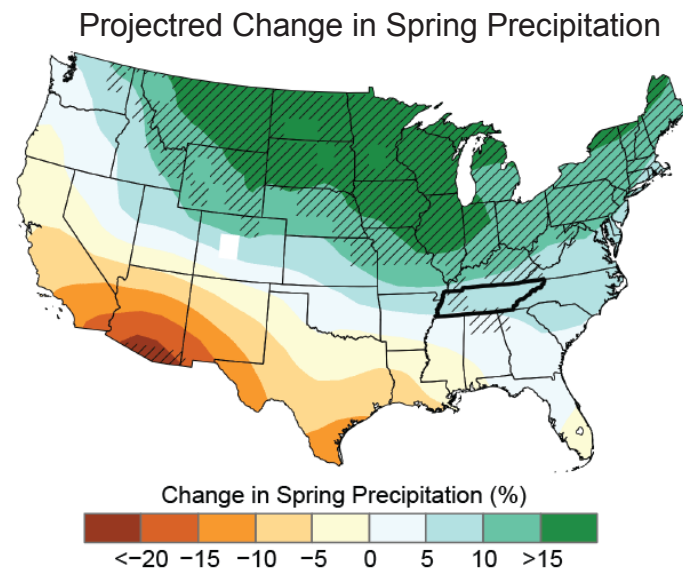


Figure 7: Projected changes in total spring (March–May) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. The white-out area indicates that the climate models are uncertain about the direction of change. Hatching represents areas where the majority of climate models indicate a statistically significant change. Precipitation is projected to increase in Tennessee. Sources: CISESS and NEMAC. Data: CMIP5.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

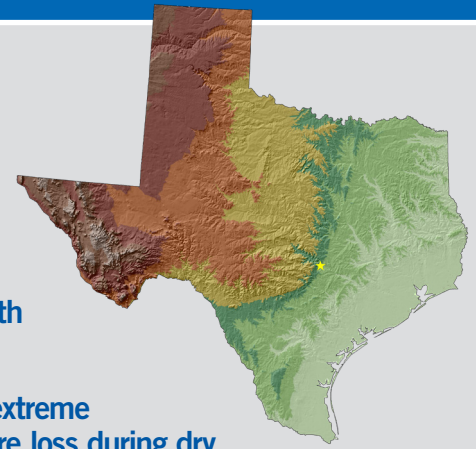
TEXAS

Key Messages

Temperatures in Texas have risen almost 1.5°F since the beginning of the 20th century. Historically unprecedented warming is projected during this century, with associated increases in extreme heat events.

Although projected changes in annual precipitation are uncertain, increases in extreme precipitation events are projected. Higher temperatures will increase soil moisture loss during dry spells, increasing the intensity of naturally occurring droughts.

Future changes in the number of landfalling hurricanes in Texas are difficult to project. As the climate warms, hurricane rainfall rates, storm surge height due to sea level rise, and the intensity of the strongest hurricanes are all projected to increase.



The Texas climate is characterized by hot summers and mild to cool winters. Three geographical features largely influence the state's varied climate: the Rocky Mountains block intrusions of moist Pacific air from the west and tend to channel arctic air masses southward during the winter; the relatively flat central North American continent allows easy north and south movement of air masses; and the Gulf of Mexico serves as the primary source of moisture, which is most readily available to the eastern part of the state. As a result of these factors, the state exhibits large east-west variations in precipitation and is subject to frequent and varied extreme events, including hurricanes, tornadoes, droughts, heat waves, cold waves, and extreme precipitation. Due to rapid population growth, especially in urban areas, increased demand for limited water supplies may increase Texas's vulnerability to naturally occurring droughts.

Temperatures in Texas have risen almost 1.5°F since the beginning of the 20th century (Figure 1). While there is no overall trend in extremely hot days (Figure 2), the number of very warm nights was particularly high during the 2010s (Figure 3). The urban heat island effect increased these occurrences in city centers. The summer of 2011 was the warmest summer on record (since 1895) and broke the state record for highest average number of days with temperatures of 100°F or more. The Dallas-Fort Worth area endured 40 consecutive days with temperatures higher than 100°F, which was the second-longest streak on

Observed and Projected Temperature Change

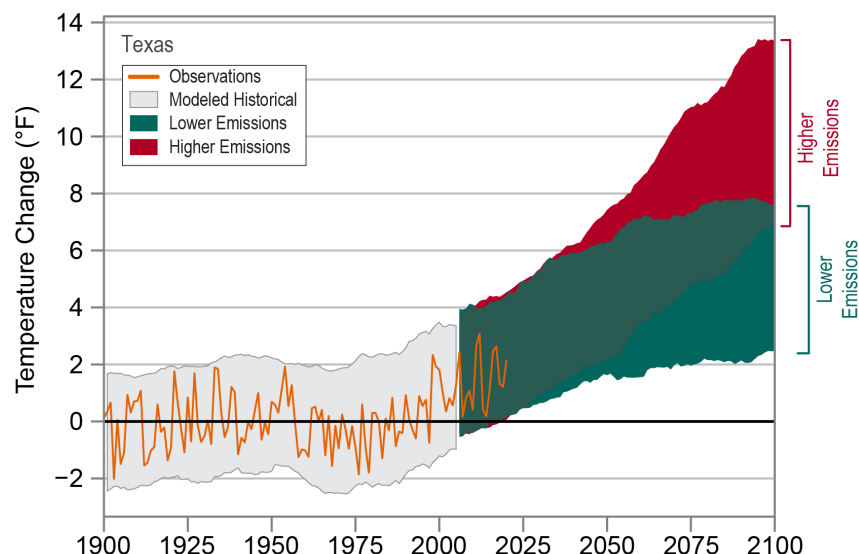


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Texas. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Texas (orange line) have risen almost 1.5°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 2°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest

years in the hottest end-of-century projections being about 10°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

record (1899–2020). The record dry conditions contributed to the higher temperatures. Daily minimum temperatures in January typically range from about 20°F in the northern Panhandle to about 50°F near the mouth of the Rio Grande River. The annual number of entire days below freezing was well above average in the 1970s and 1980s but has since been near the long-term average (Figure 4a).

Precipitation is widely variable across Texas, with normal amounts ranging from less than 10 inches in the far west to more than 60 inches in the extreme southeast. Historically significant droughts occurred in the late 1910s, the early 1950s, and the early 2010s; the driest calendar years were 1917, 1956, and 2011 (Figure 4b). The driest consecutive 5 years was the 1952–1956 interval and the wettest was the 2015–2019 period. In the 1990s and early 2000s, the number of 3-inch extreme precipitation events was above average, and after the dry period of 2005–2014, they were well above average during the 2015–2020 period (Figure 4c). The five wettest months on record have all occurred since the year 2000, led by 9.1 inches in May 2015. Hurricane Harvey (2017) was the most destructive event in Texas history, mostly due to the unprecedented rainfall, which contributed to the second wettest month on record despite affecting only part of the state. After making landfall on August 25, Harvey slowed and was nearly stationary for several days near Houston. Rainfall exceeded 30 inches in many locations, and a few locations had more than 50 inches (Figure 5). Catastrophic flooding occurred across much of southeast Texas.

Texas is consistently ranked in the top 10 states affected by extreme events. In 2020, the state was hit by eleven of the nation's billion-dollar disasters. The three most impactful events were drought, extreme heat, and wildfires. The warmest and the driest summer in the historical record helped fuel the worst wildfire season since statewide records began (approximately 1990), with nearly 4 million acres burned and almost \$750 million in damages. Since the creation of the United States Drought Monitor Map in 2000, Texas has been completely drought-free for approximately 8% of the time (2000–2014), and at least half of the state has been under drought conditions for approximately 42% of the same period. Paleoclimatic records indicate that droughts as severe as the one in 2011 have occurred occasionally in the past 1000 years (Figure 6). Higher temperatures and drought conditions are likely to increase the severity, frequency, and extent of wildfires in the future, threatening significant harm to property, human health, and the livelihood of residents.

Over the period of 1900 to 2020, Texas endured more than 85 tropical storms and hurricanes (about 3 storms every 4 years); approximately half of them (46) were hurricanes (Figure 4d). Since 2000, Texas has experienced 19 named storms, including 8 destructive hurricanes, with Hurricane Harvey (Category 4), Hurricane Rita (Category 3), and Hurricane Ike (Category 2) causing the most significant damage. While Hurricane Rita

Observed Number of Extremely Hot Days

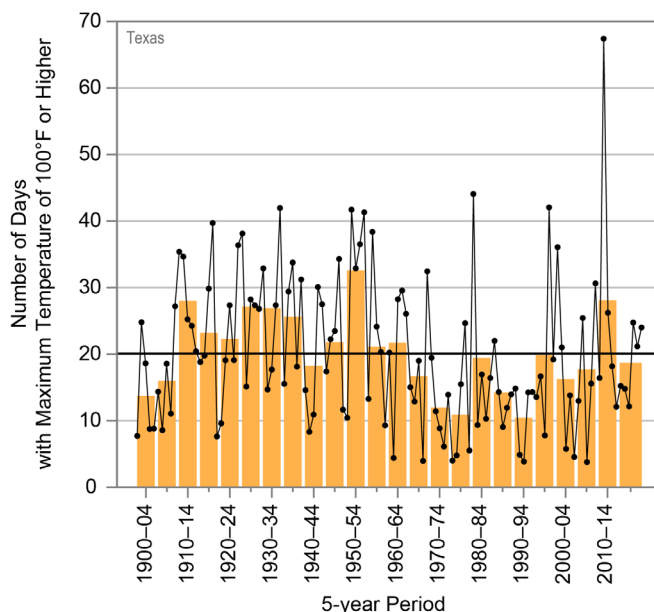


Figure 2: Observed annual number of extremely hot days (maximum temperature of 100°F or higher) for Texas from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 20 days. The number of extremely hot days in Texas was mostly above average between 1910 and 1960 and has been below average since the 1960–1964 period, with the exception of the 2010–2014 period. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 24 long-term stations.

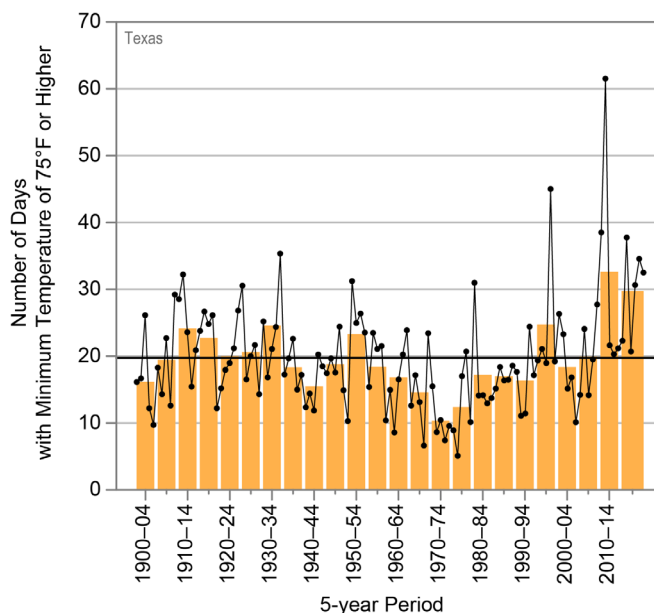


Figure 3: Observed annual number of very warm nights (minimum temperature of 75°F or higher) for Texas from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 20 days. The 1970s saw a record low number of very warm nights. That number increased in the early 21st century, with the record highest number occurring in the 2010–2014 period. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 24 long-term stations.

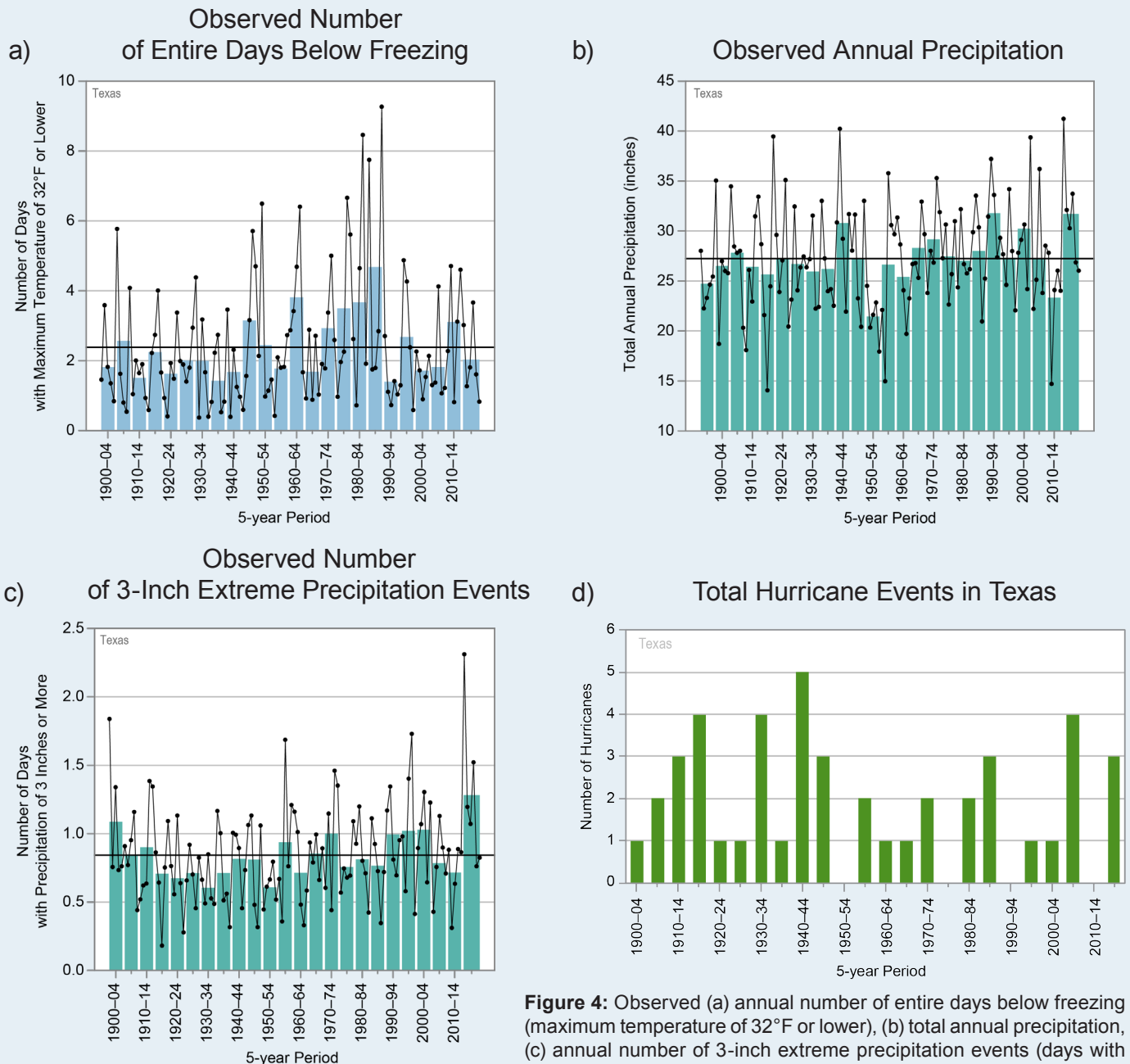


Figure 4: Observed (a) annual number of entire days below freezing (maximum temperature of 32°F or lower), (b) total annual precipitation, (c) annual number of 3-inch extreme precipitation events (days with precipitation of 3 inches or more), and (d) total number of hurricane events (wind speeds reaching hurricane strength somewhere in the state) for Texas from (a, c, d) 1900 to 2020 and (b) 1895 to 2020. In Figures 4a, 4b, and 4c, bars show averages over 5-year periods (last bar is a 6-year average), dots show annual values, and the horizontal black lines show the long-term (entire period) averages: (a) 2.4 days, (b) 27.2 inches, (c) 0.8 days. In Figure 4d, bars show totals over 5-year periods (last bar is a 6-year total). The number of entire days below freezing was above average in the 1970s and 1980s, but since then it has been mostly below the long-term average. Annual precipitation has varied year to year but was well above average during the 2015–2020 period. The number of extreme precipitation events was above average during the 1990s and early 2000s and again in the 2015–2020 period. A typical reporting station experiences about one 3-inch precipitation event per year. There is no long-term trend in the number of hurricanes. Sources: CISESS and NOAA NCEI. Data: (a) GHCN-Daily from 24 long-term stations; (b) nClimDiv; (c) GHCN-Daily from 47 long-term stations.

caused the largest U.S. evacuation in history, Hurricane Harvey is the costliest hurricane in Texas history, with an estimated \$136 billion in damages. Storm surges between 11 and 13 feet along the Texas coast typically have return periods of 25 years (Figure 7). Over the past 30 years (1991–2020), Texas has averaged 149 tornadoes and 4 tornado fatalities per year. Events can occur all year, though activity typically peaks between April and June.

Under both higher and lower emissions pathways, historically unprecedented warming is projected by the end of this century (Figure 1). However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. Increases in the number of extremely hot days and decreases in the number of

extremely cold days are projected to accompany the overall warming. By 2055, an estimated increase of 20–30 days with temperatures higher than 95°F is projected under one pathway, with the greatest increase in southwestern Texas.

Future changes in annual average precipitation are generally projected to be small (Figure 8), but an increase in extreme precipitation is likely. Furthermore, even if average precipitation does not change, **higher temperatures will increase the rate of soil moisture loss, likely leading to more intense naturally occurring droughts.** Longer dry spells are also projected.

Increased drought severity and increased human demand for surface water will cause changes in streamflow, with extended reductions of freshwater inflow to Texas bays and estuaries. These changes in streamflow will cause temporary or permanent changes to bay salinity and oxygen content, which will have potentially major impacts on bay and estuary ecosystems, such as negatively affecting organism growth, reproduction, and survival.

Future changes in the frequency and severity of tornadoes, hail, and severe thunderstorms are uncertain. However, **hurricane intensity and rainfall are projected to increase for Texas as the climate warms.**

Hurricane Harvey Rainfall, August 24–31, 2017

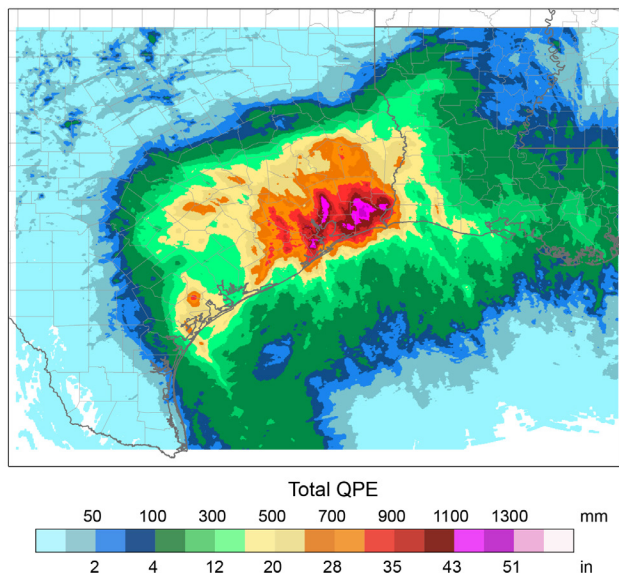


Figure 5: Rainfall totals in southeast Texas from Hurricane Harvey for August 24–31, 2017. Large areas received more than 30 inches of rainfall, with more than 50 inches in a few locations. The Houston metro area experienced massive flooding, displacing tens of thousands of residents and damaging or destroying more than 100,000 homes and businesses. Source: Martinaitis et al. 2021, Figure 12a. © American Meteorological Society. Used with permission.

Since 1900, global average sea level has risen by about 7–8 inches. It is projected to rise another 1–8 feet, with a likely range of 1–4 feet, by 2100 as a result of both past and future emissions from human activities (Figure 9). Sea level rise has caused an increase in tidal floods associated with nuisance-level impacts. Nuisance floods are events in which water levels exceed the local threshold (set by NOAA's National Weather Service) for minor impacts. These events can damage infrastructure, cause road closures, and overwhelm storm drains. As sea level has risen along the Texas coastline, the number of tidal flood days has also increased, with the greatest number occurring in 2020 (Figure 10). Future sea level rise will increase the frequency of nuisance flooding and the potential for greater damage from storm surge.

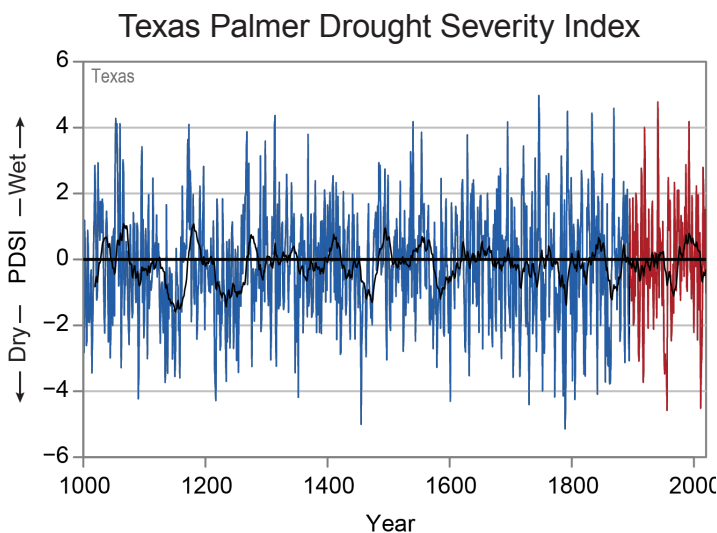


Figure 6: Time series of the Palmer Drought Severity Index for Texas from the year 1000 to 2020. Values for 1895–2020 (red) are based on measured temperature and precipitation. Values prior to 1895 (blue) are estimated from indirect measures such as tree rings. The variances between the two segments may not be homogeneous because of these data and methodological differences. The fluctuating black line is a running 20-year average. Periods of drought are common in Texas; the most severe droughts since 1895 were those in 1956 and 2011. Prior to 1895, droughts of the 1956 and 2011 severity occurred occasionally. Sources: CISESS and NOAA NCEI. Data: nClimDiv and NADAv2.

Northeast Texas Coastal Surge Return Periods

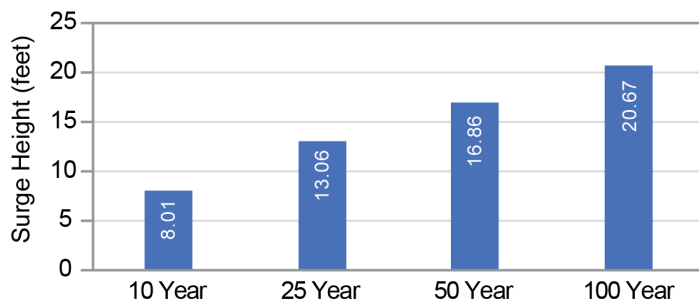


Figure 7: Storm surge heights occurring at selected average return intervals (10, 25, 50, and 100 years) along the northeast coast of Texas. Sources: CISESS and NOAA NCEI. Data: Needham et al. 2012.

Projected Change in Annual Precipitation

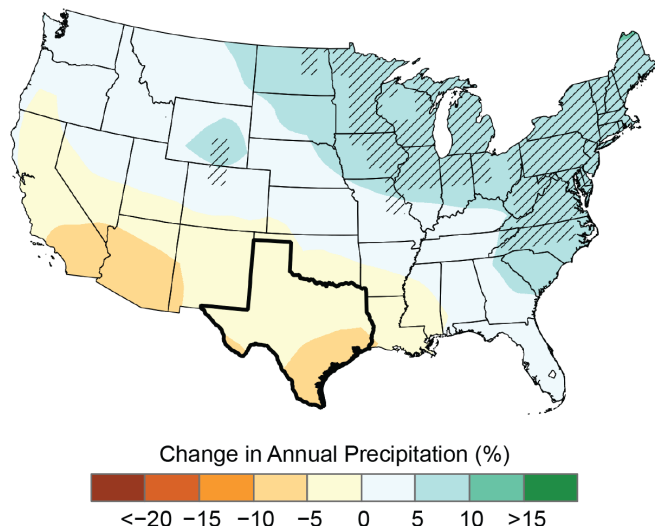


Figure 8: Projected changes in total annual precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. Texas is part of a large area in the southwestern and central United States with projected decreases in annual precipitation, but most models do not indicate that these changes are statistically significant. Sources: CISESS and NEMAC. Data: CMIP5.

Observed and Projected Annual Number of Tidal Floods for Port Isabel, TX

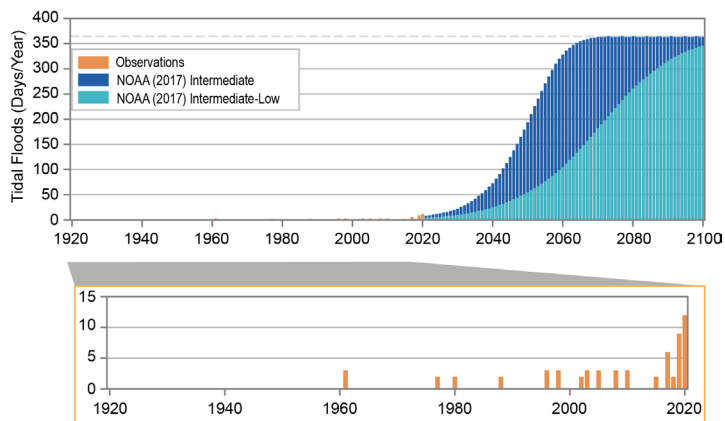


Figure 10: Number of tidal flood days per year at Port Isabel, TX, for the observed record (1944–2020; orange bars) and projections for 2 NOAA (2017) sea level rise scenarios (2021–2100): Intermediate (dark blue bars) and Intermediate-Low (light blue bars). The NOAA (2017) scenarios are based on local projections of the GMSL scenarios shown in Figure 9. Sea level rise has caused a gradual increase in tidal floods associated with nuisance-level impacts. The greatest number of tidal flood days (all days exceeding the nuisance-level threshold) occurred in 2020 at Port Isabel. Projected increases are large even under the Intermediate-Low scenario. Under the Intermediate scenario, tidal flooding is projected to occur nearly every day of the year by the end of the century. Additional information on tidal flooding observations and scenarios is available at <https://statesummaries.ncics.org/technicaldetails>. Sources: CISESS and NOAA NOS.

Observed and Projected Changes in Global Sea Level

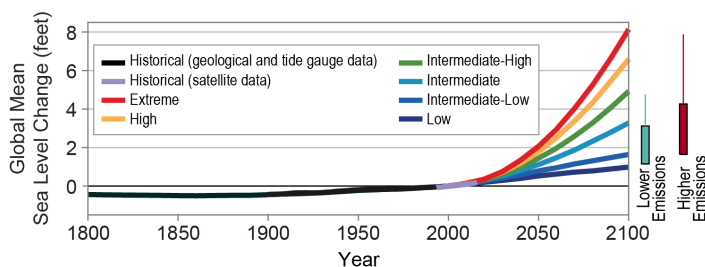


Figure 9: Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate-Low, royal blue; Intermediate, cyan; Intermediate-High, green; High, orange; and Extreme, red curves) relative to historical geological, tide gauge, and satellite altimeter GMSL reconstructions from 1800–2015 (black and magenta lines) and the very likely ranges in 2100 under both lower and higher emissions futures (teal and dark red boxes). Global sea level rise projections range from 1 to 8 feet by 2100, with a likely range of 1 to 4 feet. Source: adapted from Sweet et al. 2017.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

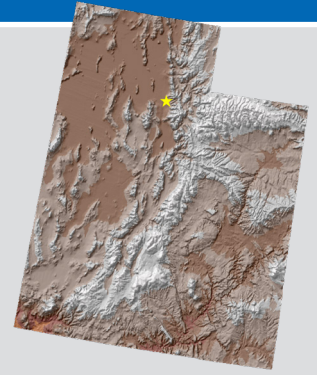
UTAH

Key Messages

Temperatures in Utah have risen more than 2.5°F since the beginning of the 20th century. Warming is particularly evident in the increase of very warm nights and a below average occurrence of very cold nights over the past three decades. Under a higher emissions pathway, historically unprecedented warming is projected to continue through this century.

Droughts are a serious threat in this water-scarce state. The intensity of naturally occurring droughts and the frequency and severity of wildfires are projected to increase in Utah.

It is projected that more winter precipitation will fall as rain instead of snow, which will decrease the snowpack water storage. The number and magnitude of extreme precipitation events are projected to increase, which could increase the risk of flooding.



Utah is a geographically diverse state with forested, mountainous, and desert regions. It has a varied climate due to its inland continental location and wide range of topography. Elevations across the state range from approximately 2,500 feet in the Virgin River Valley to 13,500 feet in the Uinta Mountains. Based on records from long-term stations, average (1991–2020 normals) temperatures in the mountains are around 20°F during the winter months, while lower elevations in the southern portion of the state frequently experience days over 100°F during the summer. In the northern part of the state, the Great Salt Lake has a moderating effect on temperatures in its vicinity. The hottest year on record for Utah was 1934 with an annual average temperature of 51.3°F, followed by 2012 with an annual average temperature of 50.9°F.

Temperatures in Utah have risen more than 2.5°F since the beginning of the 20th century (Figure 1). The period since 2012 has been the warmest on record for Utah, with 8 of the 10 warmest recorded years. The highest number of extremely hot days in the historical record occurred during 2000–2004 (Figure 2). In keeping with the overall trend of higher temperatures, the state has experienced a dramatic increase in the number of very warm nights and a decrease in the number of very cold nights since 1990 (Figures 3 and 4a).

Observed and Projected Temperature Change

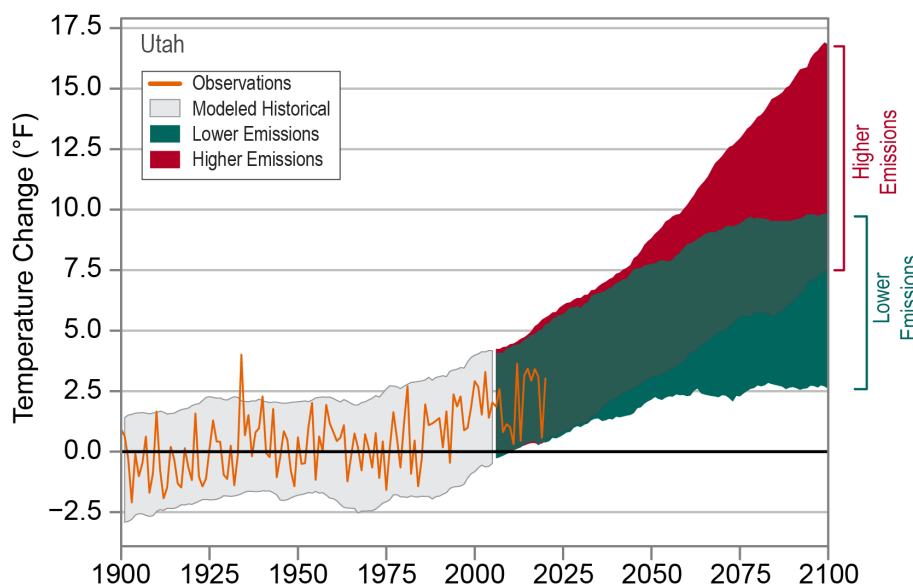


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Utah. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Utah (orange line) have risen more than 2.5°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected to continue through this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 2°F warmer than the historical average; green shading) and more

warming under a higher emissions future (the hottest end-of-century projections being about 13°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

Observed Number of Extremely Hot Days

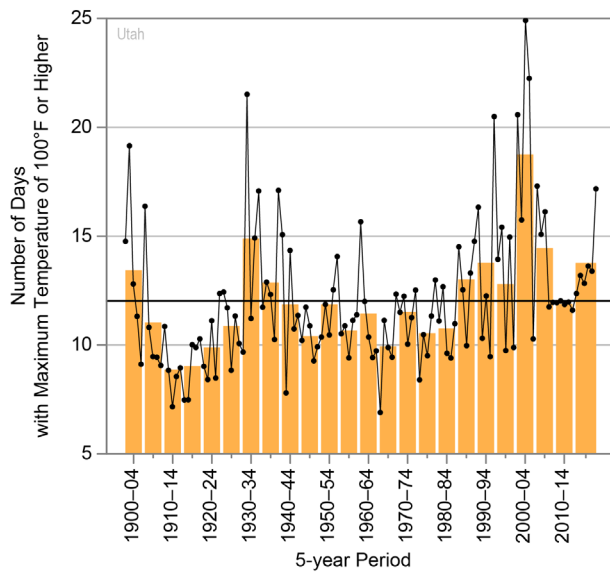


Figure 2: The observed number of extremely hot days (maximum temperature of 100°F or higher) for Utah from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 12 days (note that the average for individual stations varies greatly because of the state's large elevation range). With the exception of the 2010–2014 period, the number of extremely hot days has been above the long-term average since the late 1980s, reaching a peak in 2000–2004. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 15 long-term stations.

Most of Utah is quite dry because the Sierra Nevada and the Rocky Mountains block moisture from the Pacific Ocean and Gulf of Mexico, respectively. In the northwest part of the state, most precipitation falls during the winter and spring months, while thunderstorms fueled by moisture from the North American Monsoon provide summer precipitation in the east and south. Precipitation is highly variable across the state, with annual totals ranging from less than 5 inches in portions of the Great Salt Lake Desert to more than 40 inches in some portions of the Wasatch Mountains. Statewide total annual precipitation has ranged from 6.2 inches in 2020 to 20.3 inches in 1941. The driest multiyear periods were in the early 1900s and the 1950s to early 1960s, and the wettest periods were the late 1900s and early 1980s (Figure 4b). The driest consecutive 5 years was 1952–1956, with an annual average of 10.7 inches, and the wettest 5-year period was 1980–1984, with an annual average of 17.2 inches. Long-term periods of wet and dry spells can have critical impacts on water supplies.

Snowfall varies widely across the state, with portions of the south receiving less than 10 inches per year and

Observed Number of Very Warm Nights

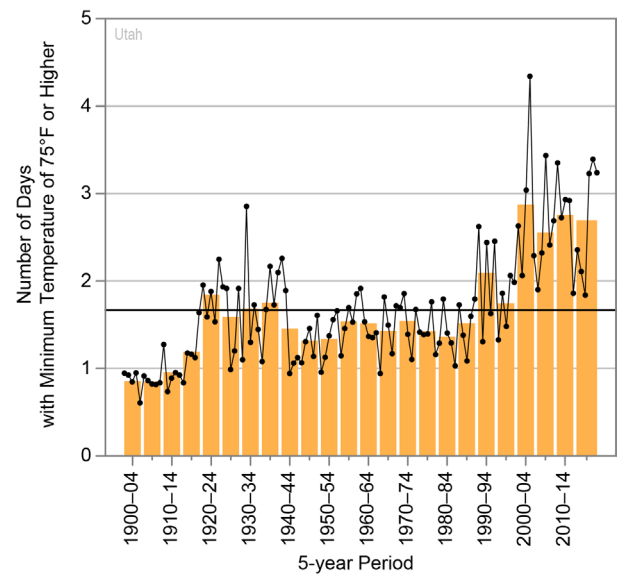
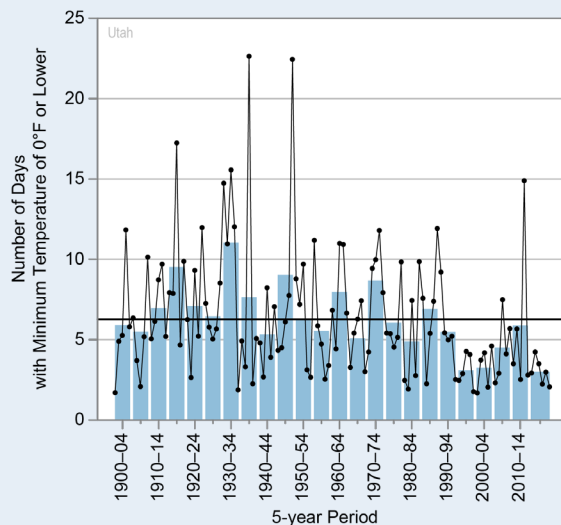


Figure 3: Observed annual number of very warm nights (minimum temperature of 75°F or higher) for Utah from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 1.7 nights (note that the average for individual stations varies greatly because of the state's large elevation range). Due to its semiarid climate and high average elevation, high nighttime temperatures are historically rare for Utah, but the number of very warm nights has risen dramatically since 2000; multiyear averages are nearly double those seen in the 1900s. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 15 long-term stations.

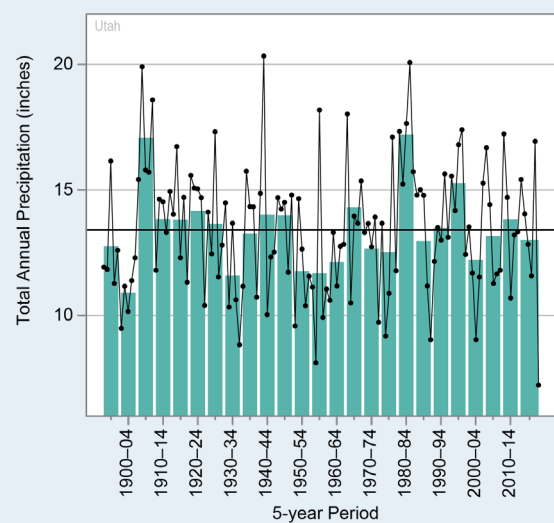
areas in the mountains receiving more than 400 inches per year. The area around the Great Salt Lake can receive significant snowfall due to lake-effect snow events. The lake's high salt content prevents it from freezing, and the open waters can efficiently warm and moisten cold air masses as they pass over the lake, occasionally triggering bands of heavy snowfall over areas to the east and south of the lake. As the state has warmed, the percentage of precipitation falling as snow during the winter has decreased, as have snow depth and snow cover.

Unlike many areas of the United States, Utah and other southwestern states have not experienced an upward trend in the frequency of extreme precipitation events (Figure 4c). **Although floods are rare in the state, both heavy rainfall and snowmelt can result in severe flooding.** Historically, floods of both types have had devastating impacts. In 1983, melting of a large snowpack during the months of April and June caused mudslides and extensive flooding in the Salt Lake Valley (Figure 4d). In January 2005, heavy rains in the Virgin River basin caused severe flooding along the Virgin and Santa Clara rivers in Washington County, resulting in more than \$225 million in damage.

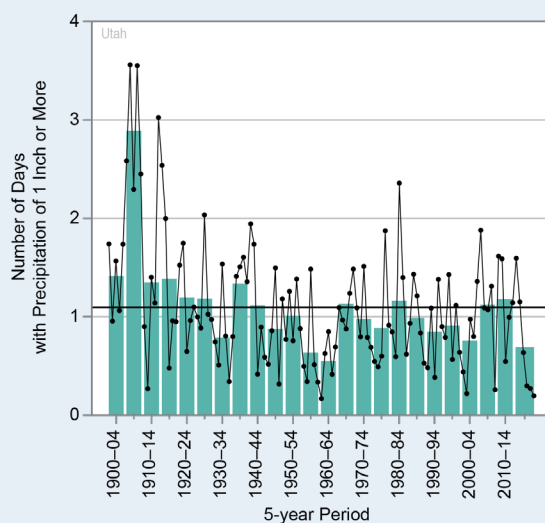
a) Observed Number of Very Cold Nights



b) Observed Annual Precipitation



c) Observed Number of 1-Inch Extreme Precipitation Events



d) April 1 Snow Water Equivalent (SWE) at Ben Lomond Peak, UT

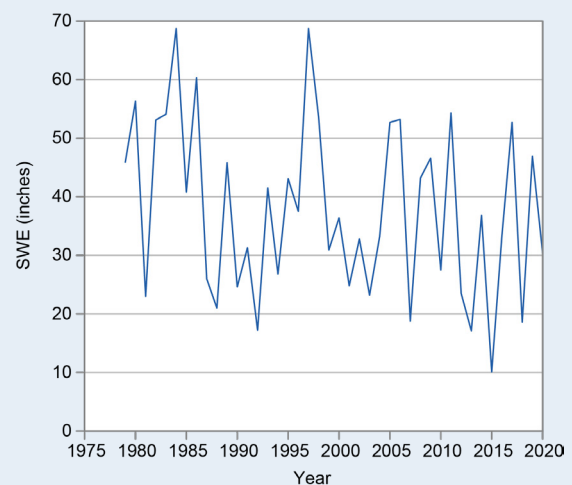


Figure 4: Observed (a) annual number of very cold nights (minimum temperature of 0°F or lower), (b) total annual precipitation, and (c) number of 1-inch extreme precipitation events (days with precipitation of 1 inch or more) for Utah from (a, c) 1900 to 2020 and (b) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 6.3 nights, (b) 13.4 inches, (c) 1.1 days. (Note that for Figures 4a and 4c, the average for individual reporting stations varies greatly because of the state's large elevation range.) Figure 4d shows variations in the April 1 snow water equivalent (SWE) at the Ben Lomond Peak, Utah, SNOTEL site from 1979–2020. Since 1990, Utah has experienced a below average number of very cold nights, indicative of warming in the region. Annual precipitation during the most recent sixteen years (2005–2020) has been near the long-term average, but 2020 was the driest year on record. There is no long-term trend in the number of 1-inch extreme precipitation events. SWE, the amount of water contained within the snowpack, varies widely from year to year and exhibits a general downward trend; it was well above the long-term average in 2017 and 2019 but was well below that average in 2015 and 2018. Sources: (a, b, c) CISESS and NOAA NCEI; (d) NRCS NWCC. Data: (a) GHCN-Daily from 15 long-term stations; (b) nClimDiv; (c) GHCN-Daily from 8 long-term stations.

Utah frequently experiences droughts. The historical record indicates periodic prolonged wet and dry periods (Figure 5). Since snowmelt from the snowpack provides water for many river basins, abnormally low winter and spring precipitation is often the trigger for drought conditions. In 2012, Utah experienced one of its driest springs since records began in 1895, resulting in severe drought conditions in areas across the entire state. The driest year on record was 2020, and by the

end of the year, 90% of the state was in extreme or exceptional drought. Dry conditions since 2000 have resulted in near-record-low water levels in the Great Salt Lake (Figure 6). El Niño and La Niña events can have major effects on precipitation in other parts of the western U.S., but in Utah the effects are not consistent and thus the occurrence of such events cannot be used as a reliable prediction tool.

Under a higher emissions pathway, historically unprecedented warming is projected to continue through this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of this century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. Increases in average temperatures will be accompanied by increases in heat wave intensity and decreases in cold wave intensity.

Climate models are not consistent in their projections of precipitation for Utah, including winter precipitation (Figure 7). However, projected rising temperatures will also raise the snow line—the average lowest elevation at which snow falls. Continuing recent trends, this will increase the likelihood that precipitation will fall as rain instead of snow, reducing water storage in the snowpack, particularly at lower elevations that are currently on the margins of reliable snowpack accumulation. **In addition, extreme precipitation is projected to increase, potentially increasing the frequency and intensity of floods.**

Droughts, a natural part of Utah’s climate, are expected to become more intense. Higher temperatures will amplify the effects of naturally occurring dry spells by increasing the rate of loss of soil moisture. Most of Utah’s water is supplied by the snowpack; observed trends toward more winter precipitation falling as rain and less as snow could result in less water storage. Additionally, higher spring temperatures can cause early melting of the snowpack, decreasing water availability during the already dry summer months. The projected increase in the intensity of naturally occurring droughts will increase the occurrence and severity of wildfires.

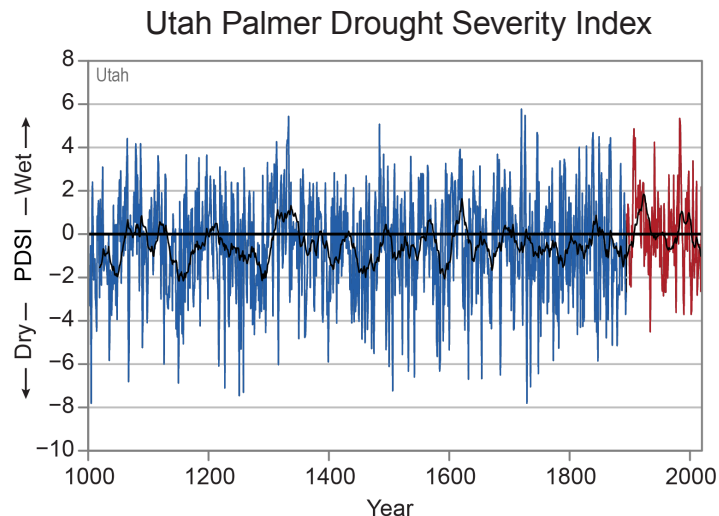


Figure 5: Time series of the Palmer Drought Severity Index for Utah from the year 1000 to 2020. Values for 1895–2020 (red) are based on measured temperature and precipitation. Values prior to 1895 (blue) are estimated from indirect measures such as tree rings. The fluctuating black line is a running 20-year average. In the modern era, the wet periods of the early 1900s and the 1980s–1990s and the dry periods of the 1950s and 2000s are evident. The extended record indicates periodic occurrences of similarly prolonged wet and dry periods. Sources: CISESS and NOAA NCEI. Data: nClimDiv and NADAv2.

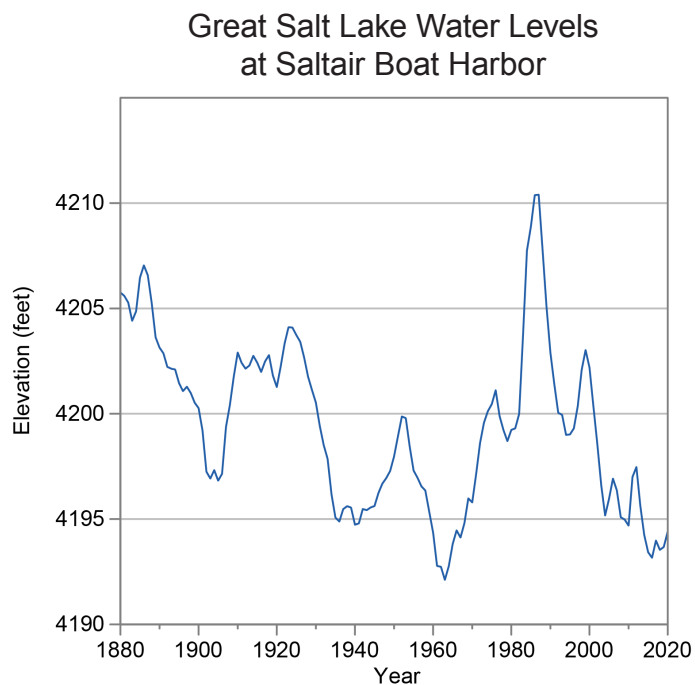


Figure 6: Annual time series of the water level of the Great Salt Lake at Saltair Boat Harbor for 1880–2019. Water levels in the Great Salt Lake have varied widely over the years. Record snowpack levels during the winter of 1982–1983 resulted in severe flooding. Recent years have seen some of the lowest levels in the historical record. Source: USGS.

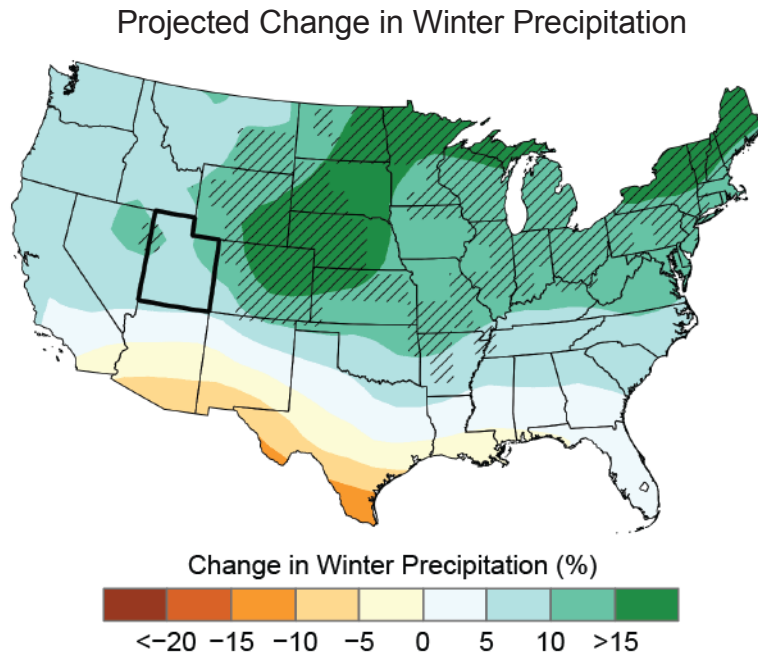


Figure 7: Projected changes in total winter (December–February) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. Utah is part of a large area across the United States with projected increases in winter precipitation, but the changes in Utah are not statistically significant. Sources: CISESS and NEMAC. Data: CMIP5.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

VERMONT

Key Messages

Temperatures in Vermont have risen about 3°F since the beginning of the 20th century. The last 11-year period (2010–2020) was the warmest 11-year period on record. Under a higher emissions pathway, historically unprecedented warming is projected to continue through this century. The intensity of extreme winter cold is projected to decrease.

Annual average precipitation has increased nearly 6 inches since the 1960s (a decade marked by prolonged, multiyear droughts and cold temperatures), with the largest increases occurring in mountainous regions of the state. Winter and spring precipitation is projected to increase throughout this century, and warming will increase the proportion of that precipitation that will fall as rain.

Extreme weather events, particularly floods and severe storms, are having a stronger impact on Vermont. At the same time, multiyear meteorological and hydrological droughts continue to pose challenges for water-dependent sectors. Extreme rainfall events are projected to become more frequent and intense in the future.



Vermont's northerly latitude and geographic location on the eastern edge of the North American continent expose it to the moderating and moistening influence of the Atlantic Ocean and the effects of the hot and cold air masses from the interior of the continent. Its climate is characterized by cold, snowy winters and pleasantly warm summers. The jet stream that is often located near the state gives it highly variable weather patterns, widely ranging daily and annual temperatures, and generally abundant precipitation throughout the year. Changes in Vermont's elevation, terrain, and its proximity to Lake Champlain and the Atlantic Ocean all contribute to variations in climate across the state. The western part of the state is moderated by the lake and experiences higher temperatures and a longer growing season than the more mountainous northeastern region (also referred to as the Northeast Kingdom). Southeastern Vermont, with its lower elevation and landlocked location, tends to be warmer and more drought-prone than the rest of the state.

Observed and Projected Temperature Change

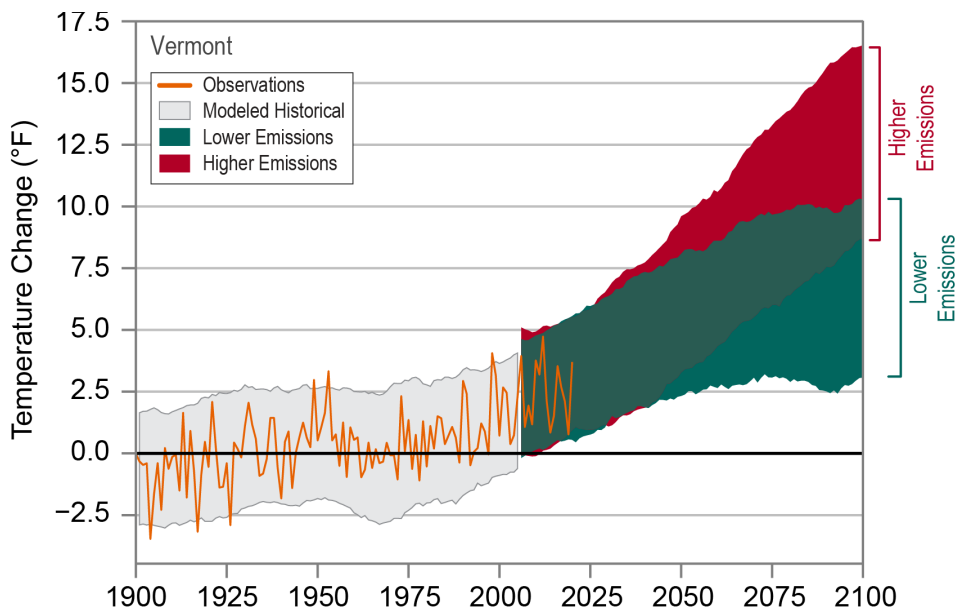
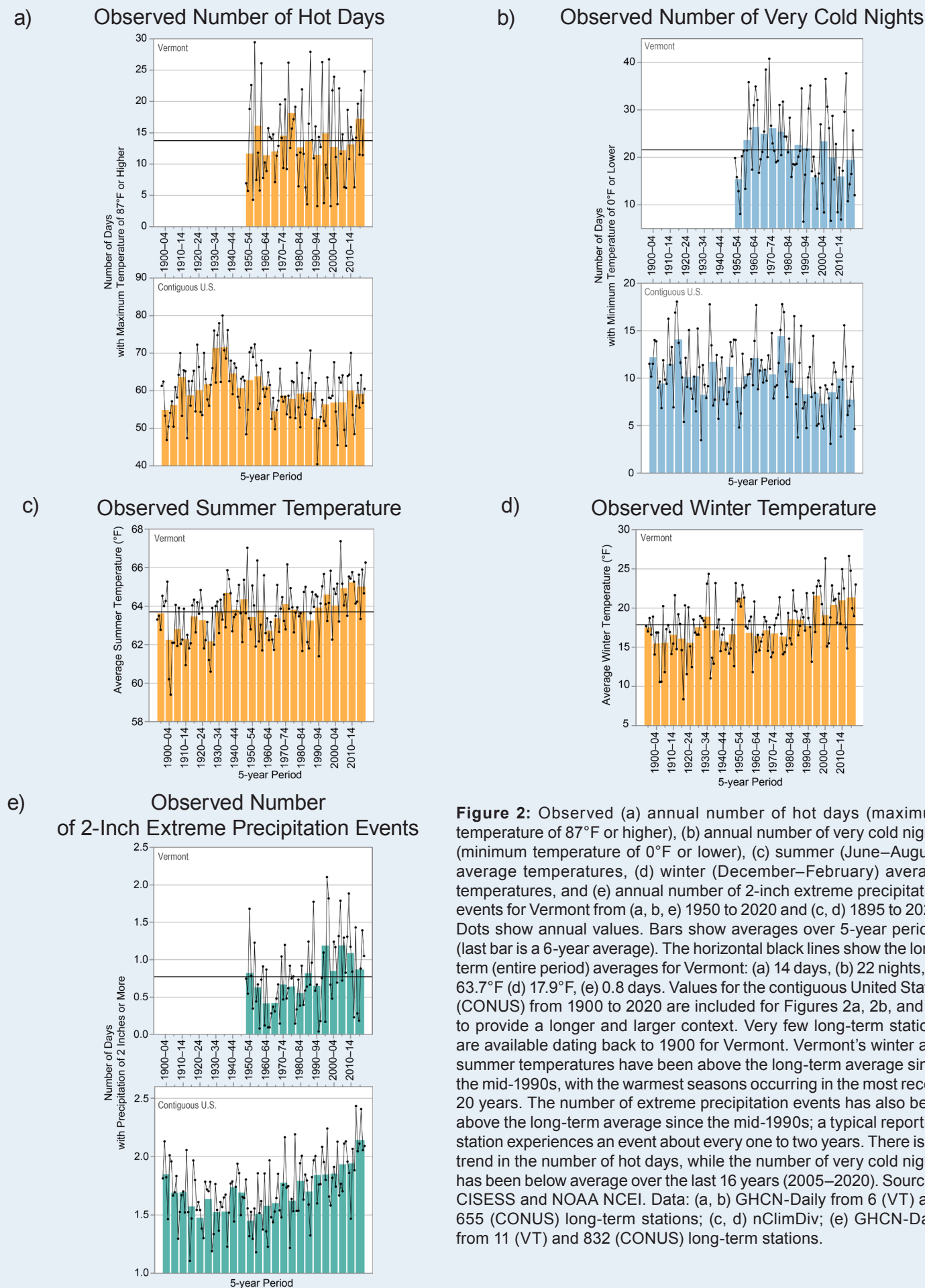


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Vermont. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Vermont (orange line) have risen about 3°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (grey shading). Historically unprecedented warming is projected to continue through this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 3°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 12°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

average; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 12°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.



Temperatures in Vermont have risen about 3°F since the beginning of the 20th century (Figure 1). While there is no trend in the number of hot days (Figure 2a), the annual number of warm nights has been near to above average for the past 21 years (2000–2020), with a historically high peak during the 2015–2020 period (Figure 3). Both winter and summer temperatures have increased considerably since 1995 (Figures 2c and 2d). The winter warming trend is reflected in a below average annual number of very cold nights since the mid-2000s (Figure 2b). Higher spring and fall temperatures have resulted in corresponding changes in the length of the freeze-free season, with later first fall freeze and earlier last spring freeze dates. Since 2005, the freeze-free season in Vermont has averaged about a week longer than the average during 1970–2004. Climate change has already increased the growing season by 3.7 days per decade. At the same time, the state continues to experience backward or false springs, which are characterized by the normal progression of warming temperatures in the late winter and early spring followed by snow and freezing rain in April–June, cold temperatures, and winds coming from the northwest.

Annual average precipitation has generally been above the long-term average since 1970 (Figure 4). The driest multiyear periods were in the early 1910s and the early 1960s. The wettest periods were observed from 2005 to 2014. The driest consecutive 5-year interval was 1961–1965, and the wettest was 2007–2011. The annual number of 2-inch extreme precipitation events has been above the long-term average over the past 26 years (1995–2020), with the highest number of events occurring during the periods of 1995 to 1999 and 2005 to 2009 (Figure 2e). Annual average precipitation has increased nearly 6 inches since the 1960s.

Extreme weather events in Vermont can take the form of prolonged heavy snowstorms, flash floods, river floods (following snowmelt and heavy rains), severe thunderstorms, droughts, tornadoes, and temperature extremes. Some of the heaviest flooding in the state's history has been due to tropical cyclones or their remnants. In 2011, Tropical Storm Irene transitioned into an extratropical cyclone as it moved quickly northeastward along the Vermont-New Hampshire border. Roughly 3 to 7 inches of rain fell in less than 18 hours, causing the worst flooding in southern and

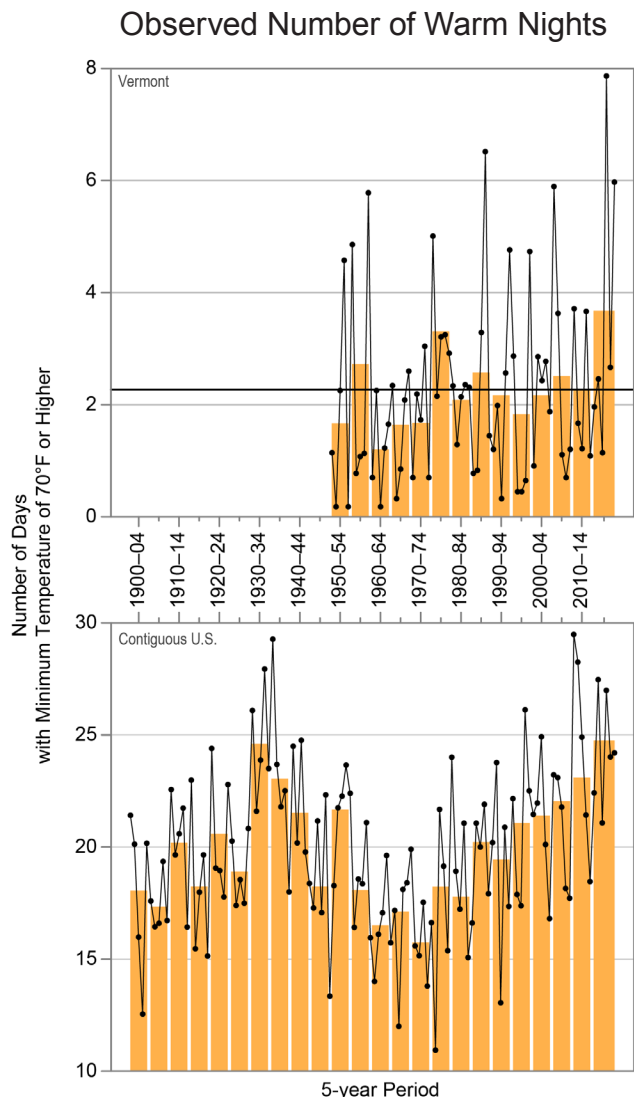


Figure 3: Observed annual number of warm nights (minimum temperature of 70°F or higher) for Vermont from 1950 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 2.8 days. Values for the contiguous United States (CONUS) from 1900 to 2020 are also included to provide a longer and larger context. Very few long-term stations are available dating back to 1900 for Vermont. The number of warm nights in Vermont has been near to above average since 2005. A historically high number of warm nights (3.7 days per year) occurred during 2015–2020. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 6 long-term stations.

eastern Vermont since the Great Flood of November 1927. Tropical Storm Irene's flooding became the new flood of record for the southern portions of the state, while the 1927 flood remains the flood of record across the north. The flooding resulted in more than \$700 million in damages across the state. Vermont continues to be susceptible to both flooding and droughts occurring in the same year. Prolonged drought conditions were observed in 1930–1936, 1939–1943, 1960–1969, 1980–1981, 1988–1989, 1991, 1995, 1998–1999, 2006–2007, 2010, 2011, 2012, 2016–2017, 2018,

and 2020–2021. During the extreme hydrologic drought of 2020–2021, new 30-year record lows were observed across the state.

Severe winter storms are common in Vermont's cold winter climate and may include snowstorms, blizzards, nor'easters, and icing events. In addition to ice jams and melting snowpack as winter hazards, freezing rain and frozen ground conditions can give rise to flooding. During the first week of January 1998, a prolonged storm brought 2 to 5 inches of rain to Vermont. Across the Champlain Valley and parts of northern Vermont, temperatures were below freezing for much of the storm. This resulted in the Great Ice Storm of '98, during which heavy ice accumulation of 1 to 2 inches caused agricultural losses (dairy industry) and severe damage to trees (at varying elevations) and utility lines. Total damage from the ice storm across the whole of the northeastern United States was about \$2 billion.

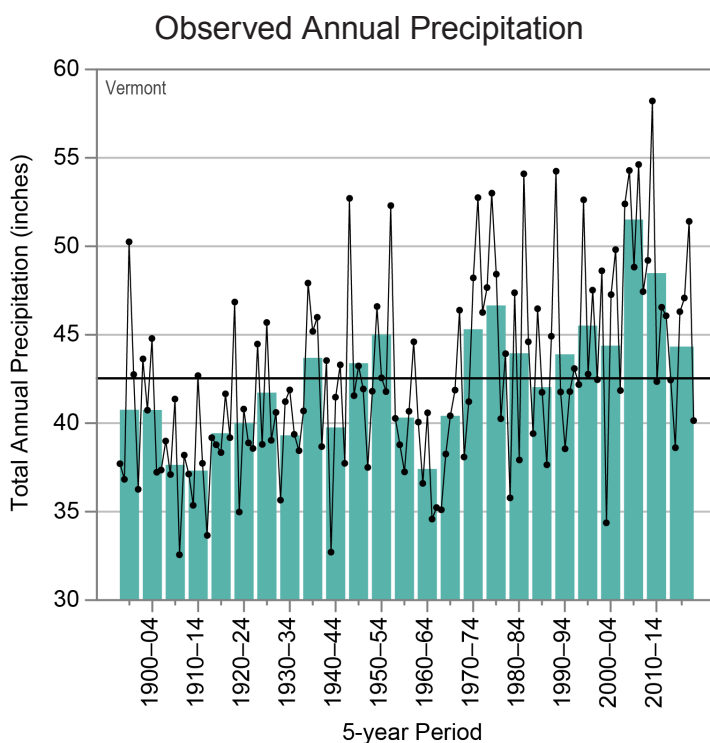


Figure 4: Observed total annual precipitation for Vermont from 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 42.5 inches. Below average annual precipitation occurred in Vermont during the early 20th century. Annual precipitation has largely remained above average since 1970, with the highest multiyear period being 2005–2009. Sources: CISESS and NOAA NCEI. Data: nClimDiv.

Under a higher emissions pathway, historically unprecedented warming is projected to continue through this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of this century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records (Figure 1). Increases in the number of hot days and decreases in the number of very cold nights are projected to accompany the overall warming.

Annual average precipitation is projected to increase in Vermont throughout this century, particularly during winter and spring (Figure 5). Corresponding increases in temperature will increase the proportion of precipitation that will fall as rain rather than snow. In addition, extreme precipitation is projected to increase, potentially increasing the frequency and intensity of floods.

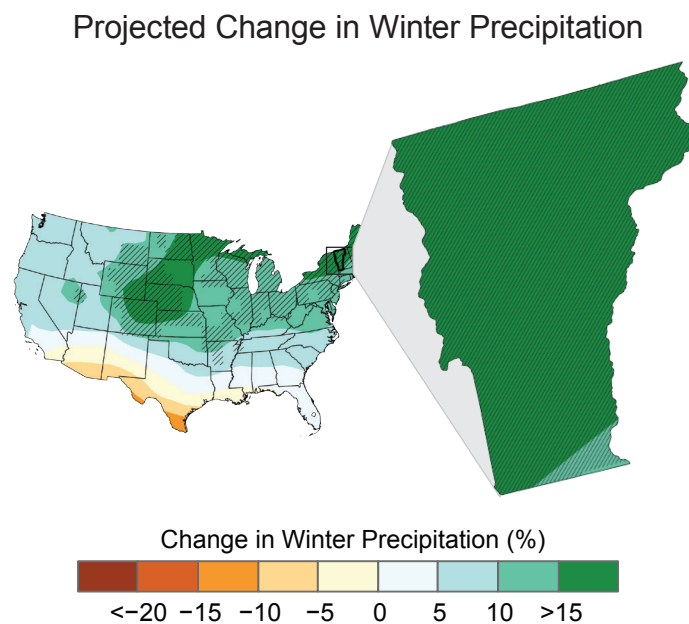


Figure 5: Projected changes in total winter (December–February) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. Vermont is part of a large area of the Northeast that is expected to experience increases in winter precipitation. Sources: CISESS and NEMAC. Data: CMIP5.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

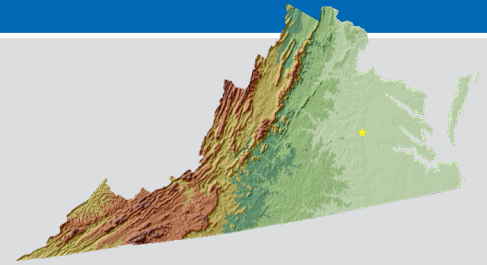
VIRGINIA

Key Messages

Temperatures in Virginia have risen more than 1.5°F since the beginning of the 20th century. Under a higher emissions pathway, historically unprecedented warming is projected during this century.

Naturally occurring droughts are projected to be more intense because higher temperatures will increase evaporation rates, accelerating soil moisture loss and adversely affecting agriculture.

The number and intensity of extreme heat and extreme precipitation events are projected to increase. Cold waves are projected to be less intense.



Virginia has a humid climate with very warm summers and moderately cold winters. There is substantial regional variation in climate due to the state's diverse geographic elements, which include the Appalachian and Blue Ridge Mountains in the west and the Atlantic coastal region in the east. Temperature and precipitation patterns are highly influenced by these geographic features, and the west and north tend to be cooler and drier than the eastern coastal region. Rainfall amounts generally decrease toward the west. For example, annual average (1991–2020 normals) precipitation is less than 40 inches in parts of the central mountain region of the state, compared to around 50 inches along the tidewater coastal region. Statewide average temperatures range from 35°F in January to 75°F in July. The Bermuda High, a semipermanent high-pressure system off the Atlantic coast, plays an important role in the summer climate of the state. Typically, the Bermuda High draws moisture northward or westward from the Atlantic Ocean and Gulf of Mexico, causing warm and moist summers with frequent thunderstorms in the afternoons and evenings. Daily and weekly variations in the positioning of the Bermuda High can strongly influence precipitation patterns.

Since the beginning of the 20th century, temperatures have risen more than 1.5°F in Virginia. The 1930s and 1950s were very warm, followed by a period of generally below average temperatures during the 1960s through the early 1980s (Figure 1). Although the highest number of very hot days and very warm nights occurred in the early 1930s (Figures 2a and 2b), gradual warming has occurred since the early 1990s. Annual average temperatures during this century (2000–2020) have exceeded the previous highs of the 1930s. A winter warming trend is reflected in a below average number of very cold nights since 1990 (Figure 3). Summer average temperatures in the most recent 16 years (2005–2020) exceeded those in the early 1930s (Figure 4).

Observed and Projected Temperature Change

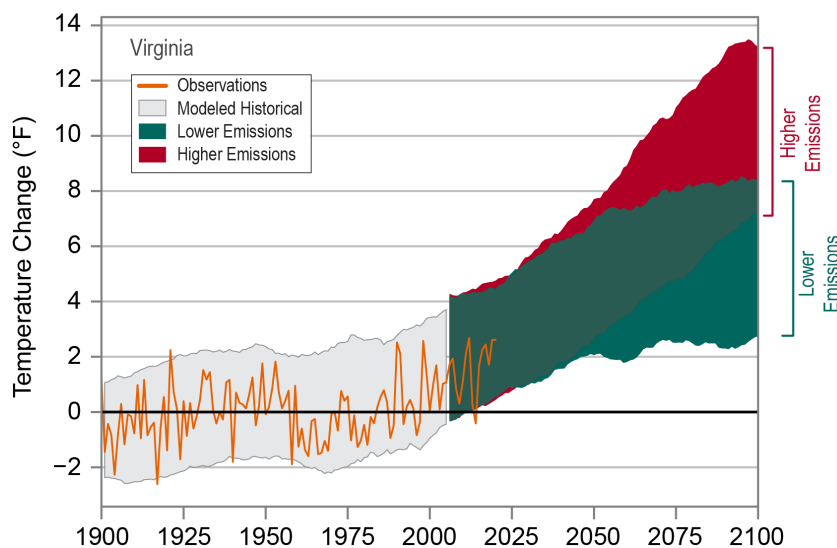


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Virginia. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Virginia (orange line) have risen more than 1.5°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about as warm as the hottest year in the historical record; green shading) and more warming under a high emissions future (the hottest end-of-century projections being about 11°F warmer than the

hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

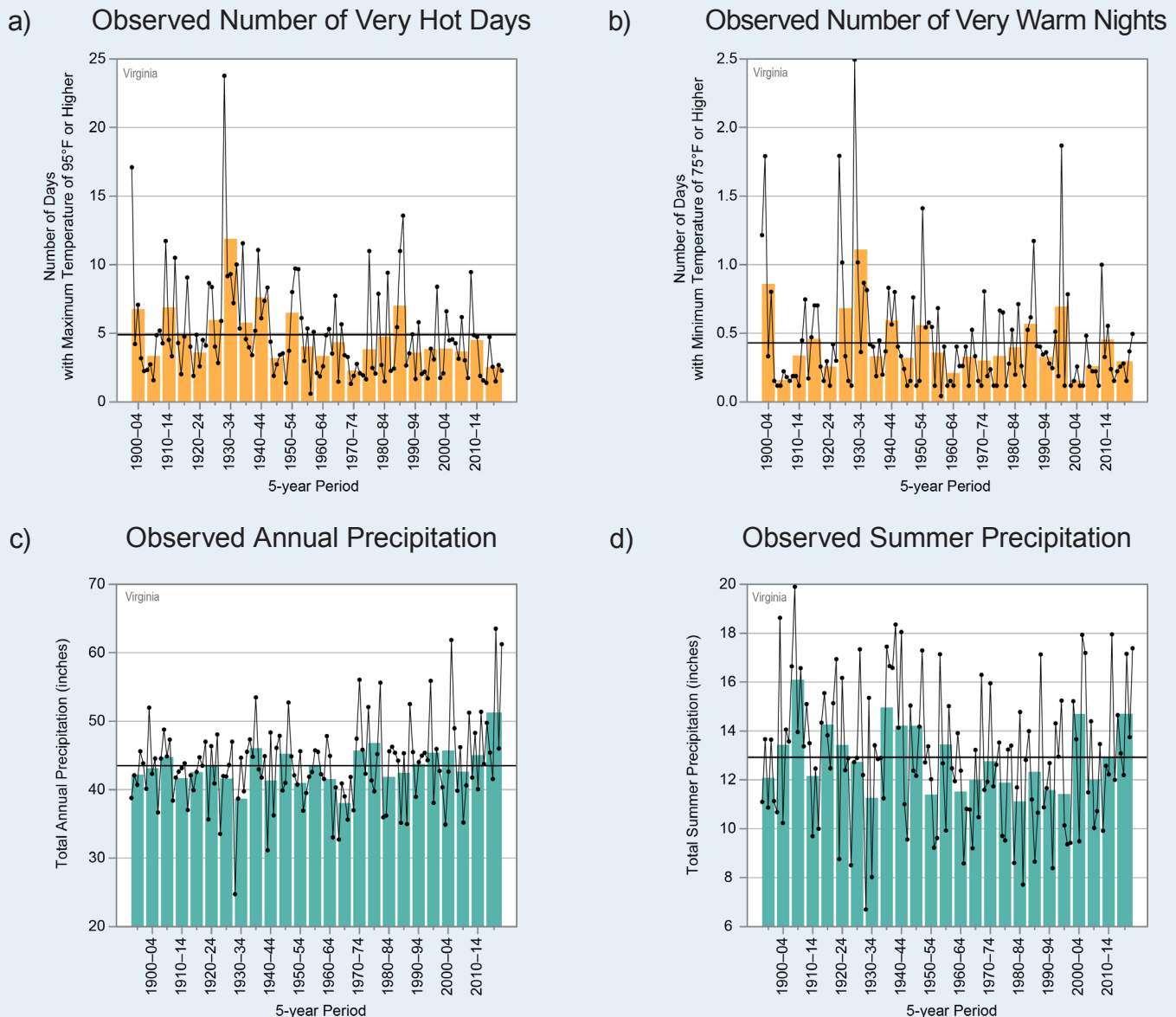


Figure 2: Observed (a) annual number of very hot days (maximum temperature of 95°F or higher), (b) annual number of very warm nights (minimum temperature of 75°F or higher), (c) total annual precipitation, and (d) total summer (June–August) precipitation for Virginia from (a, b) 1900 to 2020 and (c, d) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 4.9 days, (b) 0.4 nights, (c) 43.5 inches, (d) 12.9 inches. The number of very hot days and very warm nights peaked in the 1930s and has subsequently remained near or below the long-term average. Total annual precipitation shows a slight upward trend since 2000. Summer precipitation is highly variable but was above average during the most recent period (2015–2020). Sources: CISESS and NOAA NCEI. Data: (a, b) GHCN-Daily from 8 long-term stations; (c, d) nClimDiv.

Total annual precipitation in Virginia shows a small upward trend (Figure 2c), with multiyear values mostly above average since 1995. The driest multiyear periods were in the early 1930s and late 1960s, and the wettest were in the late 1970s and late 2010s. The driest consecutive 5-year interval was 1963–1967, and the wettest was 2016–2020. The wettest year on record was 2018 (statewide total of 63.5 inches), and 2020 was the third wettest (61.4 inches), while 1930 was the driest (24.7 inches). Total summer precipitation (Figure

2d) is highly variable and was above average during the 2015–2020 period. Since 1990, the number of 2-inch extreme precipitation events has been trending upward, with the 2015–2020 period surpassing the previous high of the late 1990s (Figure 5). Weather hazards in the state include severe thunderstorms, tornadoes, winter storms, tropical storms, hurricanes, droughts, and heat waves. **Virginia was affected by 82 of the 290 U.S. billion-dollar disaster events that occurred between 1980 and 2020.** The costliest event to ever affect the

state was Superstorm Sandy (a post-tropical storm) in 2012, which caused severe coastal flooding from storm surges. The 2012 North American derecho, an intense, long-lasting series of thunderstorms characterized by hurricane-force winds, was also very costly to the state, causing about \$3 billion in total damages. This historic summer derecho interrupted power for more than 1 million residents in Virginia, the District of Columbia, and Maryland. Winds of up to 70 mph were recorded at Reagan National Airport, causing portions of Northern Virginia to lose emergency 911 services. Tropical Storm Lee in 2011 also resulted in total damages of about \$3 billion, with Washington Dulles International Airport receiving a total of 8.74 inches of rainfall from the storm.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of this century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. If the warming trend continues, future heat waves are likely to be more intense. This will pose human health risks, particularly in the large metropolitan areas. While heat waves are projected to become more intense, cold waves are projected to become less intense.

Annual precipitation is projected to increase in Virginia (Figure 6). The state is part of a large area across the northern and central United States that shows projected increases in precipitation by midcentury. The number and intensity of extreme precipitation events are also projected to increase, continuing recent trends. Periodic droughts, a natural part of Virginia's climate, are projected to be more intense. Even if overall precipitation increases, higher temperatures will increase the rate of soil moisture loss during dry spells.

Increasing temperatures raise concerns for sea level rise in coastal areas. Since 1900, global average sea level has risen by about 7–8 inches. It is projected to rise another 1–8 feet, with a likely range of 1–4 feet, by 2100 as a result of both past and future emissions from human activities (Figure 7). **Sea level has risen even more along the Virginia coast, with a rise of 17 inches between 1927 and 2020 at Sewells Point, and greater**

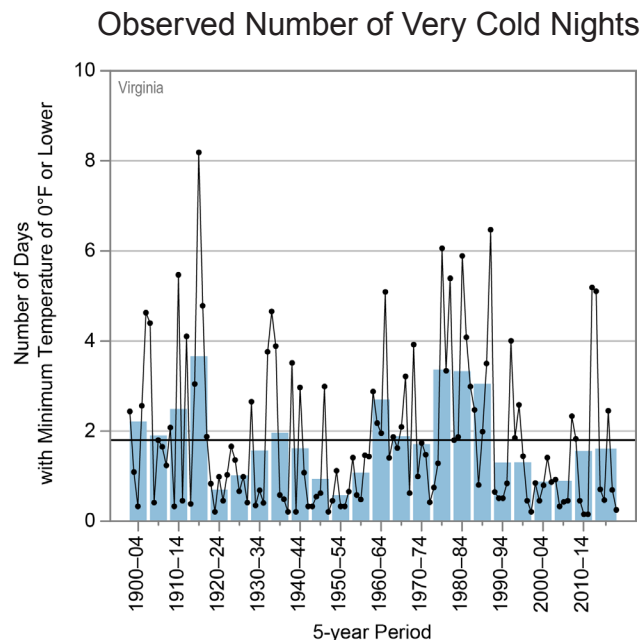


Figure 3: Observed annual number of very cold nights (minimum temperature of 0°F or lower) for Virginia from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 1.8 nights. The number of very cold nights dropped below the long-term average from the 1920s through the 1950s, followed by an above average number of such events until the early 1990s. The number of very cold nights has remained below average since 1990. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 8 long-term stations.

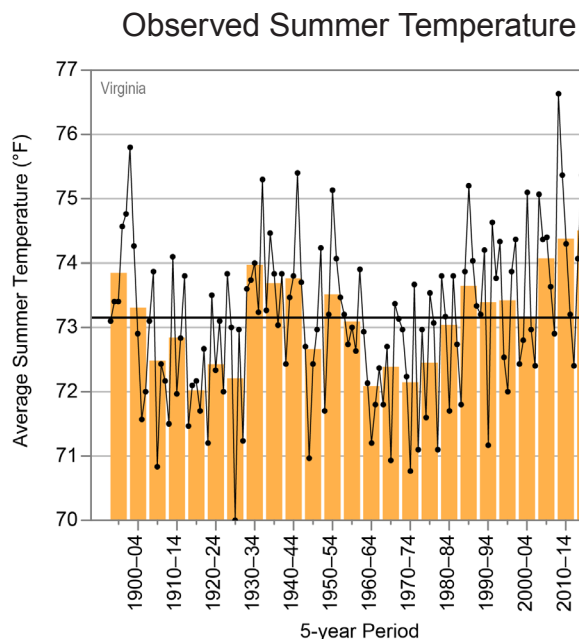


Figure 4: Observed summer (June–August) average temperature for Virginia from 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-summer average). The horizontal black line shows the long-term (entire period) average of 73.2°F. Summer average temperature has been the warmest on record since 2005. Sources: CISESS and NOAA NCEI. Data: nClimDiv.

rises are possible, following historical trends. Sea level rise has caused an increase in tidal floods associated with nuisance-level impacts. Nuisance floods are events in which water levels exceed the local threshold (set by NOAA's National Weather Service) for minor impacts. These events can damage infrastructure, cause road closures, and overwhelm storm drains. As sea level has risen along the Virginia coastline, the number of tidal flood days (all days exceeding the nuisance-level threshold) has also increased, with the greatest number (15 days) occurring in 2009 (Figure 8).

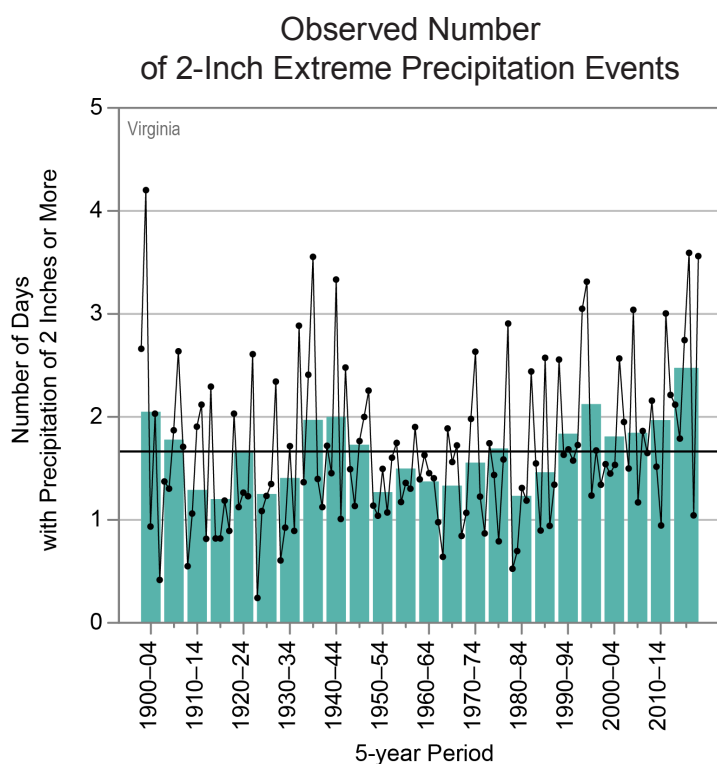


Figure 5: Observed annual number of 2-inch extreme precipitation events (days with precipitation of 2 inches or more) for Virginia from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 1.7 days. A typical reporting station experiences 1 to 2 events per year. The number of 2-inch extreme precipitation events is highly variable but exhibits a long-term upward trend. The 2015–2020 period surpassed the 1995–1999 record. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 11 long-term stations.

Projected Change in Annual Precipitation

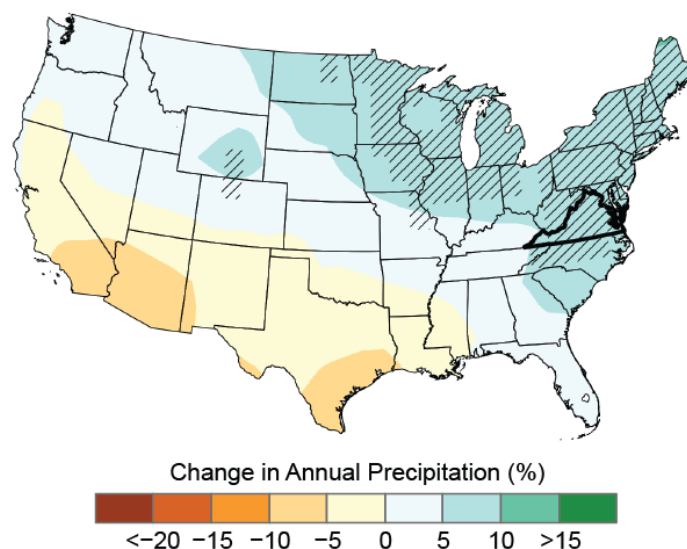


Figure 6: Projected changes in total annual precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. Virginia is part of a large area of projected increases that includes all of the Northeast. Sources: CISESS and NEMAC. Data: CMIP5.

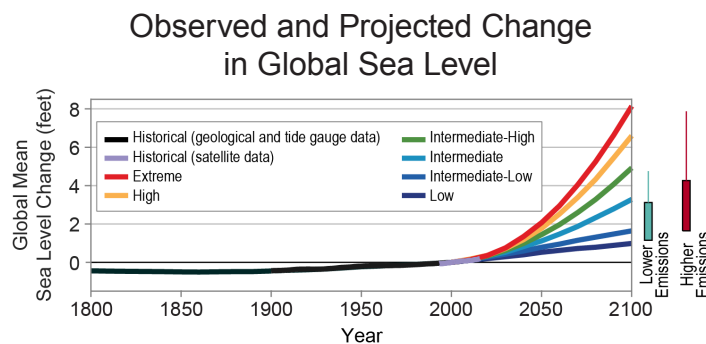


Figure 7: Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate-Low, royal blue; Intermediate, cyan; Intermediate-High, green; High, orange; and Extreme, red curves) relative to historical geological, tide gauge, and satellite altimetry GMSL reconstructions from 1800–2015 (black and magenta lines) and the very likely ranges in 2100 under both lower and higher emissions futures (teal and dark red boxes). Global sea level rise projections range from 1 to 8 feet by 2100, with a likely range of 1 to 4 feet. Source: adapted from Sweet et al. 2017.

Observed and Projected Annual Number of Tidal Floods for Sewells Point, VA

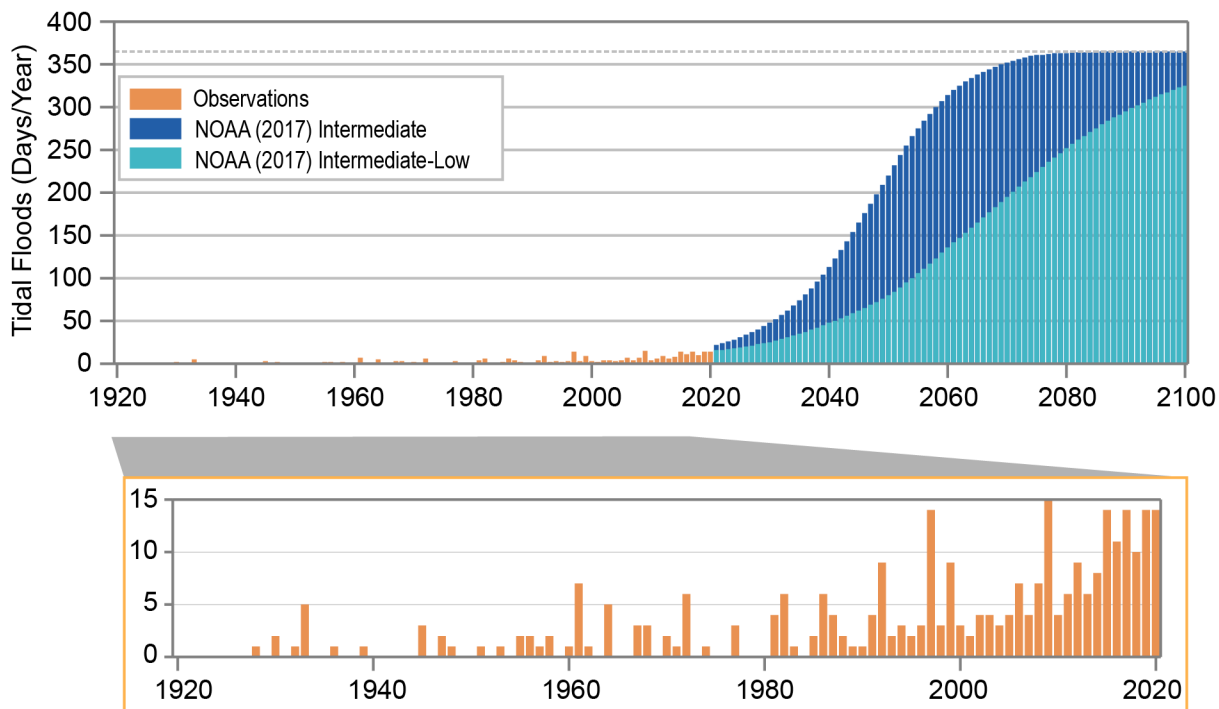


Figure 8: Number of tidal flood days per year at Sewells Point, Virginia, for the observed record (1928–2020; orange bars) and projections for two NOAA (2017) sea level rise scenarios (2021–2100): Intermediate (dark blue bars) and Intermediate-Low (light blue bars). The NOAA (2017) scenarios are based on local projections of the GMSL scenarios shown in Figure 7. Sea level rise has caused a gradual increase in tidal floods associated with nuisance-level impacts. The greatest number of tidal flood days (all days exceeding the nuisance-level threshold) occurred in 2009 at Sewells Point. Projected increases are large even under the Intermediate-Low scenario. Under the Intermediate scenario, tidal flooding is projected to occur nearly every day of the year by the end of the century. Additional information on tidal flooding observations and scenarios is available at <https://statesummaries.ncics.org/technicaldetails>. Sources: CISESS and NOAA NOS.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

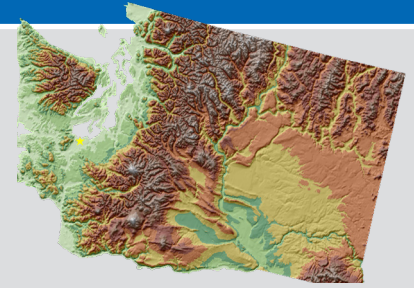
WASHINGTON

Key Messages

Temperatures in Washington have risen almost 2°F since the beginning of the 20th century. Winter warming has been evident in the below average number of freezing days and very cold nights since 1990. Under a higher emissions pathway, historically unprecedented warming is projected to continue through this century.

Rising temperatures will lead to earlier melting of the snowpack, which plays a critical role in spring and summer water supplies. The combination of this earlier melting and more precipitation falling as rain instead of snow may lead to an increase in springtime flooding.

Wildfires during the dry summer months are a particular concern for Washington, and the frequency and severity of wildfires are projected to increase.



Washington's location in the heart of the middle latitudes exposes it to frequent storm systems associated with the mid-latitude jet stream. Due to the physical barrier of the Cascade Mountains, the climate differs greatly in the western and eastern parts of the state. The Pacific Ocean provides abundant moisture, causing frequent precipitation west of the Cascade Mountains, with some locations experiencing orographic enhancement (the increase of rainfall with elevation on the upwind side of mountain ranges). The region east of the Cascades receives less precipitation due to the reduced availability of ocean moisture. Temperatures in the central and eastern portions of the state are not as strongly moderated by the ocean and exhibit a greater annual range than those in the western portion.

Since the beginning of the 20th century, temperatures in Washington have risen almost 2°F (Figure 1), and since 1986, all but 5 years have been above the long-term (1895–2020) average. The hottest year on record was 2015, with a statewide average temperature of 50.0°F, which was 3.7°F above the long-term average. The overall warming trend is evident in an increased number of warm nights. Since 1990, the numbers of very cold nights in Eastern Washington and freezing days in Western Washington have both been below average (Figure 2a). However, the numbers of very warm nights in Eastern Washington and warm nights in Western Washington have both been above average since 1990 (Figure 3). The numbers of very hot days in Eastern Washington and hot days in Western Washington have been quite variable but were both generally above average during the 2015–2020 period, after below average numbers during the 2010–2014 period (Figure 2b).

Observed and Projected Temperature Change

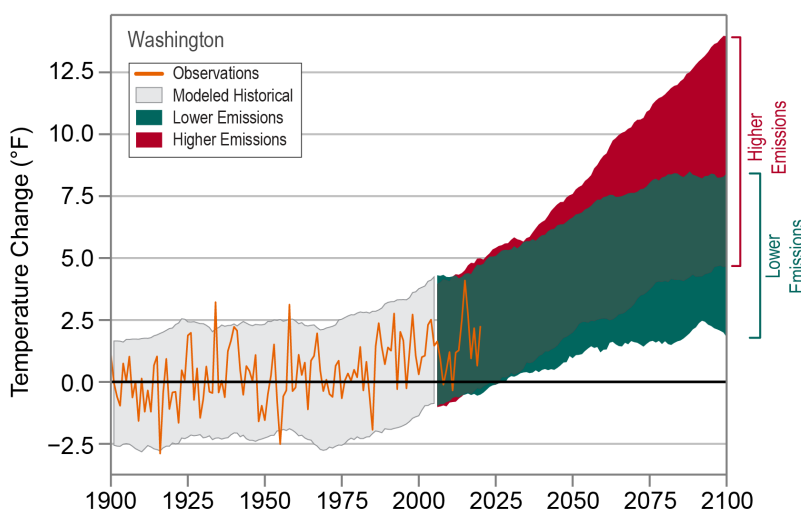


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Washington. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Washington (orange line) have risen almost 2°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected to continue through this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 1°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 10°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

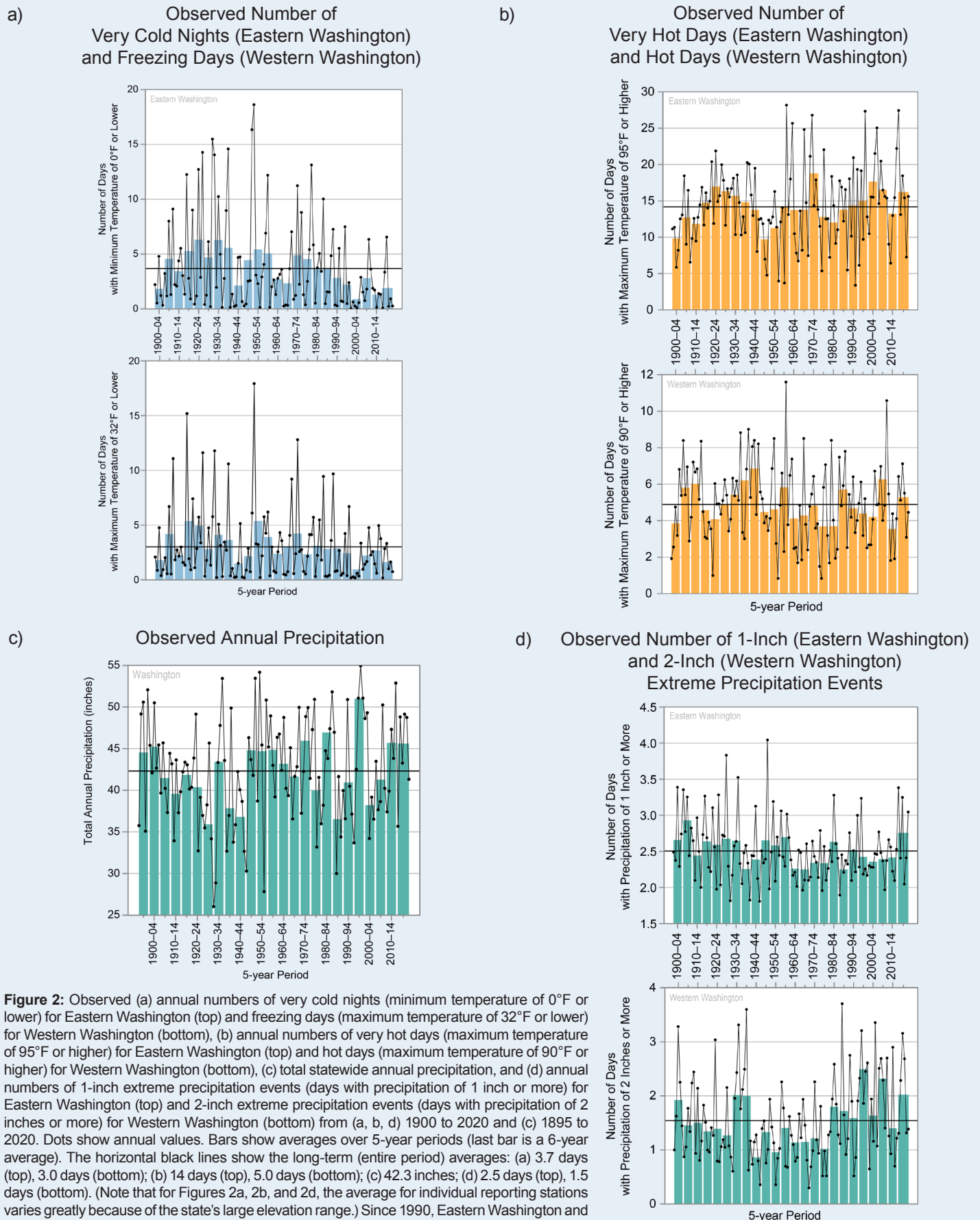


Figure 2: Observed (a) annual numbers of very cold nights (minimum temperature of 0°F or lower) for Eastern Washington (top) and freezing days (maximum temperature of 32°F or lower) for Western Washington (bottom), (b) annual numbers of very hot days (maximum temperature of 95°F or higher) for Eastern Washington (top) and hot days (maximum temperature of 90°F or higher) for Western Washington (bottom), (c) total statewide annual precipitation, and (d) annual numbers of 1-inch extreme precipitation events (days with precipitation of 1 inch or more) for Eastern Washington (top) and 2-inch extreme precipitation events (days with precipitation of 2 inches or more) for Western Washington (bottom) from (a, b, d) 1900 to 2020 and (c) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 3.7 days (top), 3.0 days (bottom); (b) 14 days (top), 5.0 days (bottom); (c) 42.3 inches; (d) 2.5 days (top), 1.5 days (bottom). (Note that for Figures 2a, 2b, and 2d, the average for individual reporting stations varies greatly because of the state's large elevation range.) Since 1990, Eastern Washington and Western Washington have experienced below average numbers of very cold nights and freezing days, respectively, which is indicative of warming in the region. The numbers of very hot days in Eastern Washington and hot days in Western Washington have both been variable since 1990. Both annual precipitation and the number of extreme precipitation events have varied widely since the beginning of the 20th century. A typical station in Eastern Washington experiences between two and three 1-inch extreme precipitation events per year. A typical station in Western Washington experiences between one and two 2-inch events per year. Sources: CISESS and NOAA NCEI. Data: (a, b) GHCN-Daily from 17 long-term stations; (c) nClimDiv; (d) GHCN-Daily from 23 long-term stations.

Annual precipitation exhibits wide regional variations across the state. Portions of the Olympic Peninsula receive upwards of 150 inches of precipitation annually, while areas along the Columbia River in eastern interior Washington average less than 10 inches. Statewide total annual precipitation has ranged from a low of 26.0 inches in 1929 to a high of 55.0 inches in 1996. The driest multiyear periods were in the late 1920s, early 1940s, and late 1980s, and the wettest were in the early 1970s, early 1980s, and late 1990s (Figure 2c). The driest consecutive 5-year interval was 1926–1930, with an annual average of 34.6 inches, and the wettest was 1995–1999, with an annual average of 51.0 inches. Washington has not experienced any long-term trend in the number of extreme precipitation events (Figure 2d).

Most of Washington’s precipitation falls during the winter months, and the Cascades can receive upwards of 400 inches of snowfall annually. **Snowpack in the mountains provides an important source of water during the drier summer months** (Figure 4). Precipitation falling as rain rather than snow can have negative impacts on critical industries, such as timber and agriculture, which are also vulnerable to extreme temperatures. Wildfires during the drier summer months are a particular concern. The 2015 wildfire season was the most destructive in Washington’s history, with more than 1 million acres burned (more than 6 times the average).

Under a higher emissions pathway, historically unprecedented warming is projected to continue through the end of this century (Figure 1). Even under a lower emissions pathway, temperatures are projected to most likely exceed historical record levels by the middle of this century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records (Figure 1). Overall, warming will lead to increases in heat wave intensities but decreases in cold wave intensities. Unlike other locations in the United States, Seattle and other urban areas are rarely exposed to very high temperatures. Future heat waves, particularly an increase in the frequency of warm nights, could stress these communities, which are not well adapted to such events.

Temperature increases will affect basins with significant snowmelt contributions to their streamflow. Projected rising temperatures will raise the elevation of the snow line—the average lowest elevation at

which snow falls. This will increase the likelihood that precipitation will fall as rain instead of snow, reducing water storage in the snowpack, particularly at those lower mountain elevations that are now on the margins of reliable snowpack accumulation. Rainfall is expected to be the dominant form of precipitation across the majority of the state by the end of this century. Higher spring temperatures will also result in earlier melting of the snowpack, with average snowpack projected to decline by up to 70% by the end of this century. This will further decrease water availability during the already dry summer months, and due to earlier spring peak flows, it will increase the risk of spring

Observed Number of
Very Warm Nights (Eastern Washington)
and Warm Nights (Western Washington)

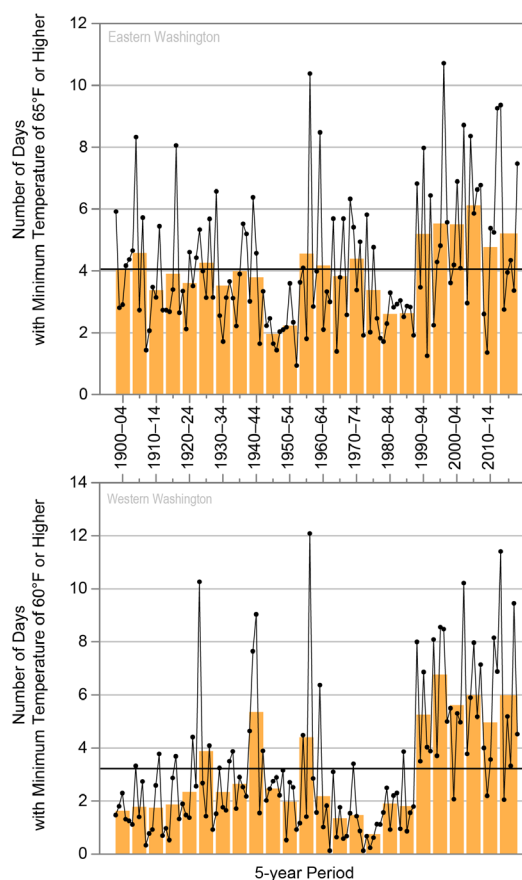


Figure 3: Observed annual numbers of very warm nights (minimum temperature of 65°F or higher) for Eastern Washington and warm nights (minimum temperature of 60°F or higher) for Western Washington from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages of 4.0 nights (top) and 2.5 nights (bottom; note that the average for individual reporting stations varies greatly because of the state’s large elevation range). The numbers of very warm nights in Eastern Washington and warm nights in Western Washington have both been above average since 1900. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 17 long-term stations.

flooding. Projected increases in heavy rainfall events by midcentury could further increase flood risk. Reductions in summer flow (projected to occur in 80% of the state's watersheds) will have important ecological implications and are a particular concern for hydropower and irrigation water supplies.

Increasing temperatures raise concerns for sea level rise in coastal areas. Since 1900, global average sea level has risen by about 7–8 inches. It is projected to rise another 1–8 feet, with a likely range of 1–4 feet, by 2100 as a result of both past and future emissions from human activities (Figure 6). Sea level rise has caused an increase in tidal floods associated with nuisance-level impacts. Nuisance floods are events in which water levels exceed the local threshold (set by NOAA's National Weather Service) for minor impacts. These events

can damage infrastructure, cause road closures, and overwhelm storm drains. As sea level has risen along the Washington coastline, the number of tidal flood days has also increased at Seattle, with the greatest number (11) occurring in 1997 during a strong El Niño event (Figure 7). Some areas of the coast are rising, which has mitigated the impacts of recent sea level rise and will reduce somewhat the local projected sea level rise.

Although projections of overall annual precipitation are uncertain, summer precipitation is projected to decrease (Figure 5). Drier conditions during the summer could increase reliance on diminishing snowmelt for irrigation. Additionally, the combination of drier summers, higher temperatures, and earlier melting of the snowpack would tend to increase the frequency and extent of wildfires.

April 1 Snow Water Equivalent (SWE)
at Fish Lake, WA

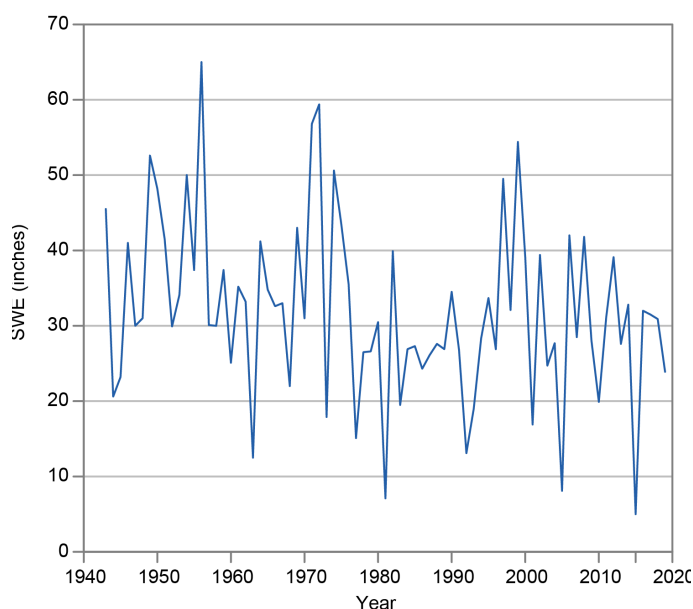


Figure 4: Variations in April 1 snow water equivalent (SWE) at the Fish Lake, Washington, snow course site from 1943 to 2019. SWE, the amount of water contained within the snowpack, varies widely from year to year, but there is a general downward trend. The extremely low snowpack levels in 2005 (third lowest) were due to below average winter precipitation and above average winter temperatures. In 2015 (record lowest), warmer than normal winter temperatures were the main driver of the drought, causing more precipitation to fall as rain rather than snow. Source: NRCS NWCC.

Projected Change in Summer Precipitation

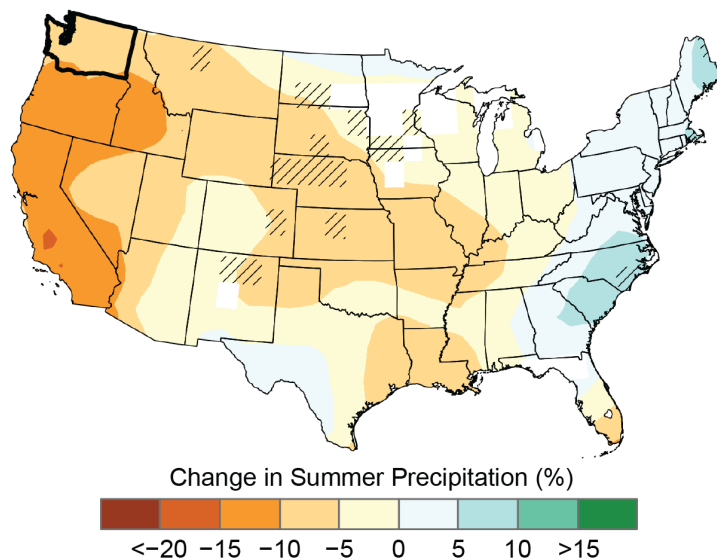


Figure 5: Projected changes in total summer (June–August) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Whited-out areas indicate that the climate models are uncertain about the direction of change. Hatching represents areas where the majority of climate models indicate a statistically significant change. Washington is projected to see a decrease in summer precipitation. Source: CISESS and NEMAC. Data: CMIP5.

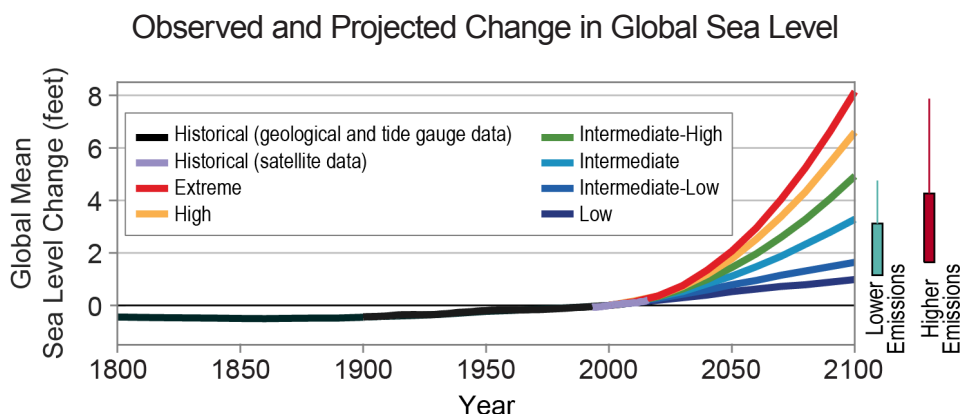


Figure 6: Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate-Low, royal blue; Intermediate, cyan; Intermediate-High, green; High, orange; and Extreme, red curves) relative to historical geological, tide gauge, and satellite altimeter GMSL reconstructions from 1800–2015 (black and magenta lines) and the very likely ranges in 2100 under both lower and higher emissions futures (teal and dark red boxes). Global sea level rise projections range from 1 to 8 feet by 2100, with a likely range of 1 to 4 feet. Source: adapted from Sweet et al. 2017.

Observed and Projected Annual Number of Tidal Floods for Seattle, WA

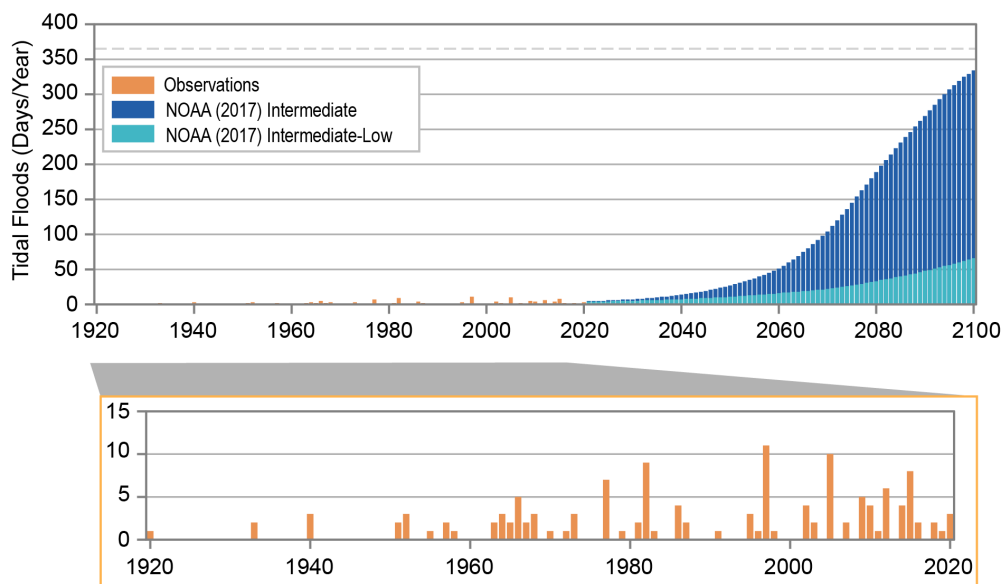


Figure 7: Number of tidal flood days per year at Seattle, Washington, for the observed record (1920–2020 orange bars) and projections for two NOAA (2017) sea level rise scenarios (2021–2100): Intermediate (dark blue bars) and Intermediate-Low (light blue bars). The NOAA (2017) scenarios are based on local projections of the GMSL scenarios shown in Figure 5. Sea level rise has caused a gradual increase in tidal floods associated with nuisance-level impacts. The greatest number of tidal flood days (all days exceeding the nuisance-level threshold) occurred in 1997 at Seattle. Projected increases are large even under the Intermediate-Low scenario. Under the Intermediate scenario, tidal flooding is projected to occur nearly every day of the year by the end of the century. Additional information on tidal flooding observations and scenarios is available online at <https://statesummaries.ncics.org/technicaldetails>. Sources: CISESS and NOAA NOS.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

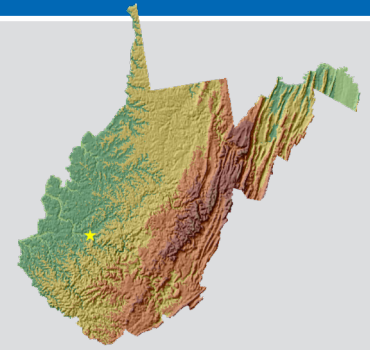
WEST VIRGINIA

Key Messages

Temperatures in West Virginia have risen 1°F since the beginning of the 20th century. Under a higher emissions pathway, historically unprecedented warming is projected during this century, with increases in heat wave intensity and decreases in cold wave intensity.

Total annual precipitation has been highly variable, with a slight increase since 1895. Winter and spring precipitation amounts are projected to increase, as well as the number and intensity of extreme precipitation events, creating an increased risk of flooding.

Naturally occurring droughts are projected to be more intense in the future due to temperature-caused increases in the rate of soil moisture loss during dry spells.



The climate of West Virginia is characterized by moderately cold winters and warm, humid summers. The jet stream, which is located near or over the Northeast region during the winter, brings frequent storm systems, which cause cloudy skies, windy conditions, and precipitation. The state is affected by a variety of extreme events, such as floods, droughts, heat and cold waves, ice storms, remnants of hurricanes, and snowstorms, including nor'easters. Due to the state's rugged topography, climate conditions vary considerably. West Virginia's elevation—the highest average elevation east of the Mississippi River—moderates summer temperatures. Summer average maximum temperatures range from around 85°F in the southwest, near the Ohio River, to less than 80°F in the east-central mountains. Winter average minimum temperatures range from the low 20s (°F) in the mountainous central and northeastern portions of the state to around 30°F in the far south. The central portion of West Virginia receives 50 or more inches of precipitation per year, while the west, along the Ohio River, receives around 40 inches. A rain shadow (an area of reduced rainfall due to sheltering hills) exists to the west of the state's Eastern Panhandle, where annual average precipitation drops to about 35 inches.

Observed and Projected Temperature Change

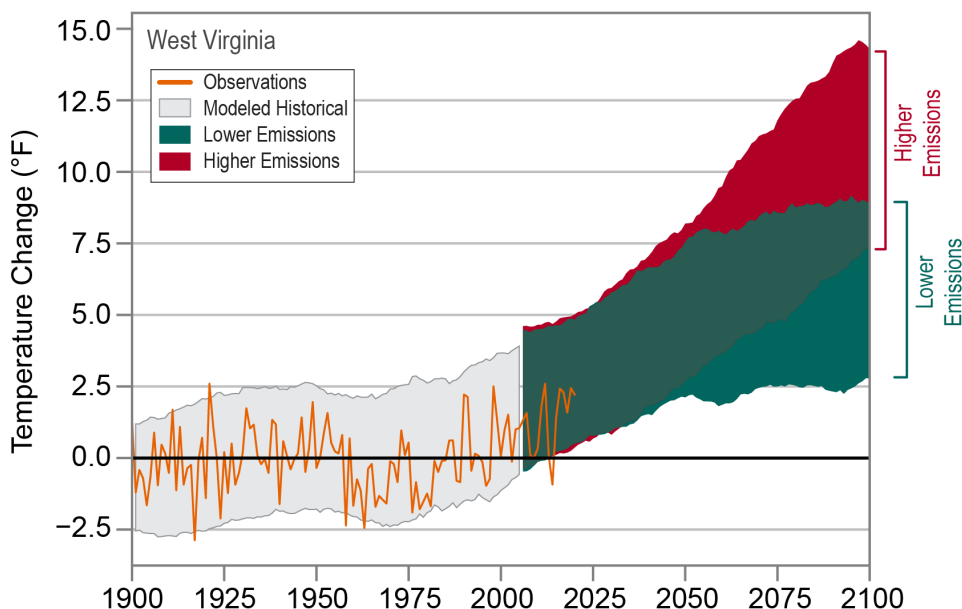


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for West Virginia. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in West Virginia (orange line) have risen 1°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about as

warm as the hottest year in the historical record; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 12°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

Observed Number of Very Hot Days

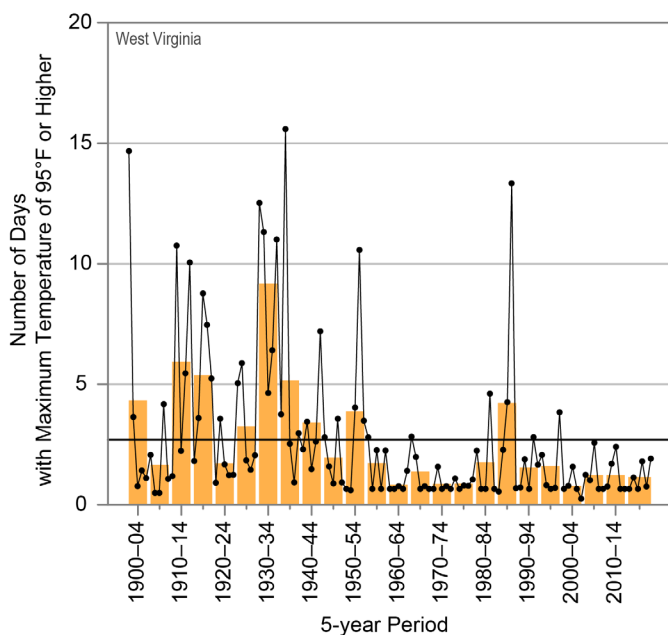


Figure 2: Observed annual number of very hot days (maximum temperature of 95°F or higher) for West Virginia from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is 6-year average). The horizontal black line shows the long-term (entire period) average of 2.7 days. The number of very hot days has been below average since the 1990s. Record-high numbers occurred during the droughts of the 1930s. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 6 long-term stations.

Observed Number of Warm Nights

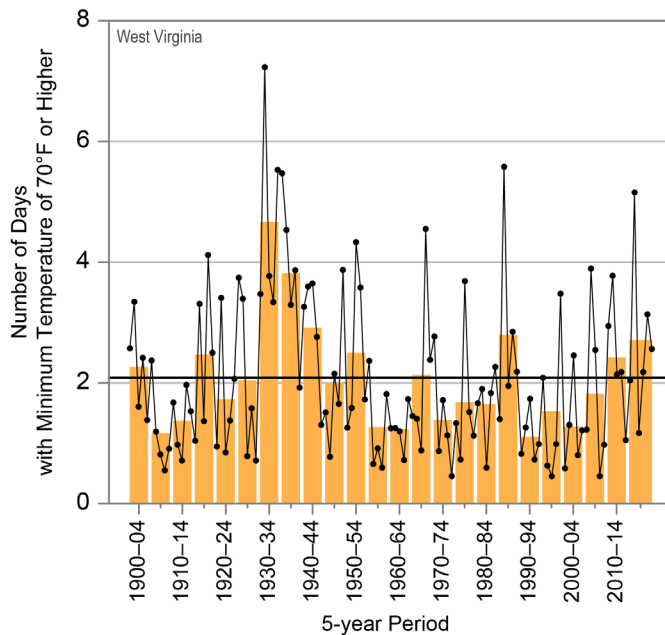


Figure 3: Observed annual number of warm nights (minimum temperature of 70°F or higher) for West Virginia from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 2.1 nights. There is no long-term trend in the number of warm nights, but the two most recent multiyear periods (2005–2009 and 2015–2020) were above average. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 6 long-term stations.

Temperatures in West Virginia have risen 1°F since the beginning of the 20th century (Figure 1). Temperatures increased during the early part of the 20th century, followed by a period of cooling. Gradual warming has occurred since the early 1980s; temperatures in this century have been above the long-term (1895–2020) average and slightly warmer than the previous warmest periods of the 1930s and early 1950s. The number of very hot days has been below average since the 1990s (Figure 2). The number of warm nights does not show any long-term trend, but above average numbers have occurred during the last 11 years (Figure 3). The number of very cold nights has generally been below average since the 1990s, although an above average number of these nights occurred recently in 2014, 2015, and 2018 (Figure 4).

Total annual precipitation in West Virginia has been variable, with a slight increase over the 126-year period of record (Figure 5). Precipitation has generally been near to above average since the early 1990s, with the last 6-year period (2015–2020) being the wettest. The driest multiyear periods were in the early 1930s and late 1960s, and the wettest were in the early 2000s and late 2010s. The driest consecutive 5-year interval

Observed Number of Very Cold Nights

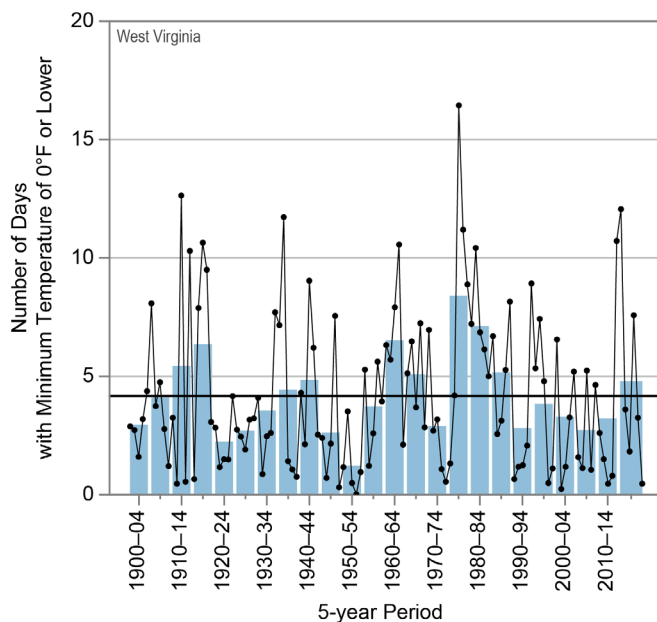


Figure 4: Observed annual number of very cold nights (minimum temperature of 0°F or lower) for West Virginia from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year period). The horizontal black line shows the long-term (entire period) average of 4.2 nights. The number of very cold nights has varied and was slightly above average during the last multiyear period (2015–2020). Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 6 long-term stations.

was 1962–1966, averaging 39.6 inches per year, and the wettest was 2016–2020, averaging 51.9 inches. The number of 2-inch extreme precipitation events was above average during the 1995–2004 interval but has been near average since then (Figure 6). The mountains of West Virginia see some of the highest snowfall totals east of the Mississippi River, with an annual average of 100 inches. A record snowfall of more than 200 inches occurred during the winter of 2009–10, with more than 100 inches falling in the month of February, when the region was impacted by three major storms.

West Virginia experiences a wide array of extreme weather, including tornadoes, thunderstorms, snowstorms, hurricane remnants, and flooding. Tornadoes occur an average of 2 to 5 times per year and are usually weak. **Flooding, caused by extreme precipitation over the rugged topography, is the costliest and most severe natural hazard for the state.** From 2010 to 2020, the state received 23 FEMA disaster declarations, 18 of which were related to severe storms and flooding events. The two most significant historical flooding events occurred in 1937 and 1985. The Great Ohio River Flood of 1937 affected numerous states, but the southwestern part of West Virginia, near Huntington, was the hardest hit. Heavy downpours occurred over a 2-week period, with rainfall averaging 6 to 12 inches throughout the region. The river level at Huntington was the highest ever recorded, cresting at 69 feet, 19 feet above flood stage. Damages to homes and buildings were in the millions of dollars. In early November 1985, an extratropical storm, influenced by the remnants of Hurricane Juan, generated up to 10 inches of rainfall across West Virginia. Extensive river flooding, mostly in the eastern portion of the state, resulted in more than \$500 million in damages to 3,500 homes and 180 local businesses. A major flood event occurred in June 2016, when 8 to 10 inches of rain fell in less than 12 hours. The Elk River rose to more than 33 feet, breaking the previous high-water record set in 1888. At least 23 people were killed by flash floods.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, temperatures are projected to most likely exceed historical record levels by the middle of this century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. Increased heat wave intensity and decreased cold wave intensity are projected.

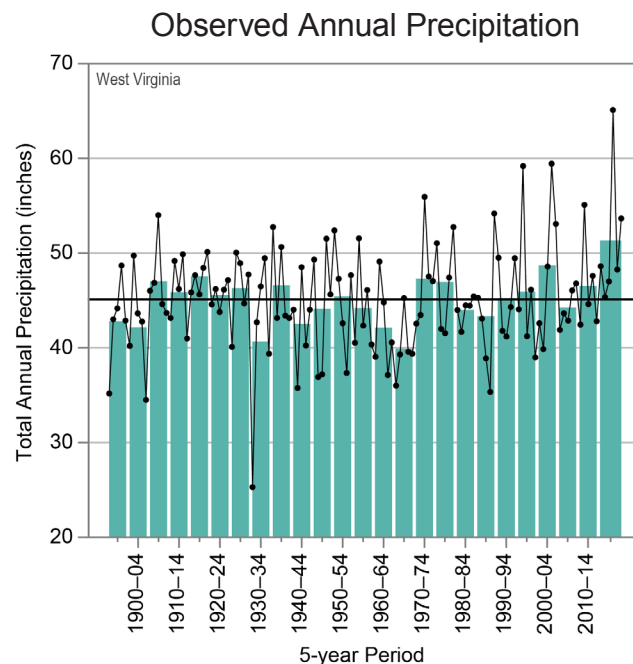


Figure 5: Observed total annual precipitation for West Virginia from 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 45.1 inches. Annual precipitation has been variable, with a slight increase over the 126-year period of record. The most recent multiyear period (2015–2020) was well above average. Sources: CISESS and NOAA NCEI. Data: nClimDiv.

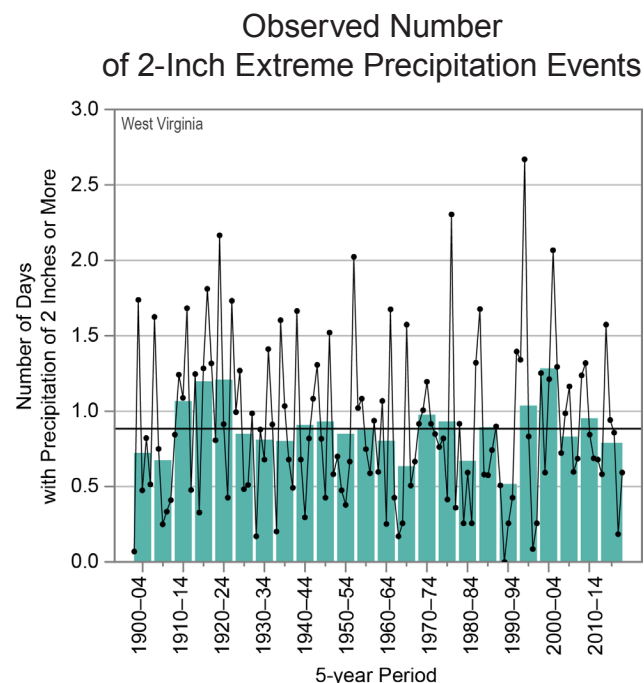


Figure 6: Observed annual number of 2-inch extreme precipitation events (days with precipitation of 2 inches or more) for West Virginia from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 0.9 days. A typical station experiences an event about once per year. There is no long-term trend in the number of 2-inch extreme precipitation events. The 2000–2004 period had the highest multiyear average. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 8 long-term stations.

Annual precipitation is projected to increase for West Virginia over this century (Figure 7), with the largest increases occurring during winter and spring. The number and intensity of extreme precipitation events are also projected to increase. These events will likely lead to greater flood risk. Drought is a periodically occurring natural phenomenon in the state. Higher temperatures are projected to increase the rate of soil moisture loss during dry spells, resulting in more intense naturally occurring droughts in the future.

Much of West Virginia's land cover is forested. These forests provide unique habitats for an abundance of plants and animals, some of which are endangered. For example, the state's red spruce habitat occupies the largest high-elevation area in the northeastern United States. Upland red spruce communities are highly vulnerable to climate change due to their topographic location on the highest mountaintops, low elevation barriers to dispersal, and fairly narrow temperature and precipitation tolerances. In the future, climate change may significantly alter red spruce forests.

Projected Change in Annual Precipitation

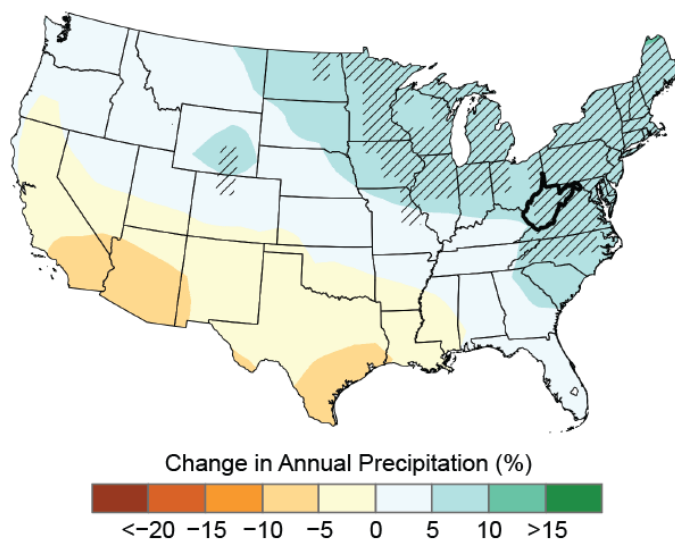


Figure 7: Projected changes in total annual precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. West Virginia is part of a large area of projected increases in the Northeast. Sources: CISESS and NEMAC. Data: CMIP5.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

WISCONSIN

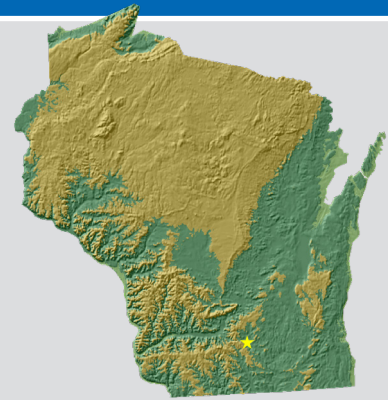
Key Messages

Temperatures in Wisconsin have risen more than 2°F since the beginning of the 20th century. Under a higher emissions pathway, historically unprecedented warming is projected during this century. Extreme heat is a particular concern for densely populated urban areas such as Milwaukee, where high temperatures and high humidity can cause dangerous conditions.

Wisconsin has experienced an increase in both annual precipitation and extreme precipitation events, and these increases are projected to continue. Projected increases in winter and spring precipitation will pose a continuing risk of spring planting delays, as well as an increased risk of flooding. Snowfall is projected to decline due to warmer temperatures.

Severe drought, a natural part of Wisconsin's climate, is a risk to this agriculture-dependent state. The intensity of naturally occurring droughts may increase due to earlier snowmelt, a greater frequency of dry days, and higher temperatures, which increase the rate of soil moisture depletion during dry spells.

Changes in seasonal and multiyear precipitation, evaporation, and temperature can affect water levels in the Great Lakes, causing serious environmental and socioeconomic impacts.



Wisconsin's location in the interior of North America and the lack of mountains to the north and south expose the state to incursions of bitterly cold air masses from the Arctic in the winter and warm, humid air masses from the Gulf of Mexico in the summer, causing a large range of temperatures across the state. The southern part of the state experiences cold winters and mild to hot summers, while the northern part of the state experiences frigid winters and generally cool summers with brief bouts of excessive heat. The winter season is dominated by dry and cold air, with occasional intrusions of milder air from the west and south. The summer is characterized by frequent warm air masses, either hot and dry continental air masses from the arid west and southwest or warm and moist air from the south. However, periodic intrusions of cooler air from Canada provide breaks from summer heat. The state has borders along Lake Superior to the north and Lake Michigan to the east, and the proximity to the lakes provides a moderating effect on temperatures for locations along the shorelines. Annual average temperatures vary from 39°F in the north to 50°F in the south.

Observed and Projected Temperature Change

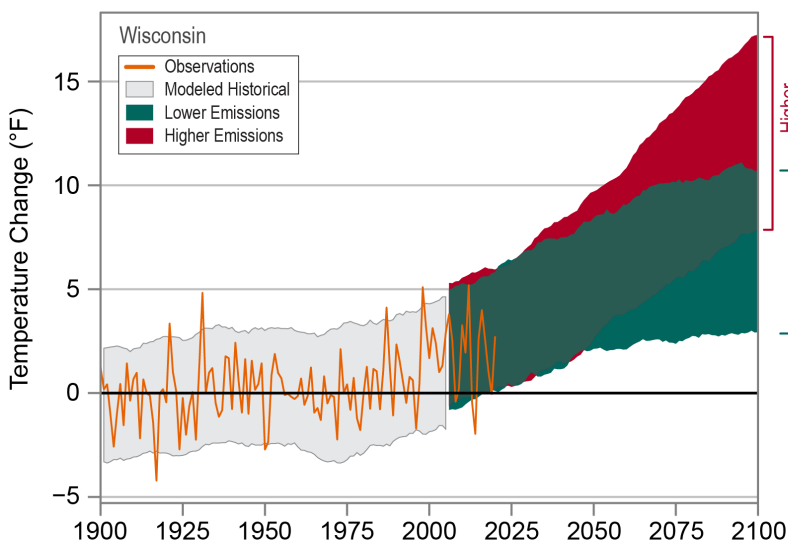


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Wisconsin. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Wisconsin (orange line) have risen more than 2°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 2°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being

about 12°F warmer than the hottest year in the historical record; red shading). Sources: CISS and NOAA NCEI.

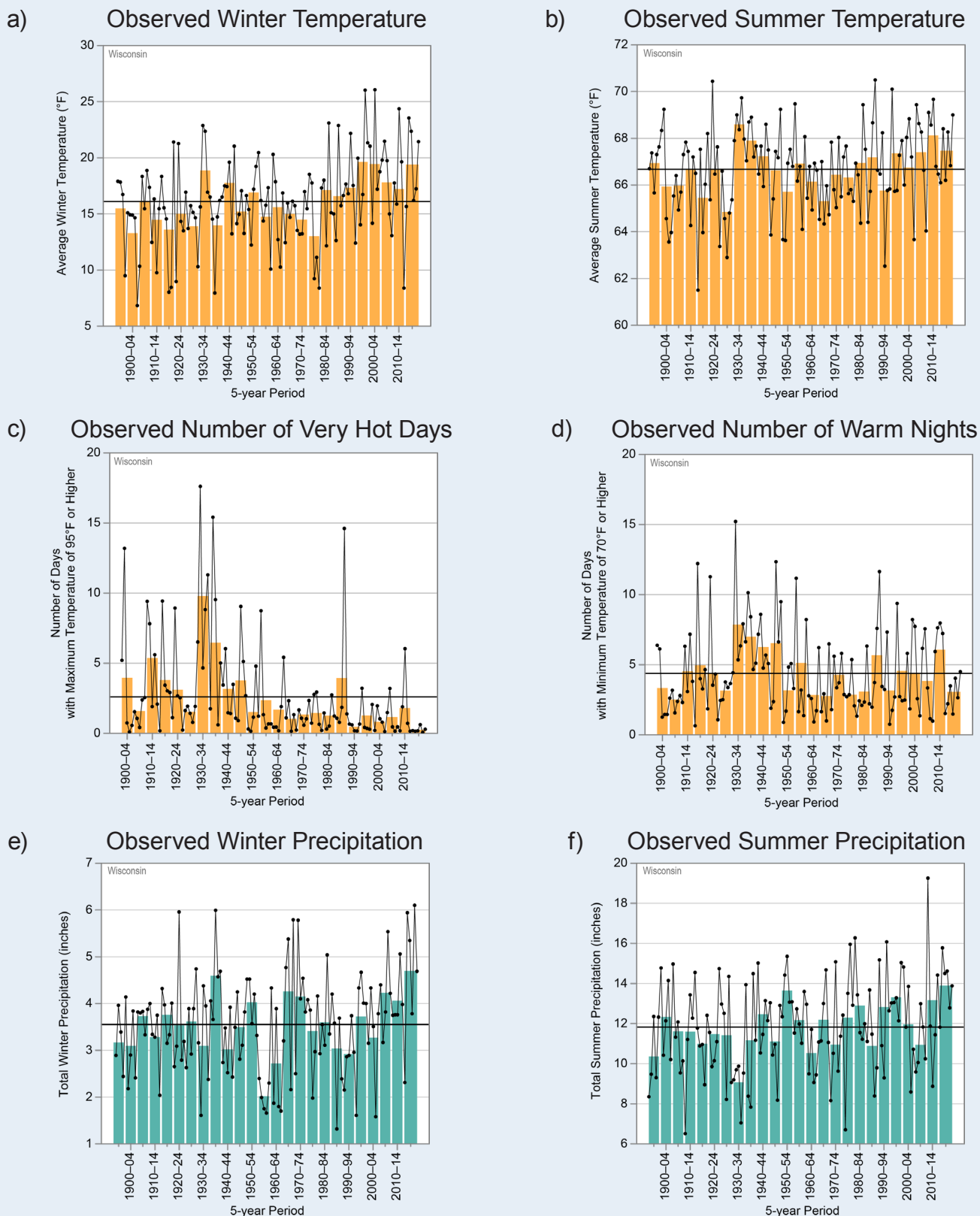


Figure 2: Observed (a) winter (December–February) average temperature, (b) summer (June–August) average temperature, (c) annual number of very hot days (maximum temperature of 95°F or higher), (d) annual number of warm nights (minimum temperature of 70°F or higher), (e) total winter precipitation, and (f) total summer precipitation for Wisconsin from (a, b, e, f) 1895–2020 and (c, d) 1900–2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: (a) 16.1°F, (b) 66.7°F, (c) 2.6 days, (d) 4.4 nights, (e) 3.6 inches, (f) 11.8 inches. Winter and summer temperatures have generally been above average since 1980. Due to extreme drought and poor land management practices, the summers of the 1930s remain the warmest on record. The number of very hot days has been below average since 1950 (excluding the 1985–1989 period), indicating a lack of summer warming, while the number of warm nights has fluctuated around the average since 1995. Winter and summer precipitation has been above average since 2005 and 2010, respectively. Sources: CISESS and NOAA NCEI. Data: (a, b, e, f) nClimDiv; (c, d) GHCN-Daily from 25 long-term stations.

Since the beginning of the 20th century, temperatures in Wisconsin have risen more than 2°F, and temperatures in the 2000s have been warmer than in any other historical period (Figure 1). The hottest 5-year period on record was 2000–2004. The hottest year was 2012, with a statewide average temperature of 47.4°F, which is 5°F above the long-term average. Like much of the Midwest, this warming has been concentrated in the winter and spring, while summers have warmed less (Figures 2a and 2b). Warmer spring temperatures present the additional threat of frost-freeze damage to early-budding fruit trees. In 2012, a “killer frost” closely followed an abnormally warm March, resulting in significant damage to fruit crops. The lack of summer warming is reflected in a below average occurrence of very hot days (Figure 2c) and no overall trend in warm nights (Figure 2d). The number of very cold days has been near or below average since 2000, reflecting a winter warming trend (Figure 3). The increase in winter temperatures has also reduced lake ice cover. Ice coverage in the Great Lakes has been declining since the 1970s. For example, the annual average maximum ice coverage during 2003–2013 was less than 43%, compared to the 1962–2013 average of 52%. Ice-cover duration on Lake Mendota has exhibited a consistent downward trend since the late 19th century (Figure 4).

Precipitation varies widely from year to year (Figure 5), and most of the state’s precipitation falls during the warmer half of the year. Statewide total annual precipitation has ranged from a low of 20.5 inches in 1910 to a high of 44.6 inches in 2019. **Recently, Wisconsin has experienced some unusually wet years in addition to 2019. The third-wettest year on record was 2018 (39.7 inches), and 2016, 2010, 2017, and 2014 were the fourth-, fifth-, tenth-, and eleventh-wettest, respectively. The driest multiyear periods were in the late 1890s, early 1930s, and late 1950s, and the wettest were in the early 1990s and 2010s.** The driest consecutive 5-year interval was 1929–1933, and the wettest was 2015–2019. Total winter precipitation and total summer precipitation have been mostly above average over the last 26 years (Figures 2e and 2f). The frequency of 2-inch extreme precipitation events has increased, with the highest number occurring during the 2015–2020 period (Figure 6). Snowfall varies from about 30 inches annually in the south to more than 100 inches along the Gogebic Range. This heavy snowfall along the Gogebic Range is partially due to lake-effect

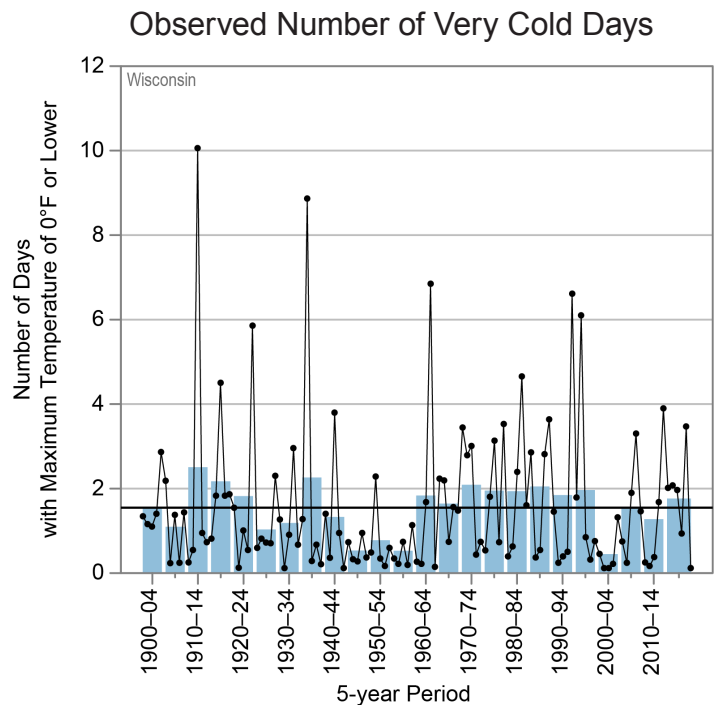


Figure 3: Observed annual number of very cold days (maximum temperature of 0°F or lower) for Wisconsin from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 1.6 days. The number of very cold days has varied widely across the historical record. Wisconsin experienced the fewest number of very cold days during the 2000–2004 period, indicative of overall winter warming in the region. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 25 long-term stations.

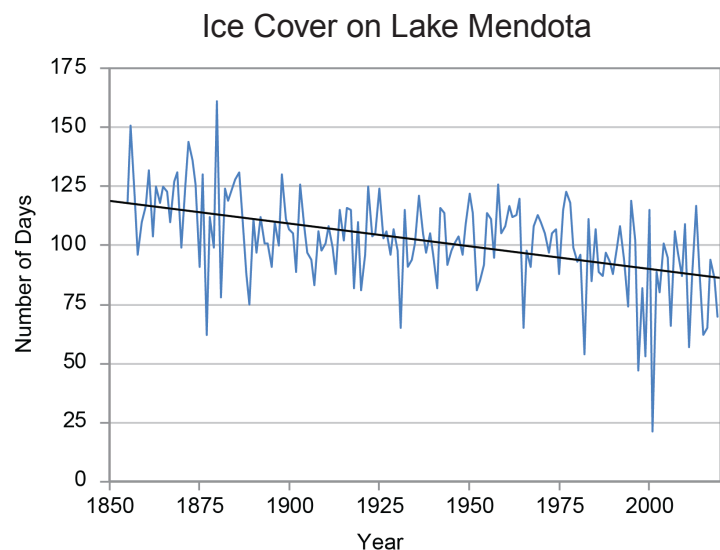


Figure 4: Annual changes in ice-cover duration (blue line) for Lake Mendota from 1855 to 2020. The total duration of ice cover exhibits a consistent downward trend (black line), decreasing from about 120 days in the late 19th century to fewer than 100 days in most years since 1990. Source: Wisconsin State Climatology Office.

snow events on the south shore of Lake Superior, which has experienced significant upward trends in annual snowfall totals. These upward trends are attributed to warmer air temperatures, which create more moisture

Observed Annual Precipitation

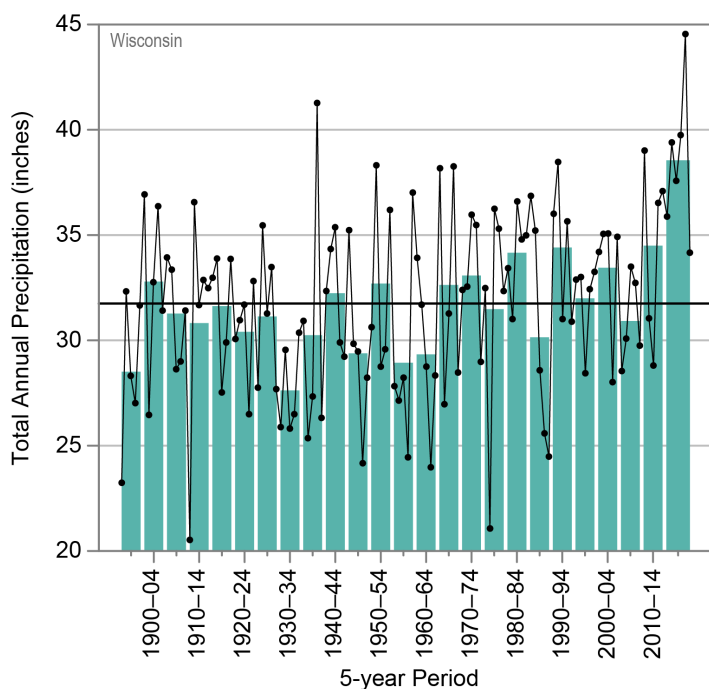


Figure 5: Observed total annual precipitation for Wisconsin from 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 31.8 inches. Annual precipitation varies widely, but recent years have seen totals well above average. The wettest consecutive 5-year interval was 2015–2019, with an annual average of 39.4 inches, while the driest was 1929–1933, with an annual average of only 27.1 inches. Sources: CISESS and NOAA NCEI. Data: nClimDiv.

availability due to warmer surface water temperatures and reduced lake ice coverage. Annual snowfall totals have also increased over the rest of Wisconsin since 1930.

Many rivers border and run through Wisconsin, and due to both ice jams and heavy precipitation, the state is susceptible to both groundwater flooding and river flooding. Heavy rain and snow during the fall and winter of 2007–2008 led to elevated water tables by the summer of 2008. The elevated water tables, combined with increased summer precipitation, caused flooding to persist for 6 months and resulted in approximately \$17 million in agricultural and property damages from groundwater flooding alone. In addition, during June 5–12, 2008, a series of storms brought heavy rain to southern Wisconsin, with multiple stations reporting more than 10 inches. The rain caused severe flooding, totaling more than a billion dollars in damages.

Observed Number of 2-Inch Extreme Precipitation Events

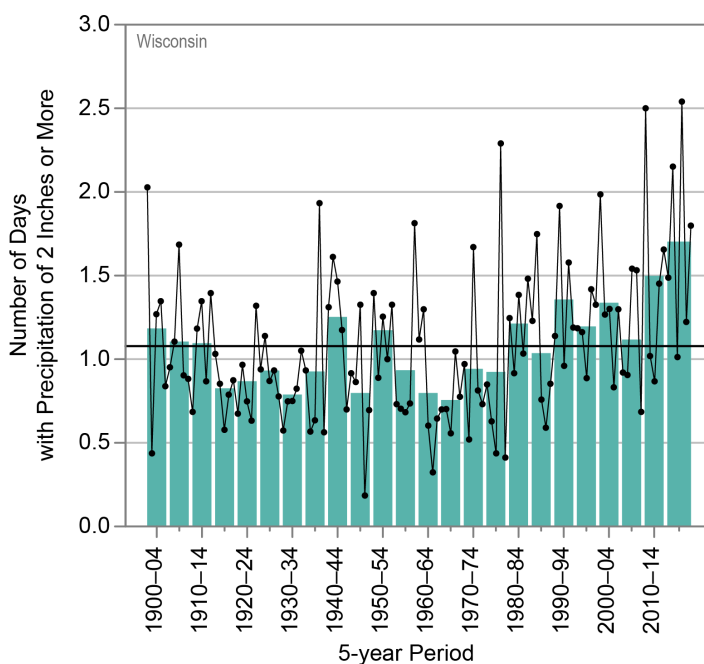


Figure 6: Observed annual number of 2-inch extreme precipitation events (days with precipitation of 2 inches or more) for Wisconsin from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 1.1 days. A typical reporting station experiences 1 event per year. Since 1990, Wisconsin has experienced an increasing number of 2-inch extreme precipitation events. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 30 long-term stations.

Due to the state's northerly location and proximity to the winter storm track, severe winter storms are a regular occurrence. During February 1–2, 2011, southern Wisconsin experienced blizzard conditions from a powerful storm tracking south of the state. Snow accumulations ranged from 12 to 26 inches, with wind gusts of 45 to 60 mph. One of Wisconsin's worst natural disasters was a devastating ice storm in the south-central and southeastern portion of the state during March 4–5, 1976. Ice accumulations of up to 5 inches were reported, downing thousands of power lines and snapping many trees and utility poles. Some rural areas were without power for 10 days.

Severe thunderstorms are a threat to the state, particularly during the spring and summer months. A strong derecho during May 30–31, 1998, caused wind gusts of 70 to 100 mph, with some areas reporting winds of up to 128 mph. More than 250,000 people

lost power, and damages were estimated at more than \$60 million. Although tornadoes are not as common in Wisconsin as in other midwestern states, they can occasionally occur and cause loss of life. The state averaged 23 tornadoes annually during 1980–2020, with a record of 62 in 2005. On August 25, 2005, twenty-seven tornadoes occurred in southern Wisconsin, the state's highest confirmed number of tornadoes in a single day. Among those tornadoes, an F3 tornado traveled about 20 miles into Jefferson County from Dane County, passing through Stoughton with maximum intensity and a width of one-half mile. It destroyed or damaged 240 houses, resulted in property damages of more than \$40 million, and killed 1 person and injured 23 more. On April 10, 2011, severe thunderstorms caused the largest single outbreak of tornadoes in northeastern Wisconsin; 4 of the 15 tornadoes were classified as strong (EF2 and EF3). Fortunately, the tornadoes impacted relatively rural areas, limiting damages to slightly more than \$10 million.

Water levels in the Great Lakes have fluctuated over a range of 3 to 6 feet since the late 19th century (Figure 7). Higher lake levels were generally noted in the late 19th century, the early 20th century, and the 1940s, 1950s, 1980s, and the late 2010s. Lower lake levels were observed in the 1920s and 1930s and again in the 1960s. For Lake Michigan–Huron, lower levels occurred during the first decade of this century. Lake levels have risen rapidly since 2013, with the highest levels since 1886 observed in 2020.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of this century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. Extreme heat is a particular concern when high temperatures combine

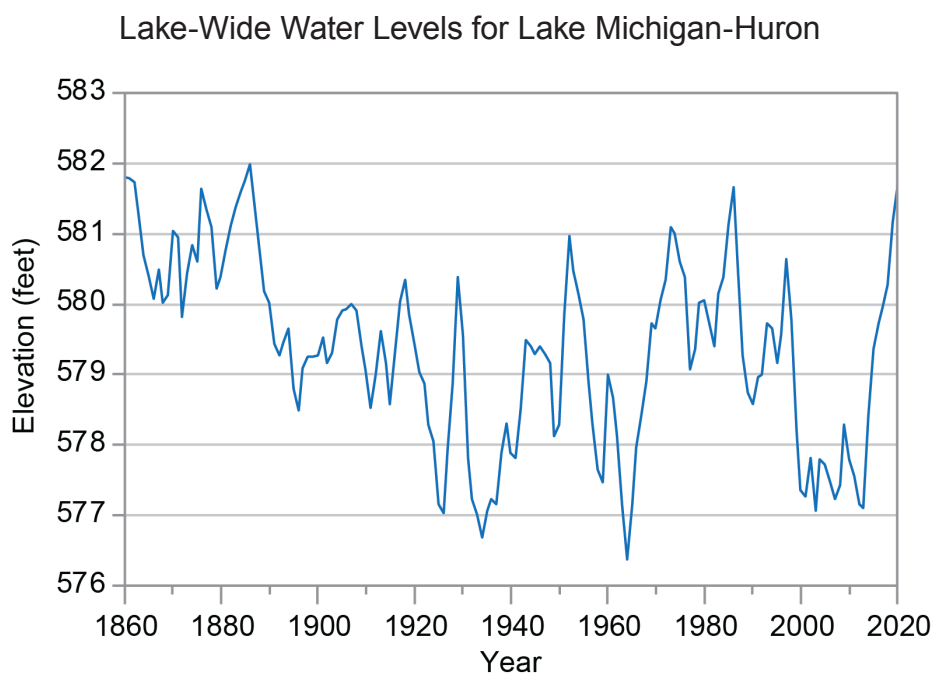


Figure 7: Annual time series of the average water levels for Lake Michigan–Huron from 1860 to 2020. Water levels in the Great Lakes have fluctuated widely over the years. Lake Michigan–Huron levels were very low during 2000–2013 but have since risen rapidly to the highest levels since 1886. Source: NOAA GLERL.

with high humidity to create dangerous heat index values, resulting in risks to human health. Urban areas are especially vulnerable to extreme heat, due to the urban heat island effect and high social vulnerability. Future heat waves are projected to be more intense, and cold waves are projected to be less intense. Winter ice cover on the Great Lakes is projected to decrease.

Precipitation is projected to increase for Wisconsin, with the most likely increases occurring during the winter and spring (Figure 8), but snowfall is projected to decline due to warmer temperatures. Additionally, extreme precipitation is projected to increase, potentially increasing the frequency and intensity of floods. Above normal precipitation enhances the risk of springtime flooding, which could pose a threat to Wisconsin's agricultural industry by delaying planting and causing yield losses.

The intensity of future droughts is projected to increase. Even if precipitation increases in the future, rising temperatures will increase the rate of soil moisture loss during dry periods. Thus, future summer droughts, a natural part of Wisconsin's climate, are likely to be more intense.

Changes in seasonal and multiyear precipitation, evaporation, and temperature can affect water levels in the Great Lakes, causing serious environmental and socioeconomic impacts. During the 1980s, high lake levels resulted in the destruction of beaches, the erosion of shorelines, and the flooding and destruction of near-shore structures. Low lake levels can affect the supply and quality of water, restrict shipping, and result in the loss of wetlands. Future changes in lake levels are uncertain and the subject of research. Reduced winter ice cover from warmer temperatures leaves shores vulnerable to erosion and flooding.

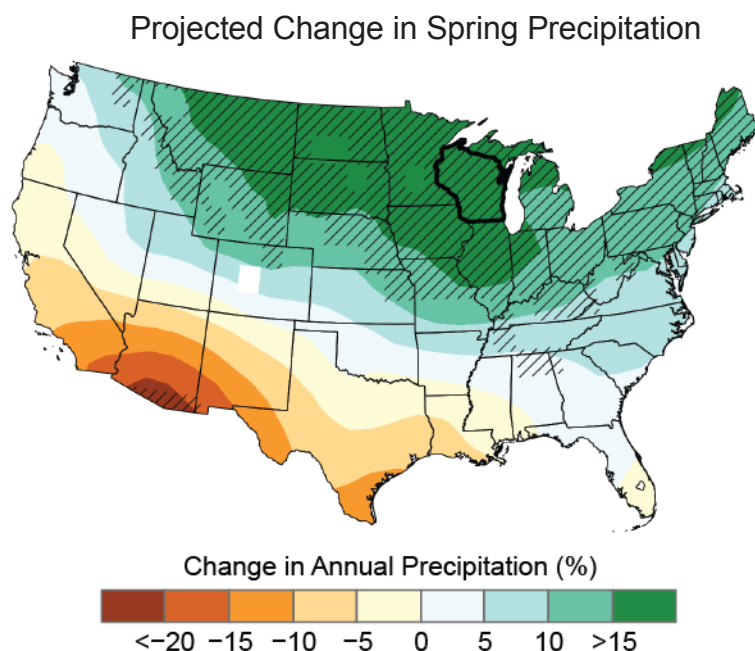


Figure 8: Projected changes in total spring (March–May) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. The whited-out area indicates that the climate models are uncertain about the direction of change. Hatching represents areas where the majority of climate models indicate a statistically significant change. Wisconsin is part of a large area of projected increases in the Northeast and Midwest. Sources: CISESS and NEMAC. Data: CMIP5.

Technical details on observations and projections are available online at <https://statesummaries.ncics.org/technicaldetails>.

WWW.NCEI.NOAA.GOV | [HTTPS://STATESUMMARIES.NCICS.ORG/CHAPTER/WI/](https://STATESUMMARIES.NCICS.ORG/CHAPTER/WI/) | LEAD AUTHORS: REBEKAH FRANKSON, KENNETH E. KUNKEL
CONTRIBUTORS: SARAH M. CHAMPION, LIQIANG SUN

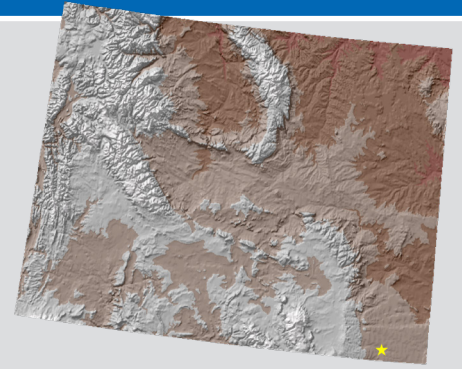
WYOMING

Key Messages

Temperatures in Wyoming have risen about 2.5°F since the beginning of the 20th century. Warming is most evident in winter and is reflected in a generally below average number of very cold days since 2000. Under a higher emissions pathway, historically unprecedented warming is projected during this century.

Winter and spring precipitation is projected to increase. Heavier spring precipitation, combined with a shift from snow to rain, could increase the potential for flooding.

Increases in evaporation rates due to rising temperatures may increase the rate of soil moisture loss and the intensity of naturally occurring droughts. The frequency and severity of wildfires are projected to increase.



Wyoming's climate is largely determined by its mid-latitude location in the interior of the North American continent, far from oceanic moisture sources. While its frequent proximity to the jet stream exposes it to periodic storm systems, its lack of easy access to moisture sources leads to a mostly semiarid climate. Wyoming also has large climatic variations due to its geographic diversity and altitudinal range. The eastern portion of the state lies within the Great Plains, while the central and western portions encompass a series of mountain ranges and basins. **Elevations across the state range from about 3,100 to 13,800 feet, causing wide variations in temperature.** The state has mild to warm (depending on elevation) summers and cold winters. Winter average (1991–2020 normals) minimum temperatures at individual locations are mostly in the range of 5°F to 18°F (depending on elevation and topography), with lower values at higher elevations. For most of the state, summer average maximum temperatures range from 75°F to 89°F, although temperatures are much lower at higher elevations. Due to the state's semiarid climate, temperatures can vary widely from day to night. The hottest year on record was 2012, with a statewide annual average temperature of 44.8°F (3.8°F higher than the long-term [1895–2020] average).

Observed and Projected Temperature Change

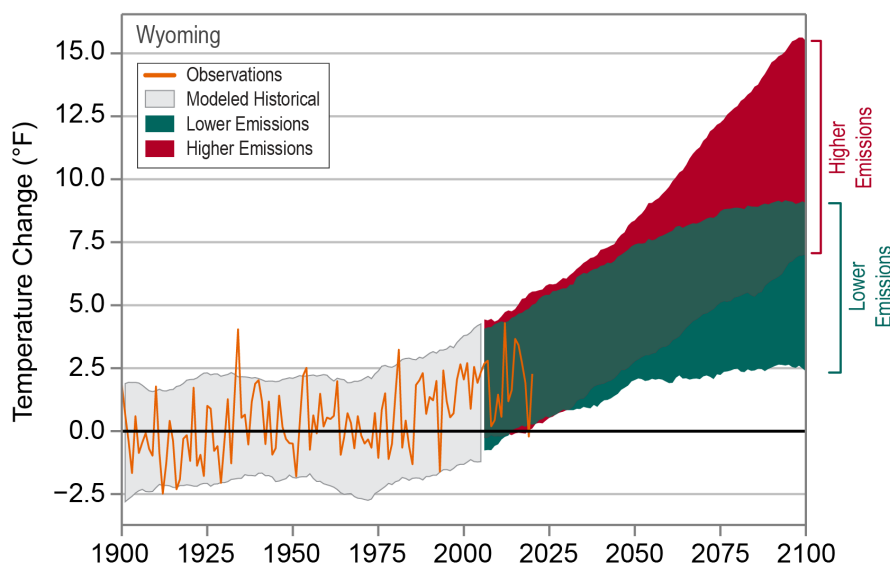


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Wyoming. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Wyoming (orange line) have risen about 2.5°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during this century. Less warming is expected under a lower emissions future (the coldest end-of-century projections being about 2°F warmer than the historical average; green shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 11°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

shading) and more warming under a higher emissions future (the hottest end-of-century projections being about 11°F warmer than the hottest year in the historical record; red shading). Sources: CISESS and NOAA NCEI.

Temperatures in Wyoming have risen about 2.5°F since the beginning of the 20th century (Figure 1), and nearly every year of this century has been above the long-term average. This warming has been observed in all seasons; since 1995, winter and summer temperatures have averaged 1.9°F and 1.3°F above the historical average, respectively (Figures 4a and 4b). The highest number of very hot days occurred during the 2000s and early 2010s (Figure 2). While warm nights are rare in Wyoming, the number of these nights has generally been above average since 2000 (Figure 3). Another indication of the overall trend of higher average temperatures is a generally below average number of very cold days since 2000 (Figure 4c).

Wyoming's topographic variability causes large regional variations in precipitation across the state.

Total annual precipitation at long-term observation stations varies from 5.51 inches in the north-central part of the state to 32.82 inches in Yellowstone National Park. Temporal variability is also large. Statewide precipitation totals have varied from a low of 11.0 inches in 2012 to a high of 20.5 inches in 1927. The driest multiyear periods were in the early 1930s and early 2000s and the wettest in the late 1940s and late 1990s (Figure 4d). The driest consecutive 5-year interval was 1931–1935, averaging 13.4 inches per year, and the wettest was 1995–1999, averaging 18.2 inches per year. Most of the state's precipitation falls during spring and summer, although some areas in the mountains experience a peak during winter. Some mountainous regions receive more than 200 inches of snowfall annually. Since the 2005–2009 period, the number of 1-inch extreme precipitation events has been increasing (Figure 4e).

During the summer months, the state experiences frequent thunderstorms, which can produce hail, lightning, and strong winds. Southeastern Wyoming lies in “Hail Alley,” the most hail-prone area in the country. Since 2010, the state has averaged 34 severe hail (1-inch diameter or larger) days annually. On August 1, 1985, a severe thunderstorm in Cheyenne dropped more than 6 inches of rain in just over 3 hours and produced hail of up to 2 inches in diameter. In some areas of the city, the hail piled up in 4- to 8-foot drifts. On June 6, 2020, Wyoming was one of the states

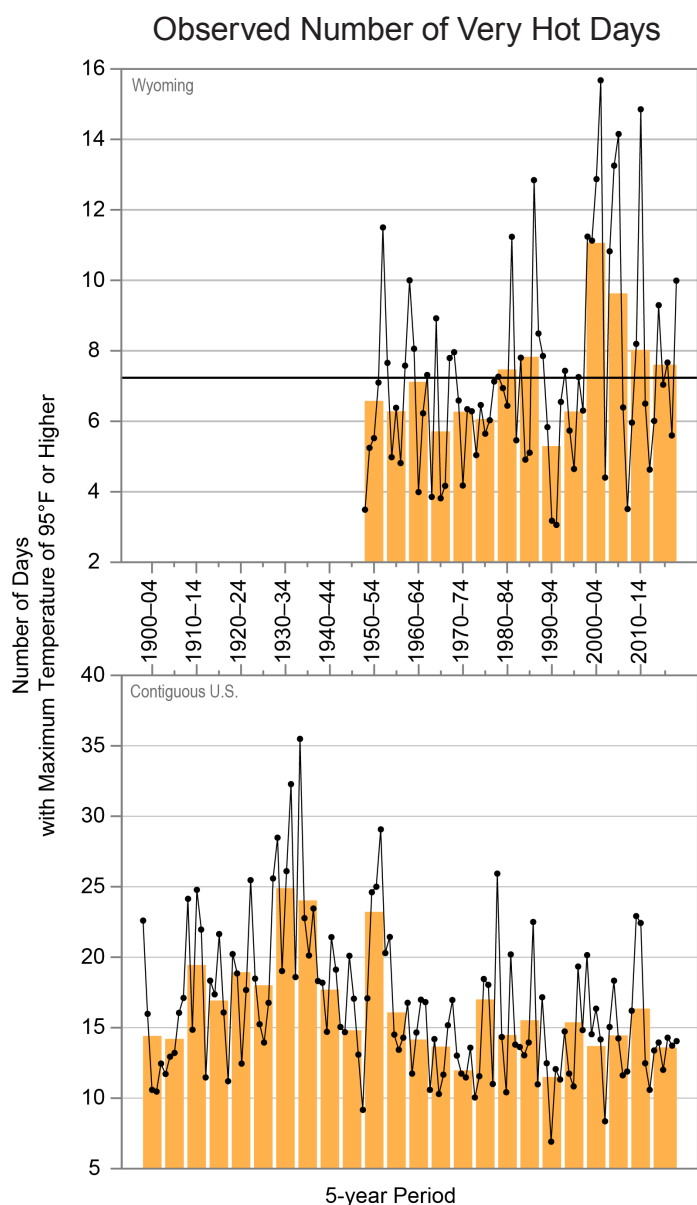


Figure 2: Observed annual number of very hot days (maximum temperature of 95°F or higher) for Wyoming from 1950 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 7.2 days. Values for the contiguous United States (CONUS) from 1900 to 2020 are included to provide a longer and larger context. Long-term stations dating back to 1900 were not available for Wyoming. The highest number of very hot days in Wyoming occurred during the 2000s and early 2010s. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 35 (WY) and 655 (CONUS) long-term stations.

hit by an exceptionally rare western-U.S. derecho. This storm began in eastern Utah and tracked northeast over 750 miles before ending in North Dakota. Of the 339 total wind reports, 55 came from the state of Wyoming. A mesonet station near the Wyoming–South Dakota border measured a wind gust of 85 mph, the highest in the state for that type of event.

Observed Number of Warm Nights

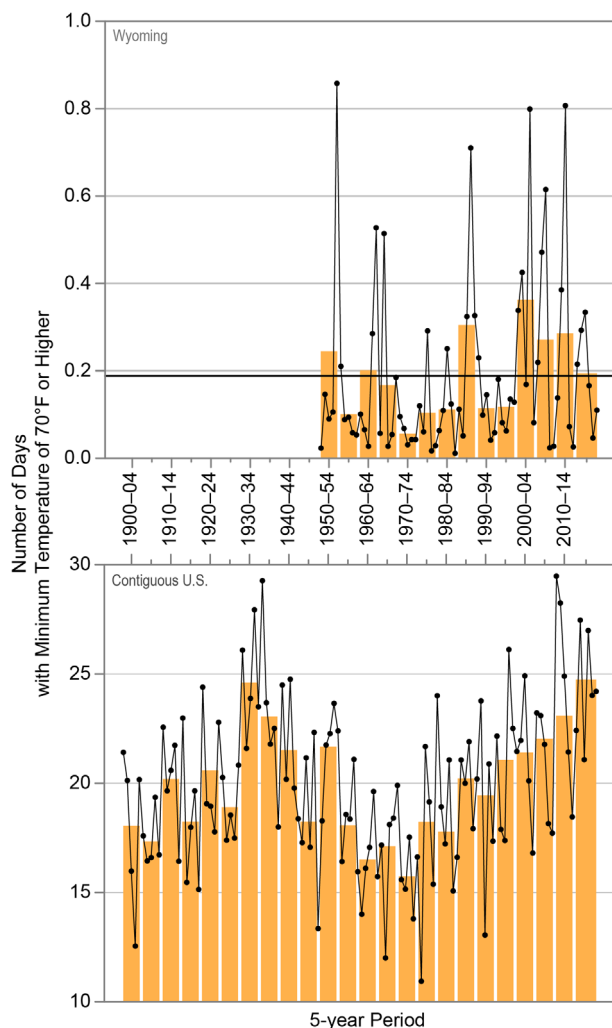


Figure 3: Observed annual number of warm nights (minimum temperature of 70°F or higher) for Wyoming from 1950 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 0.2 nights. Values for the contiguous United States (CONUS) from 1900 to 2020 are included to provide a longer and larger context. Long-term stations dating back to 1900 were not available for Wyoming. Wyoming rarely experiences warm nights due to its semiarid climate and high average elevation. However, since 2000, the number of warm nights has generally been above average. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 35 (WY) and 655 (CONUS) long-term stations.

Wyoming's northern location and associated proximity to the jet stream also make it susceptible to the impacts of winter storm systems, including heavy snows, high winds, and low wind chill temperatures.

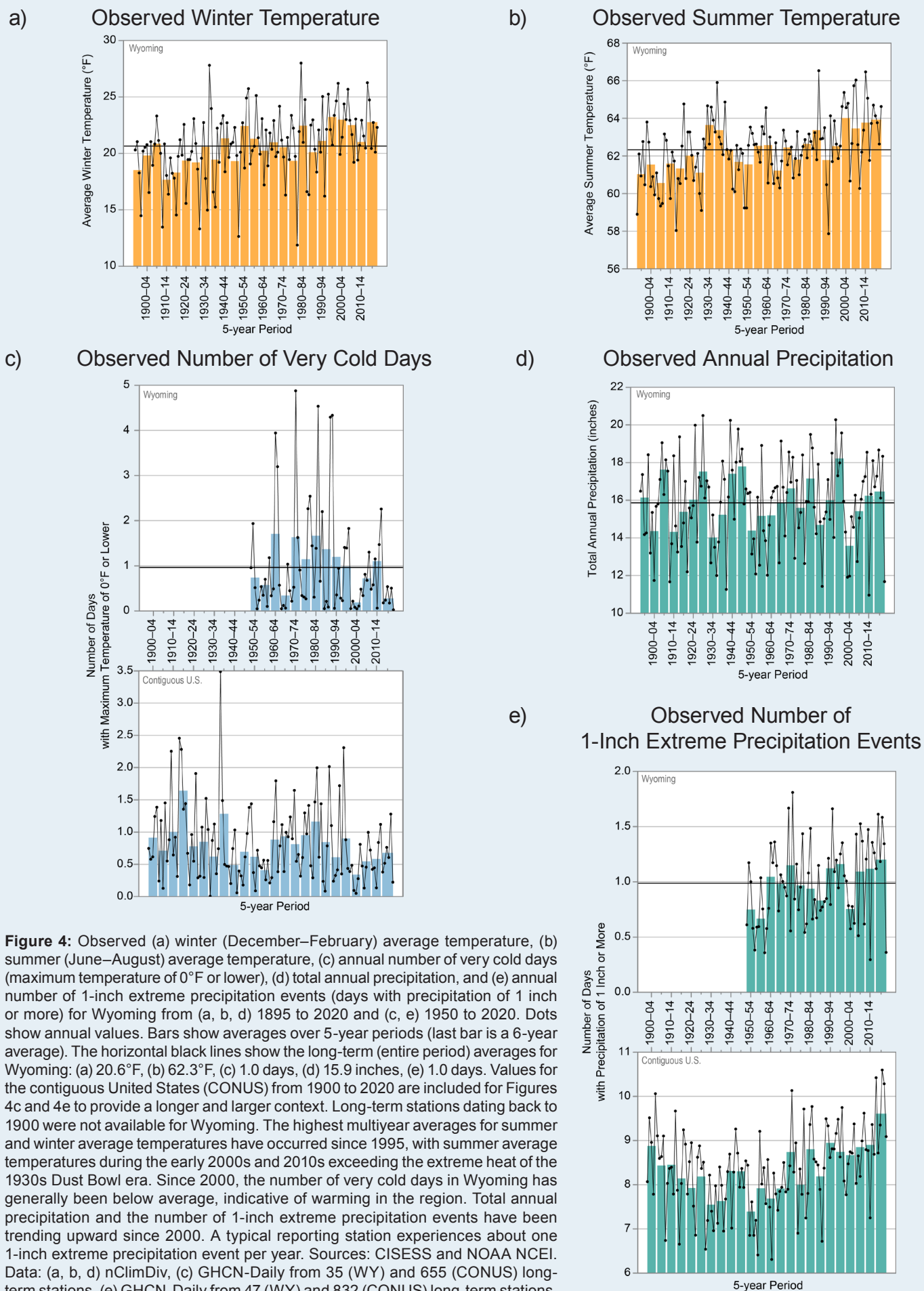
In early 1949, a series of winter storms devastated the state, killing 17 people and hundreds of thousands of livestock. More recently, eastern Wyoming was hit by an early-season blizzard (October 3–5, 2013) that knocked down power lines and closed many roads. Among long-term weather observing stations, Bates Creek No. 2

reported the highest snowfall amounts of 25 inches over the 3-day period, 20 inches of which fell on October 5th.

Chinook winds—warm and dry downslope winds that occur along the eastern slope of the Rocky Mountains—are a hazard unique to Wyoming and western mountain states. During the winter months, these winds can persist along the eastern slope of the Continental Divide and often bring large temperature increases that lead to rapid snowmelt. Chinook winds can often gust strong enough to cause property damage, as well as flooding due to the rapid melting of snow.

Wyoming is a major source of water for other states, and changes in precipitation can have broad impacts beyond its boundaries. Water from the state's rivers flows into four major river basins: the Missouri–Mississippi, Green–Colorado, Snake–Columbia, and Great Salt Lake. Yearly variations in late-season snowpack depths are large; for example, April 1 snow water equivalent (the amount of water contained within the snowpack) at Lewis Lake Divide has ranged from less than 20 inches to more than 50 inches since 1981 (Figure 5). Such variations have implications for water availability across the West, as snowmelt from the winter snowpack feeds many rivers and streams. **In years with heavy snow cover, heavy rains during the spring thaw can cause rapid melting of the snowpack and lead to severe flooding.**

Wyoming, like the rest of the Great Plains, is susceptible to droughts, which are occasionally severe. From 1999 to 2008, large portions of the state experienced drought conditions. The state then experienced several years of above average precipitation until 2012, which was Wyoming's driest year since historical records began in 1895. By October 2012, almost 90% of the state was in "severe" drought (the U.S. Drought Monitor's third-highest category of drought severity). The drought, along with high temperatures and high winds, resulted in one of Wyoming's worst wildfire seasons, with more than 350,000 acres burned (more than 3 times the yearly average [2002–2020] of 113,000 acres). Another severe wildfire season occurred in 2020; by October 2020, about 60% of the state was in severe drought and almost 340,000 acres had burned.



Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, annual average temperatures are projected to most likely exceed historical record levels by the middle of the century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. Increases in heat wave intensity are projected, but the intensity of cold waves is projected to decrease.

Winter and spring precipitation is projected to increase (Figure 6). Projected rising temperatures will raise the snow line—the average lowest elevation at which snow falls. This will increase the likelihood that precipitation will fall as rain rather than snow, reducing water storage in the snowpack, particularly at lower mountain elevations that are now on the margins of reliable snowpack accumulation. Higher spring temperatures will also result in earlier melting of the snowpack, further decreasing water availability during the drier summer months. Heavier spring precipitation, combined with a shift from snow to rain, could increase the potential for flooding.

The intensity of future droughts is projected to increase, even if precipitation amounts increase. Increases in evaporation rates due to rising temperatures may increase the rate of soil moisture loss during dry spells. Thus, future summer droughts, a natural part of Wyoming's climate, are likely to become more intense. This in turn will increase the risk of wildfires, which are projected to become more frequent and severe.

April 1 Snow Water Equivalent (SWE) at Lewis Lake Divide, WY

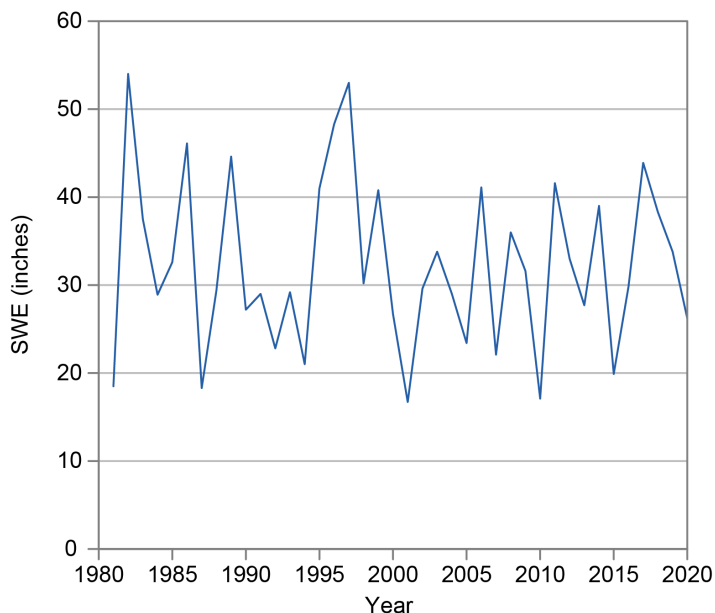


Figure 5: Variations in the April 1 snow water equivalent (SWE) at the Lewis Lake Divide, Wyoming, SNOTEL site from 1981 to 2020. SWE, the amount of water contained within the snowpack, varies widely from year to year. Source: NRCS NWCC.

Projected Change in Spring Precipitation

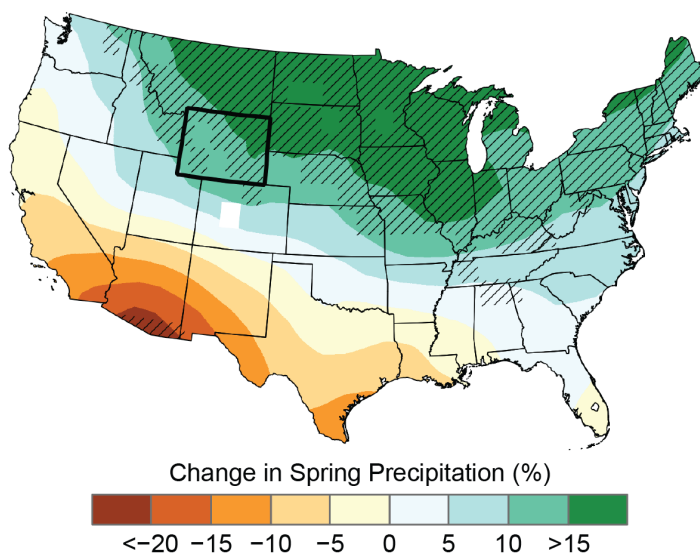


Figure 6: Projected changes in total spring (March–May) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. The white-out area indicates that the climate models are uncertain about the direction of change. Hatching represents areas where the majority of climate models indicate a statistically significant change. Wyoming is part of a large area of projected increases across the northern United States. Sources: CISESS and NEMAC. Data: CMIP5.

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