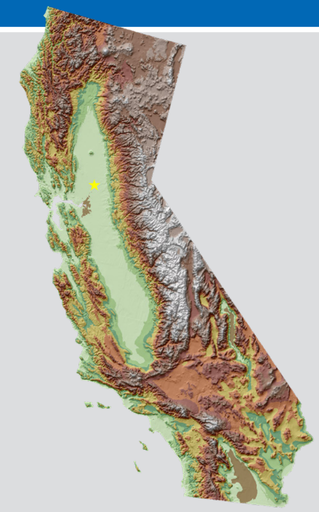
CALIFORNIA



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

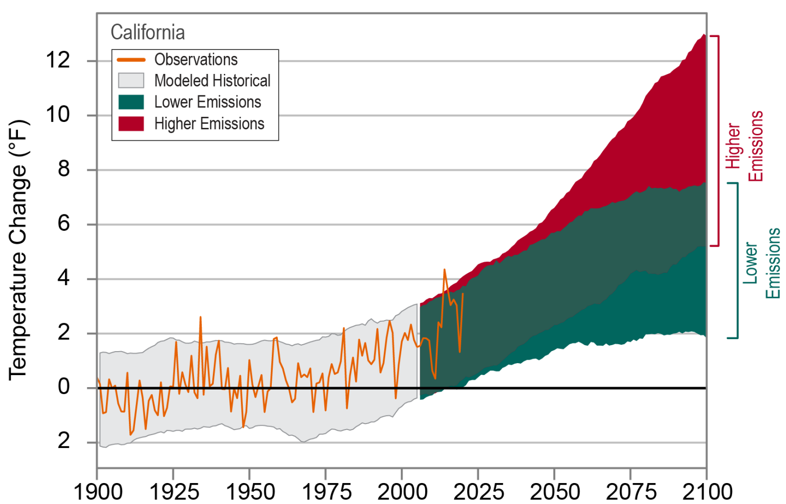


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for California. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (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.

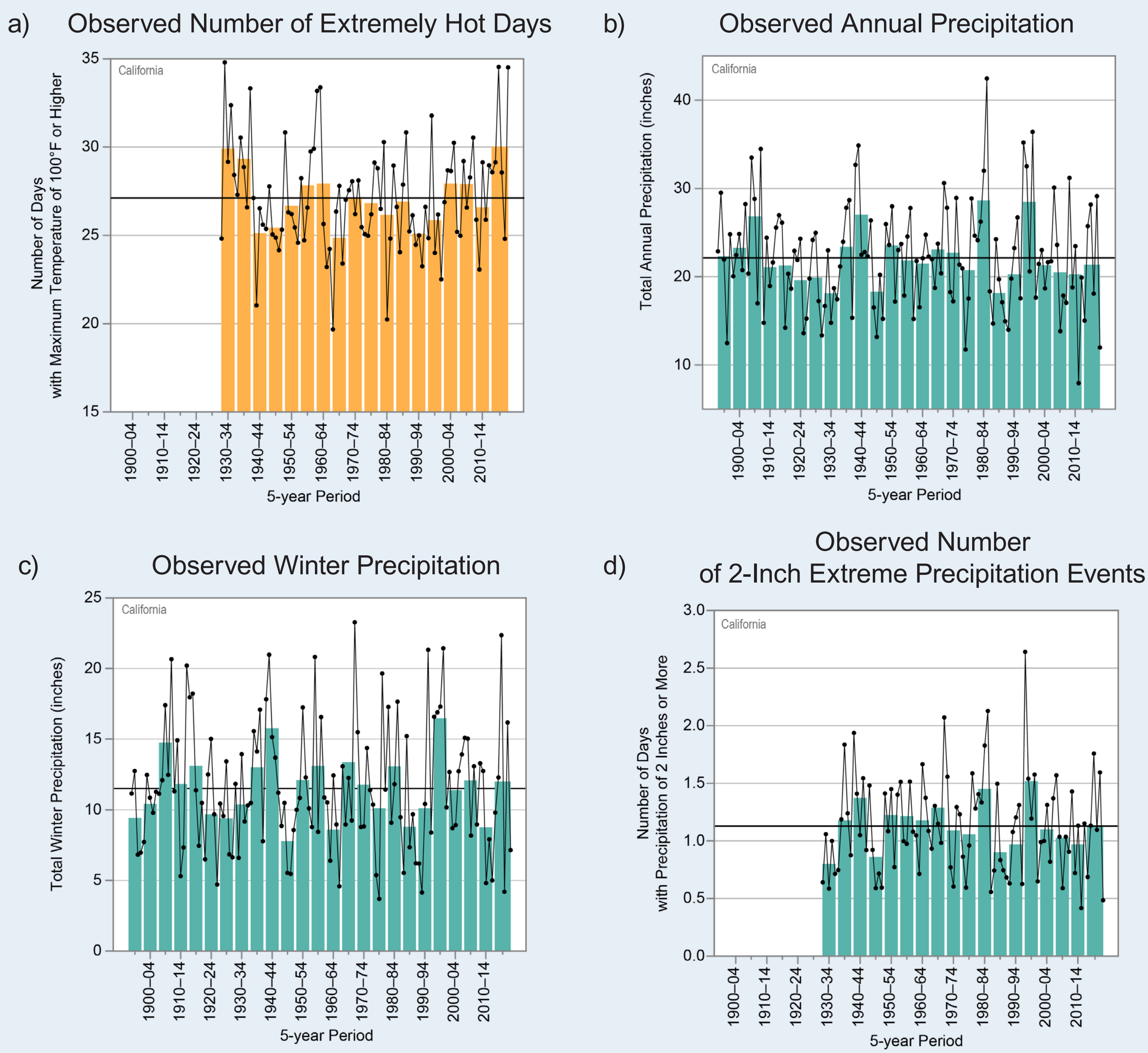


Figure 2: Observed (a) annual number of extremely hot days (maximum temperature of 100°F or higher), (b) total annual precipitation, (c) total winter (December–February) precipitation, and (d) annual number of 2-inch extreme precipitation events (days with precipitation of 2 inches or more) for California 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.

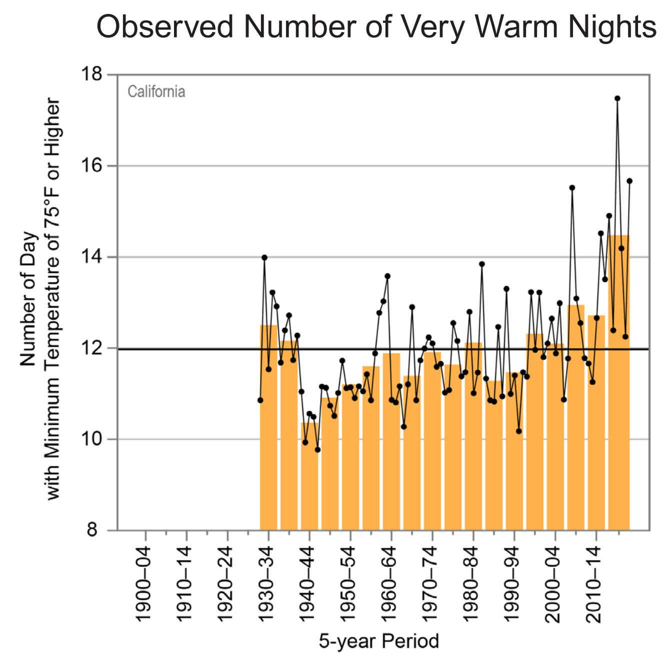


Figure 3: Observed annual number of very warm nights (minimum temperature of 75°F or higher) for California from 1930 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 12 nights (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.

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.

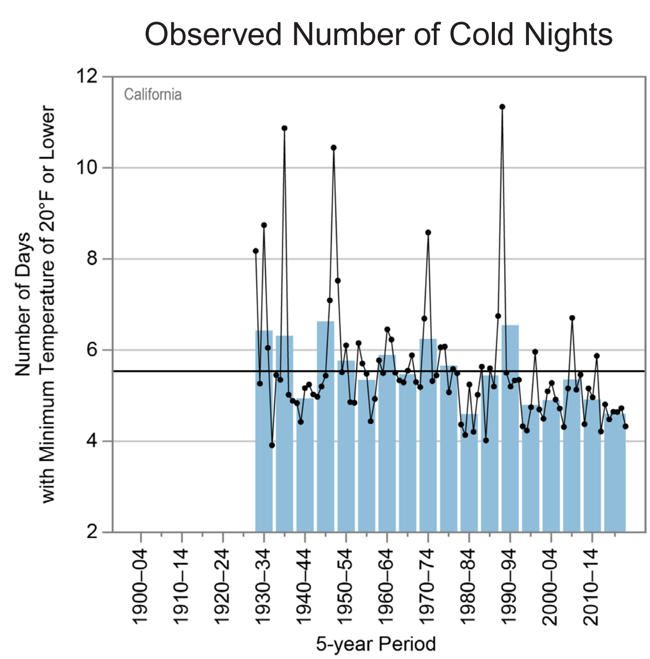


Figure 4: Observed annual number of cold nights (minimum temperature of 20°F or lower) for California from 1930 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 5.5 nights (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.

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

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

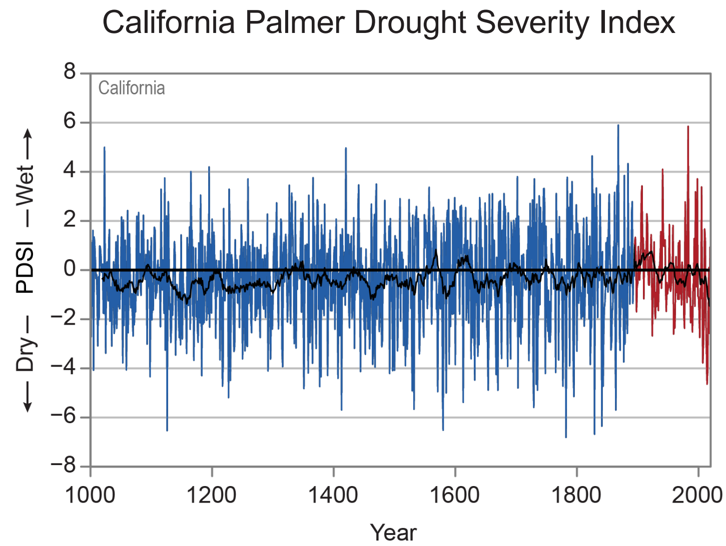


Figure 5: Time series of the Palmer Drought Severity Index for California from the year 1000 to 2020. Values for 1895–2020 (red) are based on measured temperature and precipitation. Values prior to 1895 (blue) are estimated from indirect measures such as tree rings. The fluctuating black line is a running 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.

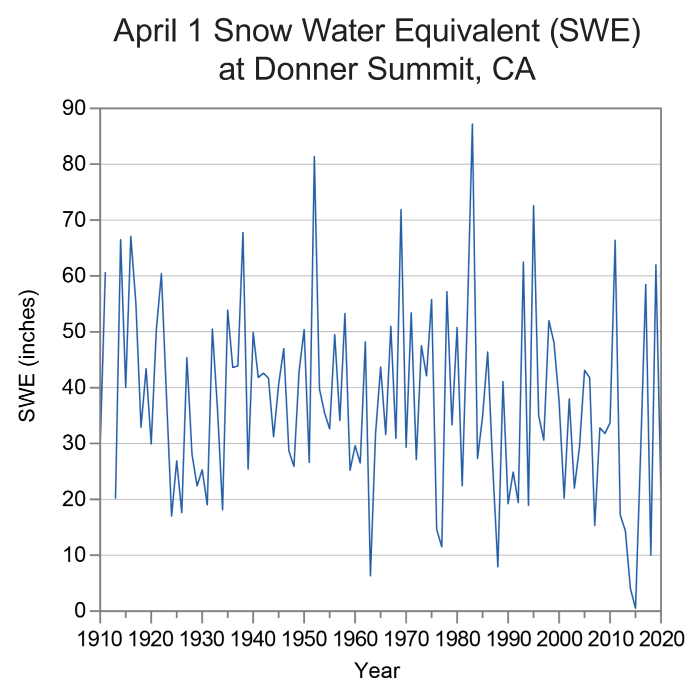


Figure 6: Variations in the April 1 snow water equivalent (SWE) at the Donner Summit, California, snow course site. SWE, the amount of water contained within the snowpack, varies widely from year to year. Snowpack levels decreased between 2011 and 2015 due to unusually low precipitation and warm temperatures 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.

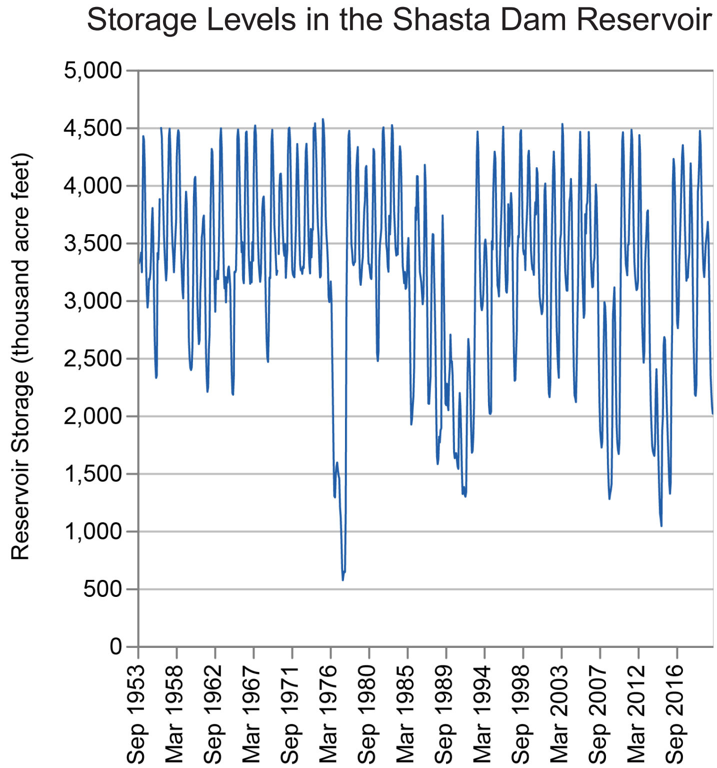


Figure 7: Monthly time series of the average water storage levels in the Shasta Dam Reservoir, California, from September 1953 to December 2020. The Shasta Dam Reservoir generally experiences similar seasonal cycles in water levels from year to year. However, water levels have dropped significantly several 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.

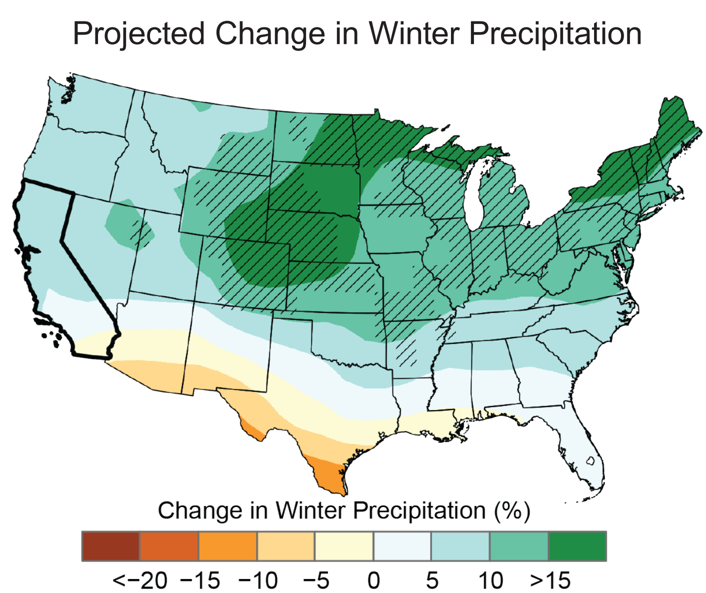


Figure 8: Projected changes in total winter (December–February) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. Winter precipitation 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.

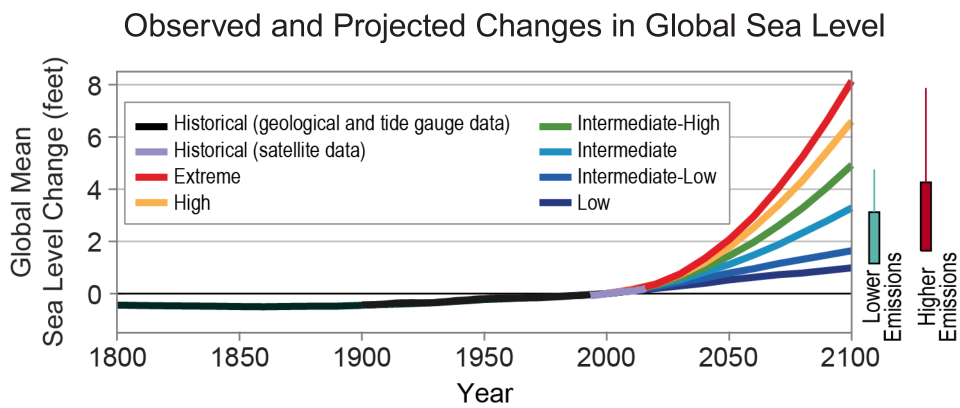


Figure 9: Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate-Low, royal blue; Intermediate, cyan; Intermediate-High, green; High, orange; and Extreme, red curves) relative to historical 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.

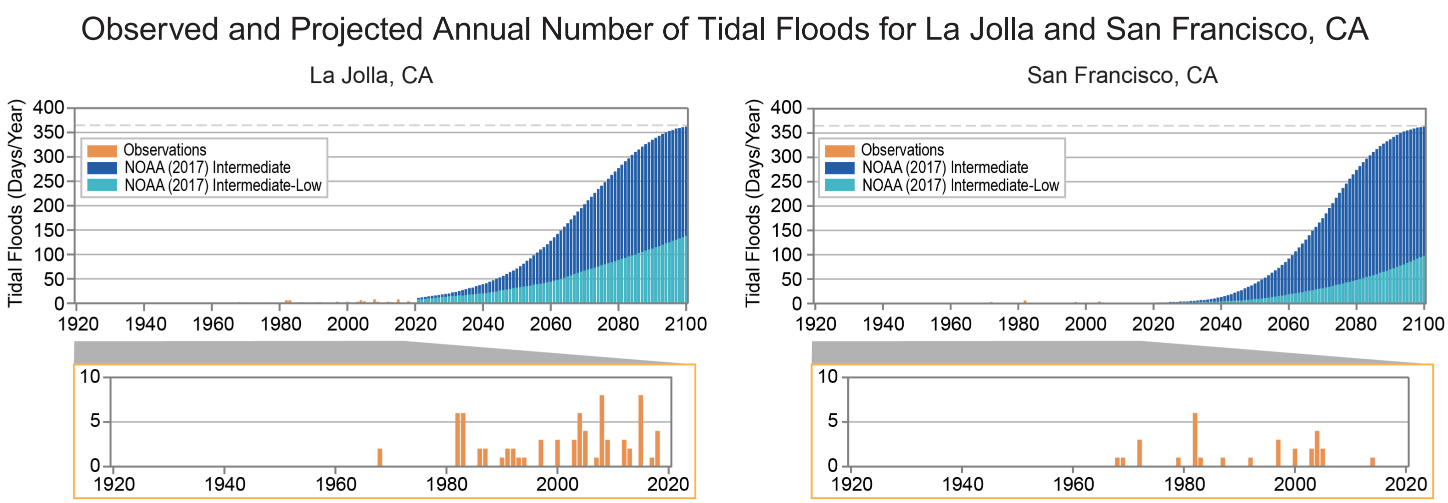


Figure 10: Number of tidal flood days per year at La Jolla and San Francisco, California, for the observed record (1925–2020 for La Jolla and 1920–2020 for San Francisco; orange bars) and projections for two NOAA (2017) sea level rise scenarios (2021–2100): Intermediate (dark blue bars) and Intermediate-Low (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.