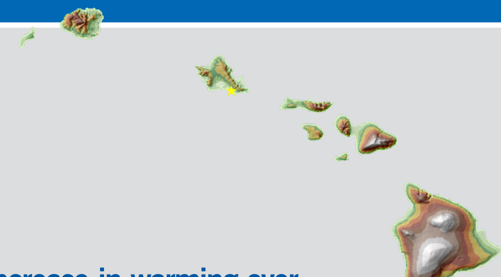

# HAWAIʻI

## Key Messages

**Temperatures in Hawaiʻi 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 Hawaiʻi 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 Kauaʻi and Oʻahu but more frequent for the Island of Hawaiʻi.**

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

Hawaiʻi 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. Hawaiʻi, 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 Hawaiʻi 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).

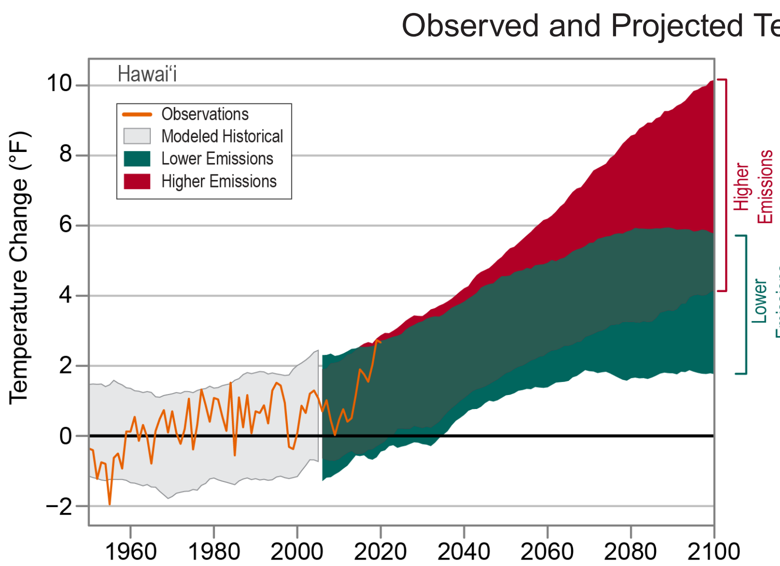


**Figure 1:** Observed and projected changes (compared to the 1951–1980 average) in near-surface air temperature for Hawaiʻi. Observed data are for 1950–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Hawaiʻi (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: CISESS and NOAA NCEI. Data: GHCN-Monthly from 5 long-term stations (observations) and CMIP5 (projections).

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,

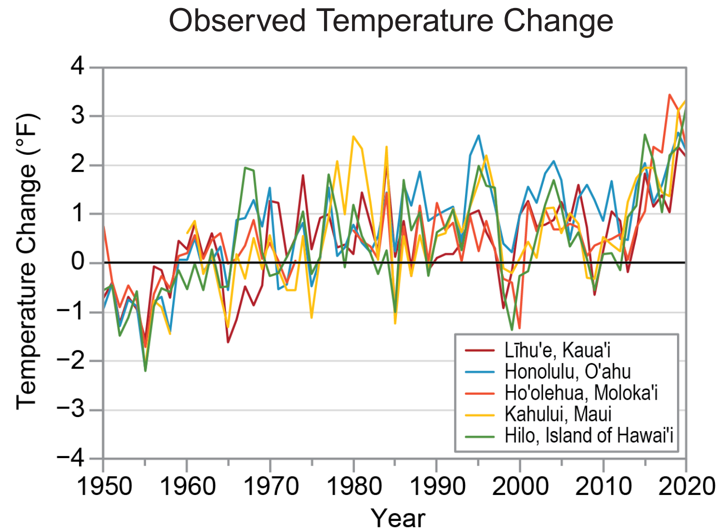


**Figure 2:** Observed changes (compared to the 1951–1980 average; horizontal black line) in annual near-surface air temperature for 5 long-term reporting stations in Hawai‘i from 1950 to 2020: Līhu‘e, Kaua‘i (red line); Honolulu, O‘ahu (blue line); Ho‘olehua, Molokai‘i (orange line); Kahului, Maui (yellow 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.

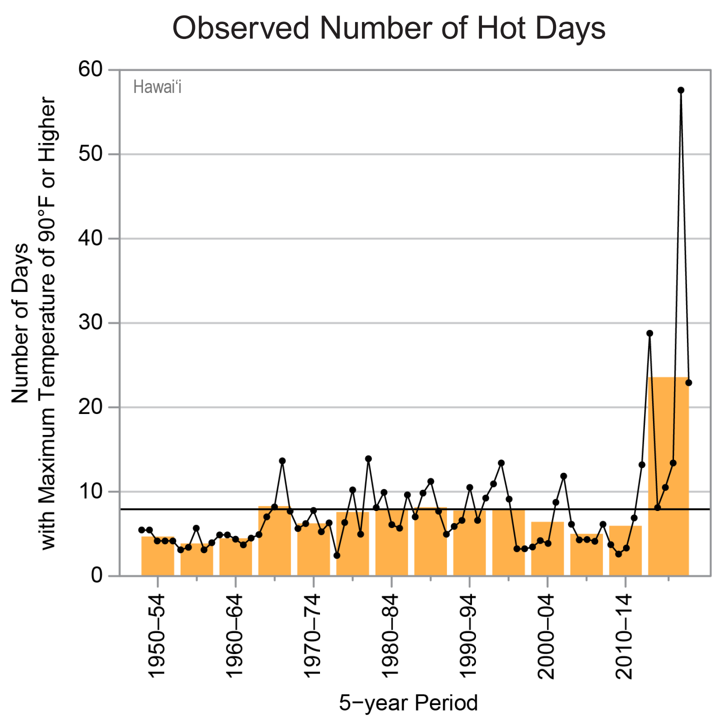


**Figure 3:** Observed annual number of hot days (maximum temperature of 90°F or higher) for Hawai‘i from 1950 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 7.9 days. The 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

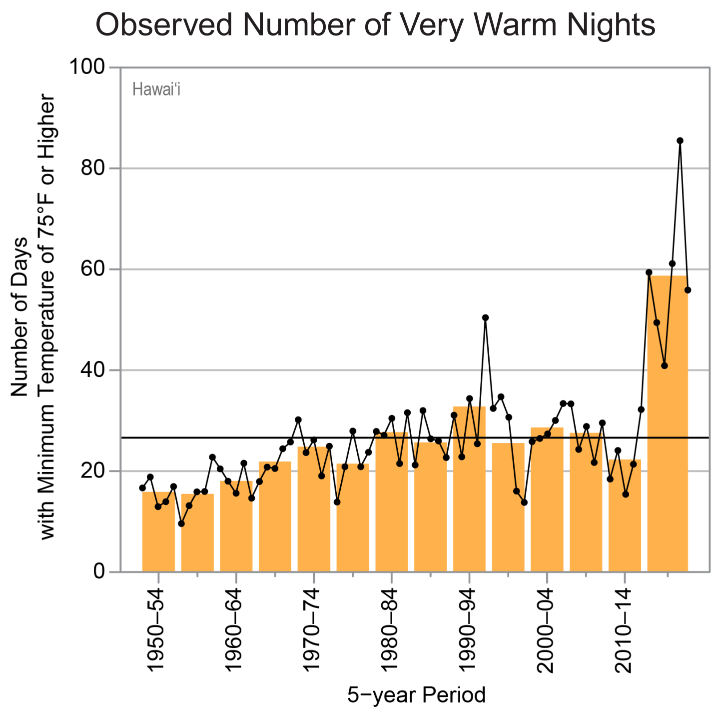


**Figure 4:** Observed annual number of very warm nights (minimum temperature of 75°F or higher) for Hawai‘i from 1950 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 27 nights. 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.

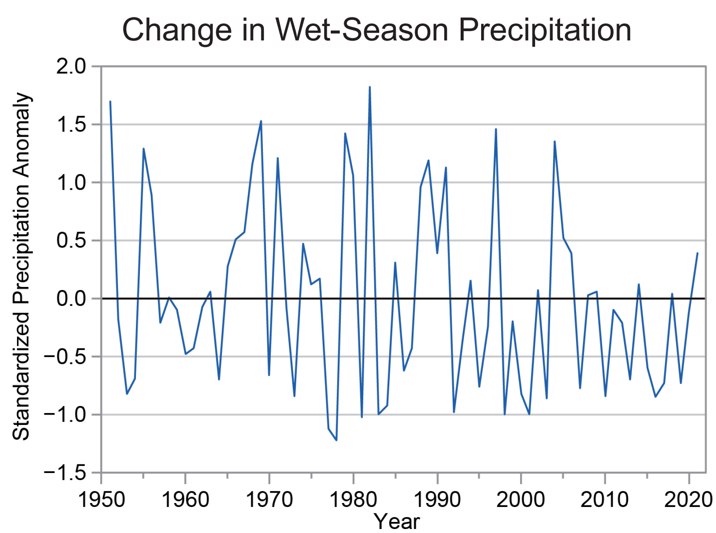


**Figure 5:** Time series of wet-season (November through March) Hawai‘i precipitation for 1950–2021 as derived from 25 long-term reporting stations. These values represent precipitation variations over different climate regions of the Hawaiian Islands. A normalization technique is applied to each individual 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 Hawaiʻi 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 Hawaiʻi 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 Hawaiʻi**. 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 Hawaiʻi vary between the islands, ranging from 0.6 inches per decade for Kauaʻi, Oʻahu, and Maui to 1.6 inches per decade for the Island of Hawaiʻi. 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 Oʻahu, 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

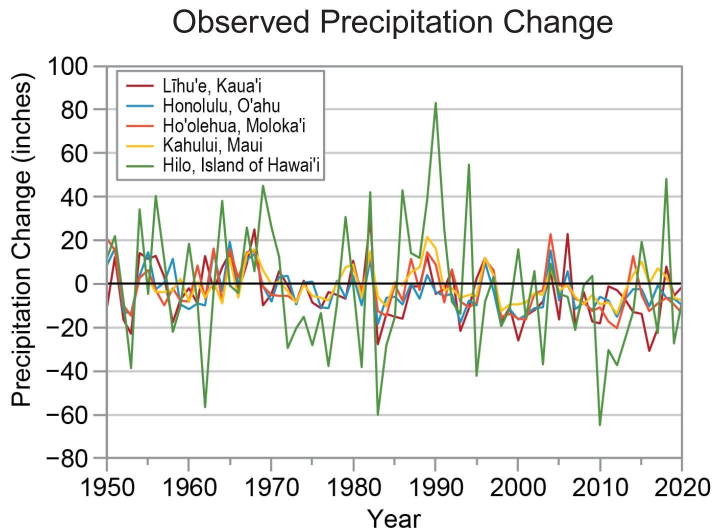


**Figure 6:** Observed changes (compared to the 1951–1980 average; horizontal black line) in annual precipitation for 5 long-term reporting stations in Hawaiʻi from 1950 to 2020: Līhuʻe, Kauaʻi (red line); Honolulu, Oʻahu (blue line); Hoʻolehua, Molokaiʻi (orange line); Kahului, Maui (yellow line); and Hilo, Island of Hawaiʻi (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.

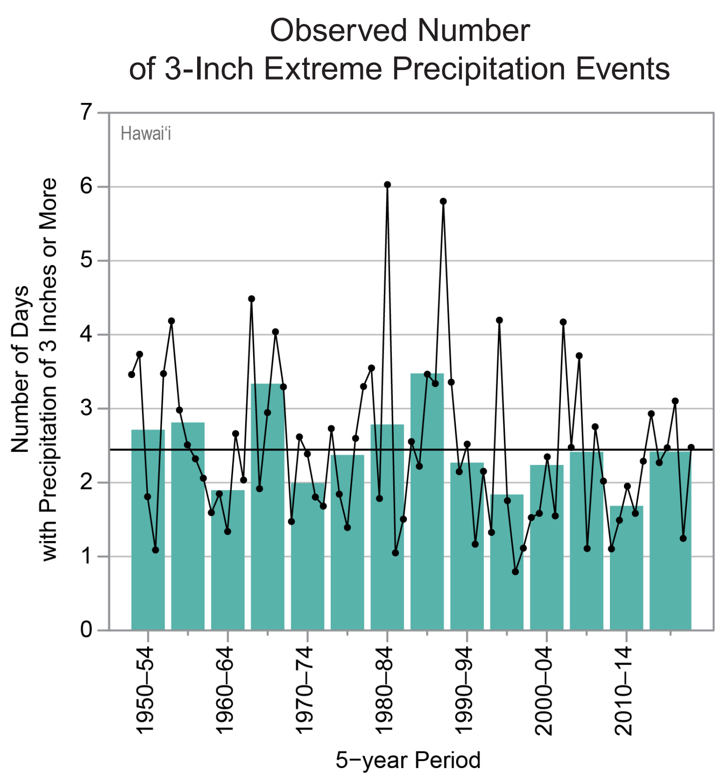


**Figure 7:** Observed annual number of 3-inch extreme precipitation events (days with precipitation of 3 inches or more) for Hawaiʻi from 1950 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire 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.

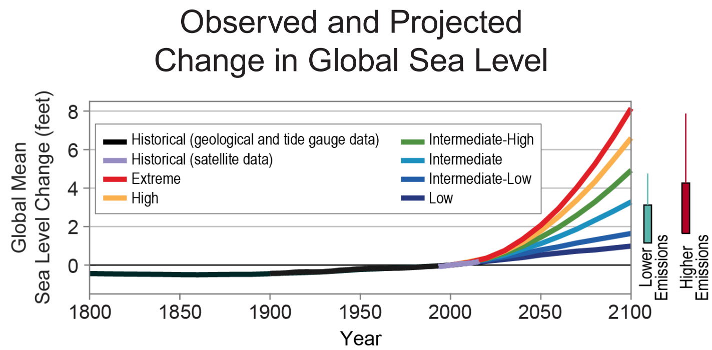


**Figure 9:** Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate-Low, royal blue; Intermediate, cyan; Intermediate-High, green; High, orange; and Extreme, red curves) relative to historical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

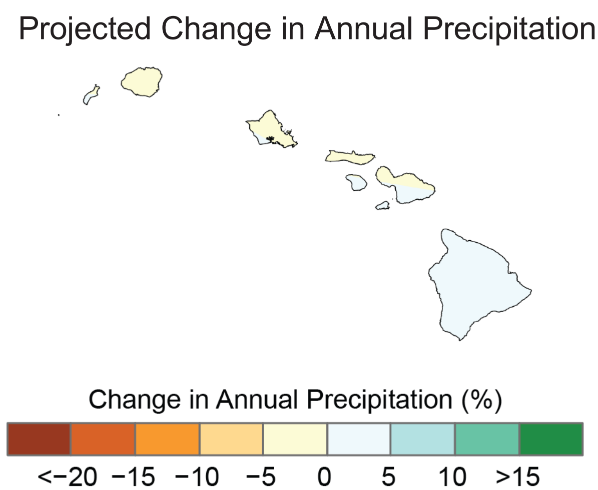


**Figure 8:** Projected changes in total annual precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Annual precipitation is projected to increase slightly across southern parts of the state and decrease across the northernmost islands.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

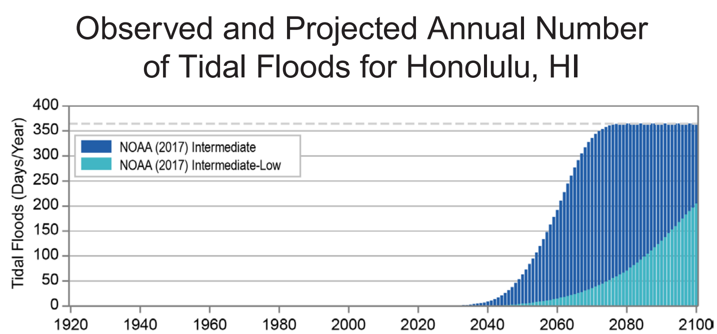


**Figure 10:** Number of tidal flood days per year at Honolulu, Hawai‘i, for the observed record (no data) and projections for two NOAA (2017) sea level rise scenarios (2021–2100): Intermediate (dark blue bars) and Intermediate-Low (light blue bars). The NOAA (2017) scenarios are based on local projections 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.