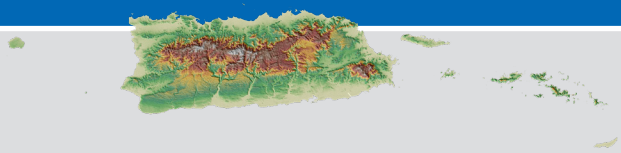

PUERTO RICO AND THE U.S. VIRGIN ISLANDS

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.

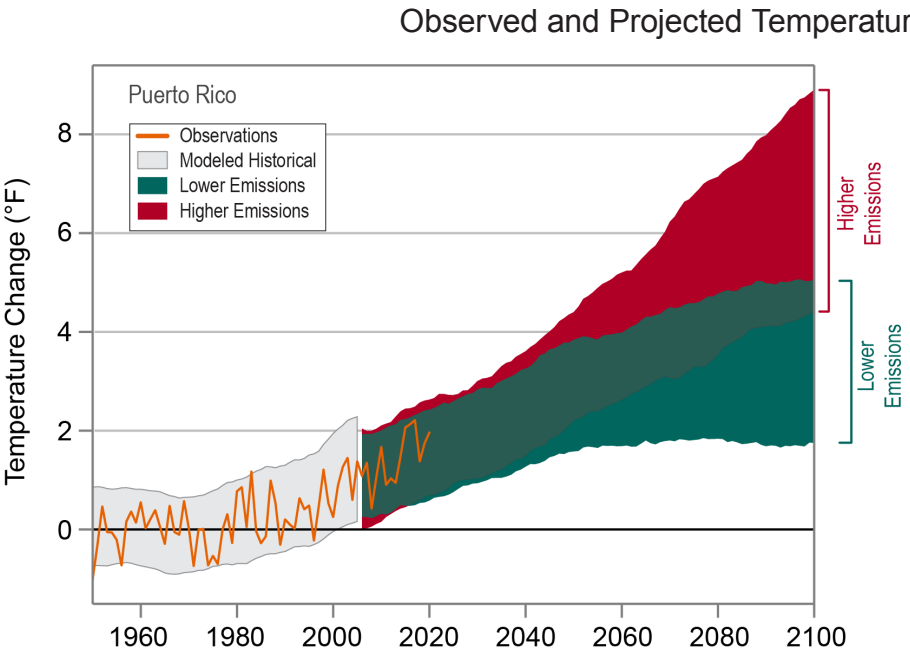

Figure 1: Observed and projected changes (compared to the 1951–1980 average) in near-surface air temperature for Puerto Rico. Observed data are for 1950–2020, based on data from six long-term reporting sites. Projected changes for 2006–2100 are from global climate models for two possible futures: one 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),

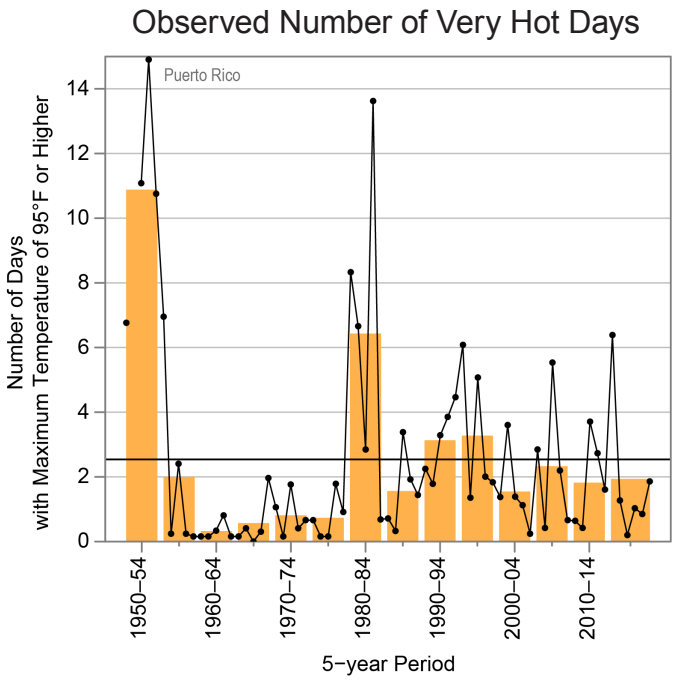

Figure 2: Observed annual number of very hot days (maximum temperature of 95°F or higher) for Puerto Rico from 1950 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year period). The horizontal black line shows the long-term (entire period) average of 2.5 days. (Data were not recorded for 1951.) There is no overall trend. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 4 long-term stations.

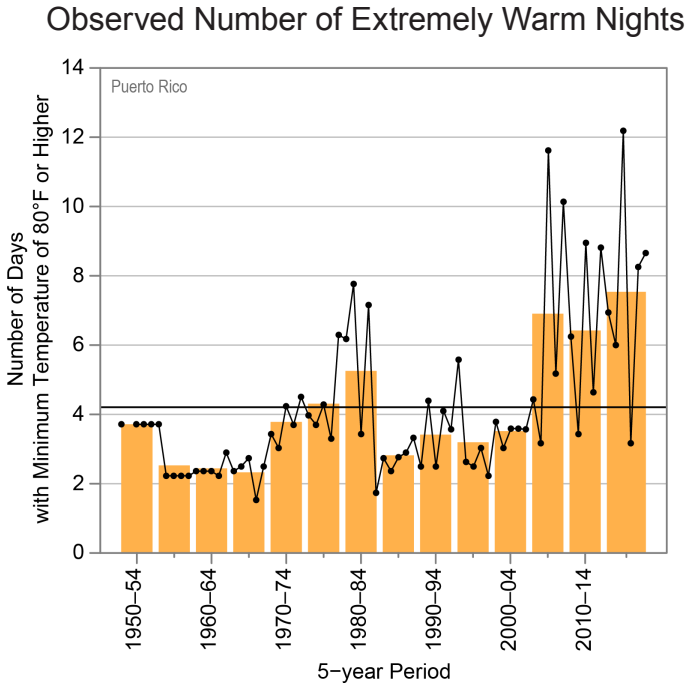

Figure 3: Observed annual number of extremely warm nights (minimum temperature of 80°F or higher) for Puerto Rico from 1950 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 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 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

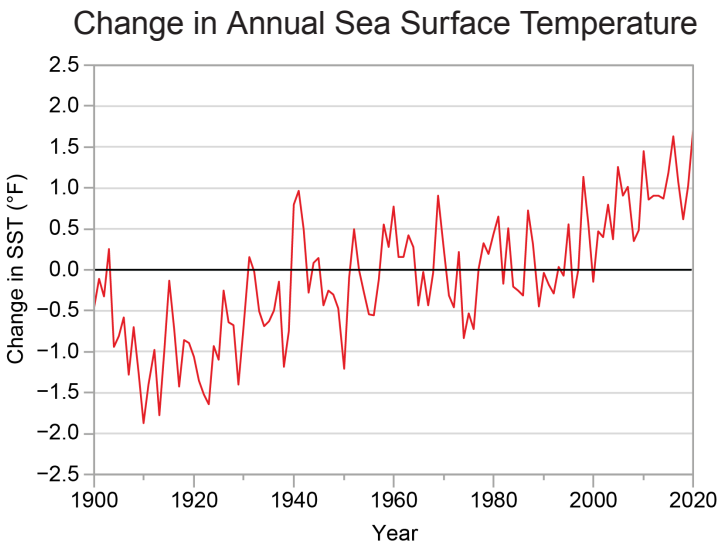

Figure 4: Observed changes for 1900–2020 (compared to the 1951–1980 average) in annual average sea surface temperature (SST) for the region surrounding Puerto Rico and the U.S. Virgin Islands (62°W–68°W, 17°N–19°N). SSTs have increased steadily since the mid-1900s. Sources: CISESS and NOAA NCEI. Data: NOAA ERSST v5.

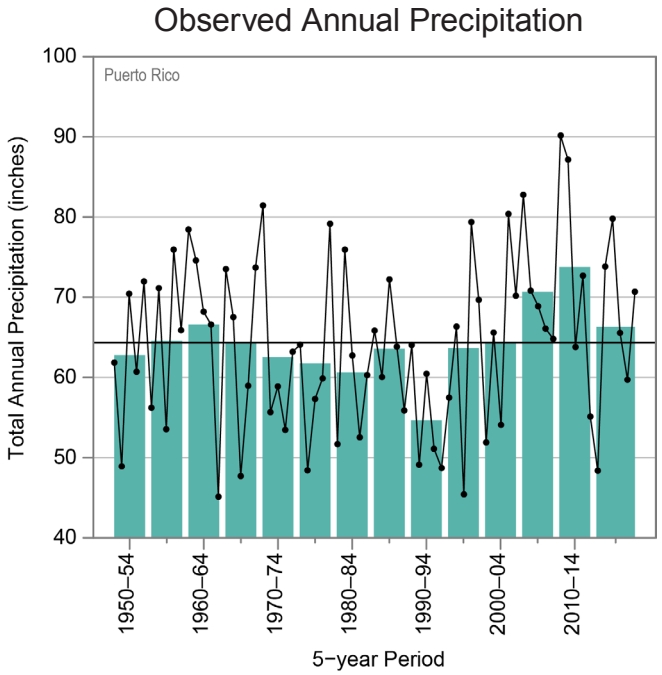

Figure 5: Observed total annual precipitation for Puerto Rico from 1950 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire period) average of 64.3 inches. Annual precipitation in Puerto Rico varies 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.

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

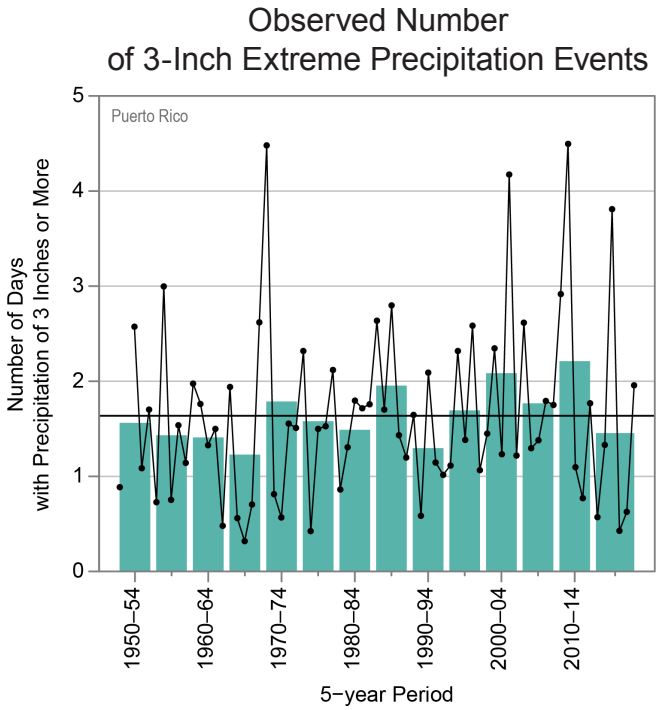

Figure 6: Observed annual number of 3-inch extreme precipitation events (days with precipitation of 3 inches or more) for Puerto Rico from 1950 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term (entire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

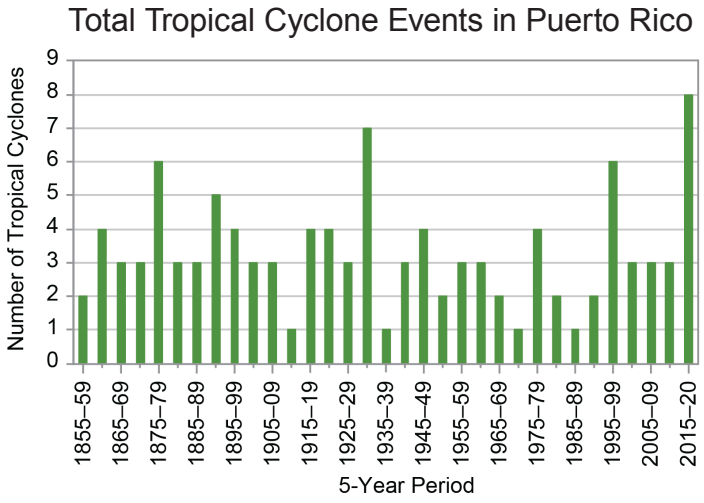

Figure 7: Number of tropical cyclone events (including hurricanes and tropical storms) within 60 nautical miles of Puerto Rico, totaled over 5-year periods (last bar is a 6-year total). Such events occur every 1 to 2 years; however, the 2015–2020 period saw 8 events. Source: CISESS and NOAA NCEI.

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.

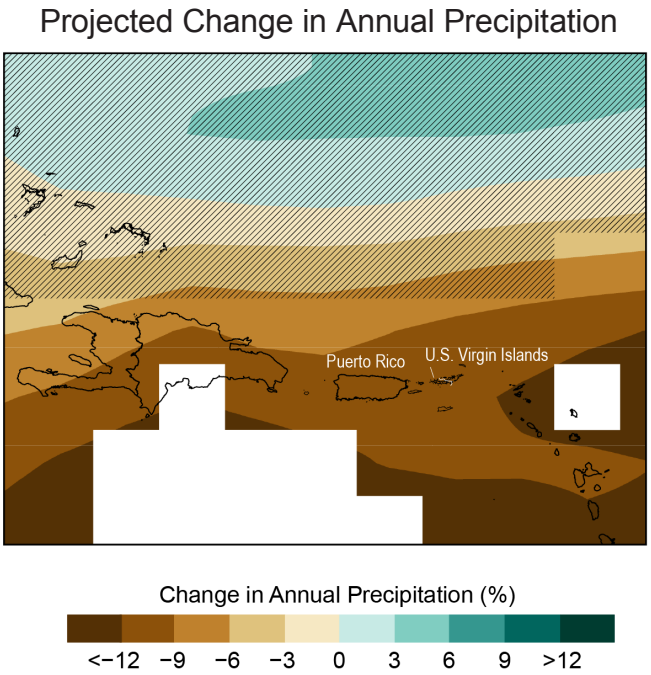

Figure 8: Projected changes in annual precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Total annual precipitation is projected to decrease in both Puerto Rico and the U.S. Virgin Islands. Hatching indicates areas where the changes 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.

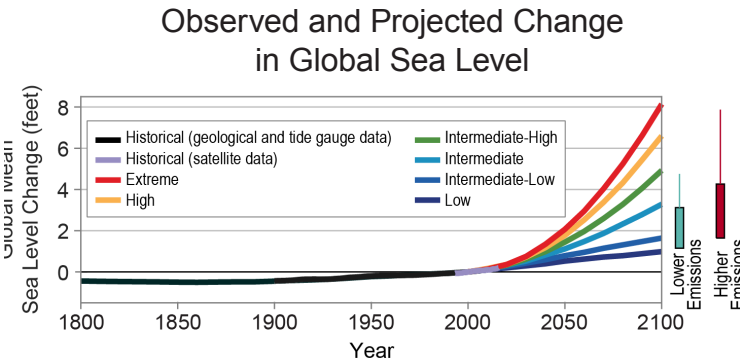

Figure 9: Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate-Low, royal blue; Intermediate, cyan; Intermediate-High, green; High, orange; and Extreme, red curves) relative to historical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

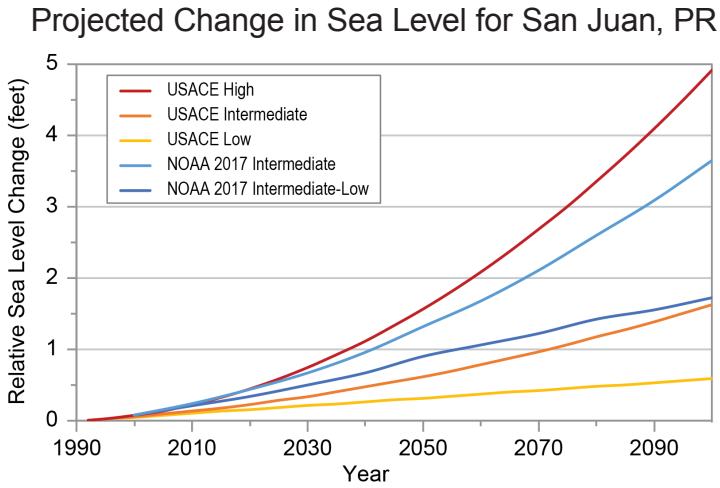

Figure 10: Relative sea level change for San Juan, Puerto Rico, from 1992 to 2100. Projected changes are shown for three U.S. Army Corps of Engineers' (USACE) Sea Level Change Curves (Low: yellow, Intermediate: orange, and High: red) and two NOAA (2017) Sea Level Rise scenarios (Intermediate-Low: dark 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.