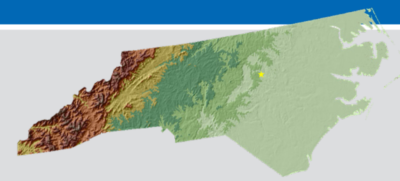
NORTH CAROLINA



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).

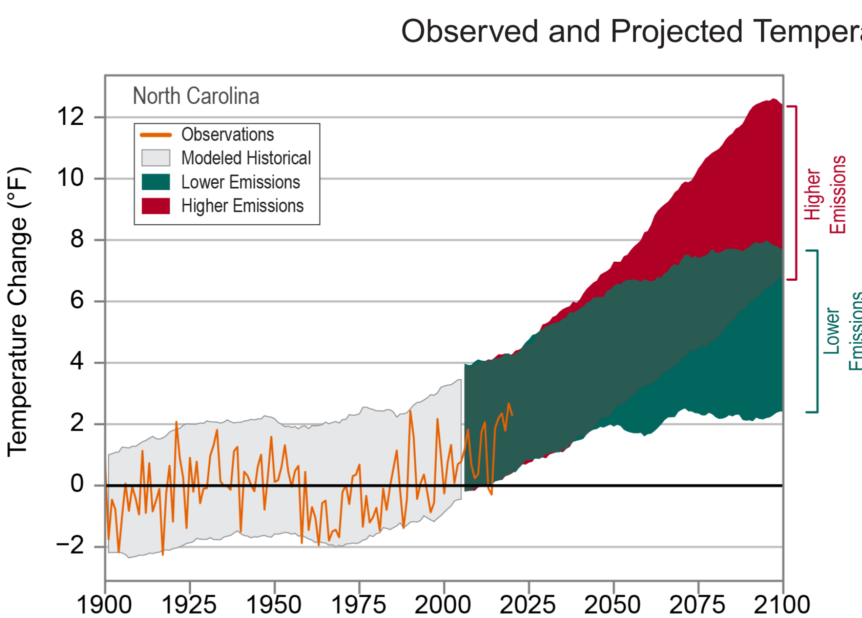


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for North Carolina. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to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

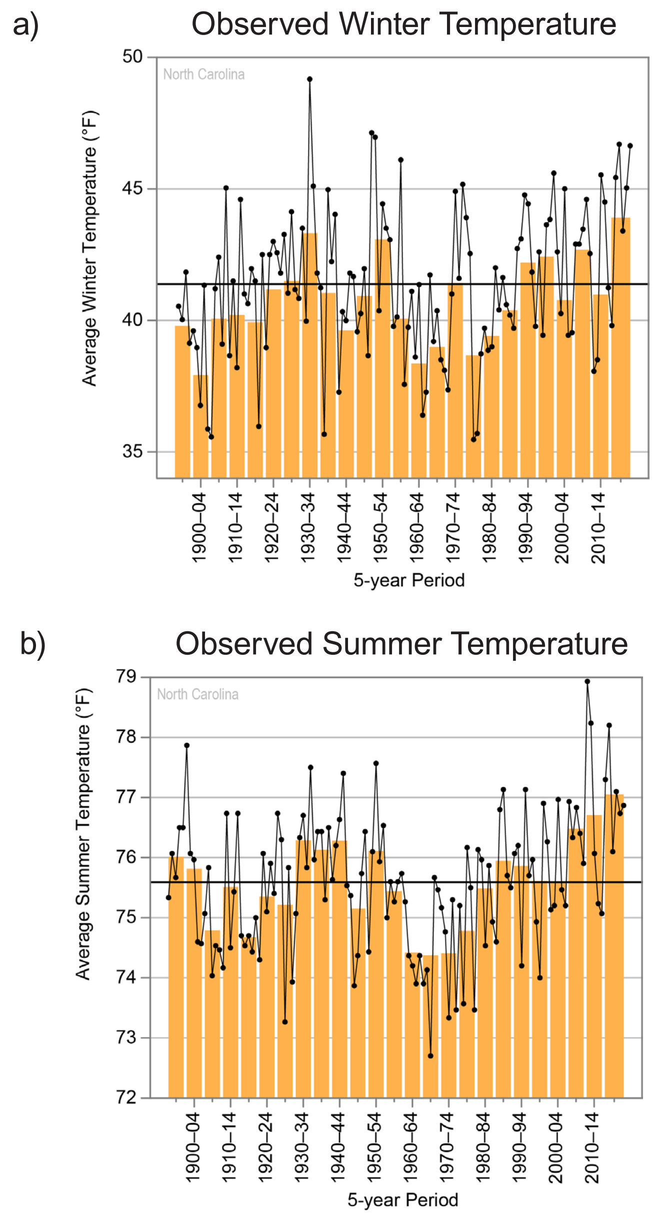


Figure 2: Observed (a) winter (December–February) and (b) summer (June–August) average temperature for North Carolina from (a) 1895–96 to 2019–20 and (b) 1895 to 2020. Dots show annual values. Bars show averages over 5-year periods (first bar in Figure 2a is a 4-winter average, last bar in Figures 2a 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.

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 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

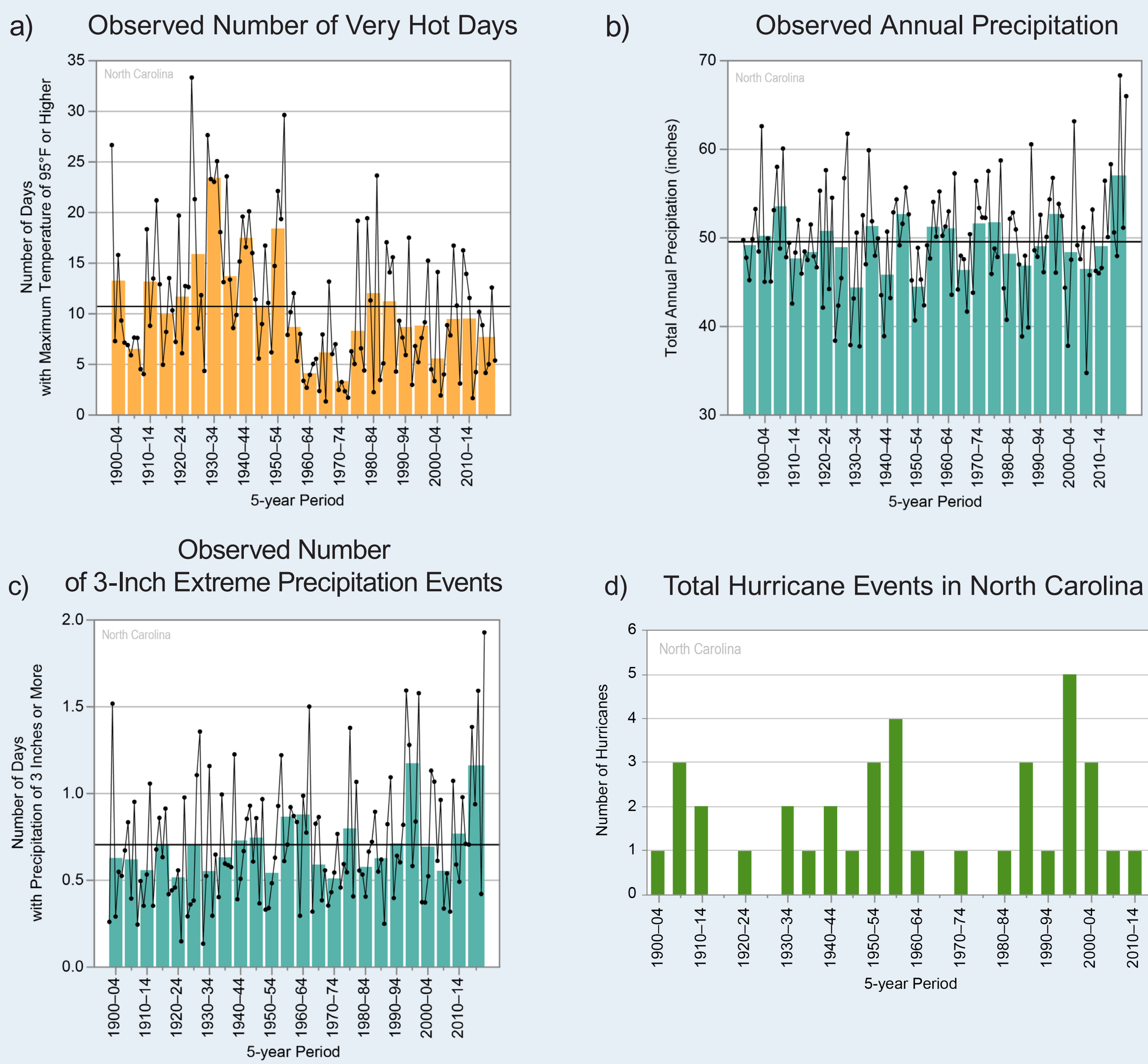


Figure 3: Observed (a) annual number of very hot days (maximum temperature of 95°F or higher), (b) total annual precipitation, (c) annual number of 3-inch extreme precipitation events (days with precipitation of 3 inches or more), and (d) total number of hurricane events (wind speeds reaching hurricane 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

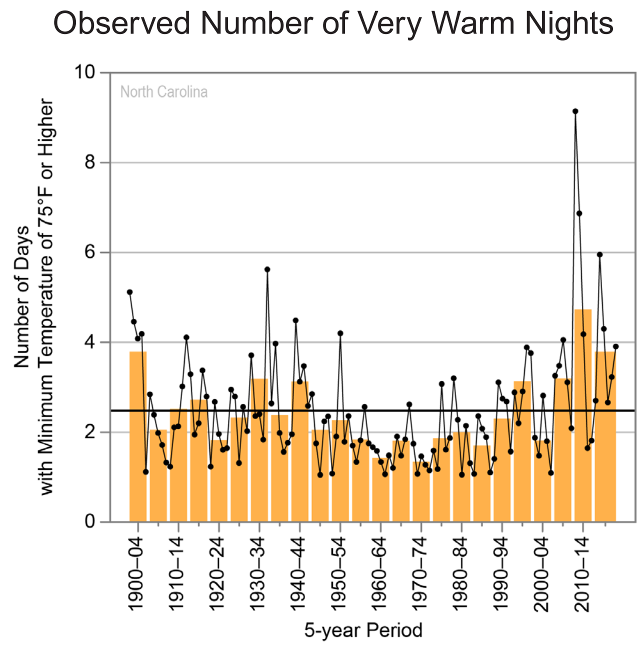


Figure 4: Observed annual number of very warm nights (minimum temperature of 75°F or higher) for North Carolina from 1900 to 2020. Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black line shows the long-term average of 2.5 nights. Since 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.

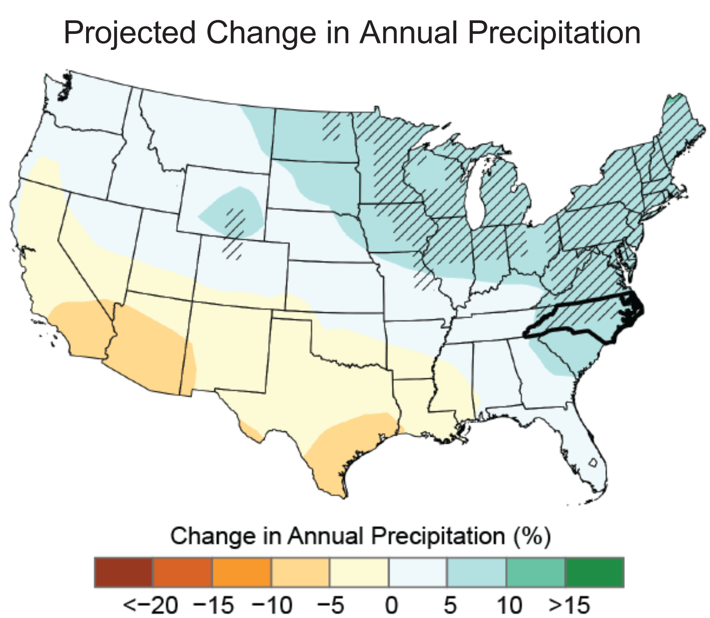


Figure 5: Projected changes in total annual precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. North Carolina is on the southern 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

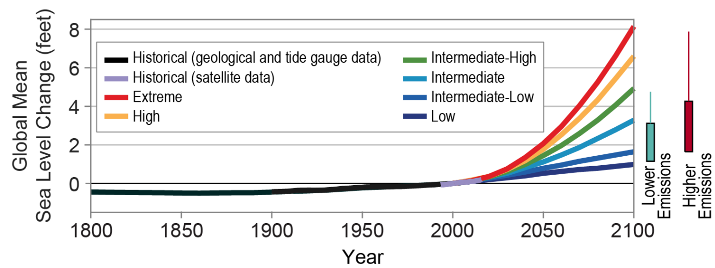


Figure 6: Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate-Low, royal blue; Intermediate, cyan; Intermediate-High, green; High, orange; and Extreme, red curves) relative to historical 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

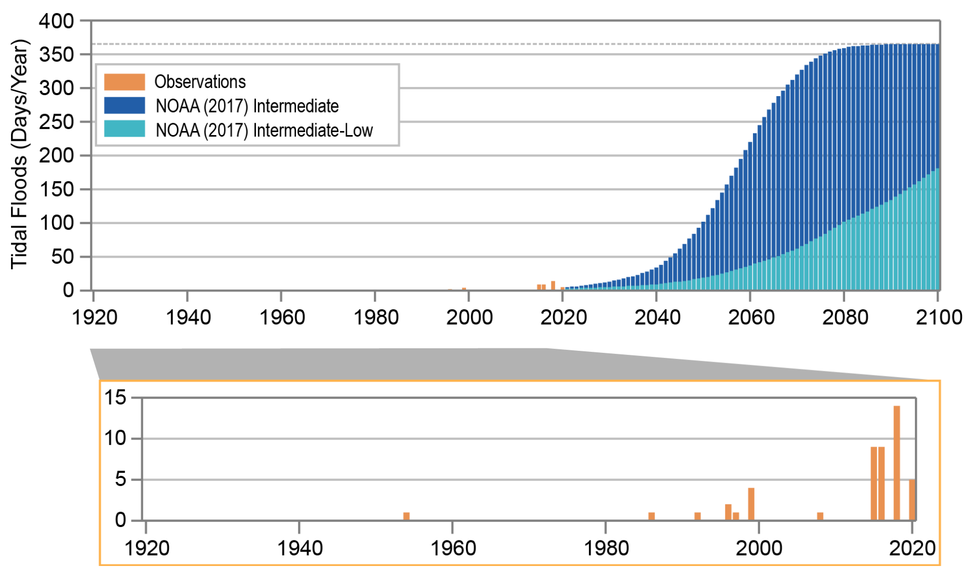


Figure 7: Number of tidal flood days per year at Wilmington, North Carolina, for the observed record (1936–2020; orange bars) and projections for two NOAA (2017) sea level rise scenarios (2021–2100): Intermediate (dark blue bars) and Intermediate-Low (light blue bars). The NOAA (2017) scenarios are based 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.

WWW.NCEI.NOAA.GOV | HTTPS://STATESUMMARIES.NCICS.ORG/CHAPTER/NC/ | LEAD AUTHORS: REBEKAH FRANKSON, KENNETH E. KUNKEL
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