humidity can create dangerous heat index values. Pennsylvania has experienced several heat waves in recent years. One of the worst heat waves 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 daily high of 106°F, while Scranton reported its highest minimum temperature of 81°F. While heat waves are projected to become more intense, cold waves are projected to become less intense.

Due to Pennsylvania's coastline along the Delaware Estuary, increasing temperatures raise concerns for sea level rise in coastal areas. Since 1880, global sea level has risen by about 8 inches. It is projected to rise another 1 to 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 in 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, enhancing the risk for more frequent and intense floods. Heavier precipitation and higher temperatures raise the risk of springtime flooding due to earlier snowmelt. Springtime flooding could pose a threat to Pennsylvania's agricultural industry by delaying planting and resulting in loss of yield.

Observed and Projected Annual Number of Tidal Floods for Philadelphia, PA

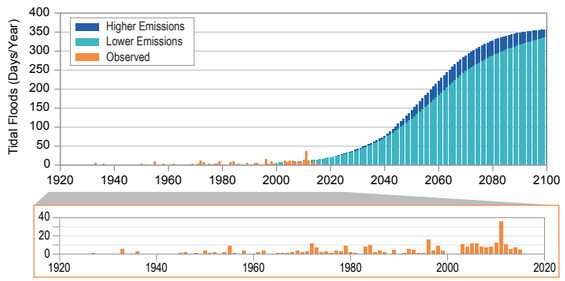

Figure 5: Number of tidal flood days per year for the observed record (orange bars) and projections for two possible futures: lower emissions (light blue) and higher emissions (dark blue) per calendar year for Philadelphia, PA. Sea level rise has caused an increase in tidal floods associated with nuisance-level impacts. Nuisance floods are events in which water levels exceed the local threshold (set by NOAA's National Weather Service) for minor impacts, such as road closures and overwhelmed storm drains. The greatest number of tidal flood days (all days exceeding the nuisance level threshold) occurred in 2011 in Philadelphia. Projected increases are large even under a lower emissions pathway. Near the end of the century, under a higher emissions pathway, some models (not shown here) project tidal flooding nearly every day of the year. To see these and other projections under additional emissions pathways, please see the supplemental material on the State Summaries website (https:statesummaries.ncics.org/pa). Source: NOAA NOS.

Projected Change in Winter Precipitation

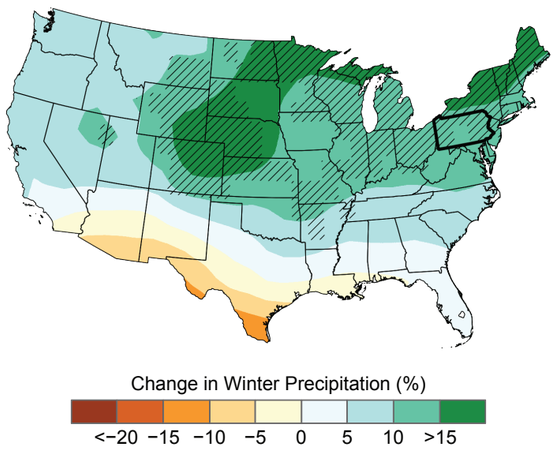

Figure 6: Projected change in winter precipitation (%) for the middle of the 21st century relative to the late 20th century under a higher emissions pathway. Hatching represents portions of the state where the majority of climate models indicate a statistically significant change. Winter precipitation is projected to increase in Pennsylvania. Source: CICS-NC, NOAA NCEI, and NEMAC.

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

Key Messages

Mean annual temperature has increased approximately 2°F over the last century. Under a higher emissions pathway, historically unprecedented warming is projected by the end of the 21st century. Extreme heat is of 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 heavy rain events. Future increases in winter and spring precipitation raise the risk of springtime flooding along rivers and streams.

Global sea level has risen by about 8 inches since 1880 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 along the Philadelphia riverfront, a serious risk in Pennsylvania where the observed sea level rise over the past century has exceeded the global average.

Pennsylvania has a diverse landscape, which includes 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 the 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 polar jet stream, which is often located near or over the region during winter, brings frequent storm systems which cause 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.

Since the beginning of the 20th century, temperatures have risen around 2°F and temperatures in the 2000s have been higher than any other historical period (Figure 1). This warming has been concentrated 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 (days with maximum temperature above 90°F) during the last 10 years (Figure 2a). However, there has been an increase in the number of warm nights (days with minimum temperature above 70°F) and a decrease in the number of very cold nights (days with minimum temperature below 0°F) (Figures 3

Observed and Projected Temperature Change

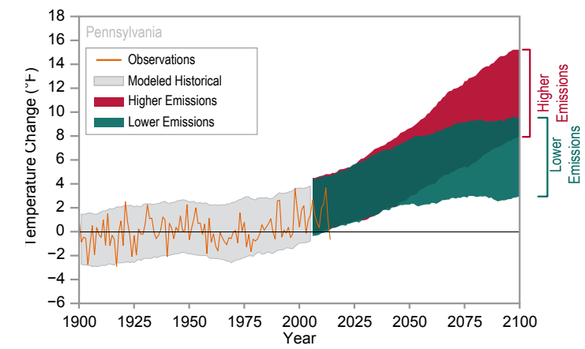


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Pennsylvania. Observed data are for 1900–2014. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions)[1]. Temperatures in Pennsylvania (orange line) have risen nearly 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 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 years being about 11°F warmer than the hottest year in the historical record; red shading). Source: CICS-NC and NOAA NCEI.

[1]Technical details on models and projections are provided in an appendix, available online at: https://statesummaries.ncics.org/pa.

and 2b). 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.

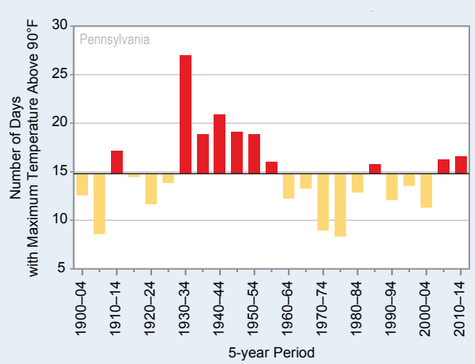
Pennsylvania experiences abundant precipitation. Statewide annual precipitation has ranged from a low of 28.86 inches in 1930 to a high of 61 inches in 2011. The driest multi-year period was the 1960s, and wettest were the 1970s and 2000s (Figure 2c). The driest five-year period was 1962–1966 and the wettest was 2003–2007. The recent above average precipitation has primarily been due to increases in 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 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, of which 27.6 inches fell in 24 hours, a record for the city.

Pennsylvania has experienced an increase in number of heavy rain events (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 caused by intense heavy rains and a catastrophic failure of the South Fork Dam upstream of Johnstown. The flood and subsequent fires killed over 2,000 people and caused millions of dollars in damages. **Heavy rains in conjunction with spring snowmelt can cause particularly damaging floods**. In 1936, runoff from rain falling on snow caused a record flood on the Monongahela River.

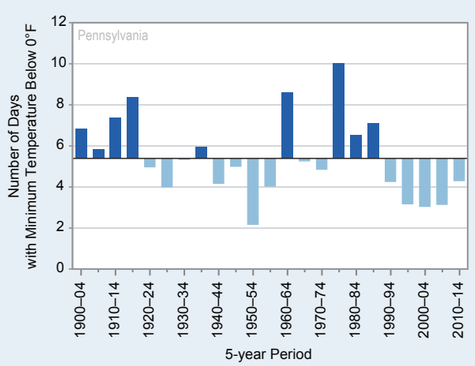
Tropical cyclones occasionally pass through the state and are yet another cause of heavy rainfall and widespread flooding. Over a two-week period in 2011, Pennsylvania was drenched by heavy rains—which caused historic flooding—from the remnants of both Hurricane Irene and Tropical Storm Lee. Several 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 be around $200 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 (in 1972 dollars).

Figure 2: The observed number of (a) hot days (annual number of days with maximum temperature above 90°F), (b) very cold nights (annual number of days with minimum temperature below 0°F), (c) annual precipitation, and (d) extreme precipitation (number of events with precipitation amounts greater than 2 inches), averaged over 5-year periods. The values in Figures 2a, 2b and 2d are averages from long-term reporting stations seven for temperature and nine for precipitation. The values in Figure 2c are from NCEI's version 2 climate division dataset. The dark horizontal lines represent the long-term average. The number of hot days has been near the long-term average since the 1950s, 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 5-year period (2010–2014), annual precipitation was the highest on record and the number of extreme precipitation events was the second-highest on record. Source: CICS-NC and NOAA NCEI.

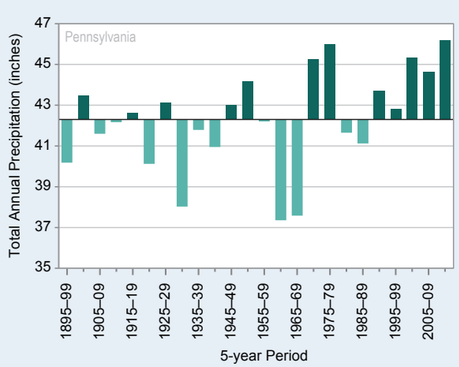
a) Observed Number of Hot Days



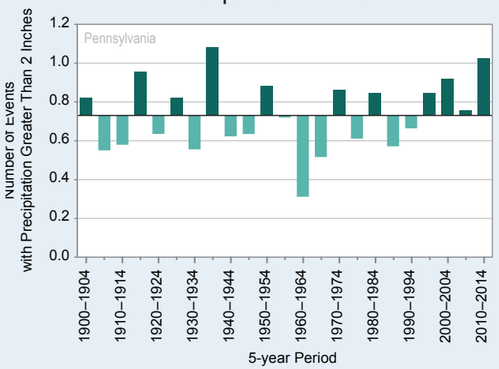
b) Observed Number of Very Cold Nights



c) Observed Annual Precipitation



d) Observed Number of Extreme Precipitation Events



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Observed Number of Warm Nights

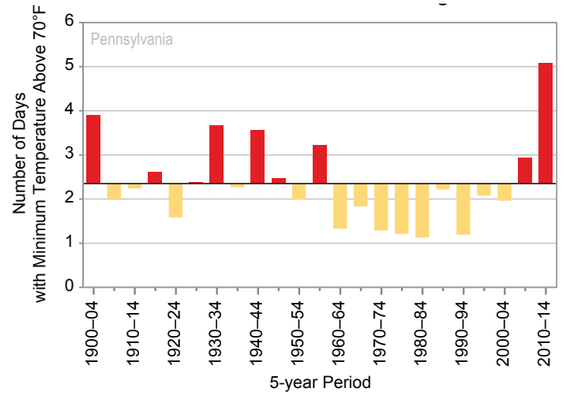

Figure 3: The observed number of warm nights (annual number of days with minimum temperature above 70°F) for 1900–2014, averaged over 5-year periods; these values are averages from seven long-term reporting stations. The dark horizontal lines represent the long-term average. During the most recent 5-year period (2010–2014), Pennsylvania experienced its highest frequency of warm nights, more than double the long-term average. Source: CICS-NC and NOAA NCEI.

Past and Projected Changes in Global Sea Level

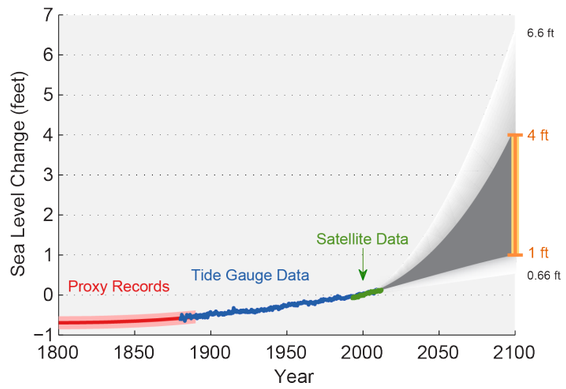

Figure 4: Estimated, observed, and possible future amounts of global sea level rise from 1800 to 2100, relative to the year 2000. The orange line at right shows the most likely range of 1 to 4 feet by 2100 based on an assessment of scientific studies, which falls within a larger possible range of 0.66 feet to 6.6 feet. Source: Melillo et al. 2014 and Parris et al. 2012.

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 only experiences a few tornadoes each year, they 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 over 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 pathway of lower greenhouse gas concentrations, average annual temperatures are projected to most likely exceed historical record levels by the middle of the 21st century. However, there is a large range of temperature increases under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records (Figure 1). **Extreme heat is of particular concern for Philadelphia and other urban areas where the urban heat island effect raises summer temperatures.** High temperatures combined with high