winters become warmer, the number of snow events in Massachusetts is expected to decline from an average of 5 each month to 1 to 3 events each month. The frequency of extreme precipitation events is also projected to more than double by the end of the 21st century. Projections of above average precipitation amounts and more frequent extreme precipitation events may also result in increased coastal and inland flooding risks, including substantial increases in riverine flooding in Boston by 2050. Increased evaporation from warmer temperatures, alterations in the timing and amount of streamflow following reductions in snowpack, as well as changes in the amount, timing, and type of precipitation, may intensify naturally occurring droughts.

From 1921 to 2006, relative sea level increased 0.10 inches per year in Massachusetts, or approximately 10 inches per century, greater than the global rate due in part to land subsidence. 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 Massachusetts coastline, the number of tidal flood days (all days exceeding the nuisance level threshold) has also increased, with the greatest number occurring in 2010 (Figure 6).

Coastal communities are particularly vulnerable to sea level rise and coastal storm surge. **Global sea level is projected to rise another 1 to 4 feet by 2100 as a result of both past and future emissions from human activities (Figure 7).** Land in the state is naturally subsiding (sinking); whereby sea level rise has and will continue to contribute to increases in coastal flooding frequency, shoreline erosion, and saltwater intrusion. While local elevation conditions and trends (e.g., subsidence and sediment compaction) need to be accounted for in the adjustment of global sea level rise scenarios to derive relative sea level rise, thermal expansion and melting glacial ice sheets are projected to dominate any local changes in land movement by 2050. State-level findings indicate that sea level rise could range between 1 (based on the current rate of SLF) and 6.6 (based on the extent of global warming) feet by 2100. Sea level rise-induced coastal flooding of densely populated, low-lying coastal communities has important future implications for the state's economy, public health, natural resources, and infrastructure.

Projected Change in Spring Precipitation

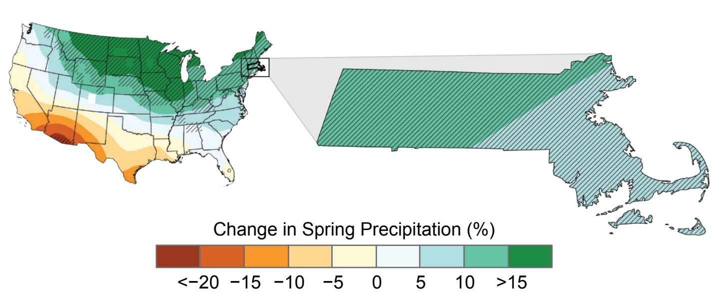


Figure 5: Projected change in spring precipitation (%) for the middle of the 21st century relative to the late 20th century under a higher emissions pathway. Hatching represents portions of the state where the majority of climate models indicate a statistically significant change. Precipitation in the spring is projected to increase in Massachusetts by mid-century. Source: CICS-NC and NOAA NCEI.

Observed and Projected Annual Number of Tidal Floods for Boston, MA

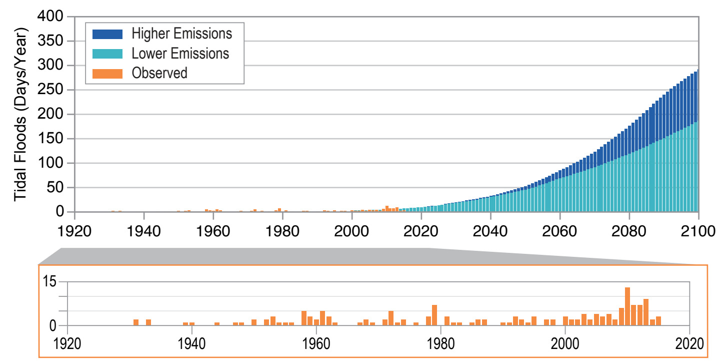


Figure 6: Number of tidal flood days per year for the observed record (orange bars) and projections for two possible futures: lower emissions (light blue) and higher emissions (dark blue) per calendar year for Boston, MA. Sea level rise has caused an increase in tidal floods associated with nuisance-level 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 2010 at Boston. 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/ma). Source: NOAA NOS.

Past and Projected Changes in Global Sea Level

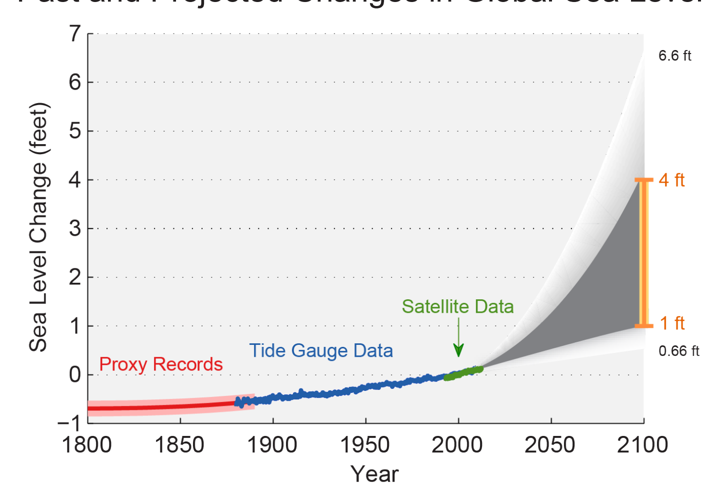
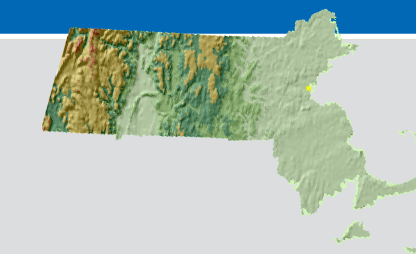


Figure 7: Estimated, observed, and possible future amounts of global sea level rise from 1800 to 2100, relative to the year 2000. The orange line at right shows the currently most likely range of sea level rise of 1 to 4 feet by 2100 based on an assessment of scientific studies, which falls within a larger possible range of 0.66 feet to 6.6 feet. Source: Melillo et al. 2014 and Parris et al. 2012.



MASSACHUSETTS

Key Messages

Average annual temperatures have increased almost 3°F in Massachusetts over the past century. Under a higher emissions pathway, historically unprecedented warming is projected by the end of the 21st century, with associated increases in heat wave intensity and decreases in cold wave intensity.

Precipitation has increased during the last century, with a record-setting number of extreme events occurring over the last decade. Winter and spring precipitation is projected to increase, as well as heavy precipitation events.

Global sea level has risen approximately 8 inches since reliable record keeping began in 1880. It is projected to rise another 1 to 4 feet by 2100. Sea level rise poses significant risks, including inundation and erosion-induced land loss and greater flood vulnerability due to higher storm surge.

Massachusetts is located on the eastern edge of the North American continent. This, coupled with its northerly latitude, exposes the state to both the moderating and moistening influence of the Atlantic Ocean, and the effects of hot and cold air masses from the interior of the continent. Its climate is characterized by cold, snowy winters and warm summers. The polar jet stream is often located near the state, giving it highly variable weather patterns, wide ranging daily and annual temperatures, and generally abundant precipitation throughout the year. Massachusetts is approximately one-eighth of New England's total land area (8,257 square miles). Though small in size, and with forestland comprising more than half of the state, Massachusetts is home to more than six million residents. The topography varies from flat coastal plains in the east to hillier and higher terrain in the west, which provides some regional variations in climate. For the most part, summer temperatures are comfortably warm and relatively uniform across the state. Average temperatures in July range from 67°F to 70°F in the western portion of the state and along the coast, and between 70°F and 74°F in central areas. January temperatures are more variable than summer, ranging from the low 20s (°F) in the west to around 30°F near the coast. Average annual precipitation varies from 40 to 50 inches across the state.

Temperatures in Massachusetts have increased almost 3°F since the beginning of the 20th century (Figure 1). The number of hot days (maximum temperature above 90°F) in Massachusetts has been consistently above average since the early 1990s (Figure 2a) with the highest number since 1950 (11.5 days per year) occurring during the most recent 5-year period of 2010 to 2014. The number of warm nights (minimum temperature above 70°F) in Massachusetts has been steadily increasing since 1995, with the highest number occurring from 2005 to 2014 (Figure 3). In 2012, Boston experienced the warmest January to July in 77 years. During that time period, Boston's average temperature was 53.5°F—almost 4°F warmer than historical average temperatures. Trends in extreme low temperatures also reflect this warming trend. The number of very cold nights (minimum temperature below 0°F) has been below average since the early 1990s (Figure 4). Despite this overall trend, the recent winter of 2014–2015 was rather severe as the eastern United States was one of few places globally with colder than normal temperatures. Heavy snowfall was the most prominent feature in Massachusetts as Boston set a record for snowfall in 2014–2015 with 108 inches. Massachusetts' winter temperature for 2014–2015 was the 24th coldest.

Observed and Projected Temperature Change

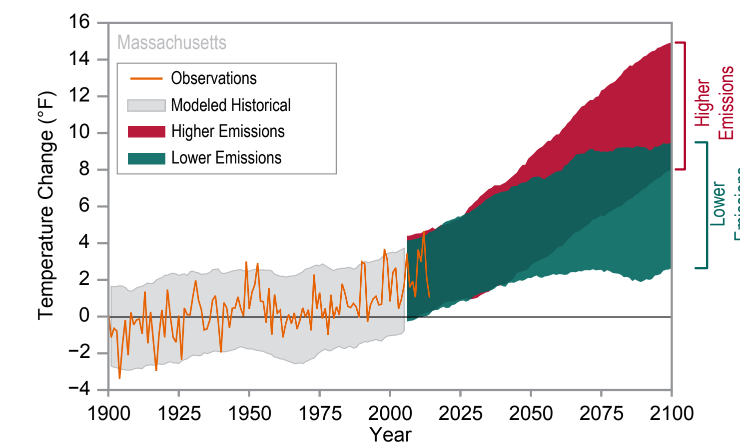


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Massachusetts. Observed data are for 1900–2014. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions)[1]. Temperatures in Massachusetts (orange line) have risen by about 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 the 21st century. Less warming is expected under a lower emissions future (the coldest years being about 2°F warmer than the long-term historical average; 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/ma.

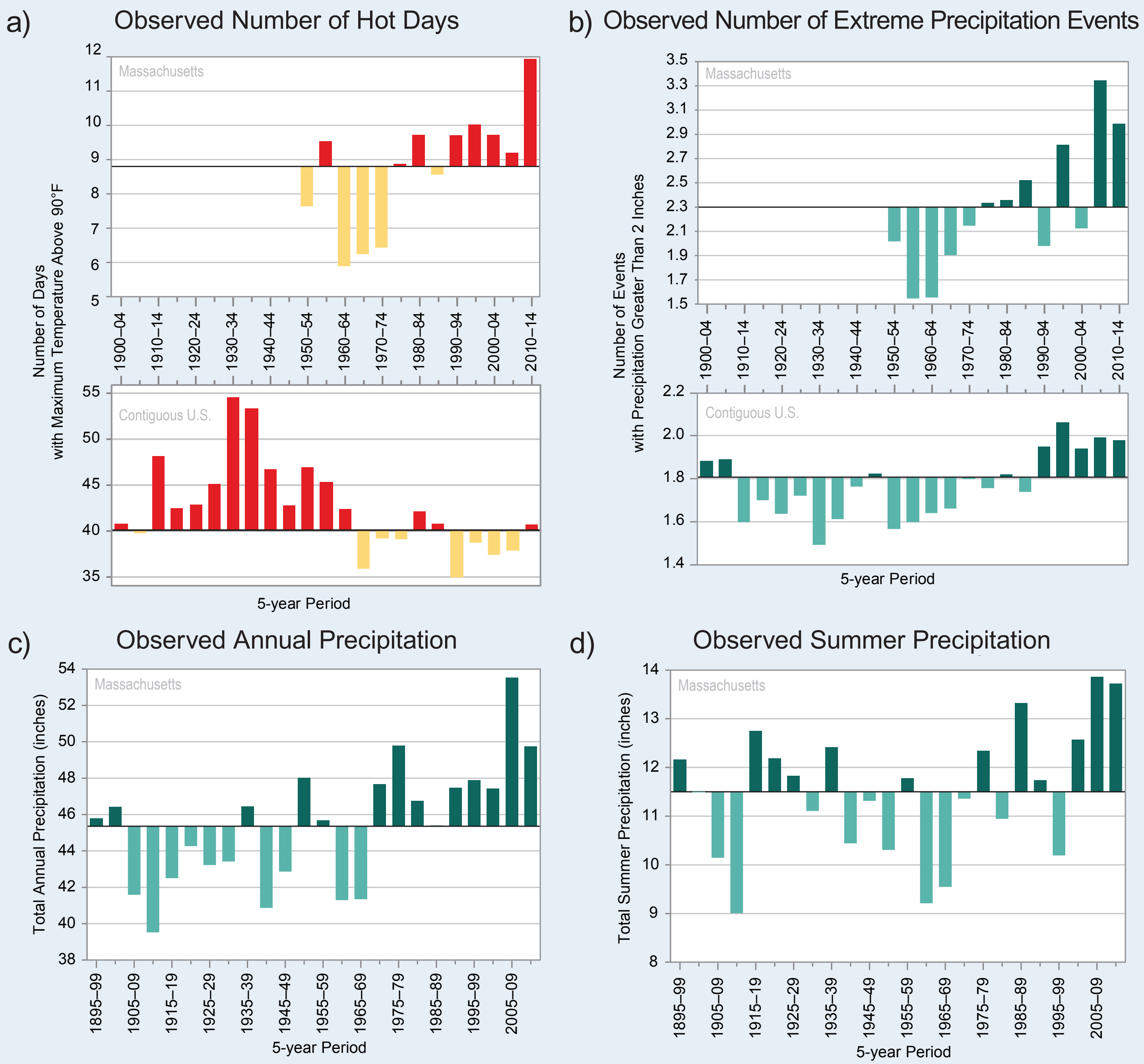


Figure 2: The observed number of (a) hot days (maximum temperature above 90°F), (b) extreme precipitation (precipitation greater than 2 inches), (c) annual precipitation, and (d) summer precipitation, averaged over 5-year periods. The dark horizontal lines represent the long-term average. Values for the contiguous United States (bottom panel) are also shown where appropriate to provide a longer and larger context (long-term stations back to 1900 were not available for Massachusetts). The values in Figures 2a and 2b are averages from long-term reporting stations, 15 for temperature and 24 for precipitation. The values in Figure 2c and 2d are from NCEI's version 2 climate division dataset. The number of hot days in Massachusetts has consistently remained above average since the early 1990s with a record high peak occurring between 2010 and 2014. All precipitation metrics have been highest during the most recent decade (2005–2014). Source: CICS-NC and NOAA NCEI.

Precipitation is abundant but highly variable from year to year. The driest conditions were observed in the early 1900s and again in the 1960s, with wetter conditions occurring since the 1970s (Figure 2c). The most recent 10 years have been the wettest such period on record, averaging about 51 inches per year, well above the long-term average of about 45 inches per year. The driest 5-year period was 1962–1966 and the wettest 2005–2009. Since 2005, Massachusetts has experienced the largest number of extreme precipitation events (days with more than 2 inches) (Figure 2b), about 30% above the long-term average. In March of 2010 alone, three intense rainstorms led to extensive flooding throughout the state and southern New England with estimated damages of $2 billion. The heaviest rain fell in eastern Massachusetts with upwards of 7 to 10 inches falling in Methuen and Gloucester. Above average summer precipitation has been observed since 2000 (Figure 2d), with 12 of 16 summers during 2000–2015 being above the long-term average.

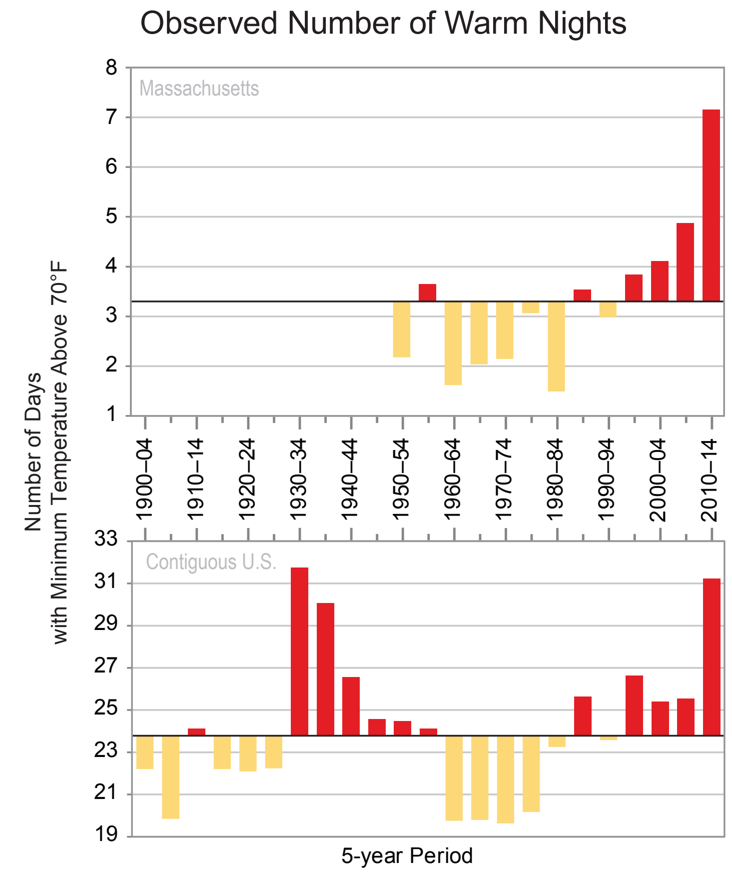


Figure 3: The observed number of warm nights (minimum temperature above 70°F) for 1950–2014, averaged over 5-year periods; these values are averages from 15 long-term reporting stations. The number of warm nights in Massachusetts has steadily increased since the mid-1990s with the highest number (since 1950) occurring between 2010 and 2014. The dark horizontal lines represent the long-term average. The number of warm nights for the contiguous United States (bottom panel) is also shown to provide a longer and larger context. Long-term stations back to 1900 were not available for Massachusetts. Source: CICS-NC and NOAA NCEI.

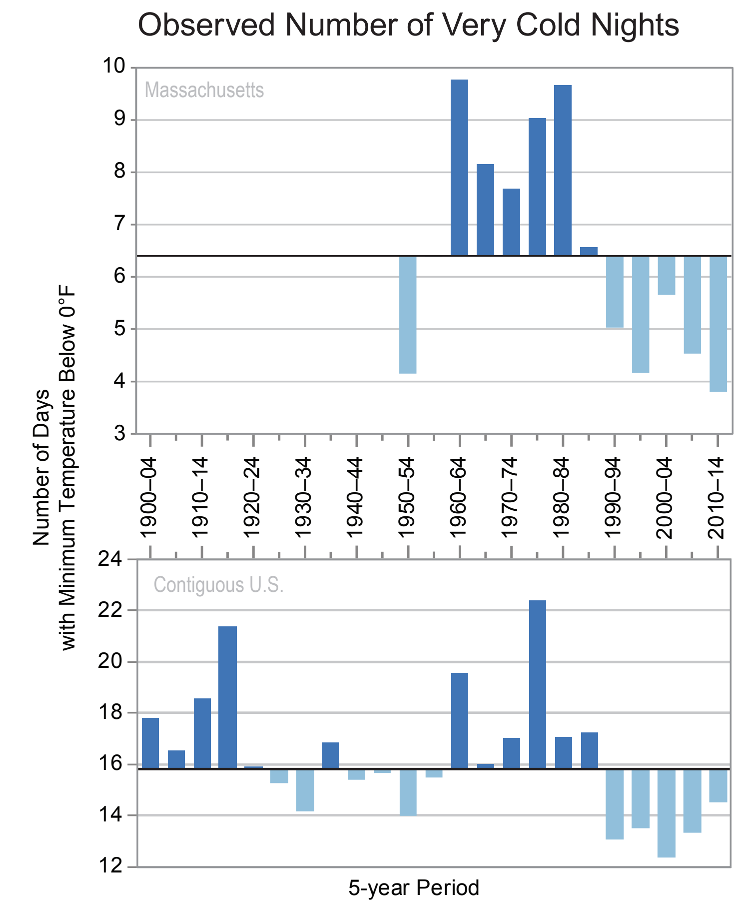


Figure 4: The observed number of very cold nights (minimum temperature below 0°F) for 1950–2014, averaged over 5-year periods; these values are averages from 15 long-term reporting stations. The dark horizontal lines represent the long-term average. The number of very cold nights has been consistently below average since the early-1990s. The lowest number of cold nights occurred during 2010–2014. The number of very cold nights for the contiguous United States (bottom panel) is also shown to provide a longer and larger context. Long-term stations back to 1900 were not available for Massachusetts. Source: CICS-NC and NOAA NCEI.

In addition to extreme precipitation and flooding, extreme weather events periodically encountered by state residents include severe storms (coastal, winter, and thunder), drought, and on occasion, tropical storms and hurricanes. The state's coastline is highly vulnerable to damage from powerful nor'easters and tropical storms and hurricanes. Since 1900, the Northeast has been affected by 15 landfalling hurricanes, 8 of which affected Massachusetts. In 2012, Superstorm Sandy (a post-tropical storm) was the most extreme and destructive event to affect the northeastern United States in 40 years and the second costliest in the Nation's history. Massachusetts was one of over a dozen Northeastern states impacted by Sandy. Storm impacts on the state included strong winds, record storm tide heights, flooding of some coastal areas and loss of power for 385,000 residents. The state of Massachusetts suffered an estimated $375 million in property losses alone. A year earlier, Hurricane Irene, dubbed the "costliest Category 1 storm" ($15.8 billion in damages), swept through northern New England. The most severe impact of Irene was the catastrophic inland flooding in New Jersey, Massachusetts, and Vermont. A number of weather stations in the central and western portions of the state received more than 4 inches of rainfall during August 27-29, 2011 with a few locations exceeding 7 inches.

Under a higher emissions pathway, historically unprecedented warming is projected by the end of the 21st century (Figure 1). Even under a pathway of lower greenhouse gas emissions, 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. Heat waves are projected to increase in intensity while cold waves are projected to become less intense. Massachusetts is vulnerable to extreme heat because of its densely populated urban areas. Excessive heat exposure is projected to contribute to more heat-related illnesses, and in severe cases, death. State-level estimates indicate the number of days above 90°F is projected to increase from 5–20 days (for 1961–1990) to 30–60 days by 2100.

Winter and spring precipitation is projected to continue to increase for Massachusetts over this century (Figure 5). In response to winter warming, projections indicate that more precipitation (12–30%) will fall as rain (compared to snow), there will be earlier lake ice-out dates, and there will be a reduction in winter snowpack. In the future, as