

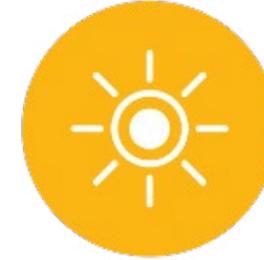
Climate Projection Consensus

To better understand climate change impacts at the local level, the City of Boston and the Green Ribbon Commission convened the Boston Research Advisory Group (BRAG), a team of the region's top climate scientists, to develop the Climate Projection Consensus.



Image courtesy of Bud Ris

EXTREME TEMPERATURES



EXTREME PRECIPITATION



RELATIVE SEA LEVEL RISE



COASTAL STORMS



The Climate Projection Consensus summarizes how Boston's climate is expected to change throughout the twenty-first century, focusing on four climate factors: extreme temperature, relative sea level rise, extreme precipitation, and coastal storms. These factors drive Boston's major climate hazards: coastal and riverine flooding, stormwater flooding, and extreme heat (see Vulnerability Assessment for more details on these hazards and their impacts in Boston).

DEVELOPING A SCIENTIFIC CONSENSUS

This chapter is a summary of the BRAG Climate Projection Consensus report, describing future climate impacts in the Boston region, including extreme temperatures, sea level rise, heavy precipitation, and coastal storms. The full report is available at climateready.boston.gov/findings.

The BRAG was overseen by the University of Massachusetts Boston School for the Environment. BRAG members were organized into four working groups, each focused on a single climate factor: extreme temperature, relative sea level rise, extreme precipitation, or coastal storms. They collaborated across working groups on phenomena that cut across multiple climate factors, such as possible changes in snow frequency and amounts of coastal and riverine flooding. From October 2015 to January 2016, the working groups reviewed both academic and non-academic literature—including sources that varied in terms of their climate models, spatial resolution (scale), future time periods considered, and historical reference periods—and reported their findings of the scientific consensus. These reports were then compiled and edited by the University of Massachusetts Boston team and peer-reviewed by an international team of experts.

BOSTON'S "80 X 50" COMMITMENT TO EMISSIONS REDUCTION

Almost a decade ago, an Executive Order in Boston set a goal of reducing greenhouse gas emissions to 80 percent below 2005 levels by 2050 for municipal operations, and Boston has since expanded this goal to include citywide emissions. By 2013, there had been significant progress, with citywide emissions reduced by 17 percent¹, but there is still much work to be done. Boston's commitment is roughly in line with the global emissions reductions needed in order to keep the global temperature from rising more than two degrees Celsius relative to pre-industrial levels and with the low-emissions scenario analyzed in this report². Boston's emissions are a very small fraction of global emissions; to avoid the worst potential impacts of climate change, the international community must enact strong emissions reduction policies.

¹ "2014 Climate Action Plan Update." Greenovate Boston, 2014.

² "Climate Change 2014: Mitigation of Climate Change." Intergovernmental Panel on Climate Change, 2014.

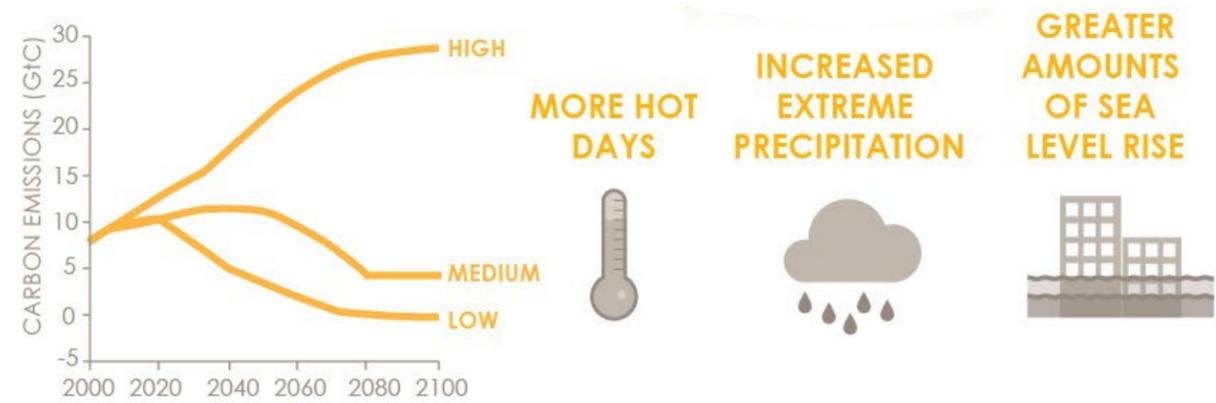
BOSTON'S FUTURE CLIMATE



For Boston to effectively plan for the impacts of climate change, there must be a shared understanding about what these impacts are likely to be.

While the Intergovernmental Panel on Climate Change publishes global climate projections, the impacts of climate change vary by location, and therefore local projections are needed for better-informed planning. Since the late 2000s, there have been a number of vulnerability assessments and adaptation plans published for the Boston region, which have included local climate change projections. Because knowledge of climate change is continually growing, the BRAG was charged with identifying and evaluating the most-recent data available for the Boston region on climate change impacts.

The findings reported here reflect a consensus among the scientific community, including a scientific approach to uncertainty. Currently, the largest source of uncertainty related to understanding the future impacts of climate change is our lack of knowledge about the future amount of carbon that humans will emit into the atmosphere. To address this issue, scientists have defined a set of possible future carbon emissions



scenarios to underlie their climate projections, based on projections about future population growth, development patterns, and energy use. Climate projections for the next few decades are relatively consistent, regardless of their underlying emissions scenario, because the past 200-plus years of human actions have already caused changes to our climate and will continue to do so. However, the projections become increasingly different further into the future, because human actions going forward will have an important and compounding effect on whether climate change accelerates or slows down. Another source of uncertainty is the complexity of natural processes, which scientists are still working to better understand. There is also a certain amount of naturally occurring interannual and interdecadal climate variability (also called "internal variability"). Finally, there appear to be "tipping points" in the climate system, which have the potential to result in larger, more rapid changes, and our understanding of these events is limited.

These climate projections use three emissions scenarios from the Intergovernmental Panel on Climate Change:

- A **high-emissions scenario**, often characterized as a continuation of business as usual;
- A **medium-emissions scenario**, in which emissions remain around their current levels through 2050 and then are slowly reduced in the second half of the century through moderate emissions reductions;
- A **low-emissions scenario**, in which net global emissions are reduced to less than a third of their current levels by 2050 and are brought to zero by about 2080 through major emissions reductions.

The magnitude of future changes depends on our actions today. Our choices about transportation, energy, and land use determine the level of greenhouse gases in the atmosphere. As greenhouse gas emissions increase, so do the impacts of climate change, like sea level rise, extreme precipitation, and extreme temperature. As we take actions now to address the change that is coming, it is critical that we continue to reduce our emissions and minimize future climate change.



EXTREME TEMPERATURES

KEY FINDINGS

Average temperatures in the Northeast have been slowly rising for over a century.

Temperatures in the northeastern United States increased by almost two degrees Fahrenheit between 1895 and 2011.

The rate of increase in average temperatures is accelerating. While over the past century, temperatures in the Northeast rose about two degrees, the increase over the next century may be greater than ten degrees.

As an urban area, Boston tends to be hotter than surrounding communities that are more suburban or rural. Urban areas generally tend to be hotter than nearby rural areas because concrete, steel, and other building materials retain more heat than vegetation. This phenomenon, known as the “urban heat island effect,” is compounded by climate change.

Boston’s summers are getting hotter. While the average summer temperature in Boston from 1981 to 2010 was 69 degrees, it may be as high as 76 degrees by 2050 and 84 degrees by 2100.

There will be more days of extreme heat. Compared to the period from 1971 to 2000, when an average of 11 days per year were over 90 degrees, there may be as many as 40 days over 90 degrees by 2030 and 90 days by 2070—nearly the entire summer.

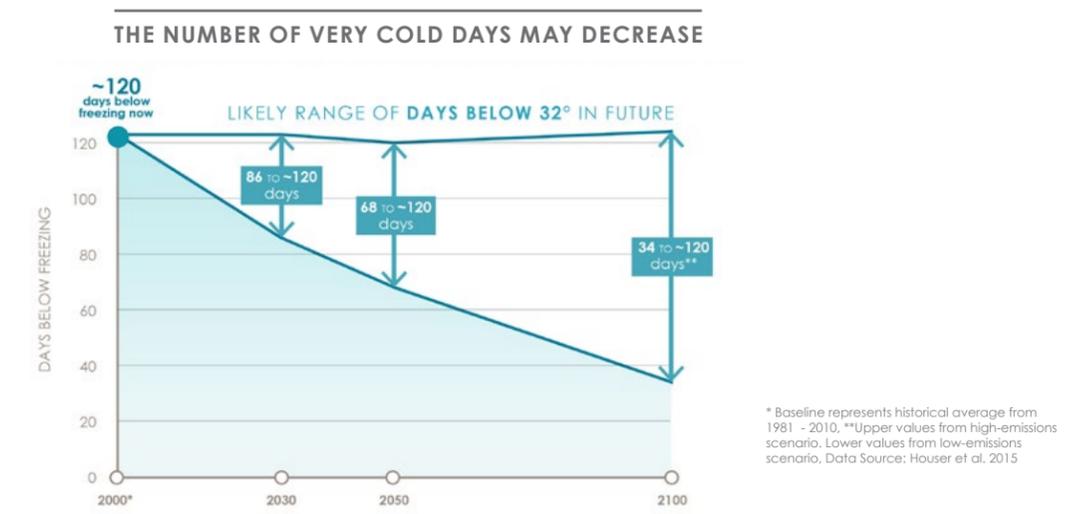
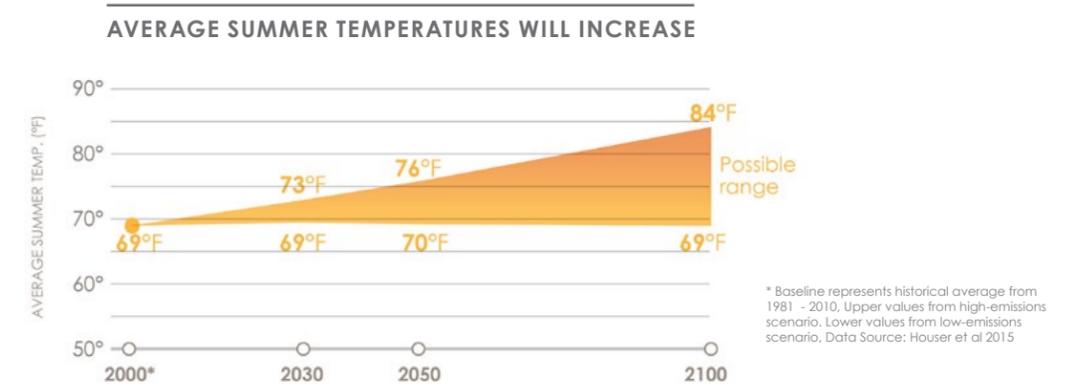
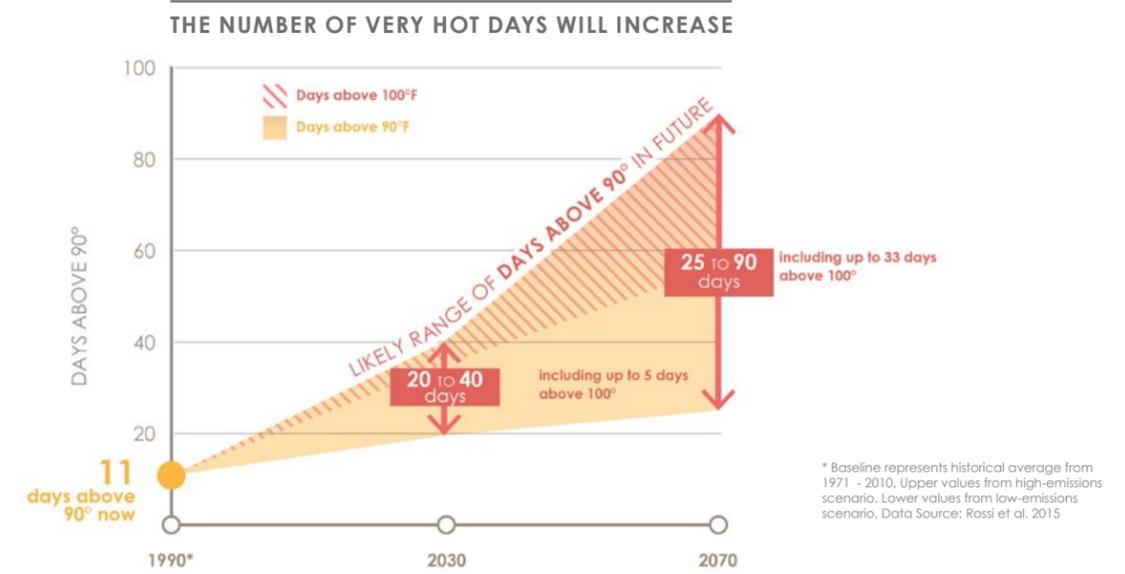
Heat waves will become more common, last longer, and be hotter.

The City of Boston defines heat waves as periods of three or more days above 90 degrees, and heat waves are a leading cause of weather-related mortality in the United States.

Although winters will likely be warmer, the risk of frost and freeze damage and cold snaps will continue. While from 1981 to 2010, Boston reached below freezing almost one out of three days per year, by the end of the century, this may happen only around one in ten days.

Future temperatures in Boston will depend on how much we are able to cut our greenhouse gas emissions.

The rise in temperatures between now and 2030 is largely consistent among all emission scenarios. However, the scenarios show that cutting emissions now can greatly slow the rise in temperatures in the second half of the century.





SEA LEVEL RISE

KEY FINDINGS

Sea level rise is caused by a combination of land ice melting, thermal expansion, and changes in land water storage.

Land ice melting includes the melting of mountain (alpine) glaciers, ice caps, and the continental-scale ice sheets on Greenland, West Antarctica, and East Antarctica. Thermal expansion describes the phenomenon that, as water warms, it generally occupies a greater volume. Land water storage describes activities that affect the amount of water stored on land, such as holding water in reservoirs or behind dams or pumping out underground water for irrigation and use by people.

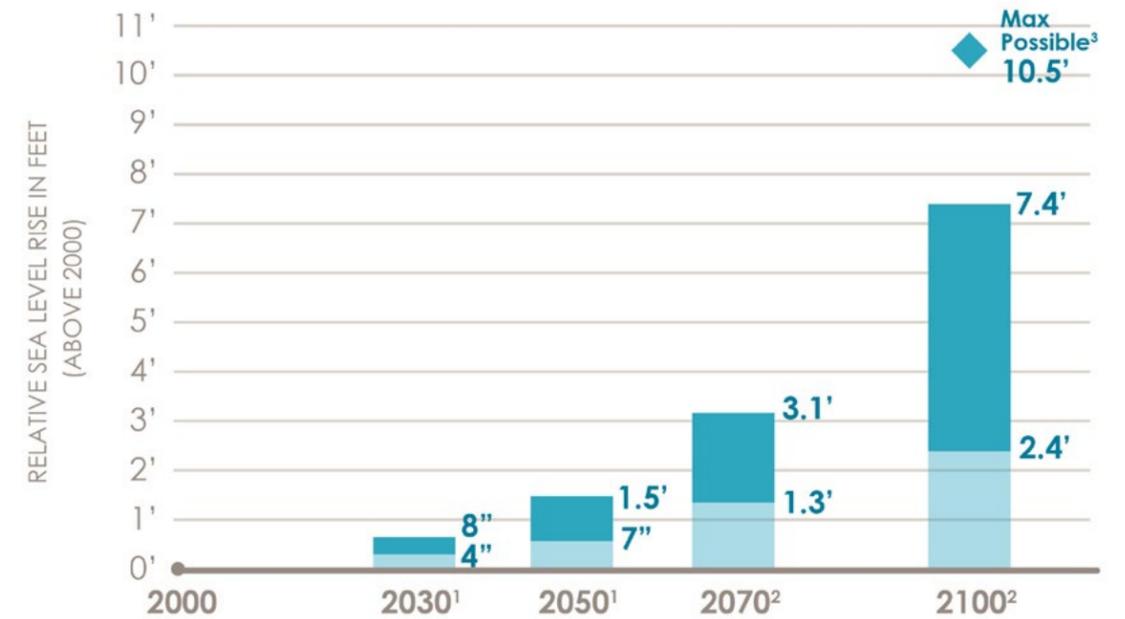
The relative sea level in Boston Harbor has risen over the past century. From 1921 to 2015, the overall trend in relative sea level rise was about 0.11 inches per year. Relative sea level is the difference in elevation between the sea surface and land surface at a specific place and time, so relative sea level rise can result from a combination of changes in the sea surface and changes in the land surface. In Boston, the sinking of the land surface—called “subsidence”—is relatively minor compared to changes in sea levels.

The pace of relative sea level rise is accelerating. Over the entire twentieth century, sea levels rose about nine inches relative to land. Another eight inches of relative sea level rise may happen by 2030, almost three times faster. By 2050, the sea level may be as much as 1.5 feet higher than it was in 2000, and as much as 3 feet higher in 2070.

As sea levels rise, a deeper harbor will mean higher and more powerful waves. Although Boston remains relatively protected from Atlantic waves by Winthrop, Hull, and the Harbor Islands, stronger waves are more likely to damage sea walls and erode beaches. The outer islands and peninsula shorelines of Boston Harbor are likely to experience these impacts to a greater extent than the Boston proper shoreline.

A major reduction in global greenhouse gas emissions can have a tremendous impact on the future of Boston Harbor. While sea level rise projections for 2030 are consistent across all emission scenarios, in later years big differences exist between scenarios. With a sharp emissions reduction, we may be able to keep end-of-century sea level rise to under two feet, while higher emissions may result in over seven feet of sea level rise.

SEA LEVEL RISE IN BOSTON DURING THE TWENTY-FIRST CENTURY



1 - Likely under all emission scenarios
 2 - Likely under moderate to high emission scenarios
 3 - Low probability under high emission scenario

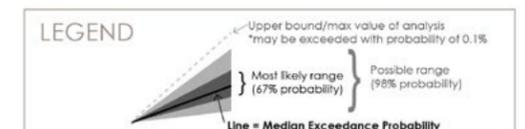
Data Source: BRAG Report, 2016

THE AMOUNT OF SEA LEVEL RISE DEPENDS ON GREENHOUSE GAS EMISSIONS



* Relative sea level rise is the change in sea level resulting from a combination of increases in ocean height and decreases in land surface elevation (“subsidence”).

Data Source: BRAG Report





EXTREME PRECIPITATION

KEY FINDINGS

In the Northeast, there has already been a very large increase in the intensity of extreme rain and snow.

From 1958 to 2010, there was a 70 percent increase in the amount of precipitation that fell on the days with the heaviest precipitation. This increase is greater in the Northeast than for any other region of the country.

The increase in extreme precipitation is expected to continue. As the climate warms, more ocean water evaporates into the air, and warmer air can hold more water, supporting heavier precipitation events. Heavy precipitation events will continue to increase in Boston. However, due to the complexity of the processes underlying precipitation as well as natural variability, the magnitude of this increase is not yet clear.

While the total amount of annual snowfall will decrease, there may still be some heavy snow events through the end of the century. Based on regional projections, total snow accumulations could decrease 31 to 48 percent by 2100, and the start of the snow season is expected to be delayed.

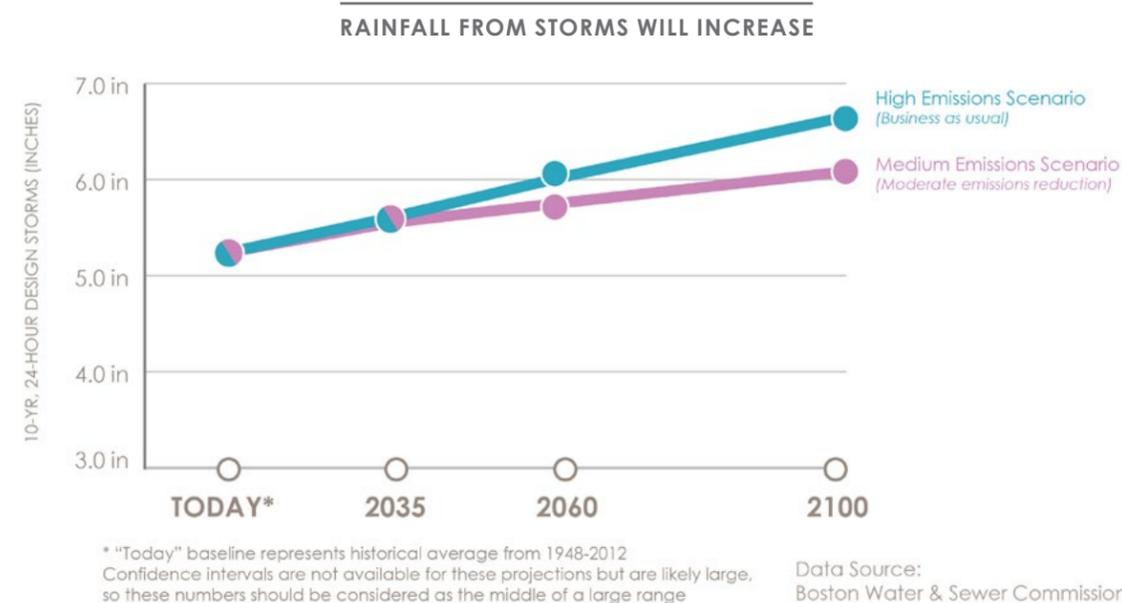
However, changes in daily heavy snowfall events can be quite different from changes in annual snowfall. Expected changes to individual heavy snow events, ice storms, and drought are not clear.

Both stormwater and riverine flooding are affected by extreme precipitation.

Boston's stormwater drainage system may be overwhelmed by major rain events. It may be further compromised by sea level rise as drain outlets are flooded by the rising ocean, reducing the ability of the drainage system to convey stormwater to the coast. River flooding is also likely to increase, but there are large uncertainties associated with river flooding due to the complexity of the climate and hydrological systems involved.

If we take action to cut global greenhouse gas emissions, we can prevent the most extreme precipitation projections from becoming a reality.

A commonly used measure of major rain and snow events is the amount of precipitation that has at most a one-in-ten annual chance of falling during a 24-hour period. While projections for these events are similar in the short term across different emission scenarios, by the end of the century, the difference between medium and high scenarios is about 10 percent.





STORMS

KEY FINDINGS

For Boston, the storms that are of greatest concern are extratropical cyclones, followed by tropical cyclones.

Extratropical cyclones, which are more common and longer lasting in the Northeast than tropical cyclones, currently produce most of the storm-induced flooding in the Boston region and will continue to do so in the near future. These are storms that originate outside of the tropics and are sometimes called nor'easters. They can form during any time of the year but are most prevalent in the extended cold-season months. Tropical cyclones are storms that originate in the tropics and are called hurricanes once they reach a sustained wind speed of more than 74 miles per hour.

Current climate projections do not provide a clear projection of how the intensity, frequency, and trajectory (tracks) of tropical and extratropical storms will change. Extratropical storms (like blizzards and nor'easters) have cold air at their centers. Tropical storms, on the other hand, have warm air, which means that they can develop into hurricanes more quickly. There are large uncertainties about how climate change will affect future storms. This is particularly true for extratropical storms. For tropical storms, there is some evidence that their intensity has been increasing. If tropical storm intensity increases, major hurricanes (Category 3 and greater) could occur more frequently, even if the total number of tropical storms does not increase.

Rising sea levels mean that any given storm will cause more flooding in the future than it would today. During a storm, winds can blow ocean water toward the land, creating a "storm surge" on top of the baseline sea level. When storm surge is combined with tidal processes, the result is known as a "storm tide." With higher seas, less precipitation and a less powerful storm surge can produce the same amount of flooding as a more powerful storm would produce when the seas are lower.



Image courtesy of Sasaki