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# Climate Change And Massachusetts

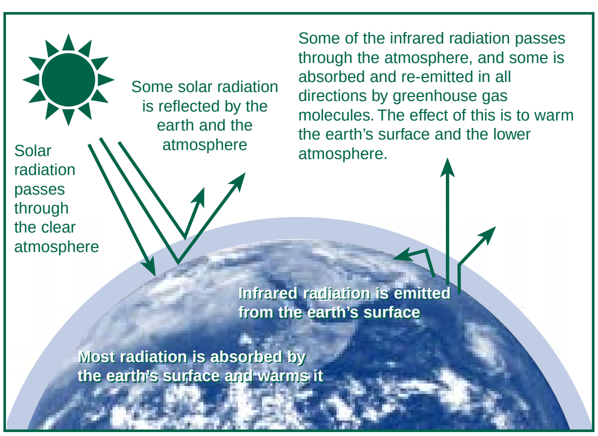
The earth's climate is predicted to change because human activities are altering the chemical composition of the atmosphere through the buildup of greenhouse gases — primarily carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons. The heat-trapping property of these greenhouse gases is undisputed. Although there is uncertainty about exactly how and when the earth's climate will respond to enhanced concentrations of greenhouse gases, observations indicate that detectable changes are under way. There most likely will be increases in temperature and changes in precipitation, soil moisture, and sea level, which could have adverse effects on many ecological systems, as well as on human health and the economy.

## The Climate System

Energy from the sun drives the earth's weather and climate. Atmospheric greenhouse gases (water vapor, carbon dioxide, and other gases) trap some of the energy from the sun, creating a natural "greenhouse effect." Without this effect, temperatures would be much lower than they are now, and life as known today would not be possible. Instead, thanks to greenhouse gases, the earth's average temperature is a more hospitable 60°F. However, problems arise when the greenhouse effect is ***enhanced*** by human-generated emissions of greenhouse gases.

Global warming would do more than add a few degrees to today's average temperatures. Cold spells still would occur in winter, but heat waves would be more common. Some places would be drier, others wetter. Perhaps more important, more precipitation may come in short, intense bursts (e.g., more than 2 inches of rain in a day), which could lead to more flooding. Sea levels would be higher than they would have been without global warming, although the actual changes may vary from place to place because coastal lands are themselves sinking or rising.

### The Greenhouse Effect




Source: U.S. Department of State (1992)

## Emissions Of Greenhouse Gases

Since the beginning of the industrial revolution, human activities have been adding measurably to natural background levels of greenhouse gases. The burning of fossil fuels — coal, oil, and natural gas — for energy is the primary source of emissions. Energy burned to run cars and trucks, heat homes and businesses, and power factories is responsible for about 80% of global carbon dioxide emissions, about 25% of U.S. methane emissions, and about 20% of global nitrous oxide emissions. Increased agriculture and deforestation, landfills, and industrial production and mining also contribute a significant share of emissions. In 1994, the United States emitted about one-fifth of total global greenhouse gases.

## Concentrations Of Greenhouse Gases

Since the pre-industrial era, atmospheric concentrations of carbon dioxide have increased nearly 30%, methane concentrations have more than doubled, and nitrous oxide concentrations have risen by about 15%. These increases have enhanced the heat-trapping capability of the earth's atmosphere. Sulfate aerosols, common air pollutants, cool the atmosphere by reflecting incoming solar radiation. However, sulfates are short-lived and vary regionally.

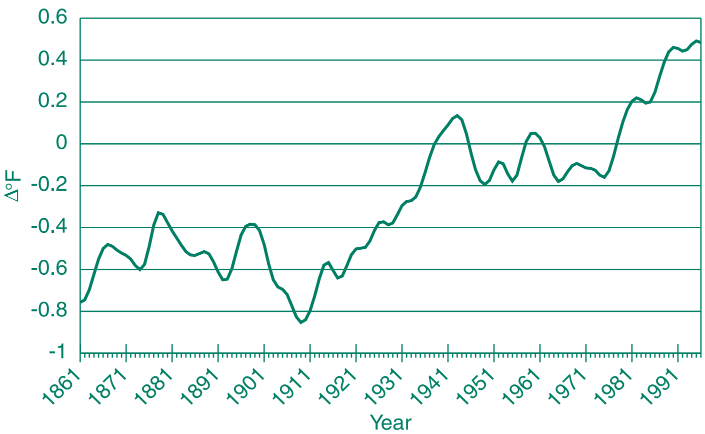
Although many greenhouse gases already are present in the atmosphere, oceans, and vegetation, their concentrations in the future will depend in part on present and future emissions. Estimating future emissions is difficult, because they will depend on demographic, economic, technological, policy, and institutional developments. Several emissions scenarios have been developed based on differing projections of these underlying factors. For example, by 2100, in the absence of emissions control policies, carbon dioxide concentrations are projected to be 30-150% higher than today's levels.

## Current Climatic Changes

Global mean surface temperatures have increased 0.6-1.2°F between 1890 and 1996. The 9 warmest years in this century all have occurred in the last 14 years.

Several pieces of additional evidence consistent with warming, such as a decrease in Northern Hemisphere snow cover, a decrease in Arctic Sea ice, and continued melting of alpine glaciers, have been corroborated. Globally, sea levels have risen 4-10 inches over the past century, and precipitation over land has increased slightly. The frequency of extreme rainfall events also has increased throughout much of the United States.

## Global Temperature Changes (1861–1996)




Source: IPCC (1995), updated

A new international scientific assessment by the Intergovernmental Panel on Climate Change recently concluded that ***"the balance of evidence suggests a discernible human influence on global climate."***

## Future Climatic Changes

For a given concentration of greenhouse gases, the resulting increase in the atmosphere's heat-trapping ability can be predicted with precision, but the resulting impact on climate is more uncertain. The climate system is complex and dynamic, with constant interaction between the atmosphere, land, ice, and oceans. Further, humans have never experienced such a rapid rise in greenhouse gases. In effect, a large and uncontrolled planet-wide experiment is being conducted.

General circulation models are complex computer simulations that describe the circulation of air and ocean currents and how energy is transported within the climate system. While uncertainties remain, these models are a powerful tool for studying climate. Scientists are reasonably confident about the ability of models to characterize future climate at continental scales.

Recent model calculations suggest that the global surface temperature could increase an average of 1.6-6.3°F by 2100, with significant regional variation. These temperature changes would be far greater than recent natural fluctuations, and they would occur significantly faster than any known changes in the last 10,000 years. The United States is projected to warm more than the global average, especially as fewer sulfate aerosols are produced.

The models suggest that the rate of evaporation will increase as the climate warms, which will increase average global precipitation. They also suggest increased frequency of intense rainfall as well as a marked decrease in soil moisture over some mid-continental regions during the summer. Sea level is projected to increase by 6-38 inches by 2100.

Calculations of regional climate change are much less reliable than global ones, and it is unclear whether regional climate will become more variable. The frequency and intensity of some extreme weather of critical importance to ecological systems (droughts, floods, frosts, cloudiness, the frequency of hot or cold spells, and the intensity of associated fire and pest outbreaks) could increase.

## Local Climate Changes

Over the last century, the average temperature in Amherst, Massachusetts, has increased 2°F, and precipitation has increased by up to 20% in many parts of the state.

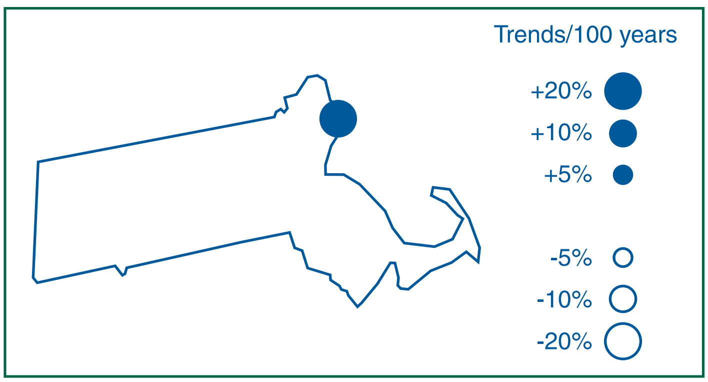
Over the next century, climate in Massachusetts may change even more. For example, based on projections made by the Intergovernmental Panel on Climate Change and results from the United Kingdom Hadley Centre's climate model (HadCM2), a model that accounts for both greenhouse gases and aerosols, by 2100 temperatures in Massachusetts could increase by about 4°F (with a range of 1-8°F) in winter and spring and about 5°F (with a range of 2-10°F) in summer and fall. Precipitation is estimated to increase by about 10% in spring and summer, 15% in fall, and 20-60% in winter. Other climate models may show different results. The amount of precipitation on extreme wet or snowy days in winter is likely to increase. The frequency of extreme hot days in summer would increase because of the general warming trend. Although it is not clear how severe storms such as hurricanes would change, an increase in the frequency and intensity of winter storms is possible.

## Climate Change Impacts

Global climate change poses risks to human health and to terrestrial and aquatic ecosystems. Important economic resources such as agriculture, forestry, fisheries, and water resources also may be affected. Warmer temperatures, more severe droughts and floods, and sea level rise could have a wide range of impacts. All these stresses can add to existing stresses on resources caused by other influences such as population growth, land-use changes, and pollution.

Similar temperature changes have occurred in the past, but the previous changes took place over centuries or millennia instead of decades. The ability of some plants and animals to migrate and adapt appears to be much slower than the predicted rate of climate change.

## Precipitation Trends From 1900 To Present




Source: Karl et al. (1996)

## Human Health

Higher temperatures and increased frequency of heat waves may increase the number of heat-related deaths and the incidence of heat-related illnesses. Massachusetts, with its irregular, intense heat waves, could be especially susceptible.

In Boston, one study projects that by 2050 heat-related deaths during a typical summer could increase 50%, from close to 100 heat-related deaths per summer to over 150 (although increased air conditioning use may not have been fully accounted for). Winter-related deaths are expected to change very little. The elderly, particularly those living alone, are at greatest risk.

Climate change could increase concentrations of ground-level ozone. For example, high temperatures, strong sunlight, and stable air masses tend to increase urban ozone levels. Air pollution also is made worse by increases in natural hydrocarbon emissions during hot weather. If a warmed climate causes increased use of air conditioners, air pollutant emissions from power plants also will increase.

A 4°F warming in New York City, with no other change in weather or emissions, could increase concentrations of ozone, a major component of smog, by 4%. Similar increases could occur in Massachusetts. Currently, ground-level ozone concentrations exceed national ozone health standards throughout the state. All of Massachusetts is classified as a “serious” nonattainment area for ozone. Ground-level ozone has been shown to aggravate respiratory illnesses such as asthma, reduce existing lung function, and induce respiratory inflammation. In addition, ambient ozone reduces crop yields and impairs ecosystem health.

Warming and other climate changes may expand the habitat and infectivity of disease-carrying insects, thus increasing the potential for transmission of diseases such as malaria and dengue (“break bone”) fever. Mosquitos flourish in some areas around Massachusetts. Some can carry malaria, while others can carry Eastern equine encephalitis, which can be lethal or cause neurological damage. Incidents of Lyme disease, which is carried by ticks, have increased in the Northeast. If conditions become warmer and wetter, mosquito and tick populations could increase, thereby increasing the risk of transmission of these diseases.

In addition, warmer seas could contribute to the increased intensity, duration, and extent of harmful algal blooms. These blooms damage habitat and shellfish nurseries, can be toxic to humans, and can carry bacteria like those causing cholera. Brown algal tides and toxic algal blooms already are prevalent in the Atlantic. Warmer ocean waters could increase their occurrence and persistence.

## Coastal Areas

Sea level rise could lead to flooding of low-lying property, loss of coastal wetlands, erosion of beaches, saltwater contamination of drinking water, and decreased longevity of low-lying roads, causeways, and bridges. In addition, sea level rise could increase the vulnerability of coastal areas to storms and associated flooding.

The coast of Massachusetts is an important resource with over 1,500 miles of shoreline. Massachusetts’ coastline includes stretches of rocky shore, barrier beaches, productive estuaries, fragile salt marshes, tidal flats, and dozens of islands. Barrier beaches, salt marshes, and other wetland resource areas buffer the coast from storms, waves, and flooding.

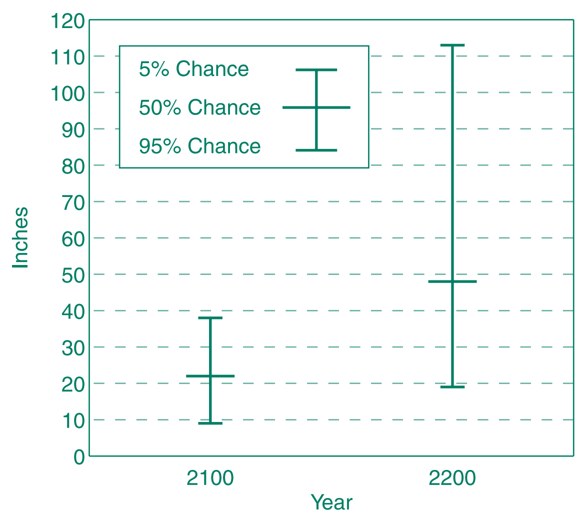
At Boston, sea level already is rising by 11 inches per century, and it is likely to rise another 22 inches by 2100. Rising sea levels are taking a toll on Massachusetts’ coastal upland. Each year, an average of 65 acres of upland is submerged by a combination of rising seas and subsiding land. Much of this loss occurs along the south-facing coast between Rhode Island and the outer shore of Cape Cod, including the islands of Nantucket and Martha’s Vineyard. Coastal land that has been lost because of erosion by storm waves or wetland erosion is not included in the estimate of annual average land lost from submersion.

Possible responses to sea level rise include building walls to hold back the sea, allowing the sea to advance and adapting to it, and raising the land (e.g., by replenishing beach sand, elevating houses and infrastructure). Each of these responses will be costly, either in out-of-pocket costs or in lost land and structures. For example, the cumulative cost of sand replenishment to protect the coast of Massachusetts from a 20-inch sea level rise by 2100 is estimated at $490 million to $2.6 billion.

## Water Resources

Water resources are affected by changes in precipitation as well as by temperature, humidity, wind, and sunshine. Changes in streamflow tend to magnify changes in precipitation. Water resources in drier climates tend to be more sensitive to climate changes. Because evaporation is likely to increase with warmer climate, it could result in lower river flow and lower lake levels, particularly in the summer. If streamflow and lake levels drop, groundwater also could be reduced. In addition, more intense precipitation could increase flooding.

**Future Sea Level Rise**
**At Woods Hole, Cape Cod**




Source: EPA (1995)

Western Massachusetts drains to the Connecticut River, and the eastern parts of the state drain directly to the Atlantic Ocean. Relatively little of the flow of the Connecticut River originates in Massachusetts, but it is the source of much of the water supply for the Boston metropolitan area. The flow of the Connecticut is strongly affected by winter snow accumulation and runoff from Vermont and New Hampshire. A warmer climate would lead to earlier spring snowmelt, resulting in higher streamflows in winter and spring and lower streamflows in summer and fall. However, warmer summer temperatures could increase water quality problems because of increased evaporation (which concentrates pollutant levels) and more favorable conditions for algae and other water organisms. Increased rainfall could mitigate these effects, but it also could contribute to localized flooding.

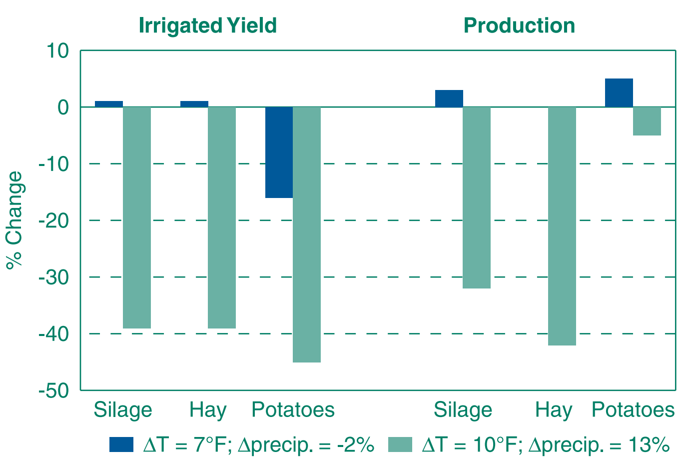
## Agriculture

The mix of crop and livestock production in a state is influenced by climatic conditions and water availability. As climate warms, production patterns could shift northward. Increases in climate variability could make adaptation by farmers more difficult. Warmer climates and less soil moisture due to increased evaporation may increase the need for irrigation. However, these same conditions could decrease water supplies, which also may be needed by natural ecosystems, urban populations, industry, and other sectors.

Understandably, most studies have not fully accounted for changes in climate variability, water availability, and imperfect responses by farmers to changing climate. Including these factors could change modeling results substantially. Analyses that assume changes in average climate and effective adaptation by farmers suggest that aggregate U.S. food production would not be harmed, although there may be significant regional changes.

In Massachusetts, agriculture is a $500 million annual industry, three-fourths of which comes from crops. Very little of the crop acreage is irrigated. The major crops in the state are silage, hay, and potatoes. Climate change could change crop yields little or cause them to fall by as much as 45%, leading to changes in acres farmed and production. For example, potato yields could decrease while production rises because of an increase in potato acres farmed.

### Changes In Agricultural Yield And Production




Source: Mendelsohn and Neumann (in press); McCarl (personal communication)

## Forests

Trees and forests are adapted to specific climate conditions, and as climate warms, forests will change. These changes could include changes in species, geographic range, and health and productivity. If conditions also become drier, the current range of forests could be reduced and replaced by grasslands and pasture. Even a warmer and wetter climate could lead to changes; trees that are better adapted to warmer conditions, such as oaks and pines, would prevail. Under these conditions, forests could become more dense. These changes could occur during the lifetimes of today's children, particularly if change is accelerated by other stresses such as fire, pests, and diseases. Some of these stresses would themselves be worsened by a warmer and drier climate.

Although the extent of forested areas in Massachusetts could change little because of climate change, a warmer climate could change the character of those forests. Maple-dominated hardwood forests could give way to forests dominated by oaks and conifers, species more tolerant of higher temperatures. This change would diminish the brilliant autumn foliage as the number of maple trees declines. Across the state, as much as 30-60% of the hardwood forests could be replaced by warmer climate forests with a mix of pines and hardwoods.

## Ecosystems

The coastal beaches and tidal marshes of Massachusetts are especially sensitive to the effects of sea level rise and changes in river flows. Sea level rise could inundate coastal wetlands, destroying habitat for commercial and game species as well as migratory birds and other wildlife. Barrier beach island refuges such as the Monomoy National Wildlife Refuge south of Cape Cod and the Parker River National Wildlife Refuge in northeastern Massachusetts could be threatened or lost. These refuges provide important habitat for migratory birds, including the threatened piping plover and the endangered roseate tern. Harbor and gray seals, which use beaches as refuge in the winter, also could lose habitat if sea levels rise.

Forests and woodlands support much of the wildlife in the state. Climate change could result in changes in these ecosystems. Fragmented land use patterns could impede migration of some plant species, resulting in loss of some native plants and increases in non-native plants. Changes in rainfall and runoff could change sediment levels in streams and wetlands, thus affecting fish and aquatic habitats.

*For further information about the potential impacts of climate change, contact the Climate and Policy Assessment Division (2174), U.S. EPA, 401 M Street SW, Washington, DC 20460.*