THE UNIVERSITY OF MAINE

Celebrating 150 years

MAINE'S CLIMATE FUTURE

2015 UPDATE

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climatechange.umaine.edu/research/publications/climate-future

February 2015, Revised March 2015 with corrected Figure 2 and Figure 9 legends and captions.

MAINE'S CLIMATE FUTURE 2015

I. Introduction

As Maine citizens, we are acutely aware of our links to the environment. What's going on in the woods, sky, and water around us influences most aspects of daily life, from business operations to food production to recreational pursuits. This is why, in 2008, Governor Baldacci asked the University of Maine's Climate Change Institute to develop an initial assessment of climate-related changes in Maine. More than 70 scientists from throughout Maine contributed their expertise in helping to develop *Maine's Climate Future*, an initial assessment and a framework for understanding climate change risks that have been instrumental in supporting subsequent adaptation initiatives in Maine.[1]

Since Maine's Climate Future 2009, concern has grown over climate change and its effects, such as the economic and human consequences of hurricanes, droughts, melting Arctic ice, flooding, and rising seas throughout the U.S. and beyond. In the fall of 2013 and early 2014, the Intergovernmental Panel on Climate Change released its fifth assessment report detailing the emerging patterns and consequences of climate change across the planet.[2] In the United States, the third National Climate Assessment emphasized that climate change is here now and that "Americans are noticing changes all around them."[3] Human influence on the global climate system is emerging as the defining environmental, economic, and social issue of the twenty-first century. Global temperature in 2014 was the warmest in 135 years of keeping records. Nine of the 10 warmest years have occurred in this century.[4] As noted in Maine's Climate Future 2009, the rise in a suite of greenhouse gases and other air pollutants in the twentieth century is coincident with the rise in human population and in stark contrast to the composition of the atmosphere over the past 5,000 years.

Maine's Climate Future 2015 builds on the Maine's Climate Future 2009 report; it is not intended as a comprehensive revision of all aspects of the original report. This update focuses on highlights of our understanding in 2015 of past, present, and future trends in key indicators of a changing climate specific to Maine, and recent examples of how Maine people are experiencing these changes. Sometimes the effects are the direct result of shifting temperature or precipitation. Other times, climate-related changes in other parts of the country and world affect Maine, directly or indirectly. Climate change often acts in concert with other stresses, including a changing chemical climate, rather than being a singular cause of any given change. Sometimes these changes represent a new opportunity.

In their responses to these climate-related changes, Maine people are realizing the value of informed decision-making and cost-effective adaptation initiatives in concert with the urgency of mitigation. Together, the data and stories from across the state reveal the challenges we face in Maine's climate future.

1 Jacobson, G.L., I.J. Fernandez, P.A. Mayewski, and C.V. Schmitt, editors. 2009. Maine's Climate Future: An Initial Assessment. Orono, ME: University of Maine. *climatechange.umaine.edu/research/publications/climate-future*

2 Intergovernmental Panel on Climate Change. 2014. Fifth Assessment Report. Geneva, Switzerland: IPCC Secretariat. *ipcc.ch/report/ar5/index.shtml*

3 Melillo, J.M., T.C. Richmond, and G.W. Yohe, editors. 2014. Climate Change Impacts in the United States: The Third National Climate Assessment. US Global Change Research Program. *nca2014.globalchange.gov/*

4 NOAA National Climatic Data Center. 2014. State of the Climate: Global Analysis for Annual 2014. *ncdc.noaa.gov/sotc/global/*

II. Maine's Climate Past, Present, Future

Temperature

Average annual temperature across Maine warmed by about 3.0 °F (1.7 °C) between 1895 and 2014 (*Figure 1*). Data have been collected continuously from meteorological stations across southern and western Maine since the mid- to late 1800s, and elsewhere since the early 1900s. Monthly compilations of these scattered data extend to 1895. Although the overall warming trend in Figure 1 is clear, Maine's temperature signal also features significant year-to-year fluctuations superimposed on a distinct pattern with periods of relative cold (circa 1900–1925, 1965–1990) and warmth (1930–1960, 1995–present). The latter pattern correlates with the Atlantic Multidecadal Oscillation (or AMO), a recognized mode of global climate variability linked to changes in sea-surface temperatures across the North Atlantic Ocean (see *Uncertainty and variability*, page 6).

Maine's Average Annual Temperature

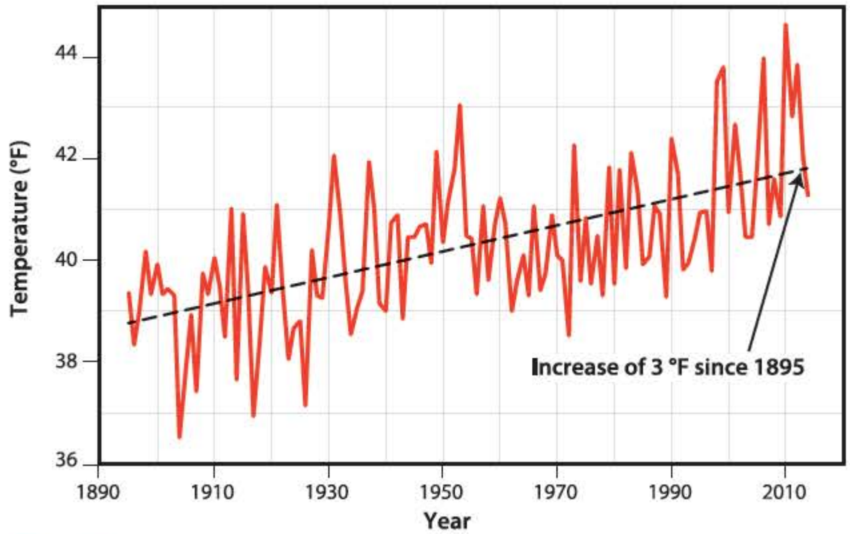


Figure 1. Mean annual temperature, 1895–2014, averaged across Maine from gridded monthly station records from the U.S. Climate Divisional Dataset (*ncdc noaa.gov/monitoring-references/maps/us-climate-divisions.php*). A simplified linear trend (black line) indicates that temperature increased 3 °F over the record period.

Numerical models of the global atmosphere and ocean have been in development for over three decades. The most sophisticated of these models, such as those used by the Intergovernmental Panel on Climate Change (IPCC) and employed in this report, account for both natural and human climate forcings to produce reasonable, physically-based estimates of future climate. IPCC models predict that annual temperature will increase another 2.0–3.0 °F (1.1–1.7 °C) across Maine between now and 2050 (*Figure 2*).[1]

Present and Future Temperature

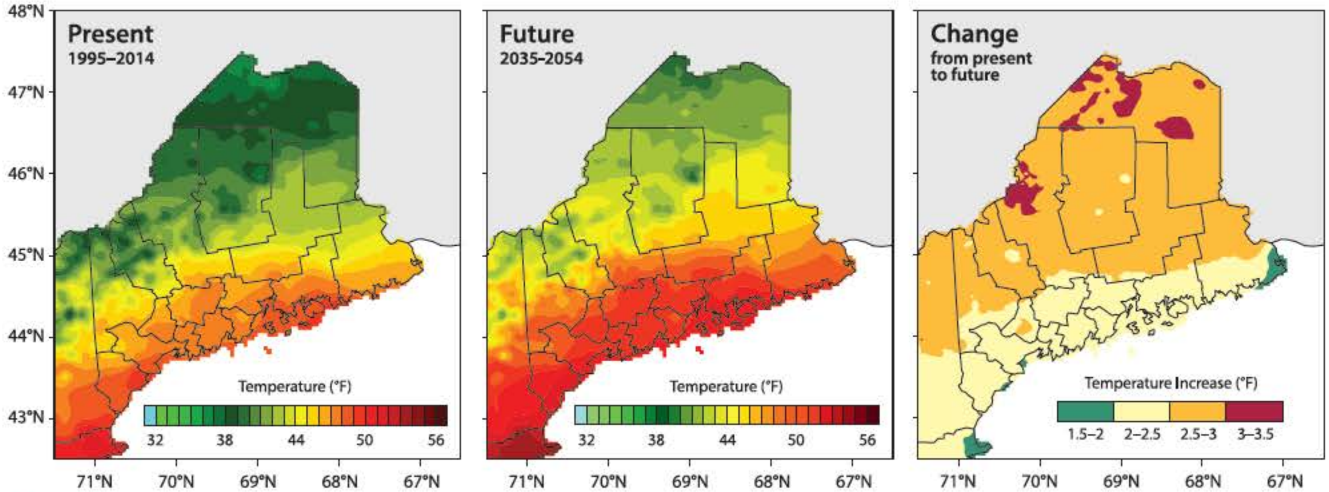


Figure 2. Maps showing mean annual temperature for 1995–2014 (left), 2035–2054 (center), and the predicted change or difference between the two time periods (right). The predicted rise in temperature by 2050 ranges 2.0–3.0 °F from the coast inland to the Canadian border. Maps derived from an ensemble simulation of the IPCC A2 emissions scenario.[1]

Changes in temperature affect our experience of the Maine year, changing the relative length and character of each season (*Figure 3*). Maine's warm season (defined here as when average daily temperature is above freezing) increased by two weeks from the early 1900s to the 2000s. Global climate models predict that the warm season will increase by an additional two weeks over the next 50 years. Winter is warming at a faster rate than summer.

Maine's Changing Seasons

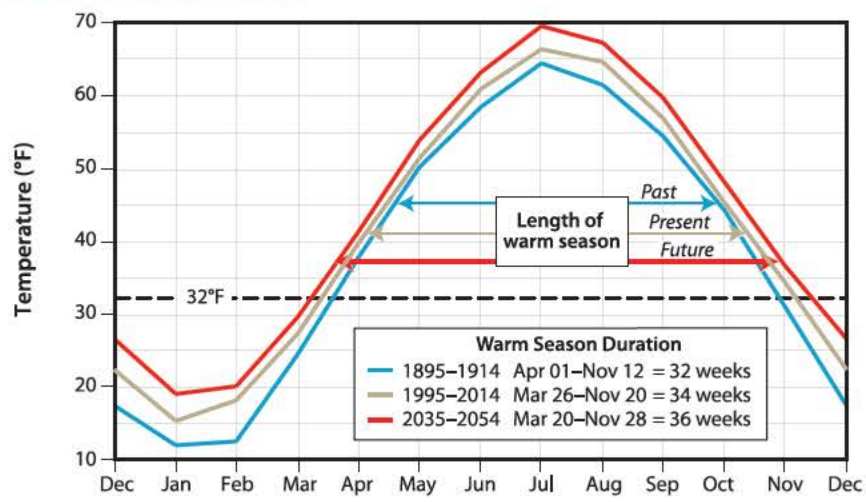


Figure 3. Mean monthly temperature averaged across Maine for historical (1895–1914), recent (1995–2014), and future (2035–2054) time periods. Historical and recent data from the U.S. Climate Divisional Dataset (*ncdc.noaa.gov/monitoring-references/maps/us-climate-divisions.php*), and future prediction from an ensemble simulation of the IPCC emissions scenario A2.

1 In this report, we use IPCC (2007) emissions scenario A2 computed by version 3 of the NCAR Community Climate System Model (CCSM3), one of several models in the Coupled Model Intercomparison Project Phase 3 (CMIP3) used by IPCC for future climate prediction. CCSM3 predates the more recent CCSM4 used in IPCC 2013. Of the two models, CCSM3 best approximates observed temperature climate for the modern control period across the U.S. Northeast, and we therefore use this previous model here. IPCC. 2007. Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Solomon, S. et al., editors). Cambridge, UK and New York, NY: Cambridge University Press.

More Hot Days

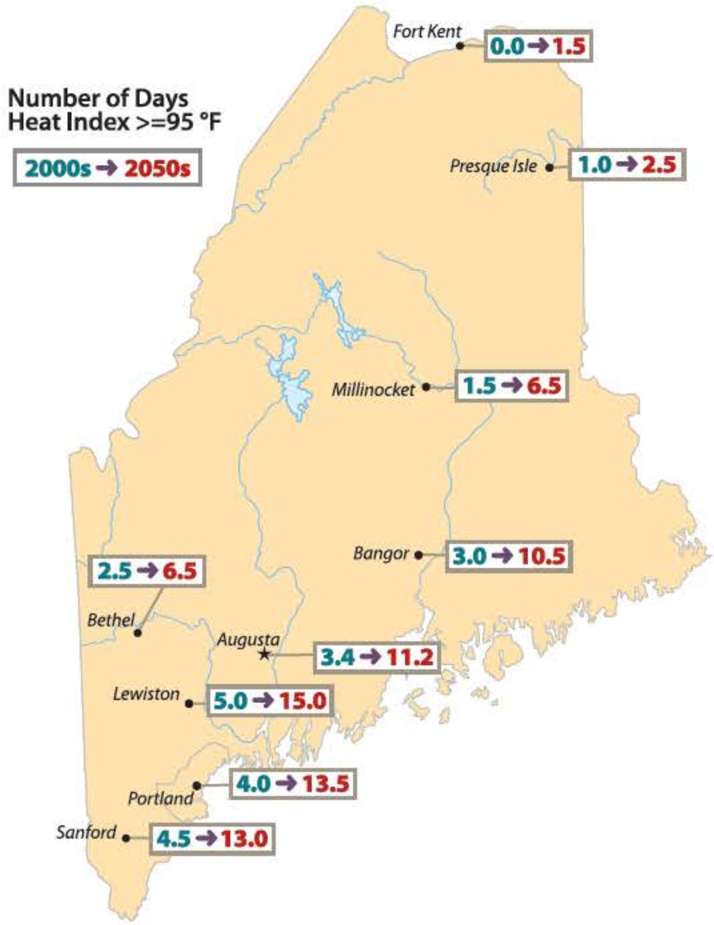


Figure 4. The average number of days when the heat index is greater than or equal to 95 °F at selected sites for 2000–2004 and 2050–2054. Predicted values derived from a 48-km downscale simulation of one ensemble member of the CCSM3 model for the IPCC A2 emissions scenario.

As Maine's summers become warmer and longer, the number of excessively hot and humid days when heat indices rise above 95 °F (35 °C) are likely to increase. Figure 4 shows information about the heat index, a measure of how hot it feels that combines temperature and relative humidity. Most places in Maine currently see fewer than four such high-heat days on average in a given year, but by 2050 some locations could see ten or more. Especially at risk are the elderly, young children, athletes of all ages, and "weekend warriors" whose bodies are not adapted to heat stress. Excessive heat caused by climate change is predicted to result in thousands of additional deaths in the U.S. by 2050.[1]

1 Brody, J.E. 2014. Too hot to handle. *The New York Times*, 23 June 2014. *well.blogs.nytimes.com/2014/06/23/too-hot-to-handle;* Li, T., R.M. Horton, and P.L. Kinney. 2013. Projections of seasonal patterns in temperature-related deaths for Manhattan, New York. *Nature Climate Change* 3:717–721; Ostro, B., S. Rauch, and S. Green. 2011. Quantifying the health impacts of future changes in temperature in California. *Environmental Research* 111:1258–1264.

How these changes are affecting Maine

Lyme disease on the rise.

The incidence of Lyme disease is increasing, according to the Maine Center for Disease Control and Prevention. The spread of Lyme disease has been linked to temperatures that make habitat more suitable for deer ticks and their hosts.[1] The rate of Lyme disease reached a record high in 2013 at 103.6 cases per 100,000 persons (1,377 cases were reported in 2013, up from 108 cases reported in 2001). Children aged 5–14 had the highest rate of reported Lyme cases in 2013.[2]

New schedules for maple syrup production.

Climate is one of the main factors affecting annual yield of maple syrup through its effects on sap flow and/or sugar concentrations. Conditions prevailing during the growing season and winter prior to sap season appear to be particularly important.[3] The optimal time to maximize sap collection is projected to advance earlier in the year—nearly three weeks earlier by 2050 compared to today. If producers adapt and shift the conventional start date of maple syrup season to early February, the current eight-week window of sap collection days in Maine can be maintained or even increased.[4]

The "New North"?

The effects of warming temperatures elsewhere present potential opportunities for Maine. In May 2014, the Maine National Guard, University of Maine School of Policy and International Affairs, and United States Coast Guard hosted a conference about the political, military, economic, and environmental consequences of a melting Arctic. The "Leadership in the High North" symposium addressed challenges and opportunities related to the opening of the Arctic.[5]

Vulnerable plants and animals.

A changing climate coupled with land use and management factors is putting Maine's wildlife at risk. In 2013, Manomet Center for Conservation Sciences and Maine Beginning with Habitat Climate Change Working Group reported that two-thirds of Maine's plant and animal species are either highly or moderately vulnerable to climate change.[6] Vulnerable species include Maine icons like moose, which are vulnerable to heat stress and ticks that survive through mild winters.[7]

Meanwhile, a changing climate and related habitat disturbance creates opportunities for the introduction and expansion of exotic species and potentially invasive diseases and pests, including some, such as the winter moth, that could affect a wide range of species in Maine.[8]

1 Leighton, P.A., J.K. Koffi, Y. Pelcat, L.R. Lindsay, and N.H. Ogden. 2012. Predicting the speed of tick invasion: an empirical model of range expansion for the Lyme disease vector Ixodes scapularis in Canada. *Journal of Applied Ecology* 49:457–464; Smith, T.M., R.W. Reynolds, T.C. Peterson, and J. Lawrimore. 2008. Improvements to NOAA's Historical Merged Land–Ocean Temp Analysis (1880–2006). *Journal of Climate* 21:2283–2296.

2 Robinson, S. 2014. Infectious Disease Epidemiology Report: Lyme Disease Surveillance Report—Maine, 2013. Augusta, ME: Maine Center for Disease Control and Prevention.

3 Duchesne, L., and D. Houle. 2014. Interannual and spatial variability of maple syrup yield as related to climatic factors. *PeerJ* 2:e428.

4 Skinner, C.B., A.T. DeGaetano, and B. Chabot. 2010. Implications of twenty-first century climate change on Northeastern United States maple syrup production: impacts and adaptations. *Climatic Change* 100:685–702.

5 Paquette, C. 2014. Melting sea ice could make Maine hub of new international shipping routes. *Bangor Daily News*, 22 May 2014.

6 Whitman, A., et al. 2013. Climate Change and Biodiversity in Maine: Vulnerability of Habitats and Priority Species. Brunswick, ME: Manomet Center for Conservation Sciences. *manomet.org/publications-tools/climate-services*

7 Fleming, D. 2014. Winter ticks raise concerns about future of Maine's moose herd. *Portland Press Herald*, 14 June 2014.

8 *maine.gov/dacf/mfs/forest_health/insects/winter_moth.htm*

Uncertainty and variability

With evidence of a changing climate in Maine comes increasing interest from citizens and businesses in building resilience and developing adaptation options to minimize risk and maximize potential benefits. Such efforts can be difficult in the face of an uncertain future.

Climate projections are uncertain for several reasons: natural climate variability, incomplete physical descriptions of the climate system in computer models, and difficulty in predicting future greenhouse gas emissions.

Climate scientists have learned a great deal about the climate system over a range of time scales, and how variability in ocean temperatures and related changes in atmospheric circulation can affect weather patterns and ecosystems worldwide. For example, climate of the Pacific Ocean varies between warm and cool phases every 20 to 30 years (known as the Pacific Decadal Oscillation or PDO). A similar phenomenon, the El Niño-Southern Oscillation (ENSO), occurs at smaller time scales: generally every three to five years, the temperature of the eastern equatorial Pacific Ocean is either warmer (El Niño) or cooler (La Niña) than normal due to changes in upwelling of deep water. Resulting shifts in the position of warm water masses alter the path of the jet stream, which in turn influences the weather across the nation, including Maine. Warm phase El Niño periods generally result in warmer conditions in Maine, particularly in winter.[1]

Background variability also occurs across the Atlantic Ocean. The North Atlantic Oscillation (NAO) involves daily to weekly changes in the position of pressure centers and storm tracks that ultimately affect the weather from eastern North America to Europe. Operating over a considerably longer time scale is the Atlantic Multidecadal Oscillation (AMO). The AMO, similar to the PDO over the Pacific, encompasses changes in sea surface temperature in cyclical fashion over many decades (*Figure 5*).[2] The overall warming trend, and distinct phases of relatively cool and warm conditions expressed by the AMO, are more or less mirrored in Maine's mean annual air temperature record (*Figure 1*). Moreover, the AMO is widely recognized as an important pattern of variability impacting global climate. The origin of the AMO (and perhaps also the PDO) may be the interplay between solar variability, cooling from volcanic eruptions that inject gases, aerosol droplets and ash into the stratosphere, and internal ocean circulation. Modeling studies indicate that natural forcings can account for most of the AMO-like variability in the climate system prior to about 1960. After 1960, the observed warming can only be accurately modeled by incorporating human industrial activity, including emission of carbon dioxide, methane, and ozone-depleting chlorofluorocarbons.[2] Further information about climate indices is available from the National Center for Atmospheric Research and NOAA.[3]

North Atlantic Annual Sea Surface Temperature

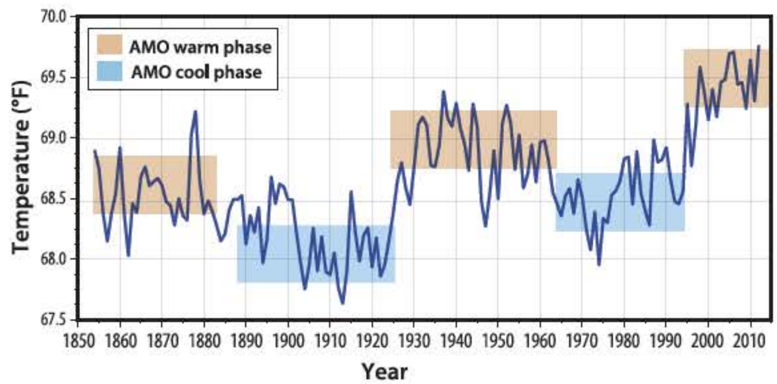


Figure 5. Mean annual sea surface temperature, 1854–2012, averaged across the North Atlantic Ocean (15°N-55°N, 80°W-0°E). Cool and warm phases of the Atlantic Multidecadal Oscillation are highlighted. Extended Reconstructed Sea Surface Temperature (ERSST) version 3b data provided by the NOAA/OAR/Earth System Research Laboratory Physical Sciences Division, Boulder, CO (*esrl.noaa.gov/psd/*).

1 Barnett, T.P., D.W. Pierce, M. Latif, D. Dommenget, and R. Saravanan. 1999. Interdecadal interactions between the tropics and midlatitudes in the Pacific basin. *Geophysical Research Letters* 26:615–618.

2 IPCC. 2013. Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Stocker, T.F. et al., editors). Cambridge, UK and New York, NY: Cambridge University Press.

3 *climatedataguide.ucar.edu/climate-data/overview-climate-indices; esrl.noaa.gov/psd/data/climateindices/list/*

The warming of recent decades was also likely influenced by declining atmospheric pollution (see *Air pollution and Maine's changing chemical climate*, page 12). "Natural" patterns of climate variability, such as ENSO, PDO, NAO, and AMO, are likely to change in uncertain ways as rising greenhouse gas concentrations alter the heat structure and circulation of the atmosphere, even though the governing physics of the climate system will remain the same.

More challenging sources of uncertainty include "tipping points" in the climate system, such as volcanic eruptions, changes in Arctic sea ice extent, changes in forest cover, and melting permafrost or methane hydrates, that can dramatically alter an otherwise linear or incremental climate trajectory.[1] Rapid shifts in climate, or abrupt climate change events, are well documented in the geologic record.[2] We have already experienced at least one recent abrupt change in climate in the last decade in response to greenhouse gas increases and warming of the Arctic.[3] Capturing these sources of variability in the numerical models of future climate projections remains imperfect.

We make decisions every day based on incomplete information. The insurance industry exists because of our desire to reduce risk in the face of uncertainties about fire, floods, travel, and life itself. Making decisions in the face of a changing Maine climate is no different. Science does not always provide absolute certainty, but it can and should be one of many factors that inform our evidence-based decisions. There is little uncertainty about the measured record of changes in our environment in recent decades, nor about the ongoing increases in global greenhouse gas emissions that are influencing Maine's climate future.

1 Mayewski, P.A., L.D. Meeker, M.S. Twickler, S.I. Whitlow, Q. Yang, W.B. Lyons, and M. Prentice. 1997. Major features and forcing of high latitude northern hemisphere atmospheric circulation over the last 110,000 years. *Journal of Geophysical Research* 102(C12):26345–26366.

2 Alley, R.B., et al. 2002. Abrupt Climate Change: Inevitable Surprises. Washington, DC: National Academies Press; National Research Council. 2013. Abrupt Impacts of Climate Change: Anticipating Surprises. Washington, DC: National Academies Press.

3 Mayewski, P.A., S.B. Sneed, S.D. Birkel, A.V. Kurbatov, and K.A. Maasch. 2014. Holocene warming marked by abrupt onset of longer summers and reduced storm frequency around Greenland. *Journal of Quaternary Science* 29:99–104.

Precipitation

The same changes in the global climate system that have brought about an overall rise in temperature over the past century also have affected the seasonal distribution and total amount of precipitation across Maine (*Figure 6*). Since 1895, total annual precipitation has increased by about six inches (15 cm), or 13%, with most of the additional amount falling in summer and fall.

Maine's Total Annual Precipitation

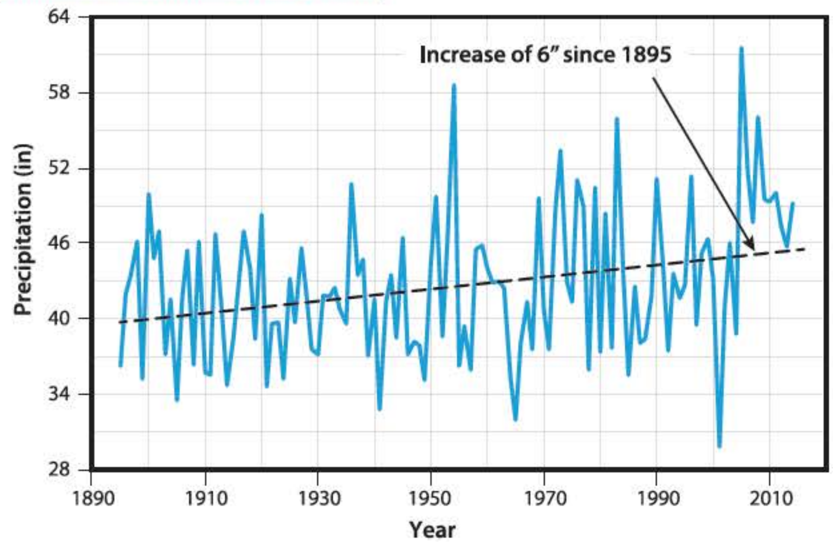


Figure 6. Total annual precipitation, 1895–2014, averaged across Maine from gridded monthly station records from the U.S. Climate Divisional Dataset (*ncdc.noaa.gov/monitoring-references/maps/us-climate-divisions.php*). A simplified linear trend (black line) indicates that precipitation increased six inches, or about 13%, during the recording interval.

IPCC models predict that precipitation will continue to increase across the Northeast by 5–10% between now and 2050, although the distribution of this increase is likely to vary across the climate zones. Model predictions show greater increases in precipitation in interior Maine (*Figure 7*), whereas measurements to date from weather stations across the Maine landscape show that precipitation has increased most along the coast (*Figure 8*).

Maine's Annual Precipitation Present and Future

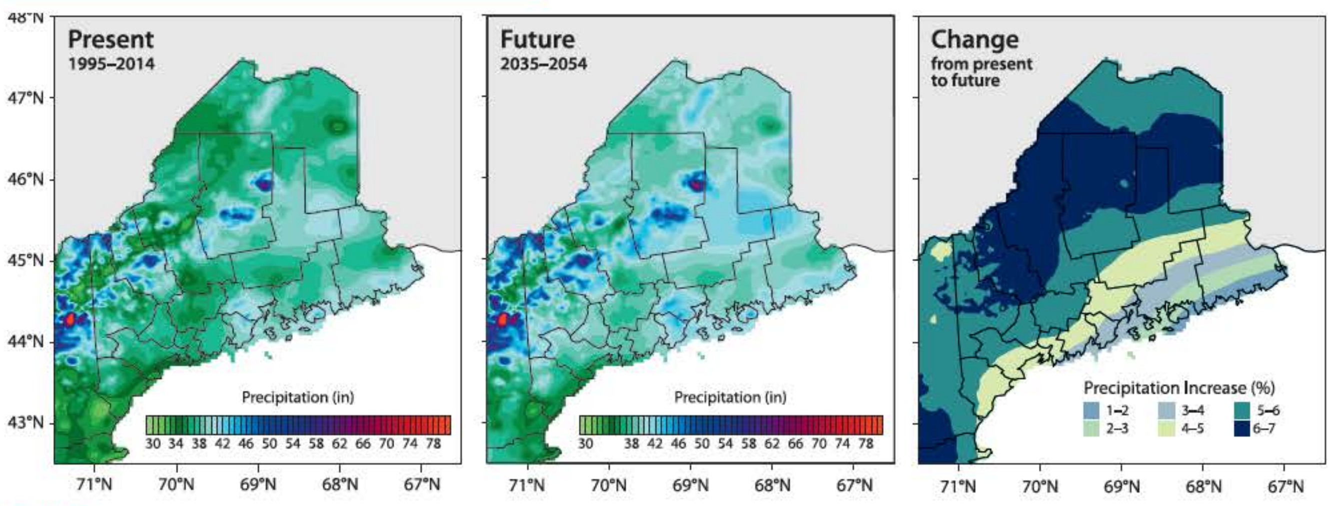


Figure 7. Maps showing total annual precipitation for 1995–2014 (left), 2035–2054 (center), and the predicted change or difference between the two time periods (right). The predicted precipitation increase by 2050 ranges 1–7% from the coast inland to the Canadian border. Maps derived from an ensemble simulation of the IPCC A2 emissions scenario.

An important characteristic of precipitation is the mode of delivery. A significant increase in extreme precipitation events (more frequent and intense storms) has been observed across Maine and other parts of the eastern U.S. (*Figure 8*). Using daily station data from the Global Historical Climatology Network, we define an extreme precipitation event for this analysis as one in which two or more inches (five or more cm) of precipitation falls within a 24-hour period. Historical measurements show that extreme events vary across the state, occuring most often in the coastal zone and western mountains.[1] The northernmost sites, like Millinocket and Caribou, show fewer extreme events overall, but with similar relative increases over the most recent decade. Higher total precipitation and a higher frequency of extreme precipitation events in coastal Maine are related to the zone's closer proximity to Atlantic storm tracks.

Extreme Precipitation Events

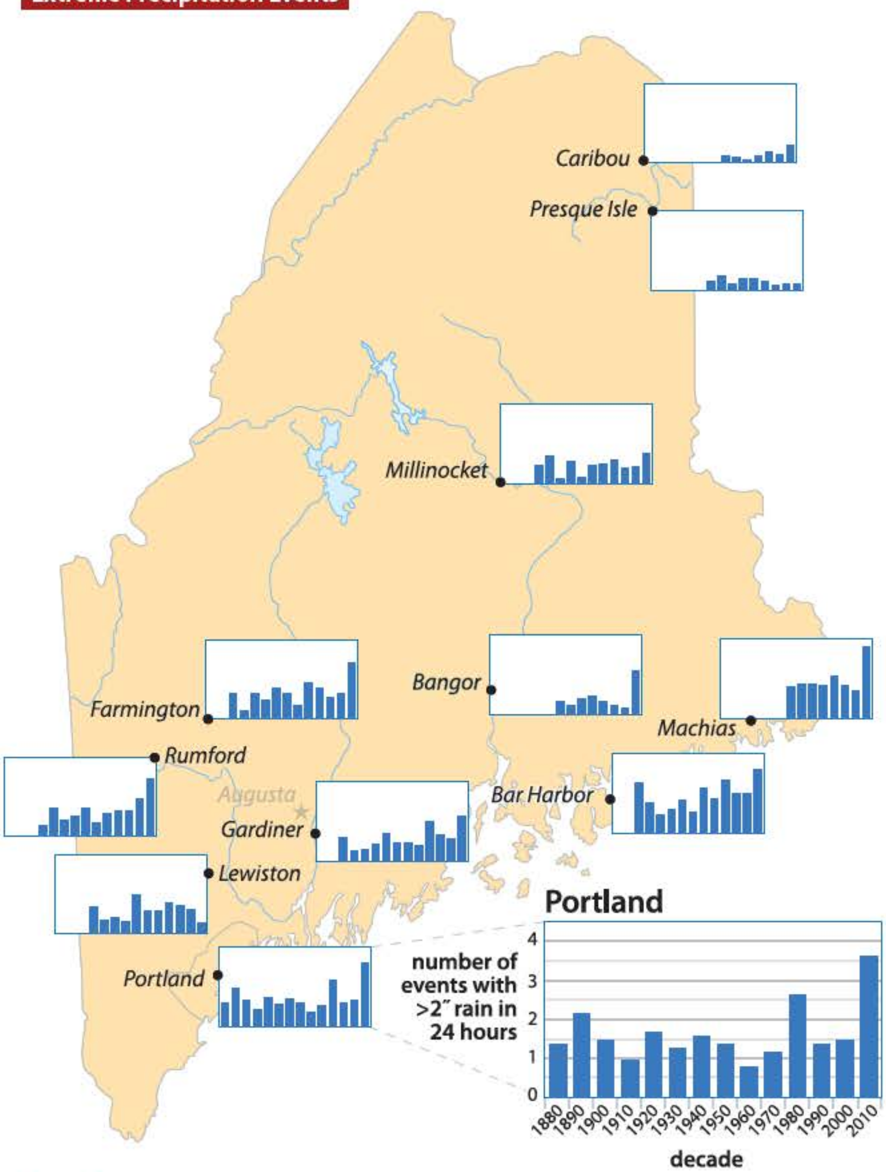


Figure 8. Extreme precipitation events recorded at 11 long-term meteorological stations across the state. Here, we use daily data from the Global Historical Climatology Network, and define an extreme event as two or more inches precipitation (rain or water equivalent snow) per 24-hour period. Bar plots show the average number of extreme events over 10-year intervals for each station. Nine out of 11 stations register the highest frequency of extreme events in the past ten years, with Bangor, Farmington, Machias, Portland, and Rumford showing the most distinct increases.

Warming ocean surface waters with enhanced evaporation, and more moisture in the atmosphere are key factors driving recent extreme weather events.[2] During the past decade, unprecedented warming in the Arctic has drastically reduced the extent and thickness of sea ice. Changes across the Arctic may be linked to a weakening of the circulation of the jet stream, which in turn increases the likelihood of atmospheric patterns that facilitate extreme events.[3] Whether extreme events become a "new normal" for Maine depends on future changes in sea surface temperature (particularly across the North Atlantic), and on future Arctic sea ice loss.

1 Peterson, T.C., and R.S. Vose. 1997. An overview of the Global Historical Climatology Network temperature database. *Bulletin of the American Meteorological Society* 78:2837–2849.

2 Walsh, J., et al. 2014. Chapter 2: Our Changing Climate. Climate Change Impacts in the United States, pp. 19–67 in The Third National Climate Assessment (J.M. Melillo, T.C. Richmond, and G.W. Yohe, eds.). U.S. Global Change Research Program.

3 Francis, J.A., and S.J. Vavrus. 2012. Evidence linking Arctic amplification to extreme weather in mid-latitudes. *Geophysical Research Letters* 39:L06801; Overland, J.E., and M. Wang. 2010. Large-scale atmospheric circulation changes are associated with the recent loss of Arctic sea ice. *Tellus A* 62:1–9.

What about snow?

Winter is a defining feature of Maine's climate, and the snow season is likewise an important part of Maine's economy. Changes in the annual cycle of temperature and precipitation over the past century have brought changes in the character of the snow season.

The evolution of the snow season can be measured in different ways. For example, by examining the presence or absence of snow, snowpack depth, or water content, depending on the question of interest. Predicting snow is particularly challenging given the influences of topography and other local factors. In general, the snow season has declined on average across Maine since the late 1800s (*Figure 9*). On a simplified linear trend, the snowfall has declined by about 15%.

Maine's Total Annual Snowfall

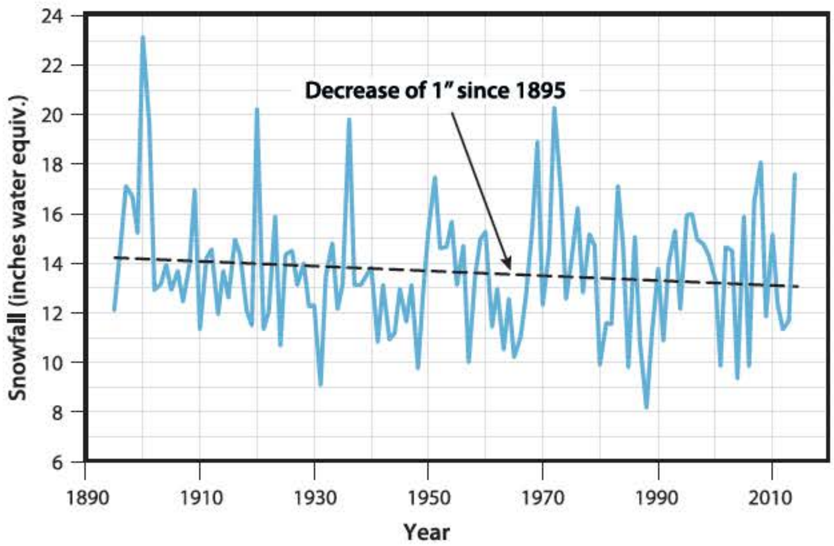


Figure 9. Total annual snowfall, 1895–2014, averaged across Maine, derived from gridded monthly temperature and precipitation station records from the U.S. Climate Divisional Dataset (*ncdc noaa.gov/monitoring-references/maps/us-climate-divisions.php*). A simplified linear trend (black line) indicates that snowfall decreased approximately 1.0 inches (6.6%) during the recording period.

The duration of the snow season in a given year is linked closely to near-surface air temperature from November to April. It follows that any change in the annual temperature cycle will serve to either decrease or increase the length of the snow season. In accord with the changing annual temperature cycle in Figure 3, the snowpack duration has decreased by about two weeks over the past century, and we can expect a further decrease of approximately two weeks by 2050 if climate predictions are correct. Total accumulated snow is likewise predicted to decline, especially along the coast where total winter snow loss could exceed 40% relative to recent climate (*Figure 10*). Although the amount and duration of snow may decline in the future, extreme snowfall events with significant accumulations—strong nor'easters—are likely to increase in frequency (see Figure 8).

Projected Snowfall Decline

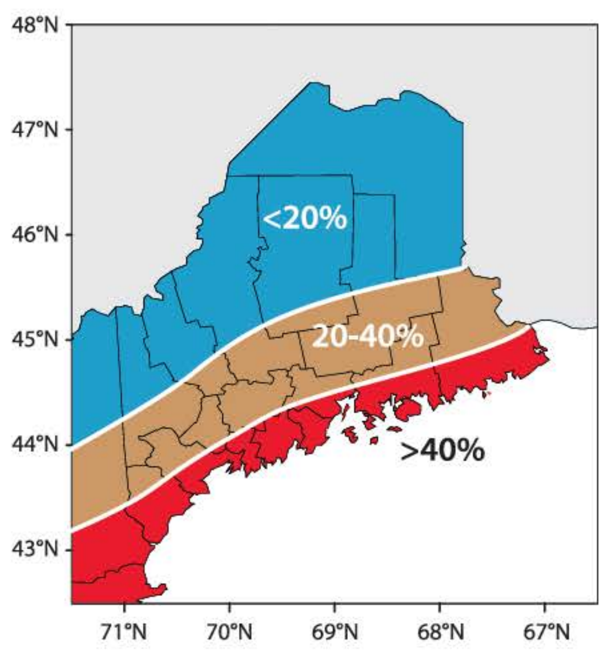


Figure 10. Map showing the predicted change or difference in total accumulated winter snow by climate zone from 1995–2014 to 2035–2054. The greatest changes are predicted to be along the coast, where many winters of the future will bring rain instead of snow. Map derived from an ensemble simulation of the IPCC A2 emissions scenario.

How these changes are affecting Maine

Intense rain events pollute lakes and streams.

In Auburn, a six-inch (15 cm) rainfall over a 24-hour period in May 2012 led to erosion around Lake Auburn, flushing nutrients into the water that, combined with a warm year in 2011 and warm spring and early ice-out in 2012, fueled an excessive algae bloom. Recorded dissolved oxygen levels in the deeper areas of the lake reached all-time lows. Many of the lake trout in Lake Auburn died as a result.[1]

Wet weather blamed for pine needle blight.

A decade of above-average spring and summer precipitation patterns have fostered an epidemic of white pine needle disease, which is caused by one or more pathogenic fungi, according to the Maine Department of Agriculture, Conservation & Forestry. The trees lose their needles, and become weak and vulnerable to further damage.[2]

Storms force towns to make costly repairs to roads and infrastructure.

The Northeast has experienced a greater recent increase in extreme precipitation than any other region in the U.S.; between 1958 and 2010, the Northeast saw more than a 70% increase in the amount of precipitation falling in very heavy events, taxing an already stressed and aging infrastructure.[3] After record-setting rains in August 2014, the Town of Freeport faced $100,000 in damages and Brunswick $200,000 in damages due to washed-out roads, collapsed culverts, and blocked storm drains. Downtown Portland experienced widespread flooding.[4]

Winter recreation not a sure thing.

Maine's ski industry relies on snow, both natural snowfall and temperatures cold enough to make snow. Maine's Camden Snow Bowl, Mt. Abram, and Shawnee Peak are among 108 ski resorts that have signed the Climate Declaration to show support for national action on climate change.

Long-term measurements from the White Mountain National Forest document increasing average winter air temperatures, less snow, more sleet and freezing rain, and shorter duration of lake ice. All of this has led to a shorter snowmobiling season in most years.

"The hard scientific numbers coming from Hubbard Brook only confirm what the snowmobiling community has suspected for years, and which it sees reflected in shorter riding seasons and declining numbers of snowmobilers," wrote David Sleeper of the Hubbard Brook Research Foundation.[5]

The unreliability of winter weather means that seasonal events and activities, many of which are important to local economies, often have to be rescheduled or cancelled altogether, which is what happened to the Plum Creek Wilderness Sled Dog Race in Greenville in 2013.[6]

Maine's farming future.

Longer growing seasons, extreme precipitation events, and greater variability in the weather offer both opportunities and challenges to Maine farmers. In 2012, the US Department of Agriculture released revised Plant Hardiness Zone Maps representing annual minimum winter temperatures. In Maine, overall zone boundaries have shifted north by half a zone.[7] Changes outside of Maine also affect Maine farmers: in 2013, drought in the Midwest forced grain prices to rise sharply, adding to the economic challenges for Maine's dairy industry, and forcing some farms out of business.[8]

1 Fleming, D. 2013. Lake Auburn: Good fishing in troubled water. *Portland Press Herald*, 4 May 2013.

2 Maine Department of Agriculture, Conservation & Forestry. Insect and Disease Conditions Update, 1 July 2014.

3 Walsh, J., et al. 2014. Chapter 2: Our Changing Climate, pp. 19–67 in Climate Change Impacts in the United States: The Third National Climate Assessment (J.M. Melillo, T.C. Richmond, and G.W. Yohe, eds.). U.S. Global Change Research Program.

4 Gardner, K. 2014. Freeport reopens roads washed out by rain storm, pegs damage at about $100,000. *The Falmouth Forecaster*, 21 August 2014; McGuire, P.L. 2014. Cost of Brunswick storm repairs doubles to $200K. *The Falmouth Forecaster*, 3 September 2014.

5 Sleeper, D. 2014. Riding Winter's Trails, A Hubbard Brook White Paper. North Woodstock, NH: Hubbard Brook Research Foundation.

6 Sarnacki, A. 2010. Greenville sled dog race cancelled. *Bangor Daily News*, 5 February 2010.

7 *planthardiness.ars.usda.gov/PHZMWeb/*

8 Richardson, W. 2013. As lawmakers debate, Liberty's last dairy farm sells its herd. *Bangor Daily News*, 29 March 2013.

Air pollution and Maine's changing chemical climate

It is important to recognize that changes in the physical climate are happening simultaneously with changes in the chemical climate, with serious implications for human health. In the U.S., the Clean Air Act[1] has resulted in significant improvements in air quality.[2] We have seen declines in atmospheric concentrations of sulfur, nitrogen, ozone, and other air pollutants in Maine over the last several decades, although these remain elevated above background concentrations and sometimes exceed Maine health standards, as is the case with ozone (*Figure 11*). Despite the dramatic progress in air quality, air pollution continues to threaten human health.[3] For example, the interaction of ozone, particles, and heat stress magnifies the human health consequences from warming alone. The University of Maine's Climate Change Institute developed the 10GREEN software application (*10green.org*) to provide information about air quality for any location as well as historical information based on existing air quality monitoring networks.

Beyond concerns for human health, the interaction of air pollution and a changing physical climate also affects ecosystems, often in complex and both positive and negative ways. Forests, for example, can be positively influenced by longer growing seasons, atmospheric nitrogen deposition, and higher concentrations of atmospheric carbon dioxide. Simultaneously, forest health can be negatively influenced by drought stress, ice storms, acid rain (which is caused by sulfur as well as nitrogen), ozone, and new pests and pathogens.[4] In agriculture, both a warming climate and ozone can negatively affect crop yields.[5]

Ozone in Maine 1981–2014

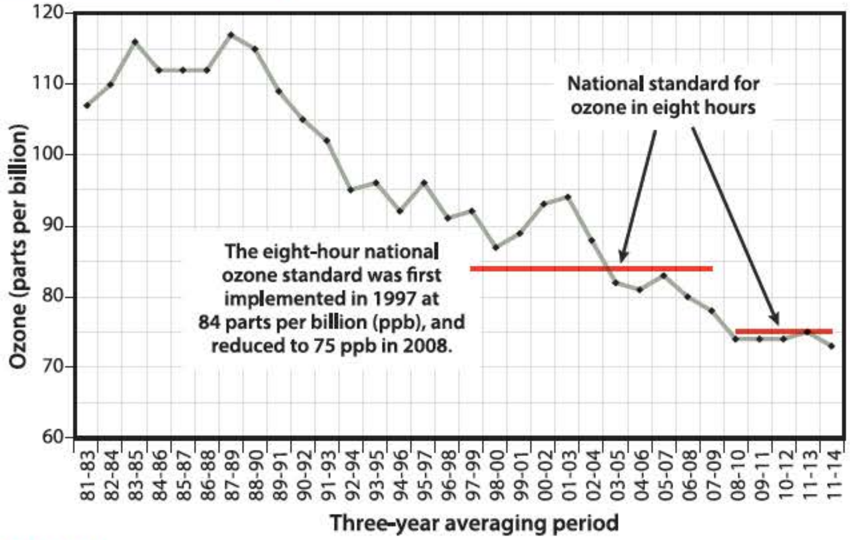
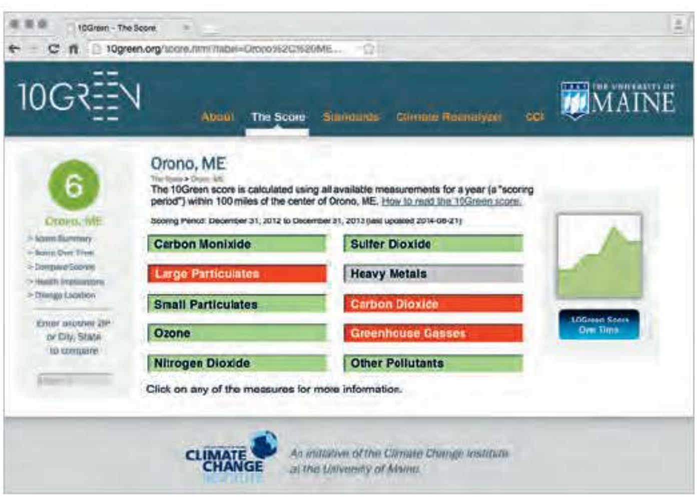


Figure 11. Maine annual statewide maximum eight-hour design value for ozone over time with the National Ambient Air Quality Standard (NAAQS) noted as red lines. The NAAQS standard was reduced from 84 parts per billion (ppb) to 75 ppb in 2008. The design value for each monitoring site is the average of the fourth highest maximum daily eight-hour ozone concentration for each of three consecutive years as long as data recovery rates meet requirements. Data and further details available at *maine.gov/dep/air/ozone/aqtrends.html*.



10green.org provides a comprehensive assessment of the health of your environment. An interactive tool, 10Green.org uses publicly available data from U.S. environmental monitoring programs. The 10 air quality measures represent some of the most significant threats to human health. 10Green.org also includes information about air quality health standards used in the U.S., Canada, and Europe.

1 *epa.gov/laws-regulations/summary-clean-air-act*

2 *epa.gov/air/criteria.html*

3 *epa.gov/air/caa/*; Farwell, J. 2014. Report: Maine's air cleaner, but still reaching unhealthy levels. *Bangor Daily News*, 24 April 2013; Physicians for Social Responsibility. 2000. Death by Degrees: The Emerging Health Crisis of Climate Change in Maine. Washington, DC.

4 Campbell, J.L., et al. 2009. Consequences of climate change for biogeochemical cycling in forests of northeastern North America. *Canadian Journal of Forest Research* 39:264–284; Vose, J.M., D.L. Peterson, and T. Patel-Weynand, editors. 2012. Effects of Climatic Variability and Change on Forest Ecosystems: A Comprehensive Science Synthesis for the US Forest Service, PNW-GTR-970. Portland, OR: USDA Forest Service.

5 Walthall, C.L., et al. 2012. Climate Change and Agriculture in the United States: Effects and Adaptation. USDA Technical Bulletin 1935. Washington, DC: US Department of Agriculture; *earthobservatory.nasa.gov/Features/OzoneWeBreathe/ozone_we_breathe3.php*; Avnery, S., D.L. Mauzerall, J. Liu, and L.W. Horowitz. 2011. Global crop yield reductions due to surface ozone exposure: 1. Year 2000 crop production losses and economic damage. *Atmospheric Environment* 45:2284–2296.

Ocean temperature

The Gulf of Maine is unique for many reasons, one of which is the way the semi-enclosed basin of the Gulf is influenced by dynamic interactions of the ocean and atmosphere. Gulf of Maine temperatures reflect the interplay between colder, fresher water coming from the north; warmer, saltier water entering from the south; and an intense annual cycle of warm air temperatures in summer and cold air in winter.

Since 1982, the average sea surface temperature increased at a rate of 0.05 °F (0.03 °C) per year, slightly faster than the increase experienced by the global ocean (*Figure 12*). While the long-term warming signal is clear, the Gulf of Maine has the potential for significant departures from the overall trend. Since 2004, the rate of warming accelerated to 0.41 °F (0.23 °C) per year, a rate that further analysis has shown to be faster than 99% of the world's oceans.[1]

The warm period in the 1950s shows how variable conditions can be in the Gulf of Maine. The warm temperatures around 1950 occurred during a time when average ocean temperatures were colder than today. Like the 1950s, the recent rapid increase in Gulf of Maine temperatures is the result of a natural cycle of variability, but now it is layered on an accelerating long-term warming trend. Adding this variability on top of the predicted warming shows the potential for extreme temperatures in the future. Changes in Gulf of Maine temperatures are also affected by related changes in atmosphere-ocean circulation.

Gulf of Maine Sea Surface Temperature

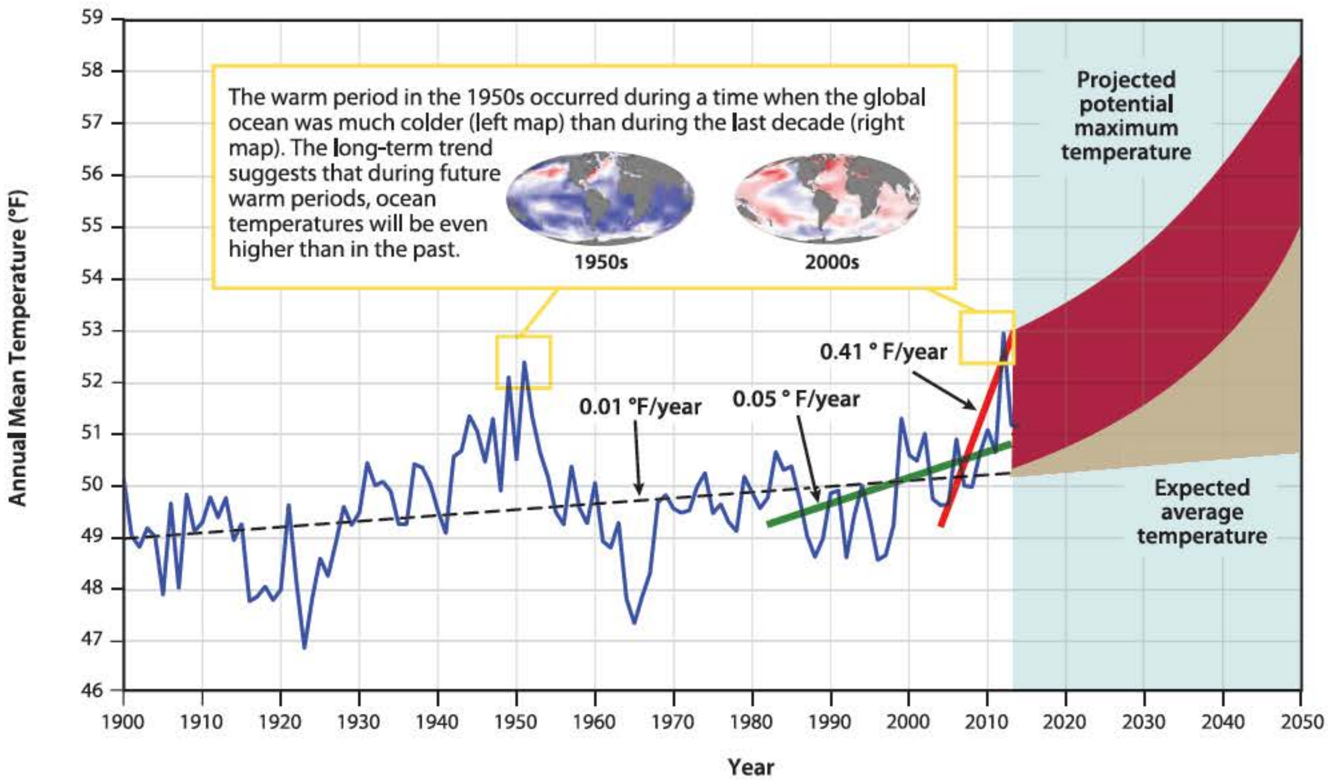


Figure 12. Mean sea surface temperature in the Gulf of Maine from 1900 to 2014 (blue), based on Extended Reconstructed Sea Surface Temperature (ERSST) version 3b data provided by the NOAA/OAR/Earth System Research Laboratory Physical Sciences Division, Boulder, CO (*esrl.noaa.gov/psd/*). The temperature trend over the entire record is 0.01 °F per year (black line). The rate accelerated to 0.05 °F per year after 1982 (green line) and was 0.41 °F per year from 2004–2013 (red line), based on NOAA Optimum Interpolation ¼ degree daily sea surface temperature analysis (*ncdc.noaa.gov/sst/*). Climate models provide a range of estimates of future mean temperatures (red and tan area), with the range driven by the uncertainty in how much carbon dioxide and methane will be added to the atmosphere.[2]

1 Record, N. 2014. Maine waters are warming fast. *Bigelow Laboratory for Ocean Sciences Transect* 6:8–9.

2 IPCC. 2013. Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Stocker, T.F. et al., editors). Cambridge, UK and New York, NY: Cambridge University Press.

How these changes are affecting Maine

Unpredictable events occurring.

The Gulf of Maine was at the center of the 2012 "ocean heat wave" that extended from Cape Hatteras to Iceland.[1] The record warm water caused lobsters to move inshore and molt three weeks earlier, resulting in high landings early in the season. When combined with record Canadian landings, the early catch in 2012 overwhelmed the capacity of Canadian processing plants, leading to low prices paid to fishermen. Prices paid to lobster fishermen dropped to as low as $1.25 per pound in some areas of Maine, 70% below normal.[2]

Marine animals shifting territory.

Climate change has shifted where many marine species are found, including at what depth in the water column. According to the Atlantic States Marine Fisheries Commission, increasing water temperatures and a decline in phytoplankton abundance (a food source for shrimp) are factors which likely have and will continue to contribute to declines in populations of Northern shrimp.[3]

The center of Maine's lobster harvest has moved north, from Casco Bay to Downeast Maine, demonstrated by both landings of adult lobsters and the population of juveniles on the sea floor, which is tracked by the American Lobster Settlement Index (*Figure 13*).[4]

American Lobster Settlement Index Trends

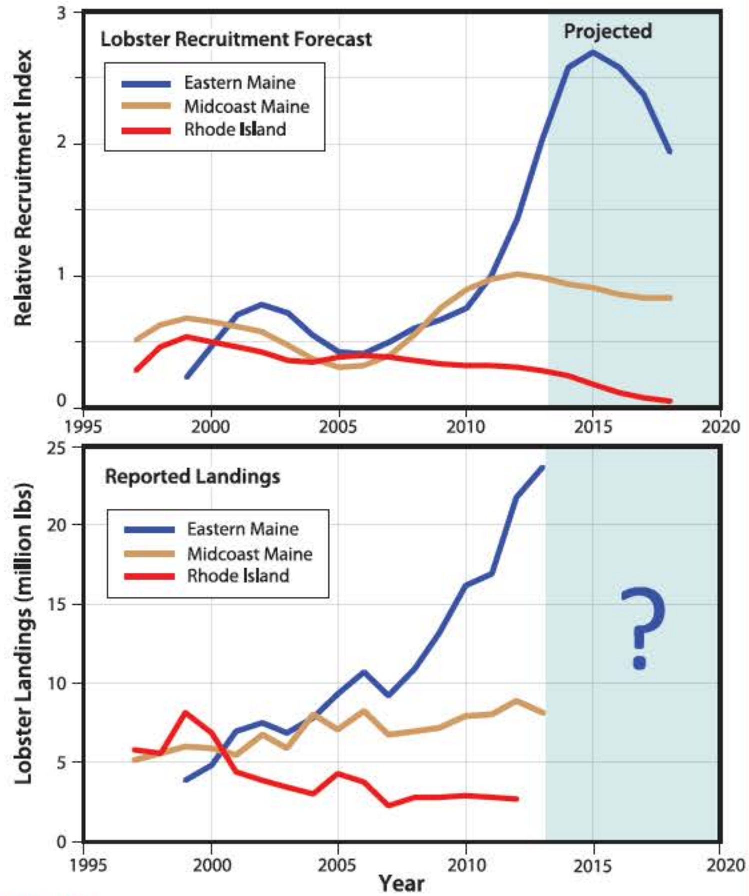


Figure 13. The American Lobster Settlement Index measures the annual pulse of larval lobsters that settle to nursery grounds on the sea floor. The index provides an early warning system for trends in the abundance of harvestable lobsters about six to eight years later. This projected "recruitment index," shown for three regions of the lobster fishery (top), correlates reasonably well with observed trends in the harvest (bottom). Harvests over the next few years will be the best test of the accuracy of the projected downturn in eastern Maine.[4]

An influx of new species, accelerated loss of others.

Commercial and recreational fishermen report new species from the south appearing in their nets, hooks, and traps: red hake, turbot, squid, black sea bass, blue crab, butterfish, longfin squid, summer flounder, yellowtail flounder, scup. They are also seeing more warm-water creatures like seahorses and ocean sunfish.[5]

Salmon migrate through the Gulf of Maine and feed in the Labrador Sea and off Greenland, where warming-driven changes in the food web may be impairing their ability to survive.[6]

Changing fish populations demand changes in how we manage fisheries: tracking and accommodating the shifting boundaries of species, addressing access and permit availability to allow fishermen to adapt and diversify, maintaining flexible processing and market infrastructure, and educating consumers about new seafoods in the market.

1 Mills, K.E., et al. 2013. Fisheries management in a changing climate: lessons from the 2012 ocean heat wave in the Northwest Atlantic. *Oceanography* 26:191–195.

2 Dicolo, J.A., and N. Friedman. 2012. Lobster glut slams prices: Some fishermen keep boats in port; outside Maine, no drop for consumers. *Wall Street Journal*, 16 July 2012.

3 *asmfc.org/species/northern-shrimp*

4 Wahle, R., and N. Oppenheim. 2014. American Lobster Settlement Index Update 2013. Orono, ME: University of Maine. *umaine.edu/marine/people/sites/rwahle/ALSIPage.htm*

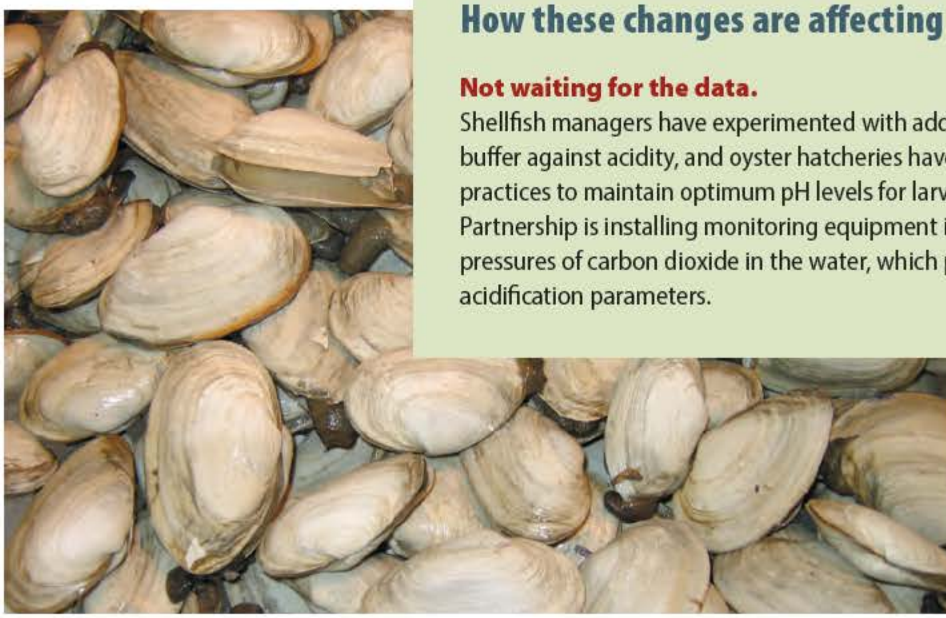
5 Canfield, C. 2013. New England sees rise in warm-water ocean species. Associated Press, 26 September 2013; Hudson, M., and J. Peros. 2013. Preparing for Emerging Fisheries: An Overview of Mid-Atlantic Stocks on the Move, Portland, ME: Gulf of Maine Research Institute; Island Institute. 2013. A Climate of Change: Climate Change and New England Fisheries, Workshop Summary Report, July 31–August 1, 2013. Rockland, ME.

6 Mills, K.E., A.J. Pershing, T.F. Sheehan, and D. Mountain. 2013. Climate and ecosystem linkages explain widespread declines in North American Atlantic salmon populations. *Global Change Biology* 19:3046–3061.

Ocean acidification

Globally, the oceans have become about 30% more acidic over the last century, a decline of about 0.1 pH units and a rate that is faster than anything the marine realm has experienced in millions of years.[1] The Gulf of Maine may be uniquely susceptible to acidification because it is cold (cold water tends to be more acidic), has a lot of freshwater input from rivers and mixing by ocean currents (fresh water is more acidic than salt water), and has less capacity to buffer against acid.[2] Coastal areas also are more affected by acidity, due to runoff of pollutants from land, depending on local factors such as upwelling, river discharge, and water quality.

While we don't have comprehensive long-term monitoring data on acidity for the Gulf of Maine, the National Oceanic and Atmospheric Administration and University of New Hampshire began measuring dissolved carbon dioxide in 2006, and pH in 2010, from a single mooring in the western Gulf of Maine.[3] Several organizations are working to understand and address coastal acidification in Maine and the Northeast and develop monitoring networks, including the Northeast Coastal Acidification Network, the Northeast Regional Association for Coastal Ocean Observing Systems, the Northeast Regional Ocean Council, the Northeast Sentinel Monitoring Program, and the Island Institute. Concerns about the potential effects of ocean acidification on Maine's valuable shellfish industry were great enough that in 2014 the Maine Legislature became the first on the East Coast to address the potential effects of ocean acidification.[4] In early 2015, the Commission to Study the Effects of Coastal and Ocean Acidification and Its Existing and Potential Effects on Species that are Commercially Harvested and Grown Along the Maine Coast released their Final Report. The report evaluated the existing science, and highlighted the critical need for monitoring and research, and climate change mitigation, remediation, and adaptation information for both open ocean and nearshore acidification.[5]



How these changes are affecting Maine

Not waiting for the data.
Shellfish managers have experimented with adding crushed shells to clam flats to buffer against acidity, and oyster hatcheries have established water management practices to maintain optimum pH levels for larval culture.[6] The Casco Bay Estuary Partnership is installing monitoring equipment in Casco Bay to measure partial pressures of carbon dioxide in the water, which provides precise monitoring of acidification parameters.

1 Feely, R.A., S.C. Doney, and S.R. Cooley. 2009. Ocean acidification: Present conditions and future changes in a high-CO2 world. *Oceanography* 22:36–47; Orr, J.C., et al. 2005. Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. *Nature* 437:681–686.

2 Wang, Z.A. et al. 2013. The marine inorganic carbon system along the Gulf of Mexico and Atlantic coasts of the United States: Insights from a transregional coastal carbon study. *Limnology & Oceanography* 58:325–342; Salisbury, J. Processes affecting ocean acidification in the coastal Gulf of Maine, Maine Ocean Acidification Meeting, 16 January 2014, Augusta, ME.

3 *pmel.noaa.gov/co2/story/GOM*

4 Veneziano, S. 2014. Ocean acification bill wins broad public support. *Boothbay Register*, 13 January 2014.

5 Johnson, C.K., et al. 2015. Final Report of the Commission to Study the Effects of Coastal and Ocean Acidification and its Existing and Potential Effects on Species that Are Commercially Harvested and Grown Along the Maine Coast. Augusta, Maine: Office of Policy & Legal Analysis.

6 Mook, B. Concerns about climate change and ocean acidification in a Maine oyster hatchery, Maine Ocean Acidification Meeting, 16 January 2014, Augusta, ME.

Sea-level rise

The boundary between land and sea has varied greatly since the last ice age. During the most recent few thousand years, however, the rate of sea-level rise was relatively slow (0.01–0.04 inches per year or 0.3–1.0 mm per year), allowing beaches to form and salt marshes to accumulate, in some places accumulating up to 16 feet (4.9 meters) or more of peat.

Today, sea level is rising at a rate of 0.07 inches per year (1.9 mm per year), much faster than any time in the past 5,000 years (*Figure 14*). Global sea level is projected to rise an additional 0.5 to 2.0 feet (0.2 to 0.6 meters) or more by 2050 according to the most recent National Climate Assessment.[1] Scientists consider these ranges of estimates to be conservative, with other estimates of global sea-level rise notably higher—*an equivalent of 3.3 feet (1.0 meter) or more by mid-century*.[2,3]

The last time temperatures increased by 3.6–5.4 °F (2–3 °C), approximately 125,000 years ago, the accompanying melting of portions of Greenland and Antarctica resulted in a sea-level rise of more than 16 feet (5 meters),[4] suggesting that current estimates of sea-level rise for the projected warming by 2100 may be on the low end.

Sea-level rise for any particular location can vary significantly from the global average. Reasons for this variability include factors such as local topography, changes in ocean circulation, land subsidence, tectonic displacements, geographic variations in rates of ice melting, and thermal expansion of marine waters. Thus, when a volume of ice melts, the meltwater is not distributed evenly around the world's shorelines.

Sea Level Trend at Portland, Maine

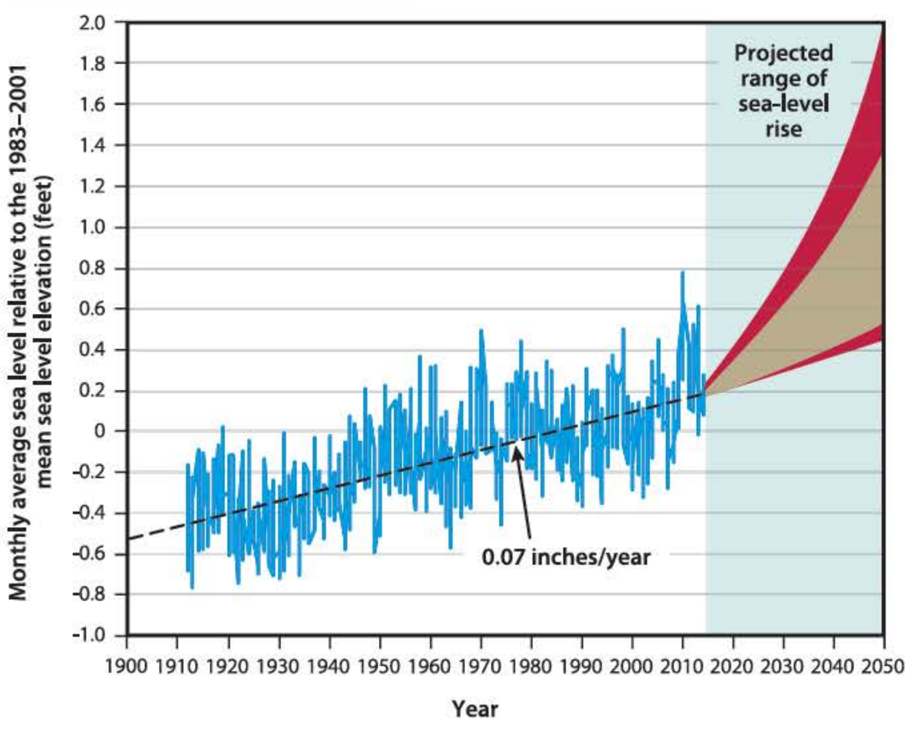


Figure 14. Sea level at Portland provided by the National Oceanic and Atmospheric Administration Center for Operational Oceanographic Products and Services (*tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8418150*). The mean sea level trend is 0.07 inches per year (1.9 mm/year) with a 95% confidence interval of +/- 0.006 in/yr (0.16 mm/yr) based on monthly mean sea level data from 1912 to 2013, which is equivalent to a change of 0.62 feet in 100 years. The plotted values are relative to the most recent 19-year mean hourly sea level elevation established by NOAA (1983–2001).[2] Monthly sea level varies due to weather and the changing orbits of the earth and moon. The projected range of sea-level rise is from the latest National Climate Assessment and figure 2.26 therein from the NASA Jet Propulsion Laboratory.[3] The projections reflect the range of possible scenarios based on other scientific studies. The currently projected range of sea-level rise of 0.5 to 2.0 feet by 2050 (1.0 to 4.0 feet by 2100) falls within a larger range that incorporates uncertainty about how glaciers and ice sheets will react to the warming ocean, the warming atmosphere, and changing winds and currents. The high end of these scenarios is provided for use by decision makers with a low tolerance for risk.

1 Walsh, J., et al. 2014. Chapter 2: Our Changing Climate, pp. 19–67 in Climate Change Impacts in the United States: The Third National Climate Assessment (J.M. Melillo, T.C. Richmond, and G.W. Yohe, eds.). US Global Change Research Program.

2 Parris, A., et al. 2012. Global Sea Level Rise Scenarios for the U.S. National Climate Assessment, NOAA Tech Memo OAR CPO-1. Silver Spring, MD: National Oceanic and Atmospheric Administration.

3 Rahmstorf, S. 2010. A new view on sea level rise. *Nature Reports Climate Change* doi:10.1038/climate.2010.29; Church, J.A., et al. 2013. Sea level rise by 2100. *Science* 342:1445; Kerr, R.A. 2013. The IPCC gains confidence in key forecast. *Science* 342:23–24.

4 Jansen, E., et al. 2007. Paleoclimate, pp. 433–497 in Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Solomon, S. et al., editors). Cambridge, UK and New York, NY: Cambridge University Press.

How these changes are affecting Maine

Protective salt marshes may disappear.

The present rate of sea-level rise may be too fast for some, but not all, marshes to keep up. As a result, some marshes are apparently drowning, with salt marsh pools expanding at the expense of plants.[1] Salt marshes help protect coastal property; when they drown and erode, they leave uplands and developed areas more vulnerable.

Some beaches getting skinnier.

While some beaches have actually expanded, other beaches such as Laudholm Beach are eroding from higher storm surges, and becoming narrower with exposed salt marsh peat. In some locations, maritime forests are getting too close to the ocean to thrive, and property, even though protected by engineered structures, is at risk. Homes and other structures built atop soft bluffs of glacial deposits are vulnerable to landslides, and properties close to the edge of low-lying rock cliffs could be damaged by large storms that hurl rocks and water into seaward-facing walls.[2]

Flood zones move inland.

Flooding has increased throughout the Nation's coastline.[3] The rising level of the ocean keeps bringing storms closer, making what would have been a bad storm 100 years ago a "great" storm of the future. Storm surges can add three or four feet of water on top of tidal heights. The National Flood Insurance Program has been updating flood maps for Maine's coastal counties. Increased flooding and storm surges, as well as more refined data and methods, have led to new areas mapped as flood zones. For example, the mapped flood zone in Old Orchard Beach increased from 28 to 42 percent. Rockland's mapped flood zone reportedly moved inland 100 feet. New and expanded flood zones result in increased costs for property owners related to flood insurance and renovation requirements, prompting Congress to delay changes to the program and towns to appeal the new maps.[4]

Insurance costs are rising.

More than 9,200 flood insurance policies are now in effect in Maine, with coverage totaling nearly $2 billion, according to state insurance data. People who own property that is reclassified as a flood hazard face thousands of dollars in annual flood insurance costs.[5] The City of Portland has allocated $2.7 million to elevate streets in the Bayside neighborhood by two feet, so that building foundation heights in development projects meet new insurance regulations that anticipate sea-level rise and flooding.[6]

1 Wilson, K.R., J.T. Kelley, B.R. Tanner, and D.F. Belknap. 2010. Probing the origins and stratigraphic signature of salt pools from north temperate marshes in Maine, U.S.A. *Journal of Coastal Research* 26:1007–1026.

2 Slovinsky, P.A., S.M. Dickson, and R.E. Dye. 2013. State of Maine's Beaches in 2013, Open-File No. 13–18. Augusta, ME: Maine Geological Survey.

3 Nelson, D.J., D. Wilson, and R. McNeill. 2014. Water's Edge: the crisis of rising sea levels. Reuters. reuters.com/investigates/special-report/waters-edge-the-crisis-of-rising-sea-levels/

4 Miller, K. 2014. King, Pingree urge FEMA to use local flood reports. *Portland Press Herald*, 23 January 2014; Daly, M. 2014. U.S. House approves bill that would limit flood insurance overhaul. Associated Press, 5 March 2014; Fishell, D. 2014. Flood map changes raising new questions. *Bangor Daily News*, 11 September 2014.

5 Van Allen, J. 2014. Updated flood zones could cause spike in insurance. *Portland Press Herald*, 10 September 2014.

6 Koenig, S. 2014. Portland allocates $2.7 million to raise street near four-tower Bayside project. *Bangor Daily News*, 15 September 2014.

III. Maine Adaptation, Risk, and Opportunity

In response to our initial report in 2009, the Maine Legislature directed the Maine Department of Environmental Protection (DEP) to lead a stakeholder-driven process to identify priority risks and strategies for initial climate change adaptation efforts in Maine (L.D. 460). After receiving the resulting report[1] in February 2010, the Maine Legislature asked DEP to continue the process with a final plan for state climate change adaptation due by 2012 (L.D. 1818). The initial stakeholder adaptation report was adopted as the final plan in 2012.

In late 2013, Governor LePage established the Environmental and Energy Resources Working Group to develop a coordinated strategy on climate change issues. In 2014, Maine DEP released a report from the working group, detailing current activities and recommendations for state agencies "to improve Maine's ability to respond and adapt to changing physical conditions in the environment due to climatic influence."[2] These recommendations provide the opportunity for greater coordination and synergies among state and federal agencies, non-governmental organizations, tribes, municipalities, research organizations, communities, and the University of Maine.

Considerable activity to address the climate change challenge has emerged in the past few years from numerous citizen groups and municipalities, as well as federal agencies.

For example:

- The U.S. Department of Homeland Security is using data on climate change to identify risks to critical infrastructure (e.g., energy, transportation, and communication systems) for Casco Bay, as part of its Regional Resiliency Assessment Program.[3]
- The U.S. Department of Defense has stated that climate change poses immediate risks to national security, and the Department has responded with plans for adaptation and mitigation. For example, Portsmouth Naval Shipyard has renovated its energy supply network to decrease costs, reduce fossil fuel consumption, and maintain critical power in the event of a grid blackout.[4]
- A federal interagency group developed the Climate Resilience Toolkit in 2014 to help people manage their climate-related risks and opportunities, and improve their resilience to extreme events.[5]
- Maine is a participant in the Northeast Climate Hub, one of a series of regional climate resources established by the U.S. Department of Agriculture for adaptation and mitigation coordination in the agricultural and forestry sectors.[6]
- Maine Physicians for Social Responsibility affirmed that climate change in Maine is a critical public health threat, citing effects on drinking water, heat waves, insects and other pests, and psychological impacts.[7]

1 Maine Department of Environmental Protection. 2010. People and Nature Adapting to a Changing Climate: Charting Maine's Course, A Summary of the Report Presented to the Joint Standing Committee on Natural Resources of the 124th Maine Legislature. Augusta, ME.

2 Environmental and Energy Resources Working Group. 2014. Monitoring, Mapping, Modeling, Mitigation and Messaging: Maine Prepares for Climate Change. Augusta, ME: Maine Department of Environmental Protection. *maine.gov/dep/sustainability/climate/index.html*

3 Department of Homeland Security. 2013. Regional Resiliency Assessment Program FY 14 Maine fact sheet. *dhs.gov/regional-resiliency-assessment-program*

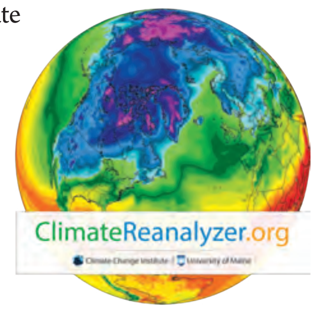
4 Science and Technology Directorate. 2014. Department of Defense 2014 Climate Change Adaptation Roadmap. Alexandria, VA: U.S. Department of Defense. *pewtrusts.org/en/about/news-room/news/2014/07/01/portsmouth-naval-shipyard*

5 *toolkit.climate.gov/*

6 *climatehubs.oce.usda.gov/northeast-hub*

7 Physicians for Social Responsibility. 2000. Death by Degrees: The Emerging Health Crisis of Climate Change in Maine. Washington, DC (updated report scheduled for release in 2015).

- The Maine Department of Transportation is evaluating the vulnerability of state-owned roads, bridges, and culverts to rising sea levels and increasing frequency and intensity of coastal storm surge events. One study developed site-specific engineering design alternatives to account for a sea-level rise of 3.3 and 6.0 feet.[1]
- Municipalities are taking action to address flooding and rising sea levels. The Portland City Council has directed staff to plan for the impacts of climate change, and changes are being made to flood-prone buildings along the waterfront. The Ogunquit Sewer District is planning for storm surges that threaten the town's wastewater treatment plant; publicly-owned treatment works throughout the coast are training to be "climate ready" with assistance from the New England Interstate Water Pollution Control Commission, Maine DEP, and the U.S. Environmental Protection Agency. From Fort Kent to Ellsworth to York, towns are swapping out inadequate culverts for larger conduits.[2]
- More than 1,000 people attended a 2014 Climate Solutions Expo and Summit in Augusta to learn more about how to reduce greenhouse gas emissions and adapt to Maine's changing environment.[3]
- Maine Sea Grant and University of Maine Cooperative Extension have developed a portfolio of adaptation initiatives for coastal communities in Maine to build resilience to storms, sea-level rise, and changing fisheries.[4]
- The Climate Change Institute at the University of Maine hosted a conference on Maine Climate Adaptation and Sustainability (Maine CLAS) in 2014 designed to introduce the public to available tools through the institute and to an alternative scenario planning approach to climate adaptation. Tools include the Climate Reanalyzer, 10GREEN, and the CLAS Layers model available through the Institute's website.[5] The Climate Reanalyzer (*cci-reanalyzer.org*) provides easy access to climate models, historical weather data, and daily weather forecasts. Popular features include a daily summary of global and regional temperature departures from normal; monthly, seasonal, and annual national climate maps for 1895–2014; climate change maps for the world; and IPCC predictions for the future as time series graphs and maps.



- The University of Maine and other education and research institutions in Maine are leaders in climate change science and engagement, and represent an important resource. In 2014 the University of Maine identified climate change as one of its seven signature research areas, building on the strength and reputation of the Climate Change Institute.

This report focuses on highlights of our understanding of past, present, and future indicators of a changing climate in Maine and points to examples of how Maine people and our environment are experiencing these changes. Our evolving understanding of these realities leads us to ask how we, as individuals, families, communities, businesses, agencies, organizations, and natural resource managers, should respond to these emerging challenges.

> **"The best way to predict the future is to invent it."**
> **—Alan Kay,**
> ***Palo Alto Research Center meeting*, 1971**

Although climate change is not the only challenge we face in Maine, few of our other challenges are not influenced in some way by a changing climate. Climate change also brings new opportunities, but in order to capitalize on these opportunities, we have to be prepared for them. Proactive and coordinated mitigation and adaptation initiatives that incorporate the realities of our present and future environment will ensure that we and future generations continue to believe we live in Maine — The Way Life Should Be!

1 Merrill, S., and J. Gates. 2014. Integrating Storm Surge and Sea Level Rise Vulnerability Assessments and Criticality Analyses into Asset Management at MaineDOT. Freeport, ME: Maine Department of Transportation and Catalysis Adaptation Partners, LLC.

2 Adams, G. 2014. Like it or not, Feds say, climate change is real, inevitable. *The Maine Townsman* June 2014:17–19; Joint Environmental Training Coordinating Committee, Climate Change Adaptation for Municipal Utilities Workshop, 3 December 2014, Saco, ME.

3 *climatesolutionsme.org*

4 *seagrant.umaine.edu/topics/climate-change*

5 *climatechange.umaine.edu*