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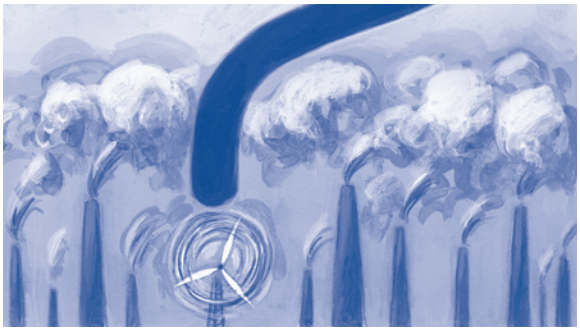

Maine's Climate Yesterday, Today, and Tomorrow

by George L. Jacobson

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Recent evidence suggests that climate change is occurring at an accelerated rate as a result of human-induced greenhouse gas emissions and associated pollutants. Based on a recently completed study, the authors of this article describe the changes Maine's climate is likely to undergo over the next century. They suggest that while reduction of greenhouse gases is crucial, Maine needs to be prepared to adapt to the impact that our already changing climate will have on various ecosystems and economic sectors within the state.

INTRODUCTION

Earth's atmosphere is experiencing unprecedented changes that are modifying the global climate. Discussions continue around the world, the nation, and in Maine on how to reduce and eventually eliminate anthropogenic emissions of carbon dioxide (CO_2), other greenhouse gases, and other pollutants to the atmosphere, land, and oceans. These efforts are vitally important and urgent. However, even if a coordinated response succeeds in eliminating those carbon emissions by the end of the century, something that appears highly unlikely today, climate change will continue. Unfortunately, increased levels of CO_2 will likely persist in the atmosphere for thousands of years to come. Therefore, an understanding of potential effects of climate change on local and regional resources is necessary for communities to adapt and prosper in the coming century.

Several well-known useful assessments have been published in recent years, each addressing the implications of climate changes likely to result from the steep increases in atmospheric concentrations of greenhouse gases. The Intergovernmental Panel on Climate Change (IPCC 2007a, 2007b) report provides an updated, comprehensive global view of the issues; the U.S. Climate Change Program (NERAG) issued a national and regional overview in 2001, and the Union of Concerned Scientists recently released a regional Northeast Climate Impacts Assessment (Frumhoff et al. 2006).

While these assessments provide a general idea of climate change-related impacts, Maine has unique characteristics that deserve more focused attention and analysis. Perhaps more than any other state, Maine's social and economic wellbeing depends on the health and productivity of the forests, fields, lakes, rivers, and the marine waters of the Gulf of Maine.

The diversity of these natural systems results from Maine's wide range of geologic, topographic, and climatic conditions. Although many regions of the world have a variety of environments, few have such variety in close proximity. In fact, the primary reason for high biodiversity in Maine is the extreme variety in climates within a relatively small area. Mainers have long recognized the extreme contrasts between the coastal and inland climates in all seasons. While the southern coast generally remains relatively mild, even in winter, northern Aroostook County has some of the coldest weather in the conterminous U.S.

Maine's character and complexity can be expected to offer unique challenges and opportunities as a result of a changing climate. Here, we consider past climate change, recent evidence of accelerated rates of change, and the implications of continued climate change in Maine as a result of greenhouse gas emissions and their associated pollutants. We also highlight the importance of addressing adaptation challenges and identifying the opportunities presented by a changing climate. These insights are taken from the report, "Maine's Climate Future" (Jacobson et al. 2009), an initial assessment of climate change in Maine, and readers are directed to that document for additional information on these issues.

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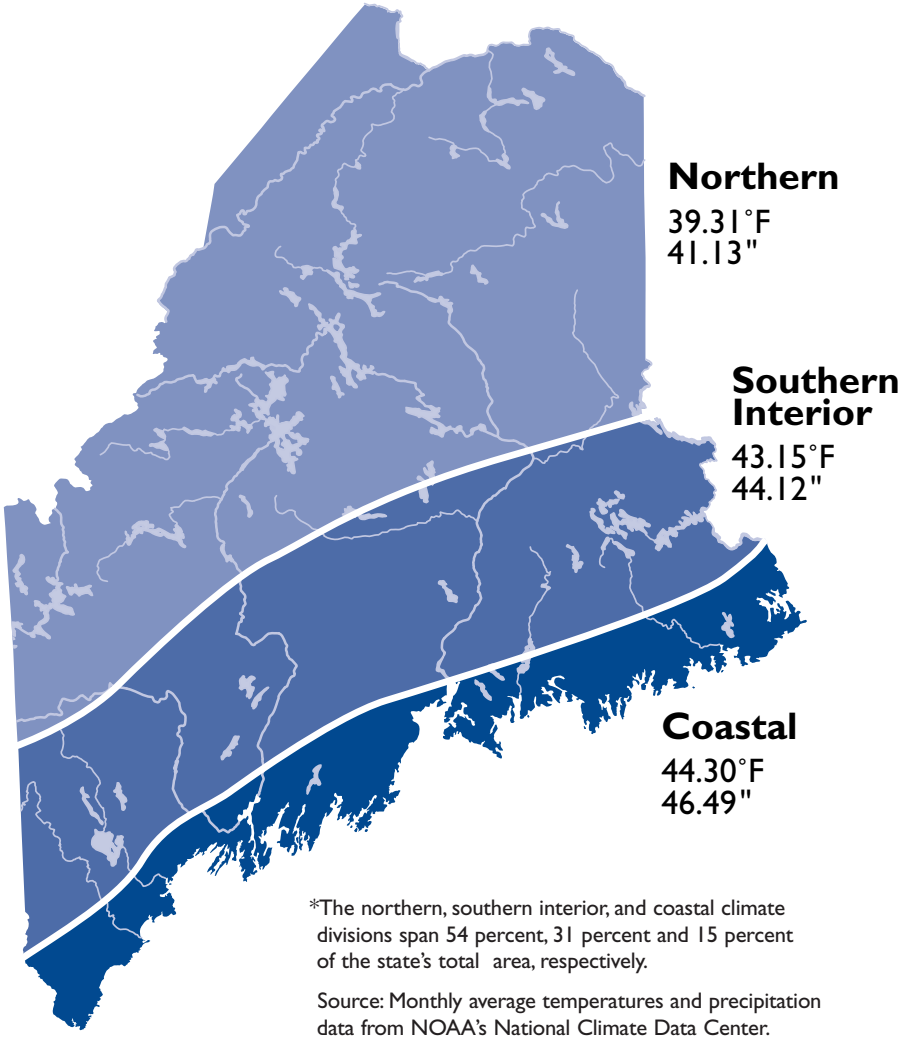
MAINE'S CLIMATE YESTERDAY AND TODAY

Maine's climate has changed continuously in the past and will continue to do so in the future. For at least the past million years, growing and melting ice sheets have covered the state and then retreated, transforming the landscape in the process. The smoothed mountains and hills, the scratched rock surfaces, the stones carried from far away, and the flat sand plains of blueberry barrens are all the result of the large glaciers that once covered Maine. The Ice Age Trail in eastern Maine now guides visitors through many of these interesting features (CCI 2006).

Maine was still completely covered by ice as recently as 15,000 years ago. Yet, in just a few thousand years, the ice disappeared and forests emerged that looked similar to the North Woods we know today.

FIGURE 1: **Maine Climate Divisions with Average Annual Temperature and Average Annual Precipitation***



*The northern, southern interior, and coastal climate divisions span 54 percent, 31 percent and 15 percent of the state's total area, respectively.

Source: Monthly average temperatures and precipitation data from NOAA's National Climate Data Center. Period of record is 1895 through 2007.

The rapid transition from glacial to warmer conditions was characteristic of the end of many of the recent ice ages. The first Native Americans who entered this area around 12,000 years ago almost certainly walked on the last remnants of the huge Laurentide ice sheet that once extended from the Canadian Arctic across the Gulf of Maine.

Yet even during the past 11,000 years of warm, ice-free conditions, the climate changed continuously. For example, the first half of that period had warmer, drier summers than today and probably colder winters. These conditions strongly affected the forests, lakes, and rivers of the region, and forest fires were common in the summer.

Then, about 4,000 years ago, Maine's climate gradually became cooler and moister. These changes influenced forest growth and must have provided challenges to the long-established Wabanaki people, as well as to the Europeans who joined them more recently. Written records from the past few hundred years, including diaries kept by early farmers in Maine, provide clear evidence that the growing seasons were at times much shorter than present, with later frosts in the spring and earlier frosts in the fall (Baron and Smith 1996; NEISA 2005).

Today, Maine has a wide variety of climates, a fact that is easy to take for granted. Although the National Weather Service divides the state into three climate divisions (Figure 1), the actual diversity of climate is much greater and accounts for the wide variety of plants and animals in Maine. Although climate division data provide only a broad view of the climatic variations within the state, they are the benchmark often used to monitor and assess long-term changes.

Statewide, the warmest month is July and the coldest month is January. But viewed seasonally, monthly average high and low temperatures from south to north vary considerably. In the summer, the southern interior division is warmer than both the northern and coastal divisions. The waters of the Gulf of Maine moderate both summer and winter temperatures along the coastal zone, keeping the coastal division relatively mild for the remainder of the year. In contrast, the interior of northern Aroostook County experiences warm summers and some of the coldest temperatures and highest snowfalls in the eastern U.S. The average annual frost-free period shrinks from close to 200 days in southern Maine to around 160 days in the northern part of the state.

Precipitation is evenly distributed throughout the year, with monthly averages between 2.9 and 3.9 inches and slight differences between climate divisions. The coast is wettest in winter, while in the north summer is slightly wetter than winter. It is worth noting that the relatively uniform distribution of monthly precipitation in Maine is highly unusual globally; most places have high variability in moisture from season to season.

The rise of the Industrial Revolution at the end of 18th century led to major advances in agriculture, manufacturing, and transportation as well as exponential growth in the world's population and resource consumption (i.e., mining activities and the burning of wood, coal, oil, and natural gas). As a result, the Industrial Revolution marked the period during which humans began to substantially alter the composition of the atmosphere that continues to the present.

The impact of increased fossil fuel burning and other practices that release pollutants into the atmosphere rapidly accelerated during the 20th century and is revealed in paleoclimate records (e.g., ice cores and cores from lake sediments and peatlands) and direct measurements of atmospheric chemicals. Increased levels of greenhouse gases and sulfate in the atmosphere influence Earth's energy balance and thus contribute to the observed changes in global temperatures ("the greenhouse effect").

Temperatures in Maine and around the globe have increased over the past century. While the U.S. Global Change Research Program's New England Regional Overview (NERAG 2001) indicated that Maine cooled over the period from 1885 to 1999 (global cooling between the 1940s and 1970s is evident in records from Maine), our closer examination of temperature trends for the length of record for each climate division in Maine over the most recent decades, reveals that for the past century the rate of warming in Maine has been increasing.

Today, all three of Maine's climate divisions are warmer than they were 30 years ago (a trend also evident globally, in part, perhaps, because emissions of sun-blocking atmospheric pollutants such as sulfate have decreased since the 1970s). According to the Arbor Day Foundation's Web site, the plant hardiness zones used by farmers and gardeners have shifted north (www.arborday.org/media/zonechanges2006.cfm), and the growing season for fields and forests is getting longer. Surface waters of the Gulf of Maine have warmed almost two degrees Fahrenheit since 1970 (Frumhoff et al. 2006), and the rate of sea level rise is accelerating from half a foot in the last century to a predicted rise of two feet or more by 2100.

The hydrologic cycle (the circulation and conservation of water) has also changed significantly over the last century. Although both the northern and southern interior climate divisions show a negative trend in annual precipitation for the entire period of record, all three climate divisions have trended toward wetter conditions over the last 50 years. The seasonality of events is also shifting, especially in winter and spring, when snowmelt and peak river flows and ice-out on Maine lakes occur earlier (Hodgkins et al. 2002; Hodgkins and Dudley 2006).

All of these documented changes provide evidence that Maine is already experiencing a changing climate, and underscore the importance of understanding and preparing for the changing chemical and physical climate we will be experiencing in the future.

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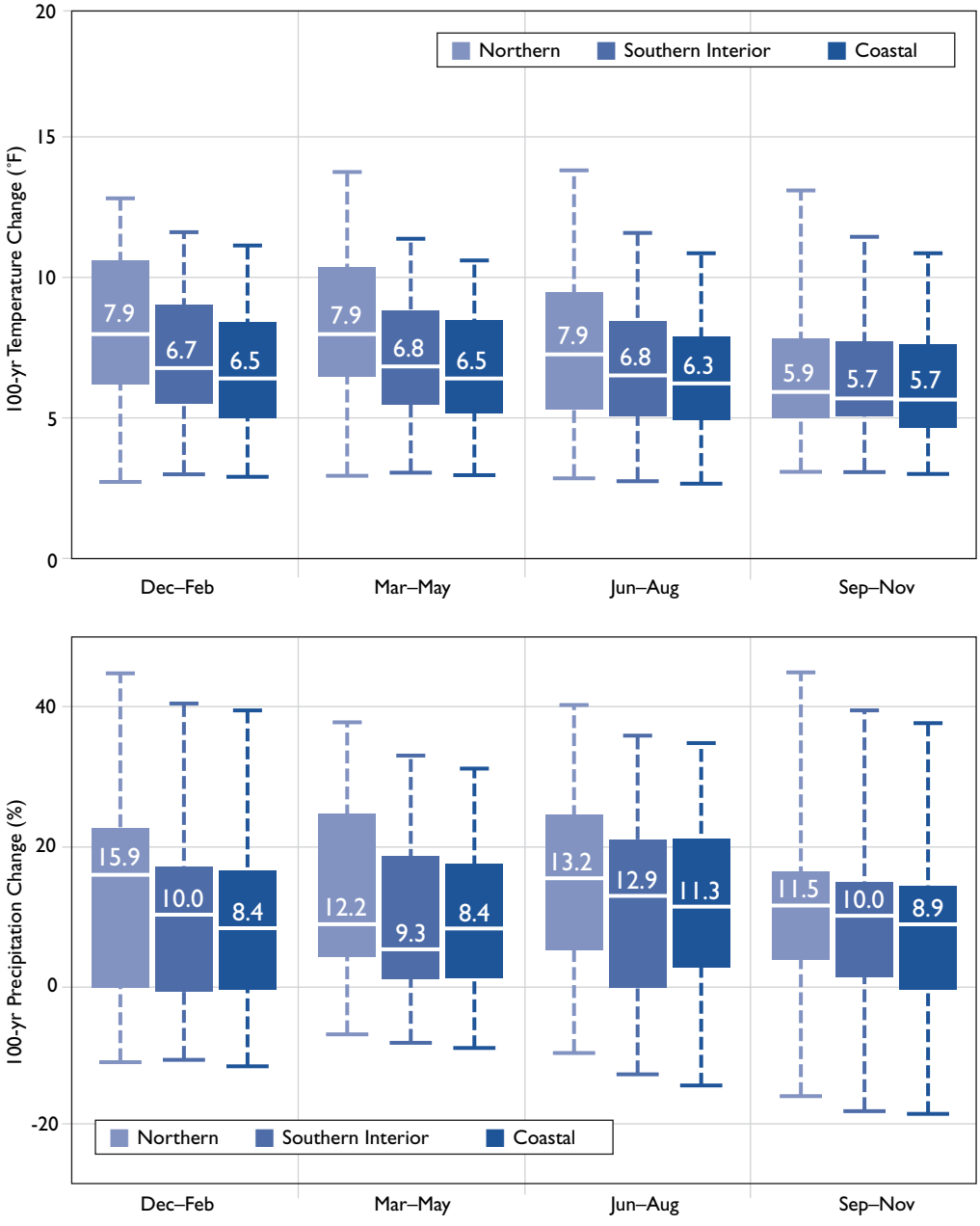
MAINE'S CLIMATE FUTURE

The Earth's climate is overwhelmingly complex and incompletely understood. Climate modelers grapple with multiple sources of uncertainty, including demographic change, social and economic development, and future greenhouse gas emissions. Any attempts to quantify predictions of the future are almost certain to be oversimplified and must be used cautiously by planners at the town or even watershed level. International and national climate change assessments use models with broad spatial resolutions, making local views fuzzy. Recent regional models,

FIGURE 2: **Multi-model Prediction of 21st Century Maine Climate Change**



Note: Boxes depict the 25th and 75th percentiles; the line is the median. Dashed lines span minimum to maximum variation among the 42 models used.

Source: Winter, spring, summer, and fall temperature and precipitation changes in each Maine climate division are from model runs forced with scenario A1B (Jacobson et al. 2009).

such as the one used for the Northeast Climate Impacts Assessment (Frumhoff et al. 2006), use a much finer scale.

To predict what further changes we can expect in Maine over the next century, "Maine's Climate Future" (Jacobson et al. 2009) used simulations of climate change forced by an assumed intermediate level of greenhouse gas emissions from the most recent assessment of the Intergovernmental Panel on Climate Change (Chandler 2008). Seasonal temperature and precipitation in Maine were predicted for the next century using a suite of models and the grid points covering Maine. The results can be used to discern the broad direction and range of likely changes in temperature and precipitation based on what we know today. It is important to recognize that unbridled economic growth, fossil fuel consumption, desertification and deforestation around the globe over the next century can result in global increases in CO_2 and other greenhouse gases to atmospheric concentrations that are three or even four times the pre-industrial levels, leading to global changes that are much larger than the commonly reported model results. We thus consider the trends and changes discussed here to be conservative estimates.

Overall, the models show a strong trend in Maine toward warmer and wetter conditions in all four seasons over the 21st century (Figure 2). Depending on future emissions scenarios,

changes in the region's climate over the next century include a three to 10 degree F increase in average annual temperature, a longer growing season, a two percent to 14 percent increase in precipitation, less snow, more rain, and highly variable precipitation. Increases in both temperature and precipitation are greatest in the north and least along the coast.

These warming trends imply a continued shift in regional hydrology, from a snowmelt-dominated regime to one that shows significant runoff during winter. This shift, coupled with projected precipitation increases, will likely pose challenges for managing water supplies, preparing for floods, and understanding ecosystem response and adaptation during this century. However, slight changes in seasonality of precipitation and increases in evaporation and plant transpiration that are likely to accompany warming all complicate predictions of the net change in water balance, resulting in scenarios that can have both increased precipitation and increased drought stress and other water deficits.

A warmer and wetter future will affect the seasons as we know them, with more winter precipitation in the form of rain. Other assessments (Hayhoe et al. 2007) forecast increased intensity of precipitation events that usually result in greater storm damage, erosion, and less effective use of water supplies. A warmer ocean could increase the frequency and intensity of hurricanes, with implications for water and wastewater management, coastal infrastructure, and water quality.

Climate change is not a single-factor, black-and-white change in the environment. Climate change occurs within and in addition to the complex realm of environmental interactions, too often with unpredictable results. For example, potential increases in commercially important fish or tree species could be tempered by simultaneous increases in toxic red tides, invasive species, pests, or diseases. Climate change is not just the physical changes in temperature and precipitation. Climate change includes, for example, the direct "fertilizing" effects of rising atmospheric CO_2 and nitrogen deposition on forests and agricultural crops, making them potentially grow faster. Oceans not only warm and expand but they chemically absorb excess CO_2, becoming more acidic at the same time.

Climate change effects must also be considered in the context of other changes in the environment. The landscape is experiencing the effects of other human activities that can enhance or mitigate the influence of climate change. For example, development pressure reduces the land base available for Maine's natural resource industries, possibly limiting their ability to respond and adapt. Development also reduces carbon stored on the landscape in forests, wetlands, and otherwise undisturbed ecosystems, adding to greenhouse gas emissions.

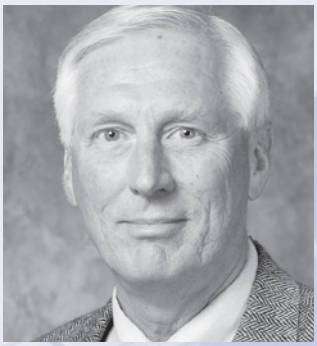
…Maine needs an adaptation plan that addresses the business of opportunity and promotes resilience.

ADDRESSING ADAPTATION WHILE CONTINUING MITIGATION

From our first inventory of greenhouse gas emissions in 1995 to the nation's first statewide climate change law in 2003, Maine has been a leader in addressing climate change and in reducing greenhouse gas emissions. These important mitigation efforts must continue; at the same time, Maine needs an adaptation plan that addresses the business of opportunity and promotes resilience.

The initial assessment of climate change in Maine (Jacobson et al. 2009) led by the University of Maine and its Climate Change Institute is designed to frame future detailed analyses of Maine's ecosystems and natural-resource based industries, and to provide recommendations for ways Maine can adapt to a changing climate. Assessments of the effects of climate change tend to focus on the negative because of the difficulty and costs of change in our society.

"Maine's Climate Future" (Jacobson et al. 2009) highlights some of the critical challenges faced during this period of transition in various ecosystems and economic sectors in Maine. This information is intended to help frame the policy and management



George L. Jacobson is professor emeritus of biology, ecology, and climate change at the University of Maine. He has been a member of the Climate Change Institute since 1979 and was its director for nearly a decade. His research has focused on long-term climate variability and specifically on forest responses to climate changes during the past 60,000 years. This past year he served as an advisor to the Finnish Academy of Sciences in their development of a paleoclimate research program.

discussions on adaptation that are urgently needed. We recognize that reducing human and ecosystem vulnerability to harm and increasing resilience in the face of change is both an economic and a moral imperative. "Maine's Climate Future" also emphasizes the idea that this period of transition is also a period of opportunity, and Maine can lead the nation by taking advantage of the opportunities presented by this transition in the 21st century.

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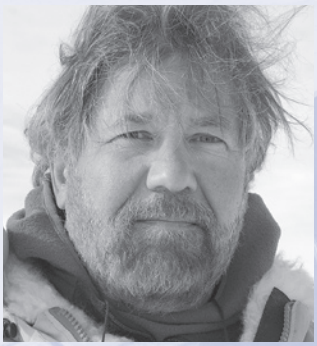

Photo by Joan Myers

Paul A. Mayewski is director of the Climate Change Institute at the University of Maine and a professor of earth sciences. An internationally acclaimed scientist and explorer, he has led more than 50 expeditions to some of the remotest reaches of the planet. His is the author of numerous scientific publications and of a climate change book written for the public, *The Ice Chronicles*. He has received numerous honors including the first-ever internationally awarded Medal for Excellence in Antarctic Research and the Explorers Club Lowell Thomas Medal.

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