PREPARING FOR A CHANGING CLIMATE

THE NEW ENGLAND REGIONAL ASSESSMENT OVERVIEW

Acknowledgements

The New England Regional Assessment (NERA) is the product of a four-year effort to characterize the impacts to the region of a changing climate since 1895, the current state-of-understanding of factors known to influence our regional climate, and projections of possible future regional climates. Many people have been involved in this project, including the authors of the chapters, the members of the Steering Committee (see Appendix A) and stakeholders (Appendix C). Dr. Lynne Carter, of the National Assessment Coordination Office (NACO), and Henry Walker, U.S. Environmental Protection Agency, were especially active in the review process of both the Overview and Foundation NERA documents. A number of state and regional groups have also taken an active role in assisting in the review of the final documents and in publicizing their release. These include the New Hampshire Department of Environmental Services, an EPA-sponsored New Hampshire Local Impacts Assessment Project (LIAP) on global climate change, and the New England Science Center Collaborative. The LIAP program developed and coordinated both a scientific review and a stakeholder review as summarized in Appendix D. In addition, many individuals have been involved in the production of the final documents, including Ryan Huntley, Clara Kustra, Faith Sheridan, Kristi Donahue, and Shannon Chisholm, all from the University of New Hampshire. Finally, we wish to acknowledge the funding provided in support of the NERA effort by the National Science Foundation (NSF).

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EXECUTIVE SUMMARY

New England Regional Assessment

Purpose

The New England Regional Assessment (NERA) is one of 16 regional assessments, conducted for the U.S. Global Change Research Program (USGCRP), as part of the National Assessment of climate change impacts on the United States. The National Assessment was conducted in response to the Congressional Act of 1990, at the request of the President's Science Advisor. The purpose of this regional assessment of potential climate change impacts on the New England Region (the six New England states plus upstate New York) is to provide a local perspective on a global issue. The intent in producing this *Overview* document is to provide the most current insight on the topic of climate change, focused on local issues and concerns, in a relevant and accessible format of use to the public.

The overall goal of the NERA was to determine the potential impacts of future climate change by evaluating selected sectors (Forests, Water Resources, and Human Health) considered to be of importance to the New England Region. For each sector we considered:

- the *current stresses* on these key sectors;
- how *additional stresses* associated with potential climate change and/or variability would impact these sectors;
- the *missing pieces* (knowledge and/or data) needed to more fully understand the potential impacts and how best to adapt to them;
- reasonable *adaptive strategies* that could be employed to reduce these impacts; and
- where possible, win/win approaches to adaptation, so that the impact of climate change is minimized and additional benefits are realized.

From the beginning, the goal of the assessment was to engage as many stakeholders as possible in the process. In so doing, a dialogue was initiated between research scientists, policy makers, and the general public. Regarding the important issue of climate change (past, present, and future) and its impact on the New England Region, stakeholder feedback was instrumental in the identification of key sectors, specific regional concerns, perceived vulnerabilities, knowledge/data gaps, research needs for the future, and possible adaptive strategies. Well over 300 stakeholders, representing a broad range of interests, participated in the NERA effort.

The New England Regional Assessment (NERA)

The New England Region Assessment (NERA) was initiated in September 1997, with the *New England Climate Change Impacts* Workshop, held at the University of New Hampshire (UNH). Additional Sector-specific Workshops were held in 1999. The New England Region includes the six New England states (CT, MA, ME, NH, RI, and VT) and upstate New York. The overall effort has been supported by the National Science Foundation. The NERA effort focused on the analysis of existing results rather than initiating new studies.

Much of the region is heavily forested, but it also includes some of the most productive agriculture (NY), especially cold-crop production, in the nation. The region has several major population centers, such as Buffalo, Albany, and Boston, but is noted for its rural setting and natural landscapes. When people think of the region, they envision spectacular fall foliage displays, winter activities such as skiing, and maple syrup production – all highly sensitive to climate variables. While the perception is of clean mountain air and sparkling streams and lakes, the reality is a region impacted by frequent episodes of poor air quality, polluted rivers, and seasonal red tides.

Stakeholders participating in the NERA identified the three key Sectors (Forestry, Water Resources, and Human Health) for detailed consideration, and three key concerns or issues likely to affect these Sectors if climate change continues (Air Quality, Seasonal Dynamics, and Extreme Weather Events). The Final Report of the NERA is offerred in two forms: A *Foundation* document consisting of peer-reviewed research papers, and an *Overview* document consisting of summary statements taken from the *Foundation* document. Both documents are organized as follows. Following an introduction to key concepts (Chapter 1), necessary background information is provided on those factors known to affect the region's notorious weather (Chapter 2). The factors, both natural and anthropogenic (human-caused), known to affect climate at the global and regional scale are presented in Chapter 3, and the global climate models selected for use in this assessment are presented in Chapter 4. Detailed treatments of the Sectors are presented in Chapters 5 (Forests), 6 (Water Resources), and 7 (Human Health). Chapter 8 presents an analysis of the social and economic impacts that climate change will likely have on three regionally-important issues: the fall foliage display, regional tourism, and human health.

The Format

The format of the *Overview* of the NERA Final Report is designed to convey maximum information content in an attractive and non-technical manner. Many of the pages are headed by quotes pulled from the text that highlight main concepts and major points. Each Sector Chapter is divided into *current stresses*, *additional stresses associated with potential climate change*, *missing pieces*, and *adaptive strategies.* Illustrative Case Studies are included in each Sector Chapter, again to provide the reader with a detailed treatment of how the Sectors are affected by present or future climate change. While many additional Case Studies could have been included, we selected only those for which specific *existing* research data were available.

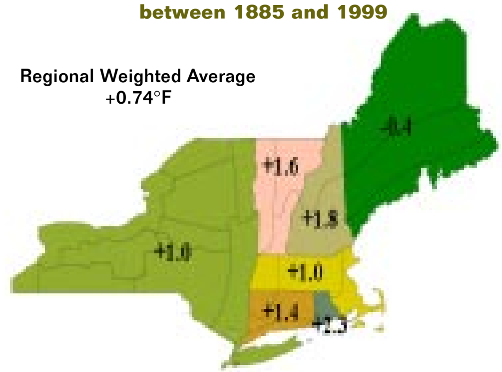
For those interested in a more detailed and technical treatment of all of the topics presented in the *Overview*, the expanded *Foundation* document is available. The *Foundation* Sector Chapters will contain more detailed treatment of each Sector, along with an expanded treatment of each Case Study. For the interest of readability, citation of references has been deleted from the *Overview.* Full references are found in the *Foundation.*

The Key Findings

In the process of conducting NERA, key findings were clearly identified.

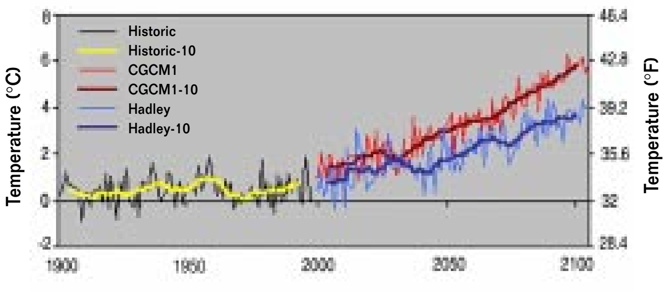
- **The Regional Climate Has Warmed over the Past Century –** In an analysis of the historic annual temperature and precipitation records, by region and by state, solid evidence exists that the climate *has* warmed over the past century (1895-1999). Overall, the region has warmed by 0.7° F, yet some states (RI, NH) have warmed by two to three times the regional average and one state (ME) has cooled. Warming in winter months has been greater than summer-time warming. Regional precipitation has exhibited a modest (4%) increase over the same time period, but as with temperature, the change has not been uniform across the region. We do not understand the heterogeneous nature or causes of these historic trends.

New England & New York temperature changes (°F) between 1885 and 1999



- **The Models Project Significant Warming Over the Next Century –** The two models used in this regional assessment project varying degrees of temperature and precipitation increase by 2090. The Hadley Model projects a warming of 6° F in annual minimum temperatures and a 30% increase in precipitation for the region, while the Canadian Model projects a 10° F warming in minimum temperatures and a 10% precipitation increase (punctuated by periodic, long-term droughts) over the next century. Both models project a significant warming and a moderate to significant increase in precipitation. It is important to recognize that these models provide "what if" scenarios for us to consider. Either temperature increase would be greater than any climate variation experienced by the region in the past 10,000 years. If either scenario occurred, the climate of the New England Region would be profoundly different than the climate of today.

Regionalized Historic and Scenario Mean Annual Minimum Temperature



- **The Impact of a Few Degrees Temperature Increase –** Although a 6-10° F increase may not seem to be very significant, a comparison of present-day temperatures is instructive. If 6° F are added to Boston's 30-year average annual temperature (an average of 51.3 ° F between 1961-1990), the resulting temperature is the approximate 30-year annual average for Richmond, VA (57.7° F). If 10° F are added to Boston's 30-year average, the 30-year average for Atlanta, GA (61.3° F) is the result! An annual average increase of 6-10° F would have a profound impact on the climate of the region.

- **Human Activities are Affecting Climate** – Our understanding of the factors, both natural and human-induced, that influence climate has improved dramatically over the past several decades. There is now strong scientific evidence that much of the global warming experienced in the last half of the 20th century is attributable to human factors including the build-up of greenhouse gases in the atmosphere. This result is consistent with the idea that continued build-up of greenhouse gases will lead to additional climate change in the future.

- **The Past and Present Changes Have Clearly Impacted the Region** – Many changes (milder winters, earlier maple sap flows, earlier ice-out dates, reduced snowfall, etc.) are likely a response to a "minor" increase in temperature (0.7° F for the entire region). The 6-10° F temperature increases projected for the region by either climate model must be viewed as serious.

- **Regional Air Quality May Worsen –** Stakeholders identified poor air quality as the single most frequent regional concern. Hot, dry summer months are ideal for converting automobile exhaust (NO_x) and volatile organic compounds (VOCs) into ground-level ozone, a major component of SMOG. The same conditions provide the environment for power plant emissions (SO_x) to form sulfate haze. Both SO_x and NO_x combine with atmospheric water vapor to produce acid clouds and acid rain. If the climate becomes hotter and wetter, and automobile and power plant emissions remain the same or increase, regional air quality and acid rain problems will become worse in the future.

- **Such Future Warming Trends Would Profoundly Change the Sectors –** All three sectors analyzed in this assessment would be significantly impacted under the scenarios of climate change considered. The human health impacts - both direct (health effects of poor air quality) and indirect (warmer winters facilitating expansion of Lyme disease-carrying deer tick habitat) - of physical and chemical climate change are likely to be the most significant. The Forest Sector, already under stress, will likely continue to be the most flexible and adaptive. The potential droughts (in the Canadian scenario) and/or flooding (the Hadley scenario) would have profound impacts on regional water quality and warming coastal waters will experience species shifts and toxic algal blooms. Sea-level rise will become a significant problem for low-lying coastal regions (Cape Cod, coastal areas of CT, RI, MA, and NH), affecting both human infrastructure and coastal wetlands.

- **The Economic Impacts –** A limited assessment of the economic impact of climate change was conducted on natural resources, tourism, and health care industries. The major conclusion from this intitial economic analysis is that the impacts of climate change will vary and be significant. The economic impacts will likely be greatest on the Human Health sector, moderate on tourism and least severe on the Natural Resource Sector. This initial economic assessment has identified the need for a more extensive analysis of a broader range of Sectors.

Executive Summary
New England Regional Assessment

Missing Pieces

In the process of conducting NERA, it was often found that something was missing that would have allowed a more complete assessment. Some missing pieces are technical, others are simply a matter of needing to analyze existing datasets. These include:

- **A Regional Climate Model –** The National Assessment required each region to use two global climate models (Hadley and Canadian) as a minimum basis for their assessment of potential future conditions. However, because of their coarse scale, these models do not capture important fine-scale characteristics of the region (land cover, topography, etc.). A regional climate model parameterized for New England was not available for this assessment, but is recognized as an important missing tool for future assessments.
- **A Focused Research Effort –** The heterogeneity, both spatial and temporal, characterizing the current warming trend for the region is not well understood. A focused research effort is needed to identify and quantify those factors responsible for the regional heterogeneity.
- **An Expanded Economic Analysis –** A more thorough economic impact analysis, focusing on all sectors and accounting for expanded multiplier factors, is needed. The limited economic assessment conducted for the NERA had a narrow focus on only a few segments of the Forest and Human Health Sectors.
- **Public Knowledge about Climate Change –** The general public is often skeptical regarding climate change issues. The public believes that: 1. scientists don't agree on the cause of the recent climate change; 2. the problem, if it occurs, will be 50-100 years in the future; and 3. the problem has no solution. All of these are false assumptions and must be addressed in a responsible and understandable way.
- **The Need for Educational Materials –** There is a present lack of clearly-stated (in plain English), well-documented educational materials for both the general public and the K-12 classroom. Such materials are key to informing the residents of the region about the potential impacts of climate change in the future. Such materials, once developed, must be made available to teachers, informal educators, policy makers, and the general public. Education was a recurring theme at all workshop discussions. It was agreed that education must start early if we are to change people's attitudes and behaviors – when you educate a third grader, you also educate the parents and grandparents of that student.

Adaptive Strategies

Given the nature of these findings, it will be important to identify and prioritize strategies for reducing uncertainties and mitigating potentially adverse impacts. Some actions that accomplish these goals may have other benefits to the region and are called "win-win" strategies. A partial list of "win-win" actions includes:

- Promoting the development of more extensive and efficient use of regional forests as carbon sequestration (enhanced CO_2 uptake and storage) tools, as well as more productive sources of wood products.
- Improving air quality by reducing NO_x and SO_x emissions, thus improving human health and forest health, also lowers greenhouse gas emissions.
- Developing high efficiency/alternative energy sources that not only reduce CO_2 emissions but also other by-products (air pollutants).
- Investing in "green technologies" that reduce both CO_2 emissions and industry/business liabilities, thus strengthening their good neighbor image and creating a stronger regional manufacturing presence.

Next Steps

To address these issues and concerns, a positive approach should be taken. Appropriate next steps include:

- **Develop an Expanded Regional Assessment –** Based on the results from this limited assessment, it would be prudent to conduct an expanded assessment that considers more sectors and improved tools. Given the pace of the problem and the rapid developments in science and technology, such an expanded assessment should be conducted every 5-10 years. This assessment should include a more extensive economic analysis.

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- **Reduce CO_2, SO_2, and NO_X Emissions (Better Air Quality)** – Most steps taken to reduce CO_2 emissions will also reduce air pollutant emissions (SO_2 and NO_X) as well. Such improvements in air quality across the region will bring benefits to human health and forest health. Such reductions will not only improve air quality, but would also reduce acid rain impacts, further improving forest health. Hybrid automobiles, alternative home energy systems, and more efficient industrial power generation offer such benefits.
- **Promote the Forests of New England as Potential Carbon Sinks (Sequestration) –** Forests are significant carbon storehouses and the heavily forested New England Region could contribute to national efforts to reduce atmospheric CO_2 levels. The actual extent to which regional forests are able to act as CO_2 sinks in the future will depend on air quality, soil nutrient status, tree species sensitivity to temperature and moisture regimes, and other factors. Additional research is needed on this issue in order to fully understand the extent to which forests can provide carbon sequestration capabilities.
- **Develop Forest Management Practices to Maximize Carbon Sequestration –** Recent studies have identified the significant role that past land use practices have played in contributing to the present carbon storage capacity of regional forests. Developing future strategies to maintain or enhance current carbon storage capacity will be important. Not only will carbon storage capacities be improved, but economic benefits to the region would also likely result.
- **Develop Economic Incentives to Promote Alternative Energy Options –** Serious efforts need to be focused on creating economic incentives to promote the development of alternative energy options appropriate for the region. Solar-based and wind-based strategies should be considered and past regional reliance on water-power could be re-introduced. Due to our coastal location, tidal and wave action could prove to be a significant source of energy generation. These and other options will need to be supported by tax credits, subsidies, etc.
- **Develop Land Cover Strategies that Minimize Climate Impacts –** Since forested land cover can act as strong absorbers of solar energy, a more focused effort is needed to educate the general public on the multiple benefits of maintaining and enhancing the region's forests.
- **Conduct Impact/Risk Assessments to Minimize Potential Climate Impacts –** As with other potential risks (flooding, fire, storms, etc.) state and regional efforts are needed to address climate change risks identified in this report. Even in the face of perceived or real uncertainties, appropriate steps must be taken to reduce the risks posed by future climate change and variability.
- **Provide Broad Public Access to Information** – A series of hardcopy documents (like this NERA *Overview*) are needed for distribution to a wide range of audiences. These hardcopy documents should include colorful, descriptive and compelling materials, designed for the public, not the scientist. Multifold Sector-specific brochures are needed, providing key graphics, major findings, and main take-home lessons in plain English for distribution to a general audience. A list of "Things You Can Do" must be provided at both the general level as well as for specific Sectors.
- **Make Difficult Decisions in the Face of Uncertainties –** While there are uncertainties associated with climate change issues, there is still a great deal of consensus among the scientific community regarding these issues. The uncertainties should not lead to inaction. Rather, rational steps should be taken to identify risks and make sound decisions. Decision making in the face of uncertainties about the future is commonplace in people's daily lives and businesses.
- **Focus on the Things We Can Change** – While many factors, both natural and human-induced, are known to affect the climate, we have no control over the natural factors. We do have control over the human-induced factors and must now consider what direction our future climate will take. The future is in our hands.

Website
New England Regional Assessment

The New England Regional Assessment *Overview* document is available online at www.necci.sr.unh.edu.

Additional Reading

The following references are suggested as additional reading for those wishing to find more information on the topic of climate change and its potential impacts on both the United States and the New England Region.

Climate Change Impacts on the United States:
The Potential Consequences of Climate Variability and Change.
Overview. 2000. Cambridge University Press. 154pp. Also on-line at: www.usgcrp.gov.

New England's Changing Climate, Weather and Air Quality.
1998. Climate Change Research Center, University of New Hampshire, Durham, NH, USA. 47pp.

New England Regional Climate Change Impacts Workshop: Workshop Summary Report.
1997. Institute for the Study of Earth, Oceans, and Space. University of New Hampshire. 149pp.

Seasons of Change: Global Warming and New England's White Mountains.
1997. The Environmental Defense Fund. 33pp.

State of Maine Climate Change Action Plan.
2000. Maine State Planning Office. University of Maine, Orono, ME. 58pp.

CHAPTER 1

NEW ENGLAND REGIONAL ASSESSMENT

AN INTRODUCTION

By Barrett Rock

The purpose of this "*New England Regional Assessment of the Potential Consequence of Climate Variability and Change*" is to provide the general public with local examples of positive and negative impacts of both recent and future climate events. Our regional climate has changed over the past century and the changes are likely to intensify over the 21st century. This report also provides examples of local strategies that may be necessary if the current climate trends continue. Taking a local view of the potential impacts that a changing climate may have on the New England region (including upstate New York) is an important first step in identifying local needs and coping strategies, improving public understanding, and identifying local and regional issues that need further study.

One way of assessing the impact of potential change in climate conditions for the New England region is to identify the current stress factors (climate-related or otherwise) impacting the region today. By looking, sector by sector, at the current stressors, one can better evaluate future climate impacts by asking the question "How would a change in climate (warmer, wetter) influence these sectors in the future?" We also offer appropriate coping strategies useful in dealing with the impacts of climate change if it occurs, and identify areas where more information would be needed to better understand impacts and how to adapt.

This assessment of the current and potential future impacts of climate change on the New England region has been conducted as part of a larger National Assessment effort, entitled "*Climate Change Impacts on the United States – The Potential Consequences of Climate Variability and Change.*" The National Assessment was mandated in 1990 by the U.S. Congress, and has been coordinated and conducted by the U.S. Global Change Research Program (USGCRP), a multi-agency effort, in response to a request from the President's Science Advisor. The National Assessment Overview document was published in December 2000. The New England Regional Assessment (NERA) was initiated in 1997, and the findings of this three-year effort are presented in the following chapters.

Developing a local perspective is important. One of the suspected culprits in the climate change debate is the emission of man-made greenhouse gases, and people assume that these greenhouse gases come from industrial sources located in mid-western states, and thus, are beyond regional control. In addition, a common view is that global warming is

Taking a local view of the potential impacts that a changing climate may have on the New England region (including upstate New York) is an important first step …

Climate change, if it occurs as projected, will fundamentally change both the character and the quality of life of the New England region…

global in scale and it is not obvious to the average person how local action could have any impact on such a large-scale problem. Finally, many citizens of the New England region may think that global warming might not be so bad, since few other than winter sports enthusiasts would mind milder winters and longer growing seasons. This NERA Final Report has identified climate change impacts on the New England region that go well beyond the effect on human comfort. Climate change, if it occurs as projected, will fundamentally change both the character and the quality of life of the New England region; and thus, these potential changes must be seriously considered and action, if appropriate, must be at the local level.

To generate the New England Regional Assessment Final Report, we have directly involved regional experts/stakeholders as active participants and contributors in discussions of climate change and its potential impacts on the region. Regional issues were identified by participants during the regional assessment workshops. The Regional Assessment Team and Steering Committee (see Appendix A) have prioritized the regional issues and identified important regional Sectors (Forests, Water Relations, Human Health, and Agriculture) considered to be especially sensitive to climate variability.

The key issues identified by stakeholders are illustrated using relevant case studies in each of the Sector Chapters. In order to be included, each key issue or case study needed to meet three criteria: (1) they are important to the New England region; (2) they exhibit a clear connection to either physical or chemical climate impacts; and (3) each case study needed to be well-documented and thoroughly-understood, based on existing data. The key regional issues and illustrative case studies are presented in Table 1.1 below.

The New England Regional Assessment is available in two versions. The NERA Final Report is published in a detailed version, subjected to scientific peer review and entitled the Foundation Document. A much shorter version, called the Overview Document, contains the key points and major highlights of the NERA Foundation Document. Both are available to the general public.

TABLE 1.1
Key issues and relevant case studies presented in Chapters 5 (Forest Resources), 6 (Water Resources) and 7 (Human Health).

Key Issues	Case Studies
Air Quality	Forest Health Impacts (ground-level ozone) – Chapter 5 Human Health Impacts (Hiker Health Studies) – Chapter 7
Seasonal Dynamics	The Maple Syrup Industry – Chapter 5 The Effects of Warming on Snow – Chapter 6 Climate Impacts on Lyme disease – Chapter 7 The Relation Between the Winter NAO and Streamflow – Chapter 6 Species Migration – The Loss of Sugar Maple in New England – Chapter 5
Extreme Weather Events	The 1998 Ice Storm Damage – Chapter 5 The 1960's Drought – Chapter 6

Recent weather-related events have raised public awareness that the "typical" New England weather may be changing…

Important Climate Change Concepts for the New England Region

The New England region is dominated by ever-changing weather and physical climate, and residents have come to expect to be able to "work around" their weather. They also expect their weather forecasts to be reasonably accurate, and their weather predictable. Recent weather-related events have raised public awareness that the "typical" New England weather may be changing, as evidenced by recent mild winters, changing seasonal patterns (earlier springs and later falls), and what seems to be an increasing occurrence of extreme weather events (heavy rains and flooding of October 1996 and June 1998, ice storms in January 1998, and the summer droughts of 1995 and 1999).

Some basic concepts underpin our current understanding of New England's weather (day-to-day and week-to-week patterns of temperature, precipitation, and cloud cover) and climate (longer-term seasonal to decadal weather patterns). To more fully appreciate the potential climate change impacts on the region, these basic concepts are discussed below.

- **New England is Down-wind From the Rest of the Country**
  As we have come to know from watching the evening weather on TV, high and low pressure systems, storms and associated precipitation patterns move rapidly from west to east across the United States (Figure 1.1). Weather affecting the west coast and mid-west soon affects the New England region. We are in the unenviable position of being down-wind from the rest of the country and parts of Canada. Our position places us in the path not only of the weather from the rest of the country, but, due to long-distance transport,

Major Storm Patterns for the U.S.

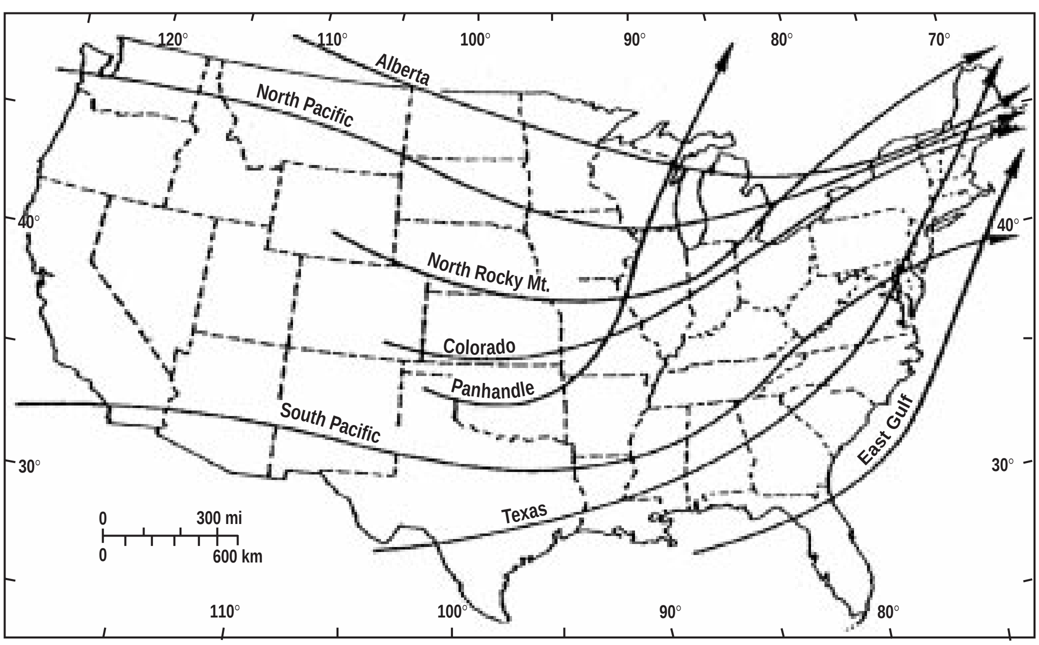

FIGURE 1.1
A plot of the major storm tracks for the United States, showing the pattern of continental weather phenomena and airborne chemical pollutants across the New England region.

It has been said that New England is the tail pipe for the United States.

also in the path of air pollution from upwind. It has been said that New England is the tail pipe for the United States.

- **Climate Change Refers to both Physical Climate and Chemical Climate Change**

It is important to recognize that the term "climate" can refer to both physical climate (temperature, precipitation, and cloud cover) and chemical climate (including the chemical composition of the atmosphere and precipitation). Changes in the regional chemical climate are well know to the public, resulting in changes in air quality and the acidity of rainfall, snowfall, and cloud chemistry. Public concern is high for the potential impacts of ground-level ozone (smog) on both the environment as well as on human health, and the New England region is well-known for the acid rain which continues to be a problem for high-elevation lakes and forests.

Because the two types of climates are interconnected, a change in one may lead to a change in the other. Hot summer days are known to be conducive to the formation of elevated levels of ground-level ozone or smog. This smog results from the interaction of nitrogen oxides (NO_X - produced largely from automobiles), and volatile organic compounds (VOCs which in New England often come from natural sources such as forests) in the presence of sunlight (see Figure 1.2). In addition to smog, emissions of sulfur dioxide (SO_2) and NO_x from the combustion of fossil fuels can combine with cloud moisture to form acidic cloud and precipitation chemistry (sulfuric acid - H_2SO_4 and nitric acid - HNO_3 respectively). In general, SO_2 is produced in the combustion of coal or fuel oil, often in the process of generating electricity, while NO_x is produced when atmospheric nitrogen and oxygen are combined by contact with hot surfaces, such as automobile exhaust systems.

- **Physical Climate and Chemical Climate are Connected**

When we think of climate change it is only natural to think of physical climate factors such as temperature and rainfall. It is important to realize that physical climate factors have an influence on the chemical climate as well, in the form of changing air quality.

In July of 1997 the Environmental Protection Agency (EPA) implemented a new National Ambient Air Quality Standard (NAAQS) for ground-level* ozone pollution (SMOG). With the previous standard, a 1-hour average value equal to or greater than 0.125 ppm (125 ppb) of ozone was

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* Ground-level ozone, a component of SMOG, should not be confused with the ozone layer in the stratosphere. Stratospheric ozone naturally occurs and acts as a filter for ultraviolate (UV) radiation, protecting life on Earth's surface. Ground-level ozone is harmful to living systems and is anthropogenic in origin.

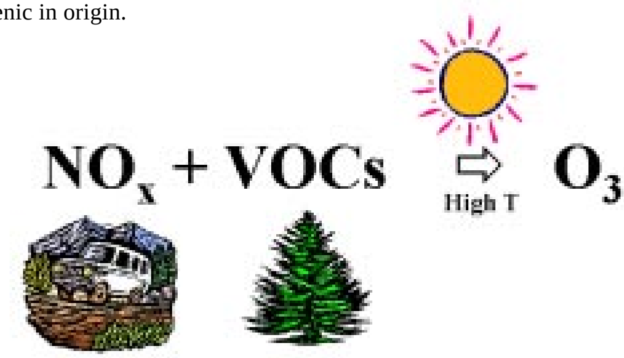


FIGURE 1.2
The relationship between NO_X, VOCs, temperature, sunlight and the formation of ground-level ozone.

This tells us that there is a strong connection between physical climate change and chemical climate change.

considered an exceedance. The new standard is more stringent and measures ozone concentrations over an 8-hour average and cannot exceed 0.080 ppm (80 ppb).

Figure 1.3 shows the number of 1-hour (.120 ppm) and 8-hour (0.080 ppm) exceedance days, compared with the number of days the temperature was at or above 90° F, as monitored at Bradley Airport, north of Hartford, CT, for the period from 1980-1998. Clearly, the years in which there were a greater number of days at or above 90° F, were also characterized by a greater number of ozone exceedances for both the 1-hour and the 8-hour standards. The years 1983, 1988, 1991, 1993, 1995 and 1997 were characterized by such exceedances. It can also be seen that a trend toward fewer days at or above 90°F leads to fewer exceedances over the same time period. This tells us that there is a strong connection between physical climate change and chemical climate change.

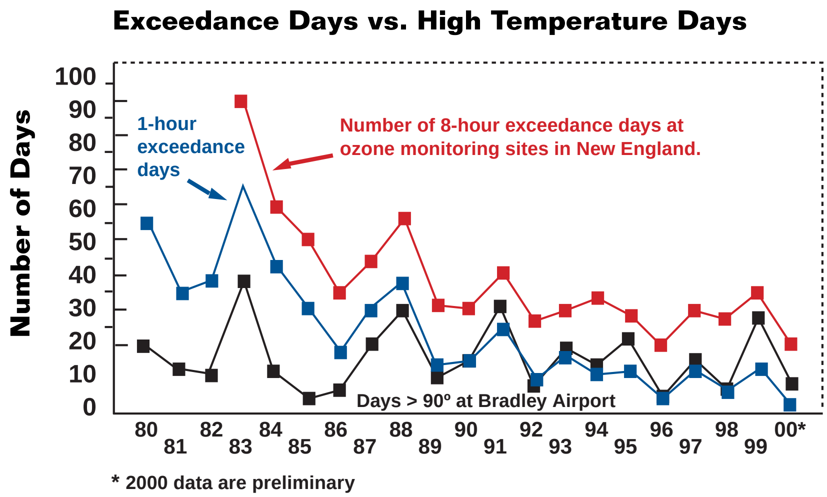


FIGURE 1.3 Number of 1-hr and 8-hr ozone exceedance days, as well as the number of days at or above 90ºF at Bradley Airport, Hartford, CT.

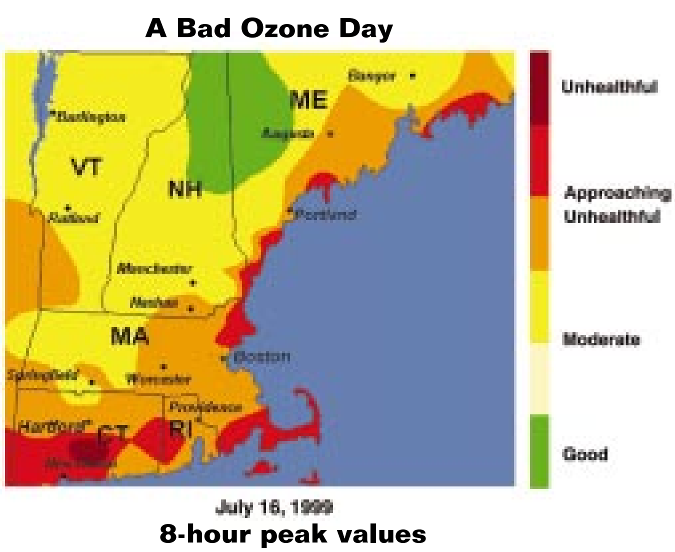
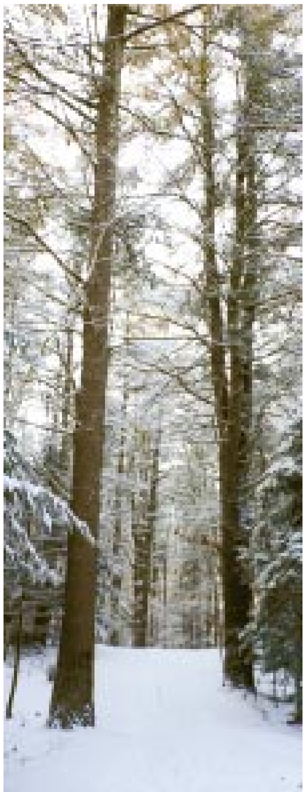


FIGURE 1.4. A high ozone day, July 16, 1999 source: http://www.epa.gov.

Figure 1.4 is a regional map for July 16, 1999, one of the worst ground-level ozone days of that year. The map is based on an interpolation of the actual maximum 8-hr average ozone concentration values at approximately 200 ground-level ozone monitoring sites from Maine to North Carolina. As can be seen in this regional portion of the overall map, unhealthful levels of ozone (8-hour concentrations of ozone above 80 ppb) occurred throughout much of the New England region. The highest ozone concentrations are commonly associated with urban centers or heavily traveled transportation corridors.

Wood represents atmospheric CO_2 stored in a stable form that is no longer able to function as a greenhouse gas.



- **The Forests of New England Sequester Carbon**

  Recent studies have shown that forests store (sequester) large amounts of carbon in the form of both structural and functional carbohydrates. Wood is composed of several types of structural carbohydrates (including cellulose and hemicellulose), along with other complex chemical compounds derived from metabolism of atmospheric carbon dioxide (CO_2).

  Although the forests of the New England region currently store 20 million metric tons of carbon per year, it is significant to understand that poor air quality adversely impacts potential photosynthetic capacity, especially in sensitive species. If air quality can be improved for the region, wood production (carbon sequestration) would increase. Reducing CO_2 and NO_x emissions, by improving gas mileage and reducing automobile traffic, would effectively improve the carbon sequestration capabilities of regional forests.

- **Why Climate Models are Used**

  The models used in this regional assessment provide dramatically different projections of scenarios. Both the Canadian General Circulation Model (CGCM1) and the Hadley Climate Model (HadCM2) were selected for several reasons, including the fact that they would provide the public with a reasonable range of scenarios or "what if" projections about future climate patterns. These models were considered robust enough to be tested at a regional scale. Since all General Circulation Models differ one from another on the basic assumptions made for producing future projections, it was decided to present two models which were considered to be based on the most reasonable assumptions.

  Thus, it is important to understand that just because these models present different scenarios, there is no reason to disregard either or both. They were selected specifically because they give different scenarios, and in the process suggest two possible "what if" futures for the region. By considering a reasonable range in "what if" scenarios, we are better able to develop possible adaptation strategies for the future. Although the two models provide two different projections, both project significant warming by 2090 (approximately 6° F or 3.1° C suggested by the Hadley Model; 9-10° F or 5.3° C by the Canadian). In either case, a 6-10° F warming over the next 100 years would represent an unprecedented warming in such a short time, based on historical data. The two models also differ in their projections of precipitation, with the Canadian Model suggesting a slight increase in precipitation (10%) by 2090, but also projecting significant periods of drought, while the Hadley Model projects nearly a 30% increase in precipitation over the same time period. The New England we know today will not be the New England of 2090 if either model scenarios becomes a reality.

- **A Few Degrees is a Big Difference**

  The projections of a 6-10° F (3-5° C) warming in the next 100 years may not seem to be very significant, since tomorrow is likely to be at least 6-10°F warmer or colder than it is today. A few degrees, either Celsius or Fahrenheit, doesn't seem to be that big a difference. However, it is very important that we understand what a few degrees in global or regional average temperature means in terms of climate. Approximately 20,000 years ago, parts of the New

Since we can't control the natural forcings, we need to address those things that we can control…

England region were under nearly 2 miles of ice. At that time, the northern hemisphere of Earth was experiencing a period of maximum glaciation. Within 1,500 to 2,000 years, the region had entered a period of warming known as an interglacial period. The current climate conditions today are very similar to those conditions characterizing the beginning of the interglacial period. The global average temperature difference between the last glacial maximum (2 miles of ice) and the current interglacial period is only 10-12^{o}F (5-6^{o}C)!

As an illustrative example of the difference that a change in climate of just a few degrees can make, a comparison of Boston is made with cities from other parts of the United States. The "normal" Boston, MA monthly average temperature for the 30-year period is 51.3^{o}F. Using the two climate model scenarios, we can look for cities that are, on average, 6^{o}F warmer (the Hadley model projection for 2090) and 10^{o}F warmer (the Canadian model projection) than the present conditions in Boston. If a 6^{o}F warming occurs over the next 100 years, Boston's "normal" temperature would be more like today's Richmond, VA (57.7^{o}F). If a 10^{o}F warming occurred for the region as the Canadian model projects, Boston's temperatures would be similar to those in Atlanta, GA (61.3^{o}F).

Of course, there is much more to climate than simply the temperature, but these comparisons are useful in relating the impact of just a few degrees increase in average temperature in the future. One can only imagine what would become of our ski industry, the maple syrup industry and our fall colors, if Boston becomes more like Richmond, VA or Atlanta, GA.

- **Uncertainties about the future should not result in inaction**

It is important that we recognize the great regional variability and unpredictability in attempting to forecast future regional climate trends. Certainly, using a global model "down-scaled" for use as a regional model is not the ideal way to do this. One of the key findings of the NERA effort is that such regional models, which take into account local geography, topography, land cover conditions, etc., are sorely needed. Until such regional models are available, the down-scaled Global Climate Models such as the Canadian and Hadley are the best that we have to work with.

The biggest uncertainties about future climate projections are not due to model failings, but rather in our inability to predict future levels of greenhouse gases (CO_2, CH_4, and others), the cooling effects of sulfate aerosols from both human and natural sources, as well as other forcings (solar output, land cover change, etc.). Since we can't control the natural forcings, we need to address those things that we can control (greenhouse gas emissions and land cover change).

Finally, we make informed decisions to protect valuable items (our homes, car, and possessions) by purchasing insurance policies. We buy fire insurance on our homes, even though the likelihood of our home burning down is very small. We buy such insurance, "just in case." We make medical decisions based on uncertainties – removal of a "suspicious" lump is a common medical practice, "just in case." We make such important decisions often based on far greater uncertainties than we have about the likelihood of climate change in the future. We need to take the same approach with confronting future climate change, "just in case."

CHAPTER 2

THE NEW ENGLAND REGION'S CHANGING CLIMATE

By Barry Keim and Barrett Rock

When people think of the climate of the New England region (the six New England states plus upstate New York), they think of crisp, clear fall days enhanced by spectacular fall foliage, hot, sunny summer days and cool summer nights, or pristine winter snowscapes with snug cabins and bustling ski slopes. While the regional weather can change on short time scales ("If you don't like the New England weather, wait a few minutes"), we tend to think that climate is stable. Just how stable is our climate, and are we seeing evidence that our climate is changing?

New England regional weather and climate are arguably some of the most varied in the world. This climate variability holds true at time scales of days to weeks, years to decades, and thousands to millions of years. Regional variability includes extremes of both hot and cold temperatures, droughts, heavy rainfall, hurricanes, tornadoes, blizzards, and more. Such variations in the weather are influenced by many factors which relate to the region's physical geographic setting, including its latitude and coastal orientation, its topographic variability, and its position relative to the North American continent and prevailing storm tracks.

This chapter will consider climate variations known to have characterized the region during the last two million years, the region's physical geographic setting, and some trends suggesting what, if any, climate change may have occurred based on climate records for selected sites.

Primary Components of the New England Regional Climate

The four components that dominate the modern climate of the New England region are: (1) latitude; (2) coastal orientation; (3) position within the zone of the westerlies; and (4) great changes in elevation. These factors interact to provide the New England region with its characteristic weather and climate patterns.

First, the region is located about halfway between the equator and the north pole (45^{o} N), which is why it serves as a battleground for warmer, moist air from the south and colder, dry air from the north. The surface air mass boundaries are made up of warm, cold, and stationary fronts, which frequently traverse the region from west to east taking us from one air mass to another in rapid succession.

Second, the region is dominated by a cold ocean current along its east coast, and a warm water current along the south shore of Connecticut and Rhode Island, as well as Long Island (NY). These currents, and the corresponding water temperatures associated with them, impact summer recreation, swimming comfort, etc, and also create a notable sea breeze in spring and summer. In winter, these waters remain warm relative to land areas, thereby influencing snow-rain boundaries, which are very difficult for weather forecasters to predict.

New England regional weather and climate are arguably some of the most varied in the world.

Third, since New England falls primarily in the zone of the westerlies, the area is dominated by drier continental airflow from various areas across North America, rather than having a prevailing flow off the Atlantic Ocean. Despite the coastal orientation of New England, it is not a maritime climate like those found on the west coast of the United States. Due to this continental airflow pattern, the New England region is downwind from much of the rest of the continent, and with that airflow comes varying degrees of air pollution from both the mid-west and from along the eastern urban corridor.

Fourth, New England has mountainous topography that also influences weather patterns. Such mountain topography enhances precipitation on the windward side of the mountain, and creates drier conditions known as rainshadows on the downwind slopes. However, the prevailing storm tracks can take storms all around the region. Hence, a south-facing slope may be in the rain shadow on one day, while the next, it could be on the windward side. Increases in elevation also lead to cooler air temperatures. The summit of Mount Washington (NH) is known for some of the most severe weather on Earth, weather so severe that hiker deaths due to exposure and hypothermia in summer months are not uncommon. Mount Marcy and the High Peaks region of the Adirondacks (NY) are also notorious for severe weather.

As a result of a combination of New England's geographical location, its continental climate, its coastal orientation, and its mountainous topography, the region's weather is notorious. It is known for its diversity over short distances and changeability in a matter of minutes.

Temperature

New England average annual temperature is 44° F, and ranges from approximately 40° F to the north, and about 50° F along the south shore of Connecticut and Rhode Island. When we factor in elevation, temperatures are generally cooler (Mount Washington has an annual average temperature of 26° F). Absolute extreme temperatures in New England have been recorded to be as high as 107° F and as low as –50° F. The record 107° F high is hotter than the all-time high temperature recorded in Miami, Florida, and the –50° F low is colder than the record low temperatures in Anchorage, Alaska or International Falls, Minnesota (commonly the coldest location in the conterminous United States).

There has been a modest (0.7° F) regional trend toward increasing annual temperatures since 1895 (Figure 2.1). As can be seen, a good deal of year-to-year variation characterizes the regional record. The coastal zone of the region has warmed by 1.7° F over the same time period while the interior has warmed by 0.6° F.

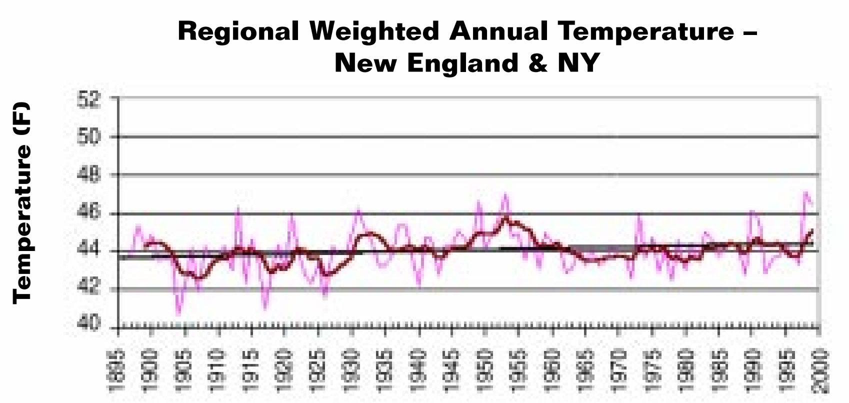


FIGURE 2.1
Regional Weighted Annual Temperature – New England and upstate New York. Annual variation is seen in pink, a 5-year running mean is dark red and the overall trend as the black line. The overall regional increase is 0.7°F.

At a minimum, the 1998 ice storm has been classified as a 200-year return event, and possibly a 500-year return event.

There are two possible explanations for these differences. First, the coastal region has experienced rapid population growth over the past century and the warming could be the effects of land cover change and resulting urban heat islands. Second, there is speculation that the sea surface temperatures around New England may have warmed, thereby warming the climate of the coastal zone.

Precipitation

The average annual precipitation for the region is approximately 40 inches per year and ranges from approximately 35 inches in the northern reaches, with higher values, to over 50 inches, along the southern coastal zone. Since elevation tends to enhance precipitation totals, Mount Washington averages approximately 99 inches of "liquid equivalent" precipitation per year.

Similar to the change-over-time patterns noted with temperature, there is a trend of slightly increasing precipitation for the entire region (a 3.7% increase - Figure 2.2), with a greater increase (16.8%) for the coastal zone over the past century, and less (2.7% increase) long-term change in the interior. In addition, there appears to be an increase in heavy rainfall events in the east coastal region, where three precipitation events with greater than 50-year return period have occurred between October 1996 (Keim, 1998) and October 1998 and a 200-year return ice storm was experienced by a large part of the region in January, 1998 (See Chapter 5). At a minimum, the 1998 ice storm has been classified as a 200-year return event, and possibly a 500-year return event.

Although the New England region is not considered to be water-limited, several periods of significant drought have occurred that were region-wide. The affect of the mid-1960s drought (covering 4-5 years) can be seen in Figure 2.2. Significant regional droughts were experienced in 1995 and 1999. As can be seen in Chapter 3, shifting patterns of high and low pressure systems over the Atlantic Ocean (the North Atlantic Oscillation or NAO) appear to correlate well with drought periods in the New England region.

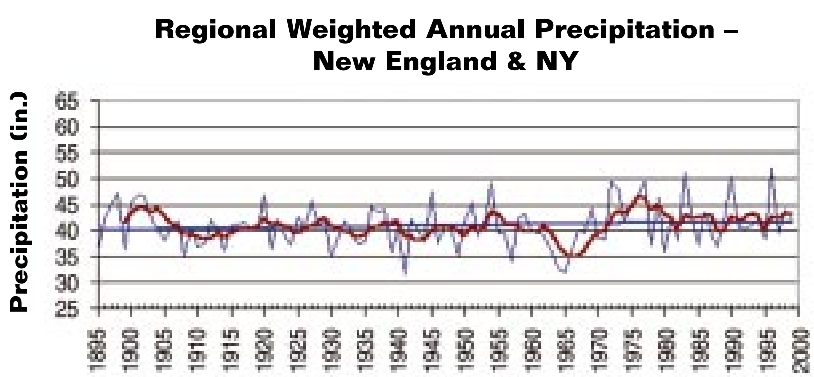


FIGURE 2.2

Regional Weighted Annual Precipitation in upstate New England and New York shows a 3.7% increase. The affect of the mid-1960's drought is clearly seen.

The New England Region has warmed slightly less than the nation, and approximately half of the overall global increase…

Annual and Spatial Temperature and Precipitation Variation within the New England Region

Annual temperatures by state and for the entire New England region (including upstate New York) have been monitored at over 300 weather stations operated by the National Climate Data Center (NCDC), as part of the Historic Climate Network (HCN - see figure 4.1). Many of these monitoring stations have been in continuous operation since 1931, and in some cases since 1895. The data provided by the NCDC/HCN constitute the most reliable long-term record of temperature and precipitation available for the region.

The 0.7˚ F increase in temperature since 1895 for the region is similar to the increase nationally (approximately 1.0 º F). The global average temperature increase is often cited as 1.2 º F. The New England Region has warmed slightly less than the nation, and approximately half of the overall global increase. The region's 4% increase in precipitation is slightly below the 5-10% average precipitation increase nationally over the 105 year period.

There is a good deal of variation within the region in both temperature and precipitation change over the past century. This heterogeneity is at both spatial (varies state to state) and temporal (seasonal) scales. As can be seen in Figure 2.3, some states have warmed more than the regional average and others less. Rhode Island has warmed the most (2.3º F), likely due to its coastal location. New Hampshire's annual temperatures have increased (1.8º F) at nearly three times the regional average (0.7º F) while Maine has exhibited a slight cooling (-0.4º F) over the same time period.

While the overall region has warmed, based on annual average temperatures, by 0.7º F, the regional wintertime months (December, January and February - Figure 2.5) have warmed by nearly 2.0º F. Summer months (June, July, and August - Figure 2.4) exhibit increases similar to the annual regional increase.

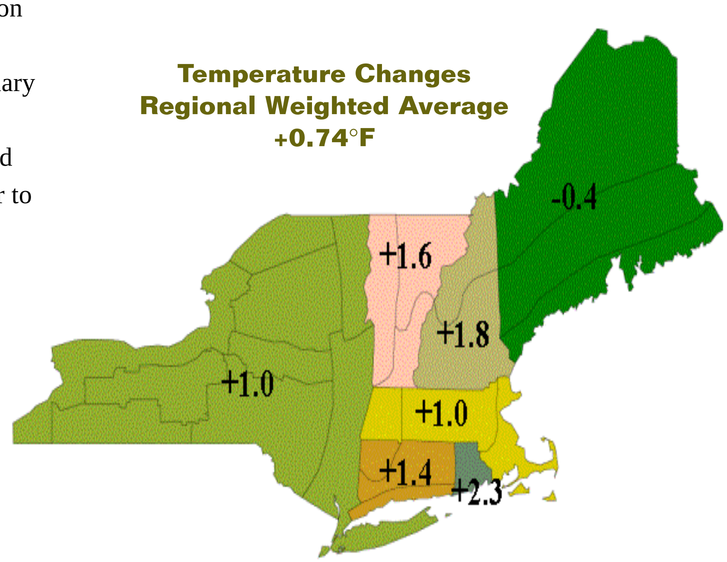


FIGURE 2.3
New England and New York Temperature Changes (˚F) Between 1895 and 1999. The faint lines within the states represent the various climate zones recognized by the National Climate Data Center.

Thus, for parts of the region, wintertime warming has been nearly three times the summertime warming.

Thus, for part of the region, wintertime warming has been nearly three times the summertime warming. In a similar fashion, annual precipitation patterns across the region have been very heterogeneous (figure 2.6). The reason for the variability in temperature and precipitation is not well understood.

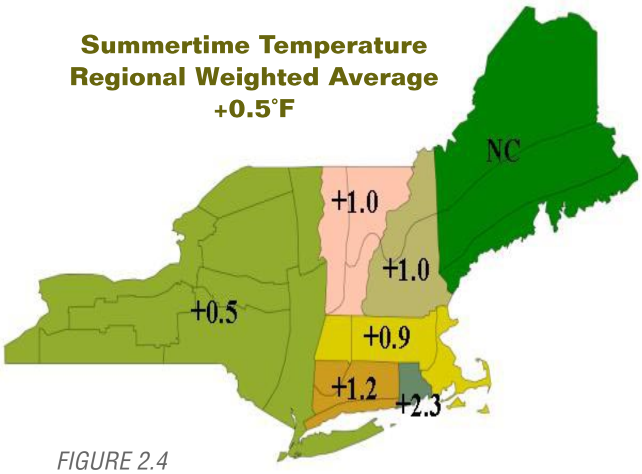


FIGURE 2.4
New England and New York Summertime Temperature Changes (˚F) Between 1895 and 1999. The faint lines within each state represent NCDC climate zones.

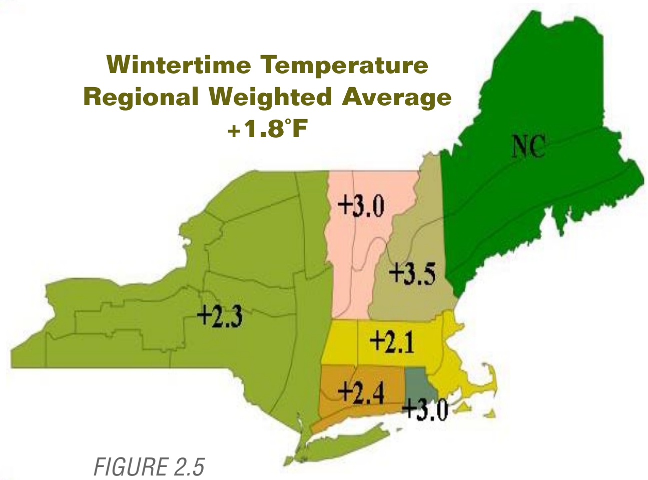


FIGURE 2.5
New England and New York Wintertime Temperature Changes (˚F) Between 1895 and 1999. The faint lines within each state represent NCDC climate zones.

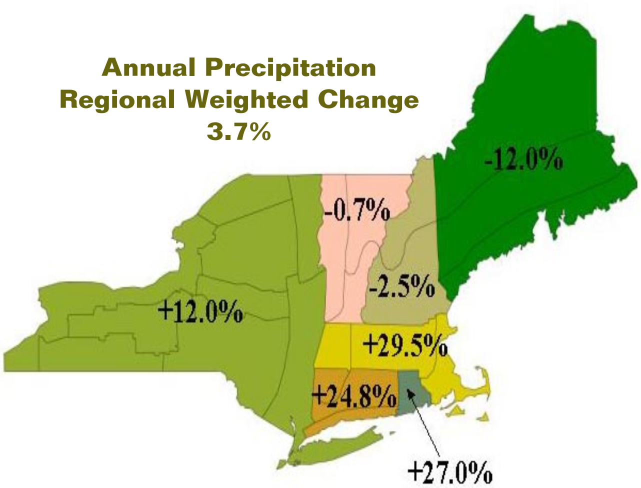


FIGURE 2.6
New England and New York annual precipitation changes (%) between 1895 and 1999. The faint lines within each state represent NCDC climate zones.

Snowfall

Snowfall is highly variable in the New England region, both spatially and temporally. Southern New England receives the lowest snowfall totals on average with approximately 35 inches per year. The Northern New England region receives substantially more snowfall, with large regions in and near the White, Green, and Adirondack mountains averaging well over 100 inches per year. Due to their locations on the shore of Lake Erie and the direction of prevailing winds, Rochester and Buffalo, NY are cities known for their heavy winter "lake effect" snowstorms. Elevation enhances snowfall totals and Mount Washington averages 254 inches of snowfall per year. As seen in Figure 2.7, there has been a nearly a 15% decrease in snowfall in Maine, New Hampshire and Vermont between 1953 and 1994. Since 1996 winters have been unusually mild, resulting in lost revenues for the ski industry. The winter of 00/01, while mild, has been more typical for the region in terms of snowfall.

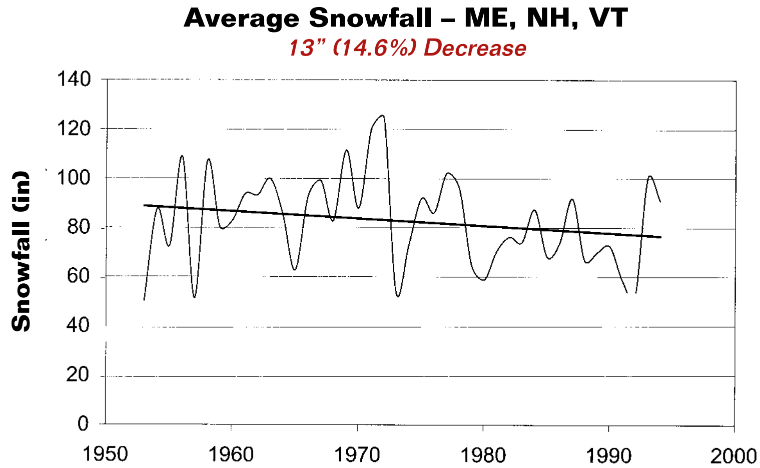


FIGURE 2.7
Annual snowfall data for Vermont, New Hampshire and Maine between 1953 and 1994.

Snow-on-Ground Data

Although snowfall, snowpack, and duration of snow-on-ground data have been acquired by many organizations (State Offices, the Army Corps of Engineers, etc.), only a limited number of these datasets have been analyzed. The duration of snow cover on the ground has decreased by approximately seven days over the past 50 years (Figure 2.8). As noted with temperature and precipitation data, the results are spatially varied. Snowpack has decreased significantly in some parts of the region (the northern climate zone in New Hampshire has decreased by 14.5 days) while showing no change in Maine's northern climate zone. These variations are correlated with the heterogeneous wintertime temperature variability across the region.

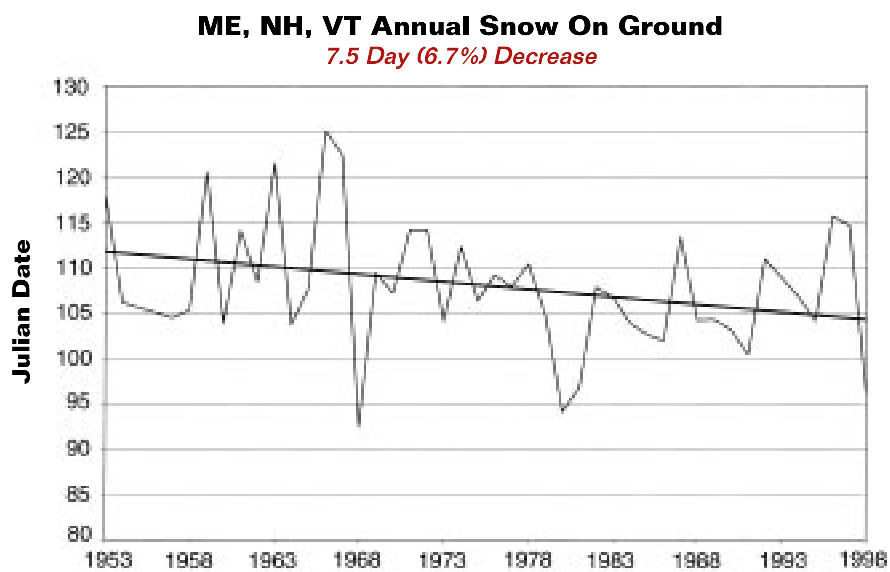


FIGURE 2.8
Annual snow on ground data for Vermont, New Hamsphire and Maine between 1953 and 1998.

…the New England region is experiencing a measurable warming trend in winter and spring that has resulted in earlier ice-out dates…

Ice-out Dates for Regional Lakes

Accurate records of ice-out dates (the earliest date for ice-free lake surfaces) for selected New England region lakes provide evidence of a changing climate, when viewed with air temperature and precipitation records. Ice-out records have been kept for Lake Winnipesaukee (Figure 2.9), where ice is an important consideration for ferry traffic on the lake, as well as for ice fishing, snow mobiling, and cross country skiing. Ice-out data are also available for Rangeley Lake in northeastern Maine, for several New York lakes (Oneida, Otsego, Schroon and Cazenovia) and one additional Maine lake (Moosehead). Decadal averages for Lake Winnipesaukee show ice-out dates that average four days earlier, similar to those reported for the New York lakes (ice-out occurring an average 4 days earlier per 100 year period), while the data for Rangeley Lake indicate ice-out dates similar to those for Moosehead Lake (5.6 days earlier/100 year period).

Although the year-to-year ice-out dates are highly variable and somewhat cyclical patterns can be seen, the overall trends are clear. These results suggest that the New England region is experiencing a measurable warming trend in winter and spring that has resulted in earlier ice-out dates for those lakes for which long-term records exist.

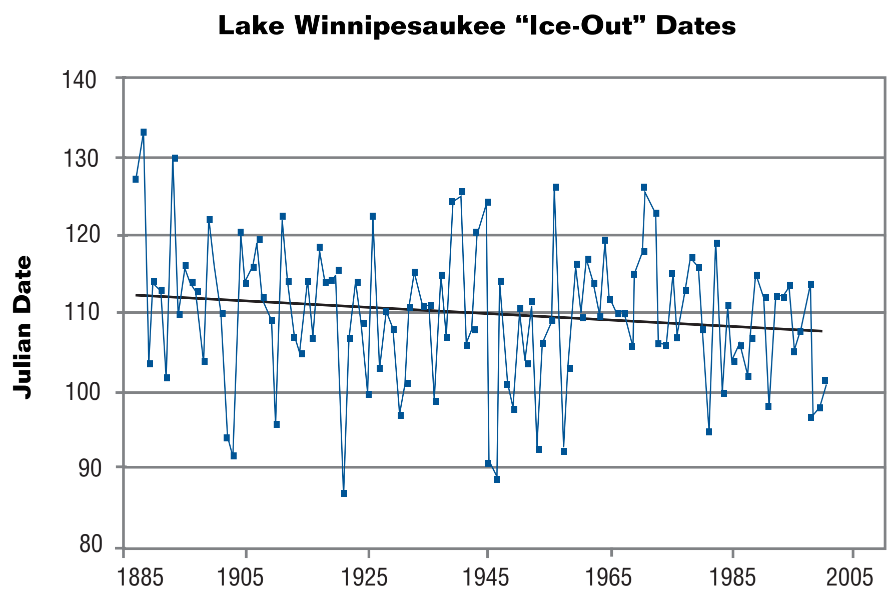


FIGURE 2.9
Ice-out dates occur an average of four days earlier than in 1886 for Lake Winnipesaukee, NH. Note that interannual variability is high.

…it is clear that the decade of the 1990s has been characterized by an unusual number of extreme events.

Extreme Events

In recent years, extreme events may have become more common in the United States, particularly in the Northeast. Note the following extremes in the region, occurring since 1996.

- Region-wide blizzard with storm snowfall totals in excess of 30 inches (January, 1996)
- Coastal New England Rainstorm producing over 19 inches of rainfall (October, 1996)
- Warmest single-day February temperature record in Seacoast of New Hampshire (1997)
- Boston's 24-hour snowfall record broken (April 1997)
- Severe Ice storm strikes northern New England, New York, and southeastern Canada (January, 1998)
- Warmest single-day March temperature ever recorded in New Hampshire (1998)
- Longest snow-free period ever recorded at Boston's Logan Airport (304 days – 1999/2000)
- The 1999/2000 winter was the mildest on record (replacing the 1998/1999 winter as the previous record, which in turn replaced 1997/1998)
- One of the hottest and driest summers on record in southern and western New England (1999)
- One of the coolest and wettest summers on record for southern New England (2000)
- One of the heaviest snowfall winters on record across the region (2000/01)

Evidence of increases in extreme events is also provided in the form of increasing trends in weather-related insurance claims. Using insurance claims to document an increase in storm severity may not be related so much to weather extremes, as to the fact that human population in the US is increasing, and more people are building more expensive homes in weather-sensitive areas (coastal property susceptible to hurricanes, and floodplains vulnerable to flooding). Research does suggest that the proportion of annual rainfall contributed by 1-day extremes has increased in the US over the past century.

While the "Top Ten Most Memorable Weather Events for the New England Region" (see next page) span the 20th Century, from the infamous 1927 flood in Vermont to the 1998 ice storm across much of New York, Vermont, New Hampshire and Maine, two of these "Top Ten" events occurred in the 1990s. While it is difficult to say with certainty that extreme events are on the increase in the New England region, it is clear that the decade of the 1990s has been characterized by an unusual number of extreme events.

Predicting future extreme events in a dynamic region such as New England has proven to be a difficult task. Most of what is known about future climates is derived from general circulation models (GCMs). The various GCMs [e.g. the Canadian Global Coupled Model (CGCM) and the Hadley model from the United Kingdom Meteorological Office] generally agree that global temperature and precipitation should increase as concentrations of atmospheric greenhouse gases increase, but regional impacts remain unclear. Furthermore, most extreme events (e.g. intense precipitation events, tornadoes, hurricanes, high winds, etc.) are too small in scale for GCM recognition and therefore the GCMs are of limited value in predicting extremes.

"Top Ten" Most Memorable Weather Events for the New England Region

Compiled by Barry Keim

1. The Hurricane of 1938 - September 21, 1938. A hurricane, named appropriately as the "Hurricane of 1938," made landfall in southern Connecticut and given the storm's path and power, impacted the entire region. Over 600 deaths are attributed to this storm, which was caused primarily by the 17 foot storm surge along the Connecticut and Rhode Island Coasts. However, high winds and rain caused large stands of trees to be blown down all the way up into the White Mountains and flash flooding was problematic in MA, VT, and NH.

2. The Blizzard of 1978 - February 5-7, 1978. The Blizzard of '78 was caused by an intense coastal nor'easter that produced winds in excess of hurricane force and very high snow totals. Northern Rhode Island received over 50 inches of snow, with most of southeastern New England buried beneath 3 or more feet. The region was paralyzed for over a week.

3. Hurricane Diane - August 17-19, 1955. Hurricane Diane produced a 24-hour rainfall total of 18.15 inches (the New England record) and a storm total of 19.75 inches rainfall. These impressive totals caused massive flooding as they fell on saturated grounds — Hurricane Connie visited the area only days prior to Hurricane Diane to soak the area.

4. The "All New England Flood" - Mid-March 1936. Two heavy rain events fell on greater than normal snowpack to produce the "All-New England Flood" which led to the most serious widespread flooding ever experienced in New England. Hookset, NH had 18-20 feet of water flowing down mainstreet and the Amoskeag Mills were badly damaged with record flood crests on the Merrimack River and beyond.

5. The 1998 Ice Storm - January 5-9, 1998. Northern New England experienced the worst ice storm (see Ice Storm Case Studies; Chapter 6) in recorded history with loss of life, widespread power outages that took months to fully restore and damage to forests that may require decades to recover.

6. The Worcester Tornado - June 9, 1953. The Worcester Tornado touched down as a F4 tornado, with wind speeds between 200-260 mph. It carved a path of 46 miles from Petersham, MA to Southboro, MA, while persisting for 1 hour and 20 minutes, killing 90 people. That same day, tornadoes also touched down in Exeter, NH and Sutton, MA.

7. Highest Recorded Windspeed on Earth - April 12, 1934. Mt Washington, NH measures a windspeed of 231 mph, which still stands as the highest windspeed ever recorded in the world.

8. Record Rainfall in Maine and New Hampshire - October 20-21, 1996. A persistent rainstorm produced the all-time state rainfall records for both Maine and New Hampshire. A storm total of 19.2 inches was produced in Camp Ellis, Maine which ranks as the second largest rain event in New England recorded history — estimated to be a 500-year rainfall event for the Maine-NH coastal area. New Hampshire also broke its all-time 24-hour rainfall total with 10.8 inches measured at Mt. Washington.

9. The Nor'easter of '69 - February 22-28, 1969. A noreaster produced over 3 feet or more of snow across large portions of ME, NH, MA, and RI, with totals of 98 and 77 inches recorded at Mt Washington and Pinkham Notch, respectively. These values are unprecedented snowfall totals for any single storm event in this region. This storm was also preceded by yet another impressive snowstorm on February 8-10 which produced between 1 and 2 feet across most of New England. The combination led to incredibly high "snow on ground" totals and large snow drifts.

10. The Flood of '27 - November 3-4, 1927. A frontal system was assisted by tropical moisture to produce rainfall totals near 10 inches across central VT, leading to massive river-basin flooding. Eighty-four Vermonters perished and to this day, this storm is still considered the worst weather catastrophe in the state.

Overall, the climate of the New England region has changed over the past 100 years…

Summary

The weather and climate of New England has proven to be highly variable over long and short time scales and across short distances. Much of this variability can be attributed to the region's unique geographic location. In a given year, the region can experience hurricanes, blizzards, drought, and more. Over the past century, the historic record indicates that regional temperatures are warming (0.7˚F), especially in the coastal zone (1.7˚F) and for selected states (RI 2.3˚F, NH 1.8˚F). The same record shows that Maine has actually cooled by 0.4˚F. Clearly, more warming has occurred during winter months (1.8˚F for the region; 3.5˚F for NH), and snowfall, snow on ground, and ice-out dates for regional lakes suggest the seasonal warming has had an effect. The limited data available indicate that regional snowfall and snowpack have decreased over the past 50 years although this varies by state and climate zone. Ice-out dates are occurring from four to six days earlier when compared with 100 years ago. Little overall change in precipitation has occurred over the past century (4% increase), but this too has been highly variable.

There is limited evidence that extreme events may be on the rise, but a more thorough analysis is needed. At the national level evidence supports the view that extreme rainfall events are on the increase. Overall, the climate of the New England region has changed over the past 100 years, exhibiting a modest warming trend along with a slight increase in annual precipitation, with a high degree of variability by state. The reason for the spatial variability is not known.

CHAPTER 3

NATURAL AND ANTHROPOGENIC FACTORS AFFECTING GLOBAL AND REGIONAL CLIMATE

By Henry Walker, Barry Keim and Martina B. Arndt

With the advent of Earth-orbiting satellites to monitor our planet and spacecraft that study the sun, an active International joint project to monitor the Sun – Earth (Solar Terrestrial) environment has evolved. Coupled with an ever increasing computational capability, we are now able to study the many factors which influence the weather (the day-to-day variations in temperature, precipitation, and storm activity) and climate (seasonal and annual patterns of weather) that characterize the New England region. In addition to recorded data and observations from space, recent advances in the study of ice core data, tree rings, lake and bog sediments, and other forms of proxy data now allow us to understand how our global and regional climates have changed in the past.

In this chapter, we discuss some of those factors which are known to have affected the New England climate in the past, so that we can better understand potential consequences of future climate variability and change. First, we discuss solar factors which operate on times scales from days to millennia and consequences of these variations in New England. In many cases the magnitude of solar radiative forcing variations is small, but a number of mechanisms including changes in greenhouse gas concentrations may amplify the effects of solar variations on the earth's climate. Variations in volcanic activity and distribution of aerosols can also affect global and regional climate and are discussed here, along with a brief consideration of the impact of changing land cover types. Finally we consider the recent rate of greenhouse gas increases due to human activity, and the possible consequences of altered atmospheric patterns such as the North Atlantic Oscillation (NAO) on climate in the New England region.

Variations in Solar Forcing and Consequences on Earth

The Sun affects Earth in many ways. Phenomena on the Sun can impact the local space (near Earth) environment, resulting in changes in "space weather." These variations can in turn affect our everyday lives. Very energetic solar events like solar flares and coronal mass ejections (CMEs) release charged particles that affect communications on Earth, including radio and television, navigational systems, Automatic Teller Machines, and even "pay-at-the-pump" operations.

The Earth's rapidly fluctuating magnetic fields stimulated during periods of solar activity can induce currents in long pipelines, affecting flow meters and pipeline corrosion. These geomagnetic storms also induce currents in power grids that are harmful to transmission equipment, sometimes resulting in power outages.

Do these phenomena affect climate changes on Earth as well?

Very energetic solar events … release charged particles that affect communications on Earth, including radio and television, navigational systems, Automatic Teller Machines, and even "pay-at-the-pump" operations.

... the present level of CO_2 is over 370 ppm (parts per million) ... at no other time during the past 160,000 years have CO_2 levels been above 300 ppm.

Orbital Variations and Glacial and Interglacial Cycles

The New England region was located at the southern end of one of the major northern hemispheric regions of continental ice sheet growth. The New England region was covered by this massive ice sheet on several occasions. This latest period of glaciation is known as the Pleistocene epoch, a period characterized by oscillations between glacial maxima or ice ages (colder periods in which the glaciers extended over New England) and interglacial ages (warmer periods in which the ice sheets retreated and/or disappeared). These glacial maxima were about 10 -12ºF (~6-7˚C) colder than interglacial temperatures.

Figure 3.1 presents data derived from the Antarctic ice cores for the past 160,000 years. Measured concentrations of CO_2 and CH_4 (methane) are plotted over time, along with a proxy record of temperature derived from oxygen isotope ratios measured in bubbles trapped in the ice. Note that portions of two glacial maxima and two intervening interglacial periods can be seen. Although the present level of CO_2 is over 370 ppm (parts per million), note that at no other time during the past 160,000 years have CO_2 levels been above 300 ppm. These past climate fluctuations are believed to be related to changes in Earth-Sun relationships known as *Milankovitch* cycles, as well as possible cyclical variations in the energy output of the Sun, and natural fluctuations of CO_2 and CH_4.

The *Milankovitch* cycles include changes in: 1) the shape of Earth's orbit around the sun (between circular and slightly elliptical) thereby affecting the distance between the Earth and the Sun; 2) the tilt of Earth's axis relative to the orbital plane (approximately a 41,000 year cycle), and 3) the distance between the earth and the sun at a given point of the year (on approximately 21,000 cycle years). The total length of these orbital cycles (approximately 100,000 years) matches well the length of cycles between ice ages (figure 3.1).

Variations in Solar Activity During Recent Centuries

Variability in solar output may also have important consequences on global and regional climate. Galileo used his primitive telescope to describe large numbers of sunspots as early as 1610AD. During the period from approximately 1645-1715AD, very little sunspot activity was recorded, a period known as the Maunder Minimum (Figure 3.2). The Maunder Minimum coincides loosely with the beginning of a longer period known as the "Little Ice Age" (see below).

Figure 3.2 shows the sunspot cycle from 1610 to 1998. This periodic solar behavior is echoed in some locations by cycles in tree ring growth, yearly rainfall in the Northern Hemisphere, and in variations of dust and chemical residues found in ice cores.

Concentrations of CO_2 and CH_4

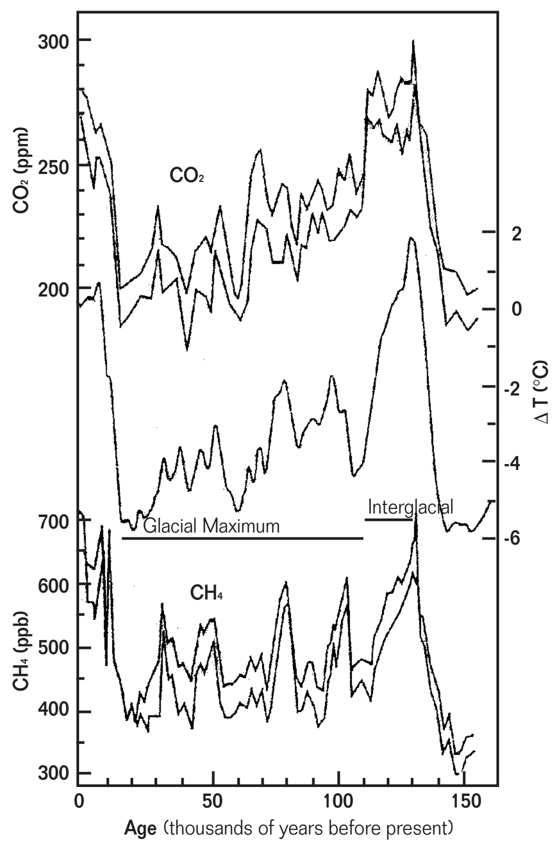


FIGURE 3.1
Data on concentrations of CO_2 and CH_4, as well as temperature inferred from O_2 isotope ratios. Modified from the Ice core Working Group (1998). It is important to note that recent CO_2 levels exceed 370 ppm and CH_4 levels exceed 1800 ppb. Note that interglacial periods are relatively short (20,000 years) when compared with the longer glacial maxima.

The total length of these orbital cycles (approximately 100,000 years) matches well the length of cycles between ice ages.

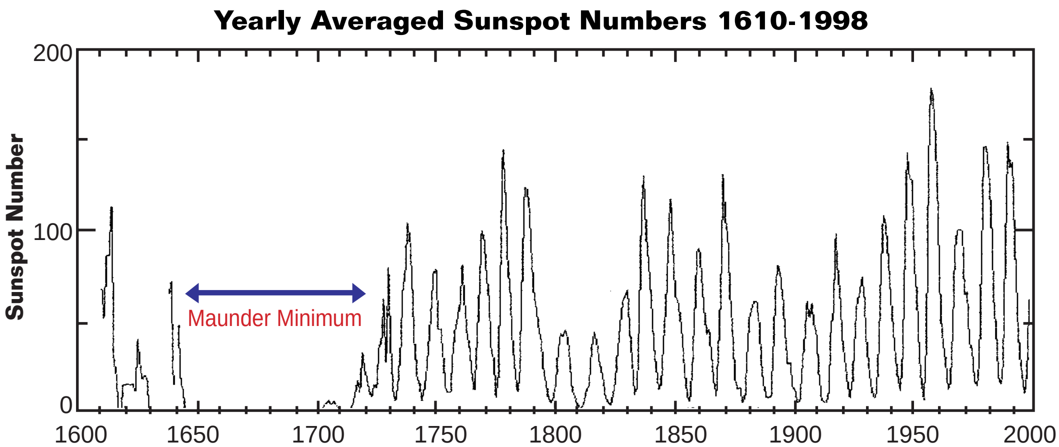


FIGURE 3.2
The Solar Cycle, yearly averaged sunspot numbers as a function of time.
From http://wwwssl.msfc.nasa.gov/ssl/pad/solar/images/.

The timing of the Maunder Minimum and the initiation of the Little Ice Age is of particular interest. Unfortunately, there are no sunspot records prior to 1610, but many scientists agree that the Maunder Minimum is only a partial explanation for that period of cooler temperatures. During the Little Ice Age, Eskimos extended as far south as Scotland, it snowed in Ethiopian mountains and orange groves in China died. Norse colonies established during the Medieval Warm Period (900-1400 AD) on Greenland failed during the Little Ice Age due to heavy pack ice which prevented supply ships from reaching them. The Anasasi people of the American southwest abandoned their pueblos at the beginning of the Little Ice Age. Although there appears to be a statistical correlation between sun spot cycle and weather patterns, no satisfactory explanation provides a clear physical mechanism for these associated changes.

Land Cover and Land Use Change Affect the Impact of Solar Forcing and Greenhouse Gas

When sunlight strikes the land surface, one of several things can happen. If the surface is extremely bright, much of the sunlight is reflected back to space through the atmosphere. This happens when the land surface is covered with snow, or when the surface is obscured with cloud cover. Little surface heat is produced when sunlight strikes a bright surface. If the surface is dark, however, much of the sunlight is absorbed, generating heat and warming the dark surface. Dark surfaces such as soil and rock are warmed by incoming sunlight, becoming heat sources which return heat to the atmosphere, even after sunlight is no longer shining on them. Some dark surfaces behave differently, as in the case of forest cover. The forests absorb much of the sunlight as part of the process of photosynthesis. In the process of light absorption by leaves, heat is also produced but evaporation of water vapor through stomates (transpiration) cools the leaves. Thus, although fairly dark, a forest canopy actually cools the surface, rather than warms it. Forests represent a land cover type that acts as a heat sink (cooling the surface) rather than a heat source (warming the surface and surrounding atmosphere).

Thus when we cut down large tracks of forests, and replace them with urban land cover (shopping malls, parking lots, buildings, roadways, etc.), we are converting a heat sink into a heat source. The concept of an urban "heat island" is well known, and changes in land cover and land use over time can contribute significantly to local and regional warming trends.

The overall effect of sulfate aerosols is to cool an area by limiting the amount of sunlight that reaches the surface.

Sulfate Aerosols Have a Cooling Effect on Climate

Fine droplets of sulfuric acid in the atmosphere (sulfate aerosols) develop when sulfur compounds such as sulfur dioxide (SO_2) combine with atmospheric water vapor. The sulfur in the atmosphere can be either natural in origin (typically from volcanic eruptions) or anthropogenic (typically from the combustion of fossil fuels rich in sulfur, such as fuel oil or coal). The sulfate haze which limits visibility during summer months in the New England region is typically the result of SO_2 emissions from coal-fired power plants in the midwest combining with humid air (Figure 3.3).

Just as bright land surfaces reflect sunlight back through the atmosphere, sulfate aerosols act as a reflective component in the atmosphere, limiting visibility and reflecting sunlight. The overall effect of sulfate aerosols is to cool an area by limiting the amount of sunlight that reaches the surface. As is often the case with volcanic eruptions, sulfate aerosols produced enter the stratosphere and can remain in the atmosphere for prolonged periods of time. “The year without summer,” 1816, was characterized by snowfalls in every month of the year across the New England region. This followed by one year the eruption of Tambora, in 1815, which ejected large amounts of debris (including sulfate aerosols) into the stratosphere, cooling the climate worldwide. More recently, the eruption of Mount Pinatubo in 1991 provides a likely explanation of the mid-1990s cooling trend seen in the New England regional temperatures presented in Chapter 2 (Figure 2.1).

FIGURE 3.3
The view from the summit of Mount Washington, NH on a clear day (8/14/81) and the same view on a hazy day (6/26/80). The light scattering haze is caused by sulfate aerosols which limit visibility and present a health hazard to people and forests alike.

Variations in Greenhouse Gas Concentrations Amplify Effects of Other Forcings

Greenhouse gases are gases which are transparent to sunlight, but are not transparent to heat energy, thus trapping heat within an atmosphere containing greenhouse gases. Variations in atmospheric greenhouse gas concentrations may amplify the effects of variations in solar forcing as well as land cover change. To help put recent human-induced increases in atmospheric CO_2 into perspective, it is instructive to consider past variations in greenhouse gases (particularly CO_2) and climate. Instrument measurements of climate variables (temperature, precipitation, storm patterns, etc.) date back to the mid to late 1800s (some temperature records go back to the 1860s). Direct measurements of atmospheric CO_2 concentrations in the troposphere (the lowest layer of the atmosphere) began in 1958 at an observatory on Mauna Loa in Hawaii. Most measurements of other greenhouse gases in the atmosphere such as CH_4 (methane - which is twenty times more powerful at trapping heat energy than CO_2), go back only a few decades.

Fortunately, our understanding of how modern changes in concentrations of greenhouse gases, such as CO_2 and CH_4, may impact

Since CO_2 from fossil fuels has a chemical signature there is no doubt that the increase is due to human activities.

climate can be improved by studying past variations in atmospheric gases and climate in ice cores (Figure 3.1, 3.4). Ice cores collected from the Greenland ice sheet are up to 110,000 years old, while cores from the Antarctic are up to 420,000 years old. In places like Greenland and the Antarctic, analysis of the chemical composition of the ice cores permits analysis of past variations in greenhouse gases in both hemispheres. Temperature can be estimated by using oxygen-isotope ratios derived from the O_2 trapped in the same ice core bubbles used to measure CO_2 and CH_4 levels (Figure 3.1).

Atmospheric CO_2 levels between 270-290 ppm are characteristic of our pre-industrial atmosphere, and also occurred during several previous interglacial periods such as the previous interglacial about 125-115,000 years Before Present (B.P.) (Figure 3.1). During the last 130,000 years, as glaciers advanced over mid-latitude continents in the northern hemisphere, the concentration of atmospheric CO_2 gradually dropped to about 190 ppm due in part to gas solubility in sea water. Colder water holds more gas, and less CO_2 is found in the atmosphere when the ocean surface is cold. Based on recent analyses of Antarctic ice cores, atmospheric CO_2 concentrations began to increase about 1800 yrs A.D. Since CO_2 from fossil fuels has a chemical signature, there is no doubt that this recent increase is due to the combustion of fossil fuels. As a consequence of fossil fuel use, atmospheric CO_2 concentrations are currently above 370 ppm, now about 30% higher than the 280 ppm level typical prior to the Industrial Revolution (1850s). Current levels are the highest in the last 160,000 years (Figure 3.4).

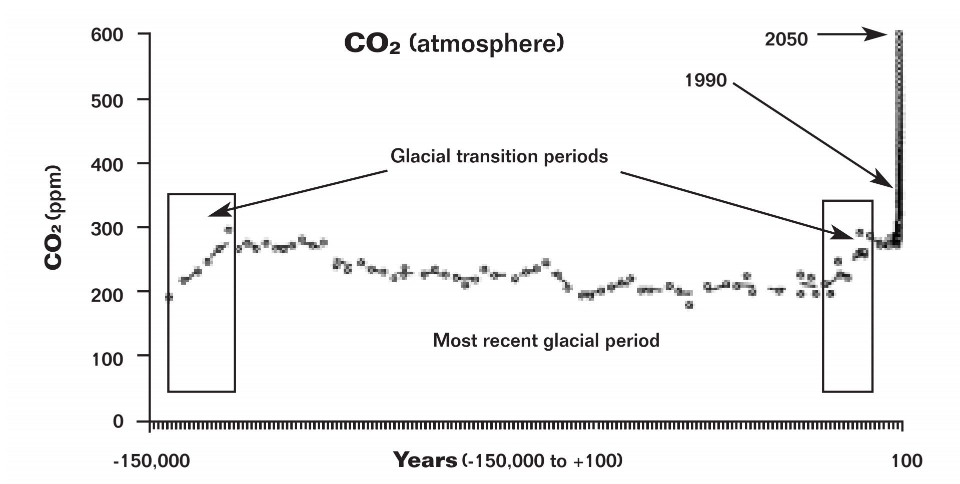


FIGURE 3.4
Estimates of CO_2 concentrations for the last 150,000 years with a projection to A.D. 2050 based on present-day rates of emission.

Evidence of Rapid Temperature Change

There have been abrupt periods of warming and cooling during the past 160,000 years particularly in the North Atlantic region, but the mechanisms are not well understood. Recent studies document periodic abrupt climate changes in the North Atlantic (recurring in cycles of 1,300 - 1,800 yrs.) based on the study of debris in deep sea sediments. A possible mechanism for this cycle may be related to a 1,800 yr. oceanic tidal cycle with periodic variation in vertical mixing and surface ocean cooling.

This would represent an acceleration in the rate of warming far beyond the warming experienced in the last century or last millennium…

Climate reconstructions based on tree ring width and density variations can provide information about past variations in precipitation and temperature. This is accomplished by analyzing variations in stable carbon and oxygen isotope ratios in the cellulose of the wood. Carbon isotope variations in tree rings have been related to variations in the amount of precipitation, while oxygen isotope variations in tree rings can record variations in both air temperature and atmospheric circulation changes.

For the past 1000 years, rates of change in Northern Hemisphere temperature have been estimated by multi-proxy analysis (Figure 3.5). As a result of these and other recent paleoclimate reconstructions, there is little debate about whether we are currently in a period of rapid global warming. The last 100 years can be seen as a period of rapid warming in the northern hemisphere relative to temperature changes during the last 1000 years.

Computer models used in the New England Regional Assessment suggest that the rapid increase in atmospheric CO_2 due to anthropogenic emissions could be followed by a rate of global warming of an additional 3.2 to 5.1°C (6.0-10.0°F) in the next 100 years. This would represent an acceleration in the rate of warming far beyond the warming experienced in the last century or last millennium, moving us into a range of global temperatures that have not been experienced in over two million years. See Chapter 1 for a sense of what the impacts of such warming trends might be.

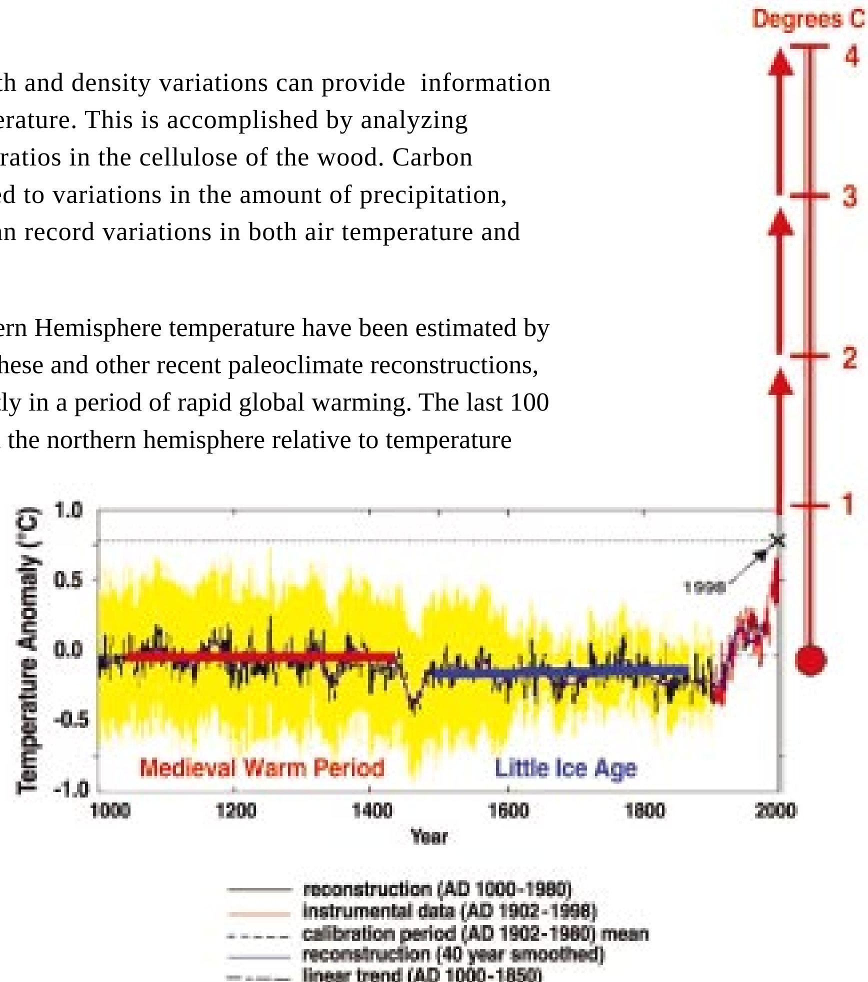


FIGURE 3.5
Northern Hemisphere temperature changes in the last 1000 years. The yellow marks the range of variability in the date.

Climate Variability and Teleconnections in the New England Region

The El Niño / Southern Oscillation (ENSO) cycle primarily affects low-latitude systems (e.g. the southwestern United States), but is associated with climate variations via teleconnections in other regions of the country. Poor air quality summers over the past two decades correspond to El Niño years. The ENSO variations can be characterized using an index of east-west atmospheric pressure variations across the equatorial Pacific, measured using the Southern Oscillation Index (SOI).

Similar variations in the mass of the atmosphere and resulting atmospheric pressure gradients also occurs over the North Atlantic, and are a prominent factor in the Northern Hemisphere winter climate. The atmospheric-pressure oscillations at the sea surface over the North Atlantic during the past century can be documented in a variety of ways. One can compute a monthly NAO index by measuring differences in monthly mean sea level pressure (SLP) and north–south differences in SLP between the Icelandic Low and Azores High (Figure 3.6).

The winter warming trend in southern New England coastal waters correlates well with the transition from a prolonged negative NAO winter index phase to a positive phase between 1950 and 1990.

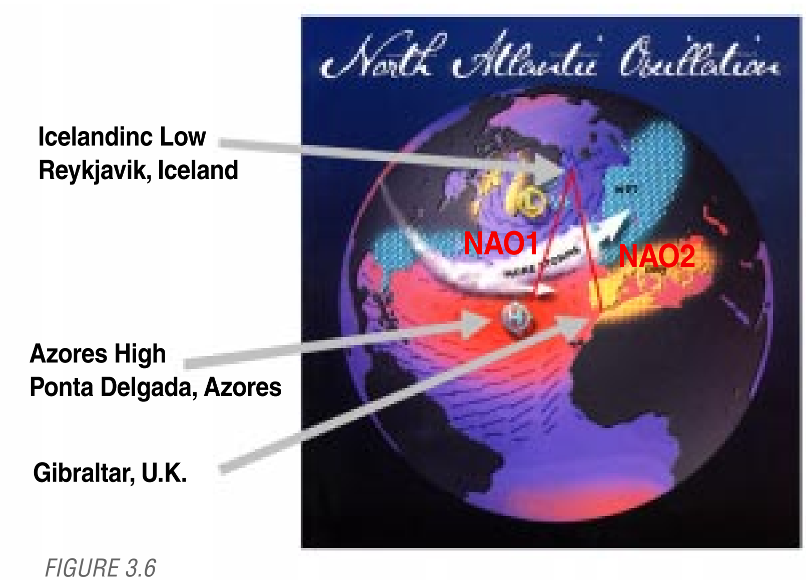


FIGURE 3.6
Climate patterns when the winter NAO index is in positive phase. This illustrates alternative ways to estimate the North to South Pressure gradient over the North Atlantic. (e.g. NAO1 - SLP difference between Iceland to the Azores, and NAO2 - SLP dirrerence between Iceland and Gibralter). Adapted from http://www.Ideo.columbia.edu/NAO/.

The NAO index is positive when either the Icelandic Low results in a particularly low SLP, or the Azores High results in a relatively high SLP, or both. A negative winter NAO index results from relatively weak pressure gradients. A shift from a negative to a positive NAO index moves moisture up into Scandinavia, drawing from the Mediterranean. Positive NAO index phases are associated with increased heat and moisture flux to northern Europe, drought in the Mediterranean, and somewhat wetter conditions along the U.S. east coast (Figure 3.6).

The winter NAO index is a bi-pole, oscillating between two stable states (steep and weak pressure gradients) with periodic fluctuations of varying duration between the two, associated with large variations downwind in European climate. With a positive winter NAO index phase come significant changes in the frequency of Atlantic winter storms and different weather behavior in New England. Negative phases of the NAO index are associated with a reduction in the frequency of winter storms over the North Atlantic and dryer conditions along the New England coast. Variations in the winter (December through March) NAO index are illustrated since 1864 (Figure 3.7) . The winter warming trend in southern New England coastal waters correlates well with the transition from a prolonged negative NAO winter index phase to a positive phase between 1950 and 1990 (Figure 3.7A).

About 49% of the variance in the winter temperature of the Northern Hemisphere over the past 60 years is associated with the Southern Oscillation Index and the winter NAO, with warm El Niño conditions in the Equatorial Pacific and positive winter NAO index phases associated with warmer winters. Variations in the winter NAO are also associated with larger-scale climate variability around the Arctic with the NAO as a component of a larger feature they refer to as the Arctic Oscillation (AO) or Arctic annular mode.

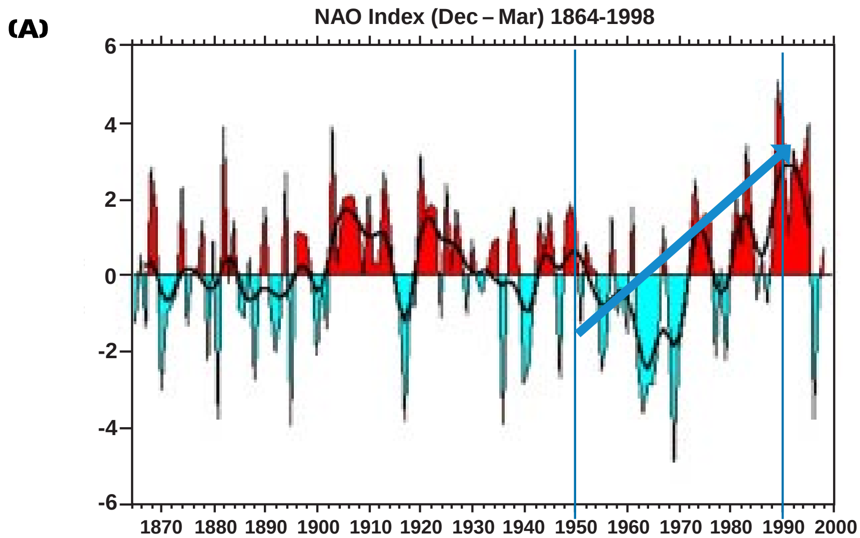
The emergence of longer-period variations in the NAO, including a persistent negative winter NAO index period in the 1950s and 1960s is not well understood. From the perspective of a 350-year NAO reconstruction based on ice core records from Greenland, the recent increase in interdecadal variability with more persistent negative and positive phases in the NAO beginning around 1900 is unique.

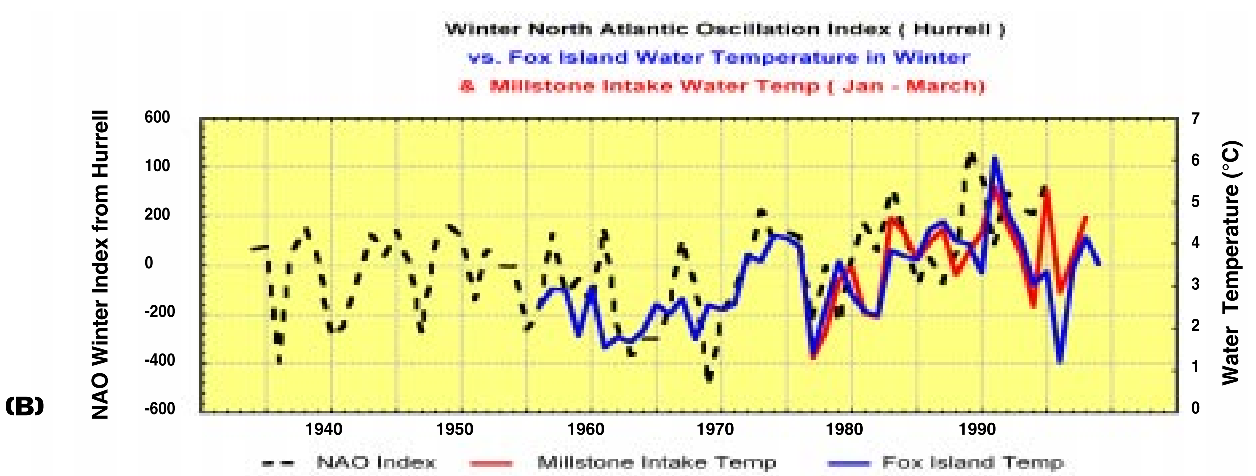
Summary and Discussion

A number of both natural and anthropogenic factors are known to influence the Earth's climate. Solar output, orbital variations, and volcanic eruptions have affected past climate variability and will continue to do so in the future. Land cover type influences how sunlight interacts with the Earth's surface, either reflecting the light back to space or absorbing it, resulting in warming or cooling (in the case of forests).

…there is a growing recognition that a significant component of the 20th century warming is due to emissions of greenhouse gases.

FIGURE 3.7
The Winter North Atlantic Oscillation index plotted for 1864-1998 (A) and winter coastal water temperatures for southern New England (B). In (A) the red indices are positive, while the blue indices are negative. The arrow marks the warming trend between 1950 and 1990. In (B) the dashed line = winter NAO Index, the blue line = winter water temperature off Fox Island, Narragansett Bay, R.I., and the red line = winter temperature (Jan.-Mar. in Niantic Bay, CT) from Northeast Utilities Millstone Power Plant intake.





Human activities often result in the alteration of the natural land cover or in the emission of greenhouse gases, factors known to affect climate. Variations in atmospheric pressure systems, such as the North Atlantic Oscillation (NAO), are also known to influence weather and climate patterns in the Northern Hemisphere, including the New England region. All of these climate forcings interact to produce our ever-changing weather and climate.

We are currently in a period of rapid climate warming (e.g. the ten hottest years since the beginning of the last millennium have all occurred since 1983). How much of this recent warming is attributable to anthropogenic factors is still actively debated, but there is a growing recognition that a significant component of the 20th century warming is due to emissions of greenhouse gases.

We have also learned that the climate is a dynamic system which exhibits bounded instability and can jump between different stable states. We know that many natural processes can force the climate, and that several anthropogenic factors also can force the climate. Since we have no control over the natural forcings (solar output, volcanic eruptions, ENSO/NAO patterns), but do have control of many of the anthropogenic forcings (greenhouse gas emissions, land cover changes), it is only prudent for us to begin to consider ways in which the future impacts of anthropogenic forcings can be reduced.

CHAPTER 4

FUTURE CLIMATES OF THE NEW ENGLAND REGION

By George Hurtt and Steve Hale

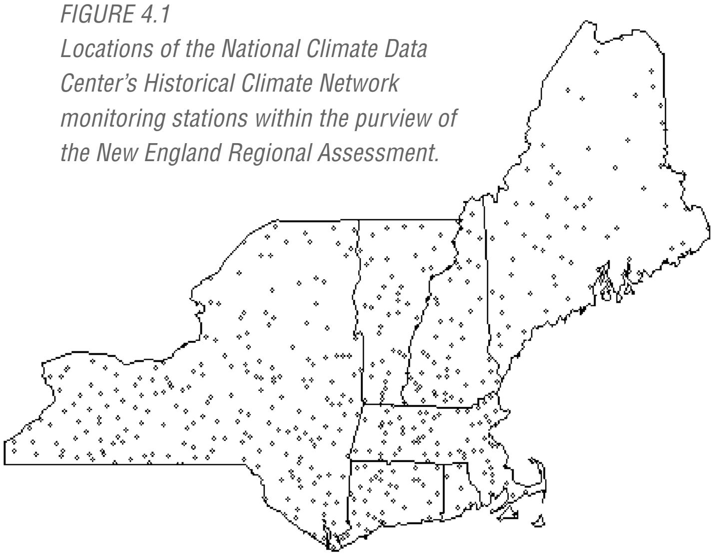
It is becoming increasingly clear that significant global climate change will result if the concentrations of greenhouse gases continue to rise. This fact has led the international community to negotiations on the control of the emissions of greenhouse gases (the Kyoto Accord), and has led to the U.S. National Assessment of the potential impacts of future climate change on this country. However, local and regional projections about the timing, magnitude, and nature of future climate changes remain uncertain and difficult to assess. The magnitude of future concentrations of greenhouse gases will be determined by human actions yet to be taken, and there are scientific uncertainties in the climate system itself, which are largest at a local scale and over short periods of time (decades to centuries).

The mandate of the New England Regional Assessment (NERA) is to identify and evaluate the potential impacts of future climate change on various components of the New England region. To address the future climatic conditions, the US National Assessment has provided data of both historical climate and future climate estimates or "scenarios" for the New England region. The historical climate data for the region is provided for context. The scenarios of possible future climate change have considerable uncertainty and are provided as a minimum basis with which to begin to assess the potential impacts of possible future climate change in New England and upstate New York.

The selection of the specific General Circulation Models (GCMs) for use in this assessment process must also recognize both time and human constraints. For these reasons, common climate scenarios were used by each region and sector, forming the minimum basis for the overall assessment process.

There are many aspects of climate that are important to New England. This first assessment has focused its efforts on three climate variables for consideration as impact agents: (1) monthly minimum temperature; (2) monthly maximum temperature; and (3) monthly precipitation.

FIGURE 4.1
Locations of the National Climate Data Center's Historical Climate Network monitoring stations within the purview of the New England Regional Assessment.



Historical Climate Parameters

Understanding the nature and extent of climate historically throughout the New England Region is important for interpreting future climate scenarios. The historical climate data used in this assessment were obtained from the Vegetation/Ecosystem Modeling and Analysis Project (VEMAP) Phase 2 historical gridded record. This regional data set, from well over 300 monitoring stations across New England and upstate New York (Figure 4.1), is comprised of data from the National Climate Data Center's U. S. Historical Climate Network (HCN), and from the USDA's Natural Resources Conservation Service's SnoTel stations for monitoring precipitation at high-elevations. These data have been spatially interpolated onto a 0.5˚ X 0.5˚ latitude/longitude grid. The New England region consists of 128 VEMAP grid cells.

These models simulate climate in response to changes in the concentrations of greenhouse gases over time.

Climate Scenarios

In the production of scenarios of possible future climate change, NERA uses the projections from two global climate models used in the National Assessment: the Canadian Centre for Modeling and Analysis's Canadian Global Coupled Model (CGCM1 – hereafter called the Canadian Model), and the United Kingdom's Hadley Centre for Climate Modeling and Analysis's model (HadCM2 – hereafter called the Hadley model). These models simulate climate in response to changes in the concentrations of greenhouse gases over time. Both models assume a 1% (of current levels) per year increase in greenhouse gas concentrations. The cooling affect of sulfate aerosols is incorporated by increasing the Earth's atmospheric albedo (brightness, a measure of reflectivity).

About the Graphics

The finest temporal resolution of the data used in this analysis is monthly. Monthly data were averaged within each year to produce annual mean time-series and averaged within each season to produce seasonal time-series for each parameter. Historical and model output presented for the annual time-series include the annual values (thin line) and the10-year running means (thick line), while seasonal output graphs only present the 10-year running mean.

A gap along the x-axis (year axis) between the historical and scenario curves is produced by this calculation. This gap results at the beginning and end of the time-series data where a centered 10-year running mean can not be computed. A gap in the time-series also occurs along the y-axis (parameter axis) and results from differences in the historical and modeled outcomes. The modeled results do not include historical values as input for calibration, so model outcomes are not expected to coincide precisely with the historical outcomes.

Seasonal time-series data were used to show parameter variation within a year. Here, Winter is represented by averaging the months January-March, Spring by April-June, Summer by July-September, and Fall by October-December. In addition to the characteristics of the annual time-series graphics, the seasonal time-series graphics have been scaled to facilitate seasonal visual comparison. Visual comparison of seasons across parameters should be used with caution, because of the change in y-axis scaling.

Annual Minimum Temperature

Both the Canadian and Hadley models suggest that the average annual minimum temperature of the New England region will increase in both the near-term (i.e. 2030) and long-term (i.e. 2100) future (Figure 4.2). However, the

Regionalized Historic and Scenario Mean Annual Minimum Temperature

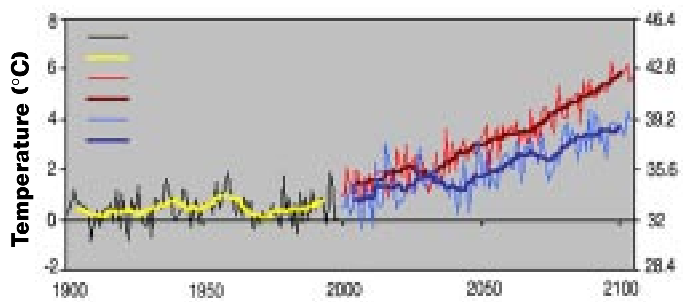


FIGURE 4.2
Graph of the 10-year running average of regional historic and modeled average annual minimum temperatures. There is no indication of a regional increase in minimum temperatures that departs from the range of exhibited variation. Both model estimates agree in predicting sustained increasing minimum temperatures that exceed expected variations. The Canadian model suggests greater increases in minimum temperatures than the Hadley model. Regional values were calculated by averaging the yearly mean values across all 128 VEMAP2 grid cell elements comprising the New England Region.

Both the Canadian and Hadley models suggest that the average annual maximum temperature of the New England region will increase in both the near-term (i.e. 2030) and long-term (i.e. 2100) future.

Regionalized Historic and Scenario Mean Annual Maximum Temperature

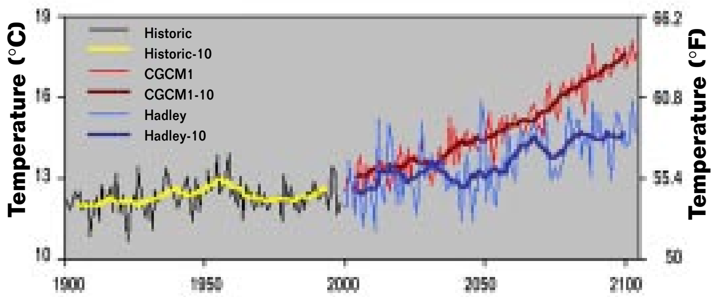


FIGURE 4.3
Graph of the 10-year running mean of regional historic and scenario average annual maximum temperatures. Model estimates agree in projecting sustained increasing maximum temperatures into the future that departs from the range of exhibited variation. The Canadian model suggests greater increases in maximum temperatures than the Hadley model.

Regionalized Historic and Scenario Mean Annual Precipitation

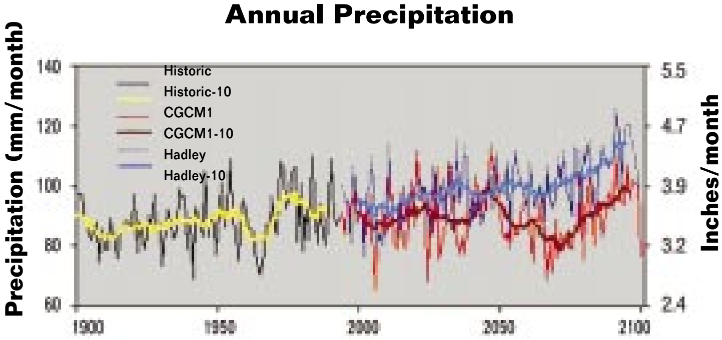


FIGURE 4.4
Graph of the 10-year running mean of regionalized historic and scenario average annual precipitation. There is a slight regional increase in the historic precipitation, however, large, rapid departures from any norm have occurred as exhibited by the mid-1960s drought. Model estimates do not agree in estimating potential future precipitation. The Canadian model suggests lesser increases in precipitation than the Hadley model.

models differ in the magnitude of minimum temperature change. Both models suggest the region may increase by 1˚ C (1.8˚ F) by 2030 but the Hadley model indicates a 3.1˚ C (5.6˚ F) rise by year 2100, while the Canadian model indicates a 5.3˚ C (9.5˚ F) rise over the same time period. These changes are very large relative to the historical record of minimum temperature variation that has occurred over at least the past 1000 years (Figure 3.6).

Annual Maximum Temperature

Both models suggest that the average annual maximum temperature of the region will increase in both the near-term (i.e. 2030) and long-term (i.e. 2100) future (Figure 4.3). However, as with the minimum temperature, the models differ in the magnitude of maximum temperature change. Both suggest an average annual maximum temperature increase of 1.5˚ C (2.7˚ F) by 2030 and from 2˚ C (3.6˚ F) to 5˚ C (9˚ F) by 2100 (Hadley and Canadian models, respectively). Both of these scenarios suggest large temperature increases in the future compared to the past 100 year record of maximum temperatures.

Annual Precipitation

Historically, annual precipitation in the New England region has varied widely and has included times of drought (Figure 4.4). Note the prolonged drought that characterized the mid-1960s. Embedded within this range of variability, lies a long-term trend (i.e. 100 years) of a modest (4%) increase in precipitation. The Hadley model predicts a continuing increase in precipitation (an approximate 30% increase) without evidence of the type of drought seen in the 1960s. The Canadian model suggests little long-term increase in precipitation (an overall increase of approximately 10%), but large fluctuations in precipitation with events similar to the drought of the 1960s.

Seasonality

Most of the seasonal trends were similar to the annual trend for each parameter (Figure 4.5). In every season, both the Canadian and Hadley models predict substantial warming, and the Canadian model generally predicts greater amounts of warming than the Hadley model. Exceptions to this occur in the Summer and Fall minimum temperatures, where the models suggest approximately equal amounts of warming. Precipitation is

In every season, both the Canadian and Hadley models predict substantial warming…

projected to increase substantially in every season except Spring in Hadley, and does not have a substantial trend according to the Canadian model in any season. Both models illustrate the potential for continued interannual year-to-year variation in seasonal precipitation of magnitudes that are similar or larger to variations experienced in the record.

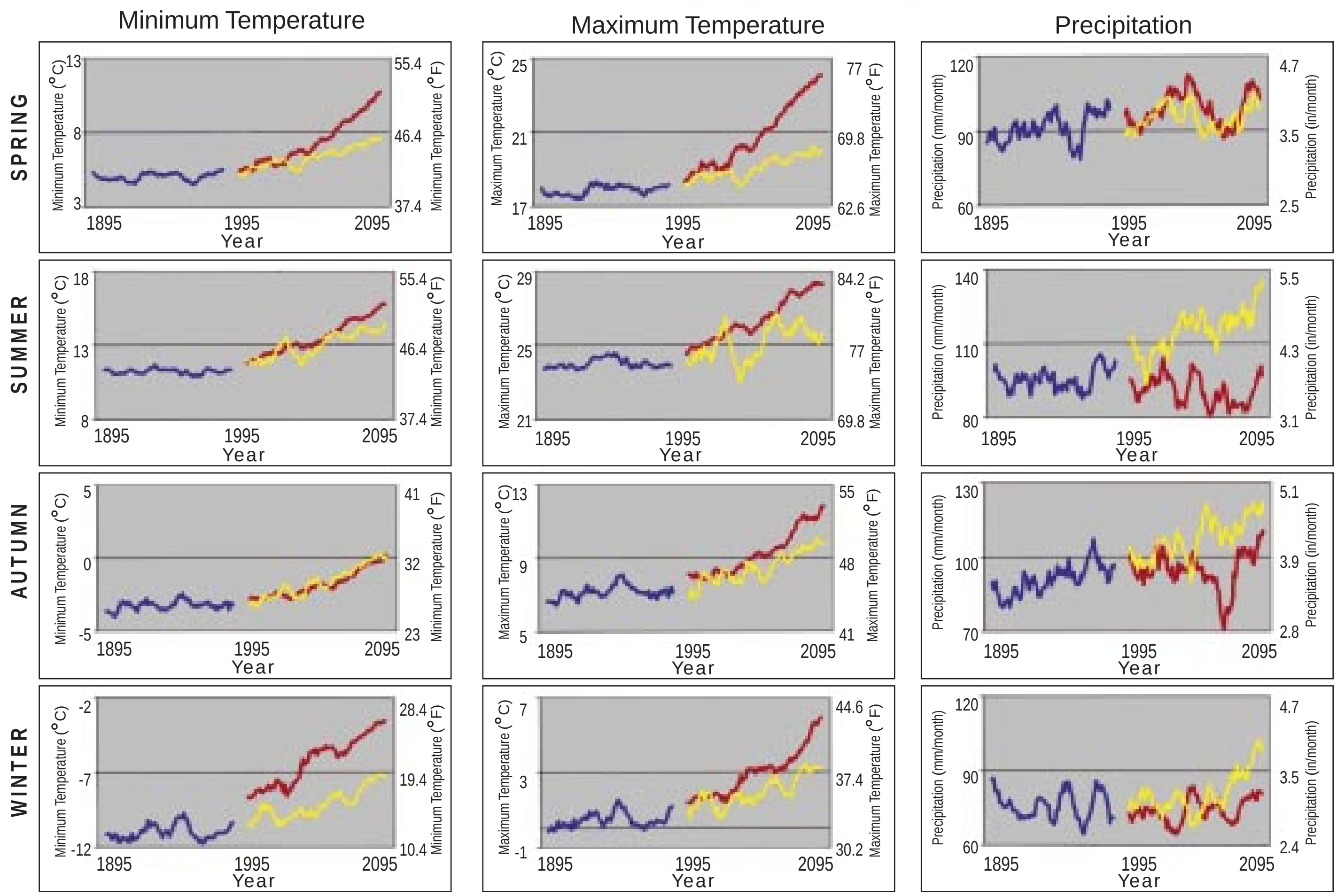


FIGURE 4.5
Seasonal trend graphs (10 year running means) for the 1895-1993 VEMAP2 historical gridded data and two model “scenario” data sets from 1994-2100.

KEY: historical Canadian Hadley
Sp=Spring; SU= Summer; AU- Autumn; WI=Winter.

The Canadian model predicts greater temperature increases inland than along the coastal regions, a result in disagreement with historic findings.

Spatial Variation

The climate models show differing amounts of spatial variation in the parameters investigated (Figure 4.6). Region-wide variation in the long-term temperature anomalies is greater in the Canadian model than in the Hadley model. The Canadian model predicts greater temperature increases inland than along the coastal regions, a result in disagreement with historic findings (Chapter 2). In contrast, the Hadley model shows little to no spatial variation in temperature changes across the entire region. In terms of precipitation regimes, the Hadley model shows a greater absolute precipitation difference, but also a greater degree of regional heterogeneity compared with the lesser absolute precipitation and clinal variation exhibited by the Canadian model.

Model Evaluation for the New England Region

The model data sets used for the New England Regional Assessment represent some of the best available. However, the down-scaling of much larger-scale global climate models to finer regional scale (used in this analysis) is problematic. Many of the geographic (i.e. coastal) and topographic (mountains) variables that are known to influence our regional weather and climate

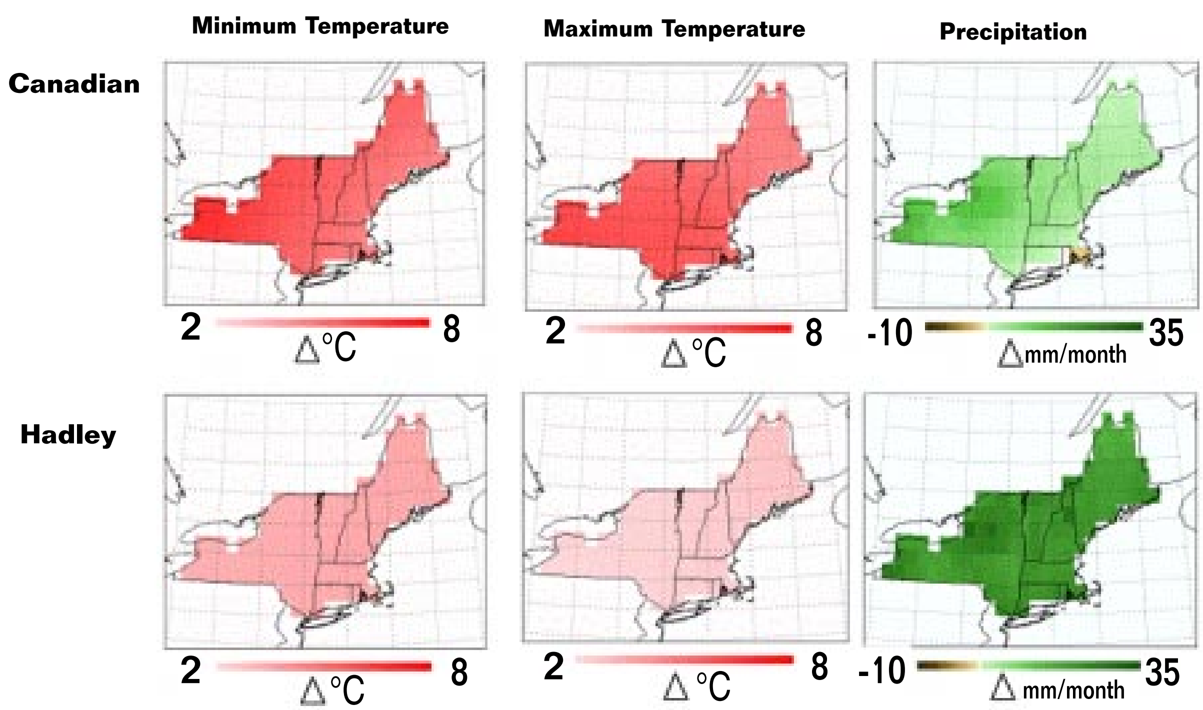


FIGURE 4.6
Graphs of New England and upstate New York spatial variation of Minimum Temperature, Maximum Temperature and Precipitation for the Canadian and Hadley models. All differences (anomalies) are computed as the [2090 - 2099] mean minus the [1961-1990] mean.

The changes projected by either model, if realized, would be much larger than the climate variation experienced by the New England region in the last 10,000 years…

(Chapter 2) are not considered in global-scale models such as the Canadian and Hadley. For this reason, the regional projections presented in this chapter must be considered "best approximations" based on what is available in the late 1990s. Both models present us with "What if" future projections (What if the region warmed by 6° F?). Clearly there is a great need for regional climate models to be developed that account for regional variability at a scale known to affect weather and climate.

Newest Climate Models Reproduce the Recent Climate Record and Identify the Human Influences

Recent work has used a new global version of the Hadley climate model to simulate recent historic global temperatures and to assess the relative importance of natural and anthropogenic (human) factors on the temperature patterns of the last 140 years (1860-1999). The model is able to simulate the global temperature record of this period very well. This is possible only when both changes in natural and human factors that affect climate are included. Changes in natural factors such as variation in solar irradiance and volcanic activity are necessary to duplicate the warming trend observed in the early part of the century. However, such natural factors alone fail to simulate temperature records in the later half of the 20th century. Human factors such as the increasing concentrations of greenhouse gases in the atmosphere are needed to explain the warming trend over the past 30 years. The ability of the model to accurately simulate the last century of warming gives one confidence that models are potentially useful representations of the climate system with which to make projections of the future. The large influence of human factors such as the increases in greenhouse gas concentrations on the climate system in the latter part of the century reaffirms the expectation that further warming is to be anticipated with continued increases in greenhouse gases that will result from "business as usual" combustion of fossil fuels.

Summary/Conclusions

Significant climate change in this century is considered an increasingly serious possibility. To provide a basis for an assessment of the potential impacts of future climate change on New England, NERA has used the regional output from two global climate models as scenarios of possible future climate change in the New England region. These models are not perfect, but represent the best scientific scenarios available, and should be viewed as possible outcomes. Both models predict substantial warming and substantial changes in precipitation for the region if greenhouse gas emissions continue to rise at 1% per year into the future. The Canadian model predicts a more dramatic warming with large fluctuations in precipitation, but without an increasing long-term trend. The Hadley model predicts a less dramatic warming, and a trend toward dramatic increases in regional precipitation. Both models suggest that minimum temperatures will rise at a slightly greater rate than the maximum temperatures. The changes projected by either model, if realized, would be much larger than the climate variation experienced by the New England region in the last 10,000-20,000 years.

CHAPTER 5

CLIMATE IMPACTS ON REGIONAL FORESTS

By Gary Lauten, Barrett Rock, Shannon Spencer, Tim Perkins and Lloyd Irland

Introduction

Every autumn in the New England region is spectacular as broadleaf trees begin a transformation, their leaves turning brilliant hues of red, purple, orange, yellow, and brown. This artist's palette of brilliant colors occurs between mid-September and late October and is responsible for a very busy tourist season throughout the region. This seasonal display is however vulnerable to future climate change variables (air quality, seasonal dynamics, species migration, and extreme weather events) because the quality and brilliance of the display is dependent on tree health, temperature variation, and the species present.

While the regional forests are a major source of livelihood to the inhabitants, this chapter will highlight the impacts of climate on the fall foliar display. It is also important to recognize that as the forest conditions change in response to climate, wildlife habitats will also change. The current assessment of the impact of potential climate change on regional forests did not include a wildlife component, but rather focused solely on the forests themselves.

Soil type and moisture, site quality, species characteristics and composition, and tree health are factors known to vary the quality, intensity, and duration of the annual display. However, climatic factors play an even more significant role, since hard frosts hasten the loss of chlorophyll and enhance the colors of the other pigments. All these factors complicate the ability to predict a good or bad foliage season. The year 1998 was the warmest on record, both for this region and the globe. Delayed killing frosts in November or December of that year led to trees keeping their leaves longer than usual, and the colors were delayed and muted in many parts of the region.

In addressing the potential impacts of climate change, current stresses on regional forests, and how these stresses may be exacerbated by future climate changes are considered. In addition, potential benefits which might derive from climate change, as well as coping strategies and missing pieces needed to more fully characterize impacts are identified. Four case studies are presented which document the impacts of current stresses on forests and potential impacts under climate change scenarios.

Current Stresses and the Impact of Climate Change

Warm temperatures allow insects and diseases to flourish and permit the introduction of exotics not previously found in the region. Currently, the northward spread of the hemlock wooly adelgid is accelerating because of mild winter temperatures. This insect has caused major damage to hemlock stands (a favorite home to deer) in southern New England and has recently spread to the northern Massachusetts border. Warmer temperatures may increase the severity and occurrence of gypsy moth (which attacks the leaves of oaks and other broadleaf species) and pear thrip (which attacks sugar maple foliar buds) outbreaks.

Air quality also has an impact on tree health and thus ultimately affects leaf color. Warm, dry summers increase concentrations of ground-level ozone known to cause cellular damage in

The climate models predict that by 2100 the major components of the New England forests will be oak and hickory.

leaves (see Case Study #1). Acid precipitation can cause nutrients such as calcium and magnesium to be leached from the soil. When these nutrients are removed, harmful elements such as aluminum may injure roots. It is important to note that an increase in carbon dioxide from fossil fuel emissions may act as a fertilizer and enhance growth. Such a fertilizer effect must be balanced against the damaging effects of poor air quality and nutrient depletion.

Ice storm damage (see Case Study #3) has had a significant impact on selected tree species. Trees which were less flexible (maples and oaks) tended to be more heavily impacted due to breakage than those species which were more flexible (pines and birches). The damage caused by the 1998 ice storms is an example of one climate variable that has had an impact on maple sugar production across the region (Case study #2).

Finally, species migration due to a changing climate may well be the most devastating impact to affect regional forests. The climate models predict that by 2100 the major components of the New England forests will be oak and hickory (see Case Study #4). The brilliant reds, oranges, and yellows of the maples, birches, and beeches may be replaced in the landscape by the browns and dull greens of oaks.

Air Quality Issues

Tropospheric or ground-level ozone (i.e. not stratospheric ozone) is one of the most pervasive and detrimental air pollutants known to affect forest growth. As was noted in Chapter 1, a strong correlation has been shown to exist between changes in physical climate (temperature) and changes in the chemical climate (air quality), notably in the production of elevated levels of ground-level ozone. Studies have shown that the most pronounced affect of ozone on plant carbon uptake is a reduction in net photosynthesis due to a loss of chlorophyll and photosynthetic enzymes. Due to the documented effects of tropospheric ozone on both vegetation health and human health (the Hiker Health Case Study, Chapter 7), improving our understanding of the variations in regional tropospheric ozone levels and changes in forest and ecosystem health is a goal of present regional research efforts.

Due to the topographic variability typical of the region and the fact that it is downwind from the rest of the country and parts of Canada, upper-elevation sites (generally above 3,000') are sometimes characterized by unhealthful levels of anthropogenic ozone. Long-distance transport of NO_x, combined with both high levels of naturally-occurring VOCs (terpenes from trees) and sunlight at high elevation combine to produce elevated levels of ozone (above 80 ppb) during much of the summer season. These elevated levels of ozone can lead to significant problems for trees, but just as significant is the finding that sensitive tree species can be affected by ambient levels.

Seasonal Dynamics Issues

Based on the regional scenarios generated using the Canadian Climate Model and the Hadley Climate Model, the New England region is likely to experience a warming trend and an increase in precipitation over the next 100 years. Both climate models suggest future warming

The climate models also project warmer minimum (nighttime) temperatures that could affect tree physiology…

by 2095, but to differing degrees (an increase of 5.2° C/10.0° F, based on the Canadian model and 3.1° C/6.0° F based on the Hadley model). In terms of precipitation, the models differ as well, suggesting a 5-10% increase based on the Canadian and a 28% increase based on Hadley models. In both models, minimum temperatures increase at a greater rate than maximum temperatures over this time frame. Such changes could have a profound affect on seasonal dynamics across the region: milder winters (especially warmer nighttime temperatures); warmer and wetter summertime conditions; etc. Such changes would have dramatic, potentially negative effects on forest and wildlife habitats that typify New England.

Extreme Weather Events

Although the links between regional climate patterns and the frequency/occurrence of extreme weather events are not well documented or understood, the warming trends and increased precipitation patterns suggested by both Canadian and Hadley models may lead to more extreme weather events such as ice storms and droughts across the region.

Impacts of Future Climate Change

Seasonal Dynamics

The climate models used in this study suggest that warm temperature will persist longer into the fall. This could mean that the leaves would just turn color later in the year, or as the fall of 1998 suggests a reduced color display. Species that are more dependent on temperature would change color later than those species that are more dependent on day length, again producing an uneven display. The climate models also project warmer minimum (nighttime) temperatures that could affect tree physiology (increased respiration rates would cause loss of sugars retained in the leaves), also leading to reduced color display.

Air Quality Issues

In addition, the warming trends projected by either climate scenario could mean an increase in the number of hot, dry days during summer months, especially in the case of the Canadian Model. Such an increase would result in more ozone exceedance days thus affecting sensitive forest species such as white pine (Case Study #1). Reduced air quality will be a byproduct of a warming trend across the region.

Insect Pests

In much the same way as the northward incursion of the hemlock wooley adelgid, a warming New England region (especially warming winters) would promote the introduction and expansion of exotic pests into the region. Insect pests such as the gypsy moth and the pear thrips could become more aggressive and have an even greater impact on regional forests than is currently felt.

Species Migration

Both the increase in air quality impacts and attacks by insect pests would combine with environmental changes associated with a warming scenario to facilitate species migrations into and out of the region. As shown in Case Study #4, species more tolerant of these conditions would replace less tolerant species over time, resulting in forest composition changes into the future.

…the most effective approach for coping with change will be to anticipate the effects of that change and initiate adaptation strategies.

Potential Benefits

Forests dominated by oak and hickory may provide a commercial benefit to the region. Increasing levels of CO_2 in the atmosphere will likely act as a fertilizer, enhancing forest growth. In addition, the longer growing seasons may result in increased forest productivity. Recent research has shown, however, that such increased growth may be limited by soil nutrient levels in which elements such as calcium may be leached due to acid rain. Thus, on balance forests in the region are likely to become less healthy, due to insects, poor air quality, and nutrient depletion, in spite of the CO_2 fertilization affects of enhanced greenhouse gas levels.

Coping Strategies

Since there is very little that can be done to stop the impact of climate change on the forest ecosystem, the most effective approach for coping with change will be to anticipate the likely effects of that change and initiate adaptation strategies. Educating and preparing both the general population and specific forest sector industries for the impending change will require such strategies.

Land use policies and conflicts will most likely become major issues as the climate changes. There will be pressure from shifts in land use, whether it be urban sprawl or increased agricultural activities, that will encroach on the natural ecosystems. It will be important to maintain contiguous forest regions and not continue the current land use practices that foster fragmentation of the landscape with subsequent impacts on wildlife. Community, county, state, and regional planners need to make educated decisions that balance all stakeholder needs.

Climate change will likely result in more severe and numerous infestations of current pests and pathogens as well as those that will invade in the years to come. Pest management practices will need to be reconsidered and integrated pest management programs revised to fully address these problems. This may well include the need for the use of pesticides in order to sustain forests that will be weakened from air pollutants, drought, and warmer temperatures.

A shift in species composition, invasion of exotic species, and loss of some habitat will require the most adaptation strategies. Some species, such as oak, hickory, beech, and sweet gum will be less affected since they are far from their northern ecological limit, while other species, such as fir, spruce, aspen, and sugar maple are near their southern ecological boundary and more sensitive to change. The forest products industries need to address a number of adaptive measures to insure continued economic prosperity as species composition changes, since these industries traditionally need a 25-30 year lead time on capital investment. Specific coping strategies include:

- Planting different species after harvesting current stands. Warmer climate species have a faster growth rate that could increase productivity.
- Forest fertilization may become necessary as forest soils are altered by changing water chemistry and warmer temperatures.
- The industry should look at possible product diversification and more altered harvesting and marketing strategies.

Information and Research Needs

In conducting this initial assessment, missing information and basic research needs were identified. Regional stakeholders are aware that the forest sector is particularly sensitive to climate change, but they feel that they do not fully understand or appreciate the issues involved. To better understand these issues the following needs are suggested:

- Prioritize research and education programs that focus on the regional impacts of climate change.
- Improve the resolution of climate models so that climatic factor variability scenarios can be created for specific areas of the region. These models should include physical and chemical climate factors and current land cover and land use change information.
- Identify environmental thresholds (critical changes in factors such as temperature, precipitation, air pollutants, etc.) beyond which an individual species or ecosystem can no longer function.
- Quantify, in terms of dollars, the impact to natural and managed ecosystems for the various climate scenarios, determining the true economic impacts of climate change on this sector.
- Improve current techniques for improving the soil quality in managed forests.
- Identify genetically selected species or varieties with adaptive traits for changing climatic conditions.
- Better prediction of extreme weather events. Since ice storms, for example, are controlled by localized meteorological conditions, elevation, land cover, and aspect, results of the new regional models will be very useful for predicting events at local scales.

CASE STUDY 1

Forest Health and Productivity in Response to Ozone Exposure in a Sensitive Species

by Barrett Rock and Shannon Spencer

White pine *(Pinus strobus)* is a forest species that occurs across New England. Commercially, it is an important timber species for the region and is one of our most common low-elevation conifers. White pine is also known to be a bio-indicator species for exposure to high concentrations of tropospheric ozone, a common component of SMOG. Diagnostic foliar symptoms, known as chlorotic (yellow) mottle and tip necrosis (browning) (Fig. 5.1), occurring in the absence of other known causes, are likely to result from exposure to ozone levels at or above 80 parts-per-billion (ppb). Such symptomology is the result of varying degrees of chlorophyll loss. Such chlorophyll loss leads to a reduction in net primary productivity (NPP), which in turn can lead to a reduction in wood production in sensitive species such as white pine. A reduction in NPP due to exposure to elevated levels of ozone (above 80 ppb) across the New England region will result in a loss of timber productivity leading to a loss in the forest's ability to sequester carbon.

An on-going science outreach program called Forest Watch, developed by researchers at the University of New Hampshire, engages pre-college students across New England in studying forest health, with a specific focus on white pine. Forest Watch students collect needle and branch samples from five white pine trees located near their schools for study in their classrooms. Branch collections are made in the spring of each year, resulting in needle samples representing the previous summer's growth. Each year, branch samples with the previous year's needles are sent to the University of New Hampshire for spectral characterization using a reflectance spectrometer.

Chlorophyll variation can be quantified using spectral reflectance measurements acquired using field and laboratory spectrometers. One of the spectral parameters, the Red Edge Inflection Point (REIP), is computed for each set of needles sent by the students. Since the REIP is highly-correlated with foliar chlorophyll content (high REIP values correlate with high chlorophyll content, low REIP values correlate with low chlorophyll levels), it may be used as an indicator of needle health.

The annual REIP values for white pine from students have been correlated with summer (June, July, and August) ozone values for seven locations monitored by the New Hampshire Department of Environmental Services around the state (Figure 5.2). These monthly maximum values are reported by the Environmental Protection Agency (EPA) on their Web site for each monitoring station.

Figure 5.3 shows the inverse relationship between the spectral measure of chlorophyll and ozone data in New Hampshire for the years 1991-1998. The resulting correlation coefficient is very significant with an r^2 =-0.81, meaning that 81% of the variation in spectral values are correlated with variation in ozone.

The data presented in Figure 5.3 indicate that when average ozone values are high for a given three-month summer period, the chlorophyll levels and inferred health are low. Conversely, when ozone values are low for a given year, the spectral values from the same 30 trees suggest healthier conditions. The higher the REIP value, the healthier the needle samples. This documents an adverse relationship between ozone and the health of the

FIGURE 5.1
Typical foliar symptoms of ozone damage seen in white pine needles.

Clearly, the elevated levels of ozone anticipated as a response to future warming could have a significant adverse impact on sensitive species.

needle samples that varies from year to year. It is important to note, however, that in science correlation does not equal causation. Other climatic factors such as rainfall during summer months and the timing of precipitation have been compared against the REIP values and are not considered to be significant variables. Because high temperatures during summer months and ozone formation are correlated, high temperatures and REIP values also show a similar inverse relationship.

What does the Health of White Pine tell us about regional air quality?

Ozone impacts white pine, and other tree species, by entering the stomates and oxidizing (breaking down) the living cellular membranes, along with chloroplast membranes. In previous controlled-exposure studies, exposure of needles to levels of ozone above 80 ppb resulted in cellular degradation and chlorophyll loss resulted in lower REIP values. There is an overwhelming theoretical basis for the assumption that exposure to elevated levels of ozone will cause loss of chlorophyll in white pine. Controlled exposure studies conducted at Acadia National Park also support the view that white pine is very sensitive to exposure to elevated levels of ozone.

In a simulation study of the potential impact of tropospheric ozone on forest productivity, researchers combined leaf-level ozone response data from a series of ozone fumigation studies of appropriate species, with a forest ecosystem model in an attempt to quantify the affects of ambient ozone on mature hardwood forests across the New England region (including upstate New York). Using ambient ozone data for the region from 1987-1992, predicted declines in forest productivity ranged from 3-16%, with the greatest reductions occurring in the southern parts of the region characterized by the highest ozone levels, and in those species most sensitive to ozone.

These results demonstate the high degree of variability in air quality across the region, and in the biological response to this variation from year to year. Clearly, the elevated levels of ozone anticipated as a resonse to future warming could have a significant adverse impact on sensitive species.

Locations of the Original Ozone Monitoring and Forest Watch Study Sites

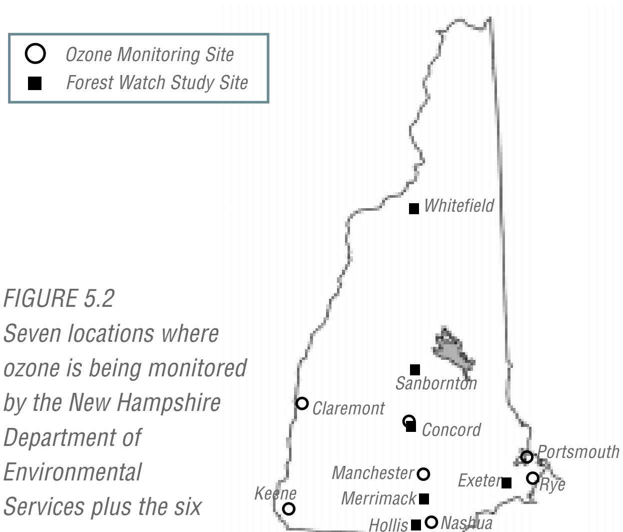


FIGURE 5.2
Seven locations where ozone is being monitored by the New Hampshire Department of Environmental Services plus the six Forest Watch schools.

Mean REIP and Mean Maximum Monthly (June-August) Ozone Concentration 1991-1998

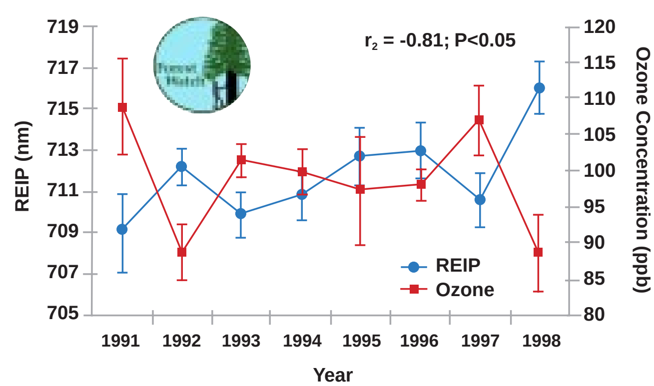


FIGURE 5.3
Inverse relationship between the REIP and ozone data in New Hampshire for the years 1991-1998.

CASE STUDY 2

The Maple Sugar Industry

by Barrett Rock and Shannon Spencer

The maple sugar industry represents an important component of both New England and New York's character and economy. The U.S. maple syrup production presently accounts for approximately 20% of the worldwide production. Prior to the 1950s, the U.S. accounted for 80% of the worldwide maple syrup production. The New England/ New York region represents roughly 75% of the total U.S. production and the average value of the New England/New York syrup production was $25 million for 1997-1999 (Figure 5.4). In Vermont, the highest volume maple syrup producing state in the region, the multiplier affect of the industry to related equipment, manufacturing, packaging, and retail sectors equals $105 million annually and represents approximately 4000 seasonal jobs. The maple syrup industry also contributes significantly to the tourism industry and other service sectors within the region.

The sugar maple tree *(Acer saccharum)* produces sap flows during late February to early March depending on geographic location and diurnal (day/night) temperature differences. This occurs due to physiological changes resulting in the conversion of stored starch to transportable sugar (sucrose). Sucrose is required for bud and leaf expansion and prolonged cold periods below 25ºF (cold recharge periods) are required for the enzymatic conversion of starch to sucrose, resulting in high sugar content (3-5%) in the sap. The occurrence of diurnal alternating freeze-thaw conditions causes positive stem pressures, resulting in sap flow. Amino acids found in the sap, microbial action, and thermal carmelization are responsible for giving maple syrup its distinctive color and taste.

The successful maple syrup season in New England depends on the proper combination of freezing nights and warm daytime temperatures greater than 40° F. Once a string of days occurs where nighttime temperatures no longer fall below freezing, sap flow stops. The first sap flow of the season generally has the highest sugar content and the lowest nitrogen content, resulting in the highest quality syrup of a given season. Therefore, the maple industry in New England depends to a large extent on the timing of these critical climate events. For Vermont this has typically been between the middle of March and the middle of April. Yet, for the last several years the sugaring season and first sap flow have occurred as early as the beginning of February. Warmer seasonal temperatures result in reduced sap flow, a shorter tapping season, and a lower grade product. The question that concerns New England regional maple syrup producers in the NERA region is: How will a changing climate affect sap flow and quality?

Current Stresses on the Syrup Industry

Tree health issues dominate the concern for most maple syrup producers in the region. In 1987 the North American Sugar Maple Decline Project, now named the North American Maple Project (NAMP), was formed out of concern for an apparent regional decline in sugar maple health. A number of biotic (pests, pathogens) and abiotic (acid rain, soil depletion) stresses are of concern. The primary biotic stressors include Pear Thrips, which had a significant outbreak in 1988, and

Value of Maple Syrup Production in New England and New York

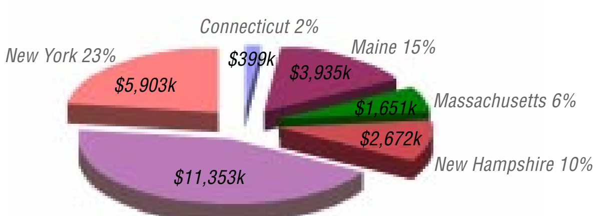


FIGURE 5.4
Average production value for New England states and New York between 1997-2000.

Early initial flows and warmer nighttime temperatures…have resulted in a shift in syrup production to the Gaspe Peninsula of Quebec.

the Forest Tent Caterpillar. These two insects affect the leaves of sugar maple during the spring and early summer which, when the outbreak is severe, can affect photosynthesis and the amount of stored stem and root sugars. Abiotic impacts to sugar maple include air pollution, atmospheric deposition, drought, and damage to stems and roots by humans. A bad drought year in 1988 significantly affected tree health for two years. Wet deposition of high levels of both sulfate and nitrate had significant impacts on maple health. Freeze injury to roots during periods of little to no snow cover may also be detrimental to tree health.

Climatic impacts, such as drought (mentioned above) and ice storms, can cause significant local and regional-scale maple tree damage, which can influence sap flow and syrup production. The Ice Storms of 1998 appear to have had significant impacts on maple syrup production and tree health in the New England/New York region (see Ice Storm Damage Case Study). In areas where maple stands were affected by the ice storms, moderate to severe damage occurred on 22% of the trees. Northern New York was severely affected by the ice storms and an average of 26% of the trees within damaged sugarbushes were severely damaged (80-100% crown loss). The Cornell Cooperative Extension Agency estimated the initial economic impact of the ice storms on syrup production in Clinton County, NY to be $4.5 million. The estimated 1998 syrup production loss for NY counties ranged from 20-100%. The damage caused by the storms includes direct structural damage to trees (broken limbs/trunks), damage to sap collection equipment, and a lost opportunity to tap trees where access to the sugarbushes was impeded by downed debris. The full impact of these ice storms will not be known for several years until tree recovery and sap production impacts can be fully assessed.

A recent study of two Vermont maple stands assessed the relative impacts of two growing seasons (1998 and 1999) on the root and stem carbohydrate reserves in sugar maple. Precipitation in 1998 was normal, while 1999 was a significant drought year. Year-to-year variations in precipitation between the two growing seasons resulted in greater difference in root and stem starch when compared with the effects of the ice storm damage. There was approximately 70% less root starch in 1999 (the drought year) when compared with 1998, and stem starch was 50% less in 1999 than in 1998. These results call into question the significance of severe weather events (the ice storms) and highlight the importance of inter-annual climate variation in terms of their impact on stored energy reserves in sugar maple.

Another current stress to the New England and New York syrup industry is market competition. Canadian production of maple syrup has tripled since the 1970s (figure 5.5) due to several factors, one of which is aggressive marketing. In addition the Canadian government now offers subsidies for Canadian syrup production. At the same time U.S. production has been constant. Market forces are making maple sugaring in New England more and more marginal, especially for small producers.

Finally, the advent of tubing-based methods of sap collection has also played a significant role in the Canadian dominance in the world maple sugar production. In the past, the success of the maple syrup industry in Canada was limited by deep snow cover (limiting access to individual trees) and fewer freeze/thaw cycles due to prolonged periods of low nighttime and daytime temperatures. The development of tubing-based sap collection methods that provide easier access to trees and early initial flows and warmer nighttime temperatures (fewer freeze/thaw cycles and reduced cold recharge periods) across New England over the past two decades, have resulted in a shift in syrup production to the Gaspe Peninsula of Quebec.

Current and Historic Syrup Production Trends

Syrup production for both the New England/New York region and other U.S. syrup producing states show a long-term trend in decreased production and more recent short-term variability (Figure 5.5). There are a number of factors that can account for these short and long-term trends in maple syrup production; some are climate related while others are socially or economically related.

From a climate perspective, there are two primary questions the industry needs answered regarding the impacts of a changing or variable climate in the future:

…approximately 30% of the variation in syrup production can be correlated with variations in January-April temperatures.

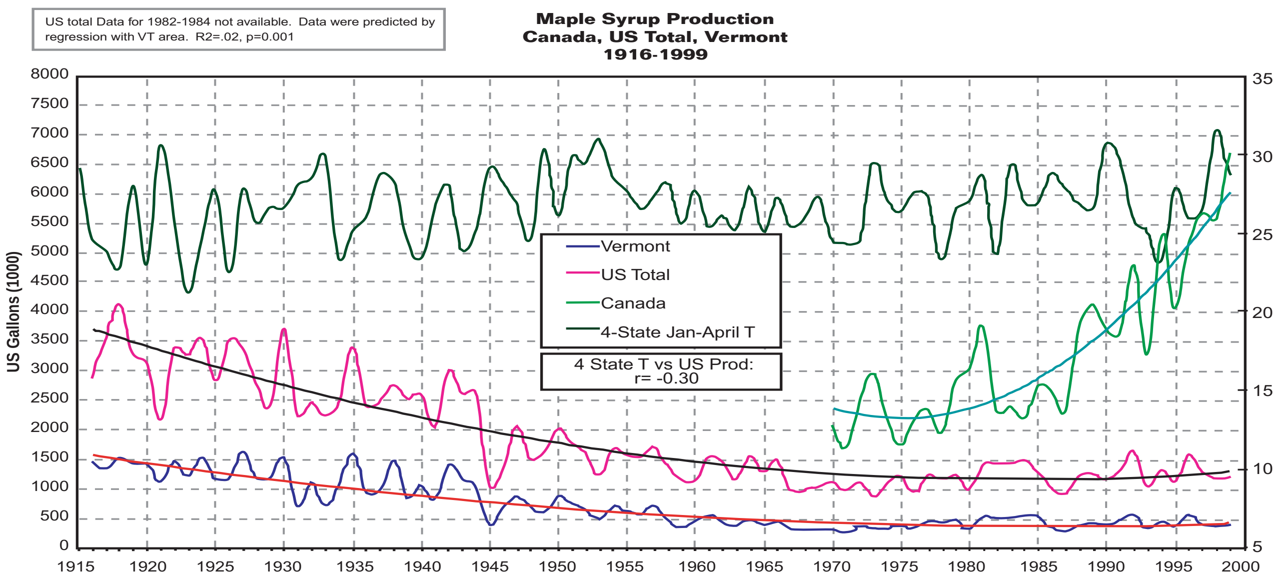


FIGURE 5.5 Maple syrup production: Canada, U.S. Total, Vermont 1916-1999.

1. What direct affect would a change in climate have on sap production?
2. What affect would climate change have on the health of maple trees in the region?

To address these concerns we must consider the various factors that affect maple sap flow and factors that affect syrup production. Poor climatic conditions may reduce sap flow, while a good sap flow year could occur but the number of trees tapped could be reduced for any number of reasons.

Figure 5.5 shows that U.S. syrup production has decreased dramatically since the early 1900s and has stayed fairly level over the last 30 years. Vermont, the largest U.S. producer, has also seen a decrease but this has been less dramatic than the U.S. total production. Since January to April is the timing for maple tree tapping and sap flow, mean temperature for this 4-month period for the four top producing states in the region (VT, NY, ME, NH in descending order) is plotted in comparison to syrup production. Interesting patterns are seen between the mean temperature data and Vermont, total U.S., and Canadian maple syrup production: In general, years with lower temperatures (e.g. 1998) exhibit an increase in syrup production. A moderate inversely related correlation (r = - 0.30) between the mean temperature and total U.S. syrup production means that approximately 30% of the variation in syrup production can be correlated with variations in January-April temperatures.

Figure 5.6 shows the syrup production and mean winter temperature trends over the last decade. Three different ways of characterizing temperature data are plotted for comparison. The VEMAP temperature curve (see Chapter 4 for a discussion of these data) shows the mean of the monthly temperature between January 1 and April 30. Additionally, daily temperature data were acquired from one first-order station from each state and the daily data averaged over two time periods: January 1 to March 15 and February 1 to March 15. Some years show a relationship

The maple syrup industry in the US has exhibited a dramatic decline since early in the 20th century.

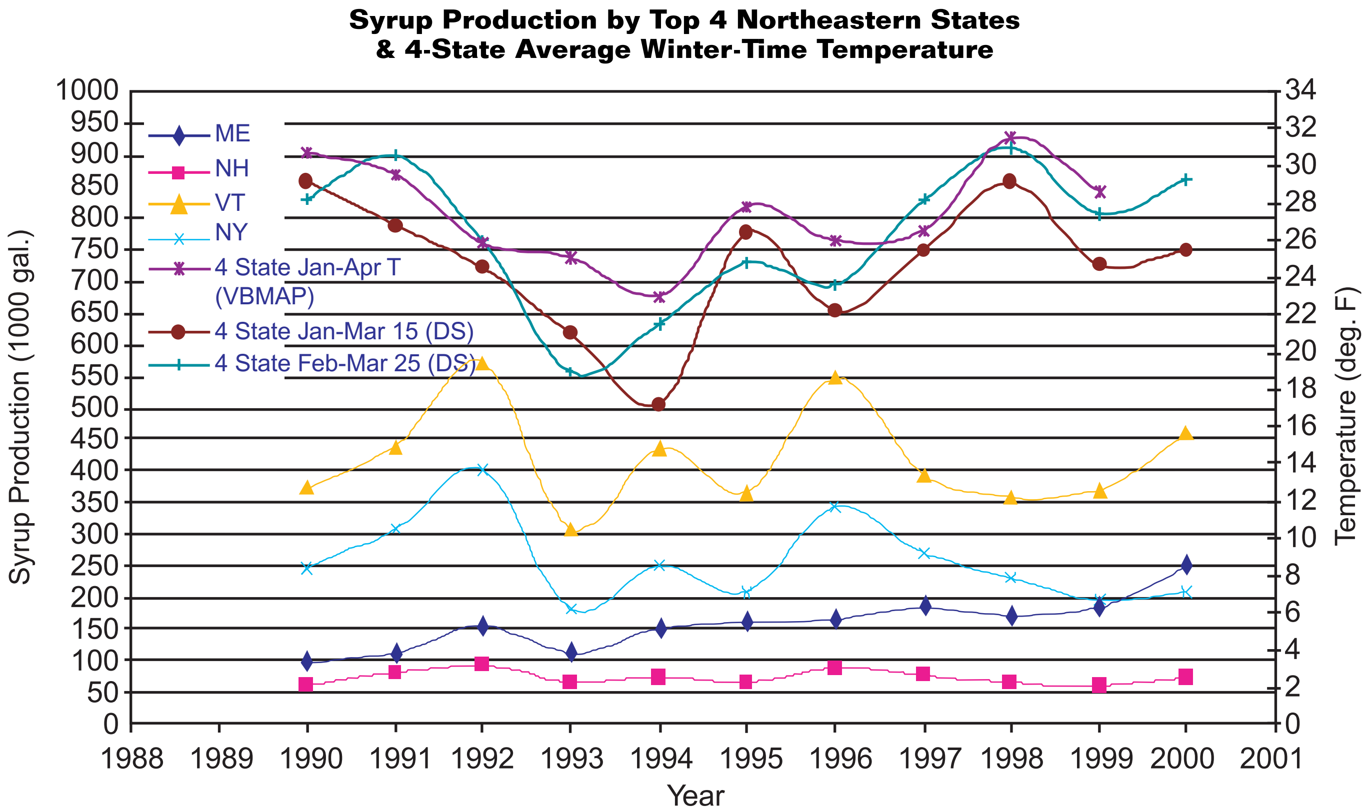


FIGURE 5.6 Recent syrup production and winter temperature trends in ME, NH, VT and NY.

with syrup production, with 1994 and 1996 "good" years corresponding to low temperature years. However, 1992 was a "good" year and 1995 and 1997 were poor years, yet all three exhibiting very similar temperature regimes.While ice storm damage may account for 1999 being a poor producion year in all states, both Vermont and Maine appear to have recovered in 2000 (unlike New York and New Hampshire.)

To accurately assess the impact of climate on syrup production, syrup production per number of trees tapped is needed. Additionally, precipitation and the previous summer's growing conditions are likely to have important implications for sap flow and syrup production during the late winter and early spring. The temporal analysis of climate data should be investigated further to better understand how climate variables and tree physiology control sap flow and quantity.

Conclusions

The maple syrup industry in the US has exhibited a dramatic decline since early in the 20th century. This decline is due to many factors, including climate. Over the past thirty years, the Canadian Maple industry has shown a dramatic increase also due to many factors, including climate. Most disturbing are the results of ecological modeling efforts that show the changes in climate could potentially extirpate the sugar maple within New England. The maple syrup industry is an important part of New England character, way-of-life, and economy that, because it is highly dependent upon prevailing climatic conditions, may be irreparably altered under a changing climate.

CASE STUDY 3

1998 Ice Storm Damage

by Shannon Spencer and Lloyd Irland

A major concern with a changing climate is the potential for an increase in the frequency and severity of extreme events in the New England region. As the New England Regional Assessment (NERA) process began, the ice storms of January, 1998 occurred, causing extensive economic and social disruption in northern New York, New England, and Quebec. This case study identifies and documents the impacts that current severe events, such as ice storms, have on the region.

Ice storms are not uncommon, but the meteorological conditions during the January, 1998 ice storms made them very geographically wide-spread (Figure 5.7) and devastating. The area of impact covered 4 states and Quebec, with 37 counties declaring Federal disaster areas (Figure 5.7). Extensive damage to forests resulted (Table 5.1). This particular event was categorized as a 200 to 500-year event with 17 deaths in New England/New York and 26 deaths in Canada. Approximately 1.5 million people across the New England/New York region were without power for up to three weeks. The economic impacts were well in excess of $ 1 billion in the U.S., and the long-term impacts of these storms are still being evaluated, especially the effects to natural and managed forest systems.

The conditions required for an ice event to occur are very specific. A temperature inversion must exist for an icing event to occur: a cold upper layer produces frozen precipitation, this falls through a warm layer at mid-altitude that melts the precipitation, this then enters a layer of cold air near the ground, which is below the freezing point. This super cools the precipitation. When this super cooled precipitation makes contact with the surface it freezes on impact, causing an ice glaze. If air temperatures near the ground are much colder than -3 degrees Celsius (26º F), then the precipitation freezes into sleet. Sleet bounces off surfaces rather than glazing them. Local variations in topography, elevation, aspect, and wind currents and speed influence the occurrence of ice glazing, resulting in patchy areas of ice glazing, as evidenced by the airborne mapping of damage in New Hampshire (Figure 5.8).

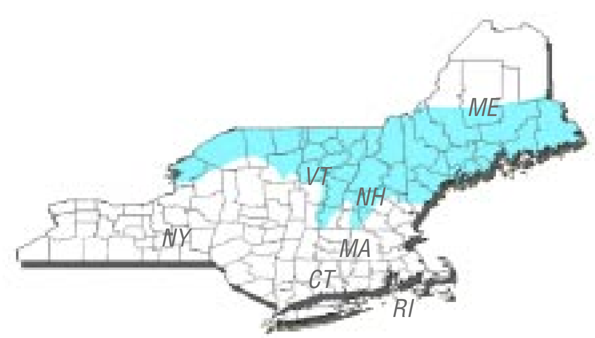


FIGURE 5.7 Ice-affected areas from January, 1998 ice storm.

Map produced by: USDA Forest Service, Forest Health Protection, Durham, NH 3/5/98

State	Area Impacted 1,000 Acres
New York	4600
Vermont	951
New Hampshire	1055
Maine	11000

TABLE 5.1. Forestland affected by 1998 ice storms

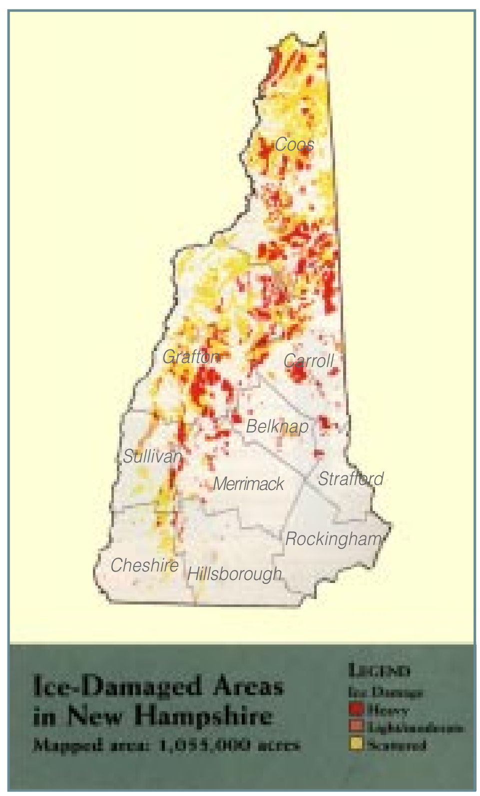


FIGURE 5.8. Sketch mapping of NH ice storm.

A standardized method of damage assessment for the entire region is needed.

Conditions for this inversion to occur include a stationary front that separates opposing air masses. The warmer air mass over-rides the cold air mass creating the cold-warm-cold temperature profile.

The National Weather Service (NWS) defines an "ice storm" as the occurrence of freezing precipitation resulting in the accumulation of 6.35 mm (0.25 inches) or more of ice. Ice accumulation typically occurs in limited areas traversed by a large storm due to the factors explained above.

Several major ice storms have been recorded in the climate record for the past century, with the following notable storms: 1909, 1921, 1929, 1942, 1950, 1951, 1953, 1956, 1961, 1964, 1969, 1976, 1979, and 1991. On average, 16 ice storms occurred each year across the U.S., from 1982 to 1994, making them more frequent than blizzards. A recent study has noted that several of the above mentioned storms were equal in severity to the 1998 ice storms, but that the geographic extent and duration of the 1998 event is unprecedented.

Concerns Regarding Ice Storm Frequency & Severity with Climate Change

The severity and wide-spread nature of the 1998 ice storms have led to questions about whether the New England region might experience increased occurrences of more extreme meteorological events, given a trend toward a warming climate; and, if so, what are potential consequences and/or mitigation steps needed to prepare for these damaging events? Though the answer to the first question at this point is not at all clear, we attempt here to address the major concerns by looking at our current knowledge of the situation.

Ice Storm Impacts on Forest & Natural Resources

Assessing the impact of historic ice storms and the 1998 ice storms can give us an indication as to the overall potential impact to the New England region if these events were to increase in a warming, more variable regional climate.

Significant damage to property, utility infrastructure and forest trees was recorded during the 1921 Great New England Ice Storm; over 100,000 trees were severely damaged. Such ice storms are usually a normal occurrence, from an ecological perspective, which have effects on forest species composition on a small geographic scale. Typically, greatest damage occurs in managed stands such as in plantations or heavily-thinned woodlots.

In the wake of the January, 1998 storms, an extensive effort was undertaken by state forestry agencies across the region to document forest impacts through aerial surveys and the study of ground plots. A common method of quickly assessing forest conditions is to conduct aerial sketch mapping using a trained observer to note crown conditions on a map. Another common method is to use a meteorological model to estimate damage.

Figure 5.7 shows the general areas affected by ice in the New England/New York region from the 1998 ice storm, while Figure 5.8 shows the specific damage sketch-mapped for New Hampshire. Power outage reports from public utilities may also be used to provide a rough proxy of the geographic distribution and severity of damage to forests and trees. Finally, detailed mapping based on interpretation of aerial photos may be used.

Based on measured impacts on forests, the degree of damage is typically highly skewed by state, due to assessment methodology. The Maine Forest Service initially assessed 1998 storm damage in broad areas based on assumed levels of damage due to a meteorological model, as defined in Figure 5.9. Comparing damage assessments for New Hampshire, based on sketch mapping (Figue 5.8), and Maine, based on a meteorological model (Figure 5.9), shows how the methodology can influence results. A standardized method of damage assessment for the entire region is needed. Based on previous work, satellite-based methods may provide such a standard assessment capability.

Field assessment during the following Spring and Summer of 1998 resulted in an improved understanding of the short-term forest damage and the geographical extent of the impact. Table 5.1 lists revised damage estimated from aerial photo analysis and field work. The extensive field work has provided a better understanding of the short-term forest

In general, more heavily managed (thinned) stands exhibited more damage than adjacent unmanaged stands.

impacts, as described below, but the long-term affects are still not well understood.

In the 1998 ice storms, icing lasted long enough that many trees, which were bent over due to the ice, had their crowns frozen to the snow/crust surface for as long as three weeks. In some instances, trees recovered to an erect posture after release from the snow, but most never recovered. Generally, softwoods seem to suffer less damage from the same degree of ice loading when compared with hardwoods and exotics and trees planted outside their natural ranges. Black Locust, and Willow suffered severely while nearby native species suffered far less damage.

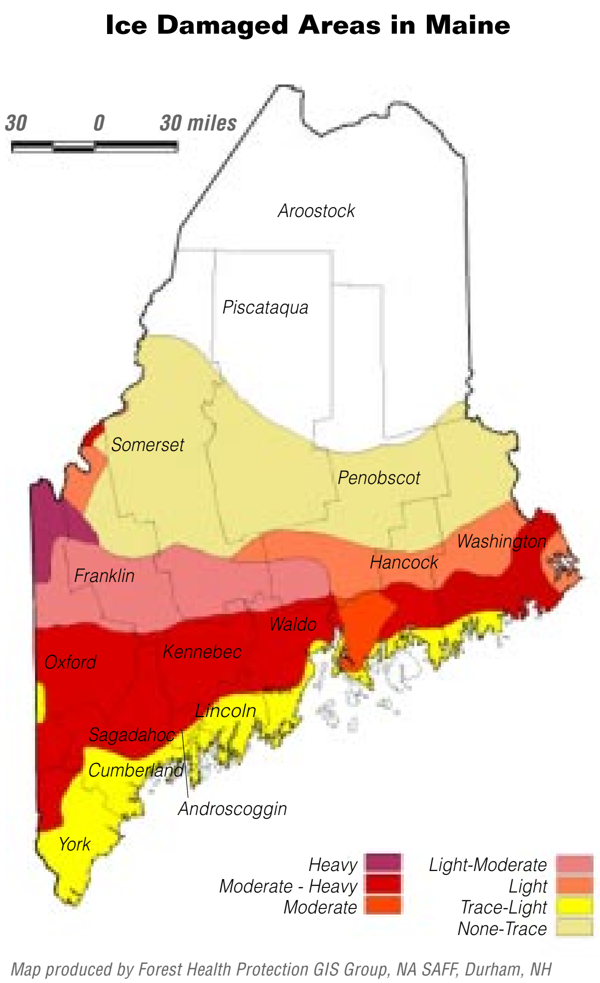


FIGURE 5.9 Damage assessment map of Maine.

Depending on stand composition, amount of ice accumulation, and stand history, damage to stands can range from light and patchy to the total breakage of all mature stems. With moderate degrees of damage, effects on stands could include shifts in overstory composition in favor of the most resistant trees, loss of stand growth until leaf area is restored, and loss of value of the growth due to staining or damage to stem bending. In general, more heavily managed (thinned) stands exhibited more damage than adjacent unmanaged stands. It is possible that damage caused by sloppy salvaging could exceed the damage caused by the storm (trunk damage to a tree is far more serious than is branch breakage).

Forest damage tended to increase with increasing elevation and northern exposure; likely due to greater icing at elevations where temperature conditions promoted greater occurence of freezing rain. Figure 5.10 shows how the ice accumulation on canopy exposed twigs, along a transect at the Hubbard Brook Experiment Station, increased with elevation.

Impacts to Forest Recreation

The ice storms significantly damaged recreational trails in forested areas that were impacted. In the White Mountain National Forest, 850 miles of trails and roads were blocked with downed woody debris, while 257 miles of trails were impacted in the Green Mountain National Forest. Additionally, 6000 miles of snowmobile trails had damage. The damage caused is anticipated to affect future trail

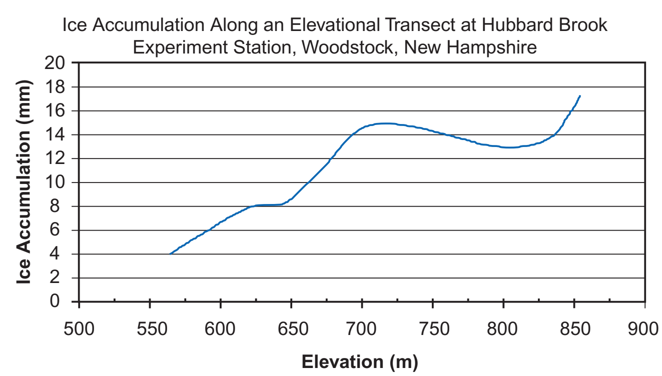


FIGURE 5.10 Elevational impact on icing.

Recovery has been substantial after two growing seasons on forest monitoring plots.

conditions as well. Less canopy cover in some steep portions are likely to result in increased erosion and waterbar washout. Additionally, the opening of the canopy will result in a flush of undergrowth that will require yearly clearing activity to those portions of the trail which were severely damaged. On the positive side, the canopy openings the ice storms created have encouraged increased wildlife activity. An increase in neo-tropical migrant bird species due to canopy openings may benefit bird populations. Increased understory forest growth has resulted in greater browsing by deer and moose, which will likely enhance a hunter's recreational experience.

Current Findings on Long-term Affects of the 1998 Ice Storm

Many studies to assess the impact of the 1998 ice storms on wildlife, ecological effects, and forest management activities are ongoing. Understory density has increased in the wake of the storms. A shift in species composition has also occurred. Recovery has been substantial after two growing seasons on forest monitoring plots in Vermont where significant foliage and crown damage were recorded in the summer following the ice storms. Greater downed woody debris, less canopy cover, less litter, taller herbs, and a greater amount of exotic species have been noted on ice storm damaged plots than on non-damaged forest plots, but tree mortality is not significantly different. Marked recovery is noted in even highly damaged trees after two years. Continued research and data analysis over the next five years will be important to achieve a full understanding of the long-term impact of the January, 1998 ice storms.

Implications for Natural Resources & Research Needs

Ice storms are frequent in the eastern U.S. and Canada. Storms of sufficient intensity to damage trees and forests occur in limited areas once every fifty years or less. Ice effects have been sufficient to affect stand composition in some areas. In today's younger, managed forests, the distinct effects of ice storms may be accentuated by management activities.

At present, it is not possible to predict how future climate change will affect ice storm incidence and severity. New research strategies, such as regional models, could shed light on this. At this point the best approach to handling the uncertainty in extreme events, such as an ice storm occurrence, is to be prepared to accept some level of risk. In general these events tend to be localized.

Lessons Learned

- The 1998 ice storms were unique in terms of recorded ice storms, due to the large spatial extent (NY, VT, NH, ME and Quebec) of the damage.
- The extent of damage to regional forests was heavy, affecting over 17,000 acres in the 4-state region.
- The economic impact on the forestry sector was approximately $400 million, including the $15 million impact on the maple syrup industry (which still continues).
- A standardized method of forest damage assessment does not exist and needs to be developed.
- Regional-scale climate models are needed to assess the impact of climate change on future ice storm frequency and severity.

CASE STUDY 4

Current & Future Potential Forest Cover Types

by Shannon Spencer

Species migration and forest cover type changes are potential issues in a changing climate. Yet, these are two very complex processes which relate not only to climate factors, but to human changes to the landscape, forest fire dynamics, disease occurrences, and geophysical attributes of the landscape, such as soil conditions, aspect (compass direction) and slope. This section takes a look at the current and potential forest cover type distribution for the New England/New York region.

Current Forest Types

The current forest types for the region, as depicted in Figure 5.11, consist primarily of maple, beech and birch in the western and central part, oak-hickory in the south coastal part and spruce-fir in northern Maine.

Forest Types of New England and New York

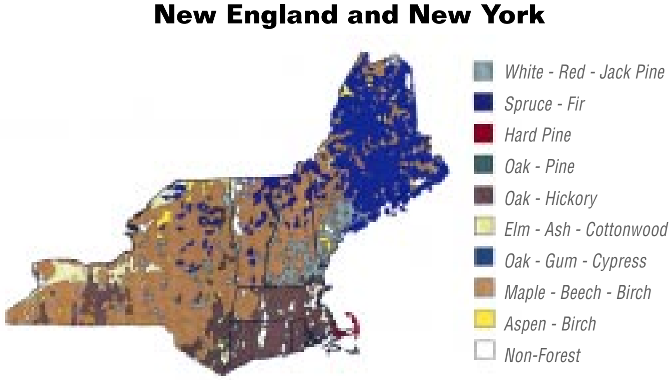


Figure 5.11 Current forest types.

Source: Adapted from USDA-Forest Service. 1993. Northeastern Area Forest Health Report. NA-TP-03-57pp.

This distribution of current forest cover types was established from USDA Forest Service Forest Inventory and Analysis (FIA) data, and the predicted potential forest cover types from modeling. The model investigates potential species importance values under a changed climate (doubled atmospheric carbon dioxide concentrations) using current species distribution and density data for the eastern US. The model is constrained by a species' ability to occupy an area, based on soil occurrence, landscape variables, land use, elevation and climate. To determine future abundance and distribution of over 80 tree species, an integrated regression model was used to predict Importance Values (IV) with several climate models (Global Circulation Models [GCMs]).

Future Forest Types

The IV model is based on several assumptions and uncertainties (such as future forest fragmentation impacts) and is therefore not an absolute prediction of future distribution. The approach provides a sensitivity analysis for possible ranges of tree distribution in the future based on predicted climate scenarios by global circulation models. Results from the authors' research predict that 30 tree species will expand their geographical range by more than 10% whereas approximately the same number of species will decrease their range by 10% or more. Four to nine species move out of the Eastern U.S., depending on the climate model used to force the Importance Value model. It was also found that for almost half of the species modeled, the biological optimum shifted more than 100 km, with seven species shifting as much as 250 km. The historic rates of migration, without human landscape fragmentation, is on the average of 10-50 km per 100 years, depending on species. Therefore, climate change could have very significant impacts on species migration and forest cover type distribution by the year 2100.

Figure 5.12 shows the current forest types as categorized by the FIA data and the IV model's predicted importance value

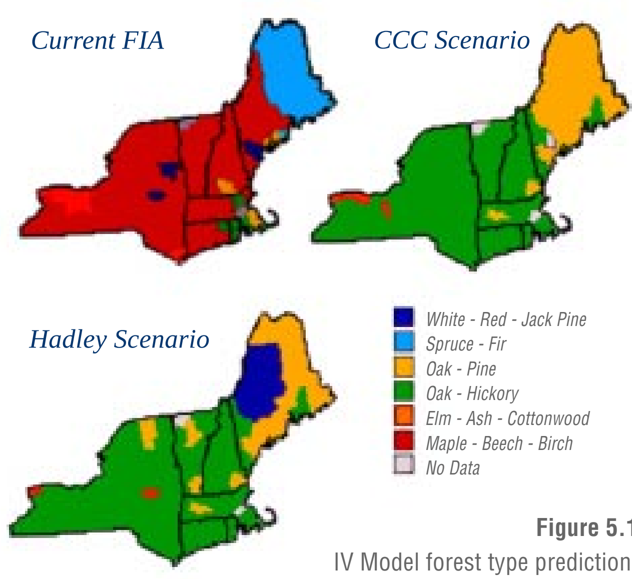


Figure 5.12
IV Model forest type predictions.
Adapted from Prasad and Iverson (2000).

Though these model results shouldn't be taken as absolute, they do indicate that the region's forest types may be very sensitive to changes in climate.

under a doubled CO_2 atmospheric environment. The results presented are based on the future climate predictions of the Canadian Climate Center and the Hadley global circulation models. The species importance values are presented for these two models because they are the ones used for the National and Regional Assessments. The IV model was forced by five different climate models in all, and very strong agreement was found for predicted potential species importance values in New England and New York (Figure 5.13). As can be seen by simple observation, significant changes in forest cover type are likely for the New England/New York region. Though these model results shouldn't be taken as absolute, they do indicate that the region's forest types may be very sensitive to changes in climate.

The impact of climate change on the top five dominant species was predicted by using the Canadian and Hadley models. In all cases maple becomes non-dominant, whereas currently it is one of the top two dominant species in all states. White pine appears to be relatively climate insensitive: in all states, but New York, its dominance increases. Since white pine is sensitive to ground level ozone, projected increases may be counteracted by poor air quality associated with warming. Oaks also become more dominant in a changed climate, while red oaks become less common.

This change in species dominance is rather dramatic and could have significant implications to both private and public sectors, as well as represent a change in the character and way-of-life of the region. Human land use changes have not been accounted for in this model, as they are difficult to predict, especially in a region dominated by small, non-industrial private landowners. Land use, especially forest fragmentation and development, could have negative impacts on species migration.

Continued research is needed to look at the effects of human landscape changes on species migration rates. Past climate changes associated with glaciation have been shown to affect species distribution, migration and forest composition at a regional scale. The question now is how will these forest species be effected by the rapid changes in climate projected to occur in the next 100 years? And, how will changes in forest type distributions affect the region ecologically, socially and economically?

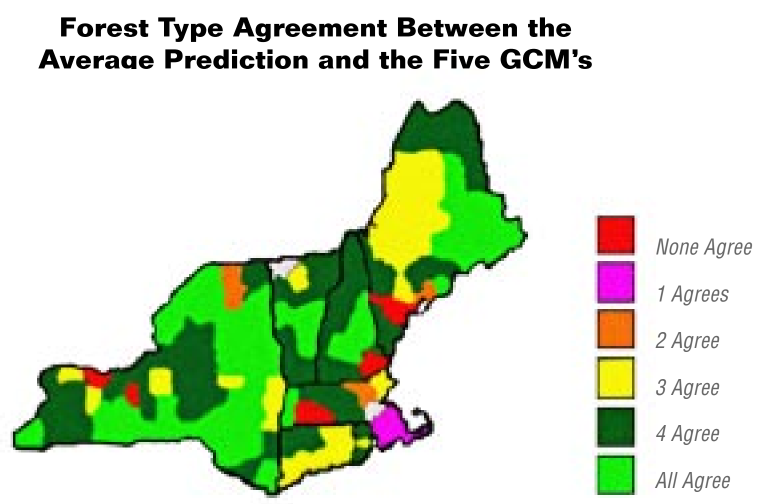


Figure 5.13 GCM model agreement in the prediction of species importance values.

CHAPTER 6

CLIMATE IMPACTS ON REGIONAL WATER

By Barrett Rock, Lynne Carter, Henry Walker, James Bradbury, Larry Dingman and Tony Federer

Introduction

The New England region is not considered limited by water availability. While the region was impacted by a serious drought during the mid-1960s, overall, images of a vast network of lush green forests and inviting waterways, extensive shorelines, and a landscape of mountain streams and lakes teeming with fish characterize our region. Water recreation, including fishing, boating, and swimming along with regional seafood such as lobster define the New England region for many. This view assumes that in the future, water will be plentiful and of the highest quality. The Canadian model projects only a modest increase (approximately 10%) in precipitation for the region over the next century, accompanied by periods of potential drought. The Hadley model projects a significant increase (approximately 30%). How would either of these projections, coupled with the warming projected by both models, impact the New England region?

Climate change could affect many facets of life in the region, with those that are climate-dependent most vulnerable. Climate change that would alter either quantity and/or quality could directly affect the viability of regional industries such as agriculture, forestry, fishing, tourism, and outdoor recreation. Changes in climate also could impact human health, and exacerbate existing health stresses posed by air and water pollutants. In the coastal region, infrastructure could be impacted by possible climate-induced rise in sea level as well as by water quality issues (harmful algal blooms, wetland loss, habitat degradation, etc.).

In the New England region, future climate impacts to the Water Sector fall into four central categories: 1) water quality issues, 2) water quantity issues (drought, flooding and sea level rise), 3) the impact of regional land use on water quality/quantity, and 4) the value of wetlands to the region (wildlife habitats, recreation, and pollution impacts). Other water-related issues include the impact of "surprise" events such as the 1998 ice storm. Warmer, wetter winters, coupled with more moisture year-round (the Hadley projection) may lead to flooding, causing a flushing of sewage and other wastes from urban areas into wetlands and coastal marine waters. The rapid temperature rise and limited precipitation increases projected by the Canadian model would also lead to poor water quality as well as droughts as significant as (or worse than) the mid-1960s drought.

This chapter investigates some of the documented impacts (current stresses) of recent climate trends for the region, and the impacts of potential climate changes over the next 100 years projected by the Climate Models, including potential benefits. It also considers reasonable coping strategies to address the impact of these changes, and identifies with significant information gaps and "missing pieces" that are needed to more fully understand just how climate change could affect regional water resources. Finally, illustrative Case Studies are included to provide more details on how current climate variability has impacted the water sector.

The region is famous for its “Nor’easters” along the coast, “lake effect” snowstorms in western New York…

Current Status and Stresses

Current Variability in Regional Temperature and Precipitation

A changing climate characterizes the New England region: severe ice storms, summertime heat-waves, spring and fall floods, and long-term and short-term droughts. The region is famous for its “Nor’easters” along the coast, “lake effect” snowstorms in western New York, and its highly changeable weather. The lush landscape is heavily forested due to the abundance of water. The historic patterns of temperature and precipitation (Chapter 2) have changed over the past century (since 1895), resulting in an overall regional temperature increase of 0.7° F, and a slight increase in regional precipitation (3.7%).

As noted in Chapter 2, the changes in temperature and precipitation across the region since 1895 have been geographically and seasonally very heterogeneous. The coastal portion of the region has warmed more than the interior portion and has received the greatest increase in precipitation. The average number of days with snow on the ground has decreased by nearly a week over the last 50 years, not surprising since regional wintertime temperatures have warmed more (1.8 °F) than the summertime temperatures (0.5 °F) since 1895. Seven of the last 20 years have been characterized by significant regional drought, with six years occurring in the 1960s (see the Mid-1960s Drought Case Study). Changes in the type of precipitation falling during winter months (snow vs. rain) also have a profound impact on water storage vs. runoff, in turn impacting regional hydrology (see the winter NAO index/surface hydrology Case Study).

The current climate variability characterizing the region, as well as variability over the past century, constitute a significant stress on the region’s water resources. Concerns voiced by the general public include sea-level rise, water quality issues and the impact of a changing climate on commercial and sports fishing.

Sea-Level Rise

One of the most likely impacts of the warming will be rising sea levels, resulting from the thermal expansion of sea water (as water warms, its volume increases), the addition of fresh water from melting glaciers, ice sheets, and snow pack, as well as local subsidence. Sea-level rise, which is already occurring, could inundate low-lying areas of the New England region, many of which include densely populated areas. Because the coast of New England is prime real estate, coastal populations in the region are likely to double by 2100.

Currently, the average rate of sea-level rise on the Atlantic coast ranges from 3.5 inches per century in Boston, Massachusetts, to approximately a foot per century in coastal salt marshes in southern Massachusetts. Different rates of sea-level rise occur at different locations due to local rates of subsidence (settling) or uplift. With the retreat of glacial ice from the region 20,000 years ago, sea coasts began to rebound (or uplift) to a greater or lesser degree from the weight of the ice. The greater the amount of ice removed, the greater the degree of

Warmer sea surface temperatures off the Atlantic Coast lead to lower snowfall totals in southern New England …

rebound. While portions of the Maine coast may still be rebounding, the coastal areas to the south appear to be subsiding following a period of rebound. About 33 acres of land are lost on Massachusetts' Cape Cod each year—73 % due to advancing seawater and 27% to erosion.

Much of the current rate of sea level rise is due to thermal expansion of the oceans due to the global warming trend that has occurred over the past century. A one degree change in ocean temperature would mean a one meter rise in sea level. The current rate of rise is less at present, because the total ocean is not heating uniformly, only the mixed upper layer has warmed to date. The second reason for sea-level rise is the melting of glaciers and ice caps. Clear documentation exists of the recession of approximately 80% of mountain glaciers around the world. There is also limited documentation for a small reduction in the Greenland ice sheet (especially in the southern region). A last reason for sea-level rise is human activity. As we mine water from aquifers as a source of drinking water, the aquifers recharge more slowly than we empty them, and the mined water finds it's way into the ocean. We also drain wetlands, pumping the water into drainage systems or directly into the oceans. Such direct human activity may account for a third of sea level rise per year.

One result of rising sea level is that the saltwater wedge, vital to the health of an estuary, would migrate upstream unless freshwater runoff is increased, causing a shift of marine ecosystems upriver. Shoreline construction often prevents wetland migration, then habitat shifts that might have occurred because of sea-level rise are prevented.

Current Impacts of a Changing Climate on Commercial Fishing

The Winter Flounder Case Study addresses the issue of current climate change impacts on abundance of this commercially important marine species. The winter flounder may well be an indicator species sensitive to increases in water temperatures. Warmer water temperatures appear to have set off a chain of circumstances that began with the loss of the winter flounder population and resulted in increased populations of warmer water invertebrates and migrant fishes.

Consequences of Climate Change in Coastal Ecosystems

During the past 50 years we have seen large variations in New England climate associated with a major shift from a surprisingly persistent negative NAO (North Atlantic Oscillation) phase in the 1950s through the 1960s, into surprisingly persistent positive NAO phase in the 1970s and the 1980s. Within this period, the winter water temperature of Narragansett Bay warmed by 3^{o} C (nearly 6^{o} F), almost a 1-degree change per decade between 1960 and 1990. Warmer sea surface temperatures off the Atlantic Coast lead to lower snowfall totals in southern New England, though the impact is less noticeable father north. Such a dramatic wintertime temperature change has probably altered food chains in temperate coastal waters in southern New England.

In the past century, there have been large changes in the abundance of bottom-dwelling "ground fish" in New England, largely attributed to changes in fishing pressure. Although speculative, warmer winters may have been a contributing factor in the decline of commercially important ground fish in southern New England in recent decades.

As temperatures increase … the current levels of variability in regional temperatures and precipitation can be expected to continue, and perhaps increase.

Freshwater Issues

Climate change impacts on freshwater in the New England region have affected both water quantity and water quality. As will be seen from the NAO Surface Hydrology Case Study, dramatic changes in amounts and forms (rain vs. snow) of meteorologic water added to the hydrologic system have profound impacts on stream flow and surface water conditions. Changes in stream flow characteristics can have dramatic affects on water quality - too much water (flooding) will result in overflows of waste water treatment facilities, leading to poor water quality, just as too little water results in concentration of toxics, also leading to poor water quality.

Climate Change Impacts on Fresh Water Quality and Quantity

The USGS is well known for its water quantity data, collecting stream flow data at multiple sites across the New England region, often done in conjunction with monitoring water usage and flow requirements. A problem with all of these data is that they are collected downstream from major impediments or dams – which could influence the characterization of the impacts of climate change.

Water quality data for New England are not consistent. These data vary from state to state, with some states having good, long-term monitoring programs, while others have abandoned their monitoring programs. The National Stream Quality Accounting Network (NASQUAN) ran from the mid-1970s to the early 1990s but was discontinued because few were using the data. The best source for long-term water quality records would be the public water suppliers for large areas, where on-going monitoring programs have been in effect for a number of years.

We know that New England as a region has suffered severe drought and flooding. We must be careful about how we manage our water resources in the dry periods. Additionally, because of the changes in regional land use due to agriculture and forestry, the impacts of variability in our future climate (even without overall change) are growing. We can do a lot in terms of adaptation strategies by learning to adapt to changing circumstances.

Impacts of Future Climate Change

Current Trends

Global and regional computer models, although imperfect at describing local conditions, suggest that the current temperature and precipitation trends may continue and both scenarios suggest warmer, shorter winters. If greater frequency and intensity of extreme events were to occur, increased frequency of winter thaw events, flooding, and summer droughts could result. Although the region is considered “water rich,” drought has been and remains a significant concern for this region.

…as sea level continues to rise, the amount of the region's coastal area subject to flooding from coastal storms will increase…

Current Variability in Regional Temperature and Precipitation

As temperatures increase in the future, the current levels of variability in regional temperatures and precipitation can be expected to continue, and perhaps increase. Since much of the current variability is not well understood, improving our understanding about cause and effect relationships across the region is needed.

Potential Benefits

Given warmer and wetter winters, some benefits may be derived in the form of improved groundwater recharge to the region. Such benefits assume that the ground would not be frozen and that the bulk of the precipitation would fall as rain. Longer growing seasons could also benefit coastal ecosystems and milder winters could benefit selected freshwater and marine organisms, while adversely impacting others (see the Winter Flounder Case Study). On balance, the adverse effects of climate change are likely to outweigh the benefits.

Sea-Level Rise

Saltwater intrusion could convert some areas of coastal freshwater wetlands to salt marshes. Groundwater could also be affected, as brackish water infiltrates aquifers that supply drinking water to coastal communities. Saltwater intrusion combined with low freshwater flow, could result in a higher chloride water content in important aquifer systems and water supplies. Low flow, a rise in sea level, or both could affect the water supplies in coastal regions.

In addition, as sea level continues to rise, the amount of the region's coastal area subject to flooding from coastal storms will increase, especially in areas of low relief. Increases in sea level can cause dramatic changes, as higher sea levels would provide a raised base from which storm surges may sweep inland, allowing for greater and more widespread damage than would occur with lower sea levels. Even if storm strength were not increased, higher sea levels will result in more damage.

Future Impacts of a Changing Climate on Commercial Fishing

Scientists suggest that warmer late winter-early spring temperatures combined with continued sea-level rise could have a significant impact for commercial fishing. The greatest portion of U.S. commercial fishery catches (except Alaska) are estuarine- dependent, with 32% of the fisheries of Cape Cod and north estuarine-dependent. Coastal wetlands, estuaries, and other intertidal areas (e.g. mud flats) are important nursery grounds for many species of comercial fish and shellfish and important feeding grounds for many migrating waterfowl. Because these ecosystems often are adapted to specific temperature, salinity, and tidal conditions, commercial species and whole ecosystems could be lost if the upstream conditions are not suitable for migration or the species are unable to migrate in response to changing sea level. A sea-level rise that is rapid enough to damage coastal wetlands would cause a significant decline in coastal fisheries. Shoreline construction which prevents erosion or submergence or is otherwise unsuitable would prevent estuarine and intertidal habitat shifts that might have

Just as recreational freshwater fishing would be compromised by climate change, so too would recreational and commercial coastal fishing.

occurred due to sea-level rise. Preserving estuarine and intertidal habitats will become more of a significant concern, as the future climate changes.

Consequences of Climate Change in Coastal Ecosystems

Wintertime temperature increases projected by the climate models will likely lead to altered food chains in temperate coastal waters in southern New England. Similar changes in coastal ecosystems may also occur in northern Maine. Reductions in amount of plant debris transported to the bottom during warmer winters may be a significant contributing factor in the decline of commercially-important ground fish in southern New England in the future.

Freshwater Issues

Climate change impacts on freshwater in the New England region will affect both water quantity and water quality. Dramatic changes in amounts and forms (rain vs. snow) of meteorologic water added to the hydrologic system will have profound impacts on stream flow and surface water conditions. Increased storm intensities and drought periods will have significant impacts on quality of the region's freshwater supplies. Although the region is unlikely to become water limited as the result of climate change, regional water quality will be reduced.

Freshwater Fishing: Environmental Impacts

A continued warming trend would impact freshwater fishing in the New England region. Significant losses of cold-water species would occur if climate change results in loss of cold-water habitats. Just as recreational freshwater fishing would be compromised by climate change, so too would recreational and commercial coastal fishing.

With climate change, the greatest losses in cold-water species would occur in the southern borders of a species' natural range, where the minimum temperatures are closest to thermal tolerances. Many species are particularly temperature-sensitive during spawning. An EPA study based on thermal modeling that assumes a doubling of carbon dioxide levels, found that the region faces a 50- to 100-percent potential loss of habitat for brown, brook, and rainbow trout—cold-water species that are highly valued by anglers.

Stream flow in the region also would be affected but is much harder to project than changes in temperature. The rate of stream flow may change or be uneven, although overall precipitation remains the same, because some of the precipitation may come in the form of downpours rather than gentle rains, causing floods in the spring, eggs could be destroyed and food availability reduced.

Coping Strategies

Three strategies are available to cope with the effects of climate change on sea-level rise in the Northeast: to retreat from advancing seas, accommodate changes imposed by a higher sea level, or protect areas/structures from sea level rise. All three coping strategies could

The increase in lobster could provide an economic benefit…

be more effectively applied through education efforts that help concerned parties cope with potential coastal changes and avoid putting themselves in harms' way to begin with. All stakeholders should be educated about the risks of building in hazard-prone areas and the potential for changes in storm frequency, intensity, and sea level.

Few strategies are now available to anglers and those in the fishing industry to cope with potential impacts of climate change. Climate change impacts will vary stream by stream, depending on whether and how stream flow is affected. However, one strategy is to fish for alternative species. Fisheries managers also could shift stocking patterns in favor of more cool and warm-water fish species. Education might increase the perceived attractiveness of cool and warm water species as well.

Changes in the distribution and composition of fish populations will impact the economy of the region's fisheries and will require adjustments in those fisheries. Winter flounder accounted for half of the total income earned by coastal fishermen in one New England port, but now provides them with no significant income. Lobster catches however, are on the increase. The increase in lobster could provide an economic benefit, but fisheries will have to work to create market demand for the other newly established fish and shellfish populations, which will change with the climate.

Information Needs and Data Gaps

The following information needs and data have been identified.

1. A regional geographic information system (GIS) for monitoring and characterizing land cover and land use change over time is needed;
2. A resurrection of the NASQAN program is needed — a national effort to monitor water quality across the country;
3. More studies need to be developed to estimate the percent of the total load in the region that could be from various sources, both natural and anthropogenic, based on the watershed information and GIS data gathering;
4. A regional water quality model for the New England region must be developed;
5. An improved understanding of the role that the NAO plays in regional weather is needed;
6. Improved understanding about cause and effect relationships that determine variability in regional temperatures and precipitation;

CASE STUDY 1

The 1960's Drought in New England and New York

by S. Lawrence Dingman

The drought of the 1960s was by far the longest, most severe, and most widespread that the northeastern United States has experienced at least since European settlement. The proximal cause of the drought was precipitation shortfalls, which began in 1960-1961 and lasted until 1968-1969. At its most intense, in July 1965, the effects of this drought on the water supplies and water quality of this densely populated region had become so severe that President Johnson declared a limited national emergency and convened the inter-agency Water Resources Council to assess how the federal government could best mobilize its resources to assist state and local governments in dealing with it.

Figure 6.1 shows the accumulated precipitation deficiency from October 1961 to December 1965. By the summer of 1965, "extreme" drought conditions covered some 60,000 square miles, with "severe" drought covering an additional 60,000 square miles (Figure 6.2). Streamflows and ground-water levels were near or below their historical lows in a swath extending from the Massachusetts and New Hampshire coasts southwestward into West Virginia. The accumulated streamflow deficiency in central Massachusetts between 1961 and mid-1966 was equivalent to two years of normal runoff.

Because water-supply systems in the northeast were generally designed to be adequate in a repitition of the drought of the early 1930s, and because of the unanticipated growth in population and industry that had occurred since then, more than 100 public water suppliers were experiencing critical water shortages.

The exteremely low flows caused water-quality problems in addition to the landward migraton of salt-water in estuaries: reduced dissolved oxygen, increased temperatures, and increased concentrations of pollutants. Scattered fish kills occurred in Maine, New Hampshire, and Massachusetts. Excessive concentrations of nutrients caused excessive harmful algal blooms in lakes and reservoirs and produced taste and odor problems in some municipal water supplies.

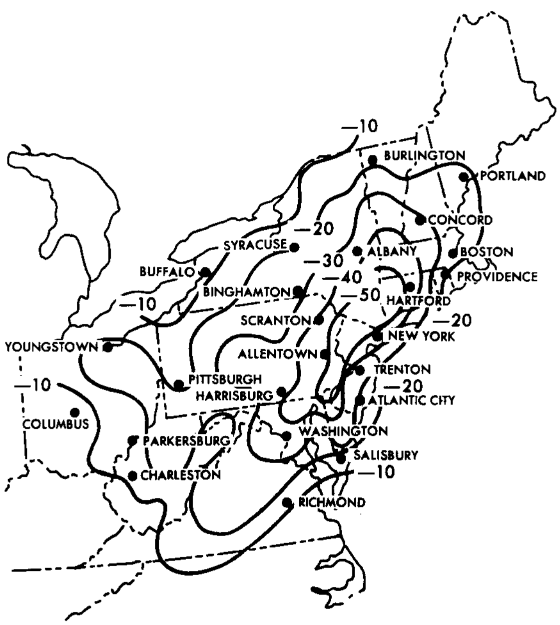


Figure 6.1 Accumulated precipitation deficiency from October 1961 to December 1965.

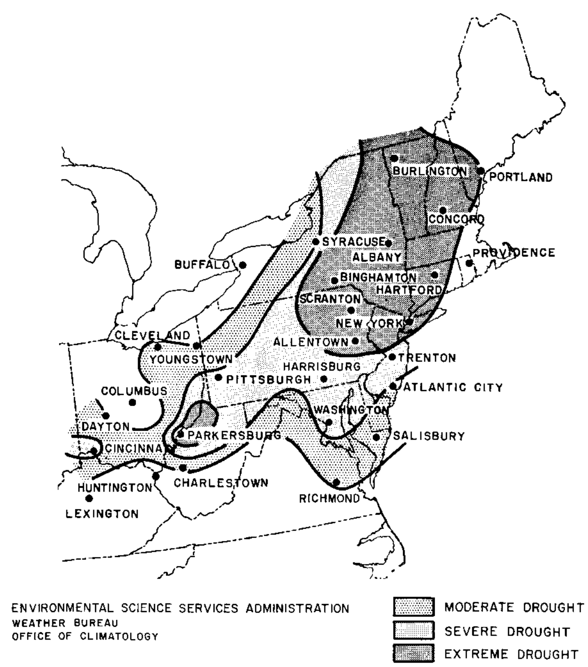


Figure 6.2 Summer of 1965 showing extreme drought conditions over 60,000 square miles with severe drought covering an additional 60,000 miles.

The 1960s drought was part of a "major aberration" in North America's precipitation regime, and was coincident with very wet conditions in the Southwest and Northern Plains.

Other effects of the drought included an increase in the number and severity of forest fires and increased forest tree mortality due to soil-moisture shortages and drought-induced insect attack. Excessively dry soils severely degraded pasture conditions, necessitating heavy supplemental feeding of livestock and curtailed agricultural operations in southeastern New York and southern New England.

The 1960s drought was part of a "major aberration" in North America's precipitation regime, and was coincident with very wet conditions in the Southwest and Northern Plains. A detailed analysis of weather conditions indicated that the precipitation shortfalls occurred largely in the spring and summer and that temperatures during the drought were cooler than normal.

The New England-New York region has experienced at least nine periods of widespread meteorologic and hydrologic drought in the 20th Century, covering approximately the years 1908-1913; 1929-1936; 1938-1945; 1947-1951; 1955-1959; 1961-1969; 1979-1983; 1984-1988; and 1991-1995. The return period of the 1960s drought was estimated to be about 150 years.

The U.S. Geological Survey began gaging the flow of the Pemigewasset River at Plymouth, NH, in 1903, and that station has one of the longest continuous flow records in New England. The drainage area contributing flow is 622 mi^2, and the flow is unregulated. The smoothed data, with an 11-month moving average of the normalized values are plotted in Figure 6.3. The drought periods mentioned above are apparent in the graph as extended periods when the line is below 0, and the extreme severity and duration of the 1960s drought is evident. Analysis of this record also indicates increased variability since the 1960s drought.

It has been speculated that the 1960s drought was triggered by a pool of anomalously warm sea-surface temperatures in the Pacific ocean north of Hawaii. However, the monthly El Niño-Southern Oscillation (ENSO) index was negative for most of the decade of the 1960s, indicating colder-than-normal temperatures in the equatorial Pacific (La Niña conditions).

Periods of high and low streamflows in various regions of the United States were compared to El Nino and La Nina, respectively, for the period 1945-1990. Thus, although there appears to be some association of El Niño episodes with dry periods and La Niña episodes with wet periods, there does not seem to be a strong basis for predicting a recurrence of a drought of this severity based on El Niño/La Niña episodes alone. The significant drought of 1999 occurred during La Niña conditions. Perhaps other indices of atmospheric circulation modes such as the North Atlantic oscillation and the Pacific-North America index are also related to New England drought.

The region has experienced significant multi-year droughts approximately once a decade in this century. Because of increased development in the last 30 years and resulting limitations on water supply that have emerged in many parts of the region, it is clear that a future drought approaching the 1960s severity, extent, and duration would have severe economic and environmental consequences. We must develop a better understanding of relationships between such events and atmospheric indices that can predict drought with some reliability.

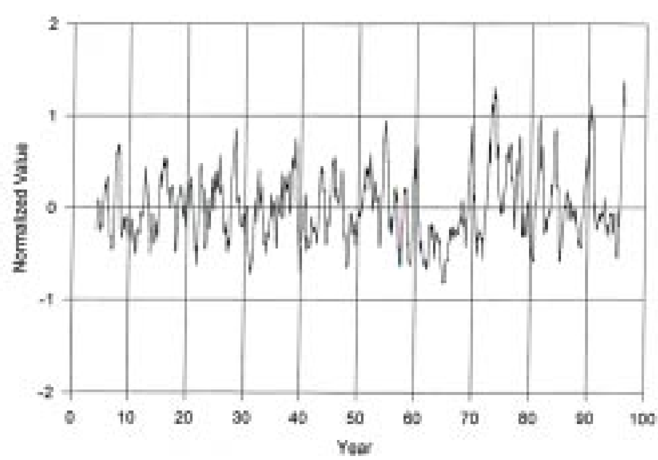


Figure 6.3 11-month moving average of the normalized montly flow values.

CASE STUDY 2
Effects of Warming on Snow at the Hubbard Brook Experimental Forest

by C. A. Federer

A hydrologic model that simulates snow accumulation and melt was used to estimate changes in snowpack that will result from climate change. The BROOK90 model has been applied to simulate snowpack under measured climate for two locations on the Hubbard Brook Experimental Forest, West Thornton NH. The simulation runs were then repeated for a simple climate warming in which all daily maximum and minimum temperatures were increased by 2˚C/3.6˚F. Snowpack is defined as the snow water equivalent.

BROOK90 Model

BROOK90 is designed to study the processes of evapotranspiration and soil water movement at a point, with some provision for streamflow generation by different flow paths. It simulates the water budget on a unit land area at a daily time step and is applicable to all land surfaces. Input of daily precipitation and maximum and minimum temperatures is required, and daily solar radiation, vapor pressure, and wind speed are desirable. The model then estimates interception and transpiration from a single layer plant canopy, soil and snow evaporation, snow accumulation and melt, soil water movement through multiple soil layers, stormflow by source area or pipe flow mechanisms, and delayed flow from soil drainage and a first-order groundwater storage. The BROOK90 model is described more fully at http://www.nh.ultranet.com/~compassb/brook90.htm.

The separation of daily input precipitation into rain or snow can cause major problems for snow simulation. BROOK90 considers daily precipitation to be all snow if the maximum temperature for the day (Tmax)is below a constant value, set at 0.5° C/0.9° F in this study, and all rain if the minimum temperature (Tmin) is above this.

Snowmelt is based on a degree-day melt factor for snow in nonforested areas, initially set at 4.5 mm d-1 °K-1 for this study. This means that for snow in the open on a day with a 10° C/50° F mean temperature, for instance, 45 mm/8 in. of snow water equivalent will melt to liquid water.

Data

The Hubbard Brook Experimental Forest is located in the southwestern corner of the White Mountains of New Hampshire. Hubbard Brook is world-renowned for research on cycling of water, energy, and nutrients in forest ecosystems (figure 6.4). Data used in this publication were obtained by scientists of the Hubbard Brook Ecosystem Study.

For this case study BROOK90 was used to simulate snowpack for Station 2, a south-facing slope at about 560 m (1840 ft) elevation in the middle of Hubbard Brook Watershed 1, and for Station 14, a north-facing slope at about 730 m (2400 ft) elevation in the middle of Watershed 7 (Figure 6.4). For the south slope, daily minimum and maximum temperatures from Station 1 were decreased by 0.6°C/1.1˚F to account for its elevation below Station 2. For the north slope Station 14 temperatures were used directly. Daily precipitation from Watershed 1 was used for the south slope and from Watershed 7 for the north slope. For the north slope simulated snowpack was compared with the average snowpack from Station 17 at 893 m (2930 ft.) and Station 19 at 610 m(2001 ft.). For the south slope data were available from 1958 through 1999, and for the north slope from 1965 through 1999.

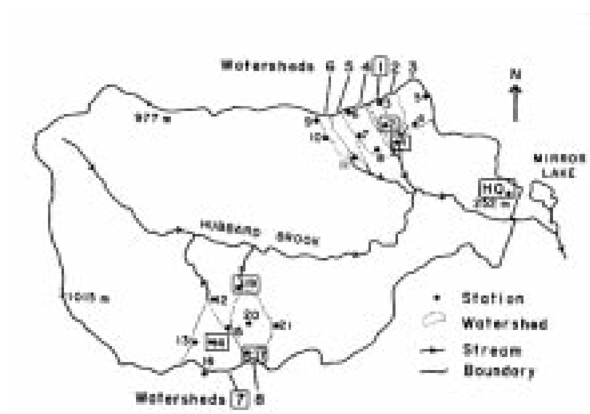


FIGURE 6.4 The Hubbard Brook Experimental Forest, with locations used in this study indicated by rectangles.

Results clearly reflect the high frequency of low snow years in the 1980's and 1990's.

Forest cover on the south-facing slope is 100% northern hardwood forest last cut before 1920. BROOK90 forest and soil parameters normally used for south-facing slopes at Hubbard Brook were used here. Forest cover on the north-facing slope includes some spruce-fir forest, particularly at higher elevations.

Snowpack at Stations 2, 17, and 19 has been measured weekly in a small "snow course" area of typical forest. Water equivalent of the snowpack is measured at 10 points 2 m (6.6 ft.) apart along a line by weighing a snow core removed by a snow tube, which has a serrated cutting edge. The 10 values are averaged.

To simulate climate warming the model was rerun with all daily maximum and minimum temperatures increased by 2°C/3.6˚F.

Results

Simulated snowpack agreed reasonably well with measured snowpack in most years for both north- and south-facing slopes at Hubbard Brook (Figures 6.5 and 6.6). However, in some years disagreement is large and persists through the season. Some of these discrepancies can be attributed to the rain-snow separation problem mentioned above. For instance, a rapid decrease in temperature late in the day after a storm preceding a cold front will cause an overestimate of the snow component of the storm.

Results clearly reflect the high frequency of low snow years in the 1980's and 1990's. Recovery in the 1990's has still not reached the average snowpacks of the 1960's and 1970's.

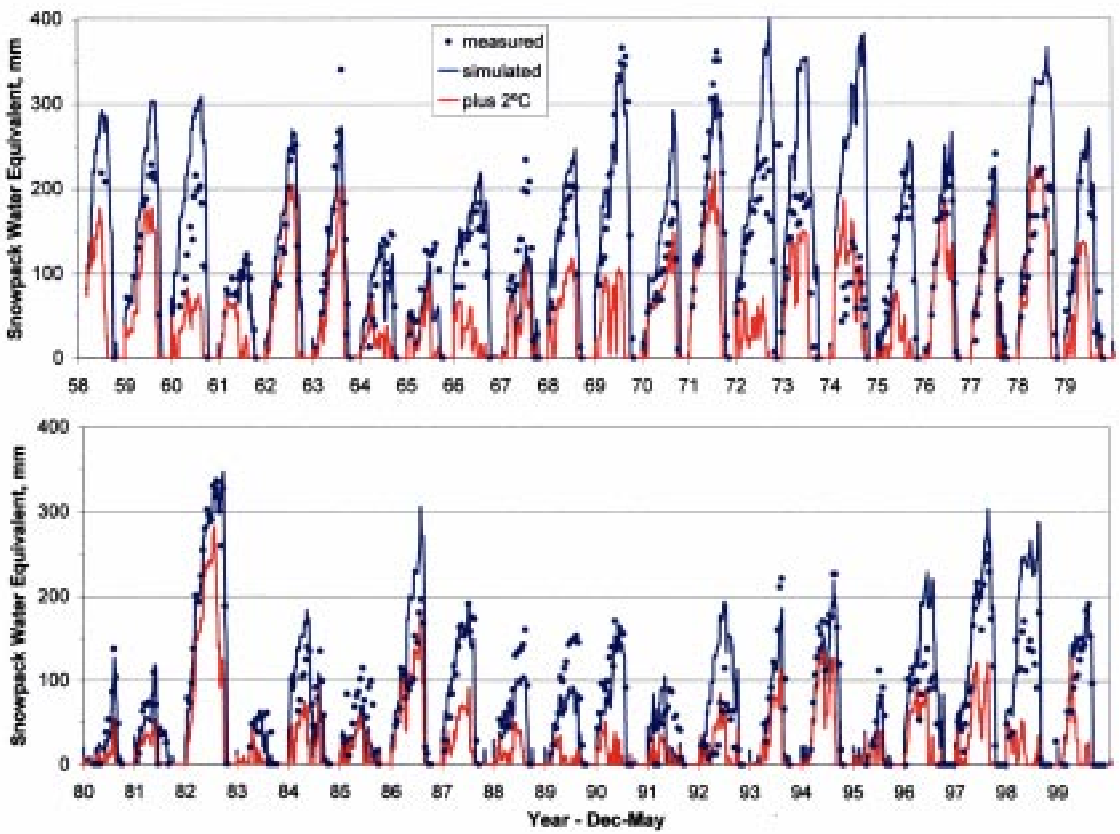


FIGURE 6.5 Simulated (blue line) and measured (blue points) snow water equivalent for a south-facing slope at 560 m elevation on the Hubbard Brook Experimental Forest, New Hampshire, and simulated water equivalent with a 2° C warmer climate (red line). Year is indicated at the beginning of the winter.

Simulated increase in minimum and maximum daily temperatures of 2° C/3.6° F produces a major reduction in snowpack in all years (Figures 6.5 and 6.6). Average February snowpack water equivalent was reduced from 161 to 76 mm (6.3-3.0 in.) for the south-facing slope and from 194 to 133 mm (7.6-5.2 in.)on the north-facing slope. February was chosen to best represent mid-winter snowpack.

Discussion

An increase of all winter temperatures by 2°C/3.6° F in the White Mountains of New Hampshire clearly will cause large reductions in snowpack. For a southfacing deciduous forest at 1840 ft elevation the simulated reduction in February snowpack is 85 mm (3.3 in.) or 53%; for a north-facing slope at 2400 feet the reduction is 61 mm (2.4 in.)or 32%. Duration and depth throughout the season are correspondingly reduced.

The largest changes will occur for times and places where temperatures are currently just below freezing. Two degree increases in these conditions change snow to rain and change from freezing to melting. Thus deep snowpacks produced under cold conditions are not as seriously affected as shallow snowpacks produced in warmer conditions. This is demonstrated by the difference between the two simulated locations.

Simulation of climate change effects on snowpack in the Swiss Alps has shown similar results to those found here.

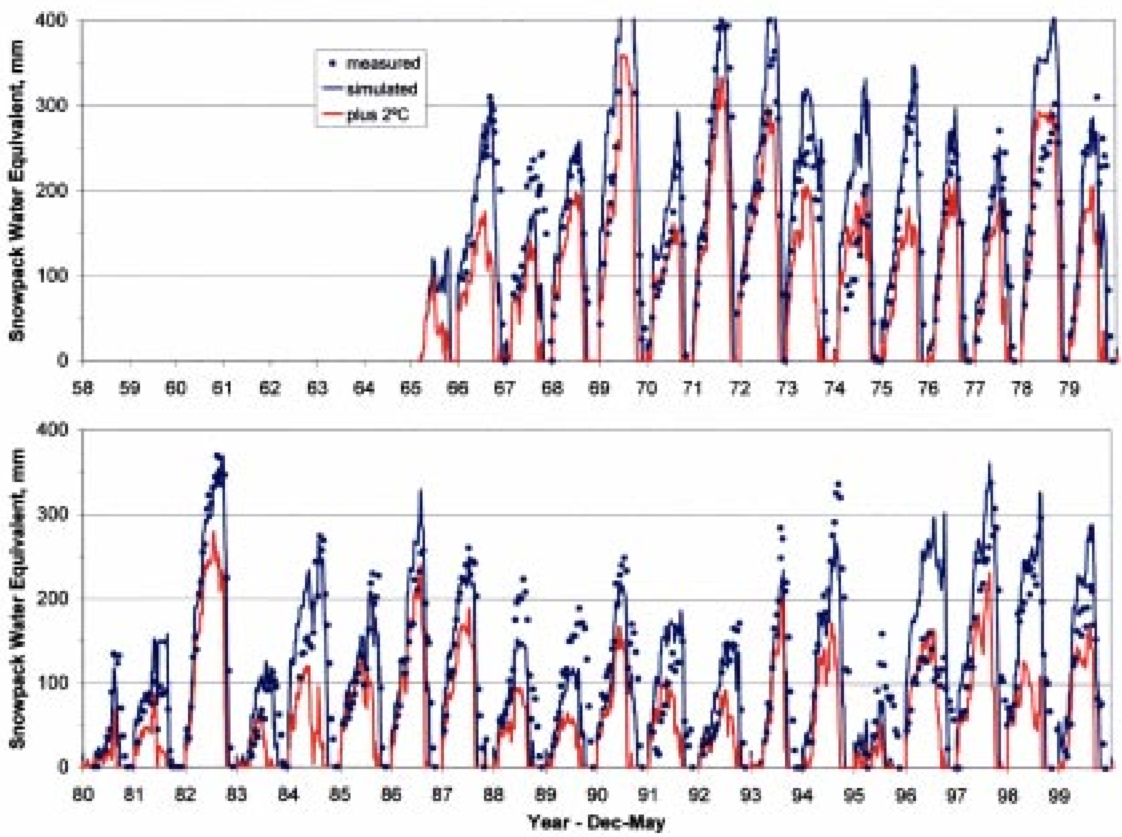


FIGURE 6.6 Simulated (blue line) and measured (blue points) snow water equivalent for a north-facing slope at 730 m (24oo ft.) elevation on the Hubbard Brook Experimental Forest, New Hampshire, and simulated water equivalent with a 2° C/3.6˚F warmer climate (red line). Year is indicated at the beginning of the winter.

…in New Hampshire the cross-country skiing and snowmobile industries will be even more severely impacted than the ski industry and may become non-existent by 2100.

Output scenarios from global climate models (GCM's) were used in a water budget/snow model generally similar to BROOK90. The Hadley Center Model for 2050 indicated a 2-3°C/3.6°- 5.4°F temperature increase and a 10% precipitation increase for eastern Switzerland. Simulation for the Landquart Basin showed a consequent 93 mm decrease in average March snowpack from 454 mm to 361 mm (17.0 - 14.2 in.). This is comparable to the average reduction in February snowpack of 73 mm (2.9 in.) for a 2°C/3.6°F warming in this study.

If climate change in New England includes increased precipitation as well as increased temperature, then the amount of snowpack reduction will be decreased somewhat. The change will depend on details in the relative changes of maximum and minimum temperatures and precipitation during snow season, particularly in the warmer months of December and March, and on the specifics of the interaction of precipitation changes with temperature changes. It is extremely unlikely, however, that snow precipitation would increase sufficiently to overcome the effects of warmer temperature in causing severe reduction of snowpack.

Year-to-year variation in snowpack is larger than the reduction by 2°C (3.6°F) warming. Therefore gradual reductions in mean snowpack content over time will not be as noticeable as periodic snow droughts like the 1980's in New England.

While snowmaking at ski areas may be able to maintain mid-winter snow cover well into the future, warming temperatures will reduce opportunities for early and late season snowmaking and will increase the intensity of mid-winter melts. Researchers have found that a 2°C (3.6˚F) warming will raise the minimum elvation of ski area profitability by 500 m (1640 ft.) in Switzerland. Due to these elevational differences, in New Hampshire the cross-country skiing and snowmobile industries will be even more severely impacted than the ski industry and may become non-existent by 2100.

CASE STUDY 3

The Relationship Between the Winter North Atlantic Oscillation (NAO) Index and Streamflow

by James A. Bradbury

Winter streamflow variability at many inland sites in New Hampshire, Vermont, western Massachusetts and Connecticut show statistically significant correlations with the North Atlantic Oscillation (NAO) on annual and decadal time scales. Consistent correlations between regional temperature or precipitation are not seen with the NAO, but snowfall seems to be the most likely climate variable controlling the NAO/New England (NE) streamflow teleconnection.

Drought in the New England Region

Sustained precipitation deficiencies (meteorologic drought) can be devastating to forest ecology and agriculture, even in the New England region where water is normally thought to be in ample supply. In the 1960's the most severe drought on record was caused by persistent spring and summertime precipitation shortfalls (meteorologic drought) across the region. Naturally, the low precipitation levels were accompanied by low levels of streamflow (hydrologic drought) in rivers all over the seven states, causing public water supply shortages, reduced water quality and a decrease of in-stream water uses such as hydroelectric power generation. Hydrologic drought causes harmful water quality issues such as higher concentrations of pollutants, increased water temperature, and low levels of dissolved oxygen. Furthermore, the impacts of hydrologic drought typically continue beyond the end of meteorologic drought episodes because it can take months for water stored in surface and ground water reservoirs to recover from significant deficiencies.

A Way to Predict Drought?

Identifying the relationships connecting local conditions and remote climate variables such as the NAO may be an important step toward predicting extreme climate events, such as regional drought. This can be done using statistical tools to compare regional climate variables (temperature, precipitation, streamflow… etc.) with indices for large-scale atmospheric circulation patterns, such as the NAO index (Figure 6.7). Modelers have had success at long-range forecasting with the El Niño/Southern Oscillation (ENSO), where the intricate coupling of the Pacific ocean and associated atmospheric variables has allowed for its predictability, with moderate success on seasonal and annual time scales. Similar models applied to the North Atlantic Region offer hope that predicting significant multi-annual changes and trends in the NAO system may be possible.

The North Atlantic Oscillation (NAO) Index

Winter weather patterns throughout the North Atlantic region have historically been greatly affected by changes in the NAO. When the NAO changes between its two modes of variability, the North Atlantic Ocean region experiences changes in wind speed and direction, which affect heat and moisture transport to the surrounding continents and seas.

The NAO index, defined as the atmospheric sea-level pressure (SLP) difference between the Azores high and the Icelandic low, simply describes the steepness of a north-south atmospheric pressure gradient between a low pressure system off the coast of Iceland and a high pressure system over the Azores (Figure 6.7). This index can be computed at any time of the year, but the significance of the NAO as a control on Northern Hemisphere climate variability appears to be most important during winter months, and most research related to the NAO involves winter climate data analysis.

The NAO and North Atlantic Region Teleconnections

Many climate researchers consider ocean and atmospheric variability in the North Atlantic region to be an important index for global climate change. When the NAO is in its positive index mode the Icelandic low tends to be at its furthest point north, and mid-latitude westerlies onto Northern Europe increase driving warm, moist air as far east as Siberia (Figure 6.7, top). During the negative index mode the Icelandic low is much weaker and sits farther southwest, centered between the southern tip of Greenland

Our understanding of how the NAO affects winter climate in the New England region is becoming increasingly clear.

and Newfoundland, causing a "blocking" of the Jet Stream and meridional air flow across the N. Atlantic region (Figure 6.7, bottom). In the negative NAO mode, southern Europe is known to experience more frequent cyclonic activity, leaving northern Europe relatively cold and dry.

NAO and New England Winter Climate

Our understanding of how the NAO affects winter climate in the New England region is becoming increasingly clear. Table 1 highlights several NAO/New England region climatic teleconnection patterns. There is little evidence to support a teleconnection between regional precipitation or temperature and the NAO. However, regional storm track variability and jet stream patterns along the eastern seaboard show important links to the NAO system. Significant changes in sea surface temperatures (SST) off the New England coast have been found when compared with conditions during extreme NAO events. Statistical evidence for an inverse relationship has been found between regional snowfall and the NAO winter index. This means that New England winters characterized by a positive NAO index have less snowfall than winters characterized by a negative NAO index. Streamflow amounts however are above average when the winter NAO index is positive.

The regional climate conditions during low snow winters are associated with more zonal (westerly) airflow (Figure 6.7) such that most of the (US coastal) Atlantic storm activity is displaced to the east (off the coast) and the St. Lawrence storm track becomes the dominant precipitation mechanism. High snow winters typically show the opposite conditions and more closely resemble the negative phase of the NAO. Heavy snow is accompanied by more frequent N. Atlantic "blocking" episodes, and meridional airflow (Figure 6.7). These conditions produce more frequent advection of low-level cold Canadian air into the NE region, a greater number of "Nor'easters" along the Atlantic coast and (as a result) greater regional snowfall.

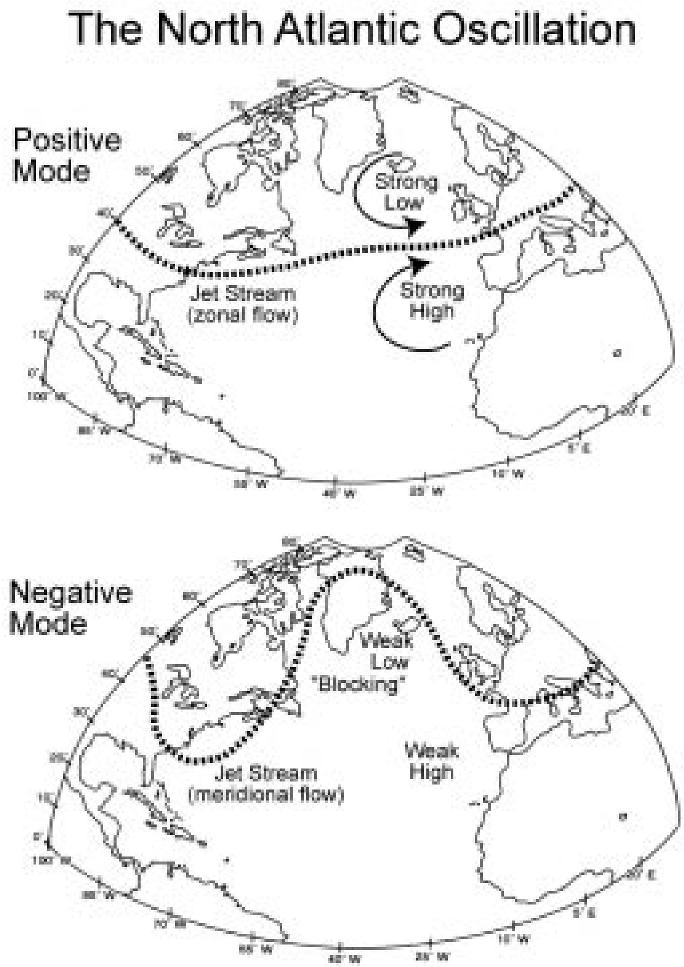


FIGURE 6.7 The positive (top) and negative (bottom) phases of the North Atlantic Oscillation (NAO). During positive NAO winters, the atmospheric pressure gradient between Iceland and the Azores is at a maximum and the mid-latitude westerlies dominate air circulation in the N. Atlantic region. During negative NAO winters the Icelandic low is weak and acts as a blocking mechanism, causing the Jet Stream to buckle, resulting in a wide range of changes in Northern Hemisphere climate conditions.

… winters characterized by below average snowfall are characterized by above average streamflow.

NAO and NE Winter Streamflow

Current research comparing streamflow rates in the New England region with the North Atlantic Oscillation (NAO) index has revealed positive statistical correlations. Time series of streamflow from the U.S. Geological Survey Hydro-Climatic Data Network are significantly correlated with the NAO index, and the strongest NAO/ streamflow correlations appear during the winter (Dec. – March), at streams away from the coast, in New Hampshire, Vermont, Massachusetts, and Connecticut. Figure 6.8 illustrates the strength of the linear correlation between standardized winter average streamflow in the White River, VT and the winter NAO index. Thus, winters characterized by below average snowfall are characterized by above average streamflow.

A physical mechanism other than precipitation, or temperature driven snowmelt, must be found to explain the NAO/ streamflow correlation. Interestingly, streamflow records from sites in Maine and Rhode Island show little to no sign of correlation with the NAO.

One possible physical explanation for the NAO/ streamflow teleconnection could be the winter snowfall variability attributed to the NAO. Since the temporal distribution of winter streamflow in the region is significantly affected by the proportion of precipitation that falls in the form of snow, rather than rain, a winter with greater snowfall would be expected to have lower average streamflows and vice versa. This is because the introduction of precipitation into the hydrologic cycle in the form of snow, rather than rain, effectively puts that water in temporary storage, rather than making it immediately available for runoff.

The NAO may be most closely associated with longer-term trends in regional climate, rather than just annual variability. Figure 6.9 tells a similar story.

The winter NAO exhibits a strong correlation with winter average streamflow, when both records are smoothed. These results suggest that the strongest climatological association between the NAO and regional climate are on a multi-annual or decadal time scale. Of utmost interest is how well these records (Figure 6.9) track one another

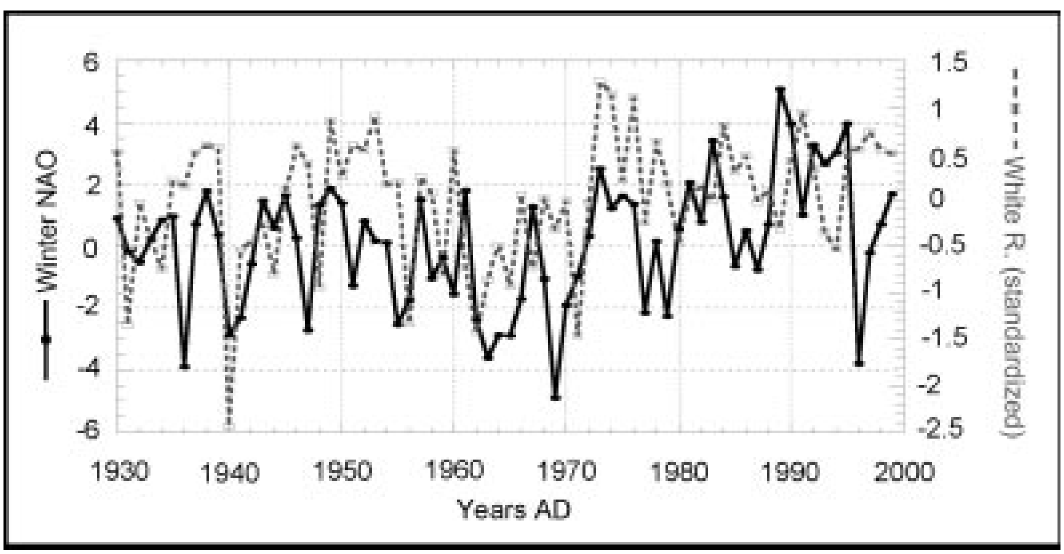


FIGURE 6.8 Time series plots of the winter NAO and standardized winter average streamflows for the White River in Eastern Vermont (R^2=0.092; alpha level =0.10).

The NAO may be most closely associated with longer-term trends in regional climate, and less so with annual variability.

through the 1960's drought, suggesting that if prediction models for the NAO prove to be accurate, then the knowledge of this teleconnection may be particularly useful for future drought forecasting in the region.

Conclusions

Winter climate in the New England region shows subtle yet important teleconnection patterns with the NAO. Regional precipitation and temperature variability appear uninfluenced by the NAO yet storm-tracking patterns caused by the NAO system have a significant impact on snowfall variability, possibly resulting in the NAO regional streamflow association identified here. The results of this study also reveal a significant long-term effect of the NAO on New England regional streamflow (Figure 6.9), suggesting that climate conditions associated with the negative phase of the NAO could be responsible for annual persistence of severe drought conditions. Figure 6.9 clearly shows that the negative NAO trend during the 1960's accompanied well below average winter streamflows during this time period. Further evidence supporting a relationship between a negative NAO and early 1960's drought comes from studies which attribute the persistence of this drought to the below average air temperatures, as well as below average SSTs, throughout the east coast region (both of these conditions are associated with a negative NAO, see table 1).

The NAO streamflow teleconnections (presented here) suggest that the NAO may be most closely associated with longer-term (decadal) trends in regional climate, and less so with annual variability. Hence, to the extent that the NAO proves to be a predictable climate index it may also become an important predictor of annual or multi-annual climate change in the region.

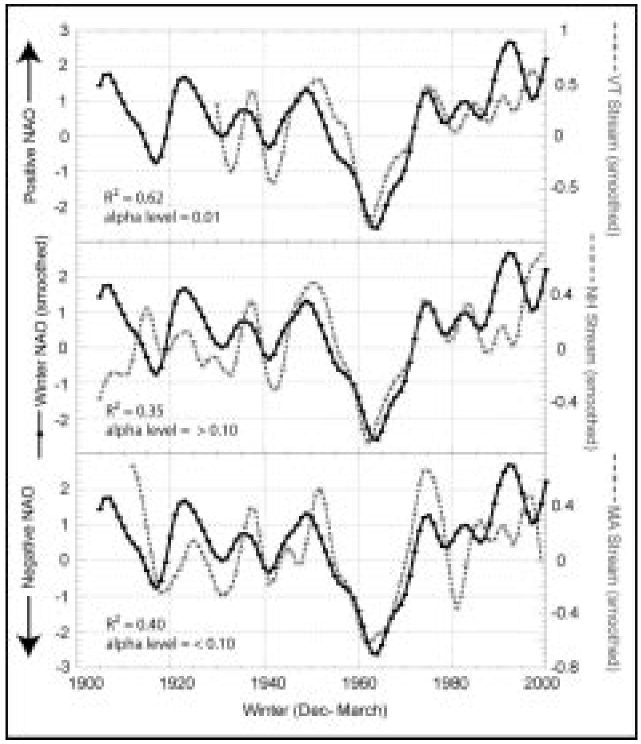


FIGURE 6.9 Standardized winter streamflow at the White River, VT (top), the Pemigewasset River, NH (middle), and a combination of the North and Westfield Rivers, MA (bottom) were smoothed and compared with a smoothed NAO index, revealing comon trends in their long-term variability.

CASE STUDY 4

Climate Variability and Winter Flounder Abundance in Southern New England

by Henry Walker

Between 1960 and 1990, the winter sea water temperature in Narragansett Bay warmed by almost 3ºC (5.4˚F), providing an opportunity to document marine ecosystem changes related to this magnitude of a temperature shift in Southern New England. In Narragansett Bay, warmer winters are correlated with smaller winter-spring phytoplankton blooms, an observation that has been experimentally reproduced by conducting a cooling experiment in marine mesocosms during a warm winter.

During the past 25 years winter flounder abundances in southern New England have been in decline. One hypothesis is that warmer sea water temperatures could result in more of the winter marine phytoplankton bloom being consumed in the water column by pelagic food chains, with reduction in the amount of fixed carbon available to benthic (bottom dwelling) food chain members such as flounder. Herring stocks (a pelagic food chain member), which feed in the water column have been on the increase. Another hypothesis would be that temperature increases could also affect predation and survival of winter flounder during critical early life stages. Are the seawater temperature increases, with the resulting reductions in the magnitude of the winter-spring phytoplankton bloom, and declines in flounder abundance due to climate change?

The abundance of winter flounder has been independently monitored and documented by Rhode Island Fish and Wildlife (RIFW) service, the University of Rhode Island (URI), and in the vicinity of Niantic River, Waterford Connecticut (Figure 6.10). There is some debate about how much of the observed decline is due to heavy fishing pressure, and how much may be attributed to warmer winters in southern New England. The physiology and ecology of winter flounder provides some interesting clues.

The winter flounder (*Pseudopleuronectes americanus,* Figure 6.11) is a former dominant member of the bottom dwelling fish community in southern New England. Most adult fish migrate into inshore waters in the late fall and early winter, and spawn in late winter and early spring when seawater temperatures are quite cold. To help accomplish this feat, winter flounder make use of unique antifreeze proteins found in a number of polar fish which allow them to survive in temperatures as low as -1.9ºC (28.6˚F). In comparison, most fish typically freeze at a temperature of -0.7º C (30.7˚ F). Winter flounder spawning occurs at night in the upper portions of estuaries. Eggs are attached to the bottom. Hatching rate, larval development rate, and mortality rates due to predation are temperature dependent. It appears that a significant component of the decline in

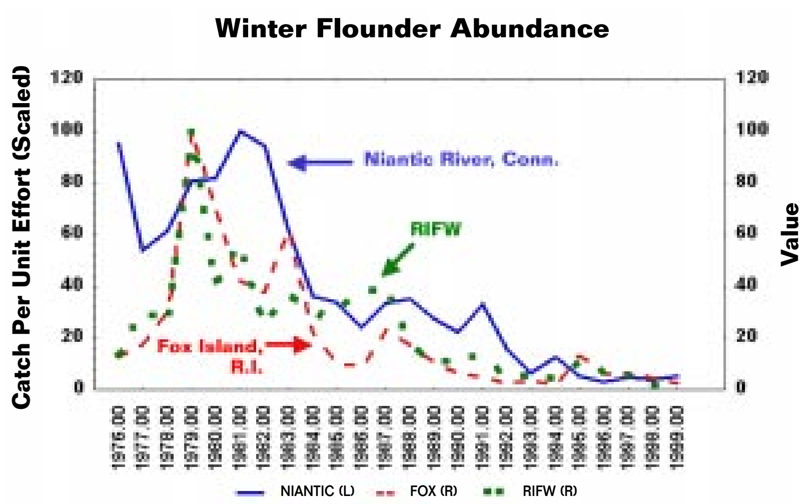


FIGURE 6.10 Abundance of winter flounder determined by the Rhode Island Fish and Wildlife service (RIFW) and others in the Niantic River and at Fox Island.

A series of warm winters such as we have recently experienced in southern New England is clearly unfavorable for winter flounder.

winter flounder abundance in southern New England is associated with a shift from a period with cold winters and seawater temperatures in Southern New England during the 1960s, into a period of relatively warmer winters during the following three decades. A series of warm winters such as we have recently experienced in southern New England is clearly unfavorable for winter flounder.

According to the recent Intergovernmental Panel of Climate Change (IPCC 2001), in the Northern Hemisphere the 1900s has been the warmest century in the last 1000 years, and the 1990s have been the warmest decade in the past century. Warming has been greatest over Northern Hemisphere continents during the winter, and the same is true for the New England region. While the New England Region has warmed by an annual average of 0.4˚ C (0.7º F) over the past century (since 1895), due to its coastal location, Rhode Island's annual temperature has warmed by 1.3˚ C (2.3º F) over the same period of time. Warming during the winter months (December, January, February) in Rhode Island has increased a full 1.7˚ C (3.0º F) since 1895.

If this warming trend continues toward milder southern New England winters in the next few decades, even with reductions in fishing effort winter flounder stocks could be slow to recover. To answer the question raised above ("Are seawater temperature increases, reductions in the winter-spring phytoplankton bloom, and declines in flounder abundance due to climate change?"), the answer at this point is "perhaps."

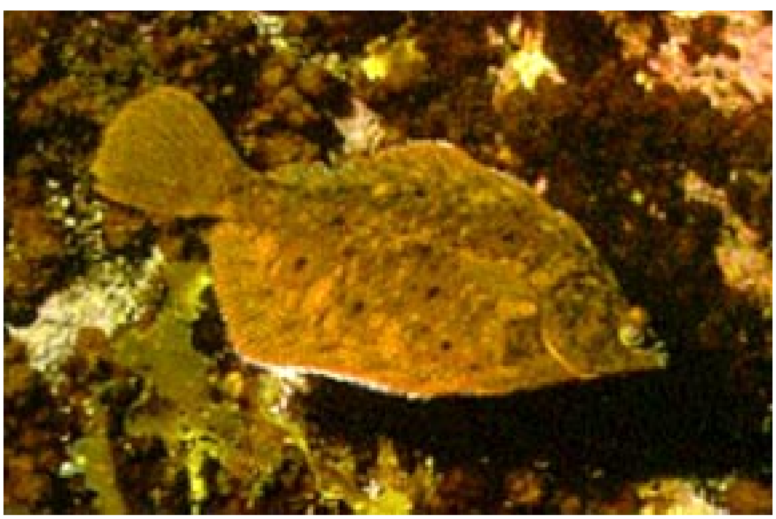


FIGURE 6.11 The winter flounder

CHAPTER 7

HUMAN HEALTH

By Barrett Rock, Lynne Carter, Ben Sherman, Steve Hale, and Paul Epstein

Introduction

Climate change could impact human health in several ways. The effect could be direct, such as heat stroke, or by impacting the geographic range of diseases and vectors (carriers, such as ticks, that transmit disease from one host to another), or indirect, through increased air pollution and decreased water quality. In the New England region, climate impacts (both present and future) to human health fall into three major categories: 1) vector-borne diseases, 2) water/marine-related diseases, and 3) air pollution-related diseases. In addition to these, regional health-related issues include heat stroke and extreme events such as fires, flashfloods, and ice storms.

Health risks associated with climate change are difficult to assess with certainty. Present and future health risks are complicated by such factors as poverty, quality and availability of healthcare, food quality and abundance, sanitation, water quantity and quality, public health infrastructure, access to air conditioners, genetics, and lifestyle choices. In addition to the difficulty of ascribing health conditions to climate change impacts, such impacts on human health vary among different populations and locales. Urban locations are more likely to be impacted by high temperatures, while more rural locations may be more susceptible to vector-borne diseases such as Lyme disease. At present, only limited data and analyses are available at the regional level that connect climate change with human health problems.

At present, climate in the region has significant impacts on human health such as seasonal allergies, winter colds and flu, and summertime air quality problems. Although some health benefits may be seen, regional concerns about the future include increased air pollution, reduced water quality, new distributions of infectious diseases and disease carriers, red tides, heat waves, storms and droughts.

Features of the region make inhabitants and visitors vulnerable to climate-related health changes. High elevation sites favored by hikers increase their exposure to poor air quality. Large deer and mice populations in areas populated or visited by humans increase the likelihood of exposure to ticks infected with Lyme disease. Downwind location and the number of large urban areas and transportation corridors make the region vulnerable to airborne pollution.

Two illustrative case studies dealing with hiker health and Lyme disease are presented at the end of this chapter. These case studies provide valuable insight regarding the present gaps in data and our understanding of climate impacts on human health.

Infectious and vector-borne diseases are extremely sensitive to climate conditions – especially temperature and humidity.

Current Stresses on Human Health

Infectious and Vector-borne Diseases

Infectious and vector-borne diseases (e.g. the encephalitis viruses and their mosquito vectors) are extremely sensitive to climate conditions – especially temperature and humidity. Their geographic distribution responds actively to changes in minimum winter time temperatures, which have increased in parts of the region from 2-3° F over much of the region during the past century.

Mild, wet winters combined with warm, wet summers punctuated by heavy rains, stimulate mosquito breeding and biting. Northerly outbreaks of mosquitoes have occurred in particularly warm years when there have been several days of above 85° F temperatures. One strain of encephalitis – St. Louis encephalitis – has occurred after excessive rainfall in January and February followed by drought in July. Of particular regional concern is the recent increase in the incidence of eastern equine encephalomyelitis, which can infect humans and horses.

Climate change also could affect the spread of tick-borne Lyme disease, as tick populations survive mild, wet winters and flourish during summer months. According to the Centers for Disease Control, the New England region accounts for 90% of the 100,000+ cases of Lyme disease reported nationwide since 1982. As will be seen in the Lyme Disease Case Study, a more thorough understanding of the impact of climate on ticks is needed.

Air Pollution Impacts on Human Health

Connecting air pollution effects to human health issues is problematic because health risks are complicated by multiple factors. The elderly, the weak, those who smoke, and access to air conditioning, are all factors that influence the impact of poor air quality on human health. As seen in the Hiker Health Case Study in this chapter, sensitive individuals are at greater risk than less sensitive. Where one lives also affects the likelihood of exposure to either chronic or acute poor air quality. In the New England region, those living in major urban centers or along the coast are more likely to be exposed to unhealthful levels of ozone. Those living or recreating at elevations above 2,500-3,000 ft. are also more likely to be exposed to elevated levels of ozone. As the Case Study demonstrates, sensitive individuals are affected even at relatively low levels (40ppb) of ozone.

At present, limited data are available on the impact of ambient air pollution on human health. The Hiker Health Case Study presented is one of the few published studies connecting lung function to exposure of fine particulates and ozone. Although a great deal of data are available, more effort is needed that connects seasonal air quality with documented cases of asthma, chronic emphysema, and other pulmonary problems. Additional work is also needed connecting other forms of air pollution (SO_2, sulfate aerosols, acidic fogs, etc.) with human health problems.

The ice storm impacts included 17 deaths across New York and New England …

Red Tides

The present warming trend has led to another growing health problem in the region is the incidence of red tides, fish kills, and bacterial contamination in shellfish. Hotter summers favor more toxic forms of algal blooms, such as blue-green algae and the dinoflagellates that often are the cause of red tides. Persistent red tides often reduce oxygen levels in the water, affecting fish populations, sea grasses and shellfish beds. The toxic algae are also taken up by shellfish and cause human health problems when the shellfish are eaten. Other water-borne diseases that may affect the region could include cholera, which can exist both in the dormant and infectious forms, depending on pH, temperature, salinity, and nutrient levels in the water. Food-borne diseases, such as E. coli, salmonella, cyclospora, and hepatitis A, are also enhanced by recent warmer, moister conditions across the New England region.

Extreme Events

In January of 1998, a series of devastating ice storms hit northern New York and New England, causing extensive damage to forests, energy and transportation infrastructure, as well as impacting human health. Over 1.5 million people across the region were without power for up to three weeks, resulting in inconvenience and frustration for many, a dramatic increase in colds and flu-like ailments for some, and carbon monoxide poisoning and deaths from asphyxiation for a few as the result of improper ventilation of power generators.

The ice storm impacts included 17 deaths across New York and New England, many due to carbon monoxide poisoning and asphyxiation. In Canada, 26 deaths were reported, many due to hypothermia. Human health and safety impacts related to the storm were significant, but certainly would have been greater were it not for the rapid response from volunteers, state and local governments, the National Guard, and others.

Other climate-related stresses on human health include the danger presented by extreme events such as floods, hurricanes, droughts, and heat waves. Each of these extreme events can pose direct and indirect health-related risks to vulnerable populations. In addition to drowning deaths, flooding can also be an indirect risk to humans, providing new breeding sites for mosquitoes, or altering water quality.

Droughts also wreak havoc on living systems. They concentrate microorganisms, reducing water quality; they encourage aphids, locusts, and white files; and, when interrupted by sudden rains, spur explosions of rodent populations that can, among other things, transmit hantavirus pulmonary syndrome. Although incidence of hantavirus is often associated with the Southwest, this disease also has surfaced in the region, particularly in New York. While these examples of extreme events illustrate climate impacts to human health, further analysis is needed before a positive link can be made between these events and the current warming trend.

During heat waves, there is less nighttime relief from heat stress.

Future Impacts of Climate Change on Human Health

Potential Benefits

Many regional inhabitants would welcome milder winters and longer springs and falls. Milder winters could mean a significant reduction in seasonal colds and cases of the flu. Certainly storm-related accidents could be reduced (assuming that ice storm frequency did not increase) and longer growing seasons (including longer springs and falls) would allow more healthful outdoor activities. Such increased outdoor activities could be adversely impacted by extended perods of poor air quality, increases in insect pests due to milder winters, and more outbreaks of infectious and vector-borne diseases. As with the other sectors, the benefits are likely to be outweighed by the negative impacts of climate change.

Infectious and Vector-borne Diseases

The projected increases in temperature and precipitation in the future could promote the further expansion of current infectious and vector-borne diseases. Milder, wetter winters, combined with warmer, wetter summers, especially if punctuated by extreme rain events, could result in more frequent and more northerly outbreaks across the region. In the case of Lyme disease, deer and mouse population dynamics play an important role in disease occurrence and distribution. Since ticks are sensitive to high temperatures, more southerly portions of the region may see a decline over present levels of outbreaks. Since "surprise" occurrences in infectious and vector-borne diseases by definition cannot be predicted, no projections can be made.

Extreme Events

Events such as the 1998 ice storms and other extreme events may be on the increase in the 1990s (see Chapter 2). However, uncertainties exist in projecting further increases in the future. Assuming droughts and flooding were to occur in association with the projected future climate changes, alteration of water quality could impact human health.

Heat-related Mortality

While heat and cold are not presently significant causes of death in the region, cities of the region could experience an increase in heat-related mortality due to climate warming. Three important factors play a role in reaching heat-related mortality thresholds: the effect of absolute temperature (highs); consecutive numbers of hot days; and humidity levels. The threshold effect occurs when a stress, for example temperature or duration of hot days and nights, goes beyond the level after which mortality rises rapidly. During heat waves, there is less nighttime relief from heat stress.

The high humidity levels typical of the region are related to the heavy forest cover combined with frequent rainfall. The evapotranspiration from the dense forest cover maintains and elevates high relative humidity levels. Increasing nighttime temperatures – a rise in minimum temperatures – are likely to be directly detrimental to human health.

The human health sector may be more sensitive to climate change than the other sectors considered in this regional report

Air Pollution Impacts

Projected temperature increases for summer months from both models will mean that air pollution (O_2, SO_2, sulfate aerosols) across the New England Region is likely to become worse. Unless the Nation adopts an active effort to lower NOx and SOx emissions in the future, air quality across the region will continue to be a significant human health problem over the next 100 years.

Information and Data Needs

The human health sector may be more sensitive to climate change than the other sectors considered in this regional report because many disease and vectors are climate dependent. However, little effort to date has been made within the human health community to correlate human health issues and climate variables such as air quality across the region, in large part due to the difficulties cited earlier. Another reason may relate to the community's short-term focus on treating the immediate needs of a patient rather than addressing long-term cause and effect relationships. The two most significant gaps in information relate to the need for a more thorough analysis of climate-realted impacts on human health and the need for effective education efforts alerting the public to the health hazards and risks associated with such climate-related impacts. An active effort is needed to promote analysis of existing data that may improve our understanding of how climate and human health are interrelated.

Adaptive Strategies

Strategies to address potential impacts of climate change on the health of those residing in and traveling throughout the region are varied in focus and in cost. Some options, listed below, relate generally to health impacts that are felt today as well as in the future, whether they are vector-borne, heat-related, or the result of extreme events. This list is not exhaustive and should be viewed only as a starting point.

- Develop monitoring and response programs to identify and detect emerging diseases and sites of potential vectors, as well as train physicians and public health workers to recognize and treat emerging diseases;
- Educate both physicians and the public on the potential risks to human health posed by climate change;
- Develop early warning systems and preventive programs for populations at-risk from extreme events, vector-borne diseases, and other potentially health-threatening events;
- Support research to investigate methods to curb the proliferation of problem species, including techniques designed to control vector populations; and
- Encourage fortification of sanitation infrastructures to withstand extreme events such as flooding.

CASE STUDY 1

Hiker Health: The Effects of O_3 and Other Pollutants on Pulmonary Function

by Barrett Rock

Mount Washington and the major peaks region in the White Mountains National Forest, NH, host some 60,000 hikers per year. During hot summer days this region is often impacted by elevated levels of ground-level ozone, suspended fine particles of soot, and acidic aerosols (droplets) of anthropogenic origin. The exposure to ozone, fine particulates and strong acidic aerosols pose a health threat to hikers.

One of the few studies of the impact of air quality, under ambient conditions was conducted on hikers engaged in day hikes on Mount Washington. This study of adult hikers was conducted during the summers of 1991 and 1992 by research scientists from the Harvard Medical School, the Harvard School of Public Health, and the Appalachian Mountain Club (AMC). The study evaluated the short term effects of exposure to ambient ozone levels, fine particulate matter ($PM_{2.5}$) and aerosol acidity, on lung function of healthy adults exposed while hiking at elevation.

Background

Mount Washington and all of the New England Region is downwind from major sources of air pollutants. Tropospheric ozone is the photochemical product of reactions of nitrogen oxides (NO_x) and volatile organic compounds (VOCs) in the presence of sunlight and high temperatures. Due to Mount Washington's geographic location, it is subjected to frequent episodic ozone exceedances (both 1-hour 120 ppb and 8-hour 80 ppb) during warm summer months. The summer of 1991 was characterized by a greater number of hot days (at or above 90°F) than was 1992. Due to the connection between temperature/amount of sunlight and ozone formation, higher ozone levels characterized the summer of 1991 than the summer of 1992.

The AMC and the Mount Washington Observatory have been monitoring ozone levels along an elevational gradient (at the base of Mount Washington - elev. 1500 ft./480 m, and at the summit at 6288 ft./1910 m) since 1987. Average ozone exposures during the period of this study ranged from 21 to 74ppb.

Ozone concentrations on a given date may vary considerably with elevation. The base layer of the atmosphere (the troposphere – extending from ground level to 10-15km/6-9 miles above the Earth) is in contact with the surface, resulting in mixing. Because of this, the lowermost layer of the troposphere is called the mixing layer (figure 7.1). The mixing layer extends up to 1km (3,280') or more above the surface, and varies in thickness based on time of day. The tropospheric layer above the mixing layer is termed the "stable layer" (due to the limited amount of turbulence characterizing this layer), and extends to the top of the troposphere. Long-distance transport of air pollutants may occur at the boundary between the mixing and the stable layers, and thus, hiking above approximately 3000' may expose the hiker to elevated levels of ozone and other pollutants not encountered at lower elevations (figure 7.2).

The Study

The lung function of adult hikers was measured before and after hiking on Mount Washington during 74 days during the summers of 1991 and 1992. The mean hourly ozone levels at both base and summit stations during the time of day of most day hikes was at or slightly above 40ppb (Figure 7.2).

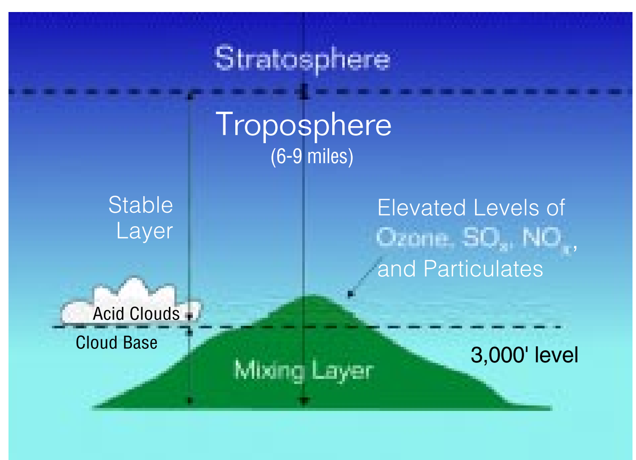


FIGURE 7.1 A diagrammatic representation of the mixing layer at the base of the troposphere, and the affect that elevation has on exposure to both acid cloud moisture and air pollutants.

These results are surprising, especially since average ozone exposure levels were relatively low…

The effects of acute ozone exposure in humans are associated with decreased pulmonary (lung) function and can result in shortness of breath, coughing, and pain while inhaling. Controlled exposure studies associate ozone-exposure (80 - 400 ppb) to acute reduction in lung function and increased respiratory symptoms. Such chamber studies are often inconsistent when compared to natural settings and ambient ozone levels.

The Study Population

Volunteers were solicited from adult hikers (between 18 and 65) beginning a day hike at the trail entrance to AMC trails on the eastern slope of Mount Washington. During the summer months of 1991 and 1992, all hikers who volunteered were evaluated (n=766). Current non-smokers were evaluated in the final study (n=530), along with hikers with self-reported history of physician-diagnosed asthma or severe wheeze symptoms (n=40), and former smokers (n=125).

The Findings

Post-Hike percentage of change was determined and adjusted for hiker age, sex, smoking status (former vs. never), health history (asthma or wheeze), hours hiked, carrying a backpack, reaching the summit, and ambient temperature. It was found that for Every 50 ppb increment in mean ambient O_3 there was a 2.6% decline in forced expiratory volume (FEV_1); 2.2% decline in forced vital capacity (FVC), and a 4-fold greater response (15% reduction) in hikers with a history of asthma or wheeze. Former smokers exhibited increased sensitivity to a lesser degree than those with a history of asthma or wheeze.

The results presented in this hiker health study indicate that the effects of ozone exposure were greater than have been described previously in either field studies or controlled exposure chamber studies. These results are surprising, especially since average ozone exposure levels were relatively low (approximately 40ppb), one third of the current EPA ambient air quality standard (1-hour exposure to 120ppb ozone). These findings suggest that chronic exposure (8-hours duration) to low levels of ozone may be as damaging to pulmonary function as acute (short-term) exposure to higher levels of ozone. Finally, these results raise the concern that suppposely healthful exercise in the great outdoors may actually be hazardous to our health.

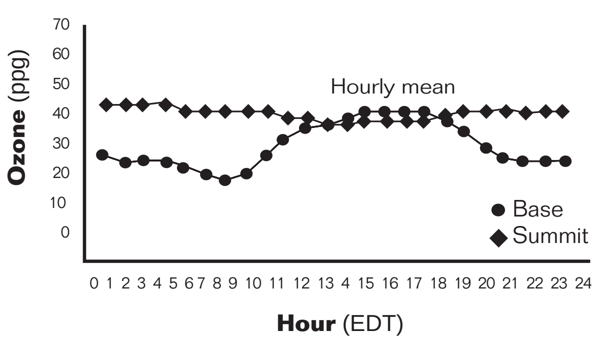


FIGURE 7.2 Mean hourly ozone levels (ppb) at the summit and base of Mt. Washington for the 74 days on which hikers were evaluated in summer 1991 and 1992. Note the pattern of the base station hourly mean ozone levels (elevated in the afternoons) and the lack of such a pattern at the summit .

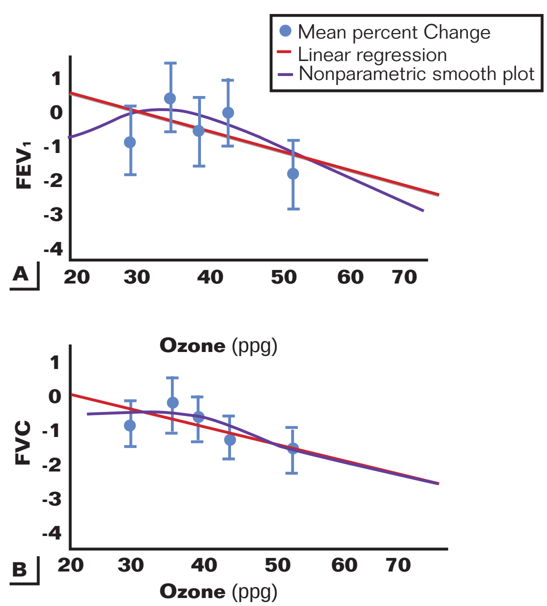


FIGURE 7.3 Posthike percentage changes in (A) forced expiratory volume in 1 sec (FEV_1) and (B) forced vital capacity (FVC) versus mean O_3 exposure after adjustment for age and other factors.

CASE STUDY 2
Lyme Disease

by Barrett Rock

One of the most important vector-borne diseases for the region is Lyme disease, borne by deer ticks. Warmer, wetter winters, coupled with more moisture year-round may promote the breeding and abundance of these vectors, their biting rates and growth of the microorganisms involved. Thus, the types of the climate change projected by the Hadley (increases of 6ºF and 30% increase in precipitation) and Canadian (increases of 10ºF, 10% increase in precipitation) climate models over the next 100 years are likely to have significant impacts on the occurrance and distribution of Lyme disease.

Most important for biology, and in particular, diseases, is the minimum temperature (both nighttime and wintertime). Over the past cenury, a regional increase of 1.8ºF in winter temperatures has occurred. Minimum temperatures are increasing at over twice the rate of the regional average annual temperature, and may account for the extension of Lyme disease across the region.

Background

Infectious and vector-borne diseases are known to be extremely sensitive to climate conditions, and their geographic distribution responds directly to changes in minimum wintertime temperatures. Research has documented a direct spatial and temporal relationship between deer tick nymphal abundance and human Lyme disease, as well as a strong correlation between the spread of Lyme disease and precipitation/soil moisture. Thus, the deer ticks and the Lyme disease virus that they carry may be highly responsive to temperature and humidity. Figure 7.4 presents the distribution of reported cases of Lyme disease in 1998, and figure 7.5 presents the "danger months" when the likelihood of coming in contact with deer ticks is the highest.

The milder wet winters, combined with warmer wet summers projected by the Hadley model could characterize the New England region in the next century, could result in more frequent and more northerly outbreaks of Lyme disease throughout the region. At present, the highest number of cases reported in the United States for Lyme disease in humans centers on the Northeast, where the highest number of cases reported for 1998 were in New York and Connecticut (Figure 7.4). However, climate change could provide a health benefit to humans vulnerable to tick-borne diseases. Ticks are sensitive to high temperatures, and the summer temperature increase projected in the Canadian model could result in tick populations declining with this more extreme warming trend, especially in southern and coastal portions of the region.

Uncertainties

Deer tick population dynamics may also be influenced by the production of acorn crops (mast) across the region. Both deer and white-footed mice use acorns as a major food source and

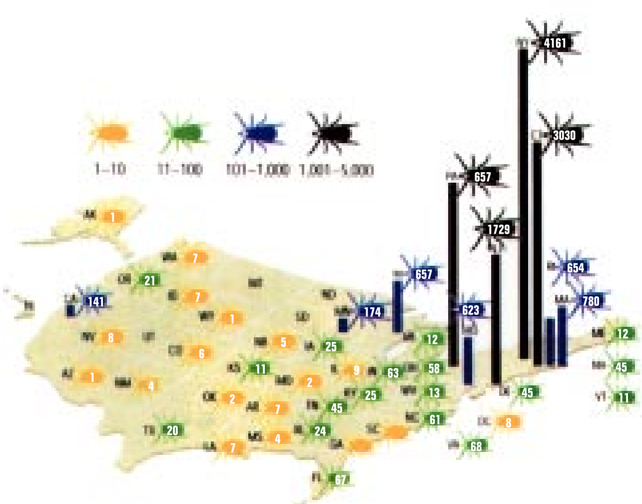


FIGURE 7.4 Reported cases of Lyme disease in 1998.

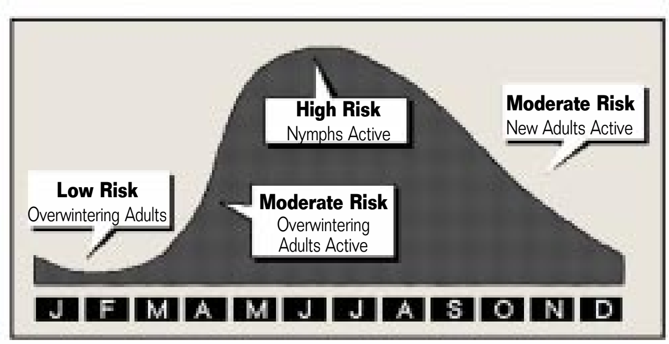


FIGURE 7.5 Lyme Disease: The Danger Months.

“At-risk” areas for high tick populations need to be identified and information provided to people living in the area.

winter survival of both species depends both on the severity of the winter and on access to, and extent of, acorn crops.

Although some years are good acorn production years for oak (up to 50,000 acorns produced per mature tree) and others are poor mast years (fewer than 1,000 acorns per tree), the actual connection between climate and acorn production is poorly understood. In Rhode Island, 1994, 1996 and 1998 were wet years and good years for ticks and Lyme disease outbreaks, while 1993, 1995 and 1997 were dry years, bad for ticks, with fewer cases of Lyme disease reported. Dry years are apparently good for mast production, and heavy mast production, coupled with a mild winter, will result in increases in mice and deer populations in the following year and (due to a larger reproducing population) the year following. To better understand the impacts that potential climate change in the future may have on Lyme disease, we must learn more about these various factors and how they influence deer tick population dynamics.

Soil moisture is also important because it allows for the survival of the tick nymphal stage across the summer months. If the soil is drying up by Memorial Day when the nymphal stage ticks are emerging, many of them may not survive, meaning a bad year for ticks, since studies suggest that the nymphal stage is the most important stage in determining the population of ticks.

Lessons Learned

- A better understanding of the key factors affecting Lyme disease transmission (masting vs. soil moisture or both) is needed.
- “At-risk” areas for high tick populations need to be identified and provided to people living in the area.
- Improved educational programs on the factors that influence tick population dynamics, as well as the methods of transmission of the infectious agent, are needed.
- Once the factors affecting Lyme disease transmission are known, “tick alert” announcements should be made public.
- Hotter summers in the future could limit tick populations, since ticks are sensitive to high temperatures.

Adaptive Strategies

To reduce human infections with tick-borne diseases, focus needs to be placed on the areas where the tick concentrations are highest. In these targeted areas, physician education, improved diagnostics, and regionally based community-implemented tick control strategies should be initiated along with effetive public education programs. For reducing human exposure to the ticks, one method would be to begin issuing “disease impact statements” made as new land is developed for use. Currently, 75% of the Lyme disease infections are in people who reside in known at-risk areas. Once the relationship between masting and soil moisture are clarified and characterized, annual public service announcements should be issued to alert the public on the health risks as they vary from year to year.

CHAPTER 8

THE ECONOMIC IMPACT OF CLIMATE CHANGE ON THE NEW ENGLAND REGION

By Greg A. Norris

This chapter describes an initial effort to evaluate the nature of cause and effect impacts of climate change on the economy of the New England Region (including upstate New York[1]). The economic impacts on three segments of the regional economy were examined on a state-by-state basis. The three segments are natural resources, tourism, and health care. Climatic changes can have impacts on the economy through myriad cause and effect chains. One such cause/effect chain was examined in detail: the potential consequences of regional climate change on fall foliage-related tourism.

Due to the narrow scope of this initial assessment, it must be seen as only the first in a series of steps needed to fully understand the true economic impacts of climate change on the region. It is important to note that this initial effort has highlighted the complexity of the problem. Due to limitations in availability of appropriate data, the present study does not provide a quantitative assessment of any of the segments considered.

Four “links” are identified in a chain of potential impacts stemming from potential climate changes to eventual economic impacts. This chapter focuses on summarizing the implications of what is known about the latter two links in Figure 8.1, with a particular emphasis on the last link: economic impacts of behavioral changes. The Inplan Economic model was used in this initial analysis.

Summary of Key Findings

The major conclusion from this initial analysis is that while each of these segments of the economy are important to the people of the region in *absolute* terms, it is not possible to quantify their economic impact on regional economic activity. Thus, the natural resources sectors employ roughly 100,000 people in New England plus upstate New York, where they pay roughly $630 million in wages and compensation (in 1996 dollars); the split between New England and upstate New York is roughly 50% each. Tourism employs 250,000 New Englanders and another 106,000 upstate New Yorkers, paying total wages of greater than $6 billion. Finally, Health Care employs 650,000 people in New England alone, where it pays in excess of $20 billion in wages and compensation. Converting these absolute figures into meaningful economic impacts is not presently possible due to the high levels of uncertainties regarding the full impact of climate change on each of these segments. As will be seen in the detailed assessment of such impacts on fall-foliage tourism, appropriate datasets on fall tourism are not readily available.

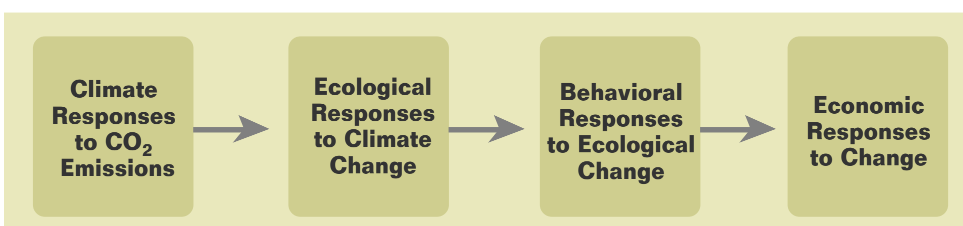


FIGURE 8.1 Links in the impact chain from greenhouse gases to the economy.

[1] Upstate New York is defined herein as consisting of all of the state of New York except the following predominantly urban counties which are in the immediate vicinity of New York city: Nassau, Suffolk, Kings, Queens, New York (county), Bronx, Rockland, Westchester, Orange, and Putnam.

In terms of the regional economy, the health care segment… accounts for the largest share…

In terms of the regional economy, the health care segment (comprised of the sectors "Hospitals, Doctors and Dentists", and "Nursing and Protective Care") accounts for the largest share, over 9% of total employee compensation (wages plus benefits) in the New England Region, with state-level shares ranging from 8.7% in New Hampshire to 11% in Rhode Island. The U.S. average share of total employee compensation for this segment is 7.7%. This high level of importance means that a large disturbance to this sector would have a significant impact on the regional economy. Identifying the appropriate multipliers needed to convert a significant disturbance into a realistic economic impact has not been possible.

Next in economic importance is tourism. Because some of the output from this segment serves local consumption, we first extract only that portion of activity in tourist-related industries which serve visitors to the states. Tourism-related shares of these industry's output range from lows of 7-30% for general retail, to in excess of 50% for lodging and for non-auto transportation. This direct tourist impact accounts for just over 3% of total New England Regional economic activity, and 3% of employment. Tourism's shares are highest in Vermont, exceeding 5% of employment there. Note that because these industries tend to pay lower than average wages, they account for smaller shares of total employee compensation (1.6% in the region, and 3% in Vermont). Again, determining the appropriate multipliers has yet to be done.

Two obvious ways that climate change might impact New England's tourism are impacts on the ski industry and fall foliage-related tourism. Economic databases and models used for this analysis classify the ski industry as part of the sector "Amusement and recreation services, not elsewhere classified." New economic models will need to be modified in order to identify and quantify the ski industry contributions to regional tourism. Out-of-state spending in this category accounts for just under 1% of Vermont's economic output, but generally under half a percent of the economic output for the remaining states in the region. So the ski industry, while important for those directly involved, does not account for a major share of the regional economy, based on this nonspecific classification in the Inplan model.

The state offices of tourism in the region provided information indicating that fall foliage-related tourism accounts for approximately 20-25% of total annual tourism in Vermont and Maine. However, calculating the potential total regional economic impact of a climate-induced loss of maples and subsequent loss of foliage-related tourism is complex. The regional economic importance of tourism, combined with an economic model of tourism impacts on all other sectors due to economic linkages, indicate that for every $1 spent on tourism, roughly 20-60 cents of additional economic activity is generated elsewhere in the state. Note, too, that this multiplier-based modeling of economic linkages does not account for the "synergistic" effects among tourism-related industries, when, for example, visitors to ski slopes also stay in hotels and eat in restaurants.

Taken together, these results make it possible to estimate that a 50% reduction in fall tourism could account for up to a 1% drop in Vermont employment, with smaller impacts in other states and for other economic measures such as output and wages. Such impacts are important in an

A final conclusion is that due to the complexity of the economic assessment process, a thorough analysis is beyond the scope of the present New England Regional Assessment.

absolute sense, since the total region's tourism employs over 350,000 people. A 50% drop in fall tourism could correspond to nearly 20,000 jobs lost if fall tourism accounts for just 10% of the region's total, which is a conservative estimate.

Finally, of the economic segments considered, the natural resource-related industries account for the smallest share of the regional economies. With 1995 sales of 2.9 billion dollars in New England and 2.8 billion in upstate New York, this segment's output accounts for 2% of total economic output in Vermont, 1.6% in Maine, but under 1% for New England as a whole, and roughly 1% for upstate New York. Shares of total natural resources employment are slightly higher, while those for employee compensation are lower, reflecting lower-than-average wages for this segment.

Taken as a whole, these results point to the following general conclusions about assessing the potential economic importance of potential climate change impacts on the region. First, we note that Vermont, and to a lesser extent Maine, appear to lead the region in terms of the relative importance of both tourism and natural resource related industries. In Vermont, tourism-related spending accounts for 5% of the economy, and natural resources 2%. Thus, direct spending of $1 million in those sectors generally stimulates an additional $200K - $500K of economy-wide output in the same state. Region-wide economic impacts of specific climate-induced impact scenarios (e.g., skiing or foliage-related tourism) on both of these segments would be profound for those persons, companies, towns and sub-state regions directly involved.

A final conclusion is that due to the complexity of the economic assessment process, a thorough analysis is beyond the scope of the present New England Regional Assessment. Developing a regionally-specific economic model will be necessary to fully quantify climate change impacts to the region.

Full Impact Chain Example: Fall Foliage-Related Tourism

Of particular significance to this initial investigation is the fact that although potential "climate change" is sometimes imagined to be a single result, it is instead a highly multi-faceted phenomenon involving changes in both physical climate (temperature, precipitation) and chemical climate (air quality and acidic precipitation), both of which may have profound impacts on the forests of the New England Region. A variety of climatic impacts are relevant to the potential response of forest ecosystems to climate change. A simplified view of important causal relationships is presented in Figure 8.2.

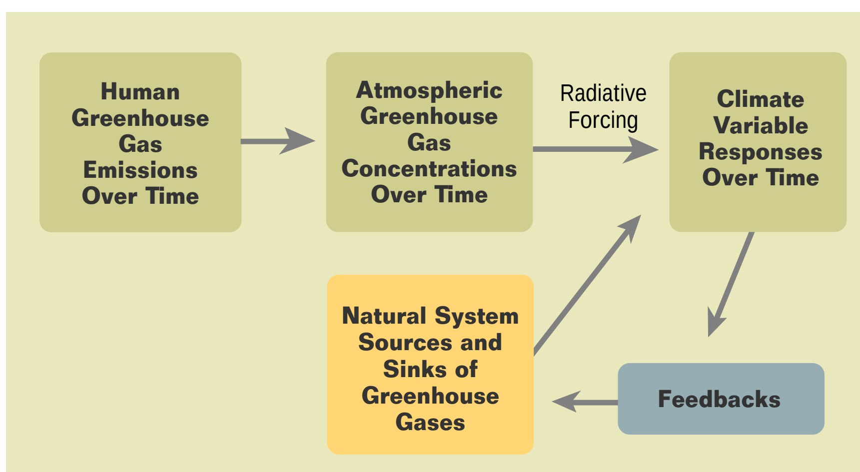


FIGURE 8.2 Schematic of climate response linkages.

The potential impacts of climate change upon fall foliage-related tourism relies on the responses of individual tree species.

Forest Responses to Climate Change

The potential impacts of climate change upon fall foliage-related tourism relies on the responses of individual tree species. The most vibrant fall foliage is displayed by the red maple and sugar maple; it is the relative abundance of these two species, interspersed with evergreens, which makes the New England Region such a popular destination for tourists pursuing fall foliage displays.

A recent study examines the influence of climatic factors upon the relative abundance of 80 individual tree species at a regional level within the Eastern U.S. Their hierarchical "regression tree" models draw from among 33 separate explanatory variables within four categories, as summarized in Figure 8.3.

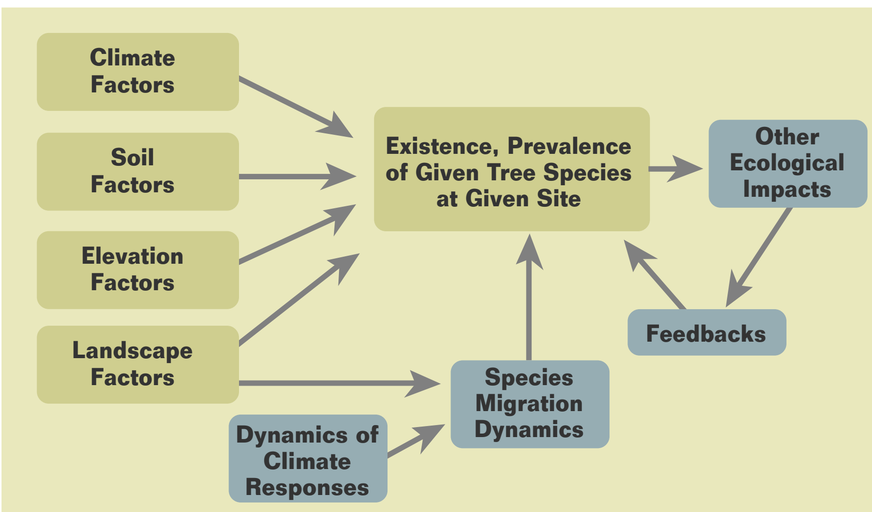


FIGURE 8.3 Schematic of forest response linkages (blue indicates additional factors which may be important but are not included in the initial 1998 model by Iverson and Prasad)

The study uses the models together with regional interpolations of global circulaton model-based projections of future equilibrium climatic responses to a doubled global atmospheric concentration of CO_2, in order to develop regionalized projections of the physical climate's potential impacts upon the abundance of individual tree species at a regional level in the Eastern U.S. (see Case Study 4 in Chapter 5). The model takes into account the influence of soil factors, climate factors, elevation and landscape factors upon the prevalence of species (Figure 8.3), as well as factors that may also be important in governing the actual regional response of tree species to climate changes, but which are not included in the model. These other factors include the *dynamics* of changes to climate (both physical and chemical), the dynamics of species migration, and interactions with other living elements of the ecosystem.

It must be emphasized that large uncertainties surround many facets of this modeling, including:

- the response of regional temperatures and precipitation to changes in atmospheric concentrations of greenhouse gases;
- the dynamics of climate response in relation to regional factors influencing climate (i.e., topography, coastal effects, etc.) and their interaction with the dynamics of species migration;
- the influence of human forest management practices over the coming century;
- the influence of other factors such as chemical climate impacts missing from the tree response model, and the uncertainties in the estimated values for the parameters that were included.

Only one state, Maine, was able to provide any information related to the factors that could influence visitors' decisions to undertake travel from out-of-state.

Thus, the model results should be looked upon as illustrative of the best sort of currently available scientific model-based results concerning foliage-relevant tree species responses to climate changes in our region, but not as *forecasts* of what will happen.

Tourist Behavior Responses to Forest Change

The uncertainties influencing this investigation do not end with environmental modeling, however. The next link in the overall impact chain (Figure 8.1) is the response of tourists to changes in foliage displays, and this link has even greater uncertainties because social, cultural, and emotional judgements must be considered.

Representatives at each of the seven states' offices of tourism were contacted, and asked for information concerning the factors that influence the decisions of fall tourists, as well as the importance of fall foliage-related tourism in their overall tourism market. Only two states were able to provide estimates of the relative significance of fall tourism within annual tourism totals. Vermont reported that 22% of its tourism occurs during the fall season, and Maine reported fall's share at 20%. It is interesting to note that only two of the seven states in the region were able to provide such data.

The following illustrates the very limited amount of relevant data that are readily available for use in an economic analysis. Only one state, Maine, was able to provide any information related to the factors that could influence visitors' decisions to undertake travel from out-of-state. The Maine Office of Tourism provided a detailed report written for that office by Longwoods International, a research consulting firm for the travel industry. The report did not address the fall tourism season directly, nor did it present results separately for visitors of different seasons, unfortunately. Results indicated that the most important reasons for visiting Maine, as cited by visitors who came for reasons other than business or visiting friends and family ("marketable tourism"), were:

- to tour the state (37%)
- to enjoy the outdoors (23%)
- to attend a special event (12%)
- for a beach vacation (9%).

Thus, the top two reasons for visiting (touring, and enjoying the outdoors) do have a strong *potential* connection to fall foliage for a significant percentage of visitors. Among three categories cited as of particular interest on trips by overnight "marketable" visitors, "eco-tourism" was cited by 20% of visitors, ahead of "historic tourism" (18%) and "cultural tourism" (12%). Sight-seeing was rated highly by 58% of marketable visitors to Maine, and within this category, "beautiful scenery" ranked highest among 13 aspects of sight-seeing, being cited 90% of the time.

These survey results do not enable us to estimate what portion of fall tourism might respond negatively to a reduction in fall foliage. They certainly do not make it possible to estimate what the reduction in tourism spending could be if foliage brilliance was no longer an attraction. The results do confirm, however, that beautiful outdoor scenery is among the most important reason that visitors come to Maine. This, together with the cited shares of annual tourism occurring in the fall

More detailed state-level data on fall tourism and its ties to foliar displays are needed before we can estimate in detail the impacts at the regional level…

(20% for Maine and 22% for Vermont) indicates that significant impacts on tourism from a climate-induced regional loss of maples would be expected. More detailed state-level data on fall tourism and its ties to foliar displays are needed before we can estimate in detail the impacts at the regional level of a loss of foliage-related tourism on the regional economy.

Economic Impacts of Tourist Behavior Changes

The final link in the impact chain concerns the consequences of changes in tourism for the wider regional economy. The way that tourism impacts the regional economy is through expenditures by tourists. These expenditures in turn can stimulate **direct, indirect,** and **induced** impacts.

Direct impacts include the revenues taken in, employment provided, and wages paid by the industries where tourists spend money directly. These industries include lodging, food service, entertainment, general retail, and transportation.

Indirect impacts occur as a result of expenditures by the directly impacted industries. For example, tourist spending on the lodging industry stimulates spending *by* the lodging industry on the goods and services of other sectors of the economy. These secondary purchases stimulate tertiary expenditures, and so on. Finally, induced impacts refer to the impacts generated by the spending activity of persons who are employed by the directly-impacted industries – namely, the "tourism" industries.

Data characterizing direct, state-level travel-related expenditures in 1996, as reported by the Travel Industry Association (TIA) in a recent research report are provided in Table 8.1a, for the New England states and upstate New York[2]. Table 8.1b shows the total wages paid by each sector in each state in 1996. Finally, Table 8.1c provides estimates of the number of jobs (full-time equivalents) associated with these tourism sectors.

($M 1996)	Public Transport	Auto Transport	Lodging	Food Service	Entertainment/ Recreation	General Retail
Upstate NY	1614	1444	2609	2678	318	1368
Connecticut	1917	495	582	752	210	298
Rhode Island	351	150	151	150	52	67
Massachusetts	3731	1112	2081	1807	583	885
Vermont	172	135	305	363	188	153
New Hampshire	671	205	294	355	172	150
Maine	393	321	367	455	150	202

TABLE 8.1a Direct state-level travel-related expenditures in 1996 (source: TIA 1999).

[2] The TIA data pertains to the entire state of New York, including the NYC metropolitan area. Here we have adjusted the TIA's figures to estimate only those expenditures occurring in upstate New York. See the discussion in section 3 of this chapter for more details.

Indirect and induced impacts of tourism are estimable using economic impact assessment models, such as input/output models.

($M 1996)	Public Transport	Auto Transport	Lodging	Food Service	Entertainment/ Recreation	General Retail
Upstate NY	583	112	615	722	143	192
Connecticut	189	43	151	213	109	53
Rhode Island	34	11	38	40	20	11
Massachusetts	653	91	591	522	281	133
Vermont	20	10	98	89	21	24
New Hampshire	47	16	84	90	53	21
Maine	35	19	91	117	49	30

TABLE 8.1b Direct state-level travel-related payroll in 1996 (source: TIA 1999).

(thousands of jobs)	Public Transport	Auto Transport	Lodging	Food Service	Entertainment/ Recreation	General Retail
Upstate NY	15	5.3	27	57	5.2	10
Connecticut	5.6	1.6	8.5	18.0	5.0	2.7
Rhode Island	1.1	0.5	2.4	4.0	1.3	0.6
Massachusetts	18.0	3.9	29.7	42.9	14.2	7.3
Vermont	0.8	0.6	6.8	9.0	1.5	0.5
New Hampshire	1.3	0.8	6.1	8.8	3.8	1.2
Maine	1.7	1.0	7.4	12.1	4.3	1.9

TABLE 8.1c Direct state-level travel-related employment in 1996 (source: TIA 1999).

Industry	Value of output stimulated (thousand $) by $1 million of hotel & lodging industry business
Real Estate Agents	53
Credit Agencies	48
Other Non-Farm Buildings	40
Electric Utilities	40
Wholesale Trade	34
Gas Utilities	27
Management Consulting Services	27
Communications except Radio and TV	26.3
Advertising	25.7
Miscellaneous Plastic Products	24
Banking	22
Personnel Supply Services	17
Auto Rental and Leasing	16
Crude Petroleum	16
Hotels and Lodging Places	3
***Total**, all sectors of the economy, not limited to those listed above*	886

TABLE 8.2 Output in other industries induced by $1 million activity by hotel and lodging.

Indirect and induced impacts of tourism are estimable using economic impact assessment models, such as input/output models. Economic input/output models make use of data on the purchases made by each sector for the goods and services from all other sectors. The most detailed input/output tables in the USA are all based on the results of the U.S. Department of Commerce's Bureau of Economic Analysis (BEA). As an example of indirect impacts stemming from direct tourism expenditures, Table 8.2 presents the total amount of indirect economic output stimulated by the hotel and lodging industry, per million dollars of output from that industry. Table 8.2 also presents results for the top industries whose output is stimulated by the purchases of the hotel and lodging industry.

Because of all the uncertainties involved at every step in the impact chain, it is not possible to make "forecasts" of climate change's true economic impacts for any scenario.

As Table 8.2 shows, the economic impacts of tourism extend beyond the tourism industry, to include industries such as real estate agents, banks, construction, utilities, advertising, etc. A significant share of this sort of indirect impact (and of the induced impacts as well) would occur in the same region as the direct impacts.

Data Gaps and Information Needs

Of the many data gaps, one important missing piece of data needed for estimating foliage-related tourism in the region was the share of total sales due to foliage-based tourism, for all states. Maine and Vermont were the only states which reported seasonal shares of tourism-related spending, and the fall season share includes some spending not tied to foliage. Even in these states, specific details related to fall foliar tourism are not available. The same is true for specific economic information on ski-related tourism where data are not available by state or for the region.

More broadly, any economic analysis relies on a chain of effects for the various causal links between climate changes and their economic impacts, and each link in this chain is modeled with a significant degree of uncertainty. As our understanding of these connections, and the inherent uncertainties improves, our ability to project economic impacts resulting from climate change will improve. Nevertheless, the current state-of-knowledge has allowed order-of-magnitude insights into the potential scale and nature of economic impacts of climate change for the region.

Conclusions

This final chapter has investigated the multiple facets of the total chain of impacts which would extend from climate change through to economic impacts of such change. The potential for economic impacts of climate change have been considered for the health, tourism and natural resources segments. In addition, a specific scenario has been studied in depth: the impacts of climate change upon fall foliage-related tourism in New England and New York.

Because of all the uncertainties involved at every step in the impact chain, it is not possible to make "forecasts" of climate change's true economic impacts for any scenario. It has been possible, however, to illustrate that the causal linkages between climate change and the region's economies are real, and to illustrate the current levels of information available, the modeling approaches which characterize each of these linkages for a particular scenario of potential consequence for the region, and the significant data gaps that must be filled before a more quantitative analysis can be conducted.

It is clear that the types of climate change projected by the climate models used in this assessment would have profound impacts on many segments of the region's economy. While these impacts are significant, this initial effort does not provide hard numbers regarding the potential economic impacts. For this, a regionally-specific economic model must be developed and applied.

APPENDIX A

New England Regional Assessment Steering Committee

David Bartlett
Associate Director, Institute for the Study of Earth, Oceans, and Space
University of New Hampshire
Morse Hall, Durham, NH 03824-3525
Phone: (603)862-0322
Fax: (603)862-1915
E-mail: david.bartlett@unh.edu

Thomas Baerwald
Program Director, Geology and Regional Science
National Science Foundation
1800 G Street, NW, Washington, DC 20550
Phone: (703)306-1502
Fax: (703)306-0372
E-mail: tbaerwald@nsf.gov

Richard Birdsey
Program Manager, USDA Forest Service
100 Matsonford Road, 5 Radnor Corp. Ctr. Suite 200, Radnor, PA 19087-4585
Phone: (610)975-4092
Fax: (610)975-4095
E-mail: rbirdsey@lunar.nena.org

Robert Brower
Director of Planning, Cayuga County Planning Department
County Office Building - 5th Floor
160 Genesee Street, Auburn, NY 13021
Phone: (315)253-1276
Fax: (315)253-1586
E-mail: brower@sycayva.cayuga-cc.edu

Ann Bucklin
Director - NH Sea Grant
University of New Hampshire
Morse Hall, Durham, NH 03824-3525
Phone: (603)862-3505
Fax: (603)862-0243
E-mail: acb@cisunix.unh.edu

Paul R. Epstein
Associate Director, Center for Health and Global Environment
Harvard Medical School
260 Longwood Society, Boston, MA 02115
Phone: (617)432-0493
Fax: (617)432-2595
E-mail: pepstein@igc.org

Kate Hartnett
Executive Director
New Hampshire Comparative Risk Project
18 Low Avenue, Concord, NH 03301
Phone: (603)226-1009
Fax: (603)226-0042
E-mail: khartnett@thejordaninstitute.org

Wanda Haxton
Policy Analyst, Climate Policy & Assessment Division
U. S. Environmental Protection Agency
Mail Code 2174, Washington, DC 20460
Phone: (202)260-2709
Fax: (202)260-6405
E-mail: haxton.wanda@epamail.epa.gov

Lloyd C. Irland
President, Irland Group
RFD #2, Box 9200, Winthrop, ME 04364
Phone: (207)395-2185
Fax: (207)395-2188
E-mail: irland@aol.com

Clara Kustra
Public Relations Coordinator, Institute for the Study of Earth, Oceans, and Space
University of New Hampshire
Morse Hall, Durham, NH 03824-3525
Phone: (603)862-3484
Fax: (603)862-1915
E-mail: clara.kustra@unh.edu

Paul Mayewski
Professor, Institute for Quaternary and Climate Studies
Bryand Global Sciences Center
University of Maine, Orono ME 04469
Phone: (207)581-3019
Fax: (207)581-3007
E-mail: paul.mayewski@maine.edu

Berrien Moore III
Director, Institute for the Study of Earth, Oceans, and Space
University of New Hampshire
Morse Hall, Durham, NH 03824-3525
Phone: (603)862-1766
Fax: (603)862-0188
E-mail: b.moore@unh.edu

Timothy Perkins
Director, Proctor Maple Research Center
P.O. Box 233, Underhill Center, VT 05490
Phone: (802)899-9926
Fax: (802)899-5007
E-mail: Timothy.Perkins@uvm.edu

Barrett Rock
Professor, Complex Systems Research Center
University of New Hampshire
Morse Hall, Durham, NH 03824-3525
Phone: (603)862-2949
Fax: (603)862-0188
E-mail: barry.rock@unh.edu

Fay Rubin
Director - GRANIT, University of New Hampshire
Morse Hall, Durham, NH 03824-3525
Phone: (603)862-1792
Fax: (603)862-0188
E-mail: fay.rubin@unh.edu

Thomas W. Spence
Senior Associate for Science Programs
Directorate for Geosciences
National Science Foundation
4201 Wilson Blvd.
Arlington, VA 22230
Phone: (703)292-5078
Fax: (703)292-9042
E-mail: tspence@nsf.gov

Shannon Spencer
Research Scientist, Complex Systems Research Center
University of New Hampshire
Morse Hall, Durham, NH 03824-3525
Phone: (603)862-1792
Fax: (603)862-0188
E-mail: shannon.spencer@unh.edu

APPENDIX B

New England Regional Assessment Participants

The New England Region Assessment (NERA) was initiated in September 1997, with the *New England Climate Change Impacts* Workshop, held September 3-5, at the University of New Hampshire (UNH). Participants in this initial Workshop identified the three key Sectors of interest, and the key areas of concern to be addressed in more detail. Three additional Sector-specific Workshops were held in 1999: March 30, 1999 – Forestry Workshop; March 31, 1999 – Water Resources Workshop; and April 7, 1999 – Human Health Workshop. These Workshops were conducted to assess the current state-of-knowledge of the potential consequences of climate variability and change on the New England Region, as well as to identify areas for which more information is needed. In the process, stakeholders participating in the Workshops identified key concerns regarding climate impacts to their specific Sectors. One of the main goals of the NERA effort has been to present the key findings in terms that are relevant and meaningful to the general public, and the participating stakeholders assisted us in reaching this goal. The overall NERA effort has been supported by the National Science Foundation.

Stakeholders participating in the NERA identified three key sectors (Forestry, Water Resources and Human Health) for detailed consideration, and three key concerns or issues likely to affect these sectors if climate change continues (Air Quality, Seasonal Dynamics and Extreme Weather Events). The table below presents a summary of NERA Workshop participants, by category and by area (state) represented. Since many participants attended two or more Workshops, they have only been counted once in the table. The names of the participants in each of the four NERA Workshops are listed in Appendix C.

Area	Local Gov.	Federal Agency	Energy/ Utility	Business/ Industry	NGO's	Education/ Outreach	Scientist/ Researcher	Interested Stakeholder	Total by State
AK							1		1
CAN	1								1
CT		1	1	1		1			4
DC		3					1		4
MA	2	7		3	5	3	7		27
ME	2		1	4		1	1		9
MD		3					1		4
NH	14	4	2	3	9	13	35	3	83
NY	1			1	1		3		6
PA		2							2
RI		2		1		2	6		11
VA		2							2
VT	3			2		1	6		12
Total	23	24	4	15	15	21	61	3	166

APPENDIX C

New England Regional Assessment Workshop Attendees

New England Regional Workshop
September 3-5, 1997

John Aber
Jim Abraham
Eleanor Abrams
Samuel Adams
Donald Anderson
Allan Auclair
Thomas Baerwald
Marian Baker
Patrick Barosh
David Bartlett
Howard Bernstein
Richard Birdsey
Doug Bogen
Robert Brower
Deirdre Buckley
Ann Bucklin
Karen Burnett-Kurie
Lynne Carter
David Cash
Michael Charpentier
Michael Cline
Kenneth Colburn
Nancy Cole
Priscilla Cookson
Robert Corell
Michael Disharoon
Claudette Donnelly
Richard Donnelly
Lesley-Ann Dupigny-Giroux
Petya Entcheva
Paul Epstein
Ivan Fernandez
Douglas Forbes
Tim Foresman
Fred Friedman
Harold Garabedian
Patrick Garner
Graham Giese
Lewis Gilbert
Daniel Goldin
Joel Gordes
Cynthia Greene
Timothy Gubbels
Perry Hagenstein
Stephen Hale
Steven Hamburg
Kate Hartnett
Paul Harris
Denise Hart
Brenda Hausauer
James Hawk
Wanda Haxton
Douglas Hill
Lloyd Irland
Glenn Juday
Naida Kaen
Barry Keim
Thomas Kelly
John Kermond
Ken Kimball
Karl Kreutz
Clara Kustra
Amy Langston
Don LaTourette
Gary Lauten
Rob Leatherbee
Stuart Leiderman
Michael MacCracken
Norman MacDonald
Jeffrey MacGillivray
Paul Mayewski
Sharon Meeker
David Meeker
Jerry Melillo
Eric Meyerson
Rakesh Minocha
Berrien Moore III
David Moss
George Musler
Scott Nixon
Alan Nogee
Ellen O'Donnell
Mila Paul
Iqbal Pittalwala
James Platts
Ronald Prinn
David Reusch
Mary Reynolds
Barrett Rock
Fay Rubin
James Russell
Larry Ryan
William Salas
Tim Scherbatskoy
Nancy Sherman
Frederick Short
John Slater
Molly Smith
Elske Smith
Leo Spencer
Shannon Spencer
Daniel Sundquist
Jennifer Supple
Marika Tatsutani
Mary Tebo
Marc Tremblay
Mark Twickler
Thomas Varrell
Henry Veilleux
Eric VonMagnus
Cameron Wake
Margeret Weeks
Tom Wessels
Bruce Westcott
Norman Willard
Steven Winnett
David Wolfe
Chirstian Zdanowicz
Julian Zelazny
Greg Zielinski

Forest Sector Workshop
March 30, 1999

Allan Auclair
Veronica Berounsky
Jennifer Bofinger
Perry Bosshart
Charles Bridges
Robert Burke
Jim Burnett
Lynne Carter
Charles Cogbill
Stephen Hale
Nancy Hubbe
Paul Hubbe
Lloyd Irland
Leslie Kane
Barry Keim
Clara Kustra
John Lanier
Eugene Lecomte
Stuart Leiderman
David Marvin
Will McWilliams
Rakesh Minocha
Morten Moesswilde
Berrien Moore
Gregory Norris
Alan Page
Jan Pendlebury
Peter Pohl
Mary Reynolds
Keith Robinson
Barrett Rock
Michael Routhier
Dork Sahagian
Benjamin Sherman
Walter Shortle
Molly Smith
Mike Stevens
Daniel Sundquist
Bob Townsend
Hal Walker
Phil Wargo
Norman Willard
Steven Winnett
Brad Wyman

Water Sector Workshop
March 31, 1999

Allan Auclair
Veronica Berounsky
Doug Bogen
Charles Bridges
Lynne Carter
Ted Diers
Lawrence Dingman
Stephen Hale
Richard Harlow
George Hurtt
Norbert Jawarski
Barry Keim
Tom Kelly
Clara Kustra
Stuart Leiderman
Gerald Livingston
Sharon Meeker
Morten Moesswilde
Pierce Rigrod
Keith Robinson
Barrett Rock
Dork Sahagian
Benjamin Sherman
Fred Short
Shannon Spencer
Mark Toussaint
Marc Tremblay
Hal Walker
Peter Wellenberger

Human Health Sector Workshop
April 7, 1999

David Bartlett
Rita Chang
Carmelle Druchniak
Petya Entcheva
Paul Epstein
Stephen Hale
Denise Hart
George Hurtt
Barry Keim
Clara Kustra
Stuart Leiderman
Thomas Mather
Leslie Morrissey
Barrett Rock
Dork Sahagian
Benjamin Sherman
Allan Silber
Shannon Spencer
Juli Trtanj
Hal Walker

APPENDIX D

New England Regional Assessment Review Process

The review process for the New England Regional Assessment (NERA) has taken four separate forms: an internal Website review by Workshop participants; an internal review by members of the NERA Steering Committee; an external review by scientists; and an external review by stakeholders. The two external reviews were facilitated by the New Hampshire Department of Environmental Services (DES) Local Impact Assessment Project (LIAP). This LIAP effort, coordinated by the DES and funded by the U.S. EPA, brought together approximately 50 researchers and scientists (primarily from the Forestry and Water Resources Sectors), as well as over 60 stakeholders, to evaluate the NERA *Overview* Document. None of the LIAP evaluators had participated in the NERA process. In the case of the research scientists, the focus of the review was on assessing the accuracy and validity of the science presented in the NERA *Overview* for the specific Sectors. In the case of the stakeholders, the focus of the review was on the impact of the material presented and on the usefulness of the public message delivered.

The table below characterizes the participants in the external review, which consisted of both scientists and stakeholders. Participants in the external reviews were sent draft copies of the NERA Overview prior to attending day-long evaluation workshops. Both written and oral evaluations were solicited. All written and oral reviews were considered and most were incorporated into the final version of the NERA *Overview* Document.

	Forestry	Water	Human Health	Economists	Biologists/ Wildlife	Climate Scientists	Recreation	Real Estate	Total
Scientists	17	10	4	5	10	4	3		53
Stakeholders	11	26	4	2	9		10	2	64
Total	28	36	8	7	19	4	13	2	117