STATE OF MAINE
LAND USE REGULATION COMMISSION

CHAMPLAIN WIND, LLC
BOWERS WIND PROJECT
DEVELOPMENT PERMIT DP 4889

PREFILED DIRECT TESTIMONY OF

Cameron Wake

ON BEHALF OF

CONSERVATION LAW FOUNDATION

Name and Qualifications

My name is Cameron Wake. I am a research associate professor at the Earth System Research Center, Institute for the Study of Earth, Oceans and Space and the Department of Earth Sciences at the University of New Hampshire. I research global climate and environmental change, reconstructing climate change in the past through analysis of ice cores from around the world and instrumental records from the Northeast U.S. I received my Ph.D. in Geochemical Systems (1993) from the University of New Hampshire. My CV is attached Exhibit A.

As part of the Northeast Climate Impacts Assessment (NECIA), I was a co-lead of the climate team, an author on three research papers (published in the peer-reviewed literature), lead editor of a special issue of "Mitigation and Adaptation Strategies for Global Change" that contained 14 peer-reviewed scientific papers, and a contributor to a series of reports detailing past and future climate change in the Northeast U.S.[1] Over the past year, I have presented these findings to fellow scientists, hundreds of policymakers, business and civic leaders, members of

[1] The full "synthesis report" of NECIA, entitled *Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions*, is available at: http://www.northeastclimateimpacts.org/pdf/confronting-climate-change-in-the-u-s-northeast.pdf. The summary specific to Maine is attached as Exhibit B.

the media, our congressional delegation (both Maine and New Hampshire), and members of the public.

More recently, I have authored the "Climate Assessment for the Casco Bay Watershed," a report on changes in extreme precipitation across the Northeast U.S., and a paper on our changing wintertime climate (published in the peer-reviewed scientific literature).[2]

I have also previously testified before this Commission in other permitting proceedings for wind power projects, including the Stetson I project on behalf of the Conservation Law Foundation and the Natural Resources Council of Maine.

Purpose of this Testimony

The purpose of this testimony is to provide the context in which renewable energy projects, such as this wind power project, must be considered. Specifically, my testimony will describe changes in climate across the Northeast U.S. over the past 100 years and the next 100 years. My focus is on the NECIA and Casco Bay Climate Assessment findings concerning potential impacts of climate change on the natural resources, economy, and character of the state of Maine – particularly impacts on Forests, Winter Recreation, and Coastal Communities – under two different scenarios of future heat-trapping emissions. The first (the higher-emissions scenario) is a future where people—individuals, communities, businesses, states, and nations—allow emissions to continue growing rapidly, and the second (the lower-emissions scenario) is one in which societies choose to rely less on fossil fuels and adopt more resource-efficient technologies, such as wind power.

[2] The Casco Bay report is available at: http://www.cascobay.usm.maine.edu/pdfs/Climate_Change_in_Casco_Bay.pdf. The winter climate paper is attached as Exhibit C.

Recent Developments in Global Climate Change

The Earth has continued to warm at a rate that is in line with scientific projections based on increases in the content of greenhouse gas in the atmosphere. Global temperatures are rising, with 2005 and 2009 being the two warmest years in the past 130 years, continuing a warming trend of 0.30°F per decade over the past four decades.[3] Human factors are by far the most significant cause of the warming. Solar variability has accounted for only 10 percent of the surface warming over the past century and an even smaller amount over the past quarter century.[4] In addition, several key components of the Earth's climate system are changing more rapidly than had been projected in the 2007 Intergovernmental Panel on Climate Change Report.[5] These include:

- accelerated melting of the Greenland and Antarctic ice sheets, and glaciers around the world;
- rapid Arctic sea-ice decline during the summer melting period;
- increasing rates of sea-level rise, consistent with an approximate doubling of the contribution from melting glaciers and ice-sheets;
- carbon dioxide uptake by the oceans which has resulted in increasing ocean acidity; and
- accelerated thawing of permafrost (permanently frozen ground) in the Northern Hemisphere, a potentially significant source of both CO_2 and CH_4.[6]

Additionally, scientists recently discovered that the permafrost under the East Siberian Arctic Shelf is perforated and is starting to leak large amounts of methane into the atmosphere, another example of a key threshold or "tipping point" in the climate system that we may be close to

[3] Temperature data analysis by NASA Goddard Institute for Space Studies. http://data.giss.nasa.gov/gistemp/
[4] Lean, JL & DH Rind, (2008) How natural and anthropogenic influences alter global and regional surface temperatures: 1889 to 2006. Geophysical Research Letters 35, L18701. http://www.agu.org/pubs/crossref/2008/2008GL034864.shtml
[5] Solomon, S, D Qin, M Manning, Z Chen, M Marquis, KB Averyt, M Tignor, HL Miller (eds.)(2007) Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007. Cambridge University Press. http://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html
[6] The Copenhagen Diagnosis, 2009: Updating the World on the Latest Climate Science.. The University of New South Wales Climate Change Research Centre (CCRC), Sydney, Australia. http://www.copenhagendiagnosis.com/

crossing. Release of even a fraction of the methane stored in the shelf could trigger abrupt climate warming.[7]

On the national front, a 2009 report published by the U.S. Global Change Research Program summarized the science of climate change and the impacts of climate change on the U.S., now and in the future.[8] The report provides a synthesis of information from a wide variety of scientific assessments and published research to summarize what is known about the observed and projected consequences of climate change on various sectors such as energy, water, and transportation. The report concludes: "Observations show that warming of the climate is unequivocal. The global warming observed over the past 50 years is due primarily to human-induced emissions of heat-trapping gases. . . . Warming over this century is projected to be considerably greater than over the last century. The global average temperature since 1900 has risen by about 1.5°F. By 2100, it is projected to rise another 2 to 11.5°F."

More recently, the National Research Council of the National Academies published its final report in the "America's Climate Choices" series. The report reinforces the notion that climate change is occurring and response efforts are needed at both the local and national level. The authors of the report suggest that mobilizing action to reduce greenhouse gas emissions today will reduce society's vulnerability to climate change impacts in the future. Major investments in equipment and infrastructure are being made today that will effectively commit us to greenhouse gas emissions for decades to come. Policies to reduce emissions must therefore be instituted now so as to guide investment in energy efficiency and low-carbon energy infrastructure. The report notes that the risks of continuing in a high-emissions direction are far

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[7] Shakhova N, I Semiletov, A Salyuk, V Yusupov, D Kosmach, Ö Gustafsson (2010) Extensive Methane Venting to the Atmosphere from Sediments of the East Siberian Arctic Shelf. Science 327 (5970), 1246. http://www.sciencemag.org/cgi/content/short/327/5970/1246

[8] Karl TR, JM Melillo & TC Peterson (eds.)(2009) Global Climate Change Impacts in the United States. Cambridge University Press. http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts

greater than the risks of continuing in a low-emissions manner. The report highlights that the scientific uncertainty associated with projecting future greenhouse gas emissions and in estimating climate change impacts is not sufficient justification for inaction. Climate change mitigation policies and emissions reductions efforts can be scaled back in the future if needed, whereas adverse changes to the climate system would be difficult or impossible to reverse. [9]

Climate Change Over the Last 100 Years in the Northeast United States

Over the past 100 years, and especially the last 30 years, all of the climate change indicators for the Northeast U.S.—including factors such as annual temperature, length of growing season, lake ice-in and ice-out dates, precipitation, sea level rise, and snowfall—reveal a warming trend. For example, the Northeast's average annual temperature has increased by about 1.8ºF, the growing season has increased by 8 days, lake ice-out dates are 9 to 16 days earlier, and there has been a decrease in total snowfall amounts.

Winter temperatures in New England have warmed much faster than in any other season over the past four decades. Since 1965, monthly and seasonal temperature records from 138 meteorological stations across the northeastern U.S. exhibited region-wide winter warming on the order of approximately 3°F. The number of snow-covered days has decreased by more than a week, while total winter snowfall decreased by about 3.8 inches. Winter temperatures can be expected to rise by an additional 5.8°F by 2100 under a lower emissions scenario and an additional 8°F to 12°F under a high emissions scenario. In other words, the decision we make today and over the next decade concerning how we produce and how we use energy will determine how much warmer the winter season in the northeastern U.S. will be in the future.

[9] http://dels.nas.edu/Report/Americas-Climate-Choices/12781

Overview of NECIA Climate Projections

NECIA climate projections found that over the next several decades, due to heat-trapping emissions released in the recent past, temperatures across the Northeast will rise 2.5°F to 4°F in winter and 1.5°F to 3.5°F in summer regardless of the emissions choices we make now. By mid-century and beyond, however, today's emissions choices generate starkly different climate futures. While these scenarios represent strikingly different emissions choices that societies may make, they do not represent the full range of possible emissions futures.

A number of factors, including unrestrained fossil-fuel use, could drive global emissions above the "high-emissions" scenario, while rapid, concerted efforts to adopt clean, efficient technologies could reduce emissions below the "lower-emissions" scenario used in the study. The lower-emissions scenario describes a world in which atmospheric concentrations of CO_2 rise from ~380 parts per million (ppm) today to ~550 ppm by the end of the century, in contrast to 940 ppm under the higher-emissions scenario. However, many lines of evidence indicate that even greater emissions reductions, and thus less severe impacts, are well within our reach. The latest assessment of the Intergovernmental Panel on Climate Change (IPCC) describes the technical and economic potential for stabilizing atmospheric concentrations of heat-trapping gases at or below the equivalent of 450 ppm of CO_2. Achieving such a target would require the U.S. and other industrialized nations to make deep emissions reductions by mid-century – on the order of 80 percent below 2000 levels – along with substantial reductions by developing countries. In the Northeast, as well as elsewhere in the U.S. and the world, there is growing momentum to pursue deep emissions reductions consistent with staying below the lower-emissions pathway.

Climate change will impact a wide range of sectors in our society, including marine resources, coastal infrastructure, winter recreation, agriculture, forests, and human health. For example, warmer winter temperatures have been associated with earlier river and lake ice-out, which shortens the ice-fishing season; a shift to earlier and decreased spring runoff has been shown to impact the survival of salmon juveniles; and an observed decrease in the number of extreme cold temperature days can lead to increases in tick populations, making vector-borne diseases like Lyme disease more widespread. Cold-temperature days are important to cool-temperature crops such as apples, blueberries, cranberries and grapes, which require 200 to 2000 cumulative winter cooling hours (between 32°F and 50°F). If the cooling period requirement is not met, flower buds may die or blossoms may drop before they open, and those flowers that do develop may not set fruit or the fruit may be undersized. Snow cover also plays an important role in soil temperature and moisture properties and, if reduced, can have negative impacts on crops such as wild blueberries. In Maine, for example, where ninety percent of the nation's wild blueberries are grown, blueberry crops in 2004 were down 43 percent from the previous year, partly due to frost damage brought on by inadequate snow cover and extreme cold temperatures.

Impacts on Forests

The character of the Northeast's forests may change dramatically over the coming century as the center of suitable habitat for most of the region's tree species shifts northward—as much as 500 miles by late-century under the higher-emissions scenario and as much as 350 miles under the lower-emissions scenario. Many tree species, including the hardwoods that generate the region's brilliant fall foliage, may be able to persist this century even as their optimal climate zones shift northward. Other species, however, may succumb to climate stress, increased competition, and other pressures. If the higher-emissions scenario prevails, productivity of spruce/fir forests is expected to decline and suitable habitat will all but disappear from the Northeast by the end of the century. Major losses are projected even under the lower-emissions scenario. This would greatly exacerbate stresses on the pulp and paper industry in the Northeast, particularly in Maine, where the forest-based manufacturing industry is key to the state's economy.

Diminished spruce/fir habitat, especially at higher elevations, would increase pressure on associated animal species such as the snowshoe hare, Canada lynx, and Bicknell's thrush, one of the region's prized songbirds. With the late-century summer warming projected under the higher-emissions scenario, suitable habitat for the Bicknell's thrush could be eliminated from the region. Substantial changes in bird life are expected across the Northeast due to rising temperatures, shifting distribution of suitable habitat, or declining habitat quality. The greatest changes are projected under the higher-emissions scenario, including declines in the abundance of many migratory songbirds such as the American goldfinch, song sparrow, and Baltimore oriole. Winter warming will threaten hemlock stands, not only by reducing suitable habitat for these trees but also by allowing northward expansion of a fatal pest known as the hemlock woolly adelgid—as far north as Canada by late-century under the higher-emissions scenario.

Pronounced Impact on Maine's Spruce/Fir Forests

The most vulnerable of the Northeast's forests are the vast cool-climate communities dominated by conifers such as red spruce and balsam fir. These include forests such as the North Woods of Maine that are vital to the pulp and paper industry in the Northeast and equally treasured for their scenic and recreational value. In Maine, where the forest-based manufacturing industry is central to the state's economy, spruce and fir species provide 50 percent of all sawlogs and 20 percent of all pulpwood harvested. Suitable habitat for the group of species that make up spruce/fir forests is projected to diminish substantially with global warming under either emissions scenario. All areas of the Northeast now dominated by spruce/fir forests are projected to become less suitable for this group of tree species and better suited to others. As this happens, habitat for different species of spruce and fir trees is projected to change at different rates, but these rates are consistently greater under the higher-emissions scenario. Under the higher-emissions scenario, balsam fir is projected to lose 70 to 85 percent of its suitable habitat across Maine, New Hampshire, New York, and Vermont, and red spruce is projected to lose 55 to 70 percent of its suitable habitat. For both species, losses will be greatest in Maine, where this forest type currently dominates the landscape.

Growth rates for spruce/fir forests are also projected to decline significantly throughout the latter half of this century under the higher-emissions scenario. The decline will begin earlier and be more pronounced if CO_2 fertilization does not occur. Even under the lower-emissions scenario, suitable habitat for balsam fir is projected to decline 55 to 70 percent across Maine, New Hampshire, New York, and Vermont, and habitat for red spruce is projected to drop 45 to 65 percent. Again, the greatest losses are projected for Maine. If lower emissions prevail, spruce/fir forests could experience some increase in growth rates as a result of more modest warming, a longer growing season, CO_2 fertilization, and more efficient water use caused by rising CO_2. Without CO_2 fertilization, however, forest productivity will likely decline even under lower emissions.

The direct impact of rising atmospheric CO_2 on forest growth represents a major uncertainty in current projections of how future forests will function. Although experiments have shown that trees exposed to increased CO_2 exhibit accelerated rates of photosynthesis and growth over the short term, whether this will translate into sustained growth increases over longer timescales is unknown. There is also relatively little evidence for historical enhancements in growth in response to the 35 percent rise in CO_2 that has taken place since the onset of the Industrial Revolution. Dramatic declines in spruce/fir forests projected under the higher-emissions scenario would greatly exacerbate stresses on the Northeast's economically important pulp and paper industry, particularly in Maine. Winter warming, in addition to its direct role in redefining tree habitat, interferes with traditional timber harvesting practices in the region, which typically take advantage of the cold winter months when soils are frozen, minimizing the soil damage that could be caused by the heavy equipment used for cutting trees. As winters continue to warm over the coming century, forest soils will remain frozen for shorter periods, freeze less deeply, or potentially not freeze at all in more southerly areas.

Impacts on Winter Recreation

Global warming is projected to profoundly affect winter recreation and tourism in the Northeast as winter temperatures continue to rise and snow cover declines, especially under the higher emissions scenario. Maine is part of a six-state network of snowmobile trails totaling 40,500 miles and contributing $3 billion a year to the regional economy. Snowmobiling, like cross country skiing and snowshoeing, relies almost entirely on natural snowfall because of the impracticality of snowmaking on such a vast system of trails. This fact, combined with projected losses in natural snow cover, means that Maine's snowmobiling season could be cut substantially by mid-century. Under the higher-emissions scenario, the average season length across Maine is projected to shrink to roughly 30 days by late-century—a nearly 70 percent decline below recent levels—and to roughly 50 days under the lower-emissions scenario—a 40 percent decline.

Maine's 17 ski areas contribute $300 million a year to the state's economy, providing recreation for Mainers and visitors. Milder winters are expected to shorten the average ski season, increase snowmaking requirements, and drive up operating costs in an industry that has already contracted in recent years. Under the higher-emissions scenario, western Maine is projected to be the only area in the entire Northeast able to support viable ski operations by late-century. However, in order to stay open, resorts in this area would require substantial increases in snowmaking capacity and, therefore, operating costs. Ice fishing and pond hockey are winter favorites in Maine. Global warming will render lake ice cover increasingly thin and shorten its duration. In fact, ice cover duration on Sebago Lake has already declined by two weeks over the past several decades. Combined with fewer opportunities for sledding, snowshoeing, and other outdoor activities, winter recreation as it is now known in Maine is at great risk. These projections may be conservative, as the climate models used in this analysis have consistently underestimated the rapid winter warming and snowpack decline observed in recent decades.

Impacts on Casco Bay Watershed and the Gulf of Maine

As greenhouse gases continue to accumulate in the atmosphere, seasonal and annual temperatures will rise in the Casco Bay watershed. Depending on the emissions scenario, mid-century temperatures may increase as much as 2°F to 6°F in the region, and end-of-century temperatures may increase as much as 3°F to 8°F. Very cold days (below 0°F) are projected to drop from their current average of 40 days per year to 24 days per year under a lower emissions scenario and 12 days under a higher emissions scenario at inland sites by 2100. Extreme heat days in the summer are projected to occur more often and to be hotter. By end-of-century, days with temperatures above 90°F may increase from a current average of 4 days per year to 14 days per year. Under a higher-emissions scenario, the increase could be as much as 60 days. This raises concerns regarding the impact of extreme and sustained heat on human health, infrastructure, and the electricity grid.

Rising sea levels caused by global warming are projected to increase the frequency and severity of storm surges and coastal flooding along Maine's coast. Changes in sea level contribute to increased erosion, saltwater contamination of freshwater ecosystems and loss of salt marshes and cordgrass. Low-lying shorelines such as Old Orchard Beach are likely to be the most vulnerable to rising seas. Preliminary estimates of coastal flooding elevations in 2100 suggest that large areas of coastal Portland could be flooded, including areas along the southern coast of Back Cove as well as areas of both Portland and South Portland adjacent to the Fore River. An increase of 2 feet over current flood elevations is estimated under a low-emissions scenario and 5 feet under a high-emissions plan. Sea surface temperatures have likewise been linked to winter storm tracks and storm intensity in the northeastern U.S. The average annual sea surface temperature in the Gulf of Maine has been increasing at a rate of about 0.06°F per decade. Warmer sea surface temperatures threaten the Gulf of Maine's $450 million dollar shellfish industry. As the Gulf of Maine warms, the waters become more hospitable to diseases such as lobster shell disease and red tide organisms.

The implications of warmer temperatures, shifting precipitation patterns, and increased coastal flooding for the Casco Bay area are pervasive. For example, warmer temperatures affect the types of trees, plants, and even crops—such as blueberries—likely to grow in the area. Long periods of very hot conditions in the summer are likely to increase demands on electricity and water resources. Hot summer weather can have damaging effects on agriculture, human and ecosystem health, and outdoor recreational opportunities. Less extreme cold in the winter will be beneficial to heating bills and cold-related injury and death; however, rising minimum temperatures in winter could open the door to invasion of cold-intolerant pests that prey on the region's forests and crops. Although little change in snowy days is expected until later in the century, rising winter and spring precipitation could increase the risk of spring riverine flooding. Under the higher emissions future, frequency of drought is projected to increase from a current average of 1 in every 10 years to one month of drought every 3 years. Coastal flood elevations will continue to increase due to sea level rise, leading to increasingly larger areas of flooding during coastal storms. All combined, these changes will have serious repercussions on the region's environment, economy, and society.

Conclusion

Of course, actions in Maine and the Northeast alone will not be sufficient to reduce global warming. But with its reputation as a state of sensible and resourceful people and a history of national leadership in environmental policy, Maine (along with the rest of the Northeast) is well positioned to drive national and international progress in reducing emissions. Decision makers have myriad options available today to move toward this goal, including accelerating the region's transition from fossil fuels to clean, renewable energy resources.

Wind energy represents one of the most attractive near-term prospects among renewable resources for making substantial, relatively low-cost contributions to electricity generation in the Northeast. Onshore wind resources have the technical potential to meet almost half of the region's annual energy needs; Maine has the largest wind resource among all New England states. Emissions choices we make today—in Maine, the Northeast, and worldwide—will help determine the climate our children and grandchildren inherit, and shape the consequences for their economy, environment, and quality of life.

Dated: 10 June 2011

CPWake
Cameron P. Wake

STATE OF New Hampshire
COUNTY OF Hillsborough

Personally appeared before me the above-named Cameron Wake and made oath that the foregoing is true and accurate to the best of his/her knowledge and belief.

Dated: June 10, 2011

Madeline E. Slocum
Notary Public
My Commission Expires:

MADELINE E. SLOCUM
Notary Public - New Hampshire
My Commission Expires April 4, 2012

Cameron P. Wake
Curriculum Vitae

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EDUCATION

1993 Ph.D. Geochemical Systems, Dept. of Earth Sciences, University of New Hampshire
The Spatial Distribution of Snow and Aerosol Chemistry in the Mountains of Central Asia
Advisor: Dr. Paul A. Mayewski

1987 M.A Dept. of Geography, Wilfrid Laurier University, Waterloo, Ontario
The Spatial and Temporal Variation of Snow Accumulation in the Central Karakoram, Northern Pakistan Advisor: Dr. Kenneth Hewitt

1984 B.Sc. Dept. of Geology, University of Ottawa, Ottawa, Ontario (Honors Program)

ACADEMIC AND RESEARCH EXPERIENCE

2009 - *Faculty Fellow,* UNH Sustainability Academy

2007 - *Director*, Carbon Solutions New England

2003 - *Research Associate Professor*
Institute for the Study of Earth, Oceans and Space, and
Department of Earth Sciences, UNH

2003 - 2010 *Faculty Fellow*
Office of the Senior Vice-Provost for Engagement and Academic Outreach, UNH

1995 – 2003 *Research Assistant Professor*
Institute for the Study of Earth, Oceans and Space, and
Department of Earth Sciences, UNH

1993 – 1995 *Research Scientist*
Institute for the Study of Earth, Oceans and Space, UNH

1988 – 1993 *Research Assistant*
Institute for the Study of Earth, Oceans and Space, UNH

TEACHING EXPERIENCE

2004 –	NR 767/867	Earth System Science: Understanding Our Global Environment
2004 –	PHP 930	Climate Change and Health
1999 –	ESCI 405	Global Environmental Change
1996 – 2001	EOS 895	Introduction to Climate
1994 – 2003	ESCI 764/864	Paleoclimate Analysis

FIELD RESEARCH EXPERIENCE

Over the past twenty-five years I have led twenty glaciological field research expeditions to the

Himalaya, Tibetan Plateau, and Arctic. The primary focus of these research expeditions was the collection of ice cores, snow samples, and aerosol samples for chemical analysis for use in reconstructing climate change.

FUNDED RESEARCH GRANTS (*Principal Investigator unless otherwise noted)*

Incubating Interdisciplinary Sustainability Science Research at UNH (2011-2012)(UNH New Ventures Fund)

New Flood Plain Maps for Coastal New Hampshire and Questions of Legal Authority, Measures and Consequence (National Sea Grant Law Center) 2011-2012 (in collaboration with the Vermont Law School)

Assessment of Climate Change in Coastal New Hampshire (Great Bay Stewards), 2010-2011

Climate Change in the Casco Bay Watershed: Past, Present, and Future (Casco Bay Estuaries Project, University of Southern Maine) 2009

Assessing the Risk of 100-year Freshwater Floods in the Lamprey River Watershed of New Hampshire Resulting from Changes in Climate and Land Use (NOAA – Cooperative Institute for Coastal and Estuarine Environmental Technology) 2009-2011

New Hampshire Energy and Climate Collaborative (New Hampshire Charitable Foundation) 2009-2011

Analyzing Greenhouse Gas Emission Reductions and Economic Impact of GHGERF Projects. (NH Public Utilities Commission – Greenhouse Gas Emissions Reduction Fund) 2009-2010

The UNH Undergraduate Research Conference (UNH Parents Association) 2008-2010

Analysis for New Hampshire Climate Change Policy Task Force (New Hampshire Department of Environmental Services) 2008-2009

Carbon Solutions New England (New Hampshire Charitable Foundation) 2007-2009

Collaborative Research: Denali Ice Core Records of Late Holocene North Pacific Climate Variability (NSF - Office of Polar Programs) 2007-2009

Inspiring the Next Generation of Earth Explorers Through Remote Sensing Studies (Co-PI)(NASA – Earth Sun System Division) 2005-2008

Environmental Public Health Tracking Demonstration Project (New Hampshire Department of Health and Human Services) 2005-2007

Advancing Earth System Science Education for the 21st Century: An Interdisciplinary Education Initiative for University Students (NASA – Universities Space Research Association) 2003-2006

AIRMAP (Atmospheric Investigations, Regional Modeling, and Prediction)(Co-PI) (NOAA – Office of Oceanic and Atmospheric Research) 2000-2009

Environmental Public Health Tracking Demonstration Project – INHALE (NH Dept. of Health and Human Services, Office of Community and Public Health) 2004-2005

The Effect of Air Quality and Weather on Human Health in New England: Assessing Vulnerability and Generating Decision Relevant Information (NOAA - Office of Global Programs) 2002-2006

The New England Regional Integrated Sciences and Assessment: Project Integration and Initial Research (NOAA - Office of Global Programs) 2001-2002

Climate Change and Agriculture: Preparing Educators to Promote Practical and Profitable Responses (Co-PI)(USDA - Sustainable Agriculture Research and Education) 2005-2006

A Glaciochemical Record of Natural and Anthropogenic Environmental Change in the Northwestern North American Arctic (NSF – Office of Polar Programs) 2002-2005

Development of a Multi-Parameter Ice Core Record from Eclipse Dome, St. Elias Mountains, Yukon Territory (NSF- Office of Polar Programs) 1999-2001

Development of an Autonomous Aerosol Sampler (NOAA-CICEET) 1999-2001

Paleoclimate and Glaciological Reconstructions in Central Asia through the Collection and Analysis of Ice Cores and Instrumental Data from the Tien Shan (DOE) 2000-2001

Paleoclimate and Glaciological reconstructions in Central Asia through the Collection and Analysis of Ice Cores and Instrumental Data from the Tien Shan (NSF - Atmospheric Sciences) 1999-2001

A New Ice Core from the Devon Ice Cap, Canadian Arctic (Co-PI)(NSF- Office of Polar Programs) 1998-2002

Ice Cores from Monsoon Asia (NSF-ATM) 1995-1999

An Ice Core Derived Multivariate Proxy Record of Holocene Climate Change from the Penny Ice Cap, Baffin Island, Canada (Co-PI)(NSF - Office of Polar Programs) 1994-1997

International Himalayan/Tibetan Plateau Paleoclimate Workshop (Co-PI)(NSF - Atmospheric Sciences) 1994-1997

Nepal '94 Himalayan Climate Research Expedition (UNH Parent's Fund) 1994

Glaciochemical Reconnaissance of Western Nepal (Co-PI)(NSF-International Office) 1993-1994

Central Asian Glaciochemical Program (Co-PI)(NSF- Atmospheric Sciences) 1990-1993

PROFESSIONAL SOCIETIES, SERVICE, AND AWARDS

2010	UNH Faculty Award for Excellence in Public Service
2009 -	New Hampshire Energy and Climate Collaborative
2009	Co-convener, AGU Fall Meeting “Paleoclimate Records of North Pacific Climate Variability”
2009	Co-convener, AGU Spring Meeting “Regional Climate Change Impact Assessments: From Predictions to Outcomes”
2007–2009	New Hampshire Climate Change Policy Task Force
2006	Co-convener, AGU Fall Meeting “Multidisciplinary Analyses of Climate Variability, Change, and Impacts on a Regional Scale”
2006-2007	Chairman, UNH Undergraduate Research Conference
2006	Co-convener, North Pacific Climate Workshop, Sidney, British Columbia
2004	Co-convener, AGU Fall Meeting “Paleoclimate Records of North Pacific Climate Variability”
2004	Co-convener, AGU Fall Meeting “Regional Climate Variability and Change: Observations and Model Applications”
2003	Board Member, Kittery Land Trust
2001–2006	UNH representative to the Arctic Consortium of the United States
1998 -	Union of Concerned Scientists – Sound Science Initiative
1996–1999	United States Ice Core Working Group (chemistry representative)
1989 – 2000	Founder and President, Seacoast Area Bicycle Routes
1988	Antarctic Service Medal (United States Congress)

1987 - American Geophysical Union
1987 - International Glaciological Society
1987 Eastern Snow Conference – Wiesnet Medal

GRADUATE STUDENTS ADVISED

NAMES IN CAPITAL LETTERS indicates students for whom I am or was committee chair.

ELIZABETH BURAKOWSKI Ph.D (in prep.) Regional Climate Change and Variability in the Northeast US.
MATT MAGNUSSON Ph.D. (in prep.) Analysis of the Economic Benefits of Reducing Greenhouse Gas Emissions in the Northeast US.
ERIC KELSEY Ph.D. (in prep.) Ice core records of changes in atmospheric circulation in the Arctic.
TRACEY WAWRZENIAK, M.Sc. (2010) Reconstruction of the North Atlantic Oscillation via Analysis of Multiple northern Hemisphere Ice Cores.
SUSAN SPIERRE (2008) Extreme Precipitation Trends in New England.
ELIZABETH BURAKOWSKI M.Sc. (2008) Records of changing snowfall in the Northeast US over the past four decades.
Ajaya Upadhyay (2007) Association between Respiratory Symptoms, Ozone, and Fine Particles in a Diverse New England Population.
TOM LAMBERT M.Sc. (2006). Air Quality and Pulmonary Function in New England during the Summer of 2004.
AMY FRAPPIER, Ph.D. (2006) Recent Extreme Events in a Tropical Stalagmite: Multi-Proxy Records and Analysis of Ecosystem d13C Value Sensitivity to Weak Climate Forcing.
KAPLAN YALCIN, Ph.D. (2005) A Glaciochemical Record of Anthropogenic and Natural Environmental Change from Eclipse Icefield, Yukon Territory, Canada.
Daniel Voisin, M.Sc. (2005) A 2000-Year History of Antarctica Volcanism From Tephra in the Siple Dome Ice Core.
Emily Fisher, M.Sc. (2004) Source Region of Ozone and Soluble Ions at Mt. Washington, NH.
ZACHARY IRONS M.Sc. (2004) Source Region identification of Extreme water-Soluble nitrate and Sulfate Aerosol Concentrations at the New Hampshire Seacoast.
ADAM WILSON M.Sc. (2003) Air Quality, Weather, and Respiratory Hospital visits in Northern New England.
Amy Frappier, M.Sc. (2002) High Resolution Stable isotope Dynamics Recorded by Speleothem Calcite: A new Tool for Paleotempestology, Paleometeorology, and Paleoecology.
KAPLAN YALCIN M.Sc.(2001) Anthropogenic and Volcanic Signals in an Ice Core frm Eclipse Icefield, Yukon Territory, Canada.
Alison Murphy, M. Sc. (2000) A Glaciochemical record from the Devon Ice Cap and Late-Holocene reconstruction of past Sea ice extent in the North Water Polynya, Eastern Canadian Arctic.
ARUN SHRESTHA Ph.D. (1998) Physical and Chemical Climate in the Nepal Himalaya
Christian Zdanowicz, Ph.D. (1999) Paleoclimatic Significance of Insoluble Microparticle records from Canadian Arctic and Greenland Ice Cores.
NANCY GRUMET M.Sc. (1997) Late Holocene Climate Variability Characterized by the Major Ion Record Derived from the Penny Ice Core.
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UNDERGRADUATE STUDENTS ADVISED

Rachel Pisa (class of 2012) Scoring New Hampshire's progress on its Climate Action Plan.
Margaret Baber (B.Sc., DePauw University, 2011) Trends in Extreme Temperatures and Dry Periods in the Northeastern United States. (Research and Discover student). Abstract GC13C-0721 presented at 2010 Fall Meeting, AGU, San Francisco, Calif.
Corey Johnson (class of 2011) Taking "STOCC": Reducing Municipal Greenhouse Gas Emissions and Saving Taxpayer Dollars. Presented at UNH Undergraduate Research Conference in 2009 and 2010 (http://www.unh.edu/urc/); Published in Inquiry Journal (UNH Undergraduate Research Journal) 2010 (http://www.unh.edu/inquiryjournal/) (UNH UROP Summer Undergraduate Research Fellowship).
Rebecca Lehr (B.Sc. 2010) Analysis of the UNH Climate Action Plan. Presented at UNH Undergraduate Research Conference in 2008 and 2009 (http://www.unh.edu/urc/), and also presented results to UNH Energy Task Force.
Jennifer Wurtzel (B.Sc. University of Michigan, 2008) New Hampshire's Changing Wintertime Climate: Impact on Forestry Practices. Presented at Fall American Geophysical Union Meeting, San Francisco. (Research and Discover student)
Tom Daigle (B.Sc. Union College 2003) Melt layer analysis of Eclipse ice cores. (Research and Discover student)
Ty Cook (2004) Linking snow chemistry signals to meteorological variables in the S. Elias Mountains, Yukon Territory. (UNH UROP Summer Undergraduate Research Fellowship).
Deana Aulisio (B.Eng. 2001) An interannual analysis if iron deposition on a Canadian Glacier: Comparing long-range dust transport to salmon populations in the North Pacific. Presented at UNH Undergraduate Research Conference in 2001. (UNH UROP Summer Undergraduate Research Fellowship.)
Sara Story (B. Sc. 2001) Melt layer analysis of two Tien Shan ice cores.

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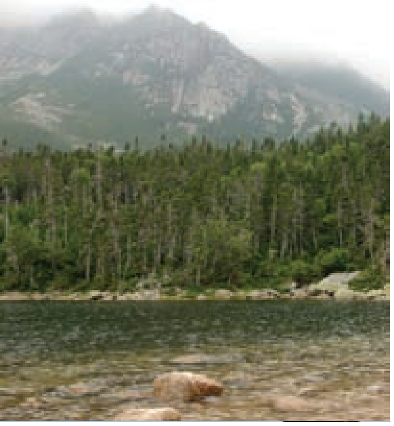
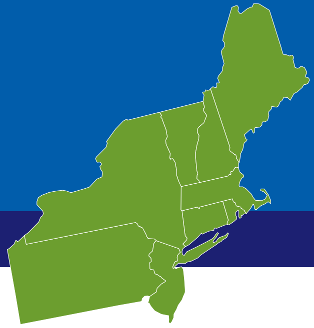




Maine

Confronting Climate Change in the U.S. Northeast



From towering Mount Katahdin to the sandy beaches of York, the climate of Maine is changing. Records show that spring is arriving earlier, summers are growing hotter, and winters are becoming warmer and less snowy. These changes are consistent with global warming, an increasingly urgent phenomenon driven by heat-trapping emissions from human activities. New state-of-the-art research shows that if global warming emissions continue to grow unabated, Maine can expect dramatic changes in climate over the course of this century, with substantial impacts on vital aspects of the state's economy and character. If the rate of emissions is lowered, however, projections show that many of the changes will be far less dramatic. Emissions choices we make today—in Maine, the Northeast, and worldwide—will help determine the climate our children and grandchildren inherit, and shape the consequences for their economy, environment, and quality of life.

The research summarized here describes how climate change may affect Maine and other Northeast states under two different emissions scenarios. The higher-emissions scenario assumes continued heavy reliance on fossil fuels, causing heat-trapping emissions to rise rapidly over the course of the century. The lower-emissions scenario assumes a shift away from fossil fuels in favor of clean energy technologies, causing emissions to decline by mid-century.

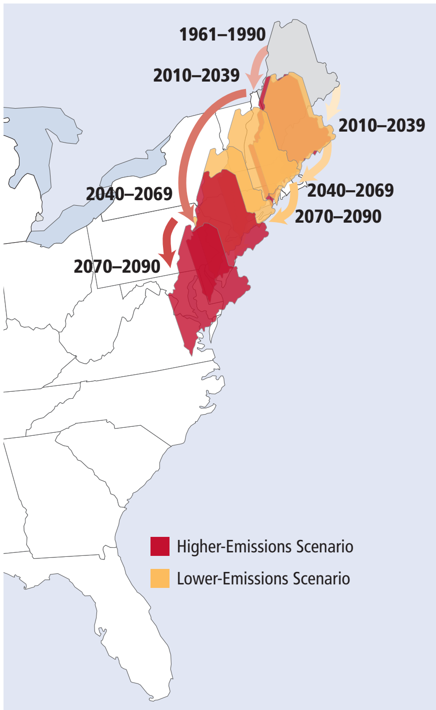
The research also explores actions that individual households, businesses, and governments in the Northeast can take today to reduce emissions to levels consistent with staying *below* the lower-emissions scenario, and to adapt to the unavoidable changes that past emissions have already set in motion.

MAINE'S CHANGING CLIMATE

Temperature. Average temperatures across the Northeast have risen more than 1.5 degrees Fahrenheit (°F) since 1970, with winters warming most rapidly—4°F between 1970 and 2000. If higher emissions prevail, seasonal average temperatures across Maine are projected to rise 10°F to 13°F above historic levels in winter and 7°F to 13°F in summer by late-century, while lower emissions would cause roughly half this warming.

Precipitation and winter snow. The Northeast region is projected to see an increase in winter precipitation on the order of 20 to 30 percent. Slightly greater increases are projected under the higher-emissions scenario, which would also feature less winter precipitation falling as snow and more as rain.

Snow is nearly synonymous with winter in Maine and an integral part of many favorite winter activities and traditions. If higher emissions



Migrating State Climate

Changes in average summer heat index—a measure of how hot it actually feels, given temperature and humidity—could strongly affect Mainers' quality of life in the future. Red arrows track what summers could feel like over the course of the century under the higher-emissions scenario; yellow arrows track what summers in the state could feel like under the lower-emissions scenario.

Photos: (from top) iStockphoto.com/Andy Thorington; Maine Department of Inland Fisheries and Wildlife; iStockphoto.com/Greg Nicholas; Captains of Industry; iStockphoto.com/Ben Thomas prevail, much of Maine—historically snow-covered for most of the winter—would see its snow season shrink by roughly half by late-century. Under the lower-emissions scenario, however, the state is expected to retain a substantial snow season—between two and four weeks of snow cover per winter month.

Heavy, damaging rainfall events have already increased measurably across the Northeast in recent decades. Intense spring rains struck the region in both 2006 and 2007, for example, causing widespread flooding. The frequency and severity of heavy rainfall events is expected to rise further under either emissions scenario.

Drought and stream flow. In this historically water-rich state, rising summer temperatures coupled with little change in summer rainfall are projected to increase the frequency of short-term (one- to three-month) droughts and decrease summer stream flow, particularly if higher emissions prevail. By late-century, for example, short-term droughts are projected to occur annually under the higher-emissions scenario (compared with once every two to three years, on average, historically), while summertime conditions of low stream flow (detrimental to native fish such as the Atlantic salmon) are projected to last an additional month, increasing stress on both natural and managed ecosystems. By contrast, little change in either drought or stream flow is expected under the lower-emissions scenario.

Sea-level rise. Global warming affects sea levels by causing ocean water to expand as it warms, and by melting land-based ice. Under the higher-emissions scenario, global sea level is projected to rise between 10 inches and two feet by the end of the century (7 to 14 inches under the lower-emissions scenario). These projections do not account for the recent observed melting of the world's major ice sheets—nor the potential for accelerated melting—and may

AP Photo/Robert F. Bukaty

A decline in spruce/fir forests would greatly exacerbate existing stresses on Maine's economically important pulp and paper industry.

therefore be conservative. However, even under these projections, Maine's coast faces substantial increases in the extent and frequency of coastal flooding, erosion, and property damage.

IMPACTS ON FORESTS

Forests cover 90 percent of Maine, providing timber and firewood, plant and wildlife habitat, and terrain for hiking, snowmobiling, snowshoeing, fishing, and birding. In addition, the forestry industry provides the state with more than 19,000 jobs.

As temperatures climb, the character of Maine's forests is expected to change—particularly its spruce/fir forests, which are vital to the state's nearly \$1.4 billion pulp and paper industry and treasured for their scenic and recreational value. Spruce and fir species provide 50 percent of all sawlogs (used for lumber) and 20 percent of all pulpwood (used for paper production) harvested in Maine.

Climate conditions suitable for these forests are expected to decline in Maine by late-century under both emissions scenarios, with the steepest losses under the higher-emissions scenario. Losses in spruce/fir forests will eventually affect the animal species dependent on them, such as the Canada lynx, snowshoe hare, and Bicknell's thrush. Under the lower-emissions scenario, patches of the high-elevation spruce/fir habitat required by the Bicknell's thrush could persist in the mountains of Maine, but under the higher-emissions scenario this bird's distinctive song could eventually be muted across the entire region as its suitable habitat gradually disappears.

Warm winters interfere with traditional timber harvesting practices in the region, which rely on frozen soil conditions to minimize damage caused by heavy equipment. With projected winter warming, the trend toward an earlier or intermittent "mud season" is expected to continue.

Long-lived trees may persist for some time even as the climate becomes unsuitable for them; however, they may also become more vulnerable to competition from better-suited species and other stresses such as pests and disease. Maine's hemlock trees (which shade streams, providing cool conditions required by native brook trout and other fish) face both shrinking suitable habitat and the northward march of the hemlock woolly adelgid, an invasive insect that has already destroyed hemlock stands from Georgia to Connecticut. With warmer winters projected under the higher-emissions scenario, the adelgid is poised to infest hemlocks as far north as the Canadian border by late-century, but would be prevented from spreading into northern Maine this century under the lower-emissions scenario.

IMPACTS ON WINTER RECREATION

The Pine Tree State has a long-established reputation as a winter getaway. But Maine winters have already changed and, over the course of the century, may look and feel profoundly different.

Snowmobiling. Maine is part of a six-state network of snowmobile trails totaling 40,500 miles and contributing $3 billion a year to the regional economy. Snowmobiling, like cross-country skiing and snowshoeing, relies almost entirely on natural snowfall because of the impracticality of snowmaking on such a vast system of trails. This fact, combined with projected losses in natural snow cover, means that Maine's snowmobiling season could be cut substantially by mid-century. Under the higher-emissions scenario the average season length across Maine is projected to shrink to roughly 30 days by late-century—a nearly 70 percent decline below recent levels—and to roughly 50 days under the lower-emissions scenario (a 40 percent decline).

Skiing. Maine's 17 ski areas contribute $300 million a year to the state's economy, providing recreation for Mainers and visitors. Milder winters are expected to shorten the average ski season, increase snowmaking requirements, and drive up operating costs in an industry that has already contracted in recent years. Under the higher-emissions scenario, western Maine is projected to be the only area in the entire Northeast able to support viable ski operations by late-century. However, in order to stay open, resorts in this area would require substantial increases in snowmaking capacity and, therefore, operating costs.

Lake ice. Ice fishing and pond hockey are winter favorites in Maine. However, global warming will render lake ice cover increasingly thin and shorten its duration; ice cover duration on Sebago Lake has already declined by two weeks over the past several decades. Combined with fewer opportunities for sledding, snowshoeing, and other favorite outdoor activities, winter recreation as it is now known in Maine is at great risk.

MARINE IMPACTS

A regional icon, Maine's coastal fishing villages contribute $393 million to the state economy each year. Commercial fish and shellfish, including cod and lobster, have water-temperature thresholds that define the conditions required for their survival, growth, and reproduction. By increasing the region's water temperatures, global warming is expected to bring more changes to a sector that has already been transformed over the past several decades.

Lobster. In 2005 Mainers landed 70 million pounds of lobster—more than half of the annual U.S. catch. As the Gulf of Maine warms this century, deeper waters and coastal areas of Downeast Maine may become increasingly suitable for lobster habitation. However, these waters may also become more hospitable to diseases such as lobster-shell disease, which is now observed

AP Photo/Robert F. Bukaty

From skiing and snowboarding to snowmobiling, ice fishing, and sledding, many residents of Maine embrace winter recreation. But the state's winters are warming. Over the course of this century more winter precipitation is projected to fall as rain, and snow and lake ice are expected to melt more quickly, reducing opportunities for popular winter activities.

only at low levels in Maine waters but has damaged the fishery farther south.

Cod. Maine's cod landings, valued at \$3 million in 2005, continue to derive mostly from the Gulf of Maine and neighboring Georges Bank. The Gulf of Maine is projected to continue to support adult cod under either scenario but, as temperatures rise, these waters are expected to become too warm to support the growth and survival of young cod later this century—a critical factor in the long-term viability of this fishery. This change would likely occur more rapidly under the higher-emissions scenario.

IMPACTS ON COASTAL COMMUNITIES

From Kittery to Quoddy Head, climate change threatens the extensive Maine coast and its communities. Rising sea levels caused by global warming are projected to increase the frequency and severity of storm surges and coastal flooding. Favorite beaches and popular tourist destinations, such as Old Orchard Beach, could experience increased beach erosion and flood-related property damage this century. The state's coastal wetlands (which provide critical nursery habitat for commercial fish and important stopover sites for migratory and other birds) would be at great risk of permanent inundation as sea levels rise.

Maine is currently the only state in the nation that has implemented shoreline regulations that take potential sea-level rise into account. Further strengthening and adequate funding of these regulations can help protect the state's coast as the climate changes.

IMPACTS ON AGRICULTURE

Maine's farms are not only an idyllic symbol of its heritage, but also a mainstay of the state economy, generating \$1.2 billion every year. Global warming will present both opportunities and challenges to Maine's growers and producers in the coming decades; for example, increases in the frequency of short-term drought (see p.2) could necessitate increased irrigation (e.g., of the blueberry barrens) and operational costs, while a longer growing season could benefit farmers seeking to invest in warmer-weather crops that are currently hard to grow in Maine.

Crops. Maine's fruit and vegetable crops generate approximately \$160 million annually. The state produces more wild blueberries than any other place in the world and ranks sixth in the nation for potato production. Increasing summer temperatures and heat stress could depress the yields of economically important crops, including certain apple varieties and potatoes, by late-century under the higher-emissions scenario. Northward expansion of agricultural pests and weeds could further impede crop production during the course of the century and pressure farmers to increase their herbicide and pesticide use. Under the lower-emissions scenario most of these impacts are expected to be relatively minor.

IMPACTS ON HUMAN HEALTH

Air quality. Air quality is a serious concern in Maine, where 1 in 10 people suffer from asthma. While the state has reduced ozone concentrations in recent years, global warming is expected to worsen air quality in the region, putting more stress on people with asthma and other respiratory diseases. In the absence of more stringent controls on ozone-forming pollutants, the number of poor air-quality days in cities like Augusta could roughly quadruple under the higher-emissions scenario by late this century. Under the lower-emissions scenario such days could increase by half.

Higher temperatures and increasing levels of plant-stimulating carbon dioxide (CO_2) in the air are also expected to accelerate seasonal pollen production in plants over the next several decades under the higher-emissions scenario. This could extend the allergy season, increase asthma risks, and exacerbate symptoms for asthma sufferers.

Ting Li Wang/The New York Times/Redux

Maine's landings of American lobster, the state's highest-value commercial catch, were valued at more than \$300 million in 2005. The industry also supported more than 7,000 commercial harvesters in Maine in 2006. As waters warm and lobster ranges shift, lobstermen will need to adapt to the changes and manage the remaining stocks in a sustainable manner.

Vector-borne disease. Mosquitoes and ticks carry West Nile virus (WNV) and Lyme disease-causing bacteria, respectively, and spread them to animals or people. Factors affecting the spread of such vector-borne diseases are complex; however, projections for the Northeast of warmer winters, hotter summers, and more frequent summer dry periods punctuated by heavy rainstorms can set the stage for more frequent WNV outbreaks.

WHAT WE CAN DO

We have an opportunity to help protect our children and grandchildren from the most severe consequences of global warming by reducing emissions today. At the same time, effective adaptation strategies are needed to help reduce the vulnerability of Maine's residents, ecosystems, and economies to those changes that are now unavoidable.

Here in Maine, and across the world, there is growing momentum to meet the climate challenge. Of course our actions alone will not be sufficient to avoid dangerous climate change. But with its reputation as a state of sensible and resourceful people and a history of national leadership in environmental policy, Maine (along with the rest of the Northeast) is well positioned to drive national and international action.

Concerted, sustained efforts to reduce emissions in the region—on the order of 80 percent below 2000 levels by mid-century, and just over 3 percent per year on average over the next several decades—can help pull global emissions below the lower-emissions scenario described here.

State and municipal governments have a rich array of strategies and policies at their disposal to meet the climate challenge in partnership with other states, businesses, civic institutions, and the public. These strategies and policies would reduce emissions in the following sectors:

New England Futures/Maine DOT

The *Downeaster* is a 116-mile Amtrak train route from Boston to Portland, Maine. In fiscal year 2006, it was Amtrak's fastest-growing service, with overall ridership up 23 percent from the previous year.

Electric power. As a participant in the Regional Greenhouse Gas Initiative, Maine can reap substantial energy cost savings, promote economic development, and reduce emissions by auctioning 100 percent of the emissions credits created under the initiative and investing the proceeds in energy efficiency and renewable energy development. Governor Baldacci's Task Force on Wind Power Development can help Maine capitalize on its wind resources (largest among New England states) by ensuring that the state has an efficient and balanced process for evaluating projects and setting targets for substantially increasing new wind generation over the coming decades.

Buildings. Maine's relatively old stock of residential, commercial, and industrial buildings offers substantial opportunities to reduce emissions associated with water and space heating. The state already requires all state building projects to achieve the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) certification; local governments could follow suit and also amend zoning laws to encourage and/or require private projects to attain LEED certification and/or designation as a U.S. Environmental Protection Agency (EPA) Energy Star Building. Significant emissions reductions and energy cost savings could be achieved by eliminating Maine's distinction as the only New England state without a residential building energy code.

Transportation. Cars and trucks account for nearly 40 percent of Maine's total heat-trapping emissions. The state has adopted California's tailpipe emissions standards, which require reductions of approximately 30 percent below 2002 levels by 2016, beginning with the 2009 model year (implementation is contingent upon a ruling expected from the EPA). Vehicle emissions can be further reduced through increased investment in public transportation, incentives to purchase low-emissions vehicles, and incentives and regulations that promote "smart growth" strategies such as concentrating development near existing infrastructure and downtowns. In addition, Maine can adopt standards to reduce the carbon content of fuels.

Industries and large institutions can reduce emissions while lowering energy costs and enhancing their energy security by installing combined-heat-and-power (CHP) and on-site renewable energy systems. For example, Eastern Maine Medical Center in Bangor commissioned a CHP system in 2006 that will save the facility $1 million per year.

Forestry and agriculture policies in Maine can be refined to promote management practices and systems that cost-effectively reduce emissions. Opportunities for capturing carbon or avoiding CO_2 emissions from forests include protection, reduced-impact timber harvesting, reforestation, and bioenergy production—provided the latter is done in a sustainable manner.

CONCLUSION

Global warming represents an enormous challenge, but the solutions are within reach if we act swiftly. The emissions choices we make today in Maine, the Northeast, and globally will shape the climate our children and grandchildren inherit. The time to act is now.

DOE/NREL/Judy Forsythe

A Citizen's Guide to Reducing Emissions

1. **Become carbon-conscious.** The problem of global warming stems from a previous lack of awareness of our "carbon footprint" and its effect on climate. Individuals and families can start by using one of several publicly available carbon-footprint calculators that will help you understand which choices make the biggest difference.
2. **Drive change.** For most people, choosing a vehicle (and how much they should drive it) is the single biggest opportunity to slash personal carbon emissions. Each gallon of gas used is responsible for 25 pounds of heat-trapping emissions.
3. **Look for the Energy Star label.** When it comes time to replace household appliances, look for the Energy Star label on new models (refrigerators, freezers, furnaces, air conditioners, and water heaters use the most energy).
4. **Choose clean power.** Consumers in Maine can purchase electricity from local utilities generated from renewable resources that produce no carbon emissions. If your local utility does not offer a "green" option, consider purchasing renewable energy certificates.
5. **Unplug an underutilized freezer or refrigerator.** One of the quickest ways to reduce your global warming impact is to unplug a rarely used refrigerator or freezer. This can lower the typical family's CO_2 emissions nearly 10 percent.
6. **Get a home energy audit.** Take advantage of the free home energy audits offered by many utilities. Even simple measures (such as installing a programmable thermostat) can each reduce a typical family's CO_2 emissions about 5 percent.
7. **Lightbulbs matter.** If every U.S. household replaced one incandescent lightbulb with an energy-saving compact fluorescent lightbulb (CFL), we could reduce global warming pollution by more than 90 billion pounds over the life of the bulbs.
8. **Buy good wood.** When buying wood products, check for labels that indicate the source of the timber. Forests managed in a sustainable way are more likely to store carbon effectively—thus helping to slow global warming.
9. **Spread the word and help others.** A growing movement across the country seeks to reduce individual, family, business, and community emissions while inspiring and assisting others to do the same.
10. **Let policy makers know you are concerned about global warming.** Elected officials and candidates for public office at every level need to hear from citizens. Urge them to support policies and funding choices that will accelerate the shift to a low-emissions future.

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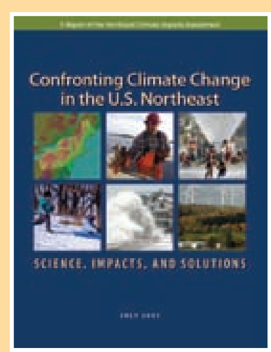
This summary was prepared by the Union of Concerned Scientists based on *Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions*, a report of the Northeast Climate Impacts Assessment (NECIA, 2007). NECIA is a collaborative effort between the Union of Concerned Scientists and a team of independent scientific experts to assess how global warming may further affect the climate of the U.S. Northeast and to explore options for meeting the climate challenge.

For more information on our changing Northeast climate and what you can do, or to download a copy of the full report and additional state summaries, visit *www.climatechoices.org*.



The Changing Character of Winter Climate in the Northeast United States

Elizabeth Burakowski and Cameron Wake

Introduction

The winter of 2007-2008 will go down in memory as one of the snowiest winters in the northeast. Skiers and snowboarders enjoyed natural snow conditions as early as mid-November and continued the season through May. Outdoor enthusiasts enjoyed snowshoeing in the Green Mountains of Vermont, cross-country skiing along the coast at Ordiorne Point State Park in New Hampshire, and snowy winter hikes in the White Mountains.

When compared to previous winters, the 2007-2008 winter makes people in the northeast appreciate the capricious nature of their winters, but also reminds them that the cold, snowy winters are becoming more of a rarity. The warmer winters of recent years remind us that the character of our winters is at stake, and we that we have the opportunity to partake in a global effort to help preserve it.

Detailed analysis of meteorological records has determined that global temperatures rose 1.3^{o}F over the past 100 years, and that the rate of warming over the past 50 years has more than doubled the 100-year trend[1]. In addition, the eleven warmest years on record (since 1850) have occurred since 1995[1]. Scientists agree that the increased rate of warming is being driven primarily by increases in levels of greenhouse gases in the atmosphere that originate from the burning of fossil fuel and land use changes[1].

Regions around the world are responding differently to the impacts of a warming globe. In the northeastern United States, winter temperatures have warmed much faster than in any other season over the past four decades. Communities in the northeast, which includes the states of Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont, generally experienced cold winters during the first half of the 20th century (Figure 1). In more recent decades, warmer winter temperatures have lead to changes in snowfall and snow cover, which have resounding impacts on the region's climate, ecosystems, and economy.

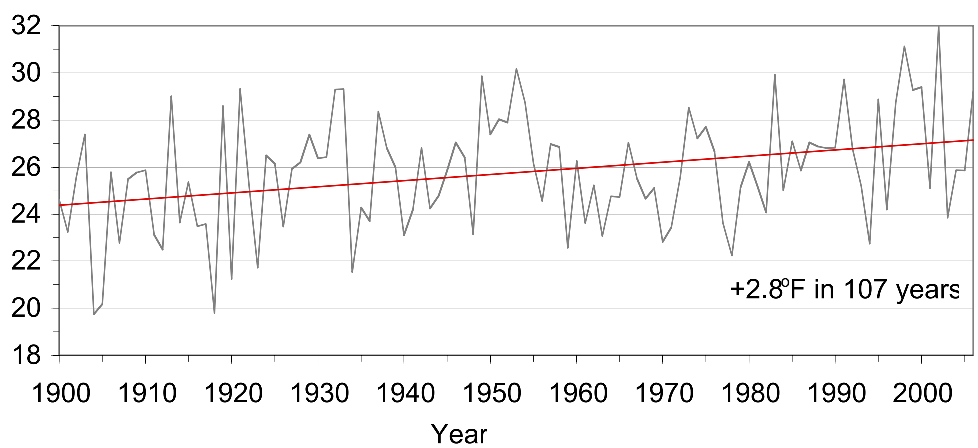


Figure 1. Time series of northeastern United States winter temperature, 1900-2006. The temperature change (+1.7°F) was estimated using linear regression (red line). The regional average was calculated as the area-weighted mean, weighted by NCDC climate division area.

This report contains a summary of findings from research conducted at the Climate Change Research Center at the University of New Hampshire (and published in peer reviewed scientific literature[2]) and includes trends in regional winter temperature over the period 1965-2006, days with snow cover (snow depth > one inch) and snowfall over the period 1965-2005. This time period was chosen because it coincides with the increased rate of warming identified in the global record that is linked to increased levels of anthropogenic greenhouse gases[1].

The data in this study come from the United States Historical Climate Network (USHCN)[3] and the National Weather Service Cooperative Observer Program (COOP) [4](Figure 2). Extensive quality assurance and quality control measures have been applied to the data set used to increase confidence in the findings[2]. In the northeastern United States, the month of March is included in the winter analysis because it is typically colder and snowier than December.

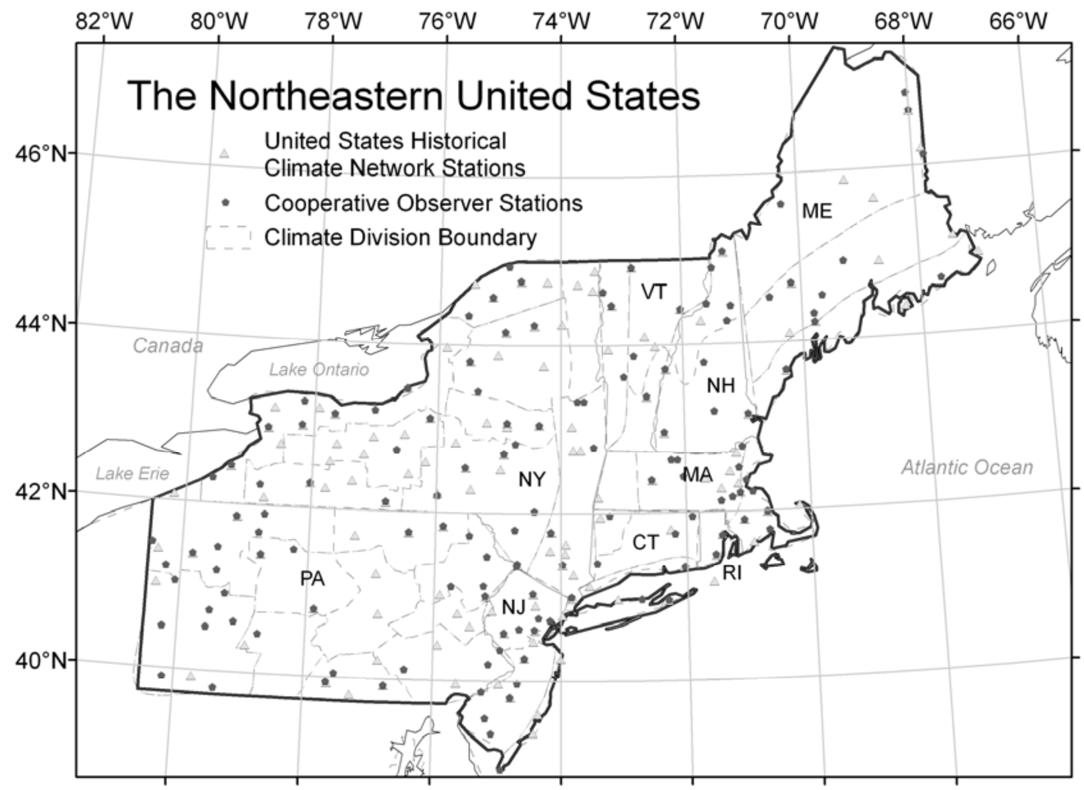


Figure 2. Distribution of northeastern United States climate stations used in this study. United States Historical Climate Network (USHCN) stations are shown as light grey triangles, Cooperative (COOP) Network stations are shown as dark grey circles. National Climatic Data Center (NCDC) climate division boundaries within each state are delineated with dashed lines. Here we define the Northeast US as the six New England states, New York, Pennsylvania, and New Jersey.

Temperature

Analysis of winter temperature records provides a first-order measure of how winter climate in the northeastern United States has changed in recent decades. For the period 1965-2006, the average winter temperature in the northeastern

United States was about 27°F. The 32°F isotherm, or the threshold between below and above freezing mean winter temperatures, is located approximately between 41°N and 42°N (Figure 3).

Mean monthly and seasonal temperature records from 138 meteorological stations across the northeastern US exhibit region-wide winter warming trends on

	Mean Temperature		Snow Covered Days		Snowfall	
	°F	°F/decade	days	days/ decade	inches	inches/ decade
December	+1.9	+0.5	-3.0	-0.7	-5.5	-1.3
January	+3.7	+0.9	-3.1	-0.8	+2.4	+0.6
February	+4.6	+1.1	-2.0	-0.5	-2.8	-0.7
March	+1.4	+0.3	-0.3	-0.01	+2.1	+0.5
Winter	+2.9	+0.7	-8.6	-2.1	-3.2	-0.8

Table 1. Summary of northeastern United States regional average winter climate trends calculated for the period 1965-2005. For each climate variable, the first column represents the total change over the 41-year period, and the second column represents the decadal rate of change over the 41-year period.

the order of +2.9°F over the period 1965-2006 (Table 1). All but two (New Bedford, MA and Lowville, NY) of the 138 stations included in the analysis exhibit winter warming trends (Figure 4).

At the monthly level, strong temperature increases in January (+3.7°F) and February (+4.6°F) are nearly twice than that observed for December (+1.9°F) and March (+1.4°F). A sensitivity analysis using a range of 30-year windows over the period 1965-1994, 1966-1995 ... 1977-2006 shows that winter temperatures are warming regardless of the start and end date used for the time series, and that statistically significant winter warming trends predominate after 1970 (See Appendix I).

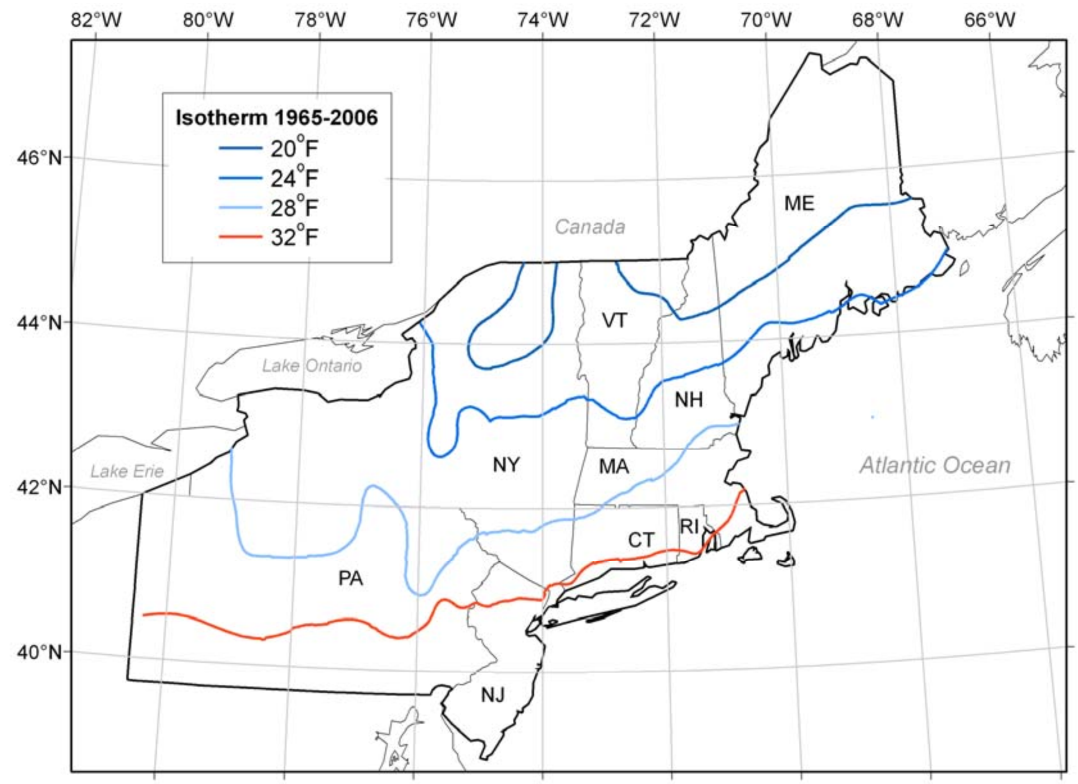


Figure 3. Mean winter (Dec-Mar) temperature isotherms derived from station-based data over the period 1965-2006. The red line marks the 32°F isotherm, or the freezing point threshold. Stations with average winter temperatures below freezing are located north of the 32°F isotherm, and stations with average winter temperatures above freezing are located south of the 32°F isotherm.

Snow Covered Days

Snow-cover depth and duration are important to the climate, ecology, and economy of the northeastern United States. Deep, long-lasting, natural snow cover can be a boon to the cross-country and snowmobiling industry, and also provides an insulating cover for frost-sensitive plants like wild blueberries. Snow cover also results in cooler air temperatures, as the white snow reflects much of

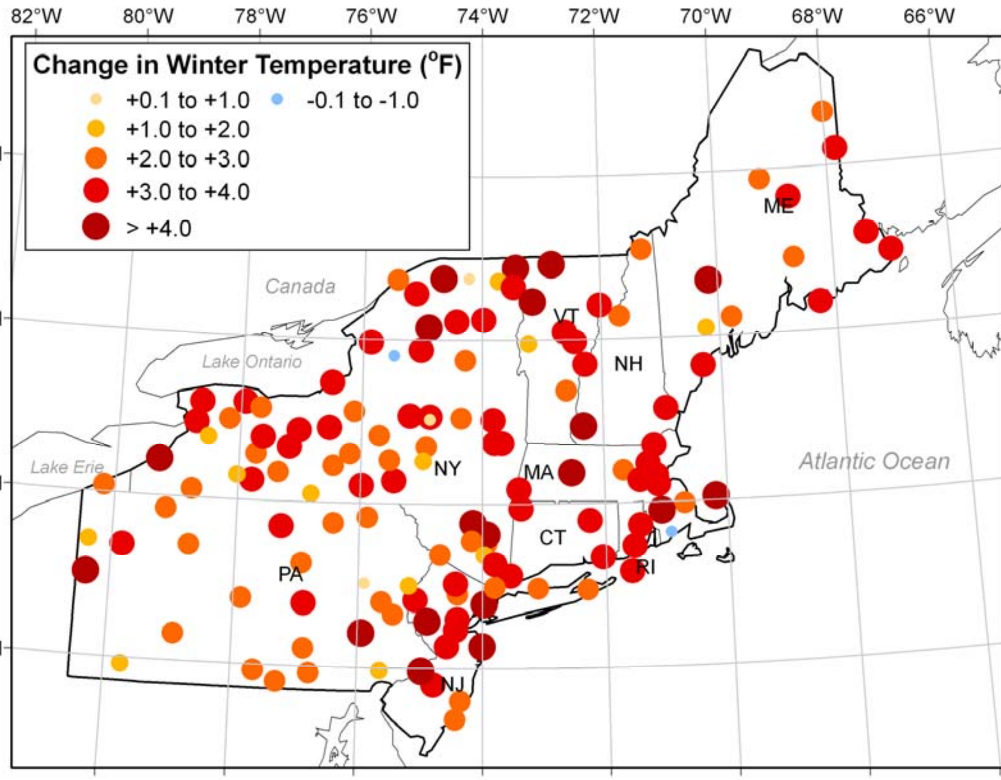


Figure 4. Spatial distribution of winter warming trends, 1965-2006. Trends are calculated using the slope of the linear regression applied to the time series. Warm colors indicate warming trends; cool colors indicate cooling trends. The size and hue of the dot indicates magnitude.

the incoming solar radiation back into space[5]. Communities in the northeastern United States located near the coast and south of 42°N typically experience between 0-60 snow covered days (snow depth > one inch), while inland stations north of 42°N typically experience between 60-121 snow covered days.

Since 1965, most stations in the northeastern United States have experienced an overall decrease in the total number of winter snow covered days. Regionally averaged, the number of snow covered days has decreased by more than week (-8.6 days) over the period 1965-2005, and is largely the result of strong decreases during the months of December (-3.0 days), January (-3.1 days) and February (-2.0 days). The stations with the greatest decreases in days with snow cover days are primarily located between 42°N and 44°N, or just north of the threshold between above and below freezing average winter temperatures (Figure 5). In addition, the decrease in January and February snow-covered days coincides with strong increases in January and February temperatures

(Table 1), a possible indication that snow cover may depend more on temperature than on snowfall[6,7]. In addition, the documented decrease in the snow to total precipitation ratio[7] suggests that increasing winter rainfall over the period 1949-2000 may also be involved in melting shallow snow cover and exposing bare ground.

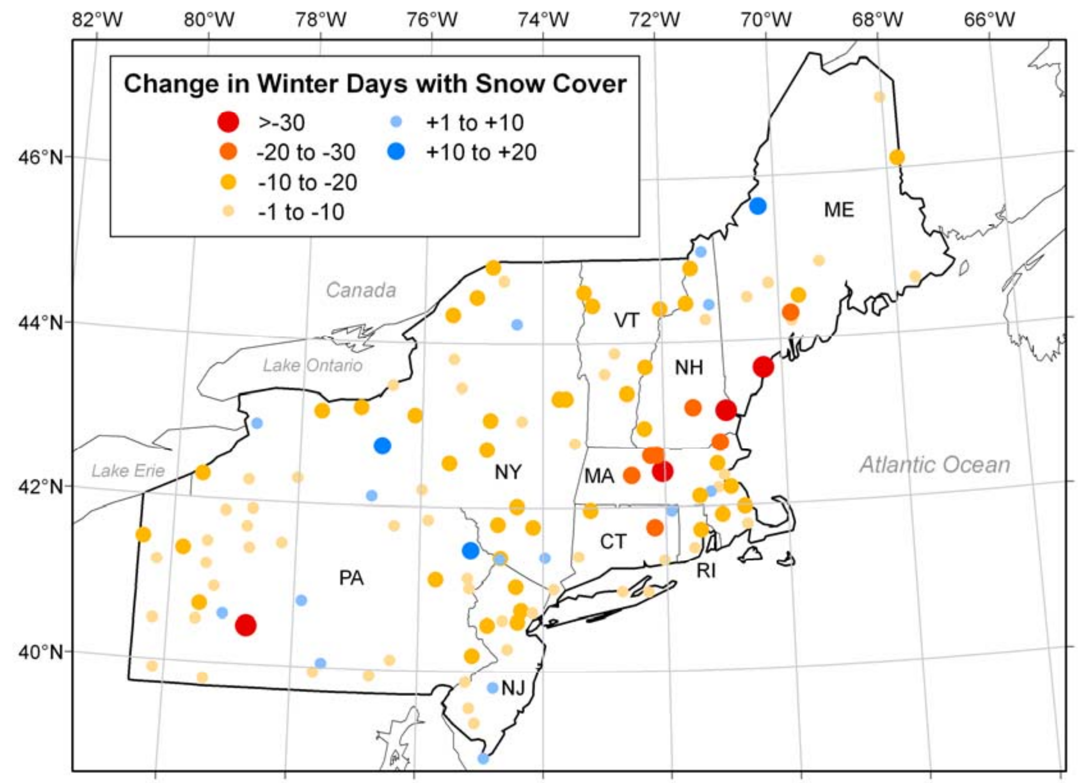


Figure 5. Spatial distribution of winter (Dec, Jan, Feb, Mar) snow-covered days trends in the northeastern United States, 1965-2005. Trends are calculated from applying linear regression to the time series. Warm colors indicate decreasing trends; cool colors indicate increasing trends. The size and hue of the dot indicates the magnitude of the trend.

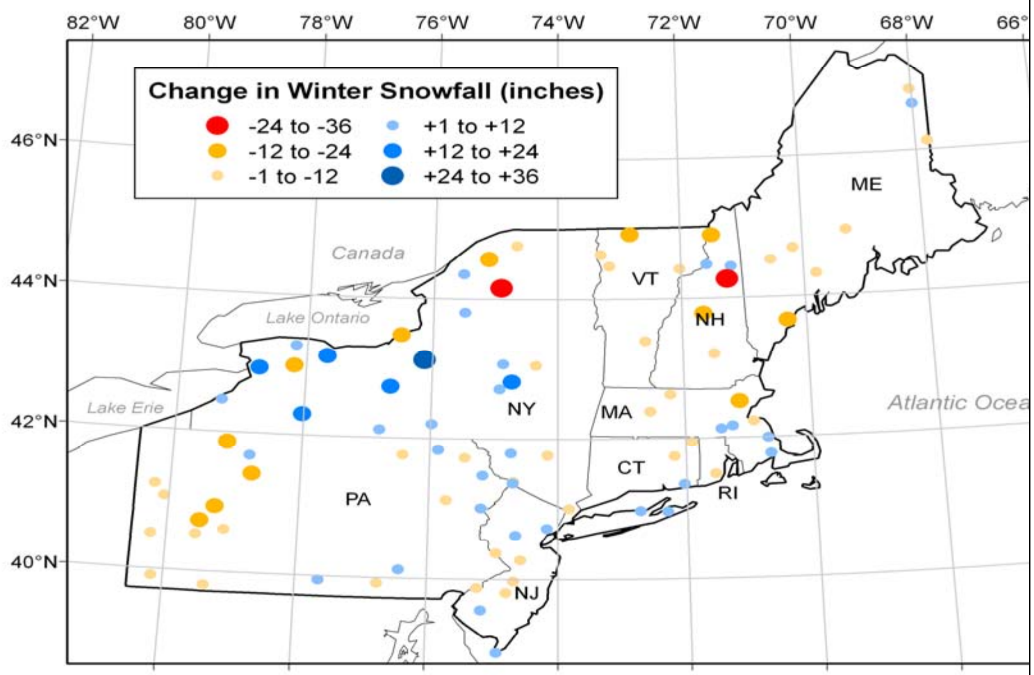


Figure 6. Spatial variability in total winter snowfall trends for the period 1965-2005. Trends are calculated from applying linear regression to 1965-2005 time series. Warm colors indicate decreasing trends; cool colors indicate increasing trends. The size and hue of the dot indicates the magnitude of the trend.

Snowfall

The detection of climate change signals in snowfall records is complex because snowfall is dependent on several factors. Moisture availability and the air temperature at various layers in the atmosphere determine whether precipitation comes in the form of rain, sleet, hail, or snow. Warmer air masses hold more moisture, which can lead to copious amounts of snowfall. Such was the case during the winter of 2007-2008, which set record seasonal snowfall totals at several locations across the northeast US despite warmer than average winter temperatures[8]. The measurement of snowfall can also introduce significant complications to data interpretation. Differences in measurement methods, and changes in station locations and time of observation can introduce non-climatic biases to snowfall records[9]. The stations used in this analysis have been screened for such factors[10], but there still exists significant variability in snowfall trends across the region (Figure 6).

Over the period 1965-2005, total winter snowfall has decreased by about 3.8 inches, averaged across the entire region. The majority of the total winter reduction in snowfall is occurring during the month of December, which has lost about 5.5 inches over the 41-year period (Table 1). The month of February (-2.8 inches) also experienced a modest decrease in snowfall. However, March (+2.1 inches) and January (+2.4 inches) snowfall records indicate slight increases in monthly total snowfall over the time period 1965-2005 (Table 1).

What Does This Mean for the Northeast US?

Over the past four decades, communities in the northeastern United States have witnessed significant changes in the character of their winters. Warmer temperatures, fewer days with snow cover, and decreased snowfall are all symptoms of a region being impacted by a warming globe. Our confidence in quantifying this warming signal comes primarily from the high-quality, reliable temperature records from over 138 meteorological stations located across the northeast. While this warming trend is likely the cause of region-wide decreases in snow cover duration, significant interannual variability remains in snowfall records, making this indicator less clear.

The impacts of warmer winters are already being observed in the northeastern United States. Warmer winter temperatures have been associated with earlier river[11] and lake ice-out[12], which shortens the ice-fishing season. In addition, decreases in the snow to total precipitation ratio and snow density are linked to warmer than average winters and can be important to the timing and magnitude of spring runoff[13]. A shift to earlier and decreased spring runoff has been shown to impact the survival of salmon juveniles[14]. An observed decrease in the number of extreme cold temperature days[15] can lead to increases in tick populations, making vector-borne diseases like Lyme disease more widespread[1]. The lack of cold winter days also allows for the northward migration of hemlock woolly adelgid, an invasive insect that has decimated stands of eastern hemlock on the east coast of the United States[16]. Cold-temperature days are also important to cool-temperature crops such as apples, blueberries, cranberries and grapes, which require 200-2000 cumulative winter cooling hours (between 32°F and 50°F)[17]. If the cooling period requirement is not met, flower buds may die or blossoms may drop before they open, and those flowers that do develop may not set fruit, or the fruit may be undersized.

The impacts of decreased snow cover have been felt strongly in the multi-billion dollar winter tourism and recreation industry. During warm and slushy winters, the state of New Hampshire alone loses an estimated $13 million dollars in revenue from alpine and Nordic ski ticket sales, ice-fishing licenses, and snowmobile registrations[18]. While large investments in snow-making technology will keep many alpine ski resorts in business during warmer than average winters[19], other winter tourism industries, like snowmobiling and Nordic skiing, have not been able to apply such adaptation strategies[20].

Snow cover also plays an important role in soil temperature and moisture properties. Reduced snow cover can have negative impacts on crops such as wild blueberries. In Maine, where ninety percent of the nation's wild blueberries are grown, blueberry crops in 2004 were down 43% from the previous year, partly due to frost damage brought on by inadequate snow cover and extreme cold temperatures[21].

Scientists use regional climate models to project temperature increases in response to higher and lower greenhouse gas emissions scenarios. Under lower emissions scenarios, winter temperatures can be expected to rise by an additional 5.8°F relative to the 1960-1990 average by 2100[22] Under higher emissions scenarios, winter temperatures may rise by an additional 8°F to 12°F by the end of the century. In other words, the decision we make today and over the next decade concerning how we produce and how we use energy will determine how much warmer winter in the northeastern United States will be in the future. This warming will impact a wide range of sectors in our society, including marine resources, coastal infrastructure, winter recreation, agriculture, forests, and human health[22,23]. Regardless of the emissions scenario chosen, the average

What's the difference between weather and climate?

(Or: How can we have a snowy winter in New England if global climate is warming?)

Writer Robert Heinlein hit the nail on the head when he wrote "Climate is what we expect. Weather is what we get". The difference between weather and climate is a matter of time. Weather is the set of conditions of the atmosphere over a short period of time. *Weather* can change from minute-to-minute, hour to hour, day-to-day, and season-to-season. *Climate* is the average weather over time.

Weather is what is happening outside right now. Snow flurry, sunny day, thunderstorm and lightning, pelting rain, very hot summer day, Nor'easter, cold front, warm front, high pressure system sliding through the region . . . .

Climate is the longer-term averages of weather, often over time periods of decades or longer. To answer the question – is our climate changing? – scientists need to look at longer-term trends – many decades to centuries to millennia . These trends include standard measures of changes in mean annual temperature and precipitation, but can also include changes in extreme precipitation events that drop more than one inch of rain in one day, or the length of the growing season, or changes of the timing and amount of spring runoff, or ice-out dates on lakes and rivers, or sea-level rise. These can be measured at individual locations, but data from many locations is often averaged to provide a regional or sometimes global average.

So, anybody who has lived in New England for more than a few years knows that the weather can change rapidly. As Mark Twain said: "Yes, one of the brightest gems in the New England weather is the dazzling uncertainty of it." But analysis of longer-term records is showing that our climate is changing as well. The overall trend towards warmer winters in the northeast does not mean we do not have any cold, snowy winters; it means we simply have fewer of them. And the odds of having a cold, snowy winter will continue to decrease if we continue on a business-as-usual energy pathway and continue to increase our collective emissions of heat-trapping gases.

- Cameron Wake

winter temperature in the northeast is projected to approach, or worse, rise above the freezing point by the end of the 21st century.

The warming trends identified in northeast U.S. meteorological station records are consistent with what scientists expect from a world being warmed by greenhouse gases. If emissions continue to rise, the average winter temperature in the northeast is likely to rise above the freezing point by the end of the 21st century, making snowfall and snow cover occur much less frequently. Even under lower emissions scenarios, we will continue to see changes in the character of our winters. The continuation of current rates of warming into the future most certainly will alter the character of winter in the northeastern United States.

APPENDIX I: Sensitivity Analysis for monthly and seasonal temperature trends.

Decadal trends are estimated from linear regression applied to twelve 30-year moving windows over the period 1965-2005. Trends in bold are statistically significant (*p-value* <0.10). An overwhelming majority of monthly temperature trends were found to be increasing trends, regardless of the 30-year window used. All trends for the months of January and February are increasing trends. Most importantly, seven of the twelve seasonal trends were found to be statistically significant increasing trends.

30-yr period	Dec		Jan		Feb		Mar		Winter	
	Trend (°F/decad)	Sig. (p-value)	Trend (°F/decade)	Sig. (p-value)	Trend (°F/decade)	Sig. (p-value)	Trend (°F/decade)	Sig. (p-value)	Trend (°F/decade)	Sig. (p-value)
1965-1994	-0.06	0.94	+0.68	0.50	+0.85	0.33	+0.30	0.66	+0.44	0.27
1966-1995	+0.25	0.78	+1.00	0.33	+0.63	0.48	+0.35	0.60	+0.56	0.18
1967-1996	+0.16	0.86	+0.97	0.35	+0.70	0.43	+0.26	0.71	+0.52	0.21
1968-1997	+0.62	0.51	+1.43	0.15	+0.73	0.41	-0.05	0.95	+0.68	0.11
1969-1998	+0.85	0.36	+1.62	0.11	+0.95	0.30	+0.30	0.66	**+0.92**	**0.05**
1970-1999	+1.08	0.26	**+1.74**	**0.08**	+1.26	0.18	+0.13	0.84	**+1.05**	**0.03**
1971-2000	+1.10	0.25	+1.22	0.21	+1.38	0.14	+0.33	0.64	**+1.01**	**0.03**
1972-2001	+0.46	0.64	+0.94	0.32	+1.48	0.11	-0.10	0.89	+0.70	0.13
1973-2002	+1.04	0.31	+1.55	0.11	**+1.57**	**0.09**	-0.29	0.67	**+0.97**	**0.05**
1974-2003	+0.96	0.35	+1.42	0.16	+1.11	0.25	+0.07	0.91	**+0.88**	**0.08**
1975-2004	+1.22	0.23	+1.15	0.26	+0.90	0.35	+0.18	0.79	**+0.85**	**0.09**
1976-2005	+1.34	0.18	+1.40	0.17	+1.02	0.29	-0.25	0.70	**+0.86**	**0.09**
Average	+0.75 ±0.46	----	+1.26 ±0.32	----	+1.05 ±0.31	----	+0.10 ±0.23	----	+0.79 ±0.20	-----

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[4] National Weather Service Cooperative Observer Network data available for download at: http://cdo.ncdc.noaa.gov/pls/plclimprod/somdmain.somdwrapper

[5] The presence of snow cover influences temperature through a property known as *albedo*, or reflectivity. Surfaces with a high albedo reflect incoming solar radiation before it can be absorbed. Surfaces with a low albedo absorb incoming solar radiation and re-radiate it as long-wave radiation, or heat. A snow covered surface is therefore relatively cooler than bare ground, which has a lower albedo.

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