Indicators of Climate Change in the Northeast over the Past 100 Years

Cameron Wake
Research Associate Professor
Climate Change Research Center, EOS
University of New Hampshire
Durham, NH
(cameron.wake@unh.edu)

Introduction
Weather in the Northeastern United States is arguably among the most variable in the world. This variability on time scales from hours to years is the result of several factors that relate to the physical geographical setting of the region, including our latitude, topography, and coastal orientation.

To track changes in our climate over the past 100 years, we have analyzed a variety of instrumental and observational data sets, including annual and seasonal temperature, length of growing season, bloom dates, lake ice-in and ice-out dates, total precipitation, snowfall, and days with snow on the ground. Despite the variability in weather in the northeast all of the indicators show that our region has been warming over the last century, and that this rate of warming has increased over the last thirty years. A few of these indicators are described in detail in this fact sheet. For more information, you can download the entire Climate Change Indicators for the Northeast 2005 report from the Clean Air – Cool Planet website (http://www.cleanair-coolplanet.org) and all of the data can be viewed online and downloaded at: http://inhale.unh.edu/Climate.

Average Annual and Seasonal Temperature
Temperature is one of most frequently used indicators of climate change and has been recorded at numerous stations in the northeastern United States since 1899. Changes in temperature affect numerous aspects of our daily lives and our region’s economy, including the ski industry, tourism, transportation, agriculture, emergency management, health, and fuel consumption for heating and cooling. Temperature is the determinant factor in the length of the growing season; it influences the amount of winter snowfall, and the comfort of a summer afternoon. The National Oceanographic and Atmospheric Administration’s National Climatic Data Center (NCDC) has maintained temperature records from various stations across the country. In the Northeast, there are 56 stations that have been continuously operating since 1899, providing the best record of temperature variations for the region.2

Annual average temperature for the Northeast (New England, New York State, and New Jersey) shows considerable variability on annual and longer time scales (Figure 1). For example, note the cooler years in 1904, 1917, and 1926 and the relatively warm years in 1949.

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1953, 1990, and 1998. There is also a trend towards warmer temperatures: the Northeast’s average annual temperature has increased by about 1.8°F since 1899. The 1990s were the warmest decade on record. Over the last 30 years, annual average temperatures have increased 1.4°F. The meteorological station data allows for an investigation of temperature change on a finer scale. As illustrated on the map of the Northeast, all of the stations but one showed an increase in temperature (Figure 2). Note that the coastal regions of Massachusetts, New Jersey, New York, Connecticut and Maine have all warmed more than the Northeast average. The monthly data also allows for the investigation of seasonal trends in temperature. Over the last 100 years, winter (December to February) temperatures show the greatest seasonal rate of warming (2.8°F). Even more striking is the 4.4°F increase in winter temperatures over the last 30 years (1970-2000). This is equivalent to a shift in wintertime climate from Boston to Washington, D.C.

![Figure 1: Average annual temperature for the Northeast from 1899 through 2000. This time-series is an areally weighted average of temperature from 56 stations.](image1)

![Figure 2: Linear trend in annual temperature (°F) by station from 1899-2000 for the Northeast.](image2)

### Length of Growing Season

Length of the growing season is defined as the number of days between the last frost of spring and the first frost of winter. This period roughly marks the period during which plants, especially agricultural crops, grow most successfully. While freezing temperatures affect all commercial, agricultural, industrial, recreational, and ecological systems, the human system most sensitive to changes in the length of the growing season is agriculture. In addition, the length of the growing season is a defining characteristic of different ecosystems. It is possible that a significant change in the length of the growing season could alter the ecology of the Northeast landscape.

Growing season length is an event-driven phenomenon. An increase in the average temperature for a region does not necessarily imply an increase in the growing season, and vice versa. The growing season is solely dependent on specific cold weather events, rather than monthly or annual averages.

There are two types of frost events, radiation and advective frosts. Energy absorbed from the sun by day radiates upward to space by night, causing the air near the surface to cool. On most nights there is enough wind to mix the warmer, upper air with the surface air and keep surface temperatures relatively warm. However, on calm, dry nights, the air near the surface radiates...
heat upward, creating very cold air at the surface — a radiation frost. This type of frost generally impacts relatively small geographic regions and occurs mostly in valleys. Advection frosts are caused by a cold, polar air mass moving into the region. This type of frost is associated with strong winds and a well-mixed atmosphere and tends to affect large geographic areas. The most damaging frosts are combinations of these two types. First the polar air mass moves through and cools down a region, after which the winds slow down and can create ideal conditions for a radiative frost.

There are seven stations in New England that have been collecting daily temperature data since at least 1900. These stations represent the best available instrumental record of growing season for this region going back a century. The length of the growing season in the Northeast has considerable variability on an annual timescale (Figure 3). However, despite this variability, a long-term trend is apparent. When the station data are averaged together, the overall increase is 8 days. The New England growing season has lengthened over the past 100 years, but there is also significant spatial variability, with some locations experiencing considerably longer growing seasons.

Spring Bloom Dates for Lilacs, Apples, and Grapes

A shift in seasonal events in the life of plants and animals, such as flower bloom, spring arrival of migrating birds and insects provide “bioindicators” of our changing climate. Plants are particularly useful to scientists as weather instruments and indicators of climate change because their phenological responses are based on a complex integration of temperature, sunshine, rainfall, and humidity that is difficult to match by simple analysis of weather records.

Changes in spring bloom date from 1965 to 2001 have been analyzed using a unique data set derived from genetically identical lilac plants (Syringa chinensis, clone ‘Red Rothomagensis’) monitored at 72 locations within the Northeastern U.S. In addition, bloom date records for apples have been analyzed. The results indicate that the blooming of lilacs has advanced by about 11 days over the past 36 years. The number of days from the last frost to the first day of the fall has decreased by about 10 days over the past 80 years. The New England growing season has lengthened over the past 100 years, but there is also significant spatial variability, with some locations experiencing considerably longer growing seasons.

Figure 3: Average growing season anomaly at 7 stations in the Northeast, defined by the number of days between the last frost (minimum daily temperature below 32 °F) and the first of the fall, 1900-2001. In the graph, zero represents 192 days, the average time

Figure 4. Trends in lilac bloom dates indicated by the blue line.

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and grapes have also been collected at several sites in the region over the same time period. In addition to the unique, geographically dispersed lilac data set, an evaluation was done of trends in bloom date of apples (‘Empire’ and similar varieties) and grape (variety ‘Concord’) collected at a few sites in New York State during approximately the same time period.

During the period 1965 to 2001, lilac bloom dates advanced about one day per decade in the northeastern U.S. (Figure 4). Although there is substantial variability from site to site and from year to year, there is a statistically significant trend. Also, the genetic similarity of the plants at all sites makes this a highly unique and powerful analysis compared to other similar studies. Analysis of the more geographically limited apple and grape data sets suggests a slightly more rapid advance in spring bloom (Figure 4), about 2 days per decade. The implications of earlier bloom for agricultural crops will depend on many factors. In some cases, it may translate in a straightforward fashion to earlier yields. This will benefit farmers who receive higher prices for earlier production, but could have a negative effect if there is increased competition from farmers in other regions earlier in the season. Earlier bloom could potentially reduce yields if spring temperatures become more variable as the climate changes and an early bloom increases the risk of frost damage to flowers and developing fruit. A recent analysis of historical apple yields in the New York State region found that warmer temperatures from January 1 to bud break period was correlated with lower, not higher, yields.

The magnitude of the climate impact on woody perennials in the Northeast is similar to that reported for bloom of other plant species, and for bird and insect spring migration arrivals, by researchers in other parts of the U.S. and Europe. Results are also qualitatively in agreement with reports of earlier spring “green wave” advancement in the northern hemisphere based on satellite imagery of vegetative cover.

Lake Ice-In and Ice-Out Dates
Observations of lake ice are tangible, readily available and technically feasible indicators of local climate conditions. Ice-out (the day the majority of the lake ice is broken up in the spring) and ice-in (the day the majority of the lake first freezes over in the winter) have been recorded at several Northeastern lakes for many years. Many areas of the world, including the Northeast, are dependent on the freeze and thaw of lakes, reservoirs, and ponds. Used for local
commerce and transportation, lakes have been important to people living in the region for centuries. When frozen, lakes are used for ice fishing, cross-country skiing, sled-dog racing, and snowmobiling, all of which are important for the Northeast’s tourism economy. However, the spring break-up of the lakes is also an important event, when boaters and ferry masters put their boats in the water to begin the warm season.

Ice-out data for the past 75 years has been collected for 27 lakes in New England. The methods used to determine the official ice-out day differ from lake to lake, but generally refer to the last day the lake has significant ice cover. The ice-in day is the first day the majority of the lake is frozen over. Methods have remained reasonably constant at each lake over the time period. For example, the official ice-out date on Lake Winnipesaukee occurs when the MS Mount Washington can safely leave port and motor, unobstructed by ice, to the ports in Center Harbor, Alton Bay, Wolfeboro, and Weirs Beach. The day of ice-out is primarily affected by the severity of the previous winter, lake temperatures, and the warmth of the spring months.

While there is considerable year-to-year variability, the average ice-out day for lakes in New England occurs 6 days earlier that it did in 1925. Over just the last 30 years, analysis of the data shows that ice-out days average 13 days earlier in 2000 compared to 1970.

For Lake Champlain, VT, only the ice-in date has been recorded over the past 150 years. Today the lake freezes over 8 days later than it did in the second half of the 1800s. But the most remarkable part of the record is the occurrence of years in which the lake did not freeze over all winter. Over the 186 year record, the lake has not frozen over in 31 winters, and almost half of them occurred since 1970. Ice-out and ice-in dates recorded in the Northeast are consistent with the warming trend evident in the annual and winter temperature records over the past 100 years.

Precipitation

Total annual precipitation includes snowfall and ice as the amount of liquid equivalent. Ecological systems depend on precipitation for hydration and human communities depend on the replenishment

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of underground water sources and water for growing crops. In addition, precipitation is important for tourism.

Precipitation in the Northeast has increased by an average of 3.3 inches (8 percent) over the past century (Figure 7).\(^5\) There has been a significant increase in precipitation following the drought that affected the region in the early 1960s, which is clearly visible in Figure 7. That drought impacted regional agriculture, water quality and quantity, forest health, and human health. By 1965, that drought reached critical levels and resulted in widespread forest fires, crop failures, fish kills, water shortages, harmful algal blooms, and heat-related deaths. Following the 1960s drought, precipitation has increased. Of the ten years with the most precipitation, eight have occurred since 1970.

Another indicator of hydrologic response sensitive to climate variability is the ratio of snow to total precipitation (\(S/P\) ratio). Changes in the \(S/P\) ratio over time could influence the magnitude and timing of spring runoff and the amount of winter snowcover. In a warmer climate, even without changes in total precipitation, one would expect the relative amount of snowfall to decrease, resulting in a decrease in the \(S/P\) ratio. Analysis of daily US Historical Climatology Network data at 21 sites across New England from 1949 to 2000 has shown that at 11 stations, concentrated in northern New England and coastal/near-coastal regions, the annual \(S/P\) ratio has been decreasing. These annual trends are predominantly a result of decreasing snowfall over the past 30 years. The other 10 sites show weak decreasing \(S/P\) ratio. None of the sites had even a weak increasing trend. When the data are aggregated, the entire New England region and the northernmost region had significant decreasing trends in \(S/P\) ratio for annual and winter periods.

**Extreme Precipitation Events**

The number of precipitation events that resulted in more than two inches of rain (or water equivalent if the storm results in snowfall) during a 48-hour period is counted for each year for six stations going back as far as 1888.

Every station investigated reveals an increase.


Figure 8: Extreme precipitation (>2 inches) events anomaly for six cities, 1914-2000. In the graph, zero represents the average number of events over this time period. Years in red experienced more than average extreme events, while years in blue experienced less. The black line is a linear regression of the data showing an increasing trend.
in extreme precipitation events during the 1980s and 1990s, as compared with the early 1900s. Storrs, CT, which has data available back to 1888, averaged about three intense storms each year prior to 1970 (Figure 8). Since 1970, however, Storrs has averaged 5.5 intense storms per year. The five other stations included here all have a similar history of intense storm events. The increase in the 1980s and 1990s is consistent with increases experienced in most of the country. For example, the contribution to the total annual precipitation of one-day storms exceeding two inches increased from 9 percent in the 1910s to 11 percent in the 1980s and 1990s.

**Snowfall**

Total winter snowfall is an important indicator of winter weather. For those living in the Northeast, snow is an important factor of everyday winter life. Snow in New England is of vital importance to the tourism industry and also represents a key aspect of New England culture. Many regions rely heavily on income from skiers, snowboarders and snowmobilers during the winter season, while snow removal represents a significant expense for municipalities and state governments across the region.

Over the past 30 years, stations in northern New York and northern New England have experienced significant decreases in snowfall, with several locations showing a decrease of 60 or more inches (Figure 9). Overall, the southern portions of the region have experienced a decrease in snowfall, although the decrease is smaller compared to northern regions.

**Days with Snow on Ground**

Like total snowfall, total days with snow on the ground are an important indicator of winter weather. Unfortunately, few meteorological stations have been recording the presence of snow on the ground for very long. As a result, this indicator is only available for many stations back to 1970.

Satellite records indicate that snow cover extent (SCE) in the Northern Hemisphere has decreased by about 10% since 1966 and is strongly related to increases in temperature. Snowfall in the Northeast is extremely variable, with some stations receiving only a few inches of snow and others receiving more than 100 inches every year. Thus the number of days with snow on ground will also be variable across the region. The data

![Figure 9: Map illustrating change (from linear regression) in total annual snowfall for stations 1971 to 2001](image)

![Figure 10. Map illustrating change (from linear regression) of days with snow on the ground from 1971-2000.](image)
from stations in the Northeast are generally consistent with the hemispheric trend and reveal a
decrease in the number of days with snow on ground. The Northeast stations reveal that there
were, on average, 16 fewer days with snow on ground in 2001 than in 1970. However, there are
several large areas that do not have snow depth data (such as most of Maine, Massachusetts,
and Connecticut). Some stations, such as Durham, NH, and Fredonia, NY, are experiencing
almost a month of fewer days, on average, with snow each year. These trends are consistent
with the measured increases in temperature over this time period. While the western areas of
the Northeast have experienced an increase in snowfall, the number of days with snow on the
ground has decreased.

Summary
All of the indicators of climate change in the Northeast that we have presented in this brief
report – temperature, growing season length, ice-in and ice-out on lakes, bloom dates,
precipitation, snow on ground – as well as others such as sea level rise and sea surface
temperature, all indicate that the northeastern United States has warmed over the past 100
years, and that the rate of this warming is increasing over the past 30 years. Of particular
interest for the region is that much of the warming is strongest in the winter and spring as
evidenced by warmer winter temperatures, earlier ice-out dates, earlier spring blooms, and
decrease in snowfall and days with snow on the ground. These changes have already had an
impact on our economy, our ecosystems, and our quality of life.