CLEAN AIR COOL PLANET

Evidence of Early Spring:

Indicators of Climate Change for the Northeast

March, 2006

The indicators presented here are extracted from *Indicators of Climate Change in the Northeast*, by Adam Markham and Cameron Wake, published by Clean Air - Cool Planet in 2005.

The section on bloom dates was authored by Dr. David Wolfe of the Horticulture Department at Cornell University.

Footnotes appearing in these indicators are from the original document, and correspond to endnotes provided in the references section.

Bar quote emphasis of data and trends was not part of the original document.

Length of Growing Season
1874 - 2001

Indicator Overview

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 is called the growing season because it roughly marks the period during which plants, especially agricultural crops, grow most successfully.

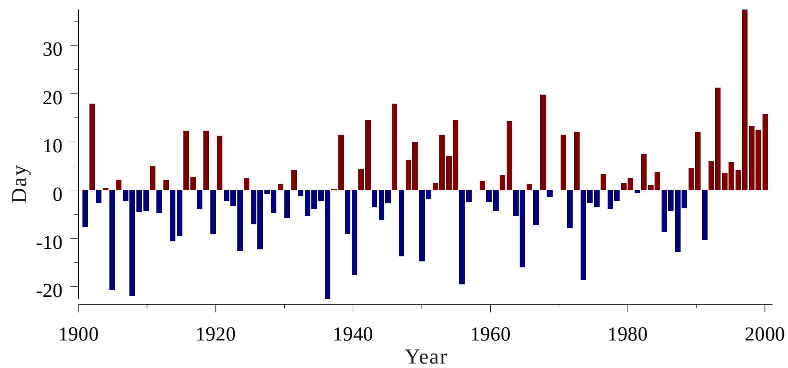

Figure 1: Average growing season anomaly at 7 stations in the Northeast, defined by the number of days between the last frost (minimum daily temperature below 32 °F) and the first of the fall, 1900-2001. In the graph, zero represents 192 days, the average time between frosts. Years in blue experienced shorter than average seasons, while years in red experienced longer.

Regional Importance

The length of the growing season is important to any outdoor activity. 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.[4]

An early fall frost may lead to crop failure and economic misfortune to the farmer. Earlier starts to the growing season may provide an opportunity to diversify crops, or to produce two or more harvests from the same plot. However, the majority of the Northeast's most competitive crops are "cool-season" crops. While it might seem that a successful response to a shorter growing season would be for farmers to switch to alternative warm-season crops, they would then have new competitors who might have advantages such as better soils and a longer growing season.[5] In either case, the length of the growing season is very important to successful agriculture in this region.

In addition, the length of the growing season is a defining characteristic of different ecosystems.[6] It is possible that a significant change in the length of the growing season could alter the ecology of the Northeast landscape.

Sensitivity to Climate and Other Factors

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. As the growing season is defined by the last frost of the spring and the first of the fall, it 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.[7] 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 without mixing with it, 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.

Advective frosts are caused by a cold, polar airmass 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 airmass moves through and cools down a region, after which the winds slow down and can create ideal conditions for a radiative frost.

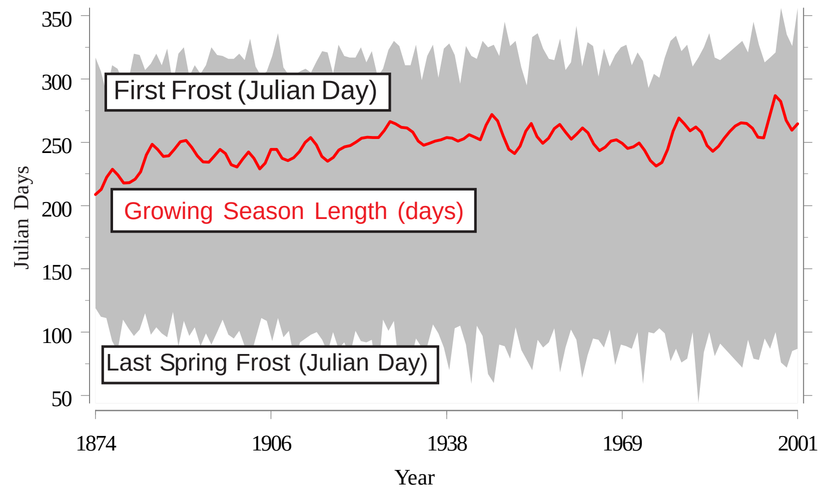

Figure 2: Growing season length and freeze dates at Atlantic City, NJ, defined by the number of days between the last frost (minimum daily temperature below 32 °F) and the first of the fall from 1874-2001. The red line represents the annual length of the growing season, while the gray area represents the date of the last spring (bottom) and first fall (top) frost, by Julian day. Over this time period, the growing season has lengthened by 38 days (19%).

Indicator Trend

There are seven stations in the Northeast that have been collecting daily temperature data since at least 1900.[8] 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 1). However, despite this variability, a long-term trend is apparent. When the station data are averaged together, the overall increase (from linear regression) is 8 days. Some locations, such as Atlantic City (Figure 2), reveal a remarkable change in the length of the growing season. Since data collection began there (1874), the growing season has increased in Atlantic City by five weeks overall. The Northeast growing season has lengthened over the past 100 years, but there is also significant spatial variability, with some locations experiencing considerably longer growing seasons.

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3.

Bloom Dates for Lilacs, Apples, and Grapes

Indicator Overview

As evidence of climate change mounts, scientists have begun to search for signs of biological or ecological responses to this change. A shift in seasonal events in the life of plants and animals, such as flower bloom, spring arrival of migrating birds and insects, etc., are potential "bioindicators" of climate change.

Researchers[9] evaluated changes in spring bloom date from 1965 to 2001 utilizing 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, they examined bloom date records for apples and grapes collected at several sites in the region during approximately the same time period. Collectively, statistical analysis of the results indicated an average advance in spring bloom of about 4 to 8 days in the Northeast during the latter half of the 20th century. This trend is qualitatively consistent with a warming trend for the region, and is consistent with shifts in bloom date and migration patterns reported for various plant and animal species in other parts of the U.S. and Europe.

Regional Importance

The timing of flowering is not only a key event in the life cycle and reproduction of individual plants, it is indicative of a broad range of seasonal biological responses to climate that will have important consequences for ecological processes, forestry, agriculture, human health, and the regional economy. In general, species differences in sensitivity and adaptation to climate change will affect species distributions, the productivity of our farms, and "ecosystem services" (such as water and nutrient cycling) provided by our natural areas.

Figure 1. Monitoring sites for S. chinensis *throughout the Northeast*

There is already evidence in some regions that climate change can encourage invasive weeds, insects, or pathogens, while increasing extinction rates of native species that cannot migrate or disperse their seeds to new suitable habitats.[10]

Climate change is likely to upset the synchrony between the activity of pollinators (e.g., bees) and bloom of some plants, even if pollen production is increased due to the stimulatory effect of warmer temperatures and higher carbon dioxide (CO_2) on growth.[11] The pollen-allergy season is likely to arrive earlier in the spring and could be more severe in a warmer high-CO_2 world.[12] Finally, flowering time and fruit set are driving factors in the food web upon which humans all depend. Pollen, nectar, fruit, or seeds are important resources for many animals, including farmers, human consumers of farm products, and those involved in the agricultural economy of the region.

Sensitivity to Climate and Other Factors

Phenology is the study of seasonal biological events in the animal and plant world as influenced by the environment.[13] 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. Phenology data are usually quite variable because other factors influence the sensitivity of plants to weather and climate, such as genetics and age of the plant, day length (photoperiod response), soil conditions, pests, diseases, and competition from other plants.

Spring bloom date is just one example of a phenological event, but it can be a useful indicator of other biological responses to climate, such as the onset of spring leaf emergence or fall leaf color change, spring arrival date of migrating birds and insects, and animal hibernation.

The practice of monitoring spring bloom date is centuries old. Phenological calendars were used by the ancient Chinese and Romans to guide agricultural operations. Historical phenological records, going back centuries in some cases, have been discovered in Europe and Asia. Analysis of these data have revealed that flowering date of many plant species has been occurring earlier in many regions as winter and early spring temperatures have increased. Species range shifts to higher latitudes and altitudes have also been documented.[14]

Fewer good data sets are available in the U.S., but one study in Wisconsin, begun by the famous conservationist, Aldo Leopold, in the 1930s, monitored 55 species and found an average advance in spring earliness of about 6 days for the period 1936 to 1998.[15] A Smithsonian-sponsored study in the Washington D.C. area found that 89 of 100 plant species monitored from 1970 to 2000 showed a significant advance (4.5 day average) in first bloom date.[16]

The results presented here focus specifically on the northeastern U.S., where average annual temperatures increased 1.8° F, and winter temperatures (December through February) increased 2.8° F from 1899 to 2000. Records were evaluated from 72 locations in this region (see map, Fig. 1) where genetically identical lilac plants (*S. chinensis*, clone 'Red Rothomagensis') were planted and monitored for first flower (bloom) date during the period 1965 to 2001. Not all sites were established in the same year, and most sites were missing some years of record. On average, the sites used had 21 years of record. These plantings were originally established by a U.S. Department of Agriculture project[17] for the purpose of using phenological information to optimize farming practices (e.g., seeding date and pest control), and predict yield

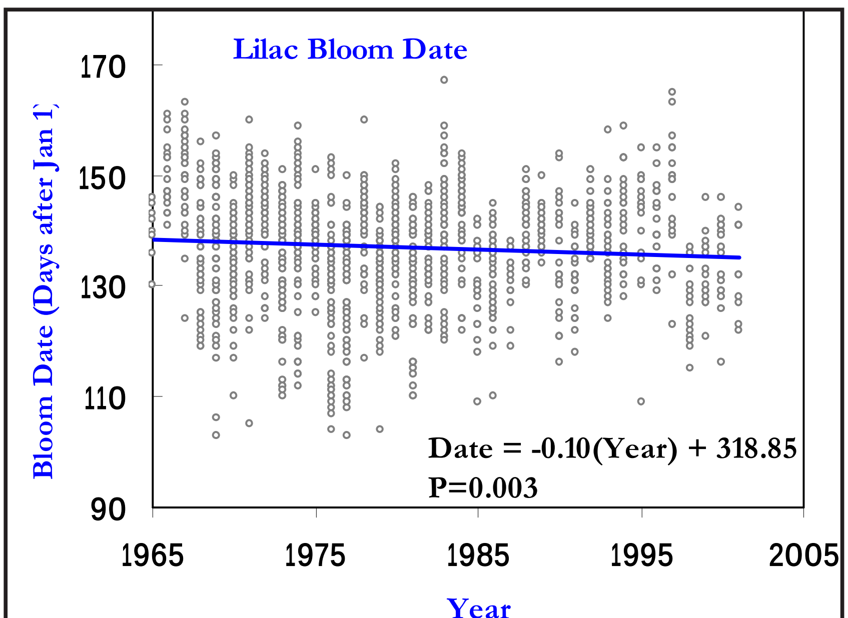

Figure 2. Trend of lilac bloom dates is indicated by the blue line.

potential (crop "futures") for several economically important crops.

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.

Indicator Trend

During the period 1965 to 2001, lilac bloom dates advanced about 1 day per decade in the northeastern U.S. (Fig. 2). Although, as observed in all phenological studies of this type, there is substantial variability from site to site and from year to year, statistical analysis of the data indicated there is less than a 1 per cent probability ($P < 0.01$) that this trend could be due to chance alone. In other words, there is a high degree of confidence that the trend for earlier bloom is real. This is because of the large sample size. Also, the genetic similarity of the plants at all sites makes this a highly unique and powerful analysis compared to other similar studies.

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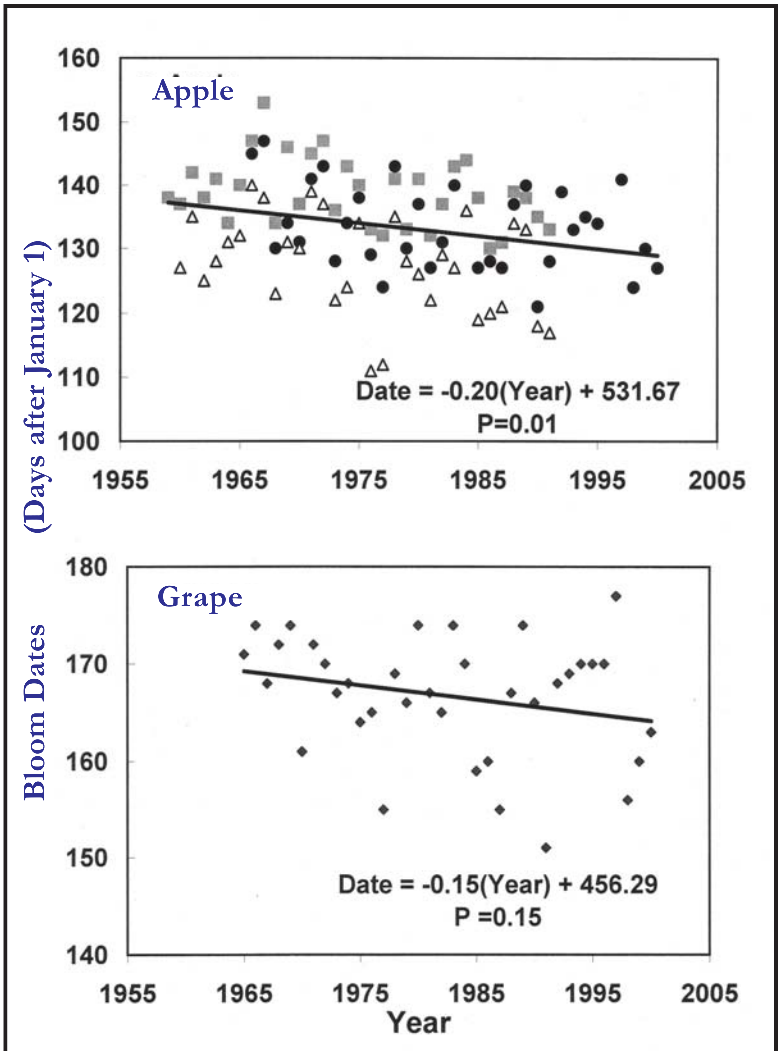


Figure 3. Apple and Grape bloom dates trends

In addition to the pooled analysis shown in Fig. 2, researchers evaluated the trend for each of the 72 sites individually. Of the 72 sites, 64 (89 %) had advanced spring bloom date, and at those few sites where spring bloom was later rather than earlier the trend was not statistically significant.

Analysis of the more geographically limited apple and grape data sets (Fig. 3) suggests a slightly more rapid advance in spring bloom (about 2 days per decade, or 8 days since the 1960s) for these species compared to lilac.

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[18] found that warmer temperatures during the January 1 to bud break period was correlated with lower, not higher yields.

Collectively, analyses for the northeastern U.S. indicate that, on average, lilacs are blooming about four days earlier, and apple and grapes are blooming about eight days earlier than they were half a century ago. The magnitude of this 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 (references: see footnotes 9-11). 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.[19]

This and other recent phenology studies have relied on historical records that were initially maintained for purposes other than examination of climate change. Given the importance of reliable data on ecological responses to climate change for policy-makers, strengthening the existing regional and global phenology monitoring networks[20] should be a high priority in the future.

7.

Timing of High Spring Flow and River Ice-Out

Indicator Overview

Measurements associated with river discharge make it possible to rigorously and consistently record both the timing of high spring flow and the dates of ice-affected flow across the New England region. Both of these variables have been collected by the U.S. Geological Survey using consistent methods for many years on a substantial number of rivers that are free from any significant flow regulation by human activities.

The date marking the point where 50% of the water flow during the period January 1 to May 31 has occurred significantly earlier at most of the sites studied for periods ranging from 50 to 95 years through the year 2000. The date in the Spring when the ice on rivers broke up (ice-out date) has also occurred earlier and the total number of ice-affected flow days during the winter has decreased on most of the rivers studied.

Regional Importance

The timing of the delivery of freshwater to estuaries and near coastal marine waters could affect estuarine and marine ecology through changes in the timing of nutrient cycling and the inland migration of the salt water. In northwestern North America, earlier spring flow has resulted in a reduction in summer flows and a longer summer base flow period. These changes in summer flow regimes have not been observed in Northeastern North America because of a more even distribution of precipitation and possibly because of increasing summertime precipitation. Changes in seasonal flow regime may also influence the timing of migration of anadromous fish.

One potential effect of these trends in river ice involves more frequent formation of anchor ice. Anchor ice does not form when surface ice is present. With fewer ice-affected flow days in the winter, there may be less continuous surface-ice cover and more frequent opportunities for anchor ice to form. Anchor ice typically forms on very cold, clear winter nights. These conditions could still be present in winters that are generally warmer. Anchor ice can restrict or even eliminate substrate flow. This has serious effects on stream biota sensitive to subfreezing conditions and (or) dissolved oxygen in the substrate water, particularly fish eggs and embryos developing within gravel beds.[21] The documented changes in the last dates of ice-affected flow in the spring could also have important effects on river ecology, including effects on primary producers, consumers, and trophic dynamics.

Sensitivity to Climate

The date on which half of the total volume of water for a given period flows by a river gauging station (center of volume date) is more sensitive to changes in the timing of bulk high-flows in a season than is the date of peak flow. This center-of-volume date is a more robust indicator of seasonal flow timing, since the peak flow date can occur before or after the bulk of seasonal flows in response to a single storm. Climate warming results in earlier winter/spring seasonal center-of-volume dates because of an increased ratio of rainfall to snowfall and an earlier snowmelt.

The presence of ice in a river channel affects the relation between river height and flow; therefore, the presence of ice in rivers has been historically determined and recorded so that discharge records can be adjusted for the presence of ice. The formation of ice in river channels is a sensitive climate indicator that affects the river height/flow relation by causing backwater (a higher-than-normal river height for a given

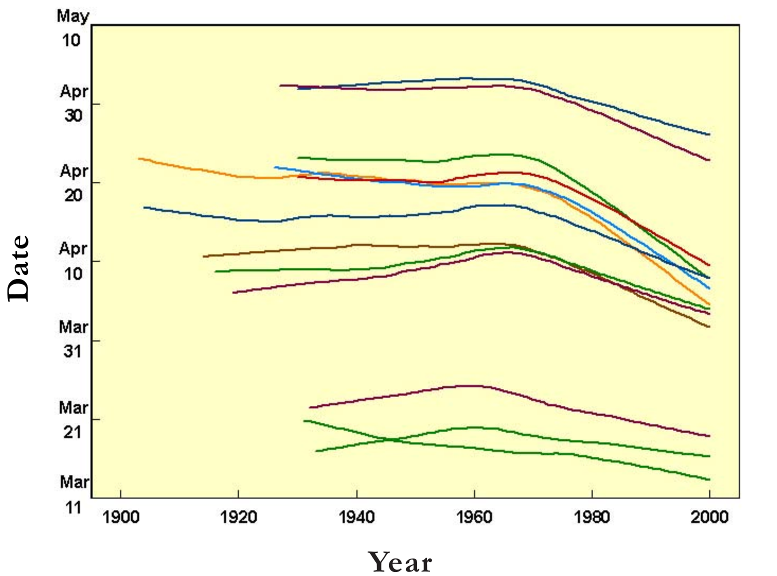


Figure 1. Smooths of winter/spring (January 1 to May 31) center-of-volume dates for the 13 longest-record, rural, unregulated rivers in New England.

flow). This backwater varies with the quantity and nature of the ice, as well as with the flow. Backwater at a gauging station can be caused by anchor ice or by surface ice. The presence of river ice is readily detected because it results in signature anomalies in the temporal pattern of river stage.

Indicator Trend

There is substantial inter-annual variation in the timing of high spring flow, but most rivers studied indicate significantly earlier flows in recent decades. In one study of 27 rural, unregulated river gauging stations in New England with an average of 68 years of recording the center-of-volume date (January 1 to May 31), 14 sites had statistically significant earlier timing. All of the remaining stations were trending towards earlier dates but these trends were not statistically significant. In northern and mountainous areas, where snowfall is highest, the center-of-volume date became earlier by 1 to 2 weeks, with most of the change occurring since 1970 (Figure 1).[22] The center of volume date was correlated with March/April surface air temperature (r=-0.72) as expected. The center of volume date was not correlated with March/April precipitation, but was weakly correlated with January precipitation.

In northern and mountainous areas, where snowfall is highest, the center-of-volume date became earlier by 1 to 2 , , with most of the change occurring since 1970.

The total annual days of ice-affected flow decreased significantly over the 20th century at 12 of the 16 rivers studied. On average, for the nine longest-record rivers, the total annual days of ice-affected flow decreased by 20 days from 1936 to 2000, with most of the decrease occurring from the 1960s to 2000. Four of the 16 rivers had significantly later first dates of ice-affected flow in the fall. Twelve of the 16 rivers had significantly earlier last dates of ice-affected flow in the spring. On average, the last dates became earlier by 11 days from 1936 to 2000 with most of the change occurring from the 1960s to 2000 (Figure 2).[23] The total annual days of ice-affected flow were significantly correlated with November through

... the last dates [of ice-affected flow] became earlier by 11 days from 1936 to 2000, with most of the change occurring from the 1960s to 2000.

9.

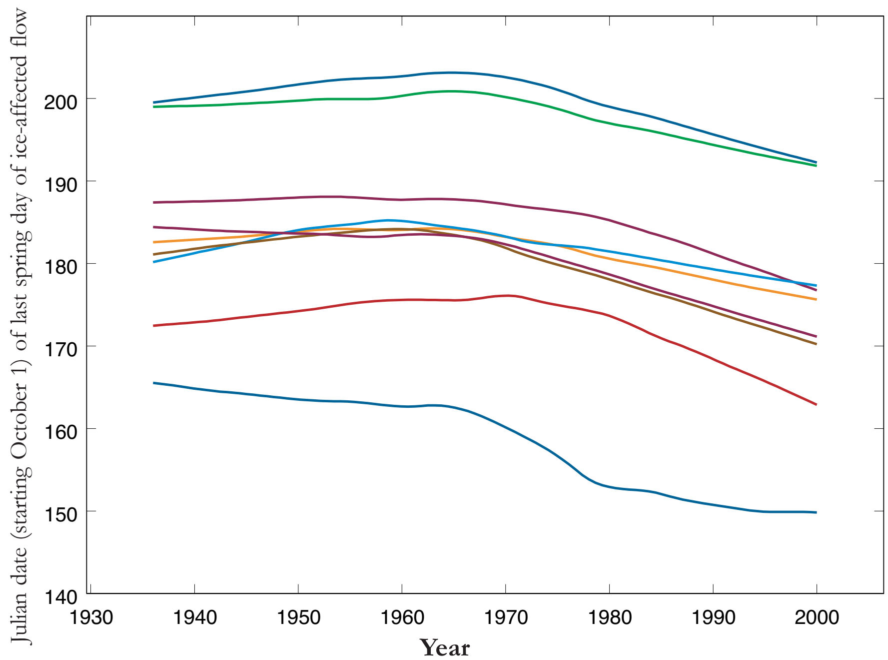


Figure 2. Smooths of last dates of ice-affected flow in the spring, over time, for the nine longest-record river gauges in northern New England.

April air temperatures (r = -0.70) and with November through April precipitation (r = -0.52). The last spring dates were significantly correlated with March through April air temperatures (r = -0.73) and with January through April precipitation (r = -0.37). March mean river flows increased significantly at 13 of the 16 rivers in this study.

Changes in the center of volume and river ice-out dates are consistent with changes in last-frost dates, lilac bloom dates, lake ice-out dates, river ice thickness and changes in the ratio of snow to total precipitation in New England.[24] This suggests that these New England spring geophysical and biological changes all were caused by a common mechanism, temperature increases.

Lake Ice-In and -Out Dates 1807 - 2000

Indicator Overview

Observations of lake ice are tangible, readily available and technically feasible indicators of local climate conditions in a geographic area. 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. The day of ice-out has, on average, occurred earlier in recent years than it did decades ago, while the day of ice-in, recorded on Lake Champlain on the New York – Vermont border, has been occurring later or not at all.

Regional Importance

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 an important event, when boaters and ferry masters put their boats in the water to begin the warm season.

In addition to impacting human systems, changes in the average ice-out date may lead to changes in lake and river ecosystems. Ice cover is a factor in the oxygen concentration, pH, fish habitat, and seasonal succession of the lake.[25] It is uncertain what the long-term ecological effects of an earlier ice-out date will be.

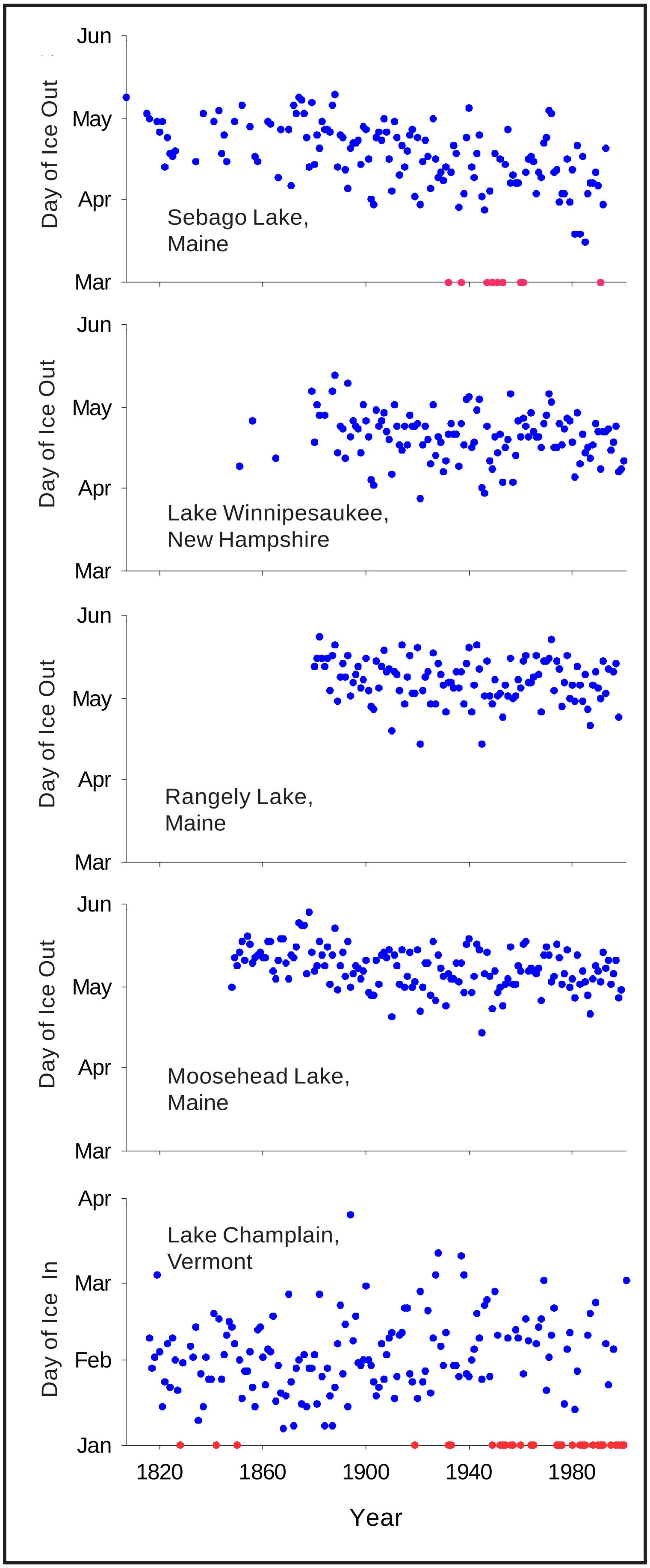
Sensitivity to Climate and Other Factors

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 ferry boat, 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.

The official ice-out day is also slightly sensitive to somewhat unrelated factors, such as wind speed or direction on a certain day. For example, imagine there was a strong westerly wind one morning that blew all the remaining ice to one end of the lake; the MS Mount Washington may have been able to complete the route and the day labeled the ice-out day. However, if the wind had blown east that day and blown all the ice into one of the ports, then that day would not have been recorded as the ice-out. While this phenomenon may happen occasionally, it would not affect the long term trends evident in the ice-out data.

Indicator Trend

In addition to considerable annual variation and some cyclical patterns, every lake with ice-out data shows a trend towards earlier ice-out dates over the length of their record.[26] Lake ice records from Sebago Lake in southern Maine and Lake Winnipesaukee in central New Hampshire are relatively continuous since the early 1800s. Sebago



Lake shows an ice-cover decrease of 14 days when comparing the period 1851-1900 to 1951-2000. The average ice-out date on Lake Winnipesaukee occurs almost eight days earlier today than it did in the late 1800s. Both Moosehead Lake and Rangeley Lake, located at higher latitudes in Maine, have been breaking up an average of six days earlier.

Sebago Lake, located in the coastal Maine flood plain 15 miles from the Atlantic Ocean, has been breaking up earlier over the past 150 years, with the rate accelerating over the past 25 years. Sebago Lake has failed to completely freeze nine times since 1807. Seven of these ice-free years were in the last 55 years. All of the ice-free years have occurred since 1932. Lake Winnipesaukee, located in the New Hampshire White Mountains, has also broken up earlier. From 1951-2000, ice-out averaged April 20, a full week earlier than the 1851-1900 average of April 27.

The date Lake Champlain, VT, was first frozen over ('ice-in') has also changed over the past 150 years.[27] Today it 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, 75% of which were since 1900, and almost half of them occurred since 1970 (years

Figure 1: Day of 'ice-out' at four New England Lakes: Sebago Lake, ME; Lake Winnipesaukee, NH; Rangeley Lake, ME; Moosehead Lake, ME and day of 'ice-in' at Lake Champlain, VT. Ice-out date refers to the day of the year on which the lake was considered to be ice free, while the ice-in date is the first day the lake is considered totally frozen. The method of determining the official ice-out or ice-in day is different at each lake, but the methods have remained relatively similar for the period of the record. For example, the official "Ice-out" date on Lake Winnipesaukee occurs when the ferry boat, the MS Mount Washington, can safely leave port and motor, unobstructed by ice, to the four ports on the lake. Red points denote years in which a lake did not freeze over.

the lake did not freeze are denoted in the figure with red points).

In general, lakes farther from the ocean and at higher elevations show smaller decreases in the length of ice cover. Lakes at higher latitudes show smaller but equally significant warming trends over the past 150 years. Lakes with larger climate variability, those prone to inclement weather and large amounts of precipitation show ice-out dates more statistically dependent on local events. Overall, ice-out dates were 9 days and 16 days earlier between 1850 and 2000 in the northern/mountainous and southern regions of New England respectively.[28]

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.

Overall, ice-out dates were 9 days and 16 days earlier between 1850 and 2000 in the northern/mountainous and southern regions of New England respectively.

Days with Snow on Ground
1970 - 2001

Indicator Overview

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.

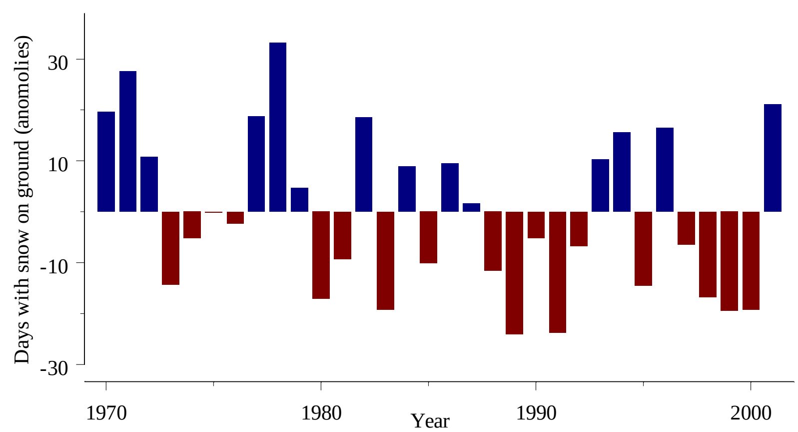


Figure 1: Total days each winter with snow on the ground at 36 stations in the Northeast, 1970-2001. In the graph, zero represents 80 days, the average number of days with snow on the ground. Years in blue had more than average days with snow on the ground, while years in red experienced fewer. Notice the increased frequency of years with below average snowfall in recent decades. On average, in 2001 the Northeast had 16 fewer days with snow on the ground each year than it did in 1970.

Regional Importance

This indicator is perhaps more relevant to outdoor recreation than total snowfall, because it is a measure of the length of the winter recreation season. While the total amount of snow is important, the length of time it stays is also a significant factor. Many forms of winter recreation, such as skiing and snowmobiling, rely on snow cover. In addition, snow affects ecological systems. Snow depth and persistence of snow cover are important factors in the reproduction and growth of plants.[49]

Sensitivity to Climate and Other Factors

The total number of days with snow on the ground for a given year is sensitive to both snowfall amounts and temperature fluctuations. For example, a single storm may drop two feet of snow in a region, but it could melt in three days of warm weather. Thus snow-on-ground is a useful indicator of overall winter severity.

Indicator Trend

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.[50] 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 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. When averaged, 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.

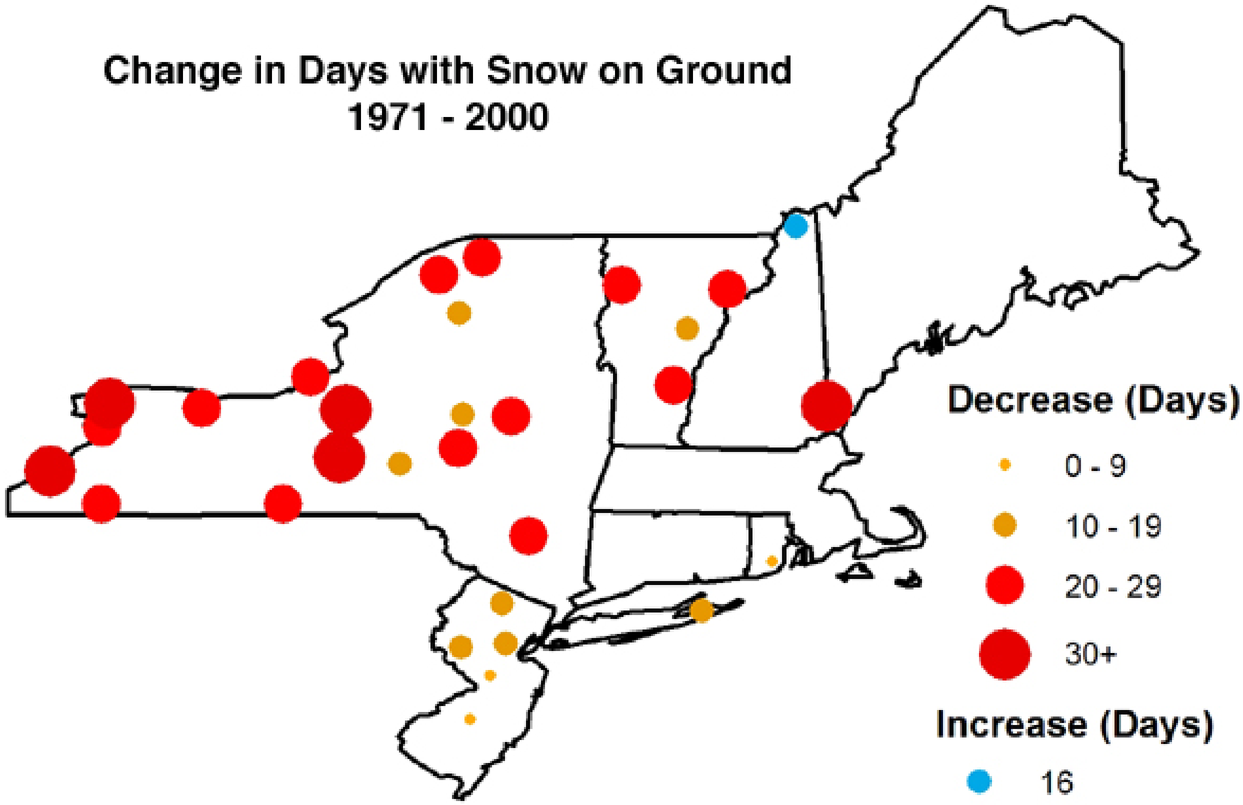


Figure 2: Map illustrating change (from linear regression) in the number of days with snow on the ground for stations 1971-2000. Points labeled in red or yellow indicate stations that have experienced a decrease in total annual snowfall, while blue indicates an increase in snowfall. Stations labeled in black did not experience much change.

> ***...the Northeast stations reveal that there were, on average, 16 fewer days with snow on ground in 2001 than in 1970. Some stations ... are experiencing almost a month of fewer days, on average, with snow each year.***

References

[1] The data used in this analysis is from the National Climatic Data Center (ftp://ftp.ncdc.noaa.gov/pub/data/ushcn/). The series for the New England region comprises areally weighted values. The station data were first averaged by climate division. Then the climate division data were averaged, giving proportional weight to the larger divisions. The mean of the series is 44.6 °F. Keim, B.D., A. Wilson, C. Wake, and T.G. Huntington. 2003. Are there spurious temperature trends in the United States Climate Division Database? Geophys. Res. Lett. 30(27), 1404, doi:10.1029/2002GL016295 30:1404, doi:10.1029/2002GL016295.Trombulak, S.C., and R. Wolfson. 2004. Twentieth-century climate change in New England and New York, USA. J. Geophys. Res. 31:L19202, doi:10.1029/2004GL020574.

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