Climate Change in Vermont

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Vermont's climate has changed substantially in the past fifty years. Continuing change is certain, as the Earth's climate is being driven towards a warmer state by the increase of greenhouse gases in the atmosphere. The primary driver is the increase of atmospheric CO_2 from the burning of fossil fuels, which reduces the cooling of the Earth to space. The small warming from the increase of CO_2 is amplified several times[1] because atmospheric water vapor, another powerful greenhouse gas, increases as temperature increases. Reductions in snow and sea-ice cover at northern latitudes also amplify the warming, because less of the sun's energy is reflected.

We have two complementary reference frameworks when planning for the future:

1) Regional projections from climate models
2) Climate trends in Vermont and New England in recent decades

Global model projections help us look into an uncertain future and explore humanity's options. For example, we can estimate how the patterns of temperature and precipitation will change, and see how reducing greenhouse gas emissions give a smaller temperature rise by the end of this century. Our models for the Earth's climate system necessarily contain simplifications, but they are continually revised as understanding improves. In 2007, a major synthesis was completed by an international team of 500 lead authors and 2,000 expert reviewers for the Intergovernmental Panel on Climate Change. This Fourth Assessment Report (IPCC-AR4)[2] documented the global and regional changes in temperature and precipitation expected this century. This report contains results from regional studies for the United States and New England that were based on the IPCC-AR4 report. Some 800 experts are now working on the next update, the Fifth Assessment Report, expected to be finished in 2014.

Our biggest challenge is that our ability to predict the future climate in detail is limited. So it is very helpful to examine climate trends in Vermont and New England in recent decades as a guide for the future. These recent observational trends are familiar to local communities and can help us understand the relationship between the local climate change that we are experiencing and projected global climate changes.

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How does predicting climate differ from forecasting weather?

Predicting climate is very different from forecasting weather. With global models we can forecast the day-to-day weather for about a week – generally forecast skill lasts a few days longer in winter than in summer. Further into the future we can only predict the general climate.

For example, we can predict with certainty that next July will be warmer than it was in January – because the sun heats the Earth more when it is high in the sky – but we can't forecast whether it will rain on the 4th of July. Furthermore, even though the sun follows the same path in the sky every year, some summers are drier and warmer or wetter and cooler than 'usual.' This is because regional weather patterns vary widely, depending, for example, on the position and movement of the jet streams. Scientists say the climate system has a lot of internal variability.

Similarly as CO_2 rises in the atmosphere, we know this will push the Earth towards a warmer climate, because CO_2 is a greenhouse gas that traps the Earth's heat. And as the earth warms, more water evaporates – and because water vapor is another greenhouse gas, the warming is further amplified. And as the Earth warms, ice and snow cover are reduced, so less sunlight is reflected. This amplifies the warming further. So we can predict that the Arctic (and northern winters) will warm faster as the reflective snow and sea ice decrease. In contrast, the Antarctic ice sheets are thousands of feet thick and will take hundreds to thousands of years to melt as the Earth warms.

We can also predict that the continents will warm faster than the oceans. As the climate warms, heat is only conducted down a short distance into the ground over land. But the oceans circulate heat down to the ocean depths, so they warm more slowly.

While we can predict a broad warming climate trend as atmospheric greenhouse gases rise, we cannot predict the detailed future weather. We must expect the large variability from year to year to continue; in fact, it may increase.

Regional projections from climate models

Based on the IPCC-AR4 model projections, the US Global Change Research Program produced a report, *Global Climate Change Impacts in the United States*. [3]

This map shows the projected mean annual temperature increases for North America for mid century and end of century for both higher and lower greenhouse gas 'emissions scenarios.' For the lower emissions scenario, the projected temperature change for Vermont is about 3°F by 2050, and about 5°F by late century. For the higher emissions scenarios, these increases in temperature are larger: 4°F and 9-10°F, respectively.

(These are annual mean increases; the northeast is likely to see larger temperature increases in winter than summer.)

The lower emissions scenario is based on the assumption that the global community makes major reductions in greenhouse gas emissions.

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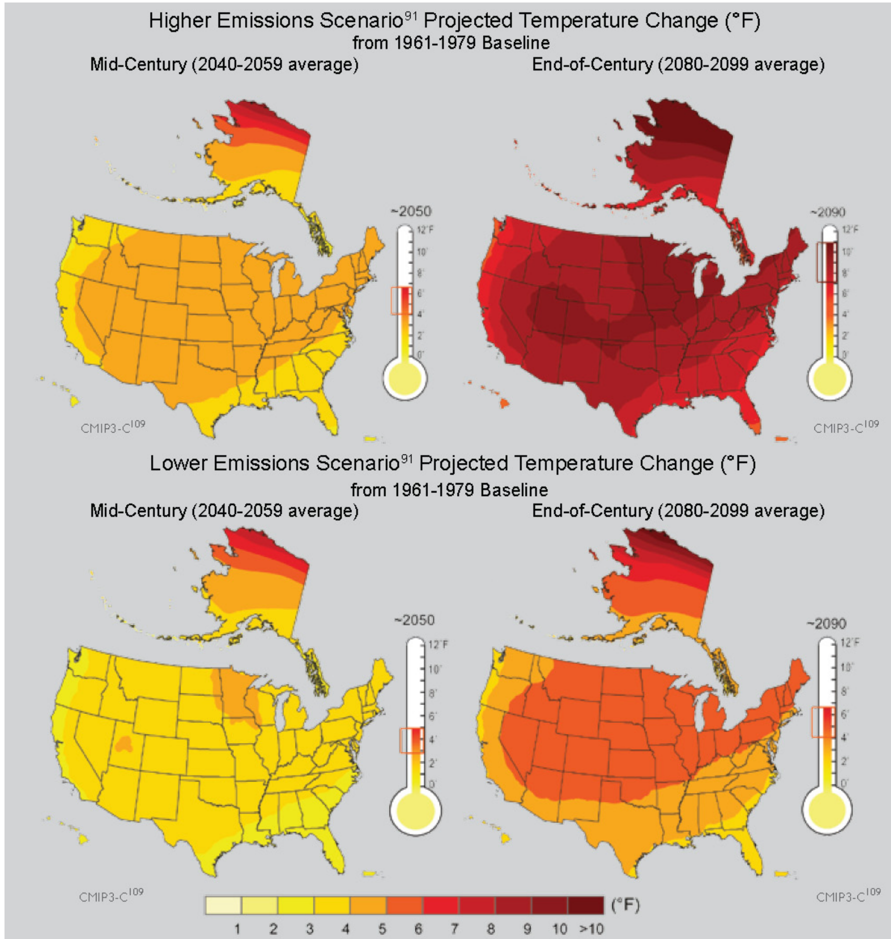
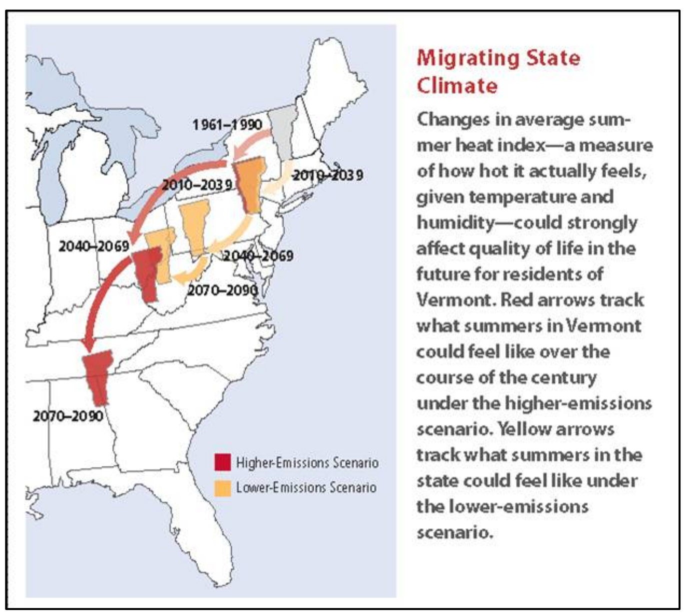


The maps on this page and the previous page are based on projections of future temperature by 16 of the Coupled Model Intercomparison Project Three (CMIP3) climate models using two emissions scenarios from the Intergovernmental Panel on Climate Change (IPCC), *Special Report on Emission Scenarios* (SRES).[91] The "lower" scenario here is B1, while the "higher" is A2.[91] The brackets on the thermometers represent the likely range of model projections, though lower or higher outcomes are possible. Additional information on these scenarios is on pages 22 and 23 in the previous section, *Global Climate Change*. These maps, and others in this report, show projections at national, regional, and sub-regional scales, using well-established techniques.[110]

This map from the Northeast Climate Impacts Assessment[4] gives a visualization of what summers in Vermont will feel like over the course of this century with high and low greenhouse gas emissions.

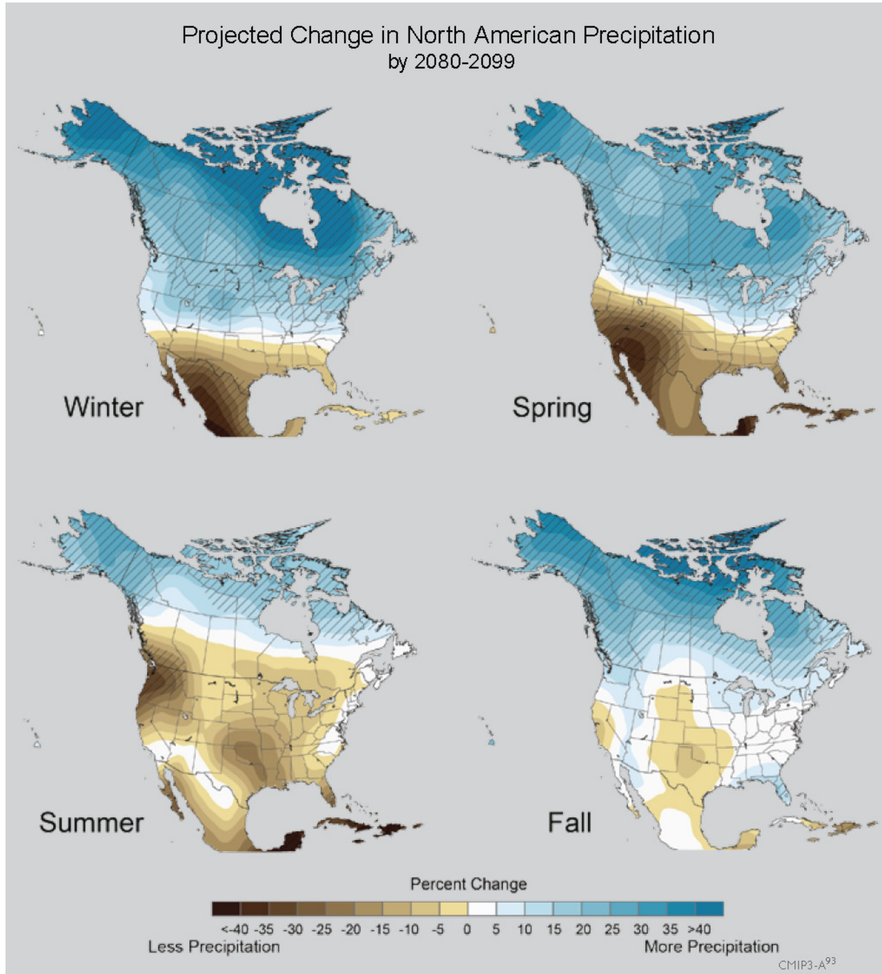
If current high emissions continue, Vermont's summer climate by 2080 will feel similar to the climate of northwest Georgia for the period 1961-1990. However, if emissions are greatly reduced, the climate of Vermont will more closely resemble the climate of southeastern Ohio.



This map shows the projected seasonal changes in North American precipitation by the end of the century for continued high emissions.[3]

For Vermont the projected increases are about 15% in winter, 10% in spring, 5% in fall, and no change in summer. The lightest precipitation is projected to decrease, while the heaviest precipitation will increase.

Precipitation is not as easy to predict as temperature, but these model projections reflect an increase of precipitation with warming at high northern latitudes, as well as a reduction of precipitation across the southern US. This reduction is associated with a poleward shift of the subtropical dry zones, which we are already observing.[5]



The maps show projected future changes in precipitation relative to the recent past as simulated by 15 climate models. The simulations are for late this century, under a higher emissions scenario.[91] For example, in the spring, climate models agree that northern areas are likely to get wetter, and southern areas drier. There is less confidence in exactly where the transition between wetter and drier areas will occur. Confidence in the projected changes is highest in the hatched areas.

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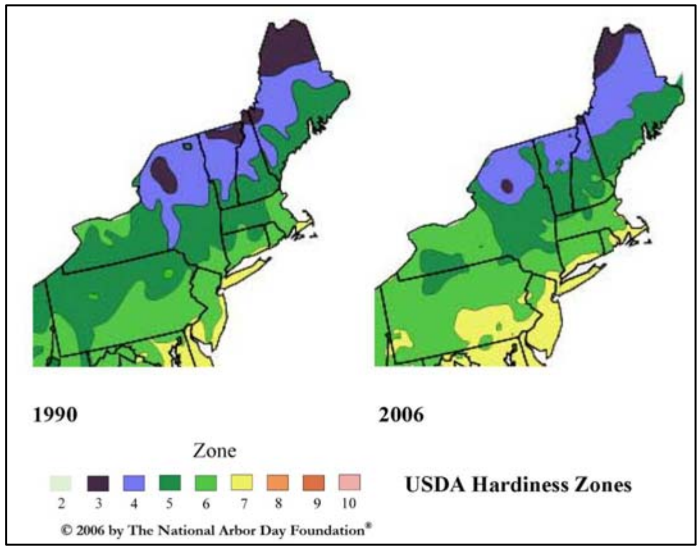
Evaporation increases with temperature; therefore in regions where precipitation decreases, an increase in drought frequency is likely.[6] In New England, earlier snowmelt, and more runoff from heavier summer rainfall, coupled with increased evaporation, are expected to increase the frequency of summer droughts – if high emissions continue.[7]

Climate trends in New England in recent decades

These projected changes are consistent with the climate trends seen in the Northeast in recent decades.[3,7,8,9,10] Since 1970 the annual average temperature in the Northeast has increased by 2°F, with winter temperatures rising twice this much. Warming has resulted in many other climate-related changes, including:

- More frequent days with temperatures above 90°F
- A longer growing season
- Increased heavy precipitation
- Less winter precipitation falling as snow and more as rain
- Reduced snowpack in some winters
- Earlier breakup of winter ice on lakes and rivers
- Earlier spring snowmelt resulting in earlier peak river flows
- Rising sea surface temperatures and sea level in coastal states

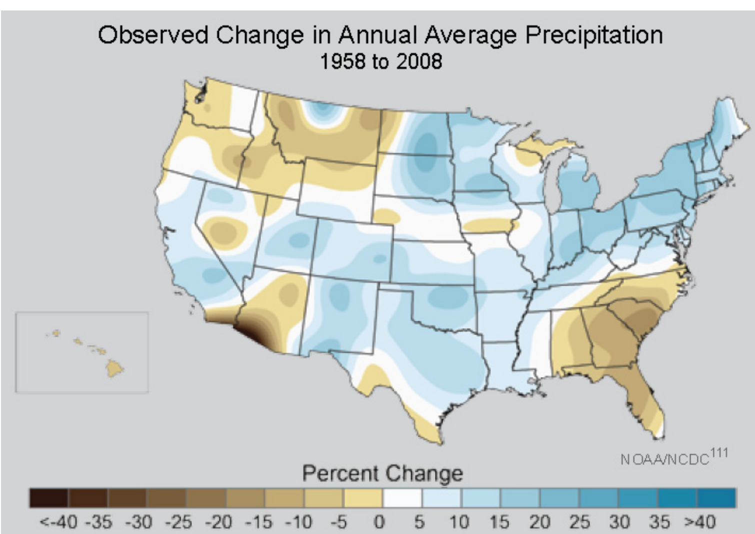
Temperatures have risen the most in winter. The USDA winter hardiness zones are determined by average minimum winter temperatures and are used to tell what plants, shrubs and trees can survive a typical winter. As the climate has warmed in winter across the whole of the Northeast, Vermont has gone from mostly Zone 4 to mostly zone 5 between 1990 and 2006; while Massachusetts has become mostly Zone 6. [11]



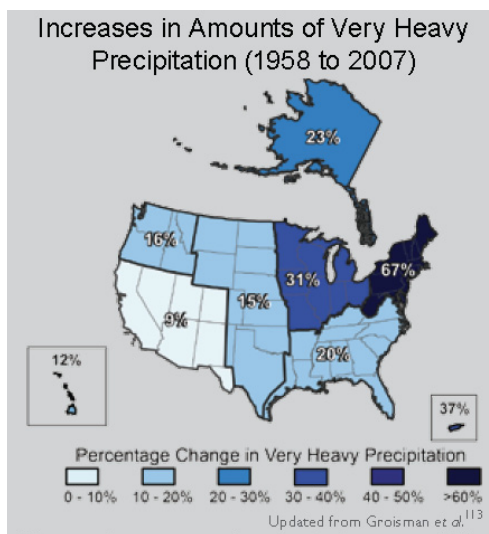
Observed changes in precipitation

Precipitation has increased in Vermont by 15-20% in the past fifty years, with increasing trends throughout much of the year. Heavy downpours have increased in frequency and intensity across most of the U.S., especially in the Northeast, where there has been a 67% increase in the amount falling during very heavy precipitation events. Water management has traditionally been based on historical precipitation statistics, but this assumption is no longer valid. [12]

The USGS has recently developed a framework for a hydrologic climate-response program in Maine, which is being extended to other New England states.[13] Preliminary results for Vermont show increases in annual mean stream flow have occurred in the past fifty years, with significant increases in monthly mean flows in the period July through December. [14]



While U.S. annual average precipitation has increased about 5 percent over the past 50 years, there have been important regional differences as shown above.



The map shows percent increases in the amount falling in very heavy precipitation events (defined as the heaviest 1 percent of all daily events) from 1958 to 2007 for each region. There are clear trends toward more very heavy precipitation for the nation as a whole, and particularly in the Northeast and Midwest.

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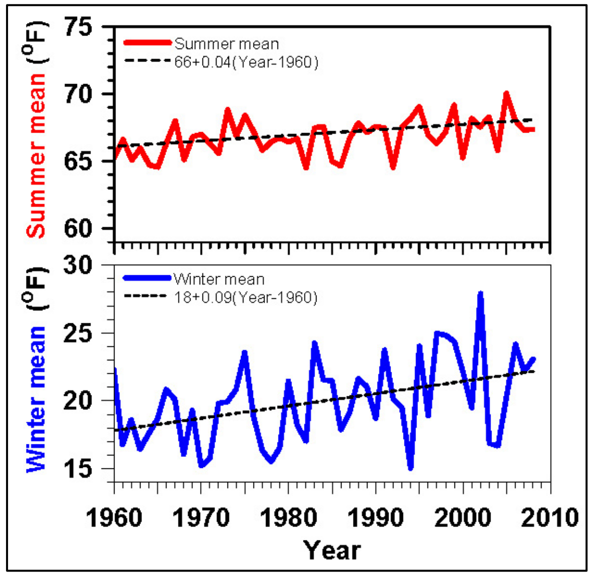
Seasonal climate trends in Vermont in recent decades

Summer and winter temperature trends since 1960

This figure shows the mean trends in Vermont summer temperatures and winter temperatures since 1960 from an average of four Vermont climate stations in Burlington, Cavendish, Enosburg Falls and St. Johnsbury.[15] From 1960-2008:



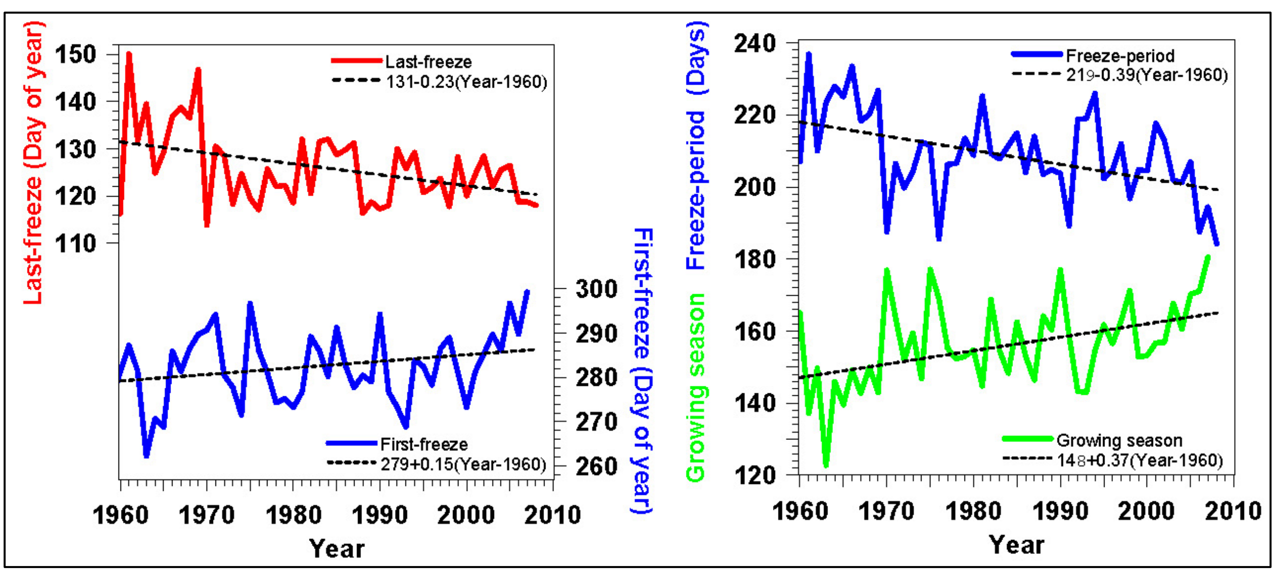
- Summer temperature trend is 0.4 (±0.12)°F per decade
- Winter temperature trend is 0.9 (±0.28)°F per decade

The upward trend in winter temperature is about twice as large as in summer. The annual mean trend for Vermont is the same as for New England, about 0.5 °F per decade. Note that the variability from year to year in winter is more than twice as large as in summer. In fifty years, mean winter temperatures in Vermont have risen about 4.5 °F; while in summer, mean temperatures have risen about 2 °F.

If we extrapolate the observed mean annual warming trend for Vermont of 0.5°F per decade from 1970 out to 2050, we get a 4°F warming, which is consistent with the model projections shown earlier.

Length of Vermont's growing season

These warming trends are affecting the timing and nature of the Vermont seasons.[15,16]
First and last freeze dates are changing, and the length of the growing season is increasing.



There is large variability from year to year, as first and last frosts are single night events, but the trend lines show that on average:

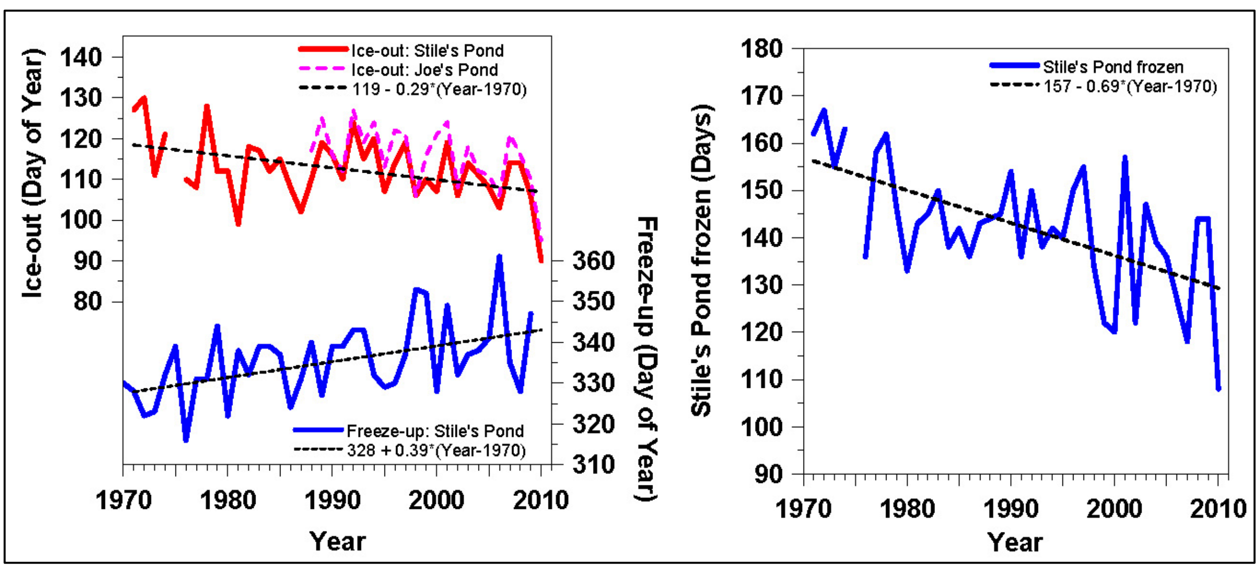
- Last spring freeze has come earlier by 2.3 (±0.7) days per decade
- First autumn freeze has come later by 1.5 (±0.8) days per decade
- Freeze-period has decreased 3.9 (±1.1) days per decade
- Growing season has increased 3.7 (±1.1) days per decade

These trends show that in the past forty years, the growing season for frost-sensitive plants has increased by about 2 weeks.

Freeze-up, ice-out and freeze-length for small lakes

The freeze and ice-out dates for small lakes are good integrated climate indicators for the length and severity of the cold season in Vermont.[15] The date of freeze-up depends on lake and air temperatures over many weeks in the fall; ice thickness depends on the severity of the winter; and the date of spring melt/ice-out depends on ice thickness and air temperatures in spring. These dates are important for the ecology of the lakes, and the frozen period and ice thickness matter to the public for winter recreation, including ice fishing.

The freeze-up and ice-out dates for Stile's Pond in Waterford, Vermont have been recorded since 1971 by the Fairbanks Museum in St. Johnsbury. There has been an annual contest to guess the ice-out date on Joe's Pond in West Danville, Vermont, and these dates have been recorded since 1988. Joe's Pond melts about 4 days later than Stile's Pond, because it is 676 ft higher in elevation.



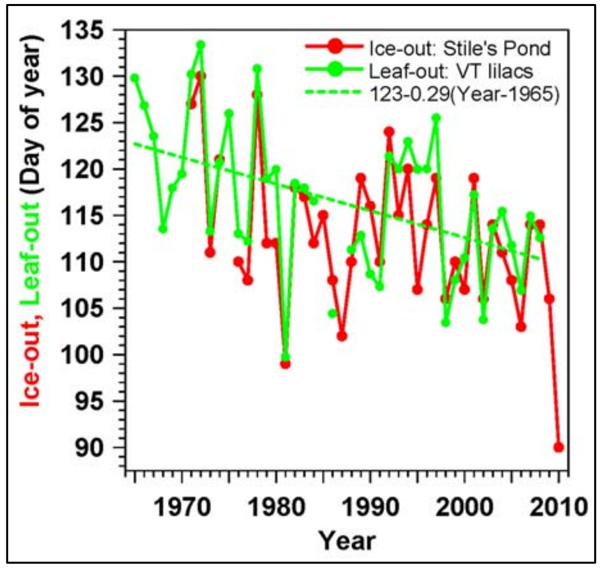
Despite the large variability from year to year, trends are clear. For Stile's Pond over the past forty winters:

- Freeze-up has occurred later by 3.9 (±1.1) days per decade.
- Ice-out has come earlier by 2.9 (±1.0) days per decade.
- Lake frozen duration has decreased by 6.9 (±1.5) days per decade.

These results show that as our northern climate has warmed substantially in fall, winter and spring, Stile's Pond is frozen for 4 weeks less on average than forty years ago. (Note that the downward trend in frozen lake duration is larger than for the winter freeze period, when a frost is likely.)

Changes in spring phenology

As lakes are melting earlier and the last frost is coming earlier, spring is arriving sooner in Vermont. The leaf-out date of lilacs, which have been tracked in Vermont since 1965 as a measure of early spring, closely follow the ice-out date of Stiles Pond in most years (a few years are missing).[15] So the leaf-out of lilacs in early spring is also coming earlier by about 3 days per decade.



Summary of expected changes in the climate of Vermont

The observed changes in Vermont's climate over the past fifty years match those seen in New England. These changes are also consistent with the changes projected by global climate models through 2050. Winter temperatures are rising fastest, so the winter season is shrinking and becoming less severe. Spring is coming earlier and fall later, so the summer growing season is lengthening. As the climate warms, total precipitation in Vermont is expected to increase in all seasons except summer. The frequency of heavy precipitation events is likely to increase in all seasons, with the heaviest precipitation events occurring in the summer season. Stream flow is likely to increase.

Although we cannot predict in detail the changes in weather patterns resulting from climate change, we can summarize the seasonal changes we are likely to see in Vermont in the coming decades:

In winter:

- Later arrival of winter
- Warmer winters: upward shift of USDA climate zones
- More overwintering of pests
- Shortened ski, snowmobile, ice-fishing, and snowshoeing season
- Increased winter precipitation
- More wet snow and freezing rain
- Multiple melt events in the winter with possible flooding

In spring:

- Reduced productivity of sugar maples
- Earlier end to sugaring season
- Earlier spring melt and run-off; possibly larger stream flows
- Earlier arrival of spring
- Earlier bloom dates of many plant species
- Earlier last spring frost
- Earlier ice-out of lakes and ponds

In summer:

- Hotter summers
- Reduced productivity of cold-weather crops
- Reduced productivity of dairy cows
- Longer growing season
- More heavy rain events
- More frequent floods and associated flood damage
- Greater frequency of 1-2 month droughts
- Increased warm-weather pest species, such as mosquitoes, ticks, and algae
- Increased threats to cold-water fish and wildlife species
- Increased hazards to human health, including heat waves and the spread of disease
- Increased hazards to human safety, such as landslides, flooding, and violent storm events
- Increased threat to infrastructure, such as roads and bridges near streams and rivers
- Worsening air quality in some areas

In fall:

- Later first fall frost
- Warmer fall temperatures
- Later fall color
- Increased fall precipitation and stream flow

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