Vermont Climate Change Indicators

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ABSTRACT

We develop climate change indicators for Vermont in recent decades based on the trends in freeze dates, the length of the growing season, the frozen duration of small lakes, and the onset of spring. These trends provide useful information for climate change adaptation planning for the state. The freeze period in Vermont has got shorter, and the growing season for frost-sensitive plants has got longer by about 3.7 (±1.1) days per decade; as the last spring freeze has come earlier by 2.3 (±0.7) days per decade and the first autumn freeze has come later by 1.5 (±0.8) days per decade. The frozen duration for small lakes, for which freeze-up and ice-out depend on mean temperatures over longer periods, has been changing more rapidly. Over the past forty years, ice-out has come earlier by 2.9 (±1.0) days per decade and freeze-up has occurred later by 3.9 (±1.1) days per decade, so that the lake frozen duration in winter has decreased by 6.9 (±1.5) days per decade. Lilac first leaf has also been coming earlier by 2.9 (±0.8) days per decade, while lilac first bloom has advanced more slowly by 1.6 (±0.6) days per decade. The first leaf of Vermont lilacs, an indicator of early spring, is closely correlated with the ice-out of our small reference lake, Stile's Pond, because both are related to temperatures in March, April and May. In the past forty years, the growing season for frost-sensitive plants has increased by 2 weeks; and for frost-hardy plants the growing season may have increased by as much as three to four weeks.

1. Introduction

The increase in atmospheric greenhouse gases, coming primarily from the burning of fossil fuels, is now driving unprecedented climate change (IPCC 2007a). However, there are large uncertainties in future regional climate scenarios. In addition, global indicators of ongoing climate change such as the melting of the Arctic sea-ice in recent decades (see http://nsidc.org/arcticseaicenews/) are remote to most communities, and they are not closely correlated with local climate on annual time-scales. On the other hand, changes in climate on local and regional scales can be directly perceived and easily understood by local communities.

In a broader sense, strategies are needed to improve climate literacy in society (Dupigny-Giroux 2008), since greenhouse gas mitigation and adaptation efforts depend on community understanding and acceptance of the reality of climate change. This paper develops some climate change indicators for the past few decades for Vermont, a mid-latitude state near 44 ^{o}N in the north-eastern United States, using local datasets. Vermont is developing a climate change adaptation plan requested by the Governor's Commission on Climate Change [GCCC 2007]. Understanding our vulnerability to climate change, and developing plans for adaptation, requires our best estimates for climate change in the coming decades. Regional scenarios for the northeastern United States have been generated by down-scaling projections from global models (Hayhoe et al. 2007, 2008). A complementary strategy is to examine the observed local trends from recent decades. Hodgkins et al. (2009) have proposed a similar framework for updating hydrologic climate trends for the state of Maine, as these have been changing rapidly in recent decades.

Mid-latitude continental regions have a large annual cycle of temperature with warm and cold seasons (when frost is likely) of comparable length. As illustration, Figure 1 shows the mean annual cycle of

temperature for Rutland, Vermont for the past decade (derived from hourly data from Central Vermont Public Service (CVPS): see Methods (a)), showing monthly mean daily minimum temperature, T_{min}, monthly mean temperature, T, and monthly mean daily maximum temperature, T_{max}. The annual mean temperature is 7.3°C (45°F), with summer mean maximum temperatures reaching 26°C (79°F) in July and winter mean minimum temperatures falling to -11.3°C (20°F) in January. Daily temperature extremes cover a wider range than these monthly means. Killing frosts in spring and fall limit the summer growing season, and extreme minimum temperatures in winter determine the survival of some plants and shrubs and overwintering insects.

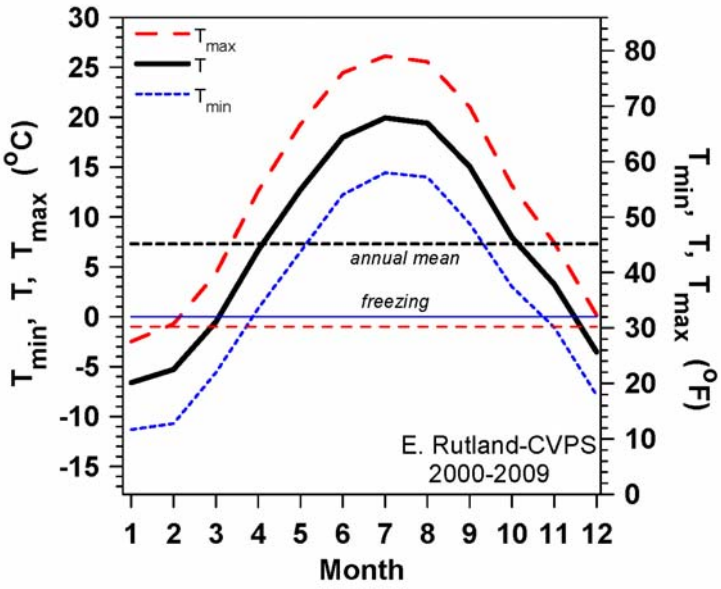

FIG. 1. Monthly mean temperature, mean daily minimum and maximum temperatures, 2000-2009 for E. Rutland.

The critical climate reference temperature is the freezing point of water: 0°C (32°F). The annual mean temperature is not far above freezing, so an upward mean shift of just 1°C (1.8°F) has a significant impact on the Vermont climate by shrinking the length of the cold season and increasing the length of the warm season. A red dashed line at -1°C has been drawn so the impact of this relative shift can be easily visualized.

As the global climate warms, winter temperatures over the northern latitude continents have generally been rising faster than summer temperatures (Hansen et al. 2010). The warming of global and regional climate is being driven by the greenhouse effect: as atmospheric CO_2 increases, this increases the surface warming by the downward longwave radiation from the atmosphere. This rather small effect is

amplified substantially by two positive feedbacks. The increase of water vapor with temperature amplifies the warming in all seasons, because water vapor is a powerful greenhouse gas. But there is an additional positive feedback in the cold season if snow cover is reduced, because this reduces the strong reflection of sunlight by the snow – this is called the shortwave snow and ice-albedo feedback. These positive feedbacks operate on global scales at northern latitudes (IPCC 2007b) and contribute to the melting of the northern polar sea ice (Screen and Simmonds 2010), but they operate on local scales as well. As Vermont's climate warms, and the temperature shifts upward relative to freezing, this reduces the length and chill of the cold season. With warmer temperatures, the cold season shrinks, and the ratio of snow to rain in winter falls (Feng and Hu 2007). This tends to reduce snow cover and the reflection of solar radiation, so that the surface absorbs more heat. At the same time, evaporation and atmospheric water vapor increase with warmer temperatures, and the water vapor greenhouse effect increases the downward longwave radiation that also heats the surface. Reduced snow cover and warmer winter and spring temperatures also change the hydrologic response, giving earlier spring runoff (Hodgkins et al. 2009).

The long-term temperature records for the Champlain basin show considerable variability over the past century (Stager and Thill 2010). This paper will focus not on the century-scale variability, but on trends in Vermont in the past fifty years (1960-present) – a period for which we can relate several long-term datasets. We will show the recent climate trends in temperature, the length of the growing season, the freeze-up and ice-out of small lakes and the spring leaf and bloom dates of lilacs.

2. Temperature trends in Vermont since 1960

Figure 2 shows the mean Vermont summer temperatures and winter temperatures (with Celsius temperature scale on the left and Fahrenheit scale on right). These are a mean of four Vermont climate

stations in Burlington, Cavendish, Enosburg Falls and St Johnsbury, preprocessed by Schwartz et al. (2006). Details and station locations are given in Methods (b). The variability from year to year in

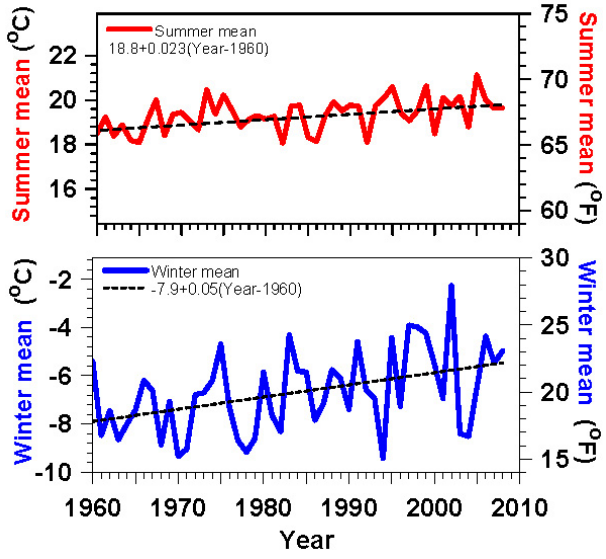

FIG. 2. Summer and winter temperature trends in Vermont since 1960.

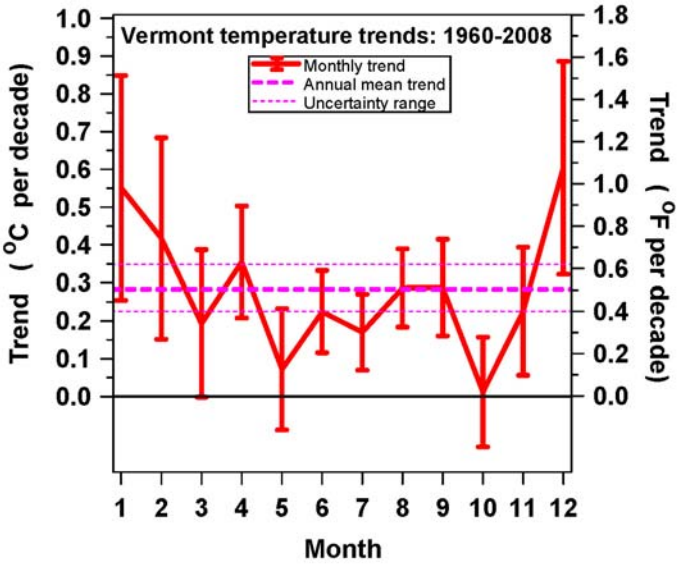

FIG. 3. Monthly temperature trends and the annual mean.

winter is more than twice as large as in summer. Trend lines have been fitted as dashed lines by linear regression. In summary, from 1960-2008:

Summer trend is 0.23±0.07◦C (0.4±0.12 ◦F) per decade

Winter trend is 0.5±0.16 ◦C (0.91±028 ◦F) per decade

The trend in winter is about twice as large as in summer. In fifty years, mean winter temperatures in Vermont have risen about 2.5 ◦C (4.5 ◦F); while in summer, mean temperatures have risen about 1.1 ◦C (2 ◦F). There is an uncertainty in the trends of about 30%, because of the large variability from year to year. For these linear regression fits, the explained variance is small ($R^2 \approx 0.18$), because the interannual variability is large.

Figure 3 shows the monthly trends from 1960 to 2008, where January is 1 and December is 12. The mean annual trend is the dashed line at 0.28 ◦**C (**0.5 ◦**F)** per decade (with the root-mean-square uncertainty range dotted above and below). We see the larger trends in winter (months 12, 1 and 2) than in summer (months 6, 7 and 8); as well as larger uncertainty bars in winter. The smallest trends

are in May and October. This might be related to the increase in length of the growing season (see later). More surface evaporation and cloud in these months than in earlier decades would cool the surface and reduce the trend.

3. Freeze period and growing season

For the same four Vermont climate stations, Schwartz et al. (2006), generated a table of first freeze date in autumn and last freeze date in spring, defined as the days when daily minimum temperature dropped below -2.2°C (28°F). The difference over the winter gives the length of freeze period. From these, we again generated a mean for the four stations for the period, 1960 to 2008 – see Methods (b). The -2.2°C (28°F) threshold gives an estimate of nights with a killing frost (Schwartz and Reiter, 2000), so the difference between last freeze date in spring and first freeze date in autumn in the same calendar year can be considered the length of the growing season for frost-sensitive plants.

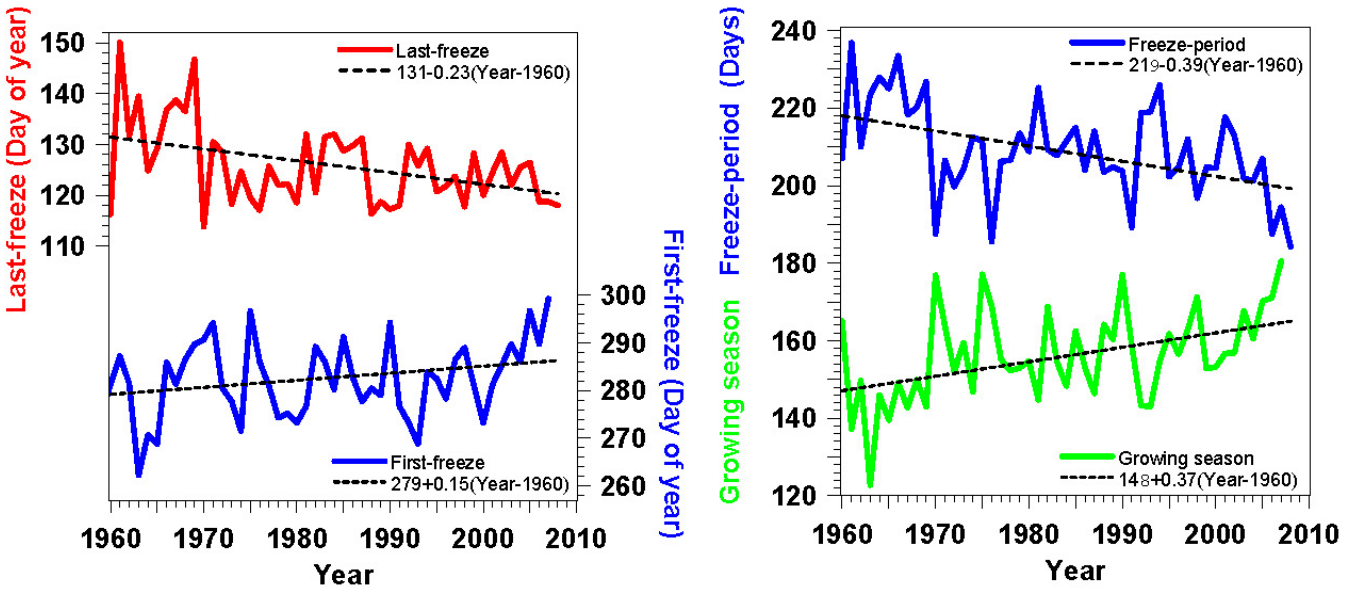

FIG. 4. Last spring freeze and first autumn frost (left) and (right) length of freeze-period and growing season (data from Schwartz et al. 2006).

Figure 4 (left panel) shows the first and last freeze dates since 1960, and the right panel shows the length of the freeze-period and the length of the growing season. The very large variation from year to year is striking. First and large frosts are single-day extreme events, which usually occur when cold dry

air is advected down from the north; so that with clear skies and less atmospheric water vapor, the water vapor greenhouse is reduced, and the earth can cool rapidly to space at night. Trend lines have been fitted by linear regression. These show that in the past fifty years, despite the large variability from year to year, on average the last spring freeze has come earlier and the first fall freeze has come later, so that the freeze period has got shorter and the growing season longer in Vermont. In summary, from 1960-2008:

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

So in the past forty years, the growing season for frost-sensitive plants has increased by 2 weeks. Note that because the interannual variability is large (±6 to 9 days), the explained variance is small (typical $R^2 \approx 0.15$). Since first and last frosts are sensitive to the local topography as well as to specific daily weather events, some colder locations in Vermont, such as mountain valleys and higher terrain, will on average have a shorter growing season than this four-station mean.

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

The first and last freeze dates shown in Figure 4 are critical to the growing season for frost-sensitive plants. In contrast, the freeze and ice-out dates for small lakes (called Ponds in Vermont) are good 'integrated' climate indicators for the length and severity of the cold season in Vermont. 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.

There has been an annual contest to guess the ice-out date on Joe's Pond in West Danville, Vermont, so these dates and the trend have been recorded since 1988. The freeze-up and ice-out dates for Stile's Pond in Waterford, Vermont at the same latitude but a lower elevation have been recorded since 1971 by the Fairbanks Museum in St. Johnsbury (see Methods (c)). This gives an on-going forty-year record.

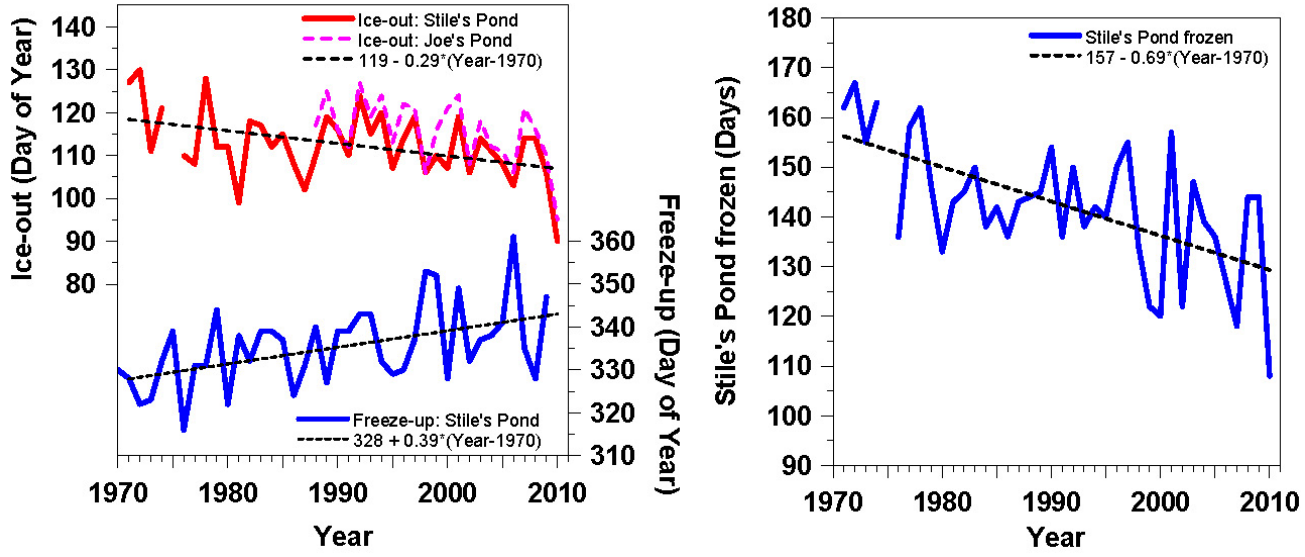

FIG. 5. Freeze-up and ice-out days for Stile's Pond and ice-out for Joe's Pond (left); (right) winter frozen period for Stile's Pond. [Ice-out in 1975 is missing.]

Figure 5 (left panel) shows the day of freeze-up for Stile's Pond and the day of ice-out for both Stile's Pond and Joe's Pond (dashed). Note that two time-series for ice-out closely follow each other, but Joe's Pond melts about 4 days later than Stile's Pond, because it is 206m (676ft) higher in elevation. The right panel of Figure 5 shows how many days Stile's Pond was frozen each winter. There is a large variation from year to year (± 11 days), because regional weather patterns have a large variability, but the trend has been downward for four decades. The dotted lines are the mean trends for freeze-up, ice-out and frozen duration for Stile's Pond (linear regression fits). Over the 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.

The mean trend shows 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 this year, 2010, was an exceptionally early melt, well below the trend line. Comparing with section 2, we see that these trends are greater than the trends of the first and last freeze in fall and spring, and the corresponding freeze-period for frost-sensitive plants. The freeze-up and ice-out dates for small lakes depend on longer period average temperatures in autumn and early spring, than the daily extremes that give frosts.

Linear regression gives the dependence of ice-out Day of Year (DOY) on February, March and April monthly mean temperatures in the form

$$DOY = A + B\,T_{Feb} + C\,T_{Mar} + D\,T_{Apr} \quad (1)$$

with the coefficients given in Table 1, line 1. The correlation with January temperatures is negligible. Defining a weighted temperature from the regression coefficients B, C and D

$$T_{wt} = (0.52T_{Feb} + 1.48T_{Mar} + 2.21T_{Apr})/4.21 \quad (2)$$

gives the regression plotted in Figure 6 (with rounded coefficients)

$$DOY(\text{ice-out}) = (123\pm4)–(4.2\pm 0.5)\,T_{wt}(^oC) = (123\pm4)–(2.3\pm 0.3)(T_{wt}(^oF)-32) \quad (3)$$

The year-to-year variability in ice-out in Figure 5 reflects the variability in February, March and April temperatures. For every 1°C (1°F) increase in weighted temperature, ice-out comes earlier by 4.2±0.5 (2.3±0.3) days. In fall, freeze-up is correlated with November and December temperatures (not shown), but the cooling of the lake from its summer maximum temperature also depends on evaporation in the fall. We now turn

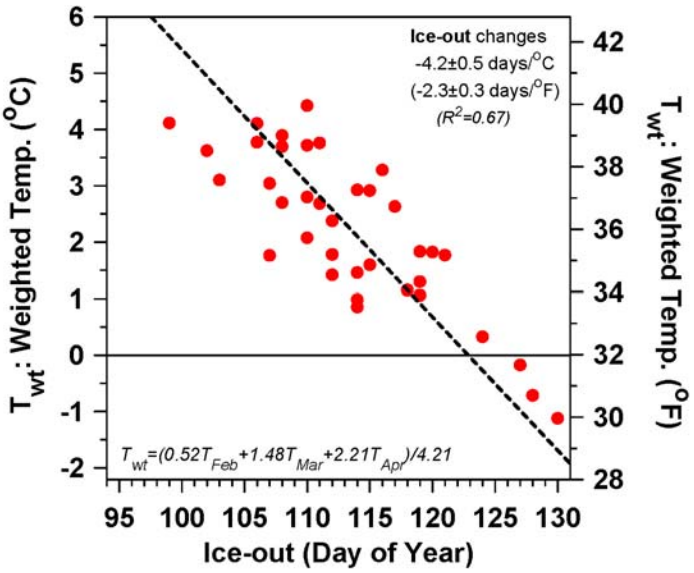

FIG. 6. Relation between ice-out and a February, March, April weighted mean temperature (see methods c))

to the first leaf and first bloom date of lilacs as climate indicators for the onset of spring, and show that lilac leaf-out and lake ice-out are related, since both depend on February, March and April temperatures.

Table 1. Regression coefficients for Figures 6 and 7

	A	B (T_{Feb})	**C** (T_{Mar})	**D** (T_{Apr})	**E** (T_{May})	**R^2**
Ice-out	**122.8±4.1**	**-0.52±0.27**	**-1.48±0.39**	**-2.21±0.52**		**0.67**
Lilac Leaf	**128.2±4.1**	**-0.82±0.25**	**-1.15±0.36**	**-3.01±0.47**		**0.75**
Lilac Bloom	**187.6±2.6**			**-1.65±0.26**	**-2.59±0.25**	**0.79**

5. Lilac first leaf and first bloom dates

There is a long Vermont record (since 1965) of first leaf and first bloom dates for lilacs (*Syringa chinensis clone*) in the North American First Leaf and First Bloom Lilac Phenology Data (Schwartz et al. 2006). From six Vermont sites we generated an annual mean, spanning the time period 1965-2008, for the first leaf and first bloom dates, as indicators for the onset of spring in Vermont (methods (d)).

Figure 7 (left panel) shows the first leaf and first bloom dates since 1965 and the trend lines (from linear regression). Again there is large variability from year to year, but the date of lilac first leaf in spring has advanced about 2.9 (±0.8) days per decade; while the later date of lilac first bloom has advanced more slowly by 1.6 (±0.6) days per decade. As a result the mean time between first leaf and first bloom has increased from about 24 to about 30 days over the 45-year period. The right panel of Figure 7 shows how the large year-to-year variability of first leaf and bloom dates is correlated with late winter and spring temperatures. Lilac first leaf (in green) is well correlated with monthly mean

temperatures for February, March and April. Defining a weighted temperature from the regression coefficients in Table 1, line 2 as

$$T_{wt} = (0.82T_{Feb} + 1.15T_{Mar} + 3.01T_{Apr})/4.98 \quad (4)$$

gives the regression plotted in Figure 7 (with $R^2 = 0.75$) with rounded coefficients

$$DOY(leaf) = (128\pm4)–(5.0\pm 0.5)\ T_{wt}(^oC) = (128\pm4)–(2.8\pm 0.3)(T_{wt}(^oF)-32) \quad (5)$$

For every 1°C (1°F) increase in this weighted temperature, lilac first leaf comes earlier by 5±0.5 (2.8±0.3) days.

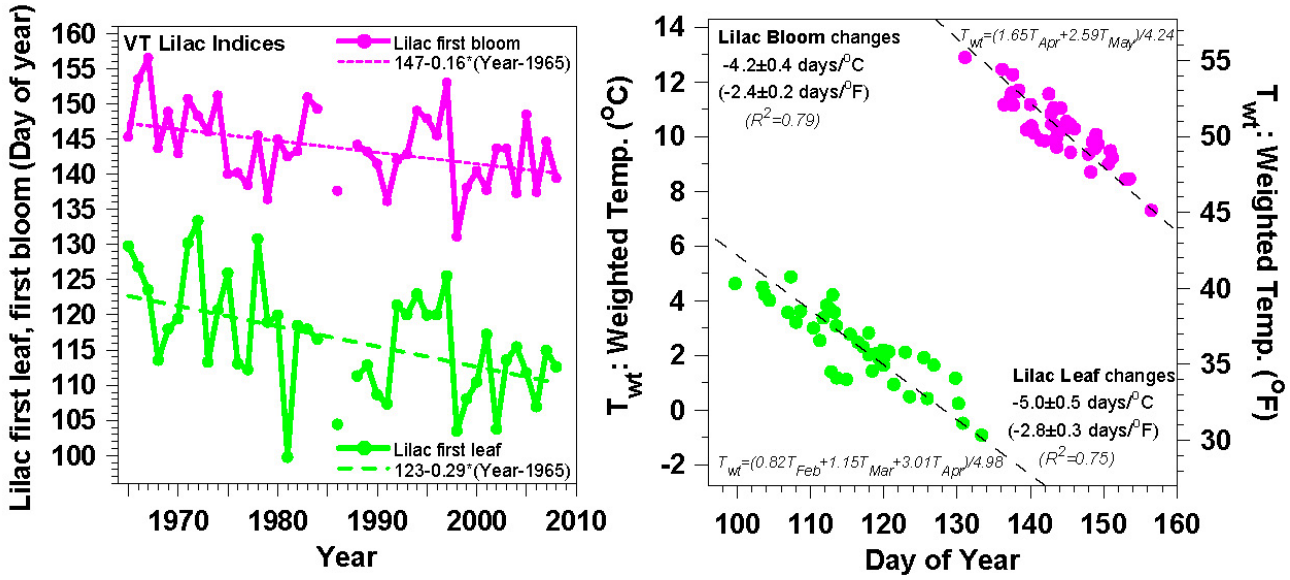

FIG. 7. First leaf and first bloom days for Vermont lilacs (left panel) and (right) first leaf and bloom days plotted against weighted mean temperatures, (4) and (6). [Years 1985 and 1987 are missing.]

Lilac first bloom (in magenta) is well correlated with monthly mean temperatures for April and May. Defining a weighted temperature from the regression coefficients in Table 1, line 3 as

$$T_{wt} = (1.65T_{Apr} + 2.59T_{May})/4.24 \quad (6)$$

gives the regression plotted in Figure 7 (with $R^2 = 0.79$) with rounded coefficients

$$DOY(bloom) = (188\pm3)–(4.2\pm 0.4)\ T_{wt}(^oC) = (188\pm3)–(2.4\pm 0.2)(T_{wt}(^oF)-32) \quad (7)$$

So for every 1°C (1°F) increase in weighted temperature, lilac first bloom comes earlier by 4.2±0.4 (2.4±0.2) days. The slower decadal advance of lilac first bloom than first leaf is consistent with the fact

that the long-term trend of May temperatures is less than the temperature trends in February, March and April (Figure 3).

Lake ice-out and lilac first leaf are independent climate indicators, but they are correlated because both depend on temperatures in February, March and April (although with different coefficients in Table 1). Figure 8 (left panel) plots together the dates of lilac first leaf and the ice-out days for Stile's Pond. The variations from the year-to-year are clearly similar, even though there are breaks where a year's

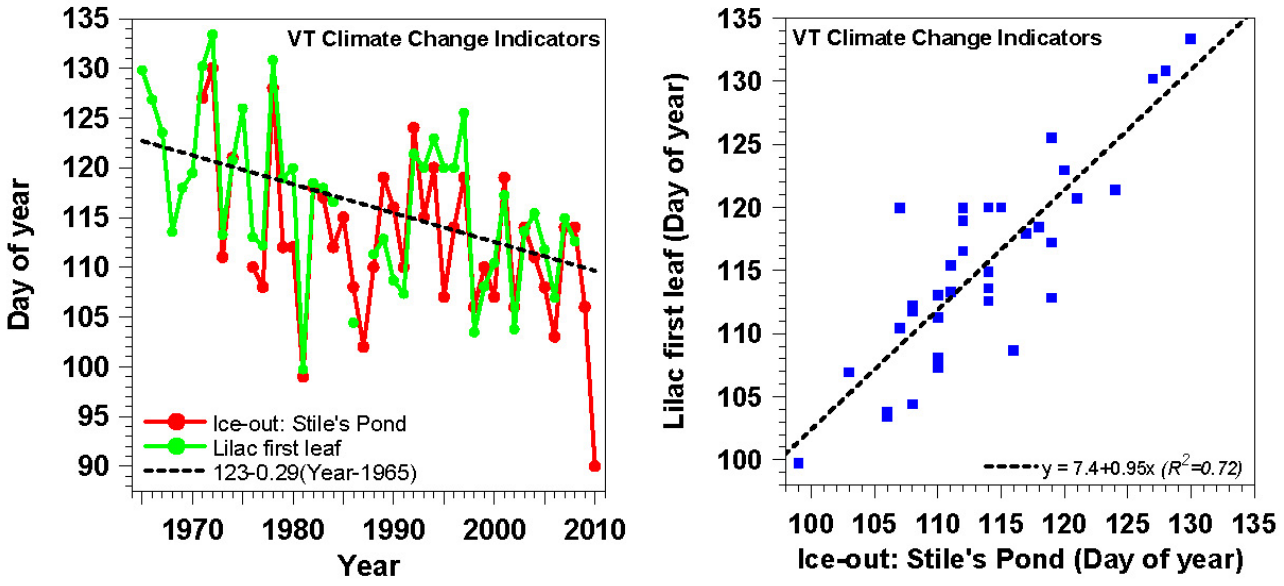

FIG. 8. Ice-out days on Stile's Pond and VT lilac first leaf days (left panel); and (right) first leaf plotted against ice-out.

observation is missing. The dashed regression fit to the lilac data is shown. The regression fit to the ice-out data has the same slope, but is shifted 2.3 days lower. The right panel of Figure 8 plots first leaf directly against ice-out and the dashed line in the linear regression fit. Lilac first leaf and lake ice-out are quite closely correlated ($R^2 = 0.72$). In most years lake ice-out and lilac first leaf occur within less than a week of each other, and both dates have advanced in spring by about 3 days per decade, consistent with the trend towards warmer temperatures in late winter and early spring.

6. Conclusions

The climate indicators presented show a consistent pattern of a warming climate in Vermont during the past few decades. With the definition of first and last freeze dates as when daily minimum temperatures fall below 28 ^{o}F (-2.2^{o}C), the freeze period in Vermont has got shorter and the growing season for frost-sensitive plants has got longer by about 3.7 (±1.1) days per decade; as the last spring freeze has come earlier by 2.3 (±0.7) days per decade, and the first autumn freeze has come later by 1.5 (±0.8) days per decade. In contrast, the frozen duration for small lakes, for which freeze-up and ice-out depend on mean temperatures over longer periods has been changing more rapidly. Ice-out has come earlier by 2.9 (±1.0) days per decade and lake freeze-up has occurred later by 3.9 (±1.1) days per decade, so that the lake frozen duration in winter has decreased by 6.9 (±1.5) days per decade.

The first leaf of Vermont lilacs, an indicator of early spring, has also been coming earlier by 2.9 (±0.8) days per decade: the same trend as the ice-out date of our reference lake, Stile's Pond. Both ice-out and first leaf are correlated with temperatures in February, March and April; so lilac first leaf and ice-out dates are themselves closely correlated, and both are indicators of the severity of late winter/early spring temperatures. Lilac first bloom, which is correlated with April and May temperatures, has been advancing more slowly in spring by 1.6 (±0.6) days per decade.

The decrease of the frozen duration of small lakes by 7 days per decade means that their unfrozen period has increased by 7 days per decade. This sets a useful upper limit for the lengthening of the growing season for frost-hardy plants. The lilac first leaf trend agrees with the ice-out trend in spring (3 days per decade), but we have no comparable phenological indicators in the fall. Thus, in the past forty years, the growing season for frost-sensitive plants has increased by 2 weeks; and for frost-hardy plants the growing season has increased more, perhaps by three or four weeks.

Climate has historically been defined in terms of 30-year normals. This has been partly a practical matter to get a long-enough period for representative statistics, but the implicit assumption that climate can be considered stationary for 30-year periods is no longer valid (Milly et al. 2008), since the climate system has a measureable warming trend, both globally and locally. The trends we show for the past four decades could be considered as likely first estimates for Vermont for the next few decades. They are independent of model projections. We suggest that these recent local historic trends should be compared with down-scaled model projections for the next few decades to give a dual basis for decision making. Other phenological and hydrological indicators should be developed.

Year-to-year variability is likely to continue to be large. Indeed, one important caveat is that the earth's climate system has many instabilities, and abrupt changes in climate and weather regimes have occurred in the past (NAP, 2002). At present, however, we are unable to predict these abrupt changes; so a strategy of extrapolating past trends, and updating them every few years, is a reasonable one. This past northern hemispheric winter (2009-2010) was exceptional – with the North Atlantic Oscillation, related to the strength of the northern polar vortex, in an extreme negative phase (Hansen et al. 2010). A study of the relation of Vermont climate indicators to global indices might also be useful.

Local and regional climate change indicators are very valuable. These trends provide useful information for climate change adaptation planning for the state. But equally important, they can be directly perceived and easily understood from the collective experience of local communities. This can deepen the appreciation of the relation between local climate change and global climate change, and perhaps motivate individual and community acceptance of the need for climate change mitigation and adaptation strategies.

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Methods.

a) CVPS data

Central Vermont Public Service supplied their hourly data from January 2000 through December 2009 from E. Rutland, Vermont, at 43.606^{o}N, 72.956^{o}W, elevation 202m (664ft). The measurements are near a sub-station in a residential area on the east side of a central Vermont town with a population of about 20,000. The dataset is 99.87% complete: only 116 hours are missing from 87672 hourly records. We filled shorts gaps of a few hours by linear interpolation; and for one period of several missing days we substituted the average of the adjacent days' data. Daily means, and daily maximum and minimum temperatures were generated, and from these the monthly means, shown in Fig. 1.

b) Climate station data

Data from four Vermont climate stations were used:

Sta#	Name		Lat (^{o}N)	Long (^{o}W)	Elev (m)
431081	BURLINGTON	VT	44.47	-73.16	101.22
431243	CAVENDISH	VT	43.39	-72.6	243.9
432769	ENOSBURG FALLS	VT	44.72	-72.82	128.05
437054	ST JOHNSBURY	VT	44.42	-72.02	213.11

Mark D. Schwartz (mds@uwm.edu) provided a Vermont subset of the data used by Schwartz et al. (2006) – updated to 2008. For each station-year of data, Schwartz et al. (2006) generated monthly

mean temperatures and an annual suite of indices, including first freeze in autumn and last freeze date in spring. These freeze dates are defined as when daily minimum temperature dropped below 28°F (-2.22°C). In this preprocessed dataset, for the 49 years, 1960 to 2008, the annual record for Burlington is complete, but for the other stations the temperature data has missing months and years. We generated a set of (non-standard) monthly temperature normals, as the mean of the 34 years, for which all four stations have complete records. Then for each station and month, we computed the temperature difference from these normals, averaged these, and added them to the mean of the normals to give a Vermont mean monthly temperature for each year. These were used for the trend plots in Figs. 2 and 3. The Schwartz et al. (2006) data give the freeze-period, the number of days over the winter from first freeze date in the previous autumn to last freeze date in spring. So the freeze-period plotted for 2008 corresponds to the 2007-2008 winter. We also calculated the growing season as the opposite difference between last freeze date in spring and first freeze date in autumn in the same calendar year. We again generated a single Vermont mean from these four stations for first and last freeze, freeze-period and growing season by adding the average departures from the climate normals (given by Schwartz et al. for the period 1961-1990) to the average of the climate normals (of the 196 station-years of data, only 10 years are missing). These are the data shown in Figure 4.

c) Frozen lake data

Joe's Pond is in West Danville, Vermont at 44° 25'N; 72°13.5'W with an elevation of 473m (1552ft), and a maximum depth of 30m (98ft). As part of the annual contest to guess the ice-out date, these dates and the trend have been recorded since 1988. Details are at "The Joe's Pond Ice-out contest", http://joespondvermont.com/iceout.html. Ice-out date and time are defined as when an electric clock tethered to a block on the ice stops as a result of the ice break-up. The freeze-up and ice-out dates for Stile's Pond in Waterford, Vermont at the same latitude but a lower elevation [44° 25'N; 71° 56.4W, Elevation, 267m (876ft)] have been recorded by an observer for the Fairbanks Museum, St Johnsbury,

Vermont since 1971. Steve Maleski of the Fairbanks Museum reviewed the records and supplied these dates for this study. The Stile's Pond ice-out date is missing in 1975. Both lakes are between 1.5 and 2 km in length.

d) Lilac first leaf and first bloom data

These data are archived though 2003 in the North American First Leaf and First Bloom Lilac Phenology Data (http://gcmd.nasa.gov/records/GCMD_LILAC_PHENOLOGY.html). Mark D. Schwartz (mds@uwm.edu) supplied an updated set for 1965-2008 for six Vermont sites that have the most complete records. We used the dates of first leaf and first bloom for these stations.

Sta#	Name		Lat (^{o}N)	Long (^{o}W)	Elev (m)
430075	SWANTON	VT	44.92	-73.13	36.6
431243	CAVENDISH	VT	43.38	-72.6	244
432843	ESSEX JUNCTION 1 N	VT	44.52	-73.12	105
435542	NEWPORT	VT	44.93	-72.2	233
438556	UNION VILLAGE DAM	VT	43.8	-72.27	141.16
439099	WEST BURKE	VT	44.65	-71.98	274.39

Cavendish and Essex Junction have the most complete record, so their mean was used as the baseline. (Data for 1985 and 1987 are missing.) There are some gaps in the leaf and bloom data for the other four sites, so for each site a mean difference from this baseline was computed based on all years for which there was data. Missing years were filled in for these four sites using this mean difference, and a mean date for first leaf and first bloom in Vermont were then computed as an average of the six sites.

Table 1. Regression coefficients for Figures 6 and 7

	A	B (T_{Feb})	**C** (T_{Mar})	**D** (T_{Apr})	**E** (T_{May})	**R^2**
Ice-out	**122.8±4.1**	**-0.52±0.27**	**-1.48±0.39**	**-2.21±0.52**		**0.67**
Lilac Leaf	**128.2±4.1**	**-0.82±0.25**	**-1.15±0.36**	**-3.01±0.47**		**0.75**
Lilac Bloom	**187.6±2.6**			**-1.65±0.26**	**-2.59±0.25**	**0.79**

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