Backward Seasons, Droughts and Other Bioclimatic Indicators of Variability

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Abstract Phenoclimatic fluctuations, biorhythms and agricultural patterns are intricately linked to the local meteorological conditions, and over time to the climate of a region. Many of these patterns were captured in the daily journal entries of diarists in the New England states of Vermont and New Hampshire in the pre-digital era. This chapter focuses on the data available from these states in the 1680–1900 time period. It presents an analysis of backward season characteristics and the concomitant influences on frost occurrences, sugar maple production and the onset of drought. The results demonstrate a unique application of historical data to reveal long-term spatial and topographic patterns. An indicator-based drought index also reveals spatio-temporal comparisons across the region, including some persistent severe droughts in the 1700s not apparent in the last century.

Keywords New England · Backward season · Drought · Phenology · Sugar maple · Frost

1 Introduction

New England's climate is often described as variable and changeable, a description that is as apt today as it was in three centuries ago. Physiographic and atmospheric factors from the local to synoptic scale are intricately linked to this variability, resulting in the precipitation and temperature fluctuations that characterise the region. The New England states of Vermont and New Hampshire are separated by the Connecticut River, with similar land cover and land use practices being found on either bank. Orographically, Vermont is dominated by the north–south trending Green Mountains, while the White Mountains run through central and northern New Hampshire. Lake Champlain exerts a moderating influence on western Vermont, while southeastern New Hampshire falls under the influence of the northern Atlantic

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Ocean. Historically, Europeans first settled the lowlands, river valleys and other easily accessible regions, with later movement into the more mountainous interior. Journal accounts of weather and climate reflect this pattern of settlement.

Written accounts by farmers, schoolchildren and state officials in the 18th and 19th century are replete with entries about backward seasons, droughts, freshets and the influence of weather and climate on agroecosystems. As far back as 1860, Vermont officials recognized the need for an ongoing, standardized system of meteorological measurement as a way of discovering the relationship between these variables and agriculture, diseases and other phenomena such as sunspots. Even at that time, it was recognized that without ongoing records, human memory is often short and that a season that may have been perceived as cold, could actually be warm in terms of the instrumental record.

A backward season refers to one that is late and/or with weather that is inappropriate for that time of year. Perhaps the most famous of these occurred in 1816, when much of New England and Québec experienced the "Year without a summer" [See the chapter by M. Chenoweth in this volume]. Apart from 1816, ships' logs document the coincidence of backward weather conditions on either side of the North Atlantic Ocean at other times in the early 1800s, while United States Fish Commission bulletins chronicle the comparative effects of backward conditions on fisheries in Gloucester, Massachusetts in 1887 vs. 1886 (Wilcox, 1887). Planting delays, changes in bloom dates and other phenoclimatic fluctuations have also been noted in backward years. Yet despite these accounts, no formal definition of a backward season exists, nor are its meteorological characteristics well quantified.

Phenoclimatic studies use flora and/or fauna with well-established responses to atmospheric forcings. Many of these studies have focused on plant responses to spring weather when the forcing is most pronounced (Schwartz, 1998). One of the goals of this chapter was to select a series of phenological characteristics that were reproducible, spatially extensive and with a direct response to climate variations. Sugar maple tapping was selected as one such phenoclimatic indicator for a number of reasons. "Maple trees were quite abundant, and every family was enabled to supply itself with plenty of maple sugar" (Wilkins, 1871). In a similar vein, the Rutland Daily Herald of 2 April, 1873 reported that

> Those who have large orchards and the apparatus for evaporating and preparing the maple sap for syrup, or making it into sugar, often reap as much income from this operation, as from any single branch of their farm work.

Finally, the close coupling between daily temperature ranges and snow depth in late winter-early spring strongly influences the timing and length of the sugaring season as well as the resulting yields. Studies of recent climate fluctuations have shown seasonal shifts in the timing and duration of the sugaring season across New England.

Droughts are a cyclical hazard that affect not only agroecosystems, but various components of the hydroclimatic cycle as well. Early New England residents battled moisture deficits that often combined with disease and insect infestations to produce crop failure. The New England agricultural landscape of the eighteenth and nineteenth centuries was highly diversified and included such crops as English and Indian corn; spring, winter and Siberian wheat; potatoes; flax seed; cotton; oats; apples; turnips; thistles; rye; barley; peas; beans; pumpkins; grass and clover seed for hay; and grapes. Homesteaders also kept bees, raised sheep, hogs, beef and dairy cattle, and tapped sugar maple (*Acer saccharum*) trees for syrup. Although crop production and livestock statistics are available from the National Agricultural Statistics Service (NASS), declines in the late 1800s and early 1900s were related to intertwined socioeconomic and biogeophysical reasons that make the link between climate and crop production or animal yields tenuous at best. This chapter uses crop yield statistics and diary accounts as indicators of moisture extremes.

In focusing on the northern New England states of New Hampshire and Vermont (Fig. 1), the main objectives of this chapter were:

- to quantify the thermal, moisture and spatial characteristics of backward seasons from 1680–1900 and to determine the underlying synoptic and mesoscale patterns;
- to explore the changing occurrences of bloom dates during backward seasons;
- to create an indicator-based drought index using hydrometeorological observations and proxy data for quantifying the spatio-temporal extent of drought in the 1680–1900 period and;
- to use maple sap production as a bioindicator of climate fluctuations in the 1800s.

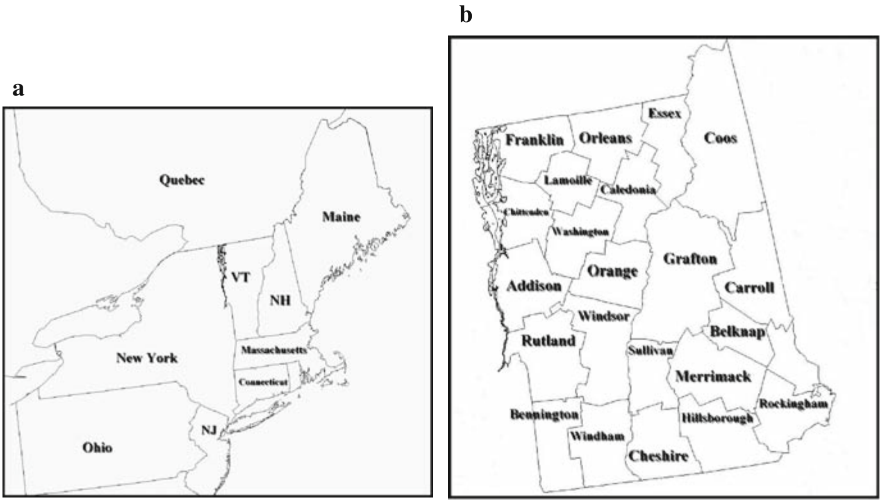


Fig. 1 Sketch map of northeastern North America showing the states of Vermont (VT) and New Hampshire (NH) (**a**) and the counties of Vermont and New Hampshire (**b**)

2 Data and Methods

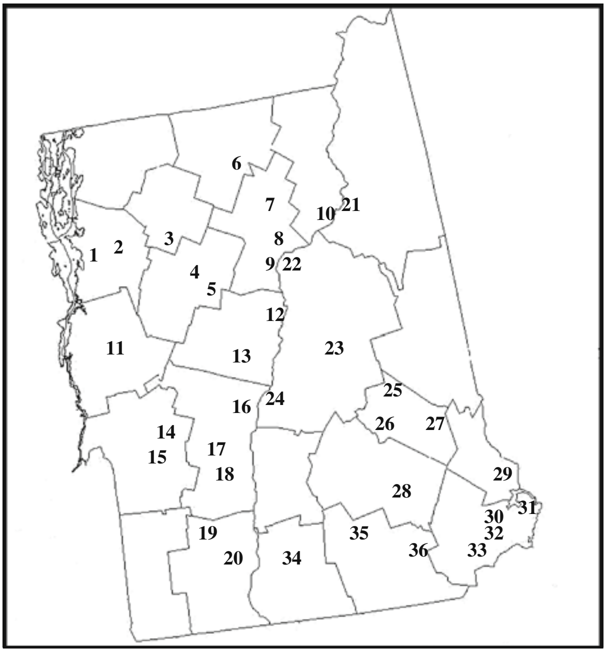
Weather and phenology records were transcribed from diaries held at historical societies, the University of Vermont Special Collections and museums or acquired from the online transcriptions on the Historical Climatology of New England and New York, Pennsylvania, New Jersey (http://www.umaine.edu/oldweather). Journal entries also included bird sightings, agricultural production, killing frosts, crop damage and maple sap quality or sweetness. Special note was made of frost occurrences during the warm season. Drought was either identified as such by the diaries' authors or derived from observations about wells drying, low river or lake levels, stunted crops, soil moisture conditions and low atmospheric moisture ("drying winds"). Additional weather entries were extracted from the Index to Manuscript Vermont State Papers and New England County Gazetteers. Many of these data were recorded daily, but the records were often interrupted by travel, crop planting, etc..

Daily meteorological data were also acquired from the Climate Database Modernization Program (CDMP) 19th Century Forts and Voluntary Observers Database at the Midwestern Regional Climate Center (MRCC). To date, data from five stations in New Hampshire (Fort Constitution and Plymouth) and Vermont (Burlington, Lunenburgh and Strafford) have been digitized and manually keyed. The period of record at these sites varied in the number of variables recorded, times of observation and record length (1820–1853 Fort Constitution, NH; 1839–1868 Portsmouth, NH; 1832–1892 Burlington, VT; 1859–1892 Lunenburgh, VT; 1873–1892 Strafford, VT). The most frequently overlapping times (0700, 0900, 1200, 1300, 2100) of daily precipitation, temperature and wind directions were selected for this study. All data were converted to SI units and the station pressures corrected to sea level, using station histories and MRCC metadata (Doty and Dupigny-Giroux, 2005; Andsager et al., 2007). Data gaps were not filled due to the lack of surrounding stations from which to homogenize the records. Observed station pressures across New England were complemented by the daily mean sea level pressure series at Montréal, Québec, Reykjavik Iceland and Gibraltar, computed by the EMULATE (*E*uropean and North Atlantic daily to *MUL*idecadal clim*ATE* variability) program for the period 1850-present. Interrupted time series analysis was therefore applied. Figure 2 identifies all of the station locations used in this study.

Finally, present-day US Geological Survey topographic maps were used to extract the large scale topography of study sites. In some cases, exact site locations were found on Beers atlases of the 1800s.

3 Quantifying the Characteristics of Backward Seasons

For a cool season to be considered to be backward, it must have so chronicled in at least one diary, county gazetteer, Monthly Weather Review of the US Army Signal Service or other documents. The characteristics of these years are summarized on Table 1. The 1812–1820 time frame was noted for the number and spatial extensiveness of backward springs, summer droughts and summer killing



STATIONS
1 Burlington
2 Essex
3 Stowe
4 Calais
5 East Montpelier
6 Irasburg
7 Wheelock
8 St. Johnsbury
9 Barnet
10 Lunenburg
11 Middlebury
12 Newbury
13 Strafford
14 Rutland
15 Tinmouth
16 Pomfret
17 Plymouth
18 Proctorsville
19 Windham
20 Townshend
21 Lancaster
22 Monroe/Lyman
23 Wentworth
24 Hanover
25 Meredith
26 Sanbornton
27 Alton
28 Concord
29 Dover/Durham
30 Stratford
31 Porstmouth
32 Exeter
33 Danville
34 Malborough
35 Weare
36 Bedford

Fig. 2 Locations of the towns from which diaries and other documentary evidence were obtained

frosts. The extended coldness of 1816–1818 was related to the aftereffects of the eruption of Tambora in 1815 and highlights the fact that crop failures and other devastation lasted beyond the 1816 "Year without a summer" commonly found in the literature [see M. Chenoweth in this volume for a more complete description of the synoptic patterns in the northeast during 1816]. The coldness in 1812 may be related to a hemispheric anomaly that coincides with similar conditions across the Baltic Region in Europe, although not preceded by any known volcanic eruption(s) (Neuman, 1990). Abnormal and highly variable conditions continued in 1813 with frost observed on 25 June at Sanbornton, NH followed by 43.8°C (102°F) temperatures on 3 July (Joshua Lane diary).

Time series of the daily temperatures were plotted for the available years in the 1820–1892 time frame at Burlington, East Montpelier, Lunenburgh and Strafford, VT as well as Fort Constitution, Portsmouth, Hanover, Dartmouth, and Wentworth, NH. The most striking observation were the low January–June values observed across the century regardless of differences in observation times at the individual stations. Several spatial patterns also emerged. Landlocked stations such as East Montpelier and Lunenburgh, VT and Hanover/Dartmouth, NH were consistently colder (e.g. January sunrise temperatures of –30°C(–22°F)) than those moderated

Table 1 Location and seasonal characteristics of backward years in New Hampshire and Vermont: 1700–1899. Very wet seasons are shown in italics and very cold ones in bold. Killing frosts are underlined

Season	Location	Year(S)	Snow	Frost	Drought
Spring	Dover, NH	1703, 1706, *1708*, 1709			Summer, fall 17008, 1709
Spring	Hampton, NH	1737			
May	Durham, NH	1740			July
Spring	Sanbornton, NH	1748	April		Summer
Spring	Stratham, Exeter, Sanbornton, NH	1751			
Spring	Dover, Sanbornton NH	1758	March		
Spring	Bedford, Exeter NH	1759	April, June	June	Summer
Spring	Bedford, NH	1761	May		
Spring	Stratham, NH	**1762**, 1772			May, August Summer
Spring	Sanbornton, Bedford, Portsmouth, NH	1763	March, April, May		
Summer	Stratham, Bedford NH				
Spring	Portsmouth, NH	1769, 1777	May		
Spring	Concord, Stratham, NH	1780			May
Spring	Stratham, NH Pomfret, VT	*1781*	May		August
Spring	Stratham, Danville NH	1784			Summer
Spring	Stratham, NH	**1785** **1786** 1790 **1793** *1794* *1795*			Fall (1786), May–June 1793 summer, fall 1794
Spring	Danville, NH	1787			
Spring	Sanbornton, NH	1795 1798 1802 1803			July 1803
Spring	Dover, NH	1812 1813 1814 1815	April, May 1812, spring 1813	June	Summer 1815
Spring	Barnet, VT	1812, 1815	May		
Spring summer	Concord, Sanbornton, NH Stowe, Newbury, Middlebury, Townshend VT Essex County, VT	1816	June May, June, July, August	July June, July, September August	Summer
Spring	Barnet, Newbury, Middlebury, Wakefield, Essex County, VT	1817	May, April, May June	June June (all crops)	

Table 1 (continued)

Season	Location	Year(S)	Snow	Frost	Drought
May	Middlebury, VT	1818			
Spring	Lancaster, NH Middlebury, VT	1819	May		
Spring	Middlebury, Townshend, Wakefield VT	1820	May	May, June	Summer
Spring	Alton, NH	1832	April (ice storm)		
May	Burlington, VT		May		
June	Essex, VT	1833	June		
Spring	Essex, Newbury, Middlebury VT	1834	May		
Summer	Middlebury, VT	1836	September	September	Summer
April, spring, June	Monroe, NH	1837 1843	June 1843	Sept 1843	July 1845 & 1850
		1844 1845 1850	May 1850	July 1844	
May, August	Plymouth, VT	1838			Summer
April–May	Monroe, NH	1841	May,		June
May	Malborough, NH		May		
Spring	St. Johnsbury, VT				
Summer	Monroe, NH	1842	June	June, Sept	Summer
	Irasburg, Wheelock & St. Johnsbury		June		
	Bennington, VT		June		
Spring	Calais, Essex County VT,	1844	June		
			April		
Spring	Alton, NH	1852 1863			Summer 1852
May–June	Monroe, NH				
Spring	Wentworth, Alton, Monroe NH	1854		June	August
Spring & summer	Wentworth, Monroe NH	1855			
Summer	Wheelock & northeast Vermont	1859	June	June, July	
Spring	Monroe, NH	1862 1866 1870			Summer 1862 1870
Spring	Newbury, VT	1874	May		
Spring	OCM	*1876*	May		Summer, fall
Spring summer	Lunenburg, VT	1884	May	August	
April–May	Windham, VT	1877	May		Summer
May–June		1878	May		
Spring		1888			
Summer	Craftsbury, VT	1879			

by the influence of a large body of water (e.g. Burlington, VT on the eastern shore of Lake Champlain or Fort Constitution/Portsmouth, NH near the Atlantic Ocean). Interestingly, the temperatures at Hanover/Dartmouth, NH were not moderated by proximity to the Connecticut River. Time series of the January–June temperatures were non-stationary, especially on a seasonal basis and for the aforementioned landlocked stations.

Temporal patterns were also evident. In the early part of the record (1820–1855), pronounced freeze/thaw cycles were observed in winter (January and February) with rapid temperature swings from –30°C to 10°C (–22°F to 50°F). The periodicity of these cycles was on the order of 11–14 days during the 1820s at Fort Constitution, NH and 1830s at both Burlington, VT and Fort Constitution. During the 1840s and 1850s the periodicity of the cycles declined to 5–7 days. Rapid swings during winter were also characteristic of the 1862–1888 period, but thaws were much less frequent. Instead, severe winter freezes (as low as –30°C (–22°F)) were very common and the 5–7 day periodicity was observed from January to June. During 1878–1880, backward conditions began around Julian date 150, shifting to around Julian date 110 in 1885–1886 before returning to around Julian date 150 in 1887.

Winter freeze/thaw cycles were an important predictor of backward conditions in the subsequent spring. When the cycles were superimposed on a lower frequency temperature oscillation and/or the freezes were severe (–10°C to –20°C (14°F to –4°F) or colder) and lasted for several days, a forward spring (i.e. gradual warming) usually occurred. However, when both the thaws and the freezes (10°C to –20°C (50°F to –4°F) respectively) were pronounced in January and February and followed by warming around Julian dates 135–140, backward conditions soon followed. As Ludlum (1976: 3) so rightly noted, “A summerish January, a winterish spring.” As the temperatures fell, often to around 0°C, precipitation would be in its frozen state – the snow and freezing rain in April, May and June documented on Table 1, including the snowstorms in April 1844 that left about 4 ft of snow on the ground in Essex County, VT (Child, 1887).

The timing of the majority of patterns (freeze/thaw cycles, warm anomalies, onset of backward conditions) was roughly coincident across the two states. Also consistent across stations and time frames was the decrease in the amplitude of the temperature fluctuations from winter into spring. Station temperatures were highly correlated (at least 0.89 with a standard error of 0.078) across observation times on a given day as well with other stations. These factors suggest that despite known data inhomogeneities (changes in observers and station height), mesoscale and/or synoptic spatial forcing functions produced similarities at the continental scale. For example, the backward spring of 1887 was also observed in southern New England, with the Bulletin of the United States Fish Commission noting “the almost continuous cold, foggy weather” during May in Gloucester, Massachusetts (Wilcox, 1887). Similarly, the spring of 1843 was backward across northern tier of US [see J. Neilsen-Gammon and B. McRoberts, this volume for the backward conditions of March 1843; H. Tompkins, this volume for cold anomalies in 1849]. With the exception of north/south flow at Burlington and Strafford, VT annual wind roses revealed a predominance of northwesterly flow at all other stations even those near the coast in New Hampshire, which today would display a strong easterly component. Such flow would be conducive to sustained cold advection into the region, especially under favourable upper level conditions. Predominantly northerly flow may have been an important factor in the development of drought conditions during or following backward seasons, by hampering the southerly or westerly flow which is conducive to moisture convection across New England.

It is important to note, however, that backward seasons were also localized in spatial extent. This was particularly true in the northeastern part of Vermont and adjacent northern New Hampshire where temperatures are least moderated by warming influences. Thus in some years, backward springs existed in southern Vermont (e.g. the snowy May of 1878 at Windham) while forward conditions existed in the northern Vermont county of Essex (Child, 1887).

3.1 Phenology Variations During Backward Seasons

A number of observations could be made about the bloom dates of apple and plum trees during backward seasons (Fig. 3). Full bloom dates occurred earlier in non-backward seasons. A station's location strongly influenced the julian date on which full blooms were observed such that they were consistently later at northern stations (e.g. Monroe, NH) than those further south in proximity to Lake Champlain

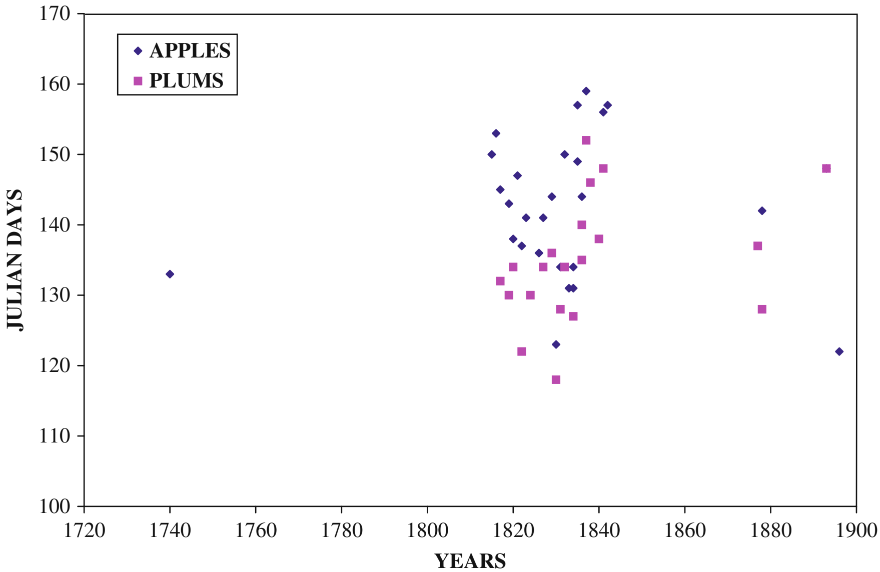


Fig. 3 Full bloom dates for apples and plums observed at Windham, Middlebury and Newbury, VT as well as Concord, Durham and Monroe, NH. Data extracted from the Emory H. Jones, Alexander Miller, Thomas Johnson, Timothy Walker, Nicholas Gilman and Albert Mason diaries respectively. Diary citations are given in the References

(e.g. Middlebury, VT). At Middlebury, VT there was a 5–7 day difference between the earlier blooming plums and the later blooming apples during normal years and 13–16 days during backward springs. Blooming delays in backward years were a function of spring temperatures, injury during cold winters (e.g. 1835), excessive snowfall in May and/or late snowmelt (e.g. 1841 at Monroe, NH). In some years (e.g. 1834 at Middlebury, VT), cold temperatures inhibited flowering even though budding had occurred.

3.2 Frost and Snow Occurrences During Backward Seasons

The average length of the growing season is usually defined as the interval between the last hard or killing frost in the spring and the first hard or killing frost in the fall. Hopp et al. (1964) have noted that the number of non-freezing days in turn affects the types of crops grown. Figure 4 summarizes 392 spring, summer and fall killing frost occurrences extracted from journal entries. Of special note was the timing of summer frosts relative to backward seasons and subsequent moisture extremes. The 1812–1820 period was marked by annual backward springs, followed by the largest number and spatial distribution of summer-long frosts, particularly across New Hampshire. The backward spring of 1834, observed across northern

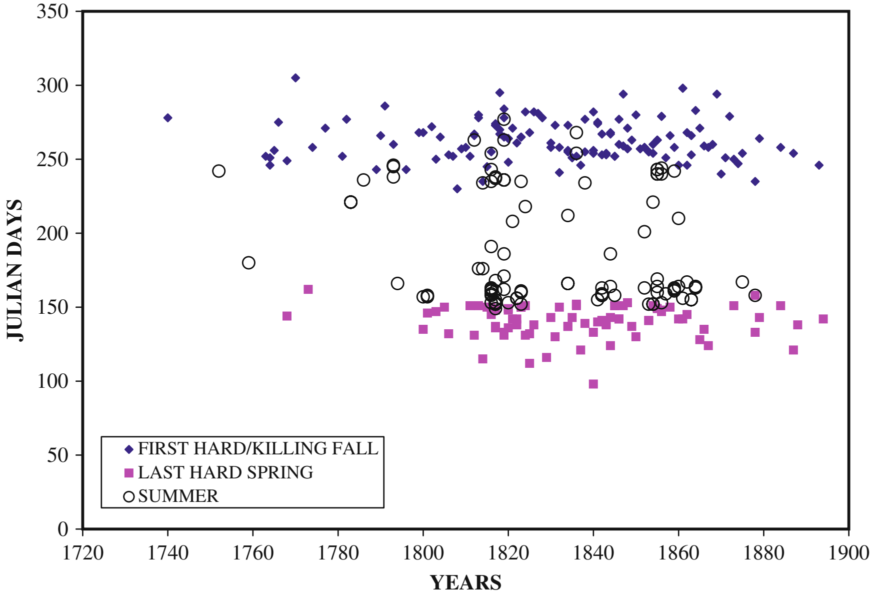


Fig. 4 Annual occurrences of the last hard/killing frost in the spring, first hard/killing frost in the fall, any hard/killing frosts in the summer at various locations in Vermont and New Hamsphire. Data extracted from the following diaries – Jonathan Carpenter, Sally and Pamela Brown, Hyde Leslie, Emory H. Jones, Allen, Sprague, Joshua Lane, Timothy Faulkner, Albert Mason, Dr. Peter Livingston Hoyt, Allen Varney, Alexander Miller, Matthew Patten, Clark, Abner Gover, Jeremy Belknap, Miriam Newton. Diary citations are given in the References

Vermont was followed by summer frosts at Middlebury, VT and Malborough, NH. Like the 1812–1820 period, 1841–1845 was marked by annual backward springs, with snow falling in May or June. Early summer frosts were less extensive spatially than during the 1812–1820 period, but were followed by summer droughts. Summer droughts were also observed following the backward springs of 1852–1855, a period characterized by a lack of snow in May/June, but frosts all summer in western New Hampshire. Finally, a large number of early summer frosts typified the 1860–1864 period, although few journal entries noted the existence of backward seasons.

Two types of frosts could be distinguished. Radiative frosts tend to localized and develop under clear, calm conditions such that freezing temperatures are confined to the ground, under a relatively shallow inversion. Advective frosts are associated more often with cold, polar air outbreaks and strong winds (Hopp et al., 1964). Radiative frosts were extracted from journal entries of air temperatures, the presence of radiation fog, the types of vegetation affected and the freezing of shallow water surfaces. Advective frosts were determined from the rapidity of onset of cool conditions, their duration and the height of the affected vegetation. Roughly 21 of the 392 frost occurrences were advective. They were more widespread and likely to affect plants at tree height, e.g. apple orchards in June 1817 across southern New Hampshire as well as plum and apple tree buds and blossoms at Middlebury, VT on 16 May, 1834.

The current definition of a killing frost is one that is severe enough to delay the start of the growing season or to bring it to an end. Of the roughly 50 killing frosts chronicled in journals, approximately 50% occurred during the summer (e.g. late 1700s at Stratham, NH; 1816 and 1817 across much of New Hampshire and western Vermont; 1821–1824 at Middlebury, VT; 1842 and 1859 at Monroe, NH). Middlebury, VT, Bedford, NH and Monroe, NH were particularly prone to killing frosts. Orographically, these locations/frost hollows had flat topography surrounded by steeply sloping land (at least to the east) that allowed for intense radiational cooling and katabatic cold air drainage. The June frosts of 1842 and 1859 at Monroe, NH which were accompanied by northerly winds, ice formation on standing water and the loss of corn, beans and leaves on trees, highlighted the role of the topography in enhancing advective frosts as well (Albert Mason diary). Other locations such as Wentworth, Sanbornton and Marlborough, NH accounted for most of the 392 frost entries, partly due to the length of the records at these stations. There, the topography was either that of a broad river valley (Wentworth and Marlborough, NH) or gently sloping uplands (Sanbornton, NH). Radiational cooling was less intense, but very frequent in these locations.

Killing frosts usually decimated potato vines, pumpkin vines, beans and melons. Cucumber stalks, corn and wheat plants were also affected. Although Landsberg (1958) and Thom and Shaw (1958) have discussed several limitations of using killing frosts for statistical analysis, some inference can be made about the existing ground temperatures from the types of crops affected. The critical or lethal temperature is the value that must be attained before plant damage occurs. For very tender crops such as cucumber, melon, pumpkins and beans, the critical temperature is 0° to –1°C (32°F to –30.2°F), but –1° to –2°C (30.2°F– to 28.4°F) for tender crops like potatoes, corn and apple or plum blossoms (Ontario Ministry of Agriculture, Food and Rural Affairs, 1985). The critical temperature depends upon the vegetation type, variety, phenology, as well as environmental factors such as soil conditions, freezing characteristics and duration, cloudiness and windiness (Cittadini et al., 2006; Ontario Ministry of Agriculture, Food and Rural Affairs, 1985).

4 Drought Characteristics, with Special Reference To Backward Seasons

In order to compare drought characteristics (including severity and duration) across time and space, a qualitative index was created using observations of precipitation deficits, soil moisture depletion, crop loss or yield reductions, atmospheric drought and the depletion of both surface water and groundwater. Atmospheric drought refers to an abnormal dryness of the atmosphere resulting from a high evaporative demand on vegetation and soil moisture amounts, where the intensity of the drying can be exacerbated by warm, moderate to strong winds (called *sukhovei* in the Soviet Union) (Dupigny-Giroux, 2001). In the historic record, *sukhovei* were pronounced under westerly flow.

The drought index created from the above indicators was qualitative in nature to account for the following sources of uncertainty:

- summer precipitation amounts often were not measured and snowfall amounts occasionally recorded, so that exact precipitation deficits, monthly totals and averages/normals could not be computed;
- daily maximum temperatures were not always recorded. The use of such terms as “warm”, “very warm” or “exceedingly hot”made it difficult to identify heat wave durations. The descriptions were used to infer the persistence of high pressure conditions;
- some diary entries summarized conditions for the entire year on 31 December. No finer scale temporal information could be extracted on either daily to monthly time steps or from one year to the next;
- some locations lacked any direct or indirect reference to precipitation, necessitating the use of inferential information;
- some entries referred to “severe”, “sharp” or “pinching” droughts, whereas others only noted “dry”, “very dry”, “earth is dry” conditions and never used the term drought;
- apart from drought, other stressors that led to crop losses were mildew, rust, frost, worm and grasshopper infestations, cool temperatures and moisture excess (sometimes consecutively in the same year);
- smokey conditions may have been due to land clearing practices in the spring and early fall (September–October), as well as local or regional forest fires;
- data gaps included entries for half the year only (e.g. some farmers only documented cool season or summer conditions), missing months or years, and changes in observers.

Table 2 An indicator-based drought index

Category	Characteristics	Indicator(S)
S1	a) 1–2 moth precipitation deficit b) precipitation deficit = precipitation in subsequent month c) no short-term or long-term effect on vegetation phenology or crop production d) local in scale	a) no rain/snow entries b & c) vegetation recovers completely
S2	a) 2–3 month precipitation deficit b) sukhovei may be present c) runs of high daily temperatures d) depletion of surface soil moisture e) some effect on vegetation phenology or crop production f) local and/or regional in scale	a) no rain/snow entries b) "drying wind" entries d) "earth is dry"entries, shallow rooted crops (e.g. grass for hay affected) f) number of coincident diary entries available
S3	a) 3–12 month precipitation deficit b) sukhovei may be present c) extended runs of high daily temperatures d) depletion of surface and subsurface soil moisture e) depletion of surface hydrology f) effect on vegetation phenology or crop production f) forest fires may occur * g) regional in scale	as for S2 d) "wells are very low" "river very low" entries e)"short crop" "middling crop" entries f) most fires observed in the woods
S4	as for S3 b) surface and subsurface waters exhausted c) large-scale forest fires including swamps and wetlands * d) regional or larger in scale	as for S3 b) "streams dry" entries c) "great fires in the country all round" entries
S5	as for S3 b) multi-year	few rain/snow entries in fall and winter, followed by summer drought with increasing number & severity of impacts

*summer and fall forest fires. Land cleared by burning in late spring.

Table 2 summarizes the five categories of the drought index which integrates both short-term moisture deficits and multi-year drought episodes. The shortest duration drought (S1 – one to two months) could be one of two types. The first were the droughts of the earliest period (1681–1730) when few details on the drought were given apart from its seasonality. The second category of S1 were "flash" droughts which exhibited a quick onset with no preceding atmospheric or land-surface moisture deficits, followed by an equally rapid termination due to precipitation in the following month. The timing of these flash droughts was critical in that spring occurrences had a temporary effect on crops, while late summer/early fall events affected surface waters and wells which tended to be at their lowest points of recharge at that time. S2 droughts tended to be summer occurrences.

One key difference between the S3 and S4 designations was precipitation effectiveness. In S3 conditions, soaking rains reversed soil moisture deficits resulting in less crop loss. S4 droughts combined both long-term moisture deficits with severity of impacts. Typical indicators included the lack of subsurface moisture and groundwater recharge (dry wells and water bodies; muck fires burning in swamps and wetlands) following moisture inputs that were sufficient for crop and vegetation requirements. S4 and S5 categories were also assigned to multi-year events observed over large spatial extents and were usually most pronounced in the late summer and early fall. It should be noted that long-term droughts (S3–S5) were not continuous periods of low to no precipitation, drying winds and high temperatures. Instead, at many locations soaking precipitation was received sporadically, although it was insufficient to either ameliorate crop losses or replenish soil moisture reserves. In extreme cases, these precipitation events included a "very great snow storm" on 7 June, 1759 at Exeter, NH and freezing rain on 30 July, 1847 at Malborough, NH.

The creation of the indicator-based drought index was not without uncertainty. There was a bias towards conditions observed in New Hampshire (Table 3). Due to the timing of settlement in both states, there was an abundance of diaries in New Hampshire during the early part of the record compared with those for Vermont. In addition, the latter part of the record exhibited a wetter climate regime such that drought and dry conditions were largely absent from the Vermont diaries of 1850–1900. This shift in climate regimes was reflected in Zadock Thompson's (1853:13) treatise on the Natural History of Vermont in which he noted that "very little damage is ever done by hurricanes or hail. The crops oftener suffer from an excess, than from a deficiency of moisture, though seldom from either" Finally, the varieties of crops grown may also have factored into the proneness to drought observed in the earlier vs. later years. Indian corn was often able to recover with sufficient effective precipitation from S1 to S2 droughts, while English crops and hay were often decimated. English crops were also more susceptible to mildew and rust which made them even more vulnerable to co-existing or subsequent droughts. It should be noted that not every drought could be classified without ambiguity. For the spring flash droughts (S1), the short term ranking often obscured the fact that excessive drying following snowmelt produced ideal fuel conditions, such that forest fires were often observed in April (e.g. in 1740 at Durham, NH). Similarly, some uncertainty exists for cases of long term dryness (S4) that caused mill ponds and streams to run dry (e.g. 1751 at Monroe/Lyman, NH; 1766 and 1773 at Bedford, NH; 1797 at Stratham, NH) in the absence of journal entries that would imply intermediate surface soil moisture deficits.

5 Maple Sap and Sugar Production

In the late 20th and early 21st century, maple syrup and sugar across northern New England are primarily made from sugar maple (*Acer saccharum*) and red maple (*Acer rubris*) trees that are tapped from late February to mid March. Sap flows best with a diurnal temperature range from about –4°C (25°F) to 4°C (40°F), and warm

Table 3 Indicator-based drought categories as extracted from New Hampshire & Vermont diaries. Split categories are shown in bold, italics (S1–S2, S2–S3, S3–S4)

Category	Location	Years
S1	Dover, NH	1683 1707 1815
	Exeter, NH	1738 1754
	Durham, NH	1740
	Concord, NH	1746 1780
	Bedford, NH	1760 1765 1769 1781
	Stratham, NH	1774 1775 ***1789*** 1791 1792
	Danville, NH	1791 1792 1797–1800 1803 1805 ***1826 1829***
	Sanbornton, NH	1817
	Middlebury, VT	1838 1850 1876 1885 1886
	Monroe/Lyman, NH	1854 1856 1876–1882
	East Montpelier, VT	1856
	Wentworth, NH	1863
	Alton, NH	
S2	Dover, NH	1709
	Stratham, NH	1746 1749 ***1757*** 1771 1772 1773 1774 1784 1793
	Exeter, NH	1748 1759
	Concord, NH	1764
	Bedford, NH	1771
	Danville, NH	1793 1796
	Sanbornton, NH	1793 1795 1796 1804 1806 1813 1818 ***1820 1823*** 1825
	Monroe/Lyman, NH	1836 1837 1842 1846 1847 1848 1851 1888
	Durham, NH	***1743*** 1840 1842
	Wentworth, NH	1852 1853
	East Montpelier, VT	1853 1859 1866
	Alton, NH	***1864*** 1865
	Weare, NH	1841
S3	Dover, NH	1708
	Stratham, NH	1748 1761 1770 1775 1780 1781 1792
	Exeter, NH	***1749***
	Lancaster, NH	1820
	Monroe/Lyman, NH	1841 1845 ***1852*** 1854 1864 1868 1870 1887
	Wentworth, NH	1854
	East Montpelier, VT	1860 1861 1862 1863 1864 1865 1868 1870–1874
S4	Portsmouth, NH	1762
	Stratham, NH	1762 1782 1786 1797
	Bedford, NH	1766 1773
	St. Johnsbury, VT,	1849
	Monroe/Lyman & parts of	1849
	northern NH	1849
	Monroe/Lyman, NH	1860
	Newbury, VT	1854
	Plymouth, VT	1887
S4–S5	Stratham, NH	1794 1798
S5	Sanborton, NH	1794

winds. In the 1800s, maple growers were also very attuned to the delicate balance between daily weather conditions and sap production. Good sap flow conditions included cloudy skies, easterly winds in the northern Connecticut Valley, as well as abundant snow late in early April in southern Vermont. Sap flow was inhibited by warm, rainy conditions in April and/or very sunny, mild and rainy conditions during the winter in the northern Connecticut valley (Albert Mason diary). In southern Vermont, little to no sap was produced under cold northwesterly winds, sleet or sub-freezing conditions even in the presence of abundant snow (Hyde Leslie diary and Emory H. Jones diary). One sugar maker in particular, Luther O. Weeks of Proctorsville, VT combined weather knowledge with his observation of sap flow from maples under varying conditions, and thus was able to produce “7,834 lbs. of good tub sugar” from only 520 white rock maples (a term used by New Hampshire residents for sugar maple trees (Cogbill, 2007, personal communication)) between 1868 and 1872. In an editorial in February 1873, he wrote

> Farmers in this county where the snow is apt to be deep in March and April, delay tapping for the snow to settle, and thus lose by far the best part of the sugar; as no frost is in the ground when the snow is deep; and as soon as the mercury stands at from 46 to 50 degrees above zero, in the shade, for a short time, sap commences to run freely. I have make 600 lbs. of sugar some springs ere a pound would be made in any adjoining sugar lot, the proprietors claiming that it was not sugar weather. (Rutland Daily Herald, February 1873, Vol. 12).

Table 4 summarizes diary accounts of maple sap and sugar production before 1916 when records of the US Department of Agriculture’s National Agricultural Statistics Service (NASS) began. With the exception of Craftsbury and Monroe in north-central Vermont and northwestern New Hampshire respectively, all of the

Table 4 Maple sap and sugar production extracted from the following diaries – Jonathan Carpenter, Albert Mason, Allen Caldwell, Emory H. Jones, Henry Allen and Clara Jones. Diary citations are given in the References

Year	Location	Season duration	Trees tapped	Sap amount	Sugar (lbs)
1781	Pomfret, VT	13 March–16 April		82 pails	80
1874	Monroe, NH	21 March–1 May[a]			
1876	Windham, VT	10–25 April	1400[b]		1 ton[c]
1877	Windham, VT	3 February–5 April	3		100
1877	Wheelock, VT	31 March–21 April			
1878	Windham, VT	8 March–9 April		400 buckets	at least 500
1878	Craftsbury, VT	11 March–11 April		760 pails	1600
1878	Wheelock, VT	16 March–18 April		∃ 31 tubs	
1888	Windham, VT	23–26 April?			
1888	Tinmouth, VT	27 March–16 April		18 pails	
1893	Windham, VT	10–29 April			355
1894	Windham, VT	9 March–17 April	50		400
1895	Windham, VT	3–8 April	∃ 100		at least 125
1896	Windham, VT	26 March–13 April	50		300
1897	Windham, VT	last week March–24 April	50		450
1898	Windham, VT	20–26 March		500 lbs	

[a] only season duration records were available at Monroe, NH with an average length of 29 March–16 April during 1864–1876.
[b] records for the diary author’s neighbour Mr. Dimicks.
[c] original entry given without conversion to pounds. If the short ton unit was used, the equivalent would be 2,000 lbs.

towns listed in Table 4 are in southern Vermont. Of note are the varying season start dates and durations. Maple sap production was, and still is highly variable spatially and from one season to the next. Delayed tapping was a function of deep snow or severe snowstorms such as the Blizzard of March 1888, when the season extended into late April. Similarly, the particularly stormy, snowy spring conditions of 1873 in southern Vermont retarded the start of the season until early April (Rutland Daily Herald, 5 April 1873 Vol. 12, No. 288). The extension of the sap flow season into April in the1800s corresponds with the March–April duration observed during the 1940s and 1950s (Taylor, 1956), but is decidedly later than the February–March season length of the late 20th century. This late excursion of sap flow into April is probably related to the extended freeze/thaw cycles discussed in Section 3 as well as the snowfall that often accompanied backward seasons. As Charles Nelson Morse wrote in letter to his brother Dane on 13 April 1861:

> There has been one snow storm since I wrote that sheet the 2nd day of April. It fell about 10 inches. Regular sugar snow and I believe it too for it has frozen every night and been warm every day, wind (what little there has been) in the North. Grand time for Still. I think he has made a lot of syrup, but have not heard. (Dwinell, 1996).

During some backward springs, e.g. 1815, maple sap "ran with great freedom and never before or since was so large a product gathered per tree" in the northern Vermont counties of Caledonia and Essex (Child, 1887: 25). In other years, the relationship was not straightforward. The spring of 1878 was a forward one in northern Vermont's Essex County that led to early May bloom dates for red plum, strawberry and apples (Child, 1887), while backward conditions prevailed in the southern town of Windham, VT. Between 21–25 March, journal entries in both northern (Craftsbury) and southern (Windham) Vermont recorded temperatures so low the sap froze, although the season extended into mid April.

The presence of ideal weather conditions was not a guarantor of good or abundant sap. As Emory H. Jones observed at Windham, VT on 26 March 1898, "A week of sap weather but not very good, about 500 lbs sap poor, watery." Such variability was also observed in the 1884 and 1885 U.S. government's chemical studies of maple sap (Wiley, 1885). Fluctuations in the timing, duration and quality of sap production at Windham, VT continued into the late 1890s with 1895 being a late and poor sugar season, followed by unseasonable warmth in mid-April of 1896 that curtailed the season (Emory H. Jones diary). Finally, journal entries indicate a relationship between the sweetness of the sap and the length of the season. Emory H. Jones at Windham, VT recorded "A poor season but sap very sweet wh[ich] is sign of short season" on 25 April 1876.

6 Conclusion

Backward springs and occasionally backward summers, were frequent occurrences in the late 1700s–1800s in New Hampshire and Vermont. They were often accompanied by snow in May or June, with frost and drought recurrences in the summer.

Backward seasons tended to be regional events that occurred under strong northwesterly flow into the region. Localized backward seasons were also observed in the northernmost interior parts of the study area which were removed from the moderating influences of a body of open water. This pattern of spatially extensive and frequent backward springs, summer droughts and summer killing frosts was particularly pronounced in the 1812–1820 time frame, with linkages to hemispheric anomalies in 1812 and the eruption of Tambora in 1815. Winter freeze/thaw cycles were an important of indicator of a backward spring with marked fluctuations in the amplitude and periodicity of these cycles across the 1800s.

The incidence of backward seasons also affected the phenology of common plants as well the viability of crops in the summer. Delayed full bloom dates were observed for apples, plums and other species as a function of low spring temperatures, preceding winter injury, excessive snowfall in May and/or late snowmelt. Summer frosts were particularly marked in the 1812–1820 and 1860–1864 periods. Of the 392 frost occurrences extracted from journal entries, about 21 were advective in nature and the remainder were radiative. Advective frosts tended to be widespread and affect tree species such as apple orchards and plum blossoms. Radiative frosts were more prevalent, especially in orographically conducive locales, and often resulted in the complete loss of crops such as corn, wheat, potato vines and melons.

The creation of an indicator-based drought index highlights how drought-prone the region was especially in the late 1700s. This may reflect the shift to a wetter climate regime that occurred around 1850, as well as the selection of crops grown in the later part of the study period. Multi-year, severe droughts (categories S4 and S5) were often interrupted by sporadic precipitation including a summer snowstorm, and were particularly evident in 1762, 1794, 1849 and 1864.

While maple sap production and collection in the 21st century are less reliant on the vagaries of the weather than was the case in the 1800s, key differences in climate regimes can be noted. The sap flow season from February/March into April in the 1800s is much longer and later than that observed in recent decades, although strikingly reminiscent of the 1940s and 1950s seasons. The extension of the season was probably a function of the extended freeze/thaw cycles in the spring as well as the snowfall often observed during backward seasons. It should be noted that the relationship between weather and sap production was not a straightforward one and the discovery of additional data sources and diaries may assist in better quantifying the spatio-temporal characteristics of the patterns observed.

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References

Abner Gover diary, 1796–1856, Weare, NH
Albert Mason diary, 1834–1886, Monroe and Lyman, NH
Alexander Miller Diary, 17 April 1816–27 December 1836, Middlebury, VT.
Allen Caldwell diary, February 1878–March 1879, Wheelock, VT.
Andsager K, Kruk MC, and Spinar ML (2007) DSI-3297. CDMP COOP Summary of the Day Forts, National Climatic Data Center, Asheville North Carolina.
Charles Mooney Diary, November 1865–May 25 1908, Alton, NH.
Child H (1887) Part First. Gazetteer of Caledonia and Essex Counties, VT. 1764–1887, the Syracuse Journal Company, Printers and Binders, Syracuse, New York.
Cittadini ED, de Ridder N, Peri PL and van Keulen H (2006) A method for assessing frost damage risk in sweet cherry orchards in South Patagonia. Agricultural and Forest Meteorology, 141: 235–243.
Clara Doty diary, 1888, Tinmouth VT.
Dartmouth College Meteorological register, November 1827–December 31 1890, Hanover, NH.
Diary of Henry Allen, January 1–December 10, 1878 Craftsbury, VT.
Doty SR and Dupigny-Giroux L-A (2005) Station History Report to the Climate Database Modernization Program of NOAA's National Climatic Data Center, Midwestern Regional Climate Center, 61pp. [Available from Midwestern Regional Climate Center, 2204 S. Griffith Drive, Champaign, IL 61820.]
Dr. Peter Livingston Hoyt, personal meteorology register, 1852–1856, Wentworth, NH.
Dupigny-Giroux L-A (2001) Towards characterizing and planning for drought in Vermont. Part I. A Climatological Perspective. Journal of the American Water Resources Association, 37(3): 505–525.
Dwinell JM (1996) Letters to Dane: November 1860–July 1862. Written by Charles Nelson Morse and Ellen Morse.
Emory H. Jones diary, 1875–1879, 1888–1906, Windam, VT
Fairbanks ET (1913) The Town of St. Johnsbury, VT. The Cowles Press, St. Johnsbury, VT, pp. 513–520.
Hopp RJ, Varney KE and Lautzenheiser RE (1964) Late Spring and Early Fall Low Temperatures in Vermont. Agricultural Experiment Station, University of Vermont – Burlington, Vermont, June, Bulletin 639.
Jeremy Belknap diary, 1758, Dover, NH.
Jonathan Carpenter diary 1781–1783 Pomfret Vermont. Transcribed and edited by Miriam and Wes Herwig, Greenhills Books, Randolph Center, VT, 1994.
Joseph & Charles Mooney Diaries, 1831–November 25 1865, Alton, NH.
Joshua Lane diary, 1788–1829, Sanbornton, NH
Landsberg H (1958) Physical Climatology, Gray Printing Co. Inc., DuBois, PA.
Ludlum DM and the editors of Blair & Ketchum's Country Journal (1976) The Country Journal New England Weather Book, Houghton Mifflin, Boston.
Matthew Patten diary, 1754–1798, Bedford, NH
Miriam Newton diary, 1820–1852 Malborough, NH.
Neuman J (1990) The 1810s in the Baltic region, 1816 in particular: Air temperatures, grain supply and mortality. Climatic Change, 17(1): 97–120.
Ontario Ministry of Agriculture, Food and Rural Affairs (1985) Freeze Protection Methods for Crops, Factsheet 85–116.
Rutland Daily Herald, 5 April 1873, Vol. 12, No. 288.
Schwartz MD (1998) Green-wave phenology. Nature, 394: 839–840 (27 August).
Seneca Ladd, meteorological register,1867–1891, Meredith, NH.
Sprague diary, 4 May–30 December 1884, Craftsbury, VT.
Taylor FH (1956) Variation in Sugar Content of Maple Sap. Vermont Experiment Station Bulletin 587.

The Diaries of Sally and Pamela Brown 1832–1838 [Jan.–Feb.1839] and Hyde Leslie 1887, Plymouth Notch, Vermont. Blanche Brown Bryant and Gertrude Elaine Baker (eds.), The William Bryant Foundation, Springfield, Vermont, 2nd edition, 1979.

Thom HCS and Shaw RH (1958) Climatological analysis of freeze data for Iowa. Monthly Weather Review, 86: 251–257.

Thomas Chandler diary in Eleanor Hutchinson (1961) History of the Town of Wheelock, VT. Emerson Publishing Co., Rochester, Vermont.

Thomas Johnson diary, 1761–1895, Newbury, VT.

Thompson Z (1853) Natural History of Vermont with Numerous Engravings and an Appendix. Stacy and Jameson.

Timothy Faulkner Diary, 1818–1821, Lancaster NH

Varney A, 1861–1865, Alton, NH

Weather Journal by Benjamin Wheeler, 1851–1883, East Montpelier, VT.

Wilcox WA (1887) The Fisheries of Gloucester Mass, in May 1887, with notes on those of other localities. Bulletin of the United States Fish Commission 1887.

Wiley HW (1885) The sugar industry of the United States. U.S. Bur. of Chem. Bull. 5.

Wilkins MN (1871) History of Stowe to 1869. As originally published in The Vermont Historical Gazetteer, a Magazine Embracing a History of Each Town Civil, Ecclesiastical, Biographical and Military. Vol. II (Burlington, Vermont, 1871) Edited and Published by Miss A.M. Hemenway.