Revisiting the Winter Severity Index and Winter Climate Changes at the Blue Hill Observatory

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Winter snowstorms and cold temperatures greatly influence the perception of winter severity, though comparing their combined effects objectively and consistently over time can be challenging. The impact of winter weather on human activities and whether it is perceived to be severe generally depends on the frequency, magnitude, and duration of significant snowfalls and outbreaks of cold air during the winter season. Trends in these winter features can be characterized by examining temperature and snowfall separately, though their combined effects are typically perceived to have a larger influence on winter severity. In order to represent the overall harshness of winter seasons in eastern New England, *Conover* (1951) devised a Winter Severity Index (WSI) to compare the combined effects of winter temperature and snowfall from season to season and to address the question of whether New England winters were getting milder, and this investigation was later extended by *Conover* (1992). The present report will summarize and update the long-term trends in these measures of winter severity at Blue Hill.

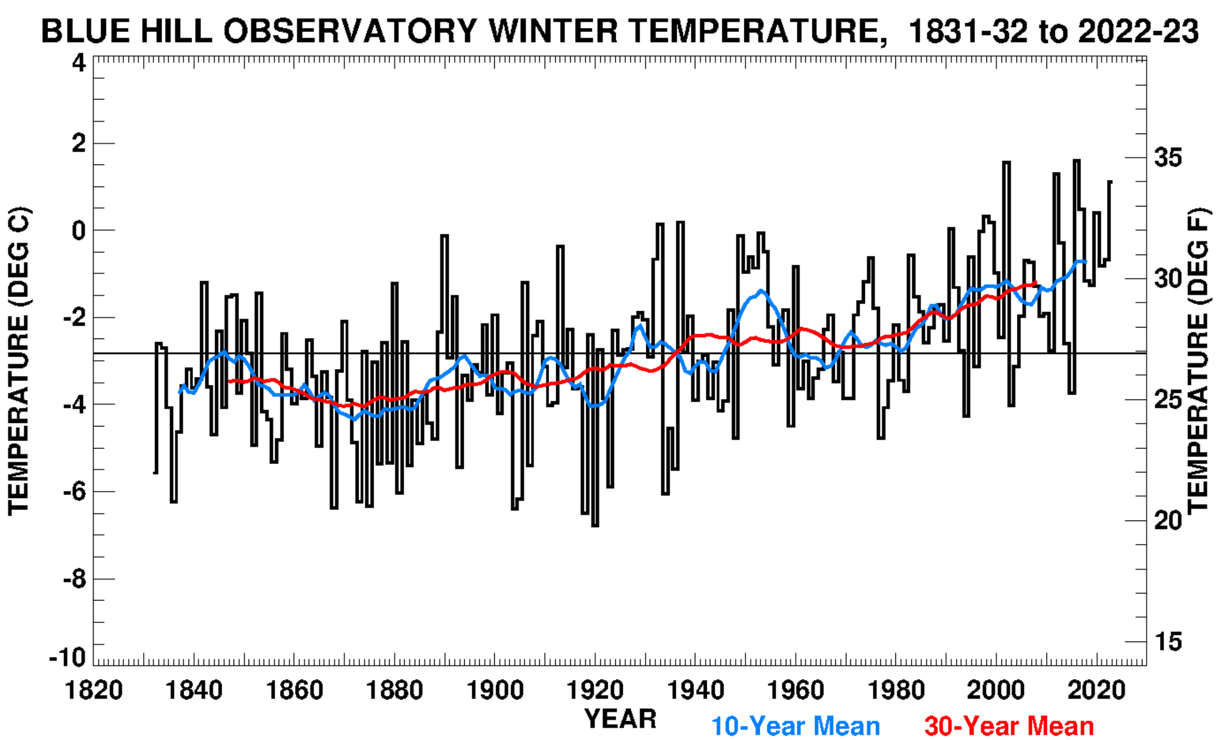

Figure 1. Seasonal mean winter (December-February) temperature for the Blue Hill Observatory and the 10-year and 30-year centered running means.

Looking first at winter temperature, Figure 1 shows the mean temperature for each winter season (black) since the middle 19th century at the Observatory. Also plotted in Figure 1 are the centered, 10-year (blue) and 30-year (red) running means. The running means are derived as the average of nine (or 29) consecutive seasons plus one-half of the winter seasons preceding and following each nine (or 29) year period. Each value is then plotted on the year at the center of the corresponding interval. Figure 1 clearly shows that winter mean temperature has large variations from season to season, though a statistically significant upward trend is apparent. The 30-year mean has climbed nearly 5 deg F since the 1870's and has currently reached its highest value during the entire period of record at BHO. The six warmest winters on record have all occurred in the last twenty-one years. However, cold winters do still occur, though since the early 1980's only five have averaged colder than the long-term winter mean with the last occurring in 2014-2015. Also apparent are large decadal-scale swings in winter mean temperature as seen most dramatically in the 10-year running mean. Overall, the winter mean temperature indicates a tendency for warmer winters than in past decades, though this change does not preclude the possibility of either harsh winters or shorter intervals of severe winter weather.

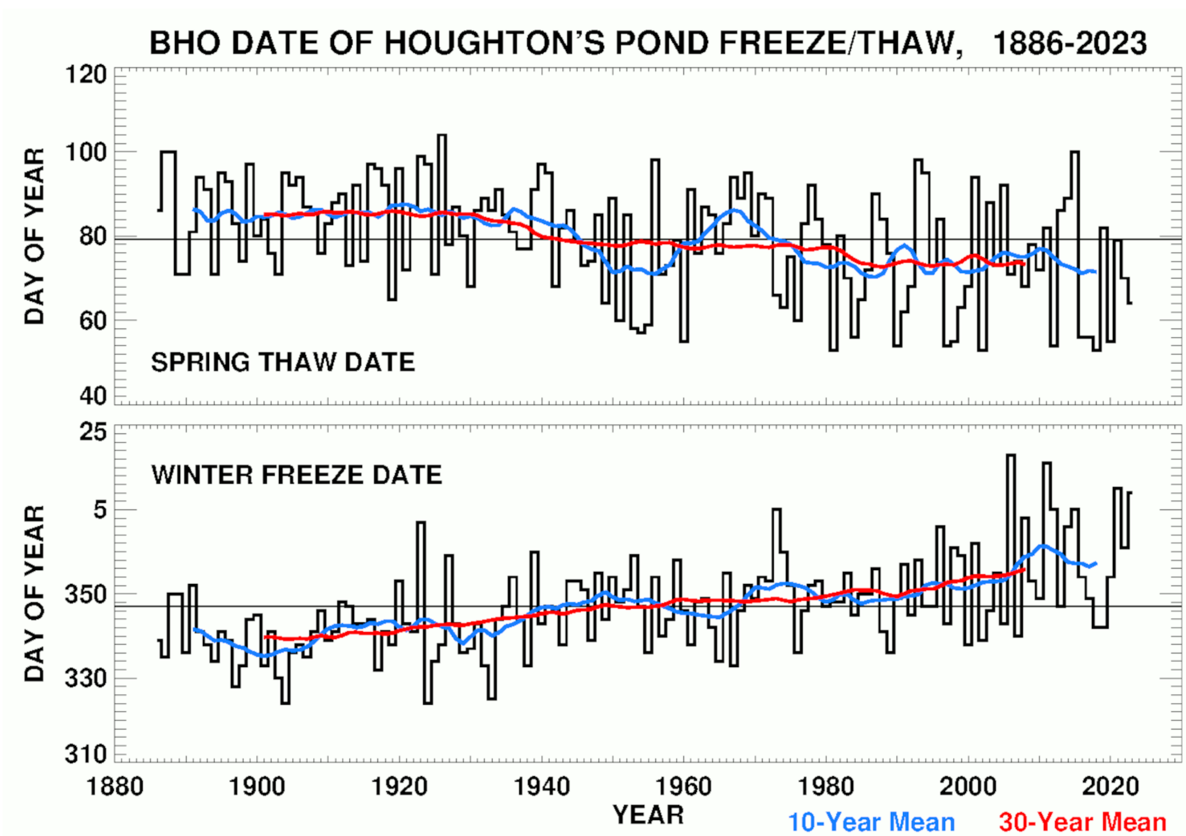

Figure 2. Winter freeze date (bottom) and spring thaw date (top) for Houghton's Pond as recorded from the Blue Hill Observatory and the 10-year and 30-year centered running means.

At the Observatory, the freeze and thaw dates of two local ponds are recorded each season, and these indicators, which reflect winter temperatures, are changing over time independently of thermometer and thermograph measurements. The pond freeze date is the first day of the winter season during which ice fully covers the pond, and the thaw date is the last day on which the ice cover drops to a trace or less with no later recurrence of ice. Figure 2 shows the freeze date (bottom panel) and the thaw date (top panel) of Houghton's Pond (about one mile east-southeast of the Observatory) since the late 19th century. The converging running means over time show that the interval during which this pond remains ice covered in winter is gradually getting shorter. Over the whole period of record the mean freeze date for Houghton's Pond is December 13th and the mean thaw date is March 21st. However, the 30-year mean freeze date has advanced from the 5th to the 20th of December since the late 19th century and the 30-year mean thaw date has shifted earlier from the 26th to the 14th of March over that time. This is a reduction in the ice cover interval of nearly four weeks during the period of record at Blue Hill. Furthermore, the character of the ice cover has been changing in recent years in the sense that once it has first frozen over the pond is now more likely to partly or fully thaw and then refreeze one or more times during the winter, which was a much less common occurrence in the past. In general, the pond ice cover data qualitatively indicate a tendency in recent decades for the coldest winter weather to occur over shorter durations that are less able to sustain the ice cover.

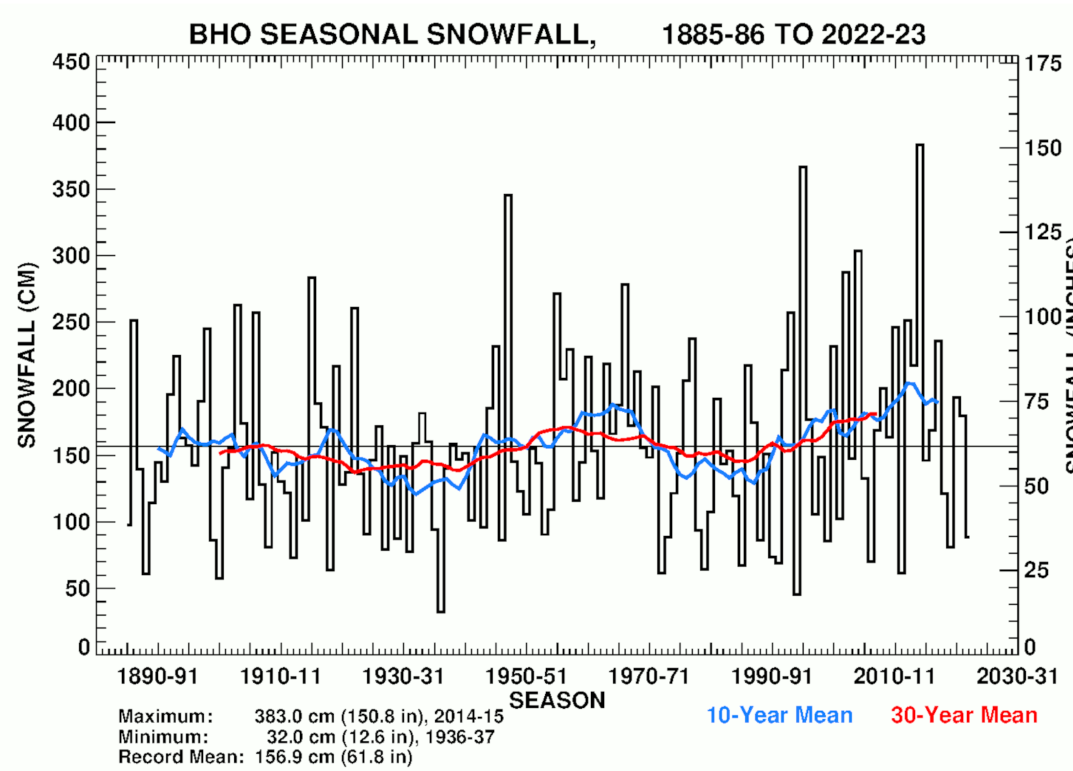

Figure 3. Seasonal snowfall as measured at the Blue Hill Observatory and the 10-year and 30-year centered running means.

Seasonal snowfall includes all frozen precipitation (snow and sleet) measured over the entire period from October through May (no measurable snowfall has ever been observed at Blue Hill during the months of June through September). Figure 3 shows the total snowfall measured at the Observatory for each winter season (black) and the centered, running means. Snowfall displays very high variability from year to year with very long-period cycles but little or no trend over the period of record. It must be noted that snowfall generally represents a relatively low sample of 10-20 events, or fewer, during a given winter season. As a result, seasonal totals are very variable and can be highly skewed by a single large storm, so it is difficult to demonstrate statistically significant trends in snowfall. For the same reason, seasonal snowfall by itself is not necessarily a good indicator of winter severity, since much of a season's snow total may occur during a few scattered days or may occur very late in the season and thus have a lower effect on the perception of overall winter severity.

As defined by *Conover* (1951), the Winter Severity Index was designed to combine the effects cold and snow to provide a consistent and improved way to quantify harsh winter weather over the decades. The winter severity index is the combined number of days of two measures during the cold season. One measure is the number of days that have a daily maximum temperature of 32 deg F or colder (MX32), and the other is the number of days that have a snow depth of six inches or more (SD6). The former is intended to reflect the frequency of days that are noticeably cold. A daily maximum of 32 deg F is close to the coldest average maximum in the depth of winter in the middle of January, so days with temperatures that remain below freezing will be noticeably cold during most of the winter season. The latter measure is intended to reflect the persistence of deep snow cover during winter, which is arguably a more stable indicator than the snowfall itself if above average snowfall and cold temperatures both occur. Figure 4 shows the WSI for each cold season as recorded at Blue Hill from the 1890's to the present. The 1894-1895 season was selected by *Conover* (1951) as the starting point for tabulation of the WSI, since that marks the beginning of reliable and consistent measurements of snow depth at BHO. The centered 10-year and 30-year running means are also plotted to show the index smoothed over two different periods. For comparison, the average winter severity index over the whole period shown in Figure 4 is 65 days. Individual winter seasons vary over a wide range around this mean from an extreme high value of 152 days during the winter of 1922-1923 to an extreme low value of 14 days during the winters of 2011-2012 and 2022-2023. Single storms generally do not cause harsh winters, but some of the most severe winters were associated with some of the largest snowstorms in the Observatory's history, including 38.7 inches on 24-28 February 1969, 30.8 inches during the Blizzard of 2015 on 26-29 January 2015, 30.1 inches during the Blizzard of '78 on 6-7 February 1978, and 24.7 inches on 17-18 February 2003.

The harshest winter seasons during the entire BHO period of record as identified by the highest WSI indices are listed in more detail in Table 1. Also listed for each season in Table 1 are the MX32 and SD6 components of the WSI, along with the total seasonal snowfall and the December-February mean temperature. It's notable that four of the top twelve most severe winters have occurred since the 1990's, and that three of those seasons were among the five snowiest on record, and although cold, none were among the ten coldest winters. This suggests that snowfall (and its contribution to persistent snow cover) was the more important factor in high WSI values in recent decades and to the perception of severe winters over that time than was the duration of extreme cold. Not surprisingly, all but one of the ten most severe winters were among either the top ten snowiest or coldest, and several severe winters (including three of the top four) reached the top ten in both categories. For comparison, Table 1 also lists the 1894-1895 to 2022-2023 averages for each of the listed winter parameters.

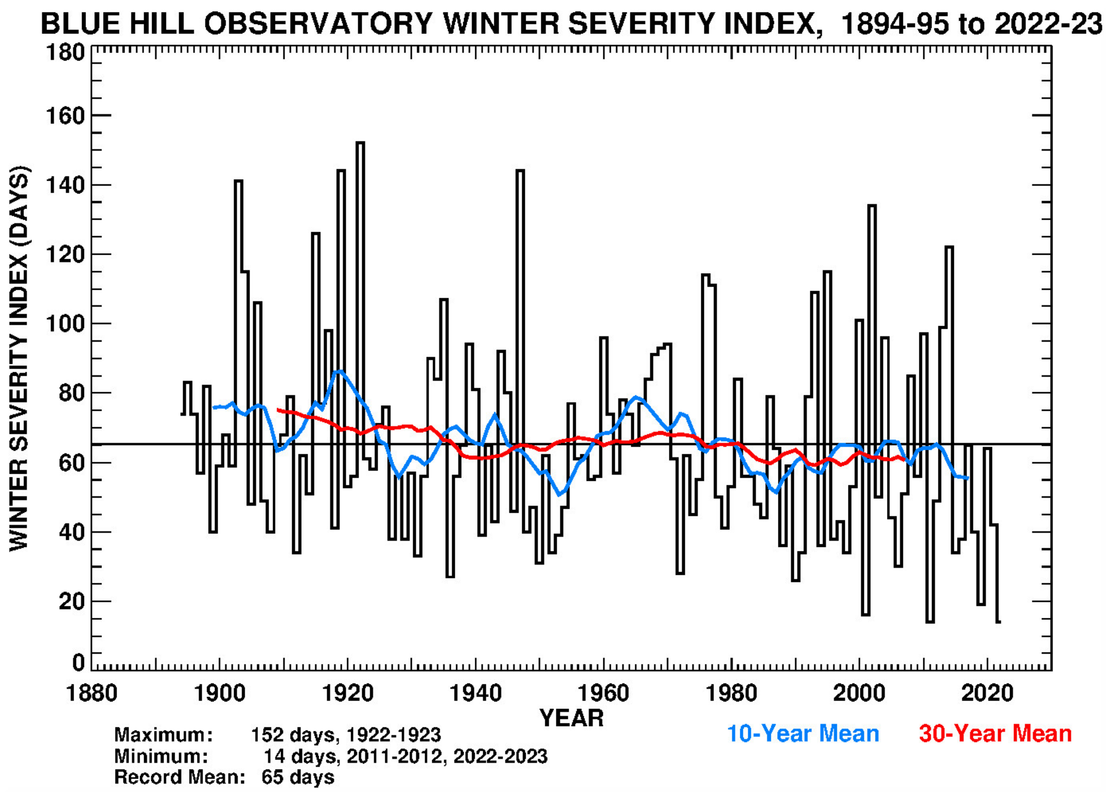

Figure 4. Seasonal Winter Severity Index (black) for the Blue Hill Observatory following *Conover* (1951) and the 10-year and 30-year centered running means.

The least severe winter seasons during the entire BHO period of record as identified by the lowest WSI values are listed in Table 2. Also listed for each season in Table 2 are the MX32 and SD6 components, along with the total seasonal snowfall and the December-February mean temperature. The least severe winters were 2011-2012 and 2022-2023 with both having a WSI of only 14. Five of the least severe winters had no days during the entire season with a snow depth

Rank	Winter Season	Winter Severity Index (WSI)	No. Days Max. Temp. ≤ 32 deg F (MX32)	No. Days Snow Depth ≥ 6 inches (SD6)	Seasonal Snowfall, inches (rank)	December - February Mean Temp., deg. F (rank)
1	1922-1923	**152**	68	**84**	102.5 (10th)	21.4 (6th)
2	1919-1920	144	**73**	71	85.3	**19.8 (1st)**
	1947-1948	144	60	**84**	136.0 (3rd)	23.4 (10th)
4	1903-1904	141	71	70	103.4 (9th)	20.5 (3rd)
5	2002-2003	134	52	82	113.1 (5th)	24.8
6	1915-1916	126	68	58	111.5 (6th)	25.4
7	2014-2015	122	56	66	**150.8 (1st)**	25.3
8	1904-1905	115	68	47	68.4	20.9 (4th)
	1995-1996	115	54	61	144.4 (2nd)	26.4
10	1976-1977	114	54	60	81.2	23.4 (10th)
11	1977-1978	111	55	56	93.5	24.7
12	1993-1994	109	53	56	101.1 (11th)	24.3
13	1935-1936	107	56	51	37.1	22.1 (7th)
14	1906-1907	106	58	48	101.1 (11th)	22.3 (8th)
15	2000-2001	101	47	54	91.4	27.6
16	2013-2014	99	52	47	85.6	27.3
17	1917-1918	98	67	31	67.4	20.3 (2nd)
18	2010-2011	97	38	59	96.8	27.0
19	1960-1961	96	48	48	88.1	25.5
	2004-2005	96	38	58	119.4 (4th)	28.4
21	1939-1940	94	65	29	57.9	25.0
	1970-1971	94	53	41	58.4	25.0
23	1969-1970	93	56	37	61.3	25.1
24	1944-1945	92	44	48	72.9	24.5
25	1968-1969	91	47	44	83.8	26.9
26	1933-1934	90	55	35	71.5	21.1 (5th)
	Average 1894-1895 to 2022-2023	65	40	25	61.9	27.7

Table 1. Highest values of the seasonal winter severity index (WSI) as recorded at the Blue Hill Observatory along with the two components of the WSI (MX32 and SD6), the snowfall and winter mean temperature for each season and the 1894-1895 to 2022-2023 mean values for each category. Bold numbers denote the highest or lowest recorded values in each category.

on the ground of six inches or more. The top five least severe winters have all occurred since the early 1990's. Every season listed in Table 2 had below average snowfall, and the top six were all among the ten warmest winters on record. Interestingly, neither the warmest winter (34.9 deg F in 2015-2016), nor the least snowy season (12.6 inches in 1936-1937) produced the lowest winter severity index, though each does appear in Table 2.

Rank	Winter Season	Winter Severity Index (WSI)	No. Days Max. Temp. ≤ 32 deg F (MX32)	No. Days Snow Depth ≥ 6 inches (SD6)	Seasonal Snowfall, Inches (rank)	December - February Mean Temp., deg F (rank)
1	2011-2012	**14**	13	1	24.2 (5th)	34.3 (3rd)
	2022-2023	**14**	14	**0**	34.9	34.0 (4th)
3	2001-2002	16	**11**	5	40.3	34.8 (2nd)
4	2019-2020	19	17	2	31.9	32.7 (6th)
5	1990-1991	26	22	4	29.0	32.1 (10th)
6	1936-1937	27	27	**0**	**12.6 (1st)**	32.3 (8th)
7	1972-1973	28	28	**0**	24.2 (5th)	29.0
8	2006-2007	30	30	**0**	27.6 (11th)	30.7
9	1950-1951	31	22	9	41.5	30.9
10	1931-1932	33	27	6	30.5	30.8
11	1912-1913	34	25	9	28.8	31.3
	1952-1953	34	21	13	56.8	31.9
	1991-1992	34	34	**0**	27.2 (10th)	29.6
	1998-1999	34	25	9	58.5	32.3 (8th)
	2015-2016	34	19	15	57.5	**34.9 (1st)**
	Average 1894-1895 to 2022-2023	65	40	25	61.9	27.7

Table 2. Lowest values of the seasonal winter severity index (WSI) as recorded at the Blue Hill Observatory along with the two components of the WSI (MX32 and SD6), the snowfall and winter mean temperature for each season and the 1894-1895 to 2022-2023 mean values for each category. Bold numbers denote the lowest recorded values in each category.

As seen in Figure 4, a gradual downward trend in WSI is apparent during the BHO period of record, suggesting that winters are becoming less severe over time. The 30-year mean WSI has decreased from about 75 days during the early 20th century to about 61 days during the early 21st century. However, the trend is not very statistically significant since the standard deviation of WSI (the typical departure for any single season from the long-term mean) of 29 days is much larger than the change in the mean over this interval. In other words, the season-to-season variability of WSI is very high, and this factor still dominates the change in the mean.

Another way of looking at the shift toward less severe winters is to examine whether this trend is equally due to changes in temperature and snowfall, or whether one component is changing more than the other. Figure 5 shows the time series of the seasonal MX32 parameter, and Figure 6 shows the time series of the seasonal SD6 parameter. Figure 5 shows that the average number of days during the cold season with maximum temperature of 32 deg F or less is 41 days and that this statistic has trended downward from 48 to 34 days over the last century.

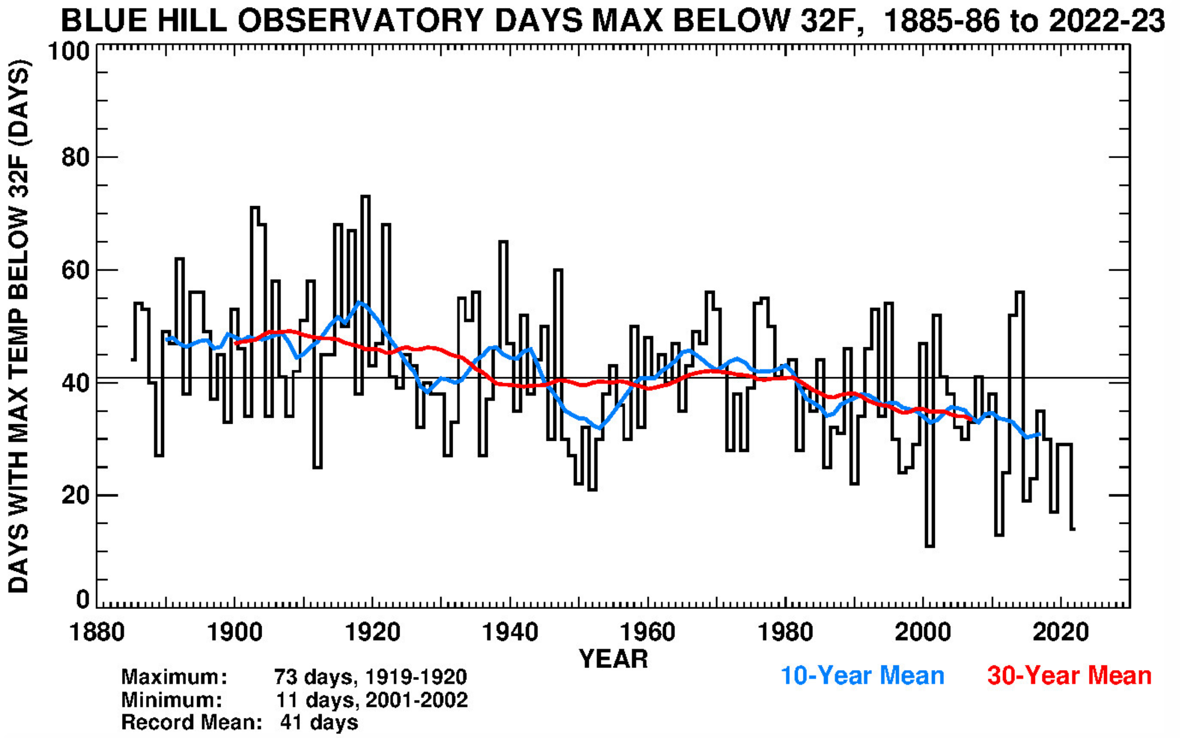

Figure 5. Seasonal number of days with maximum temperature of 32 deg F or below (black) for the Blue Hill Observatory following *Conover* (1951) and the 10-year and 30-year centered running means.

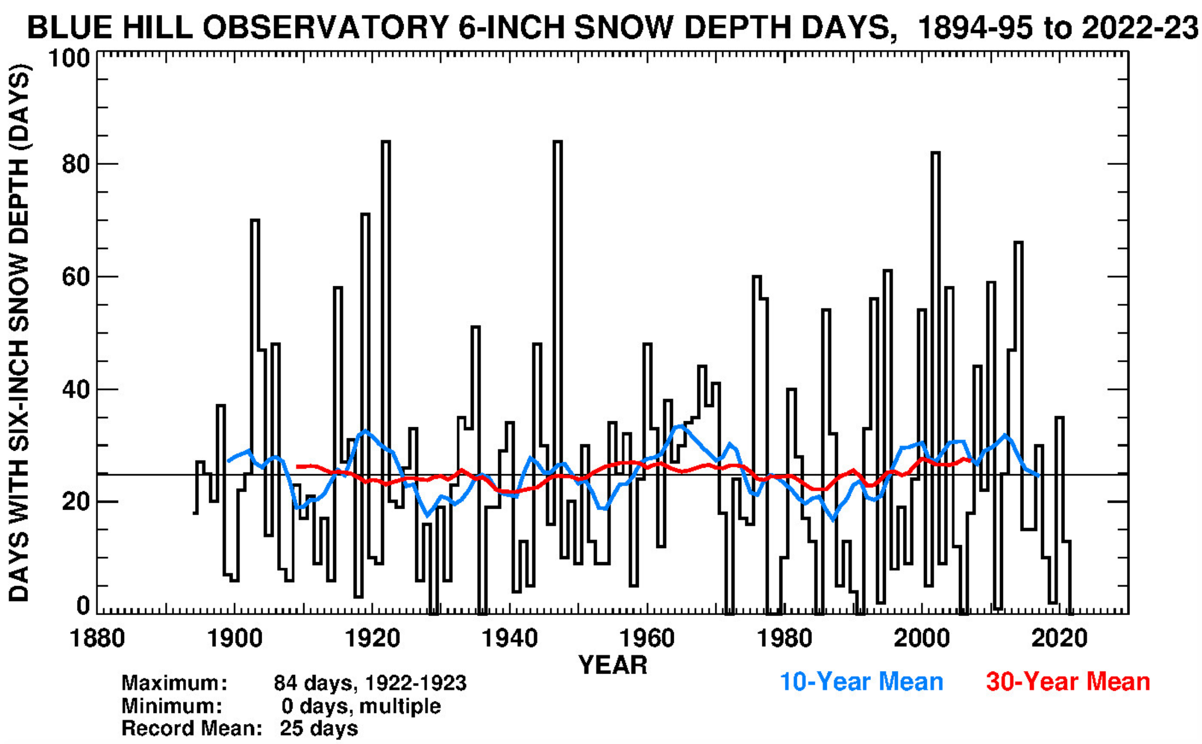

Figure 6. Seasonal number of days with snow depth of six inches or more (black) for the Blue Hill Observatory following *Conover* (1951) and the 10-year and 30-year centered running means.

This decrease is very similar in magnitude of the drop of WSI over the same time from about 75 to 61 days seen in the 30-year running mean WSI plotted in Figure 4. This strongly suggests that warming temperatures over the past century are the primary reason for the steady decrease in WSI. Reinforcing this conclusion is the number of days with six inches of snow depth during winter plotted in Figure 6, which shows very high variability from year to year but very little trend in the 30-year mean away from the long-term average of about 25 days. Another interesting aspect of these parameters is the cyclical behavior seen in the 10-year running means of temperature, snowfall, snow depth, and WSI, though the cause or causes of these decadal variations has not yet been established.

In conclusion, the Winter Severity Index of *Conover* (1951) remains an insightful metric that quantifies the perception of winter harshness by reflecting the contributions of cold temperature, snowfall, and snow cover duration. It is clear that increasing temperature is the dominant factor in the observed gradual reduction in WSI at Blue Hill, while the role of snowfall and deep snow cover duration has so far changed very little despite the current trend toward warmer winters at Blue Hill Observatory.

Acknowledgments

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References

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