State of the Climate at Blue Hill Observatory: 1885-2024

The founding objective of the Blue Hill Meteorological Observatory (BHO) in 1885 was to establish the first private observatory for the measurement of weather and climate in the United States in support of special investigations in meteorology. The continual and meticulous recording of temperature, moisture, precipitation, snowfall, wind, pressure, clouds, sunshine and many other parameters at a location that was distinctly elevated above the surrounding surface obstructions was intended over time to provide a unique perspective of the state of the lower atmosphere and the local weather. Considerable care has been taken to continue the use of traditional instrumentation and observing methods to ensure the highest degree of continuity in the measurements as possible. After more than 140 years, the BHO observations form the most consistent and most extensive climate record in North America. They are an irreplaceable resource that today supports the mission of the Blue Hill Observatory and Science Center to advance climate research and public education of atmospheric science. In recognition of the quality and long duration of the Blue Hill climate record, the World Meteorological Organization has recognized BHO as a Centennial Observing Station, one of only sixteen such sites in the United States.

The location of BHO at the 635-foot summit of Great Blue Hill within the 7000-acre Blue Hills Reservation ten miles south of Boston, Massachusetts has provided a relative degree of isolation from the local urban growth over the last century. The extent to which urban warming in the vicinity of Boston and vegetation changes on Great Blue Hill have affected the Observatory climate data has not been fully established. However, these are only two of the complex and overlapping factors on multiple scales that may influence the observations at BHO. With a great deal of certainty, the science community has attributed the recent rise in global temperature to human activity related to the burning of fossil fuels, and this "greenhouse warming" is consequently one of the contributing factors in the significant temperature increase recorded at the Observatory since the late 19th century. The purpose and relevance of the BHO climate record are to provide a reliable, accurate and invaluable historical context in which to improve our understanding of Earth's climate. This report will focus on the daily climate measurements at Blue Hill.

While long-term, annual means provide one measure of climate trends, an analysis of daily data can provide much greater detail to diagnose changes in means and variability on shorter time scales. An extensive effort has been underway at BHO for many years to prepare a complete and quality-controlled database of the daily Blue Hill climate record, and this report presents (for the first time for some parameters) an analysis of the daily observations that have reached this state of archival preservation. This database is now digitized and validated for the full period of record for daily maximum and minimum temperature, precipitation, snowfall, snow depth, and sunshine, and it is complete for part of the period of record for several other parameters including station pressure, water vapor pressure, wind speed and wind direction. The effort to continue building the daily database for additional parameters remains in progress.

Looking first at the last calendar year, 2024 tied as the third warmest year on record at Blue Hill, continuing a long upward trend in temperature since the late 19th century. Much of the year was warm: the spring season (March-May) was the tenth warmest on record, summer (June-August) 2024 was the seventh warmest, and fall (September-November) was the fifth warmest. Annual precipitation was about one inch more than the 30-year normal during 2024, and after a wet start to the year a five-month dry period from July to November brought intervals of severe to extreme drought to the area. Snowfall was about thirty inches below average for the year. The annual mean wind speed was the second lowest on record, extending a dramatic drop in wind speed in recent decades.

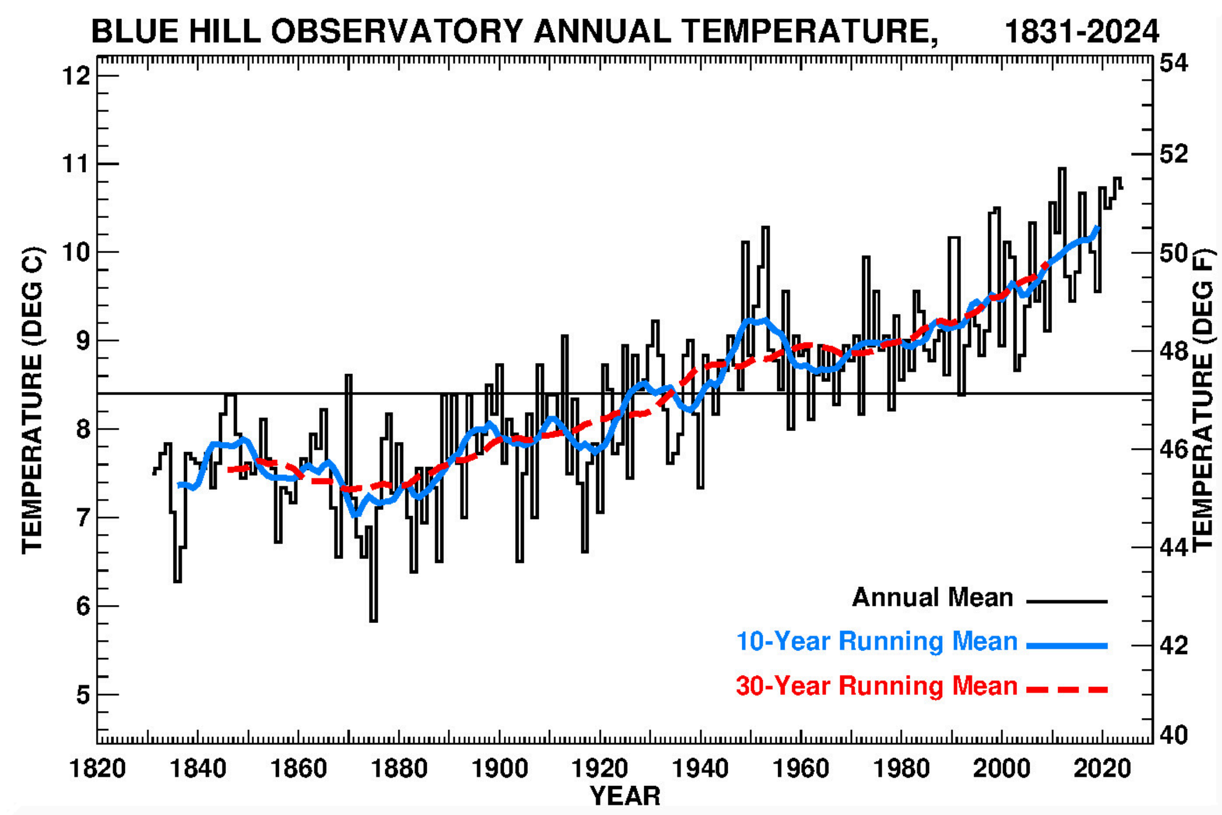

Figure 1. Blue Hill Observatory annual mean temperature (black, histogram) from measurements taken on the summit of Great Blue Hill (1885-2024) and adjusted to the summit from two nearby surrounding locations (1831-1884). Units are labeled in degrees Celsius and degrees Fahrenheit. Centered running means are also shown for 10-year (blue, solid) and 30-year (red, dashed) periods. The thin, horizontal black line is the 1831-2024 mean.

Temperature

Among the many parameters recorded at Blue Hill, multiple indicators reflect the changes that have occurred at this location over more than a century, though the trend in surface temperature is among the most prominent. The BHO annual mean temperature since the middle 19th century is shown in black in Figure 1. All data from 1 February 1885 to the present were observed on the summit of Great Blue Hill. Earlier temperatures from 1831 through January 1885 were observed from two nearby valley locations that overlapped with BHO measurements for several years in the 1880's, which allowed the valley data to be adjusted to the summit location, and these temperature data are shown for historical context. Most of the upward trend since the 19th century was observed directly on the summit. Centered running mean temperatures are also shown for 10-year (blue) and 30-year (red) periods that smooth the data to illustrate decadal scale changes.

Applying a linear fit to the annual temperature data over the period 1885 to 2024 indicates an upward trend of +0.18 °C/decade (+0.33 °F/decade) with a better than 99.9% confidence that the trend is statistically significant due to the long duration and magnitude of the trend relative to the annual variability. The warmest year on record was 2012 at 10.9 °C (51.7 °F), and nine of the ten warmest years on the entire period of record at Blue Hill have occurred in the last 25 years. The coldest year on record was 1875 at 5.8 °C (42.9 °F), and the most recent of the ten coldest years at Blue Hill was 1917.

The mean daily maximum temperature for each day of the year (hereinafter excluding leap day) is plotted as the thick, central black line in Figure 2. Also shown in Figure 2 are the standard deviation (typical variation from the mean for each date) around the daily mean (green shading) and the extreme high (red shading) and extreme low (blue shading) daily maximum temperature for each day of the year. Despite the 140-year length of the temperature data record at BHO, there is still noticeable "noise" in the daily mean in that it departs from a theoretical smoothed curve by about 1-2 °F. The daily standard deviation for maximum temperature varies from about 10 °F in winter to about 7 °F in summer. Daily maximum temperature extremes extend over a much wider range in the cold season than in the warm season from an average span of 55 °F in winter to about 40 °F in summer. The absolute extreme daily maximum temperatures are two instances of 101 °F on 10 August 1949 and 2 August 1975 and a daily high of only -3 °F on 30 December 1917.

The comparable plot of minimum temperature means, variability, and extremes for each day of the year is shown in Figure 3. The statistical "noise" in the daily mean low temperature is comparable to that seen for high temperature. The daily standard

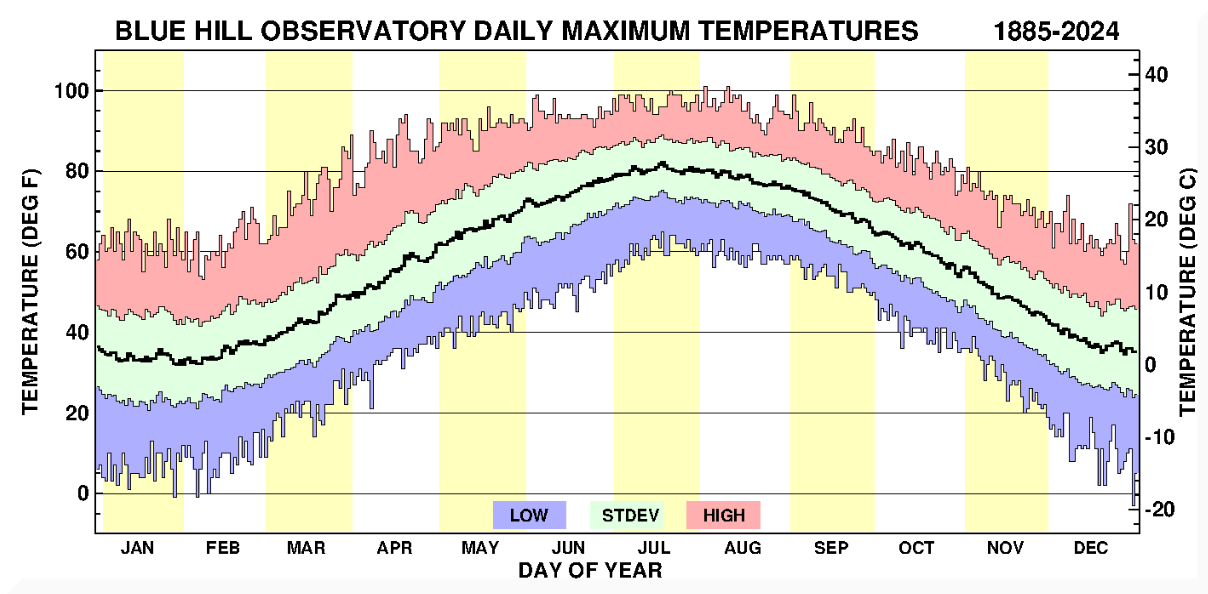

Figure 2. Blue Hill Observatory daily mean maximum temperature for 1885-2024 (thick black line), daily standard deviation (green shading), and the extreme high (red shading) and extreme low (blue shading) daily maximum temperature for each day of the year. Data exclude leap day and are in units of °F and °C.

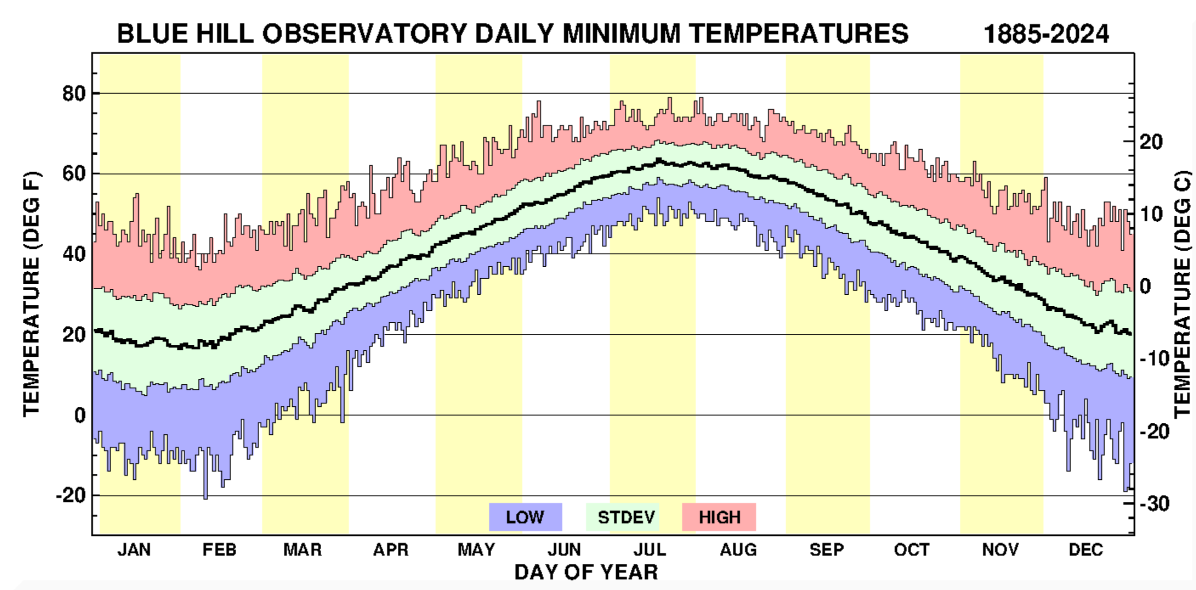

Figure 3. Blue Hill Observatory daily mean minimum temperature for 1885-2024 (thick black line), daily standard deviation (green shading), and the extreme high (red shading) and extreme low (blue shading) daily minimum temperature for each day of the year. Data exclude leap day and are in units of °F and °C.

deviation for low temperature is somewhat different than high temperature and varies from about 11 °F in winter to about 5 °F in summer. This reduced variability in summer translates to the daily minimum temperature extremes, which extend over an average span of nearly 60 °F in winter to about 25 °F in summer. The absolute extreme daily minimum temperatures are two instances of 79 °F on 22 July 1926 and 2 August 1975 and a station record daily low temperature of -21 °F on 9 February 1934.

Looking on a seven-day time scale, the warmest week of the year averaged over 1885-2024 for maximum temperature is 15-21 July with a mean of 81.1 °F, and the warmest week for minimum temperature is 17-23 July with a mean of 62.8 °F. The coldest week of the year on average for high temperature is 28 January to 3 February with a mean of 32.7 °F, and the coldest week for low temperature is 31 January to 6 February with a mean of 16.9 °F.

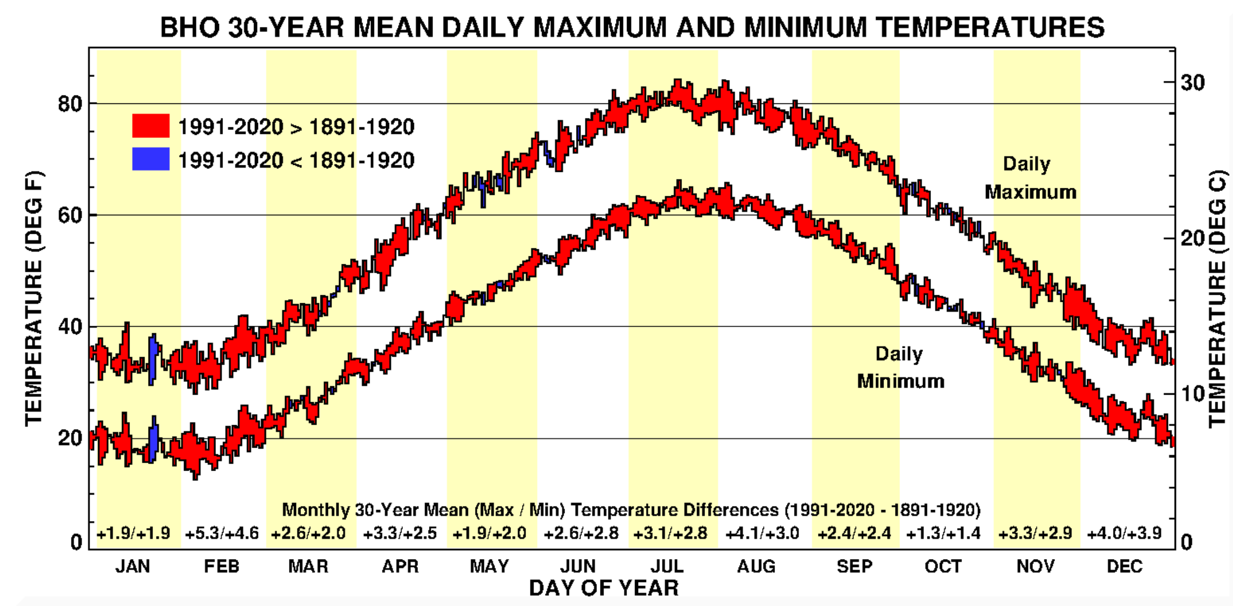

Figure 4. Blue Hill Observatory 30-year mean maximum and minimum temperature for each day of the year averaged over 1891-1920 ("past") and 1991-2020 ("current") with the difference between the two time periods ("current" – "past") shaded red when positive ("current" period is warmer) and shaded blue when negative ("current" period is colder). Listed above the x-axis are the monthly mean differences between the two time periods for both high and low temperature.

It is also of interest to examine whether the daily mean temperatures have varied in time over such a long record. In other words, does the upward trend in annual mean temperature (see Figure 1) appear consistently throughout the year, or is it apparent on some days more than others, and has this condition changed over time? Presented in Figure 4 are daily maximum and minimum temperatures averaged over two 30-year periods (1891-1920, "past" and 1991-2020, "current") near the beginning of the BHO record and for the recent past to establish whether daily mean temperatures have changed over time. For both maximum and minimum temperatures the difference ("current" minus "past") between the two time periods is shaded red if the difference is positive (the current period is warmer than the past) and is shaded blue if the difference is negative (the current period is colder than the past) for each day of the year. It can be seen that the majority of days are warmer for the "current" period than for the "past" period, though there is considerable variability in the magnitude during the year. In general, days during late January through February and late November into mid-December show the largest temperature increases, while periods during May and October show the smallest increases. A particularly anomalous period is 21-23 January, which is substantially warmer in the "past" than in the "current" 30-year mean. For maximum temperature the 21-23 January mean is 38.0 °F for the 1891-1920 period and 31.7 °F for the 1991-2020 period, which is a difference of +6.3 °F. For minimum temperature the 21-23 January mean is 22.7 °F for 1891-1920 and 16.4 °F for 1991-2020, which is also a difference of +6.3 °F. Since the dates 21-23 January are close to the time of the traditional "January thaw" phenomenon, this result appears to provide some evidence that the January thaw may have been a more prominent feature in the early 20th century than in recent decades, and that subject will be investigated in a future report.

Precipitation/Snowfall

The highly disruptive effects of flooding events and severe winter snowstorms make rainfall and snowfall among the most impactful aspects of New England weather, so it is especially important that historical changes in precipitation be carefully monitored and investigated to provide context for improving our predictive capabilities. Figure 5 shows the annual precipitation since 1886 and the 10-year and 30-year running means, which smooth the highly variable yearly amounts and illustrate the decadal and long-term changes. At Blue Hill, the total annual precipitation, which includes rainfall and the liquid equivalent of all frozen precipitation (snow and sleet), shows a slow, steady increase since the late 19th century. A linear fit to these data shows an upward trend of +0.17 cm/decade, or about +0.43 inches/decade over the period of record. In terms of annual extremes, six of the ten wettest years at BHO have occurred since 1990 including 1998, the wettest year, with 180.3 cm (71.00 inches), and nine of the ten wettest years have occurred since 1970. The driest year on record was 1965, with 65.8 cm (26.96 inches), which was part of an unusually dry four-year period from 1963-1966.

Frozen precipitation, defined for this study as hydrometeors that accumulate on the ground in frozen form during the winter, spring and fall months such as snow, ice pellets (or sleet), snow pellets, etc., is even more temporally variable than total liquid equivalent

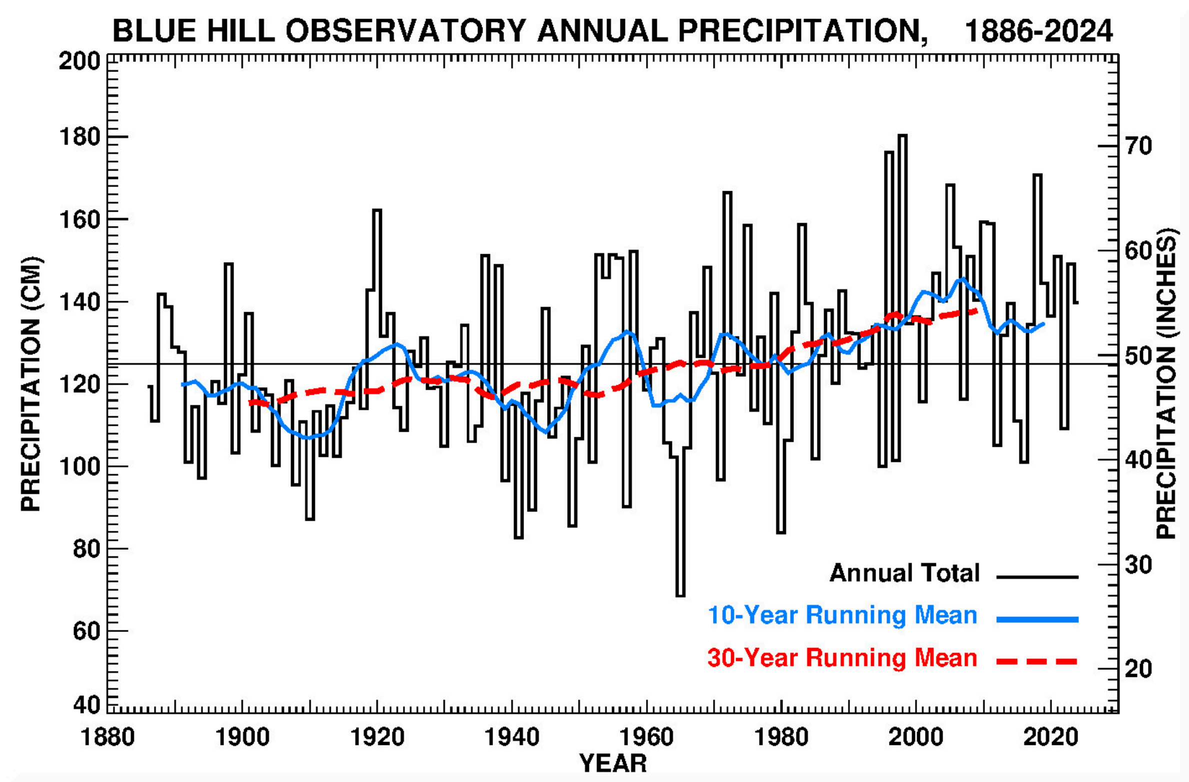

Figure 5. Blue Hill Observatory annual precipitation (black, histogram) from measurements taken on the summit of Great Blue Hill (1886-present). Units are labeled in centimeters and inches. Centered running means are also shown for 10-year (blue, solid) and 30-year (red, dashed) periods. The thin horizontal line is the 1886-2024 mean.

precipitation. Other than a single instance of a trace of sleet in early June 1907, these precipitation types have never occurred at BHO from June through September. Hail, which occurs infrequently during some convective events at Blue Hill, is frozen precipitation, but it is not counted in the snowfall totals presented here. Although freezing rain occurs more frequently than hail at Blue Hill, that is not frozen precipitation since it falls in liquid form and freezes on contact with the ground when the surface is sufficiently cold. The time series of total snowfall for the season from October through May is shown in Figure 6. A linear fit to these data shows a modest upward trend of +2.4 cm/decade, or just under one inch per decade over the period of record. The 10-year running mean (blue curve in Figure 6) shows that decadal variations in total snowfall follow a roughly 50-year cycle since the early 20th century. From 1885-86 to 1990-91, twelve seasons exceeded 228 cm (90 inches) of snowfall; since 1990-91, nine seasons have exceeded this amount, including 2014-2015, the snowiest season on record, with 383.0 cm (150.8 inches) and 1995-1996, the previous record season, with 366.8 cm (144.4 inches). Seven of the ten largest snowstorms at BHO have occurred since 1997, and all ten have occurred since 1960.

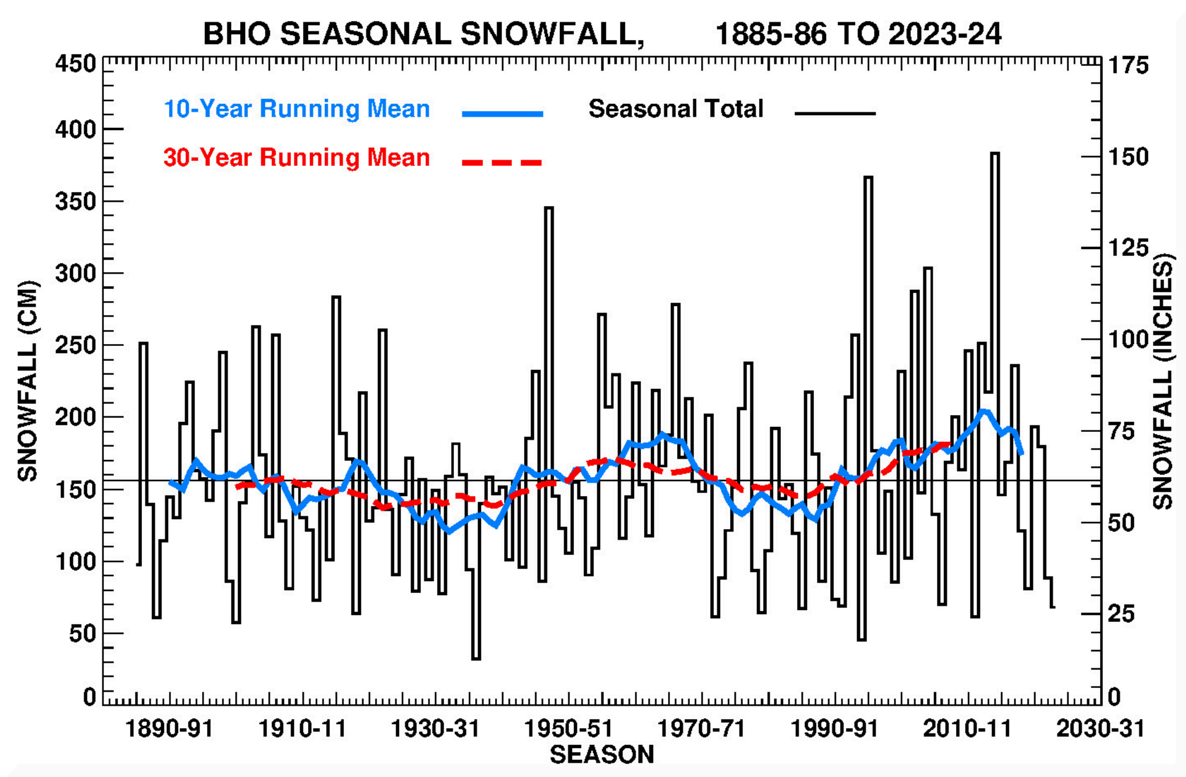

Figure 6. Blue Hill Observatory total October to May seasonal snowfall (black, histogram) from measurements taken on the summit of Great Blue Hill (1885-present). Units are labeled in centimeters and inches. Centered running means are also shown for 10-year (blue, solid) and 30-year (red, dashed) periods. The thin horizonal line is the 1886-2024 mean.

Mean precipitation at Blue Hill for each day of the year averaged over 1886 to 2024 has only a very subtle annual cycle, shown as the dark black line in Figure 7, with a peak in early spring near 0.17 inches per day and a low in middle summer near 0.13 inches per day. The upper panel of Figure 7 highlights the extreme daily maximum rainfall (red shading), while the lower panel emphasizes the much lower daily averages. Both the daily standard deviation (green shading) and the daily extremes show the very high variability of precipitation. The typical departure from the daily mean is about one-half of an inch throughout the year, though for some days the standard deviation is around 0.90 inches. Most of the daily extremes exceed two inches and about twenty days throughout the year have extreme daily precipitation exceeding four inches. The wettest calendar day on record was 8.07 inches on 19 August 1955, which was part of a storm total of 12.77 inches on 18-20 August 1955 caused by Tropical Storm Diane (the greatest flooding event in southern New England during the 20th century). Other notable wet calendar days include 7.10 inches on 20 October 1996 and 6.07 inches on 13 June 1998. Looking on a seven-day time scale, the wettest week of the year on average is 28 March to 3 April with a mean of 0.20 inches per day (about 1.41 inches for the week), and the driest week of the year on average is 14-20 July with a mean of 0.12 inches per day (about 0.81 inches for the week).

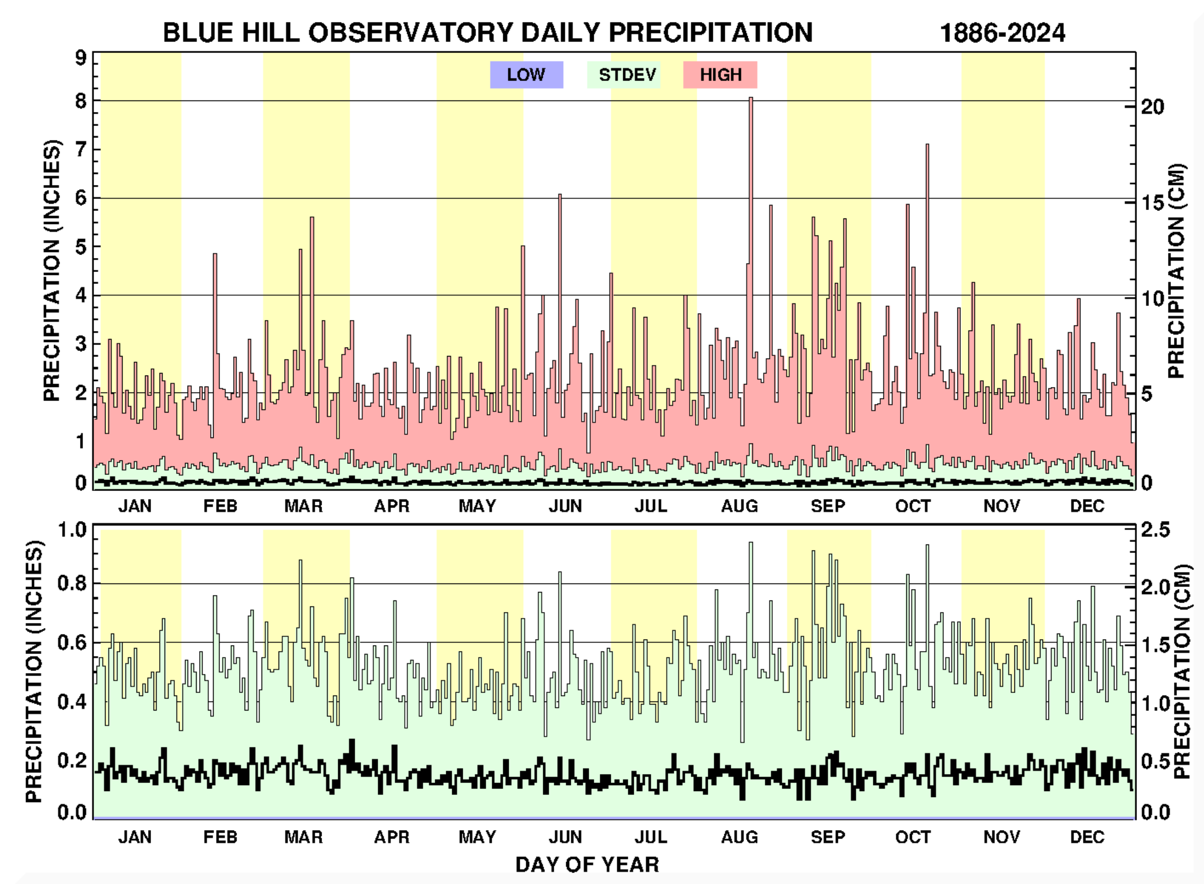

Figure 7. Blue Hill Observatory daily mean precipitation for 1886-2024 (thick black line), daily standard deviation (green shading), and the extreme high daily precipitation (red shading) for each day of the year. The extreme low precipitation for all dates is zero. Two vertical scales are used to highlight daily high extremes (upper panel) and daily means and standard deviations (lower panel). Data exclude leap day and are plotted in units of inches and cm.

Mean snowfall at Blue Hill for each day of the year averaged over 1891 to 2024 is shown as the dark black line in Figure 8. The upper panel of Figure 8 highlights the extreme maximum snowfall on each day (red shading), while the lower panel emphasizes the much lower daily averages. Both the daily standard deviation (green shading) and the daily extremes show the very high variability of snowfall during the cold season. The typical departure from the daily mean is about two to three inches, though for some days the standard deviation is near four inches. Most of the daily snowfall extremes exceed ten inches while six days have extreme daily snowfall of 20 inches or more. The snowiest calendar day on record was 27.4 inches on 24 February 1969, which was part of the largest single-storm snow total on record at Blue Hill of 38.7 inches on 24-28 February 1969. Other notable snowy calendar days include 27.1 inches on 29 January 2022, which was most of the storm total of 27.6 inches on 28-29 January 2022, and 25.2 inches on 27

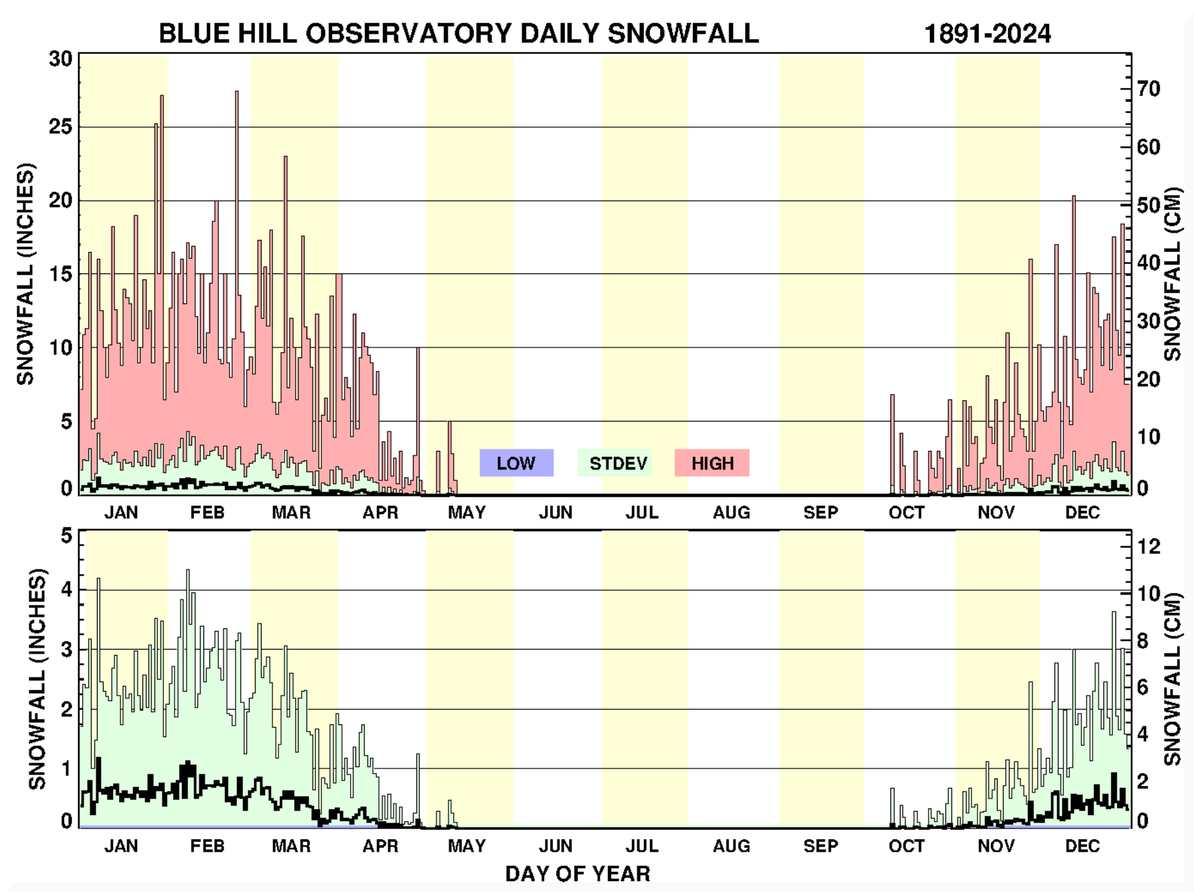

Figure 8. Blue Hill Observatory daily mean snowfall for 1891-2024 (thick black line), daily standard deviation (green shading), and the extreme high daily precipitation (red shading) for each day of the year. The extreme low precipitation for all dates is zero. Two vertical scales are used to highlight daily high extremes (upper panel) and daily means and standard deviations (lower panel). Data exclude leap day and are plotted in units of inches and cm.

January 2015, which was most of the second largest snowstorm on record at Blue Hill of 30.8 inches on 26-28 January 2015. Looking on a seven-day time scale, the snowiest week of the year on average is 4-10 February with a mean of 0.84 inches per day, or about 5.9 inches for the week.

Water Vapor Pressure

From dry and wet bulb temperature measurements taken several times per day, both the dew point temperature and relative humidity, which reflect the moisture content of the atmosphere, are derived. Using a table based on a complex formula, the dew point temperature is converted to the water vapor pressure, which is a more absolute measure of the amount of moisture in the air, and it represents the contribution of water vapor to the total surface pressure. As an annual average, the pressure caused by water vapor is about one percent (10 mb) of the total surface pressure (1013 mb), though it ranges from a small fractional value on dry winter days to nearly three percent of the total surface pressure on very humid summer days. The annual mean water vapor pressure measured at BHO for 1891-1912 and 1932-2024 is shown in Figure 9. Data for 1913-1931 are under review to ensure consistency. Records of this parameter show a notable increase from about 9.7 mb to 10.6 mb since the 1950's, which is especially apparent in the last 30 years. As the air temperature warms (see Figure 1), evaporation from local water sources is expected to increase, which raises the amount of water vapor in the air, and the observed water vapor increase in recent decades is consistent with the observed temperature increase.

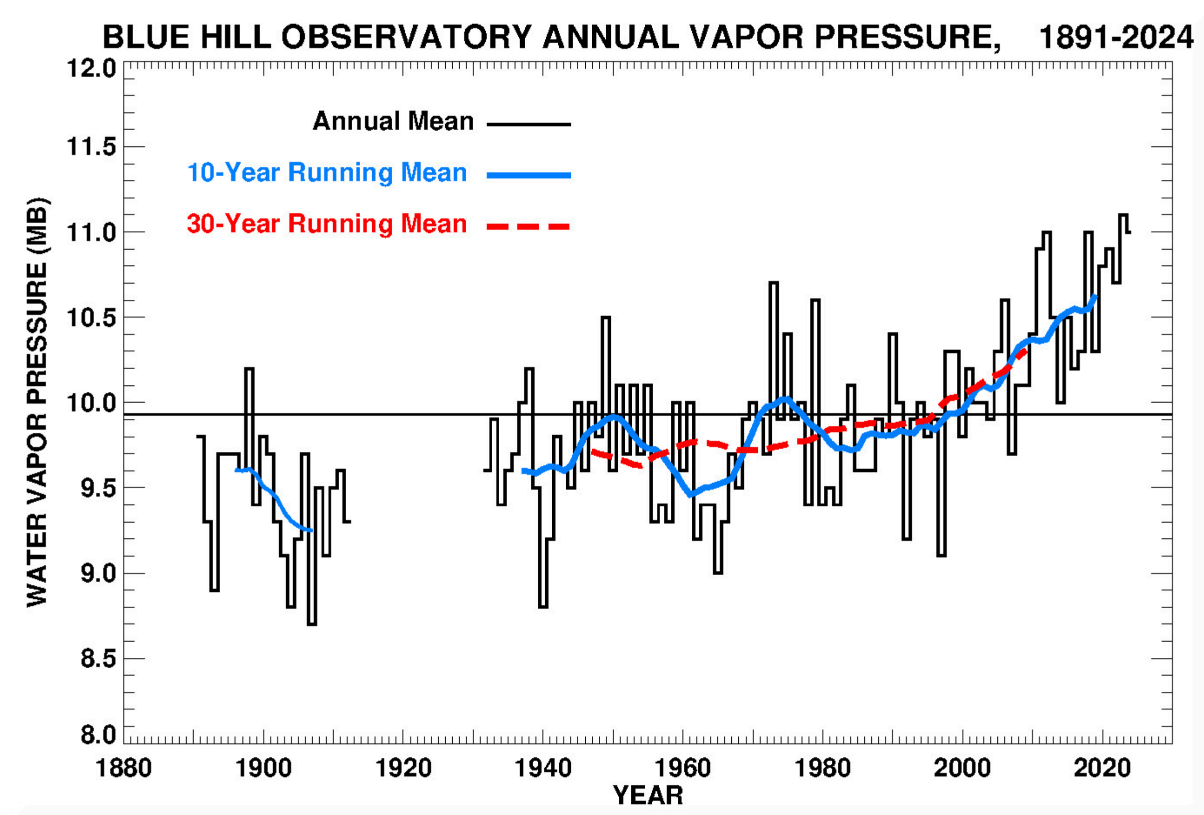

Figure 9. Blue Hill Observatory annual mean water vapor pressure (black, histogram) from measurements taken on the summit of Great Blue Hill (1891-1912 and 1932-2024). Units are labeled in mb. Centered running means are also shown for 10-year (blue, solid) and 30-year (red, dashed) periods. The thin horizontal line is the 1932-2024 mean.

Mean water vapor pressure at Blue Hill for each day of the year averaged over 1965 to 2024 (the years that have been digitized for this parameter to date) has an annual cycle that tracks the temperature as shown as the dark black line in Figure 10, which also shows the dew point temperature equivalent for the plotted range of vapor pressures. Daily mean values range from about 3 mb (dew point near 17 °F) in winter to about 21 mb (65 °F) in summer. The daily standard deviation varies from about 2 mb in winter to about 4 mb in summer, though due to the non-linear conversion from vapor pressure to dew point, the

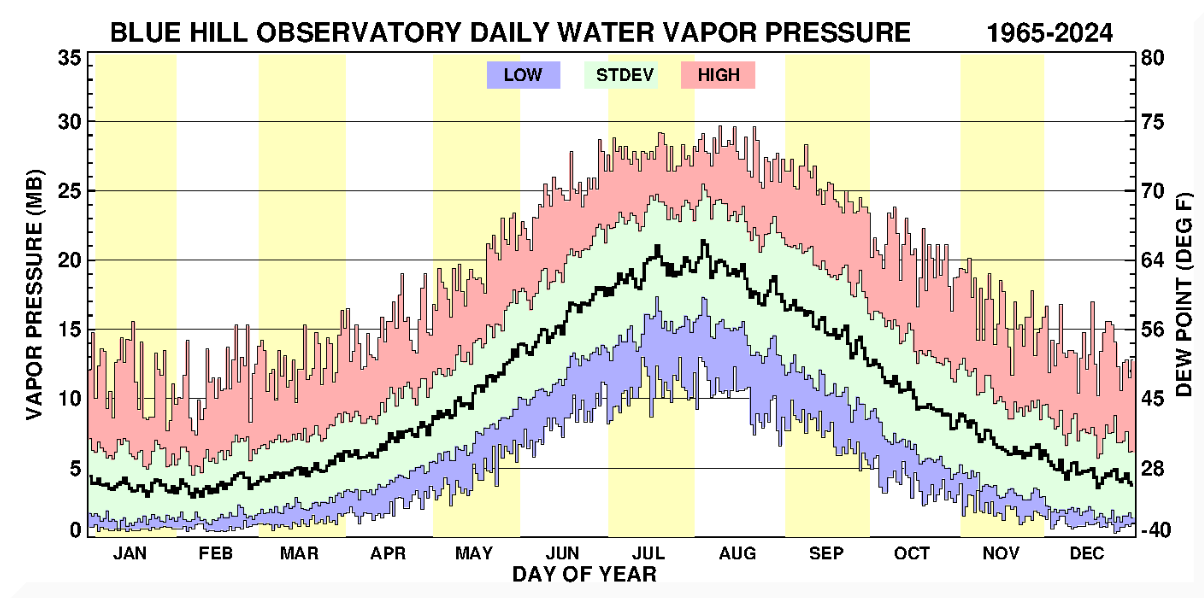

Figure 10. Blue Hill Observatory daily mean water vapor pressure for 1965-2024 (thick black line), daily standard deviation (green shading), and the extreme high (red shading) and low (blue shading) mean water vapor pressure for each day of the year. Data exclude leap day and are plotted in units of mb and the dew point equivalent (°F).

lower standard deviation in winter represents a larger variation of dew point (at lower vapor pressure values) than the higher standard deviation in summer. Daily mean extreme water vapor pressure varies from a high of 29.7 mb (75 °F) to a low of 0.3 mb (-26 °F).

Surface Pressure

The barometric surface pressure at the elevation of the Observatory (also called the "station pressure" here) is among the most consistent of BHO measurements, since it has been observed with the same mercury barometer since January 1, 1888. Furthermore, this instrument, which is generally read once per day at 7 AM EST, has a precision of 0.1 mb (0.003 inches), and it is used to apply corrections to the continuous trace recording of station pressure from a modern barograph that is utilized at BHO to derive the station pressure at 7 PM EST. Station pressure is also converted to sea-level pressure, though the former values are reported here. The daily mean station pressure is the average of the readings at 7 AM and 7 PM.

The annual mean station pressure at BHO since 1885 is shown in Figure 11; data for the years 1913 to 1931 are under review to ensure consistency. The long-term mean station pressure for the continuous years from 1932 to 2024 is 991.9 mb (29.29 inches). Although there is no significant trend in station pressure since the late 19th century, recent decadal variability shows a slow increase since the 1960's. Going against this trend, the lowest value for any year of 988.8 mb (29.20 inches) occurred in 2010.

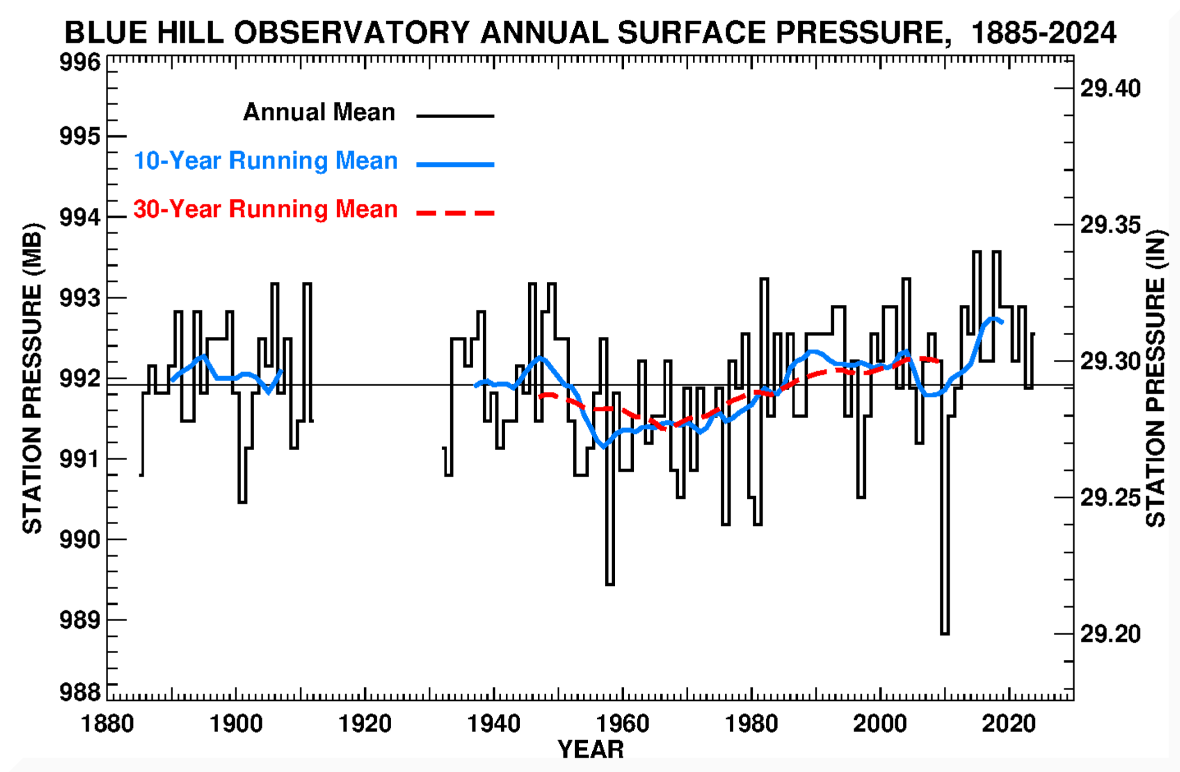

Figure 11. Blue Hill Observatory annual mean station pressure (black, histogram) from measurements taken on the summit of Great Blue Hill (1885-2024). Units are labeled in mb and inches. Centered running means are also shown for 10-year (blue, solid) and 30-year (red, dashed) periods. The thin horizontal line is the 1932-2024 mean.

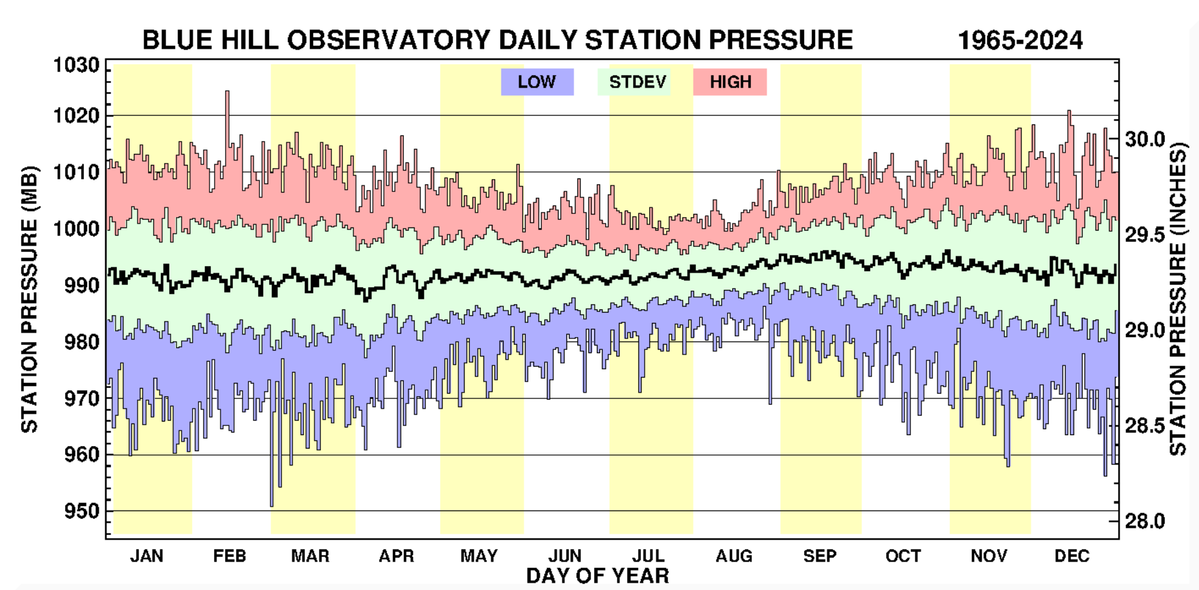

Figure 12. Blue Hill Observatory daily mean station pressure for 1965-2024 (thick black line), daily standard deviation (green shading), and the extreme high (red shading) and low (blue shading) mean station pressure for each day of the year. Data exclude leap day and are plotted in units of mb and inches.

The mean station pressure for each day of the year averaged over 1965 to 2024 (the years that have been digitized for this parameter to date), which is shown as the dark black line in Figure 12, varies slightly through the year with the highest mean surface pressures occurring in early fall, while the lowest mean pressures occur in spring. For this period of years, the overall mean is near 992.1 mb (29.30 inches). The daily standard deviation varies from about 10 mb from late fall to early spring to about 4 mb in late summer. The extremes of daily mean station pressure vary over a wide range (more than 50 mb) during winter and shrink to a much narrower range (about 20 mb) during August. On a seven-day time scale, the week with the lowest average daily station pressure during the year is 1-7 April at 988.7 mb (29.20 inches) and the week with the highest average daily station pressure is 15-21 September at 995.5 mb (29.40 inches).

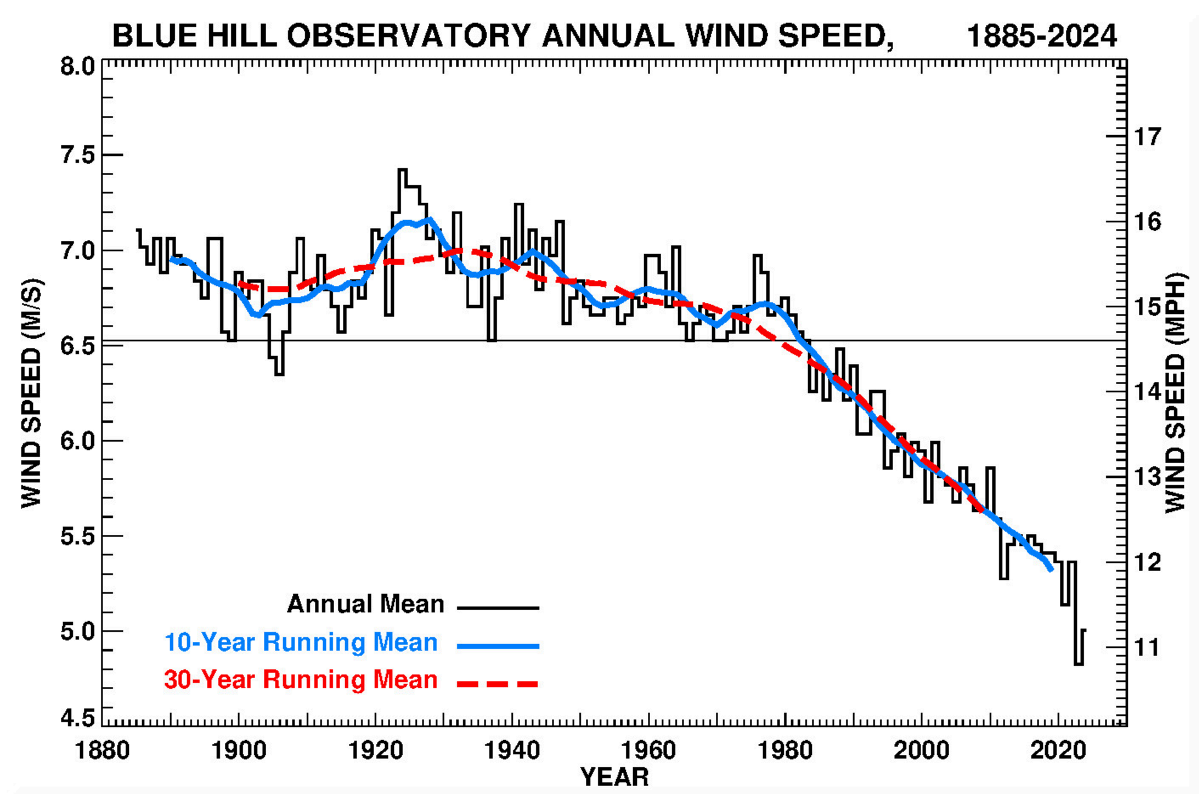

Figure 13. Blue Hill Observatory annual mean wind speed (black, histogram) from measurements taken on the summit of Great Blue Hill (1885-2024). Units are labeled in meters/second and miles/hour. Centered running means are also shown for 10-year (blue, solid) and 30-year (red, dashed) periods. The thin horizontal line is the 1885-2024 mean.

Wind Speed

One of the most dramatic changes in any climate parameter measured at Blue Hill is the steady drop in the annual mean wind speed in recent decades as shown in Figure 13 for 1885-2024. A slow decline in the 10-year average annual wind speed (blue) that began in the 1940's became a sharper, steady drop after 1980, falling nearly 20 percent from 6.7 m/s (15.0 mph) in that year to 5.3 m/s (11.9 mph) recently, and a new record low annual wind speed of 4.8 m/s (10.8 mph) was set in 2023. The cause of the decline remains under investigation, though it may be related to the shifting of mid-latitude storm tracks and their higher winds to higher latitudes, or to the poleward expansion of the lower wind speeds associated with the tropics. This so-called global stilling is consistent with wind speed changes at other locations across North America and Europe in recent decades, though is nowhere seen more dramatically than in the Blue Hill annual wind speed record.

Mean wind speed at Blue Hill for each day of the year averaged over 1950 to 2024 (the years that have been digitized for this parameter to date) varies through the year as shown as the dark black line in Figure 14. Daily mean values range from about 7.5 m/s (16.8 mph) in the winter months to about 4.7 m/s (10.5 mph) in summer. The daily standard deviation of wind speed varies through the year from a high of about 3 m/s (6.7 mph) in winter to a low of about 1 m/s (2.2 mph) in summer. The low extremes of daily mean wind speed show almost no annual cycle near 3 m/s (6.7 mph), while the high extremes of daily wind speed show a very strong annual cycle varying from a few values exceeding 18 m/s (about 40 mph) in winter to about 8 m/s (about 18 mph) in summer.

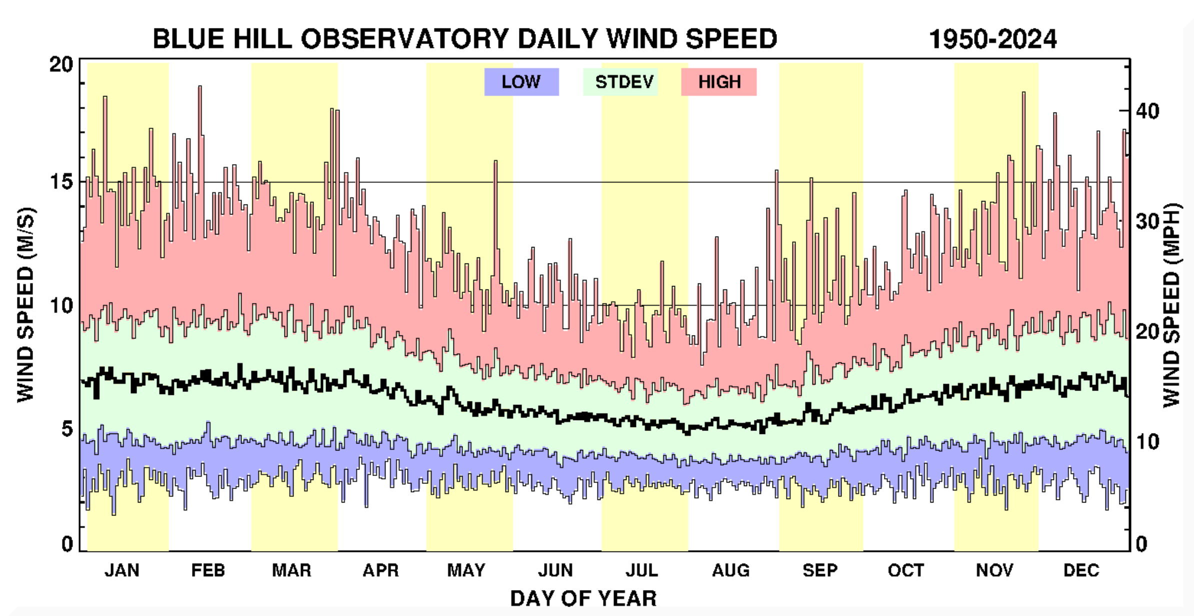

Figure 14. Blue Hill Observatory daily mean wind speed for 1950-2024 (thick black line), daily standard deviation (green shading), and the extreme high (red shading) and low (blue shading) mean wind speed for each day of the year. Data exclude leap day and are plotted in units of m/s and mph.

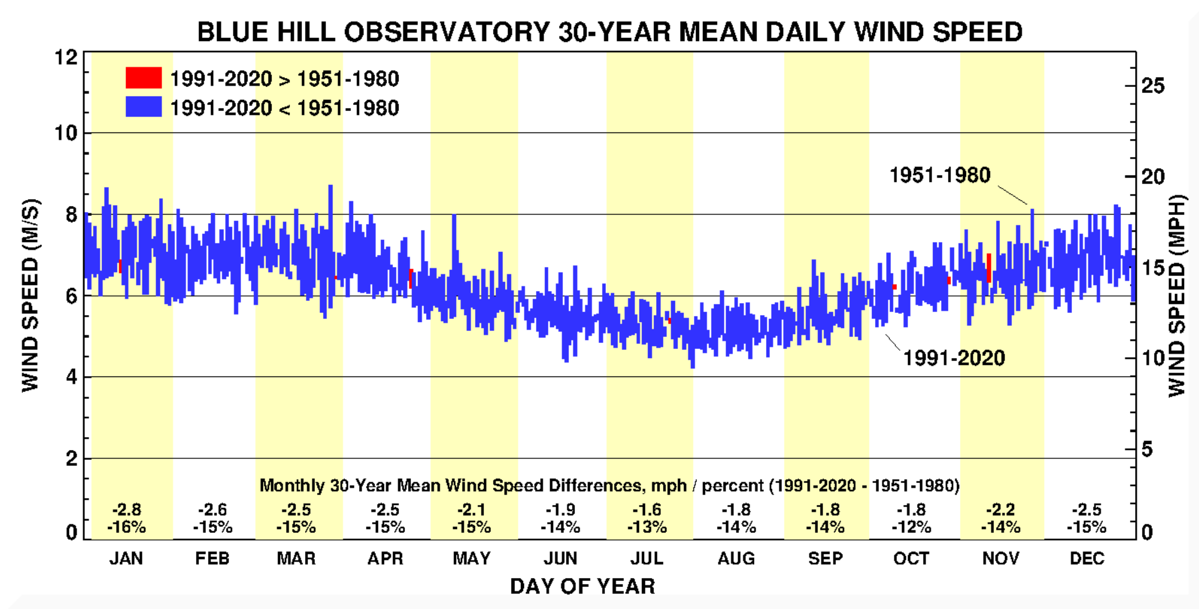

Figure 15. Blue Hill Observatory 30-year mean wind speed for each day of the year averaged over 1951-1980 ("past") and 1991-2020 ("current") with the difference between the two time periods ("current" – "past") shaded red when positive ("current" period has higher winds) and shaded blue when negative ("current" period has lower winds). Listed above the x-axis are the monthly mean wind speed differences between the two 30-year periods in mph and as a percent change relative to the "past" period.

The strong downward trend in annual mean wind speed since 1980 in Figure 13 raises the question of whether this significant change is consistent throughout the year. Figure 15 shows the daily mean wind speed averaged over two 30-year periods (1951-1980, "past" and 1991-2020, "current") for the period just before the strong downward trend began and for the recent past to establish how daily wind speeds have changed throughout the year over time. The wind speed difference ("current" minus "past") between the two 30-year periods is shaded red if the difference is positive (the current period has higher wind speed than the past) and is shaded blue if the difference is negative (the current period has lower wind speeds) for each day of the year. Nearly all days in the "current" period have lower wind speed than in the "past" period, though there is considerable variability in the magnitude during the year. Also shown in Figure 15 are the monthly average differences between the two 30-year periods, which are all negative in both absolute terms and as a percent change from the "past" period. These data show that for this range of years, the downward trend in wind speed is slightly larger during the cold season than during the warm season with the largest decrease occurring in January and the smallest decrease occurring in July, both as a percent change and as an absolute change in daily wind speed.

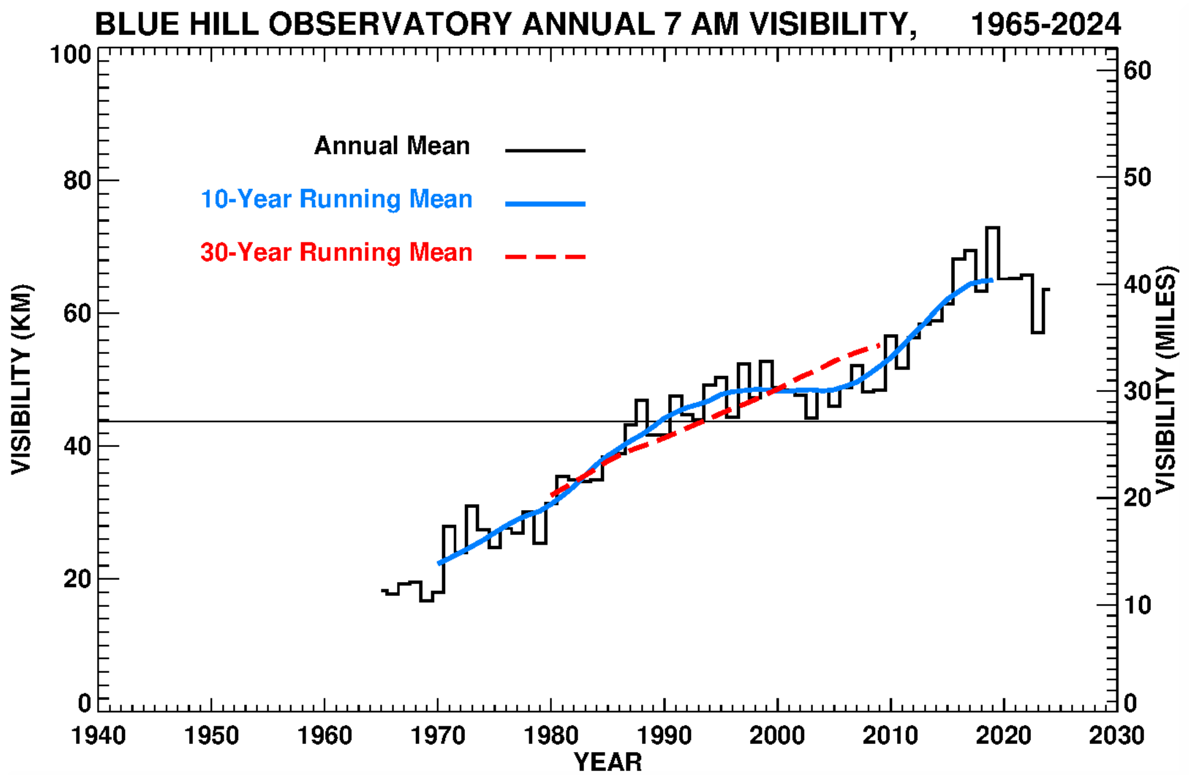

Figure 16. Blue Hill Observatory annual mean 7 AM prevailing visibility (black, histogram) from measurements taken on the summit of Great Blue Hill (1965-2024). Units are labeled in km and miles. Centered running means are also shown for 10-year (blue, solid) and 30-year (red, dashed) periods. The thin horizontal line is the 1965-2024 mean.

Visibility

One of the parameters that is visually observed and recorded several times per day at BHO is the prevailing visibility around the entire horizon. Numerous fixed markers are used to estimate the visibility over a wide range from 0 to 90 miles, which are the lowest and highest reportable values. Natural markers include Nobscot Hill (20 miles, WNW), Wachusett Mountain (44 miles, WNW), and Grand Monadnock in southern New Hampshire (68 miles, NW). The visibility is in part estimated from the visual clarity of these and other markers. Visibility can be obscured by fog and clouds during storms, by water vapor on humid summer days, and by particulate matter (aerosols) that can be either diffuse or more densely trapped below temperature inversions. The gradual return of cleaner, less polluted air to the region over the last 40-50 years has had a remarkable effect on the annual mean visibility as shown in Figure 16 (for data observed at 7 AM EST) over the years 1965-2024 (the span of years that have been digitized for this parameter to date). Over this period the annual average 7 AM visibility has steadily increased from about 18 km (11 miles) to about 65 km (40 miles), reaching a peak of 74 km (45 miles) in 2019.

The variation of daily mean visibility throughout the year is unlike any other parameter in that it peaks at two different times of year as shown in Figure 17. The highest mean visibilities are observed during mid-spring and again in late fall, with the lowest visibilities on average occurring in mid-winter and mid-summer. One possible explanation for the double peak relates to the factors that influence visibility. In winter, drier air tends to allow higher visibility, while storm clouds and fog and temperature inversions that trap aerosols counter that tendency and produce lower values. In summer, there are fewer storms, but much higher water vapor content increases both haze and early morning fog. By contrast, in the spring and fall, water vapor amounts are lower at a time when there are also fewer storms, which allows more frequent occurrences of higher visibility. The daily standard deviation is relatively constant all year at about 20 miles. On the seven-day time scale, the week with the highest visibility on average is 9-15 April with a mean of 33.6 miles, and the week with the lowest visibility is 17-23 July with a mean of 20.9 miles.

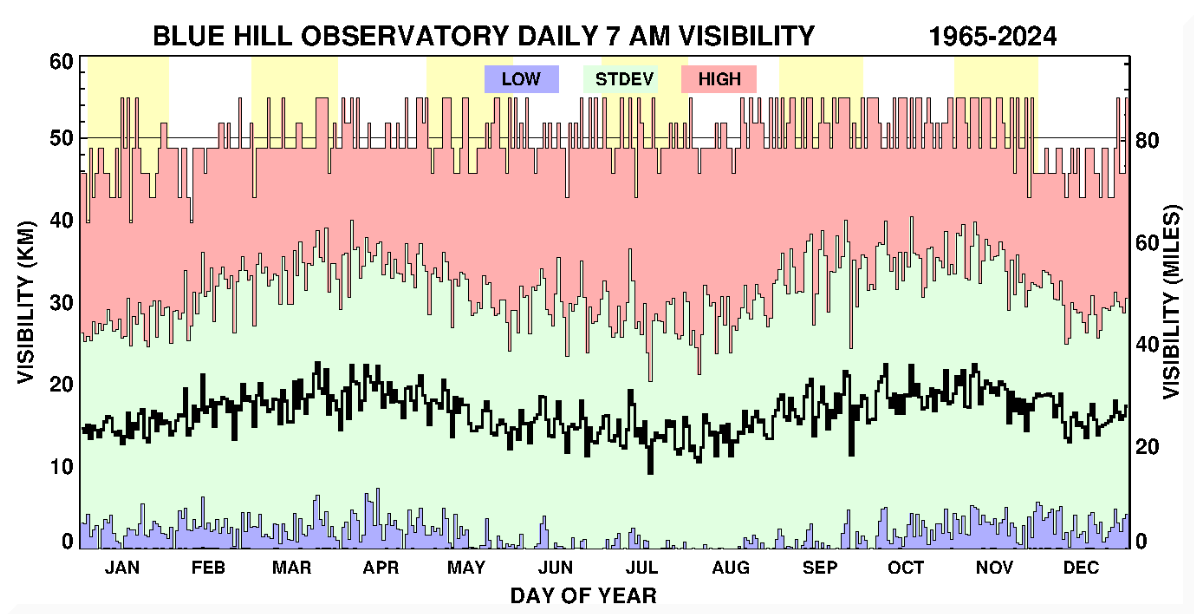

Figure 17. Blue Hill Observatory daily 7 AM EST visibility for 1965-2024 (thick black line), daily standard deviation (green shading), and the extreme high (red shading) and low (blue shading) visibility for each day of the year. Data exclude leap day and are plotted in units of km and miles.

Bright Sunshine

Among the most consistent parameters observed at Blue Hill is the daily duration of bright sunshine, which has been measured with three very similar Campbell-Stokes sunshine recorders that were used consecutively from 1886-1897, 1898-1993, and 1993 to present. This instrument consists of a solid glass sphere that focusses direct sunlight onto a replaceable, treated paper card held in a metal frame below the glass. As the sun moves across the sky each day, the focused sunlight scorches or burns through the card leaving a

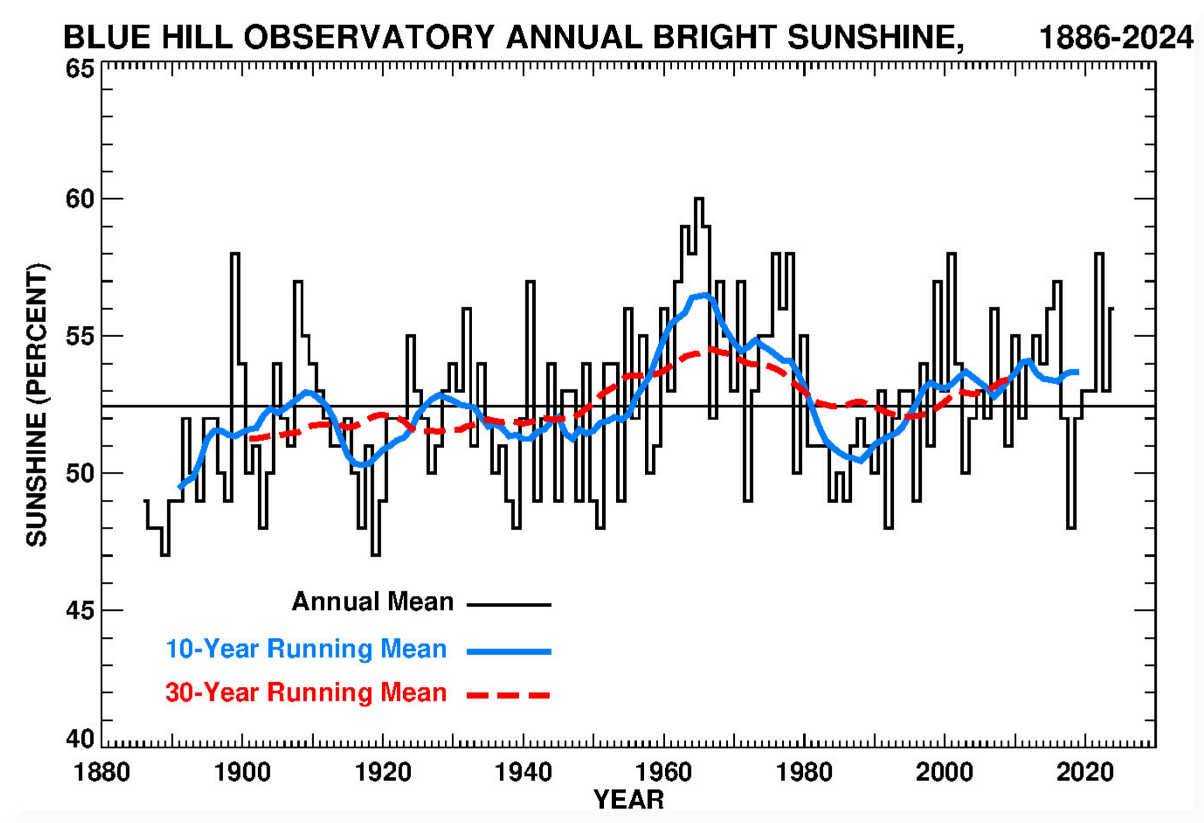

Figure 18. Blue Hill Observatory annual mean bright sunshine (black, histogram) expressed as a percent of possible sunshine from measurements taken on the summit of Great Blue Hill (1886-2024). Units are labeled in percent. Centered running means are also shown for 10-year (blue, solid) and 30-year (red, dashed) periods. The thin horizontal line is the 1886-2024 mean.

permanent record of sunshine duration for times when the direct solar beam is sufficiently intense (or "bright") to surpass the burn threshold of the card. The cumulative length of the burn marks is converted to minutes of bright sunshine and to a percent of possible sunshine for each day. Figure 18 shows the annual bright sunshine and the smoothed running means for the full period of the sunshine record at BHO. The long-term annual mean is just over 52 percent, which varies among the years from the lowest value of 47 percent in 1889 and 1919 to a high of 60 percent in 1965, which was also the driest year on record. While there is little overall trend, a period of higher-than-average bright sunshine occurred during the 1960's to early 1970's that decreased to a minimum in the 1980's with generally recovering sunshine in recent decades despite reaching a minimum of 48 percent in 2018, which was the lowest annual sunshine in the last 30 years. Ongoing research shows some dependence of the variation in annual bright sunshine since the 1960's on cloud cover changes and on the presence of atmospheric aerosols. The latter effect was especially apparent during years of increased aerosols and air pollution in the 1970's and 1980's, which caused the intensity of sunlight to be reduced when the sun was near the horizon as the solar beam was more strongly attenuated by the atmosphere, which hindered the sun from burning the card. Reduced aerosol emissions in recent decades have allowed both the bright sunshine duration and observations of horizontal visibility to improve substantially since the 1980's.

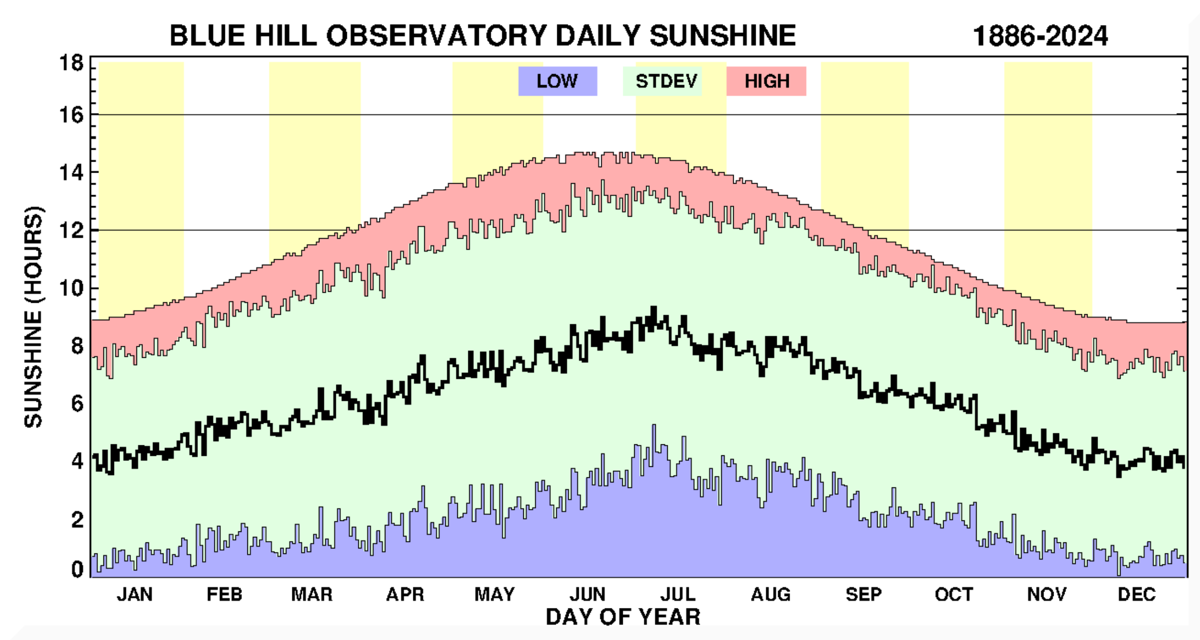

Figure 19. Blue Hill Observatory daily mean bright sunshine for 1886-2024 (thick black line), daily standard deviation (green shading), and the extreme high (red shading) and low (blue shading) bright sunshine for each day of the year. Data exclude leap day and are plotted in units of hours.

The mean daily duration of bright sunshine in hours has an obvious annual trend that tracks the peak solar zenith angle through the year as shown in Figure 19, and it varies from about four hours in early winter to about eight hours in early summer. This parameter is different from all others in that both the high and low extremes are bounded: the high extreme is limited to the possible number of hours of sunshine from sunrise to sunset on any day, and the low extreme is obviously limited to there being no direct bright sunshine, which has occurred on all days of the year. The high extreme daily sunshine ranges from about nine hours in winter to about 15 hours during summer. The standard deviation of bright sunshine is exceptionally high throughout the year due to the strongly variable impact of cloud cover on sunshine, and it varies from about three hours in winter to about five hours in summer. Looking at the seven-day time scale, the least sunny week of the year on average is 9-15 December with 3.8 hours of bright sunshine per day, and the sunniest week of the year on average is 5-11 July with 8.9 hours of bright sunshine.

The long duration of the Blue Hill climate record provides an essential historical context for studying climate change and these data are especially well-suited to this effort, since many decades of continuous, accurate data are necessary to establish the significance of trends relative to natural variability. Maintaining the extensive BHO climate record into the future and using it to inform the public about atmospheric science are critically important objectives of the Blue Hill Observatory and Science Center that will help ensure that this irreplaceable scientific and educational resource will continue to provide an invaluable historical perspective on ongoing, long-term, local climate changes.

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