

State of the Climate at Blue Hill Observatory: 2020

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 speed and direction, 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. Now more than 135 years later, the BHO observations form the longest, most consistent, and most extensive climate record in North America, and they are an irreplaceable resource that supports the BHO mission 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 seven 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 state of the seasonal climate measurements at Blue Hill.

Looking first at the past calendar year, 2020 was the second 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: winter (December-February) 2019-2020 was the fifth warmest, summer (June-August) 2020 was the third warmest, and autumn (September-November) 2020 was the fifth warmest on record. Precipitation was about ten percent more than average during 2020, though dry periods in July and September brought

intervals of moderate drought to the area. Snowfall was well below average for the year until a 15-inch snowfall occurred in mid-December. Annual mean wind speed was the second lowest on record, extending a dramatic drop in wind speed in recent decades.

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 temperatures since the middle 19th century are shown in black in Figure 1. All data from February 1, 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.

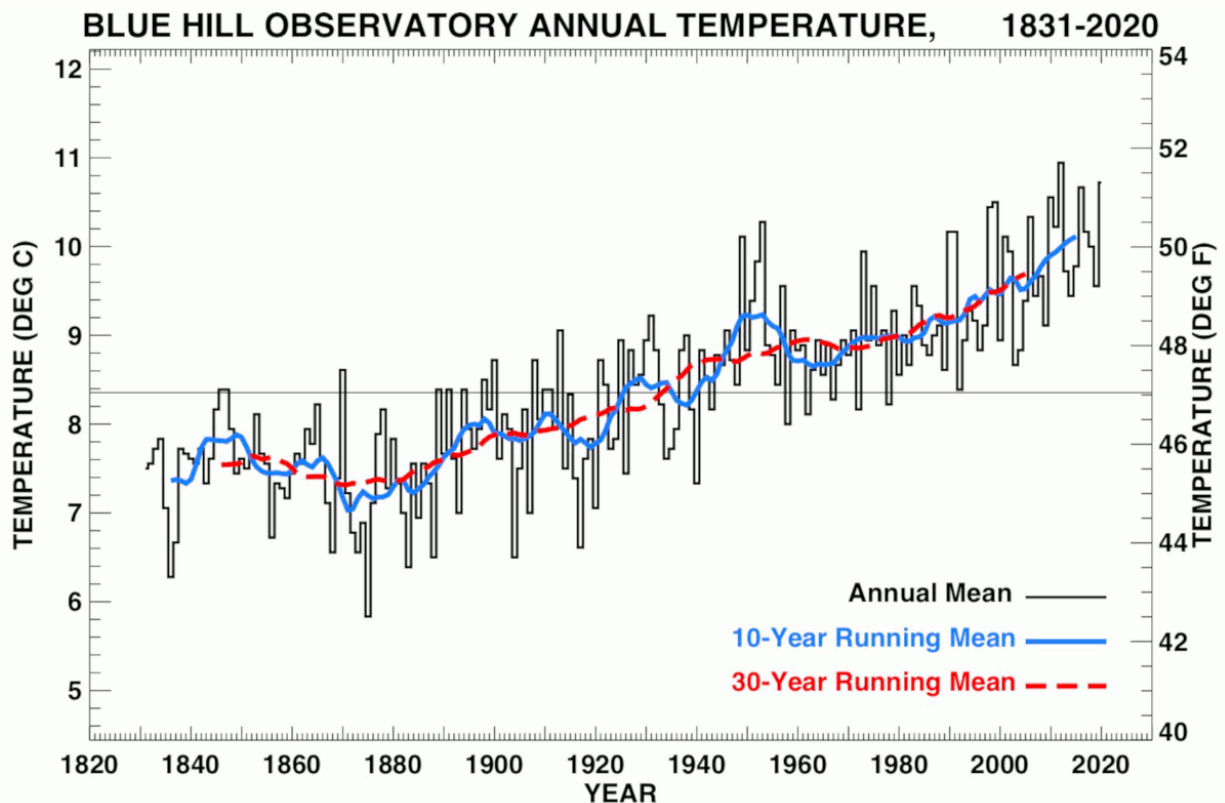


Figure 1. Blue Hill Observatory annual mean temperature (black, histogram) from measurements taken on the summit of Great Blue Hill (1885-present) and adjusted to the summit from two nearby surrounding locations (1831-1884). Units are labeled in degrees Celsius and degrees Fahrenheit. Centered running means are also shown for 10-year (blue, solid) and 30-year (red, dashed) periods. The thin black line is the 1831-2020 mean.

Applying a linear fit to the annual temperature data over the period 1885 to 2020 (see Table 1) indicates an upward trend of $+0.18\text{ }^{\circ}\text{C}/\text{decade}$ ($+0.32\text{ degrees F}/\text{decade}$) with a better than 99.9% confidence that the trend is statistically significant. This change is more than twice the U.S. national trend of $+0.07\text{ }^{\circ}\text{C}/\text{decade}$ ($+0.13\text{ degrees F}/\text{decade}$) and the global (land and ocean) trend of $+0.08\text{ }^{\circ}\text{C}/\text{decade}$ ($+0.15\text{ degrees F}/\text{decade}$) since 1880.

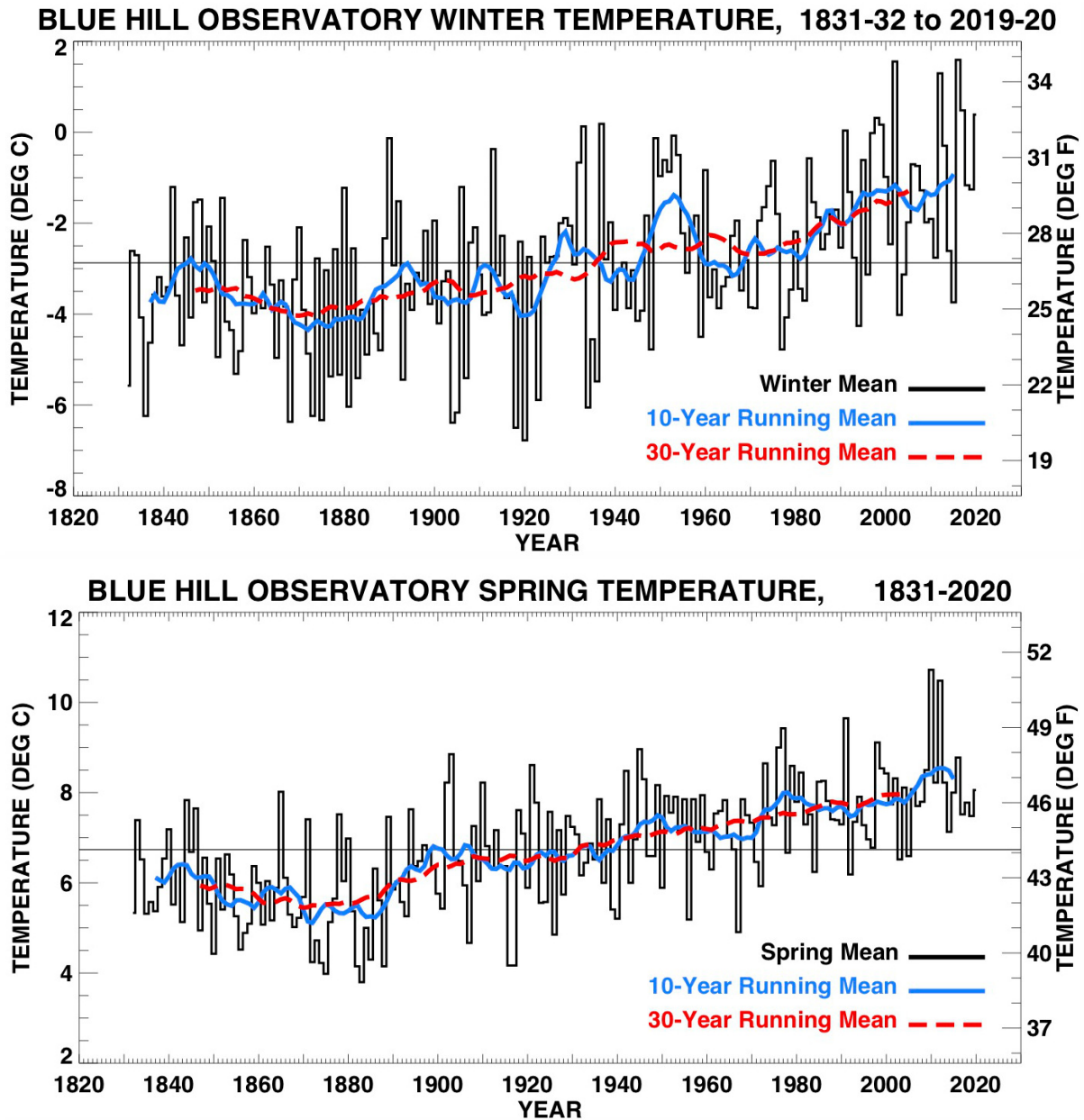


Figure 2. Blue Hill Observatory winter (December-February; top) and spring (March-May; bottom) mean temperature (black, histogram) from measurements taken on the summit of Great Blue Hill (1885-present) and adjusted to the summit from two nearby surrounding locations (1831-1884). Units are labeled in 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 line represents the long-term mean over the years shown.

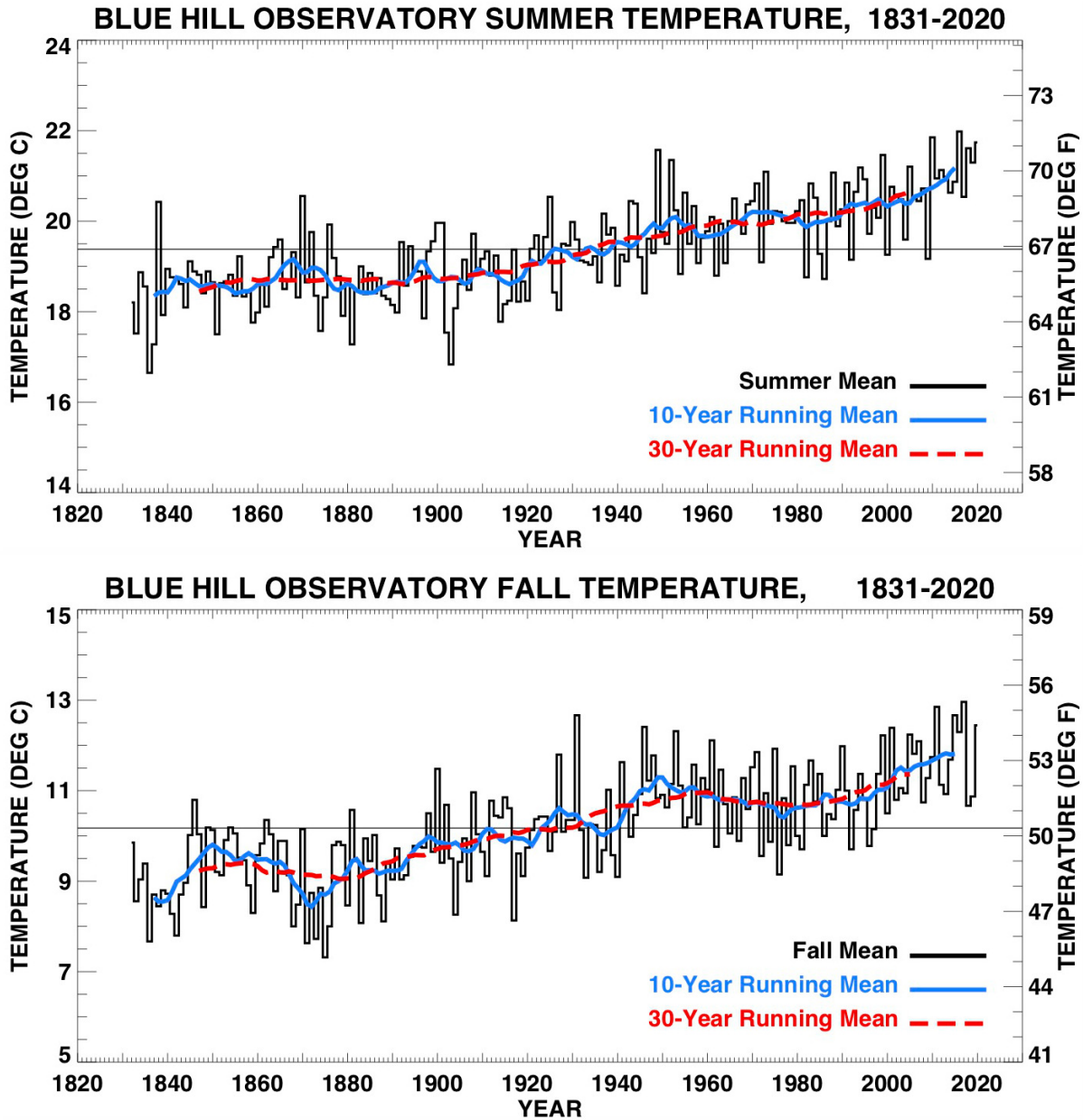


Figure 3. Blue Hill Observatory summer (June-August; top) and fall (September-November; bottom) mean temperature (black, histogram) from measurements taken on the summit of Great Blue Hill (1885-present) and adjusted to the summit from two nearby surrounding locations (1831-1884). Units are labeled in 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 line represents the long-term mean over the years shown.

Significant temperature increases are also seen in all seasons, though the nature of the change is slightly different for each season. Figure 2 shows the Blue Hill mean temperatures for winter (December-February) and spring (March-May), and Figure 3 shows the temperatures for summer (June-August) and autumn (September-November).

Centered 10-year (blue) and 30-year (red) running means that smooth the data are also shown to illustrate decadal scale temperature changes. Long-term linear trends in the seasonal temperature data over the period 1885 to 2020 are listed in Table 1. The largest upward trend, in winter, implies a total mean temperature change of +4.7 degrees F over the 135-year period, while the smallest upward trend, in autumn, implies a total change of +3.7 degrees F in that season. All of these trends are statistically significant with a confidence of better than 99.9% due in part to the duration of the trends and their magnitude relative to the inter-annual variability. Winter temperature shows the largest variations from year to year, while summer temperature is the least variable of the four seasons. During the 20th century, both fall and winter show a temporary leveling or a slight decrease in mean temperature from the 1940's through the 1970's before strongly rising after that time, while spring and summer show steadier rises in the 30-year running mean temperature since the late 19th century.

Season	Temperature		Precipitation		Snowfall	
	°C/decade	°F/decade	cm/decade	in./decade	cm/decade	in./decade
Annual	+0.175	+0.316	+1.688	+0.665	+2.402	+0.946
Winter	+0.192	+0.346	+0.618	+0.243	+1.776	+0.699
Spring	+0.166	+0.298	+0.593	+0.233	+0.440	+0.173
Summer	+0.183	+0.329	+0.157	+0.062	-----	-----
Fall	+0.156	+0.281	+0.459	+0.181	-0.105	-0.041

Table 1. Blue Hill Observatory seasonal trends in temperature, precipitation and snowfall derived as linear fits to the observed seasonal data over the 136-year period from 1885-2020.

The most recent 30-year (1991-2020) mean temperatures at BHO are the highest on record in all four seasons. Looked at another way, eight of the ten warmest winters on record, for example, have occurred since the early 1990's including the warmest winter, in 2015-2016, which averaged 1.6 °C (34.9 °F). However, cold winters do still occur. In fact, the last winter to average below the long-term winter mean occurred one year earlier in 2014-2015, which averaged -3.7 °C (25.3 °F), largely due to an historically cold and snowy February that year.

Looking at the cold season months in more detail, Figure 4 shows the centered 30-year mean temperatures for winter and the individual months of December, January, February and March. Among the four months, March and December are the warmest, and each shows a steady upward trend in temperature that closely parallels the rise in winter mean temperature. However, the changes in January and February temperature over the

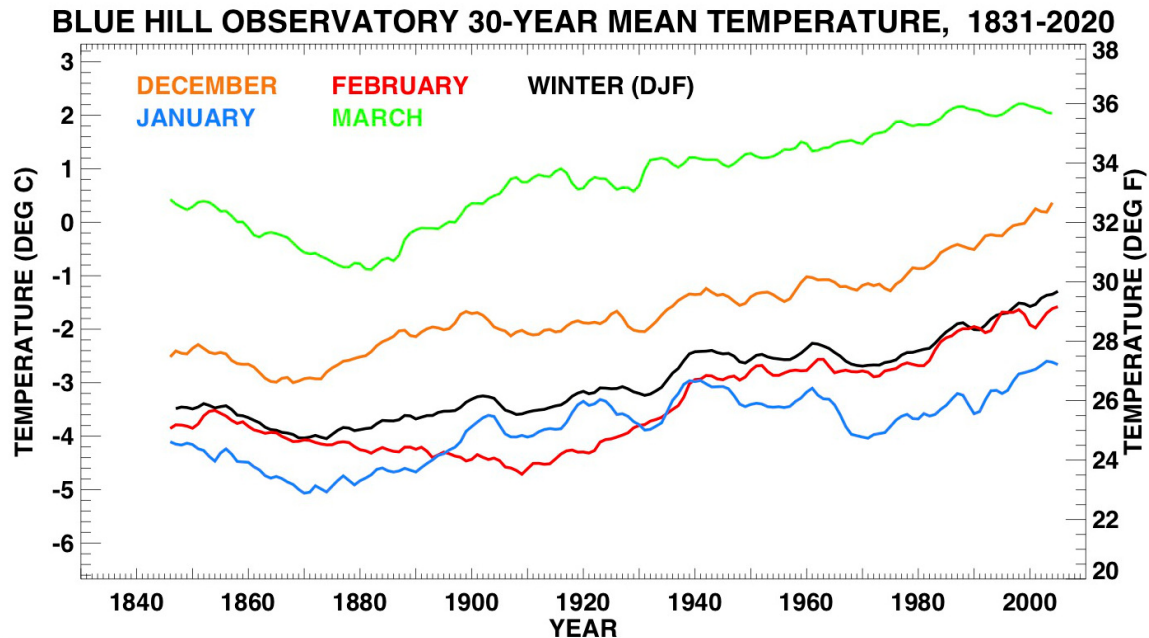


Figure 4. Blue Hill Observatory centered 30-year running mean temperature for winter (black), December (orange), January (blue), February (red) and March (green) from measurements taken on the summit of Great Blue Hill (1885-present) and adjusted to the summit from two nearby surrounding locations (1831-1884). Units are labeled in degrees Celsius and degrees Fahrenheit.

last century tell a somewhat different story. Since the middle 19th century, January and February show remarkably different changes, and in terms of which month has been warmer, the two months have switched places twice (in the 30-year mean illustrated). After a steady decline in the late 19th century, February mean temperature changed direction, and since that time shows a large and steady rise to the present. By contrast, January temperature has climbed more gradually and shows substantially more cyclical decadal changes. January has been on average much colder than February since the middle 20th century. The reason for this unusual and unexpected behavior in January and February temperatures has not yet been investigated.

Precipitation/Snowfall

The highly disruptive effects of flooding events and winter snowstorms make rainfall and snowfall among the most impactful aspects of the weather, so it is especially important that changes in precipitation means and extremes be carefully monitored and investigated to improve our predictive capabilities. At Blue Hill, total precipitation, which includes rainfall and the liquid equivalent of all frozen precipitation (snow and sleet), has shown a gradual increase in recent decades, except in summer. Figure 5 shows the total annual precipitation since 1886 and the 10-year and 30-year running means, which illustrate the decadal and long-term changes. A linear fit to the annual precipitation over

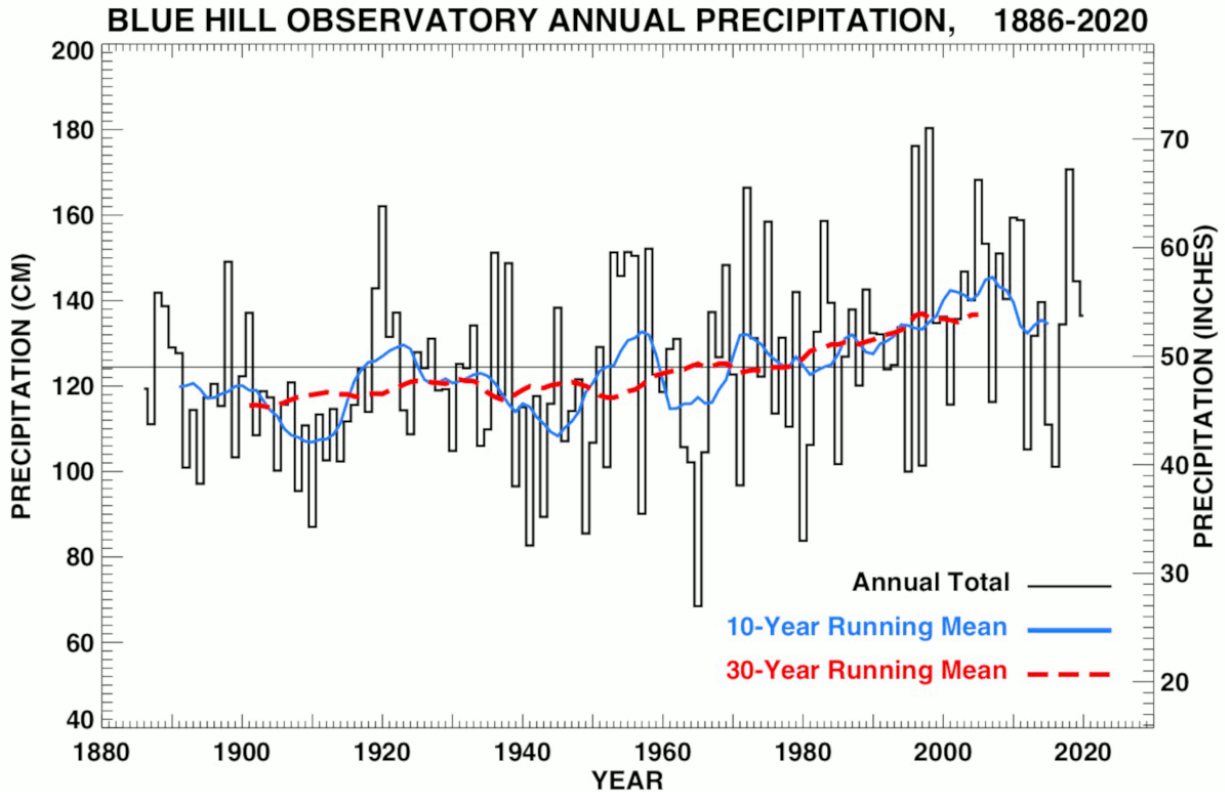


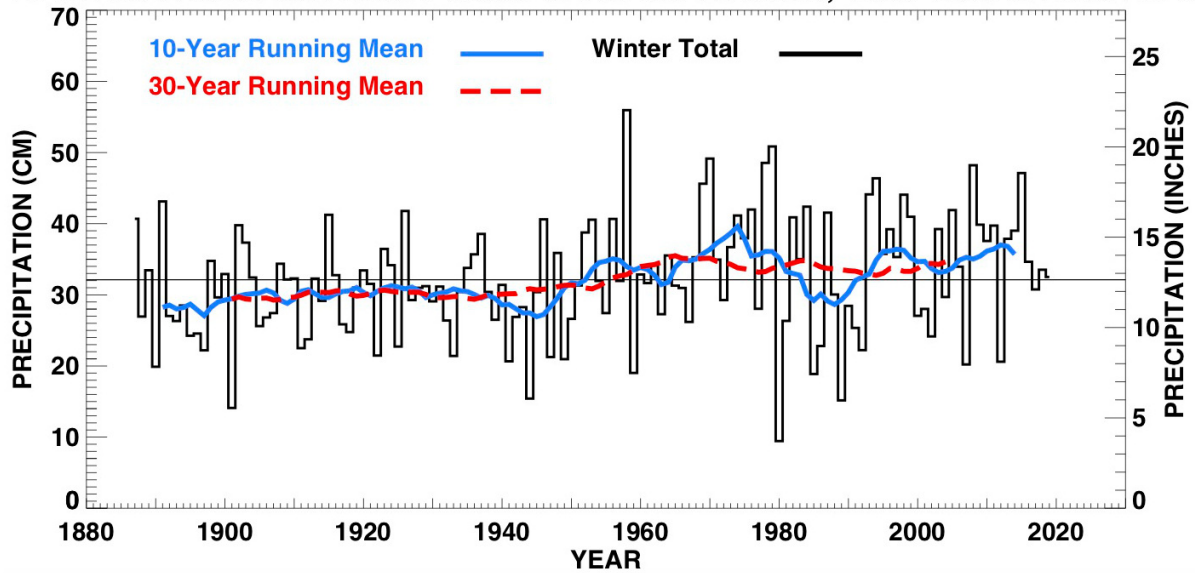
Figure 5. Blue Hill Observatory annual precipitation (black, histogram) from measurements taken on the summit of Great Blue Hill (1886-present). Units are labeled in centimeters and inches. Centered running means are also shown for 10-year (blue, solid) and 30-year (red, dashed) periods. The thin horizontal line is the 1886-2020 mean.

the period 1886 to 2020 (Table 1) indicates an upward trend of +1.69 cm/decade (about two-thirds of an inch per decade) with a better than 99.9% confidence that the trend is statistically significant. In terms of 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.

Looking at seasonal precipitation, Figure 6 shows the total precipitation at Blue Hill for winter and spring, and Figure 7 shows the precipitation for summer and autumn. Summer and autumn precipitation show much larger variations from year to year than winter and spring due in part to the generally more convective and spatially variable nature of rainfall in the former seasons. During the 20th century, precipitation has increased steadily in all seasons except summer, which on average shows long-period cyclical behavior with a very small upward trend over the BHO period of record. Long-term linear trends in the seasonal precipitation over the period 1886 to 2020 are also listed in Table 1. The largest upward trend, in winter, implies a total precipitation increase of +3.28 inches over the 135-year period, while the smallest upward trend, in summer, implies a

total increase of +0.84 inches in that season. All of these trends are statistically significant with a confidence of better than 99.9% due in part to the duration of the trends and their magnitude relative to the inter-annual variability.

BLUE HILL OBSERVATORY WINTER PRECIPITATION, 1885-1886 to 2019-2020



BLUE HILL OBSERVATORY SPRING PRECIPITATION, 1885-2020

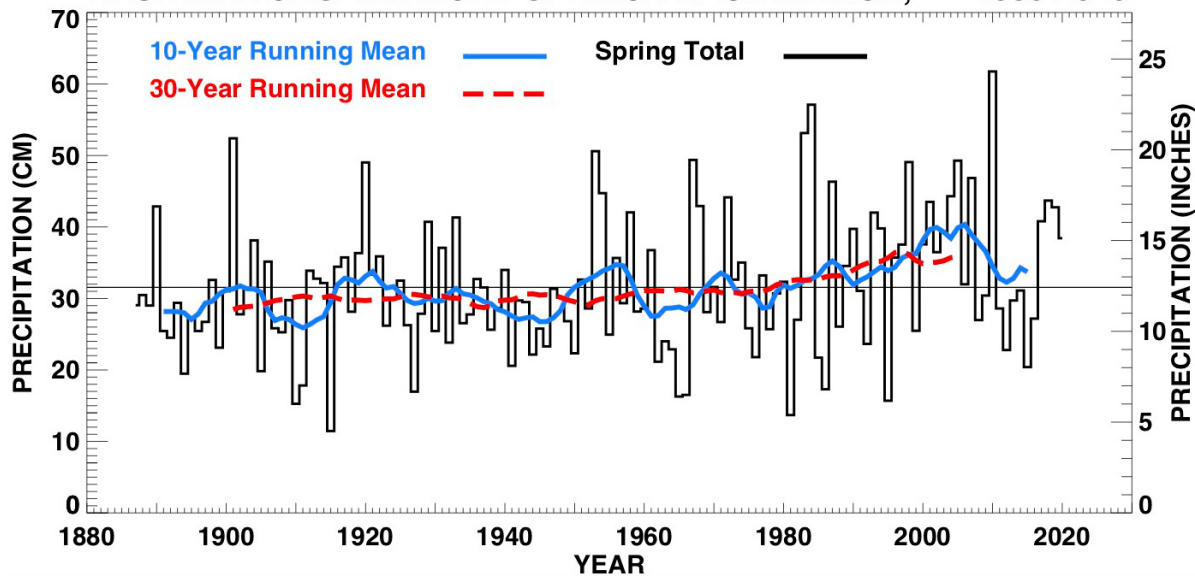


Figure 6. Blue Hill Observatory winter (top) and spring (bottom) precipitation (black, histogram) from measurements taken on the summit of Great Blue Hill. Units are labeled in centimeters and inches. Centered running means are also shown for 10-year (blue, solid) and 30-year (red, dashed) periods. The thin horizontal line represents the long-term mean over the years shown.

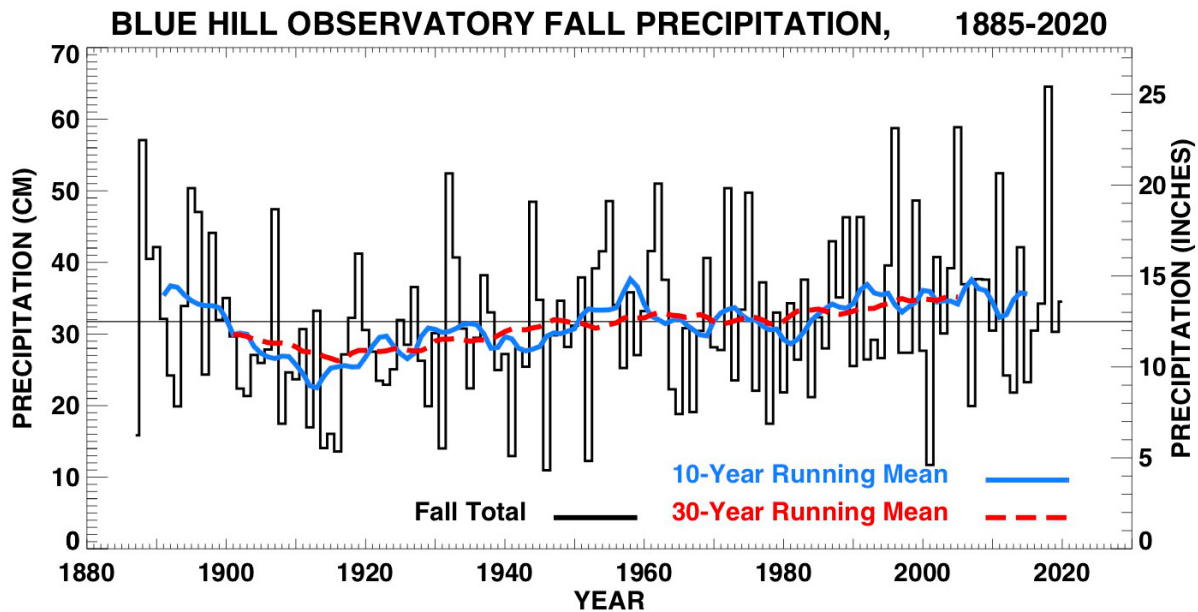
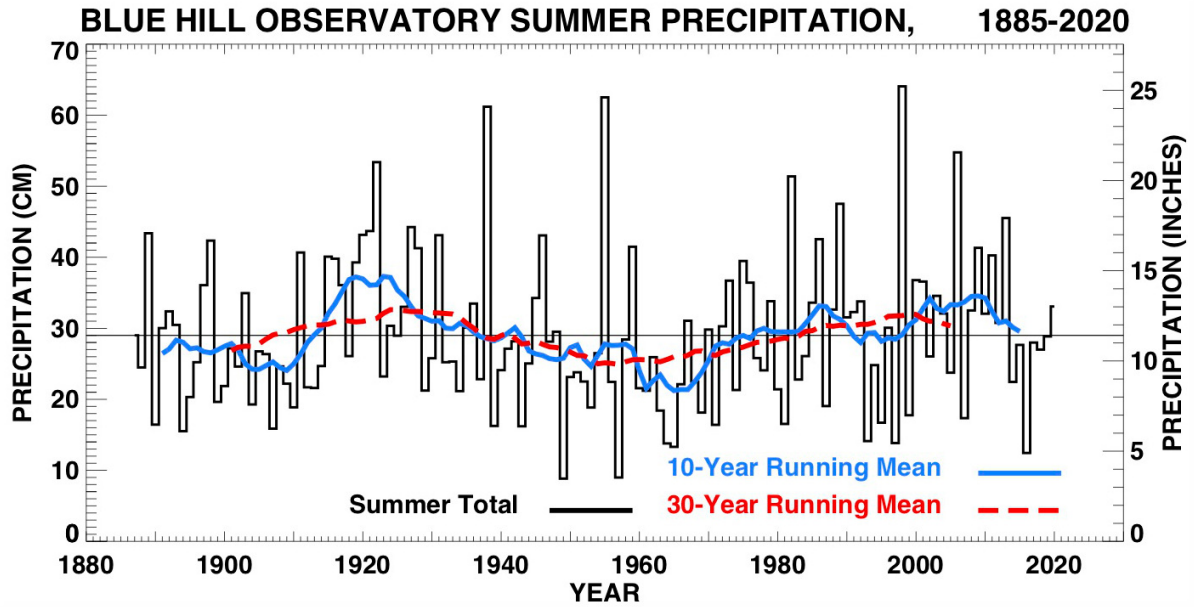


Figure 7. Blue Hill Observatory summer (top) and fall (bottom) precipitation (black, histogram) from measurements taken on the summit of Great Blue Hill. Units are labeled in centimeters and inches. Centered running means are also shown for 10-year (blue, solid) and 30-year (red, dashed) periods. The thin horizontal line represents the long-term mean over the years shown.

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 precipitation. Other than a single instance of a trace of sleet in early June 1907, these types of frozen precipitation have never occurred at BHO from June through September. Hail, which occurs infrequently during some convective precipitation events at Blue Hill, is

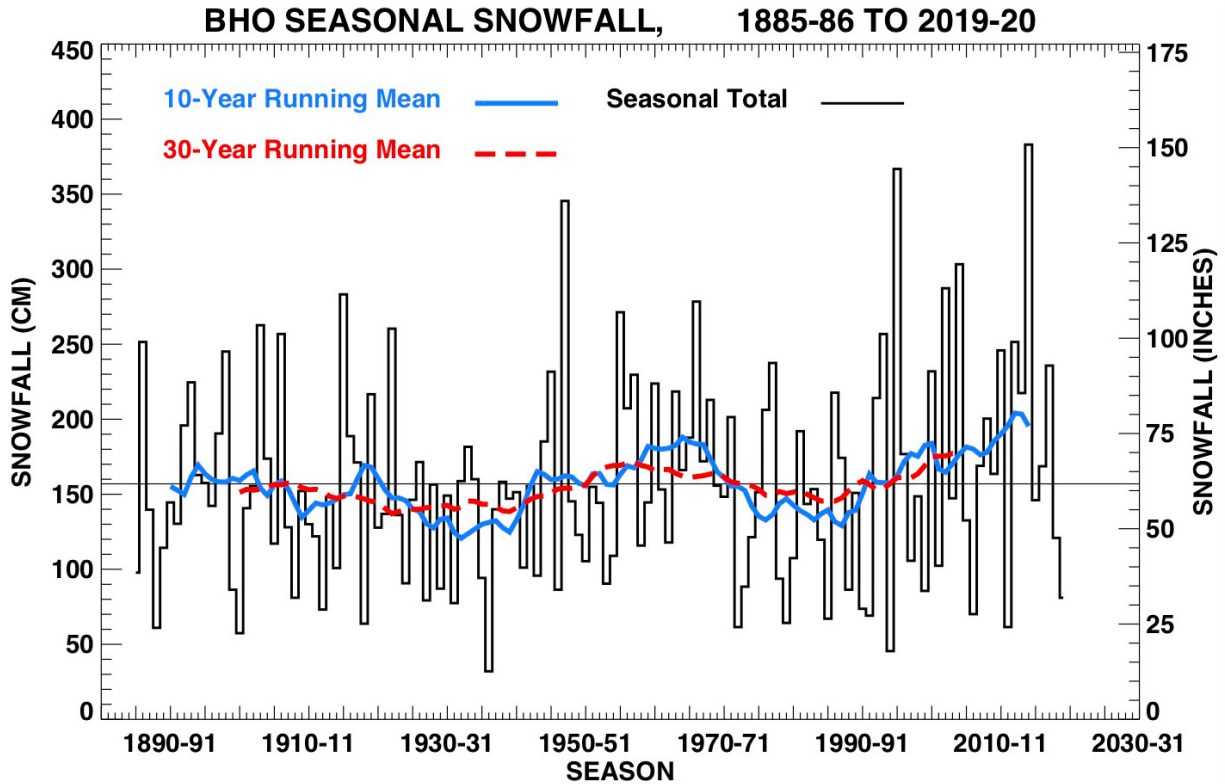


Figure 8. Blue Hill Observatory total October to May seasonal snowfall (black, histogram) from measurements taken on the summit of Great Blue Hill (1885-present). Units are labeled in centimeters and inches. Centered running means are also shown for 10-year (blue, solid) and 30-year (red, dashed) periods. The thin horizontal line is the 1885-2020 mean.

frozen precipitation, but it is not considered in this study. 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. Total snowfall for the entire cold season from October through May is shown in Figure 8. A linear fit to these data (Table 1) 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 8) shows that decadal variations in total snowfall followed a roughly 50-year cycle since the early 20th century. From 1885 to 1990, 12 seasons exceeded 228 cm (90 inches) of snowfall; since 1990, 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 1990, and all ten have occurred since 1960.

Total snowfall can also be examined separately for the autumn, winter and spring seasons, which show slightly different variations. Figure 9 shows total frozen precipitation (snowfall) at Blue Hill for winter and spring, and Figure 10 shows the snowfall for autumn.

Despite high inter-seasonal variability in winter from year to year from the record lowest amount of 3.3 inches in December-February 1936-1937 to the record highest amount of 128.8 inches in 2014-2015, the long-term mean has remained relatively steady with only a small upward trend as indicated by the 30-year running mean. The apparent cyclical behavior in the 10-year running mean is most often the result of one or more well above average winters skewing this shorter-term average. Even less trend is apparent in spring

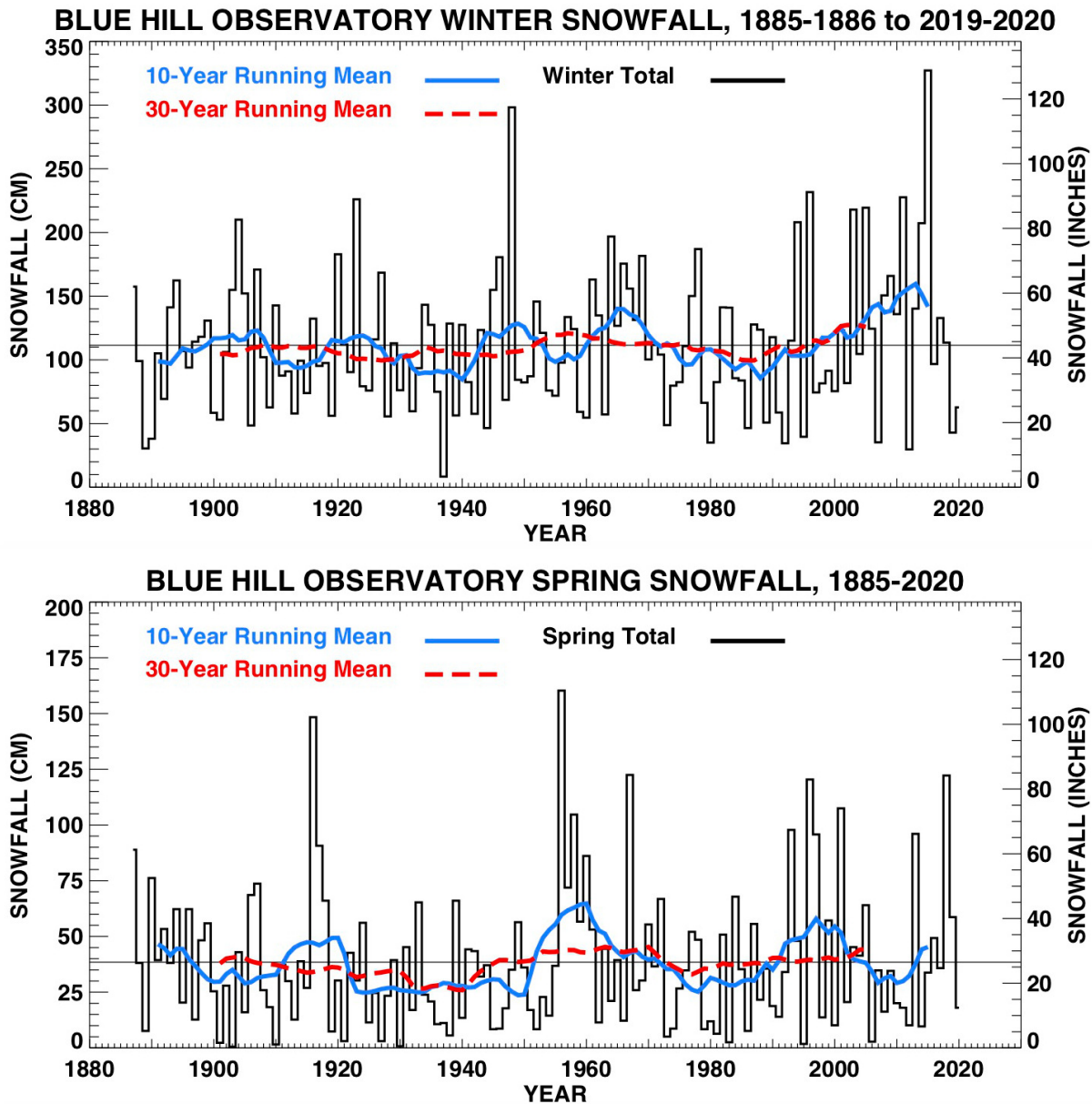


Figure 9. Blue Hill Observatory frozen precipitation (black, histogram) during the three winter months (top) and the three spring months (bottom) from measurements taken on the summit of Great Blue Hill. Units are labeled in centimeters and inches. Centered running means are also shown for 10-year (blue, solid) and 30-year (red, dashed) periods. The thin horizontal line represents the long-term mean over the years shown.

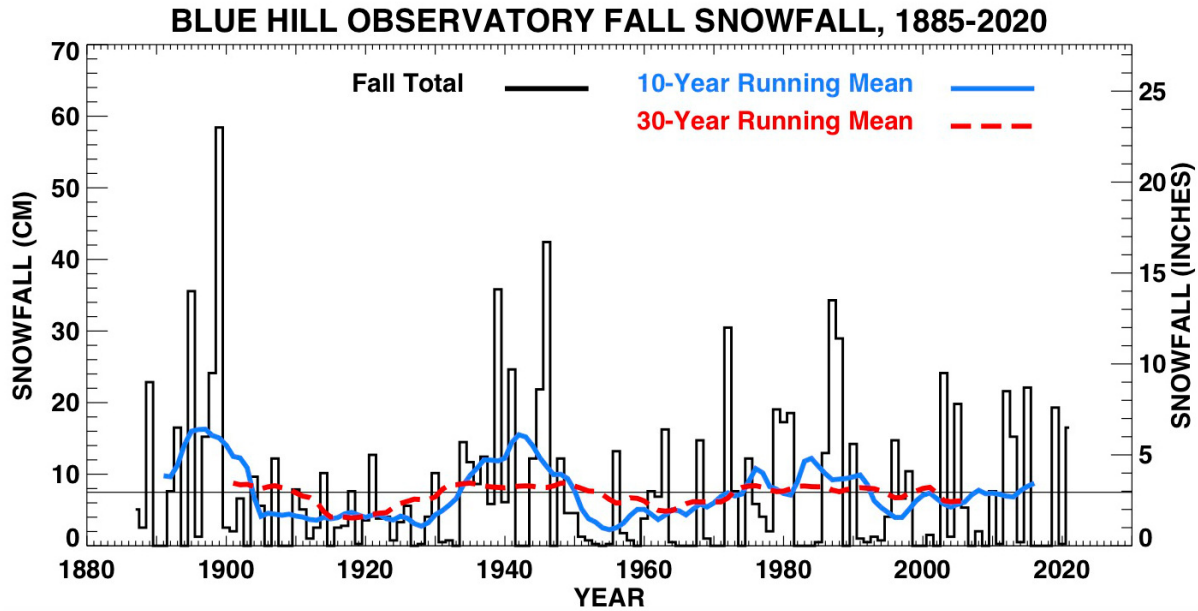


Figure 10. Blue Hill Observatory autumn (September-November) snowfall (black, histogram) from measurements taken on the summit of Great Blue Hill. Units are labeled in centimeters and inches. Centered running means are also shown for 10-year (blue, solid) and 30-year (red, dashed) periods. The thin horizontal line represents the long-term mean over the years shown.

snowfall with once again a few very anomalous seasons with large snowfall strongly influencing the 10-year running mean. Table 1 also includes the linear trends for winter and spring snowfall (in inches/decade) fit to the individual seasonal values. In winter, the trend translates to an increase of about +9.5 inches over the whole period of record with a long-term mean of just under 45 inches for the winter months, though this trend is being strongly impacted by the very high snowfall in 2014-2015. The small positive trend in spring converts to a total increase of just +2.3 inches since the 1880's. Autumn snowfall (Figure 10) is generally very small, with a long-term mean of only 2.9 inches and just seven autumn seasons exceeding 10 inches (25 cm). The trend in autumn snowfall is slightly negative though the change is negligible.

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 11. A slow decline in the 10-year mean annual wind speed (blue) that began in the 1940's became a sharper, steady drop after 1980, falling 18 percent from 6.7 m/s (15.0 mph) in that year to 5.5 m/s (12.3 mph) recently, though the decrease has begun to level off in the last few years. 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

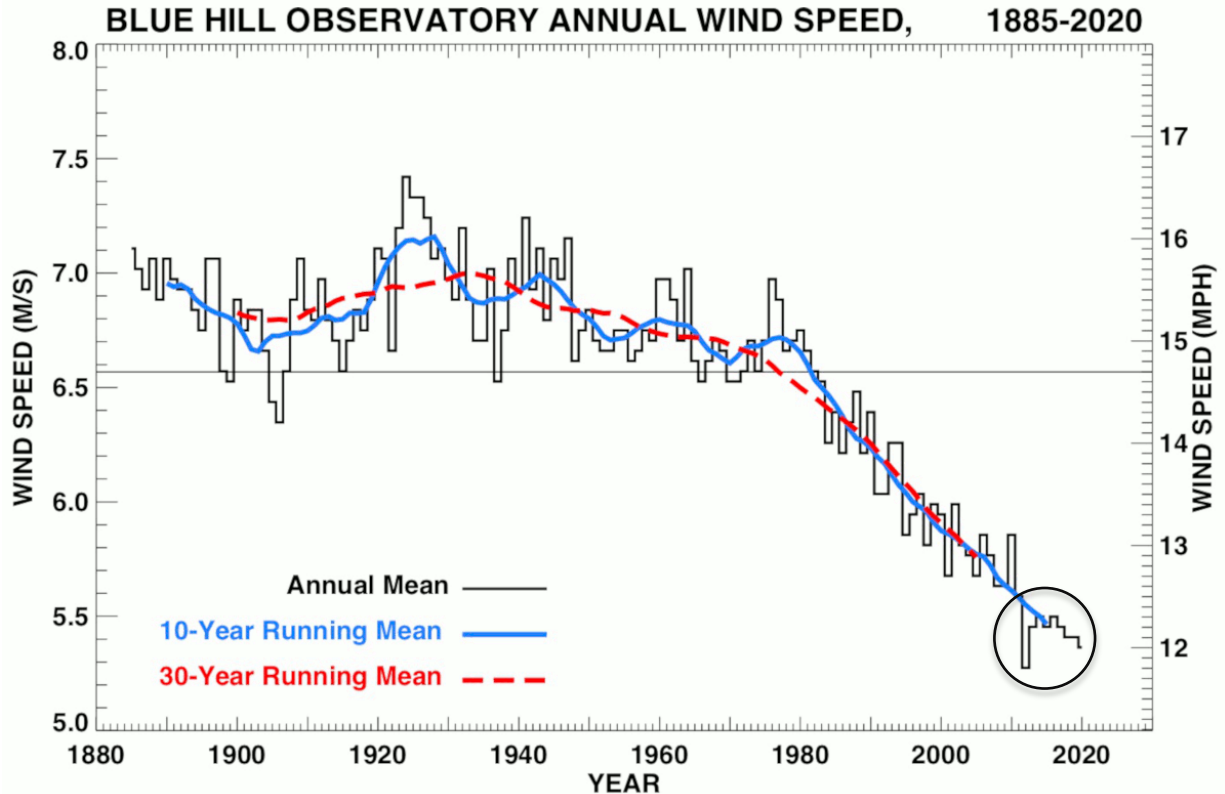


Figure 11. Blue Hill Observatory annual mean wind speed (black, histogram) from measurements taken on the summit of Great Blue Hill (1885-present). Units are labeled in meters/second and miles/hour. Centered running means are also shown for 10-year (blue, solid) and 30-year (red, dashed) periods. The thin horizontal line is the 1885-2020 mean.

tropics. This so-called global stilling is consistent with wind speed changes at other locations across North America and Europe in recent decades. However, since reaching a minimum in 2012, the annual wind speed has leveled off (circled data points in Figure 11), and this slowing of global stilling is also being observed at other sites around the world.

Seasonal mean wind speeds show similar changes since about 1980, though the recent leveling of the downward trend in annual wind speed is not apparent during winter. Figure 12 shows the Blue Hill mean wind speed for winter and spring, and Figure 13 shows the mean wind speed for summer and autumn. A slow decline in the 10-year running mean wind speed (blue) that began in the 1940's became a sharper, steady drop after 1980 in all seasons, falling 20 percent in winter from about 7.5 m/s (16.8 mph) in the late 1970's to 6.0 m/s (13.5 mph) recently, with the lowest December-February mean wind speed on record of 5.7 m/s (12.8 mph) occurring in winter 2019-2020. By contrast the summer mean wind speed has dropped more gradually by about 17 percent since 1980 from about 5.7 m/s (12.7 mph) to 4.7 m/s (10.6 mph).

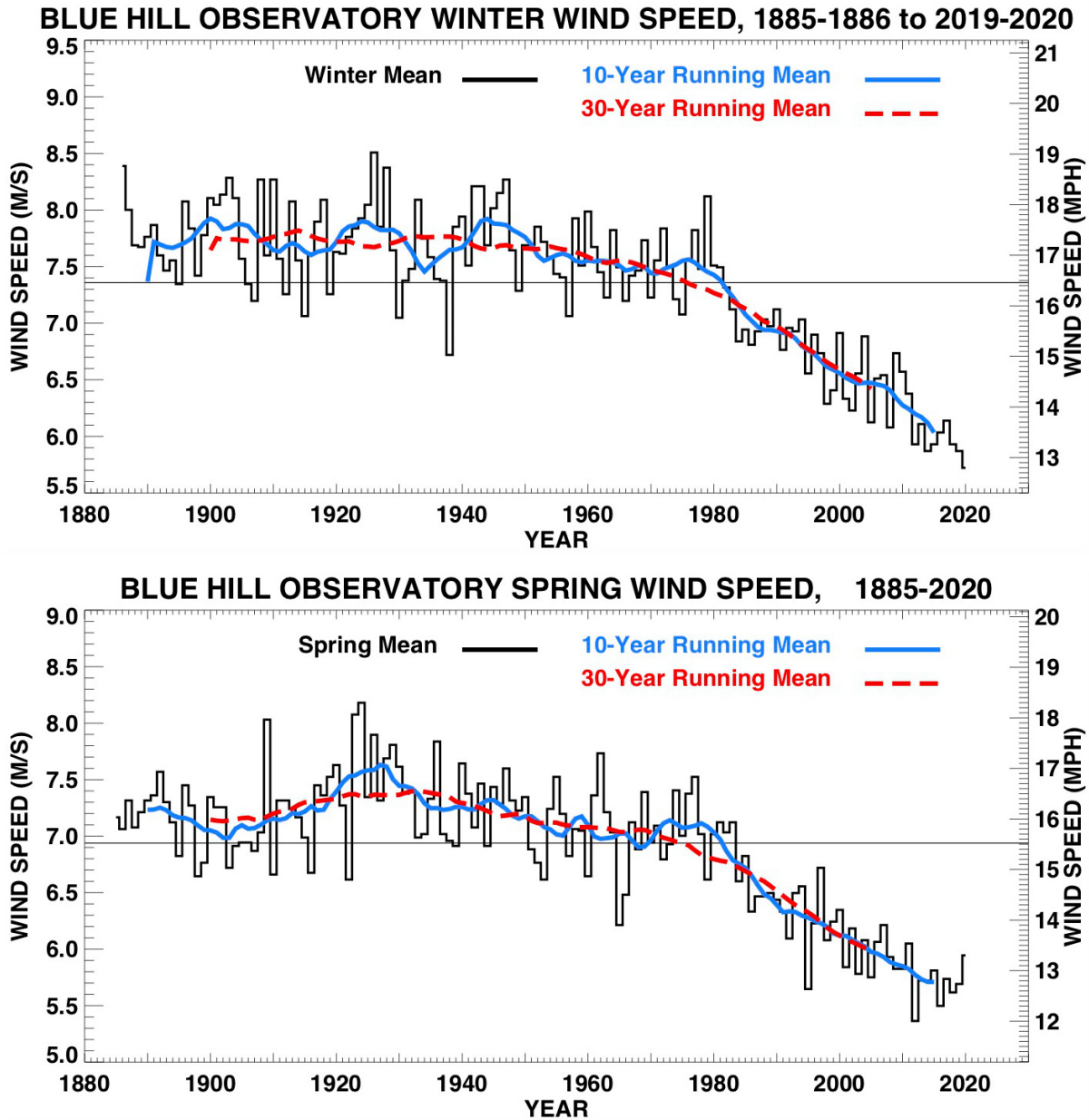


Figure 12. Blue Hill Observatory wind speed (black, histogram) during the three winter months (top) and the three spring months (bottom) from measurements taken on the summit of Great Blue Hill. Units are labeled in meters per second and miles per hour. Centered running means are also shown for 10-year (blue, solid) and 30-year (red, dashed) periods. The thin horizontal line represents the long-term mean over the years shown.

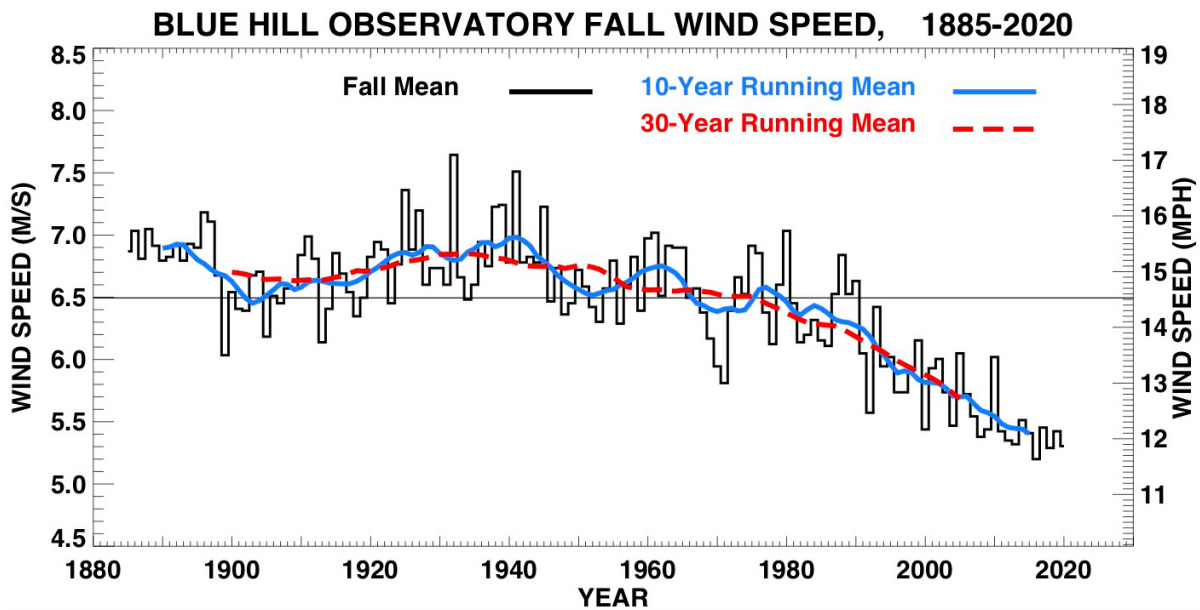
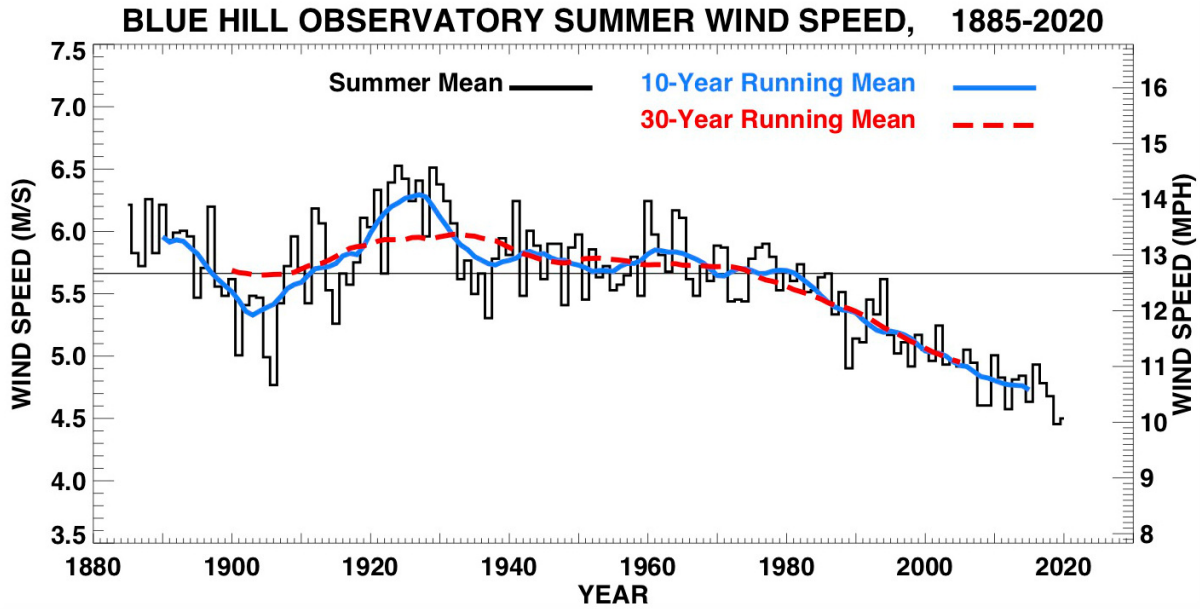


Figure 13. Blue Hill Observatory wind speed (black, histogram) during the three summer months (top) and the three autumn months (bottom) from measurements taken on the summit of Great Blue Hill. Units are labeled in meters per second and miles per hour. Centered running means are also shown for 10-year (blue, solid) and 30-year (red, dashed) periods. The thin horizontal line represents the long-term mean over the years shown.

Sunshine, Cloud Cover, and Visibility

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

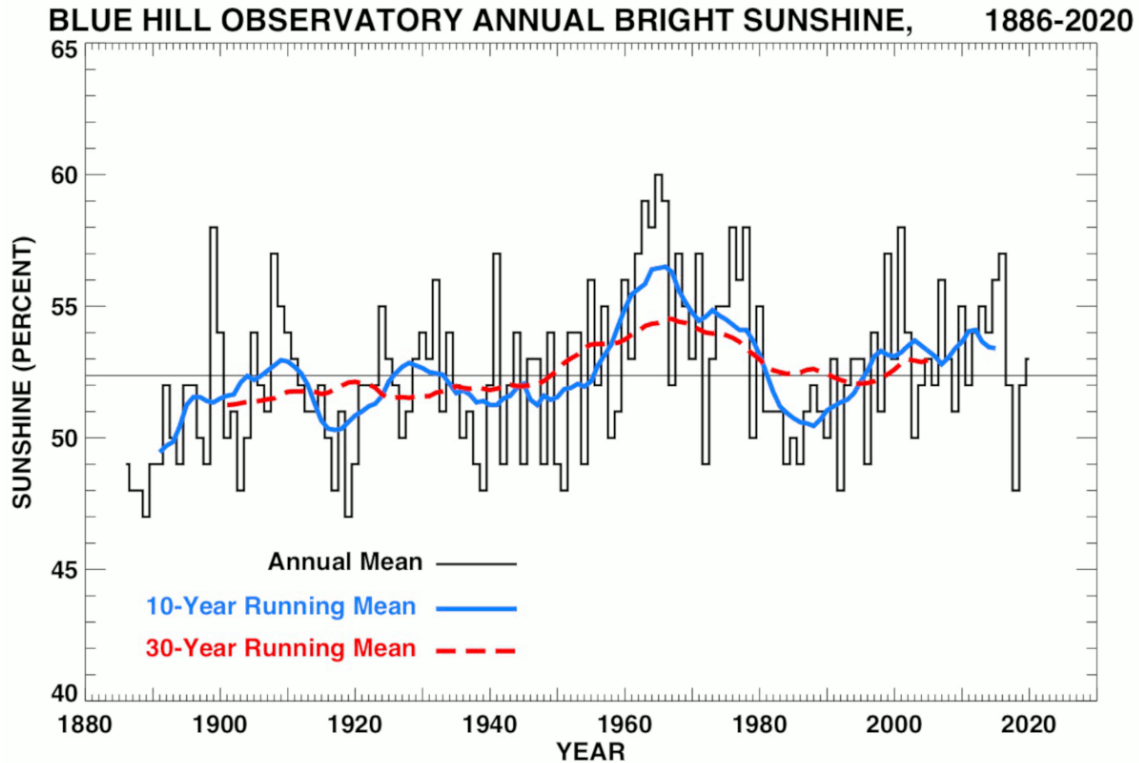


Figure 14. Blue Hill Observatory annual mean bright sunshine (black, histogram) expressed as a percent of possible sunshine from measurements taken on the summit of Great Blue Hill (1886-present). Units are labeled in percent. Centered running means are also shown for 10-year (blue, solid) and 30-year (red, dashed) periods. The thin horizontal line is the 1886-2020 mean.

replaceable, treated card held in a metal frame below the glass. As the sun moves across the sky each day, the focused sunlight will scorch or burn through the card leaving a 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. The annual average bright sunshine is 52 percent, which ranges among the seasons from the lowest value of 47 percent in winter to 57 percent in summer. Figure 14 shows the annual bright sunshine and the smoothed running means for the full period of the sunshine record at BHO. 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. Figure 15 shows the Blue Hill mean bright sunshine for winter and spring, and Figure 16 shows the mean bright sunshine for summer and autumn for the whole period of record. The decadal variations noted above are seen in all seasons with the smallest decadal variations occurring during autumn. The bright sunshine during the fall of 2018 of 37 percent was anomalously low and more than 15 percent below the long-term mean. This amount was not only a record for that season, it was one of the lowest values for any season.

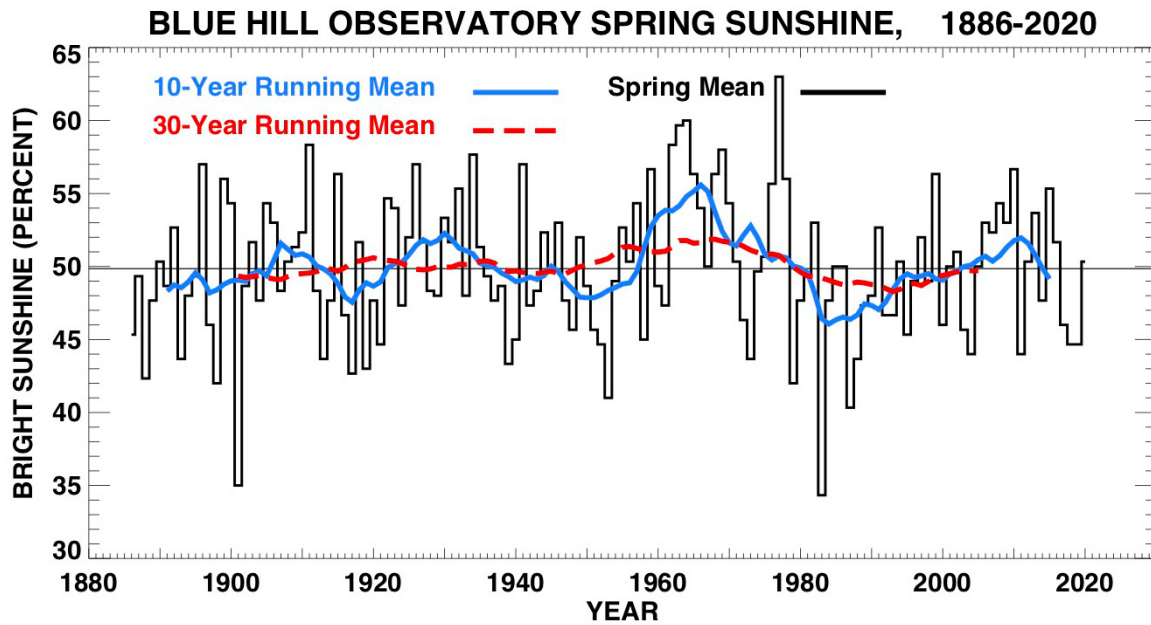
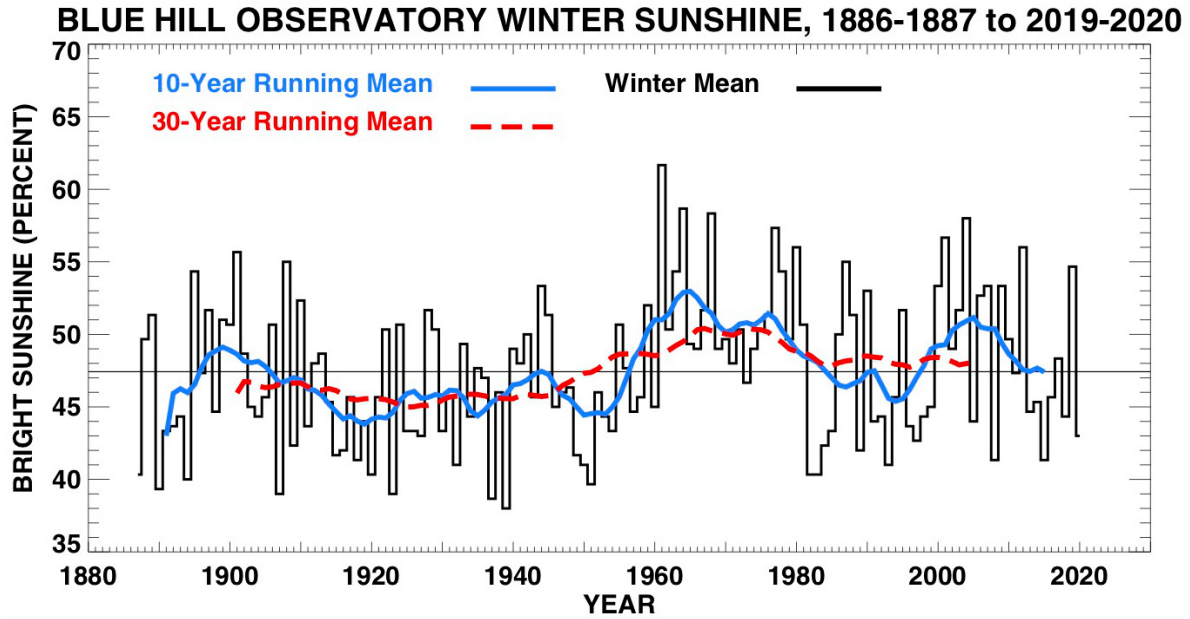


Figure 15. Blue Hill Observatory bright sunshine (black, histogram) during the three winter months (top) and the three spring months (bottom) from measurements taken on the summit of Great Blue Hill. Units are labeled in percent of possible sunshine. Centered running means are also shown for 10-year (blue, solid) and 30-year (red, dashed) periods. The thin horizontal line represents the long-term mean over the years shown.

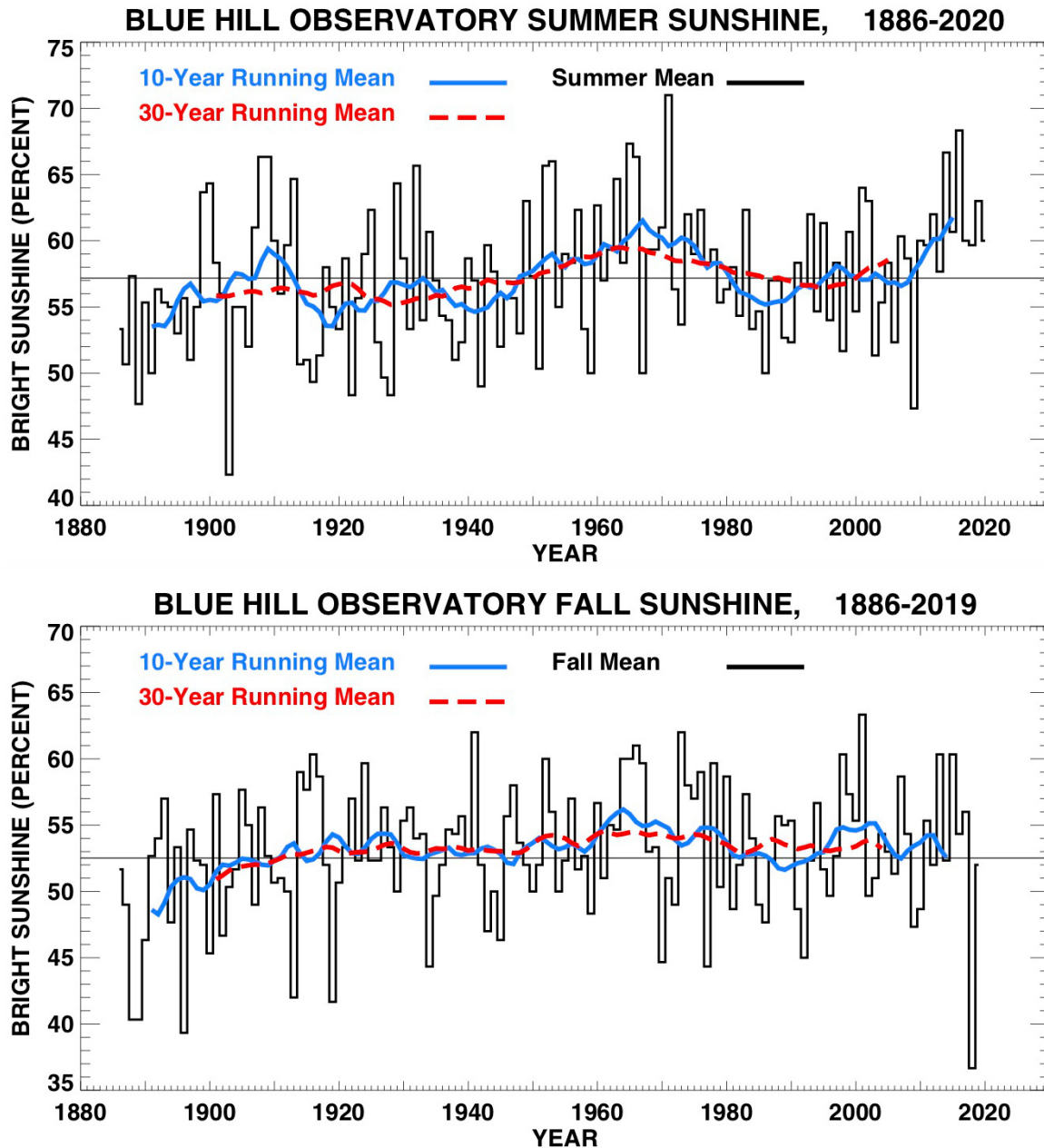


Figure 16. Blue Hill Observatory bright sunshine (black, histogram) during the three summer months (top) and the three autumn months (bottom) from measurements taken on the summit of Great Blue Hill. Units are labeled in percent of possible sunshine. Centered running means are also shown for 10-year (blue, solid) and 30-year (red, dashed) periods. The thin horizontal line represents the long-term mean over the years shown.

The measurement of bright sunshine duration has sensitivities to several other factors that may be impacting the observed decadal variations. For example, Figure 17 shows the 10-year running mean cloud cover for each season and for the entire year for the years that have been tabulated to date (1965-2020). The plotted quantity is the visually observed cloud cover at 7 AM local time only, so it does not represent the extent of daylight

hours that are reflected in the sunshine duration. Nevertheless, a period of reduced cloud cover is seen in all seasons from the late 1960's through the 1970's that is consistent with the elevated sunshine duration observed in these decades. However, the cause of the reduced cloud cover in these years has not yet been investigated. Looking at winter cloud cover (blue curve in Figure 17), a period of relatively high 7 AM cloudiness in the 1990's followed by a drop in the 2000's nicely matches the reduced winter sunshine during the 1990's and the subsequent sunshine increase in the following decade as seen in the top panel of Figure 15.

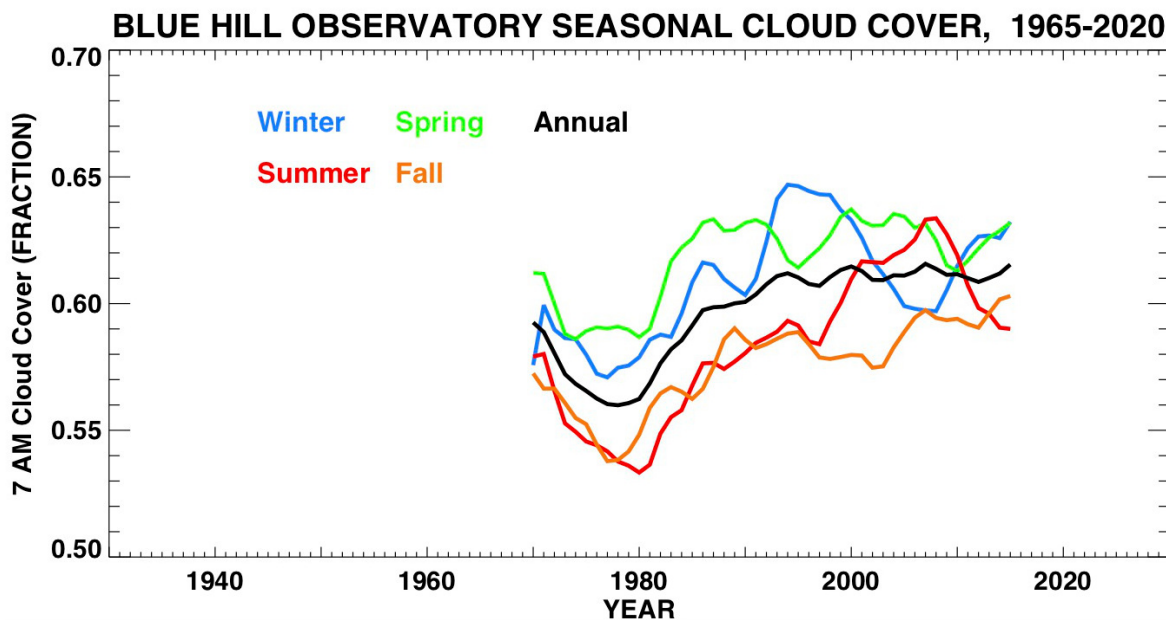


Figure 17. Blue Hill Observatory centered, running 10-year mean seasonal cloud cover for the years 1965-2020 for winter (blue), spring (green), summer (red) and autumn (orange) and for the entire year (black) from visual observations taken at 7 AM local time on the summit of Great Blue Hill. Units are in fraction.

Another factor that can influence the observed sunshine duration is the presence of atmospheric aerosols, which can reduce the intensity of the direct sunshine and the length of the recorded burn marks, especially when the sun is close to the horizon. Although aerosols are not observed directly at Blue Hill, the visually recorded horizontal visibility, which is a measure of the opacity of the atmosphere, is highly sensitive to obstructions such as particulate matter (aerosols), water vapor, or hydrometeors (fog and precipitation) in the line of sight to the horizon. Figure 18 shows the 10-year running mean visibility for each season and for the entire year for the period that has been tabulated to date (1965-2020). The plotted quantity is the manually observed prevailing visibility (defined as the greatest distance that can be observed over at least one-half of the entire horizon) at 7 AM local time only. A substantial upward trend in visibility is apparent for all seasons, which is

a response in part to the reduction of atmospheric pollution (aerosols) from the 1960's to the 1990's resulting from efforts to improve air quality nationally during these decades. The disruption in this increase in summer during the 2000's (red curve in Figure 18) and the rapid return to an increase during the 2010's may be a response to the cloud cover changes in this period during summer. The apparent increase in visibility (and associated reduction in aerosols) in recent decades is consistent with the increases in bright sunshine seen in Figures 15 and 16, especially in spring and summer.

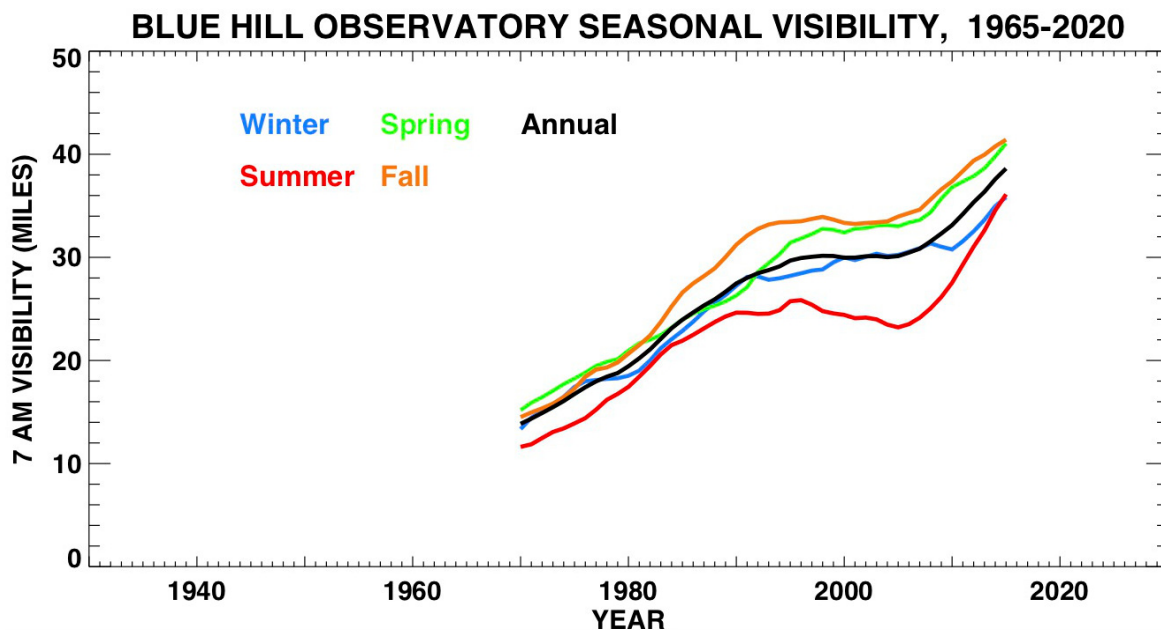


Figure 18. Blue Hill Observatory centered, running 10-year mean seasonal visibility for the years 1965-2020 for winter (blue), spring (green), summer (red) and autumn (orange) and for the entire year (black) from visual observations taken at 7 AM local time on the summit of Great Blue Hill. Units are in miles.

Water Vapor Pressure

The amount of water vapor in the atmosphere is expected to increase in a warming climate (by about seven percent for each °C of warming), since higher temperatures allow more evaporation and a higher saturation equilibrium between air and water. At Blue Hill, the water vapor amount is measured indirectly through psychrometric readings of dry bulb and wet bulb temperatures, which are converted to dew point temperature and relative humidity. As the temperature to which the air with a given amount of moisture must be chilled to saturate the air, the dew point is only an indirect measure of atmospheric moisture. As the name implies, the relative humidity is relative to temperature, and so it also is not an absolute measure of water vapor. However, through a complex relationship, the dew point can be converted to a water vapor pressure, in millibars, which represents

the actual pressure that water vapor in the air contributes to the total surface pressure. Thus, the vapor pressure is a more direct measure of water vapor in the air.

At the Observatory, the annual mean water vapor pressure (since 1932) is just under 10 mb, which is roughly one percent of the total mean sea level pressure near 1015 mb. Throughout the year, water vapor pressure measurements at Blue Hill vary from less than 1 mb (under one-tenth of a percent of the total pressure) on very cold and dry winter days to nearly 30 mb (or about three percent of the total pressure) on very warm and humid summer days. Figure 19 shows the annual mean water vapor pressure for the years 1891 to 1912 and 1932 to present along with the smoothed running means. Water vapor pressure data for 1913-1931 are excluded, since the continuity of the data during those years is under review. Figure 20 shows the Blue Hill mean water vapor pressure for winter and spring, and Figure 21 shows the mean vapor pressure for summer and autumn. For the period since 1932, the 30-year running mean shows increases in water vapor pressure in all seasons, especially in the last few decades, consistent with the rising temperature. Large decadal variations are also apparent, particularly in spring and summer.

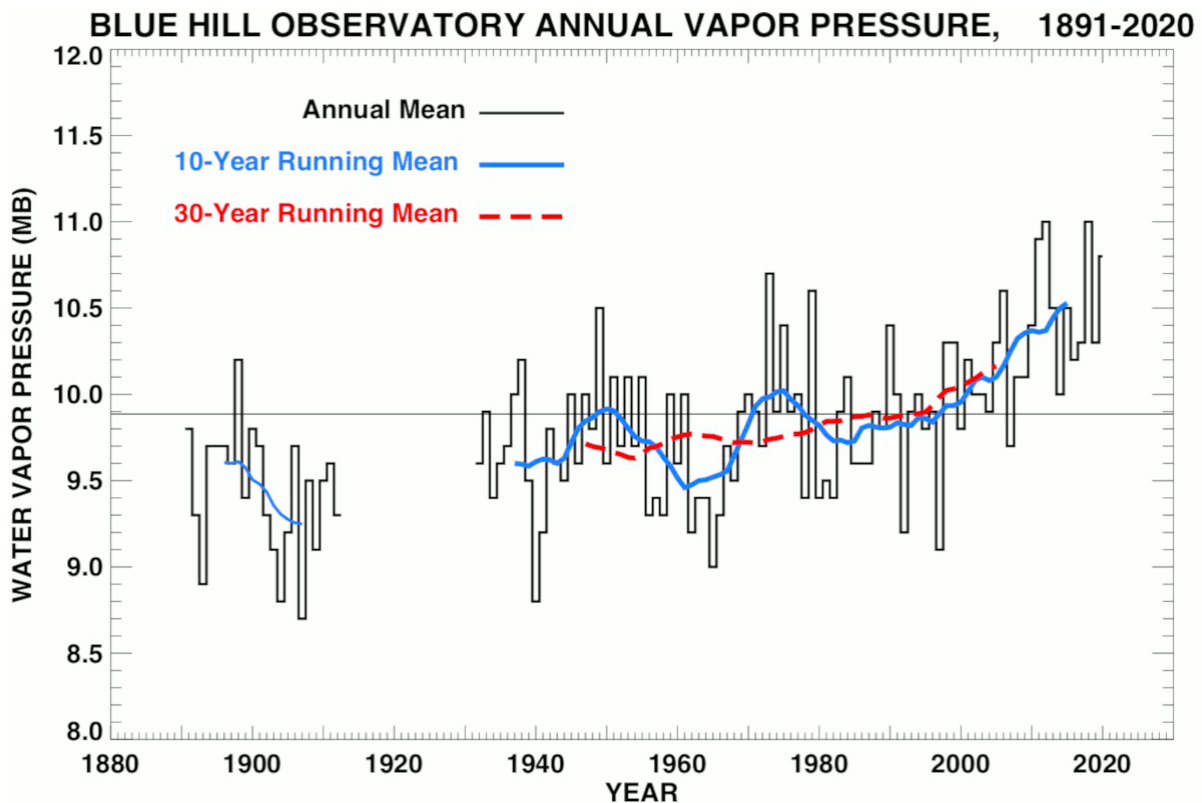


Figure 19. Blue Hill Observatory annual mean water vapor pressure (black, histogram) derived from dew point temperature measurements taken on the summit of Great Blue Hill (1891-present). Units are labeled in millibars. Centered running means are also shown for 10-year (blue, solid) and 30-year (red, dashed) periods. The thin horizontal line is the 1932-2020 mean.

Is the increase in vapor pressure consistent with the observed temperature change? Since the early 1930's, the 10-year mean water vapor pressure has increased by about 9.4 percent from 9.6 to 10.5 mb (blue curve in Figure 19), while over the same time period the annual mean temperature has increased by about 1.8 °C (from 8.3 to 10.1 °C; blue curve in Figure 1). Thus, as the climate has warmed since the mid-20th century, the atmospheric

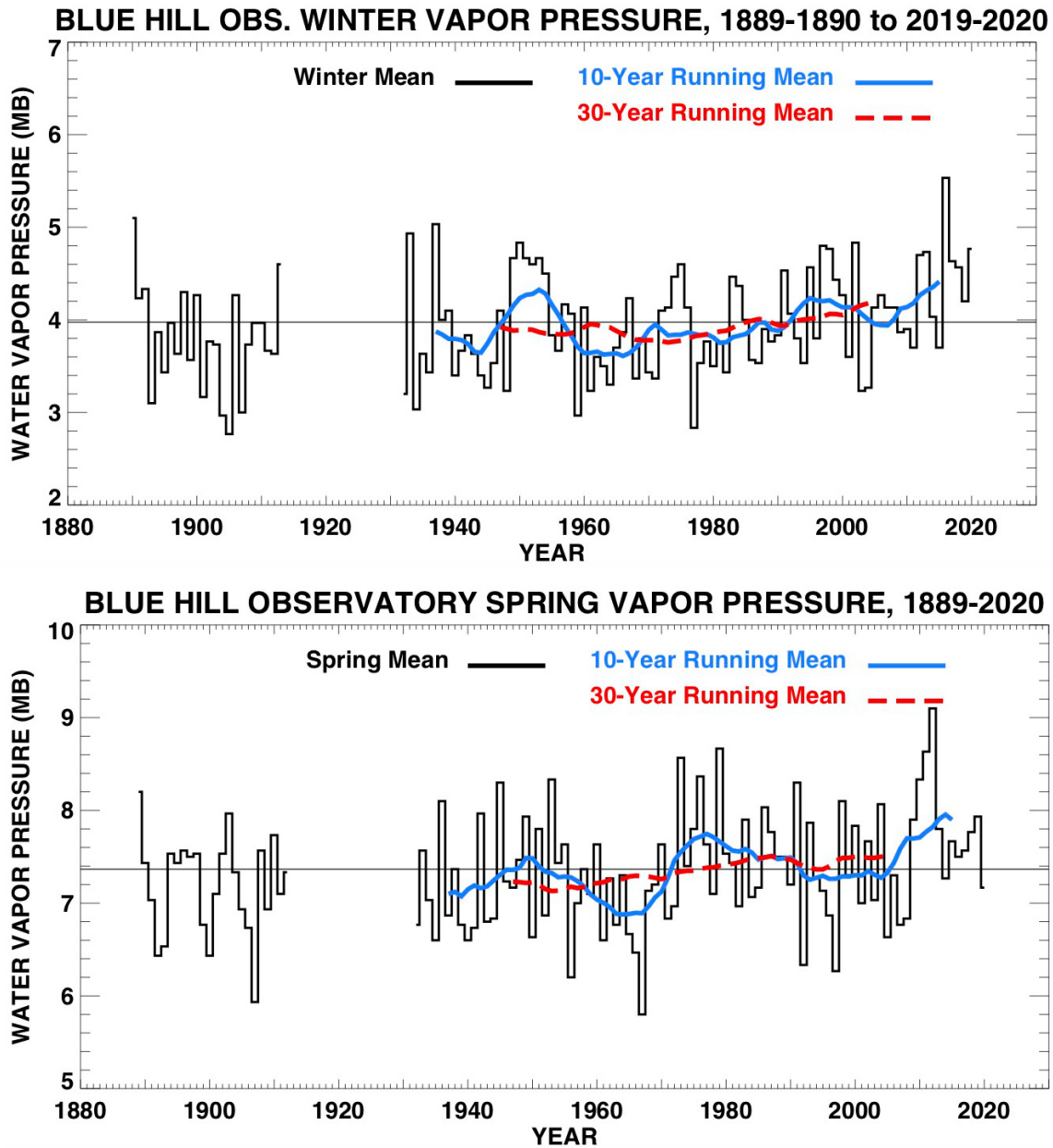


Figure 20. Blue Hill Observatory water vapor pressure (black, histogram) during the three winter months (top) and the three spring months (bottom) from measurements taken on the summit of Great Blue Hill. Units are in millibars. Centered running means are also shown for 10-year (blue, solid) and 30-year (red, dashed) periods. The thin horizontal line represents the mean over the years 1932-present.

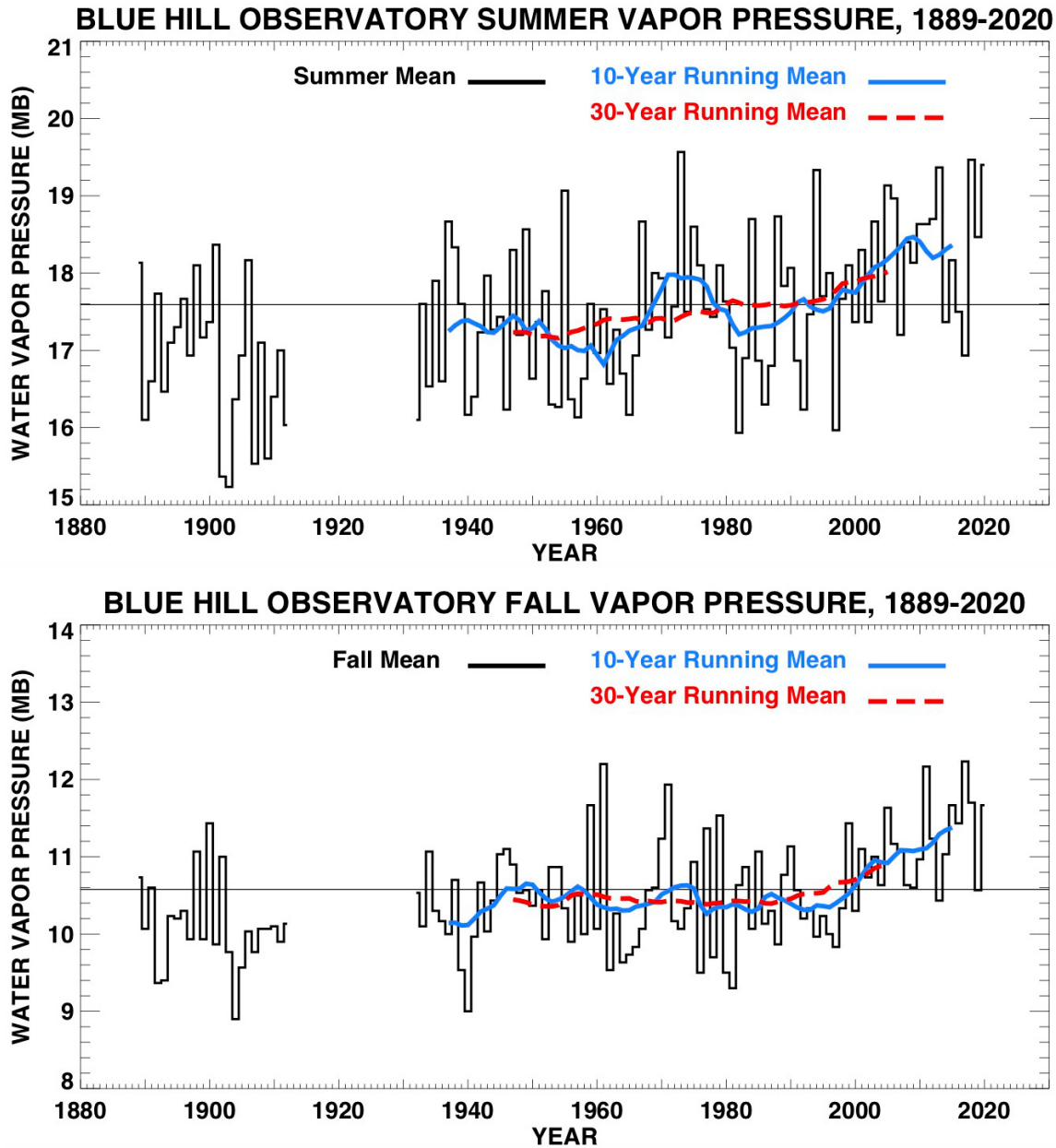


Figure 21. Blue Hill Observatory water vapor pressure (black, histogram) during the three summer months (top) and the three autumn months (bottom) from measurements taken on the summit of Great Blue Hill. Units are millibars. Centered running means are also shown for 10-year (blue, solid) and 30-year (red, dashed) periods. The thin horizontal line represents the long-term mean over the years shown.

water vapor has increased by about 5.2 percent per °C of temperature change, which is somewhat less than but consistent with the theoretically expected value of seven percent per °C. These data provide further evidence of the ongoing climate changes at BHO in both annual and seasonal means, and the connections that are apparent among the extensive set of parameters observed at Blue Hill.

The long duration of the Blue Hill climate record provides an essential context in which to study climate changes and these data are especially well-suited to this effort, since several decades or more 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.

[For more information about the Blue Hill measurements, observing practices, history and educational programs, visit the Observatory web site at bluehill.org/observatory.]