AGU FALL MEETING
Chicago, IL & Online Everywhere
12–16 December 2022

ATMOSPHERIC SCIENCES GENERAL SESSION:
ATMOSPHERIC DYNAMICS & CLIMATE IV - POSTER # A51G-02

LONG-TERM DECLINING TRENDS IN HISTORICAL WIND MEASUREMENTS AT THE BLUE HILL METEOROLOGICAL OBSERVATORY, 1885-2021

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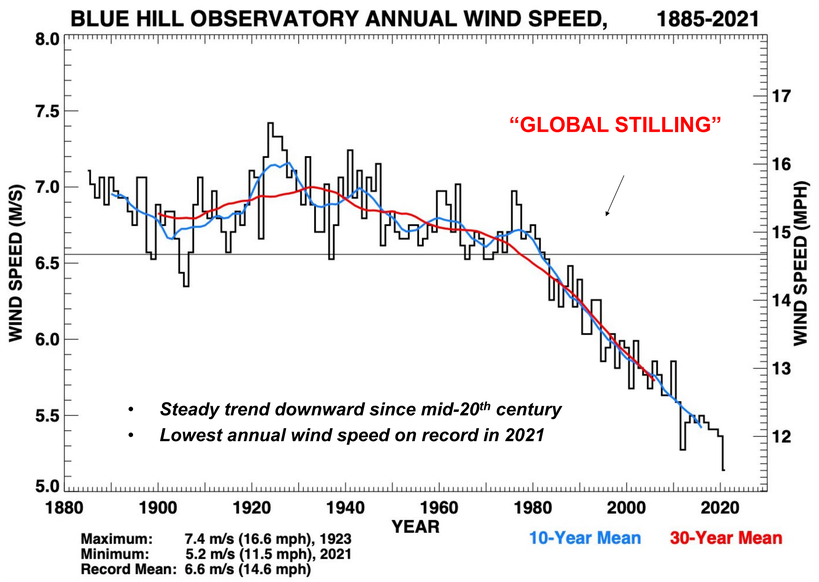
ABSTRACT. The Blue Hill Meteorological Observatory, located on the 635-foot summit of Great Blue Hill ten miles south of Boston, Massachusetts, has been the site of continuous monitoring of the local weather and climate since its founding in 1885. The meticulous, extensive, and high-quality climate record maintained at this location has included the measurement of wind among many other parameters since its earliest days, and this provides a unique opportunity to examine seasonal and annual wind speed trends at this site over more than 135 years. Although multiple wind sensors have been in use during this time and the height of the anemometers was raised in 1908, the wind records have been made as consistent as possible through careful analysis of these changes and the application of adjustments to ensure consistency. An analysis of wind data homogeneity is being performed to associate statistical change points in monthly mean wind speeds to the documented wind instrument metadata. The running 30-year mean wind speed at Blue Hill Observatory has decreased from 7.0 m s^{-1} in the middle 20th century to its present value of 5.7 m s^{-1} with an increase in the rate of the decline beginning around 1980, and these changes persist in all seasons. The annual wind speed time series shows a significant ($p < 0.05$) downward trend over the entire period of record from 1885-2021 (-0.103 m s^{-1} $decade^{-1}$) that is steeper and is also significant for the sub-periods from 1961-2021 (-0.274 m s^{-1} $decade^{-1}$) and 1979-2012 (-0.339 m s^{-1} $decade^{-1}$; the lowest annual mean wind speed was recorded in 2021). In addition, daily wind data for the last 60-70 years have been digitized including wind speed, peak gust, fastest mile, and prevailing direction, and this detailed data provides further characterization of the wind changes in recent decades at this location. The declining wind speed trend at Blue Hill has significant implications for the efficiency of wind power generation in the area if it reflects a regional shift in the near-surface wind regime and for the analysis of causal changes in large-scale climate dynamics.

Blue Hill Observatory Wind Measurements

- **Location:** Summit of Great Blue Hill, Milton, Massachusetts (10 miles SSW of Boston)
- **Founder**: Abbott Lawrence Rotch on February 1, 1885
- **Elevation:** 635 feet (i.e. 194 meters) above mean sea-level
- **Wind series**: Longest continuous wind records in North America (1885 to present)
- **Monthly wind data**: Averaged from daily means derived from hourly measurements
- **Webpage**: For more information visit www.bluehill.org

Blue Hill Observatory's Program Director Don McCasland on the wind tower adding oil to the 1960s-era contacting anemometer, allowing wind records to continue using historically similar recording devices to those once available in the 1880s.

Annual and Seasonal Wind Speed Trends, 1885-2021



Wind Speed Metadata, Quality Control and Adjustments

High-quality near-surface wind series were obtained after (i) recovering meta information (from the BHO´s archives), (ii) passing some quality controls to remove aberrant data and to check for data consistency, and (iii) applying the following height adjustments:

Time Period	Anemometer Height	Anemometer Type	Wind Speed Recorder Type	Correction Applied
Feb. 1885 – Jun. 1908	34-35 feet (10.5-m)	Robinson 4-cup (USWB)	Draper recorder	Unknown
Jun. 1908 – Oct. 1931	50-52 feet (15.5-m)	Robinson 4-cup (USWB)	Draper recorder	Unknown
Oct. 1931 – Feb. 1940	52 feet (15.8-m)	3-cup (640 revs/mile)	Draper recorder	Eq. 1
Feb. 1940 – Oct. 1959	52 feet (15.8-m)	3-cup (640 revs/mile)	Draper recorder	Table 1
Oct. 1959 – Jul. 1994	52 feet (15.8-m)	NWS 3-cup (660 revs/mile)	Esterline-Angus contacting chart recorder	Eq. 2
Jul. 1994 – Present	52 feet (15.8-m)	NWS 3-cup (640 revs/mile)	Esterline-Angus contacting chart recorder	Table 1

(Eq. 1*) Corrected = (Recorded + 0.5508) / 1.019

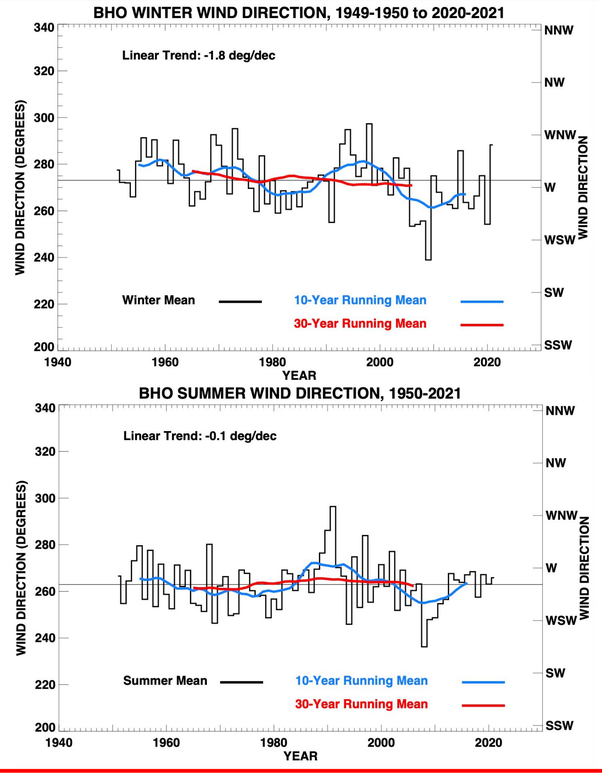
(Eq. 2*) Corrected = (Recorded · 1.03 + 0.5508) / 1.019 **

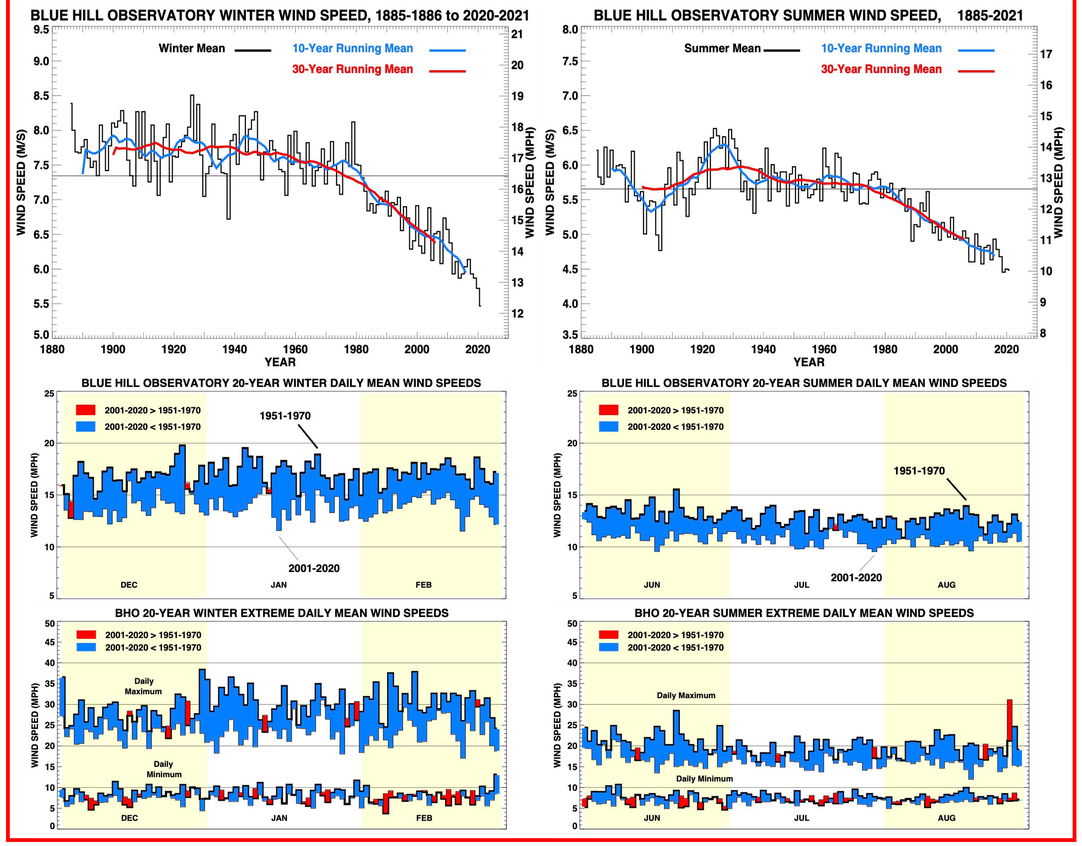
* Applied to monthly wind speed data.
** Note: Scaling factor of 1.03 in Eq. 2 comes from ratio of gear speeds (660/640)

Table 1. Hourly Wind Speed Corrections

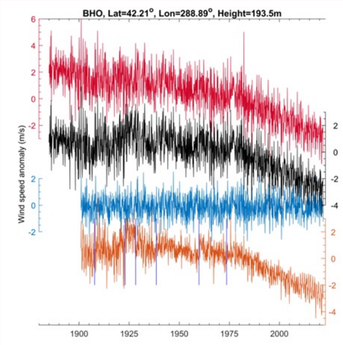
Speed (mph)	Correction (mph)
0-10	+1
11-41	0
42-54	-1
55-66	-2
67-77	-3
78-85	-4
86-94	-5
95-102	-6

Seasonal Wind Direction Trends, 1950-2021





Annual Wind Speed Homogeneity Testing



We performed an analysis of the annual wind speed homogeneity using the **Penalized Maximal *F* Test** (PMFT) method (*Wang*, 2008) to identify potential disruptions in the mean data that are unrelated to linear trend changes.

RED: Homogenized BHO Annual Wind Speed
BLACK: Raw BHO Annual Wind Speed
BLUE: CERA-20C & ERA5 Wind Speed (at BHO)
BROWN: Black - Blue

PMFT Breakpoint Dates	Likely Cause
October 1907	Height Change
January 1923	Unknown
April 1928	Unknown
August 1938	Unknown
November 1959	Recorder Change
September 1973	Unknown

Summary

The 30-year mean annual wind speed as measured at the Blue Hill Observatory has dropped by about 15 percent over the last forty years. After remaining in a range of 6-7 m/s for much of the last century, the annual average wind speed began a slow decline in the mid-20th century that has steepened significantly since 1980 to a record low value for any year of 5.2 m/s in 2021. This downward trend is observed in all seasons and months, being strongest in winter. The mean wind direction in winter has shifted about ten degrees over the last seventy years.

The precise cause of this local reflection of "global stilling" (termed by *Roderick et al.* 2007) remains largely uncertain and preliminary results show a weak influence from changes in the large-scale atmospheric dynamics. Further research is needed on this cause, but also on the hypothetical role played by, for example, an upward trend in land surface roughness due to an increase in vegetative biomass, land use changes and urbanization across the continental United States.