LONG-TERM DECLINING TRENDS IN HISTORICAL WIND MEASUREMENTS AT THE BLUE HILL METEOROLOGICAL OBSERVATORY, 1885-2013

MICHAEL J. IACONO[1,2] and CESAR AZORIN-MOLINA[3]
(1)Atmospheric and Environmental Research, Lexington, MA, USA (miacono@aer.com)
(2) Blue Hill Meteorological Observatory, Milton, MA, USA
(3) Instituto Pirenaico de Ecología, Agencia Estatal Consejo Superior de Investigaciones Científicas (IPE-CSIC), Zaragoza, Spain (cazorin@ipe.csic.es)

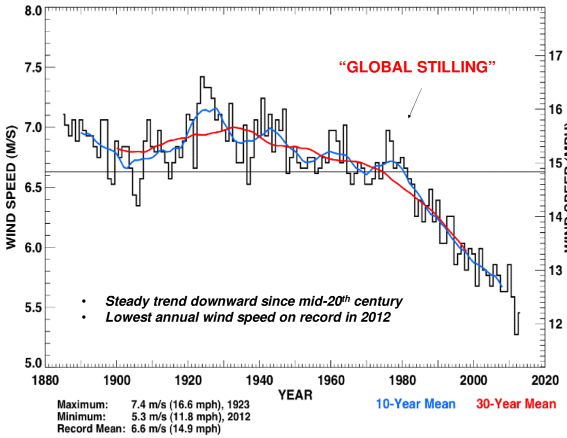
ABSTRACT. The Blue Hill Meteorological Observatory, located on the 635-foot summit of Great Blue Hill ten miles south of Boston, Massachusetts (MA), has been the site of continuous monitoring of the local weather and climate since its founding in 1885. The meticulous, extensive and high-quality climate 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 wind speed trends at this site over nearly 130-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. The 30-year mean wind speed at this location has decreased from 6.8 m s^{-1} in the middle 20th century to its present value of 6.0 m s^{-1} with an increase in the rate of the decline beginning around 1980. The wind speed time series shows a significant (p<0.01) downward trend over the entire period from 1885-2013 (-0.088 m s^{-1} decade^{-1}) that is stronger and also significant for the sub-periods from 1961-2013 (-0.268 m s^{-1} decade^{-1}; p<0.01) and 1979-2008 (-0.341 m s^{-1} decade^{-1}; p<0.01). This declining trend persists in all seasons and has significant implications for the efficiency of wind power generation in the area, if it reflects a regional change in the near-surface wind regime. Preliminary analysis of the influence of large-scale atmospheric circulation is presented (a very weak impact of the North Atlantic Oscillation index and other northern hemisphere teleconnection patterns is found) in the context of global stilling (i.e. the theory of a widespread decline in measured near-surface wind speed), including an analysis of the wind speed change as a function of wind direction.

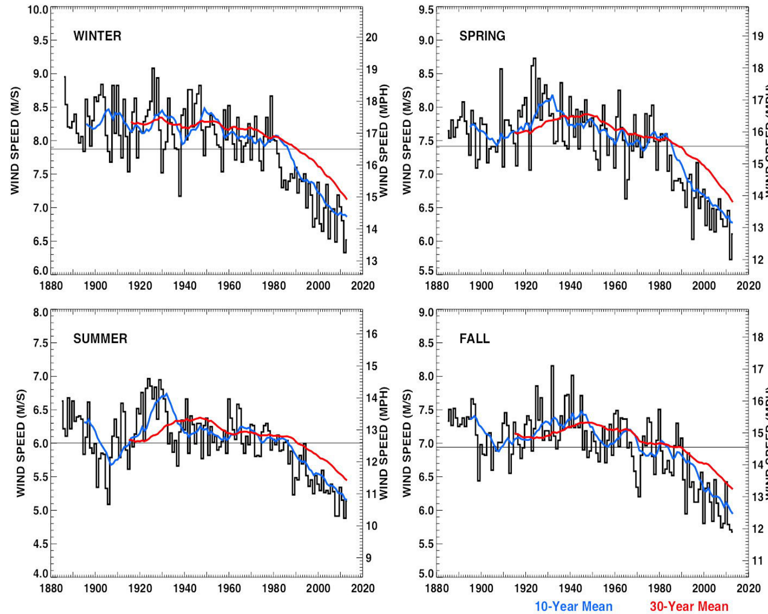
Blue Hill Observatory and Wind Data

- **Location:** Summit of Great Blue Hill, Milton, MA (10 miles -16 km- SSW of Boston)
- **Founder**: by Abbott Lawrence Rotch on February 1, 1885.
- **Elevation:** 635 feet (i.e. 194 meters) above mean sea-level.
- **Wind series**: Longest continuous wind record in North America (1885 to present).
- **Monthly wind data**: averaged from daily means derived from 24-hourly measurements.
- **Webpage**: for more information visit http://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, 1885-2013





Metadata, Quality Control and Adjustments

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

130-yr Wind Speed Trends

Periods	1885-2013	1961-2013	1979-2008
Annual	-0.088**	-0.268**	-0.341**
Winter (DJF)	-0.106**	-0.286**	-0.404**
Spring (MAM)	-0.097**	-0.304**	-0.358**
Summer (JJA)	-0.064**	-0.232**	-0.284**
Fall (SON)	-0.082**	-0.244**	-0.360**
January	-0.107**	-0.341**	-0.382**
February	-0.123**	-0.293**	-0.422**
March	-0.112**	-0.287**	-0.352**
April	-0.099**	-0.326**	-0.476**
May	-0.078**	-0.299**	-0.246**
June	-0.068**	-0.264**	-0.381**
July	-0.070**	-0.200**	-0.184*
August	-0.054**	-0.231**	-0.286**
September	-0.064**	-0.244**	-0.291**
October	-0.083**	-0.222**	-0.244*
November	-0.098**	-0.266**	-0.544**
December	-0.094**	-0.246**	-0.289**

Annual, seasonal and monthly wind speed trends at the BHO for 1885-2013, 1961-2013 and 1979-2008 (to be compared with Vautard et al. 2010). Values are expressed as m s^{-1} dec^{-1}. Statistically significant trends were defined as those p <0.05 (*) and p <0.01 (**).

The computation of **running 30-year trends** revealed the most downward and upward wind speed periods:

Annual: -0.397** (1976-2005) ; 0.202** (1898-1927)

Winter: -0.447** (1976-2005) ; 0.102** (1919-1948)

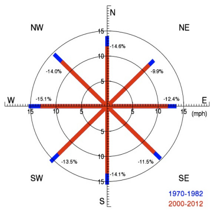
Spring: -0.457** (1976-2005) ; 0.280** (1901-1930)

Summer: -0.321** (1976-2005); 0.427** (1901-1930)

Fall: -0.350** (1979-2008) ; 0.186** (1899-1928)

It is noticeable that increasing wind speed trends occurred in the beginning of the past century (this was a period when maintenance of the instruments was less rigorous than earlier and later years), whereas wind speed has declined ("global stilling") since late of the 1970s for all periods.

Wind Speed Trends by Wind Direction



Annual mean wind speed by wind direction for 1970-1982 (in blue) *vs.* 2000-2012 (in red), derived from daily mean wind speeds and prevailing wind directions.

- Percent wind speed decrease between time periods (1970-1982 *vs.* 2000-2012) is larger for S (-14.1%), SW (-13.5%), W (-15.1%), NW (-14.0%) and N (-14.6%) directions, than for NE (-9.9%), E (-12.4%) and SE (-11.5%).
- May indicate larger impact from reforestation over continental US or shifts in circulation rather than intensity of ocean storms.

Large-scale Atmospheric Influence

We evaluated the impact of the large-scale atmospheric circulation on the wind speed variability by analyzing the North Atlantic Oscillation (NAO) index. Preliminary analysis in the table below shows that the NAO exerted a weak and non-significant relationship (with a few exceptions indicated by * p<0.05 and ** p<0.01) with the wind speed variability at BHO.

Periods	R-Pearson	Sig.
Annual	-0.076	0.389
Winter (DJF)	-0.106	0.230
Winter (DJFM)	-0.154	0.081
Spring (MAM)	-0.120	0.177
Summer (JJA)	0.136	0.125
Fall (SON)	-0.128	0.147

Hurrell NAOi station based

Periods	R-Pearson	Sig.
Annual	0.180	0.041*
Winter (DJF)	-0.026	0.768
Winter (DJFM)	-0.083	0.352
Spring (MAM)	-0.066	0.458
Summer (JJA)	0.188	0.033*
Fall (SON)	0.000	0.997

CRU NAOi station based

We also analyzed other northern hemisphere teleconnection patterns available at http://www.cpc.ncep.noaa.gov/data/teledoc/telecontents.shtml obtaining the following R-Pearson and statistical significance: EA (-0.179**), WT (0.082*), EP/NP (0.049), PNA (-0.138**), EA/WR (0.02), SCA (0.108**), TNH (-0.048), POL (0.133**), and PT (-0.116).

Summary and Discussion

The annual mean wind speed as measured at the Blue Hill Observatory has dropped by more than ten percent over the last thirty years. After remaining in a range of 6-7 m s^{-1} 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 5.3 m s^{-1} in 2012. This downward trend is observed in all seasons and months, being stronger in winter.

The precise cause of this "global stilling" (termed by Roderick et al. 2007) remains largely uncertain and preliminary results show a weak contribution from changes in the large-scale atmospheric circulation. Further research is needed on the cause, but also on the hypothetical role played by e.g. the upward trend in land surface roughness due to an increase in vegetative biomass, land use changes and urbanization in the continental US.

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