# Climatology of Tropical Cyclones in New England and Their Impact at the Blue Hill Observatory, 1851-2009

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## Introduction

Over the past four centuries, extreme hurricanes have occurred in New England at intervals of roughly 150 years, as evidenced by the three powerful storms of 1635, 1815, and 1938. Histories and personal accounts of these infamous hurricanes make for fascinating reading (*Ludlum*, 1963; *Minsinger*, 1988), and they serve as an important reminder of the devastating impact that tropical cyclones can have in the Northeast. Most tropical systems in New England are less damaging, but they can still disrupt our daily lives with strong winds, heavy rain, and flooding. This article, which updates an earlier report in the Blue Hill Observatory Bulletin (*Iacono*, 2001), will describe the climatology of all 247 tropical cyclones that have affected New England since the mid-19$^{th}$ century and will summarize their intensity, frequency, and specific meteorological impact at the Blue Hill Observatory.

A hurricane is a self-sustaining atmospheric process in which sunlight, water, and wind combine to transfer energy from the tropics to higher latitudes. The uneven distribution of solar heating at the Earth's surface ultimately drives much of our weather as the atmosphere continually circulates to equalize the tropical warmth and the polar cold. In the tropics, this process is normally tranquil and slow, brought about through the life cycles of individual thunderstorms, the prevailing winds, and ocean currents. However, under the right conditions very warm air and water in the tropics trigger the formation of the most efficient heat transfer mechanism available to the atmosphere: a hurricane. Tremendous amounts of water are evaporated from the ocean during the development and mature stage of a tropical cyclone. This cools the ocean surface, and cloud cover temporarily contributes to this cooling by reducing the solar heating at the surface. However, as clouds and rain form, this water vapor is lifted into the atmosphere and converted back to liquid water, which transfers heat to the air. This process, called condensational heating, encourages upward motion that causes surface pressure to drop. Winds at the surface pick up more water vapor while rushing into the center of the storm to replace the rising warm air. Many hurricanes eventually carry this heat energy out of the tropics and distribute it at higher latitudes.

By the time tropical cyclones affect New England, their strength or path usually have been influenced in some way by the prevailing winds and synoptic features present at mid-latitudes such as the jet stream, cold fronts, or areas of high pressure (anticyclones). More often than not, one or more of these features are present to guide cyclones either toward or away from New England. One typical result of this interaction causes tropical systems to move northward at much higher speed than their usual speed in the tropics. This may allow the storm to reach New England before its passage over colder water weakens it substantially, and this large forward speed typically enhances its damaging impact. For example, the Great New England Hurricane of 1938 was racing northward with an incredible forward speed of about 50 miles per hour when it reached Long Island, as a strong anticyclone to its east and a deepening trough to its west guided this powerful hurricane directly into New England.

On other occasions, mid-latitude weather conditions have protected the area from hurricanes. On September 21, 1961, Hurricane Esther was moving northeastward along the East Coast at a forward speed of 15 mph and came within hours of making landfall on Cape Cod as a Category 3 hurricane with winds in excess of 120 mph. Weather in the vicinity, possibly an approaching cold front, forced the hurricane to turn sharply eastward sparing the area extensive damage. The cyclone weakened rapidly to a tropical storm in less than 12 hours, though it still caused strong winds and heavy rain. Esther then turned to the southeast, made a large clockwise loop that carried it most of the way to Bermuda, and returned northward to cross Cape Cod five days later as a tropical storm. Due to its peculiar and instructive interaction with surrounding weather systems, Hurricane Esther easily wins the award for the most unusual storm track of any major tropical cyclone to affect New England since the mid-19$^{th}$ century.

Surface features also contribute to the eventual impact of a tropical cyclone. Of course, as a tropical system moves over land it is separated from the warm ocean water critical to its survival, and it begins to dissipate. Elevated terrain quickens the decline further by disrupting the vertical structure of the storm, while forcing surface air upward and locally increasing both rainfall and wind speeds. This orographic enhancement noticeably increases rainfall at Blue Hill, which on average receives about 5% more precipitation than nearby stations. Higher wind speeds are especially likely from the south or southeast, since glacial erosion left that side of Blue Hill steepest, thus allowing southerly winds to climb the hill with less slowing due to friction. Competing with this effect is the advancing growth of vegetation on Blue Hill, which has likely contributed to reducing annual mean wind speeds in recent decades (Iacono, 2000). The effect of this tree growth on wind gusts and rainfall has not yet been studied.

**Data**

A recently updated archive of Atlantic tropical cyclones, which dates back to 1851, has made it possible to analyze tropical cyclone activity for the last 150 years. Prepared by Colorado State University and the National Hurricane Center (NHC) and based on a National Oceanic and Atmospheric Administration (NOAA) database, this hurricane database (HURDAT) is the most complete listing available of the location and intensity of tropical systems (*Landsea* et al., 2004). This database has been used to select the New England tropical cyclones that are examined here. It should be noted that although aircraft flights into hurricanes are commonly used to take storm measurements today, this did not occur on a regular basis until the 1940s. As a result, tropical cyclone data prior to this period are considered to be incomplete. Thus, statistics based on these data should be used cautiously and the results described in this article should be interpreted in this context. The hurricane archive and further information about it are available at the NHC web site (www.nhc.noaa.gov) and the Unisys web site (weather.unisys.com).

The climate records of the Blue Hill Observatory provide a means of examining the local impact of tropical systems at the same location for an extended time. Renowned for the duration and homogeneity of its records, the 125-year-old Observatory is located at the 635-foot summit of Great Blue Hill in Milton, ten miles south of Boston. While not as elevated as the interior mountains of New England, Blue Hill is located on the coastal plain of eastern Massachusetts, which offers it greater exposure to ocean storms. Measurements of precipitation (since 1885) and extreme wind gusts (since

1938) were obtained from the published Blue Hill records for the last 40 years and from the original hand-written observation books for the earlier years. All of the weather records used in this study are available for use at the Observatory.

**Climatology**

The long-term characteristics and frequency of tropical systems in New England can be demonstrated in several ways. For the purposes of this paper, tropical cyclones are divided into three intensity categories and three location categories. For intensity, systems are grouped into hurricanes (H; maximum sustained surface wind speed of 74 mph or greater), tropical storms (TS; wind speed of 39-73 mph), and tropical depressions/extra-tropical storms (TD/ET). All storms are categorized by their strength at their closest approach to Blue Hill, not their maximum intensity. The list of 247 tropical cyclones includes all storms from 1851 to 2009 that retained tropical characteristics while passing through the geographic area around New England bordered by 37N – 47N and 67W - 77W. Cyclones are further grouped by location as storms that made direct landfall in New England or Long Island, NY (Type I), storms that made landfall elsewhere in the United States and later passed through the defined area (Type II), and storms in which the center remained entirely offshore while crossing this area (Type III). Storms that entered the above geographic region and caused both no measurable precipitation and a wind gust less than 35 mph at Blue Hill were excluded. It is assumed that storms that did not enter this geographic region had negligible effect on New England.

## Tropical Cyclones That Affected New England, 1851-2009

| | All Types | | | | New England Landfall (Type I) | | | |
|---|---|---|---|---|---|---|---|---|
| Decade | H | TS | TD/ET | Total | H | TS | TD/ET | Total |
| 1851-1860 | 8 | 7 | 0 | 15 | 1 | 1 | 0 | 2 |
| 1861-1870 | 13 | 7 | 0 | 20 | 2 | 1 | 0 | 3 |
| 1871-1880 | 9 | 10 | 3 | 22 | 1 | 0 | 1 | 2 |
| 1881-1890 | 8 | 15 | 1 | 24 | 0 | 4 | 0 | 4 |
| 1891-1900 | 10 | 4 | 5 | 19 | 2 | 2 | 1 | 5 |
| 1901-1910 | 1 | 0 | 5 | 6 | 0 | 0 | 1 | 1 |
| 1911-1920 | 1 | 1 | 3 | 5 | 1 | 0 | 0 | 1 |
| 1921-1930 | 1 | 2 | 5 | 8 | 0 | 1 | 0 | 1 |
| 1931-1940 | 7 | 3 | 6 | 16 | 1 | 0 | 3 | 4 |
| 1941-1950 | 3 | 6 | 4 | 13 | 1 | 0 | 1 | 2 |
| 1951-1960 | 10 | 5 | 7 | 22 | 3 | 1 | 1 | 5 |
| 1961-1970 | 7 | 4 | 2 | 13 | 0 | 1 | 1 | 2 |
| 1971-1980 | 2 | 5 | 3 | 10 | 1 | 1 | 0 | 2 |
| 1981-1990 | 1 | 6 | 3 | 10 | 1 | 0 | 1 | 2 |
| 1991-2000 | 5 | 7 | 10 | 22 | 1 | 1 | 1 | 3 |
| 2001-2009 | 4 | 4 | 14 | 22 | 0 | 3 | 2 | 5 |
| Total | 90 | 86 | 71 | 247 | 15 | 16 | 13 | 44 |

**Table 1**: Number of tropical cyclones that affected New England per decade since 1851. 'All Types' includes storms making direct landfall in New England or Long Island (Type I), those making landfall elsewhere in the United States and later crossing New England (Type II), and those passing closely offshore (Type III). The four columns at right list the Type I storms only. (H: Hurricane; TS: Tropical Storm; TD/ET: Tropical Depression/Extra-Tropical Storm).

A listing of the number of tropical cyclones to affect New England for each decade since the 1850's is shown in Table 1. All three types are combined in the first four columns, while Type I storms only are shown in the four columns at right. A number of interesting things jump out of this table. Of the 247 total tropical cyclones, 15 hurricanes and 16 tropical storms have made direct landfall during this time period. Hurricanes and tropical storms affect New England in about equal numbers. The rate of hurricane landfall in New England over the last 150 years is once per decade, while general tropical activity occurs at a rate of 1-2 per year. Note that Esther is counted as both a Type III hurricane and a Type I tropical storm, since it impacted New England twice at different strengths within several days.

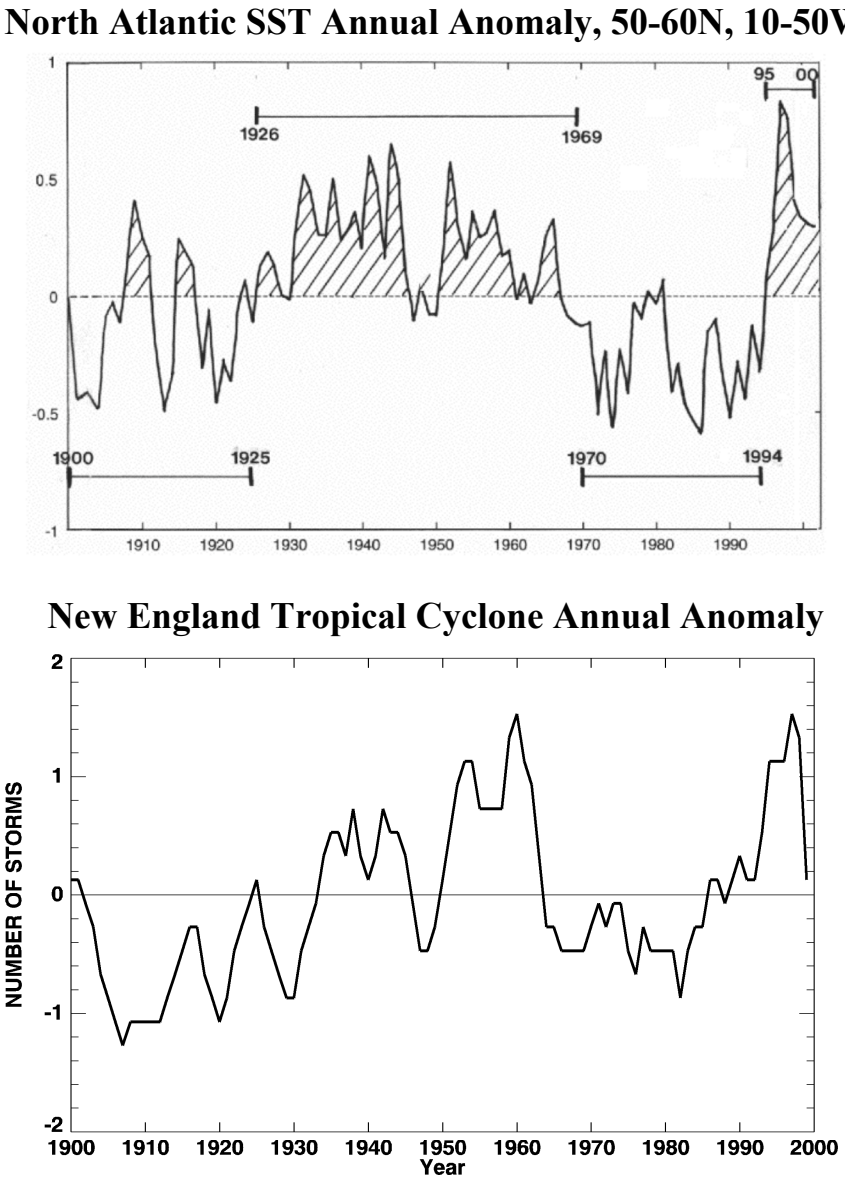


**Figure 1:** Annual anomalies of North Atlantic sea surface temperature in deg. C (top panel) from *Gray et al.* (2000). 5-year running mean of annual number of tropical cyclones affecting New England (bottom panel) plotted as an anomaly from the 1901-2000 average of 1.25 cyclones per year (see Table 1).

Also, there is a distinct enhancement of tropical activity during two periods: the 1860s to 1890s and the 1930s to 1960s. This is especially apparent when all types are considered, since the number of landfalling storms alone is too small to support this inference. Two cycles are not sufficient to establish a pattern, but these data suggest a roughly 70-year cycle in New England tropical activity over this time period.

A more scientific means of establishing the presence of a cycle in Atlantic tropical activity is to determine whether physical processes exist that can produce one. Although many processes influence tropical cyclone development (e.g. El Nino, West African rainfall, vertical wind shear, etc.), North Atlantic sea surface temperature (SST) is discussed as an example. The upper panel in Figure 1 shows annual anomalies of SST in the North Atlantic south of Greenland over the last century. Warmer than average water in this region is associated with higher salinity. The greater salt content makes the water more dense, which causes it to sink. Surface water is replaced by warm, salty water from lower latitudes, while the cold, dense water on the ocean floor moves southward. This increased thermohaline circulation in the ocean induces warmer water over the tropical Atlantic, which enhances cyclone development. It also produces greater flow of northward moving warm water, which allows cyclones to move from the tropics and survive at higher latitudes. This condition existed in the Atlantic through much of the 1930s

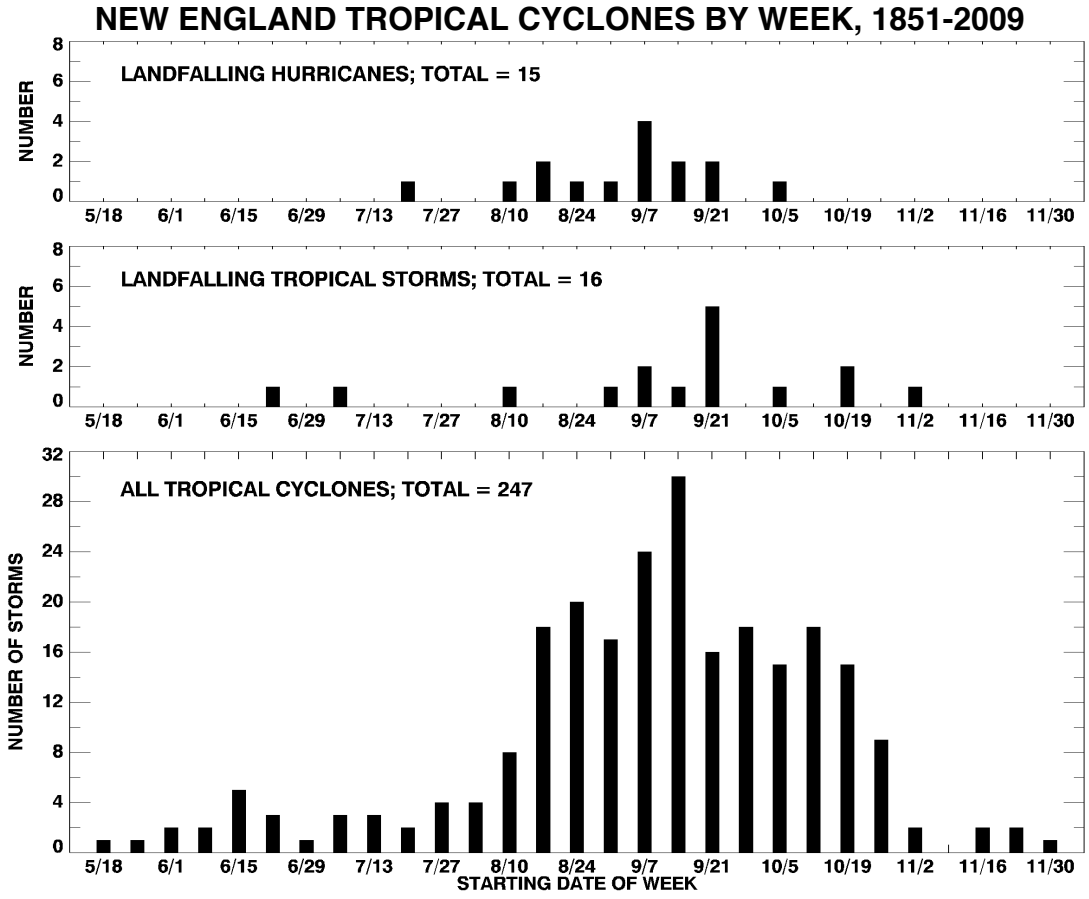


**Figure 2**: Weekly distribution of 15 landfalling New England hurricanes (top), 13 landfalling tropical storms (middle), and all 247 tropical cyclones (bottom) that have affected New England since 1851. The number of storms in each week is plotted on the first day of the week for the June to November Atlantic hurricane season.

to 1960s, and it corresponds closely to the period of more frequent tropical activity in New England shown in the lower panel of Figure 1. Conversely, a weaker thermohaline circulation existed from 1900-1925 and from 1970-1994, and this may have contributed to the lower frequency of cyclones during those decades. Note that the thermohaline circulation has begun to strengthen in recent years, and this partly explains the returning pattern of increased tropical activity since the mid-1990s (*Gray et al.*, 2000).

The standard hurricane season in the Atlantic Ocean extends from June 1 to November 30, and only four storms have affected New England outside this period. However, cyclone frequency varies substantially during the season. Figure 2 shows the weekly distribution of tropical activity during the hurricane season. Landfalling hurricanes (top plot) have occurred most frequently during the second week of September, which is close to the traditional peak of the hurricane season in the Atlantic. The earliest occurred on July 19, 1916, and the latest arrived on October 5, 1869. The 16 tropical storms to make landfall in New England (middle plot) tend to distribute earlier and later than hurricanes, with a few in late June and a peak in late September. The earliest made landfall on June 22, 1972 (Agnes) and the latest came ashore on November 3, 1861. The distribution of all New England tropical cyclones (bottom

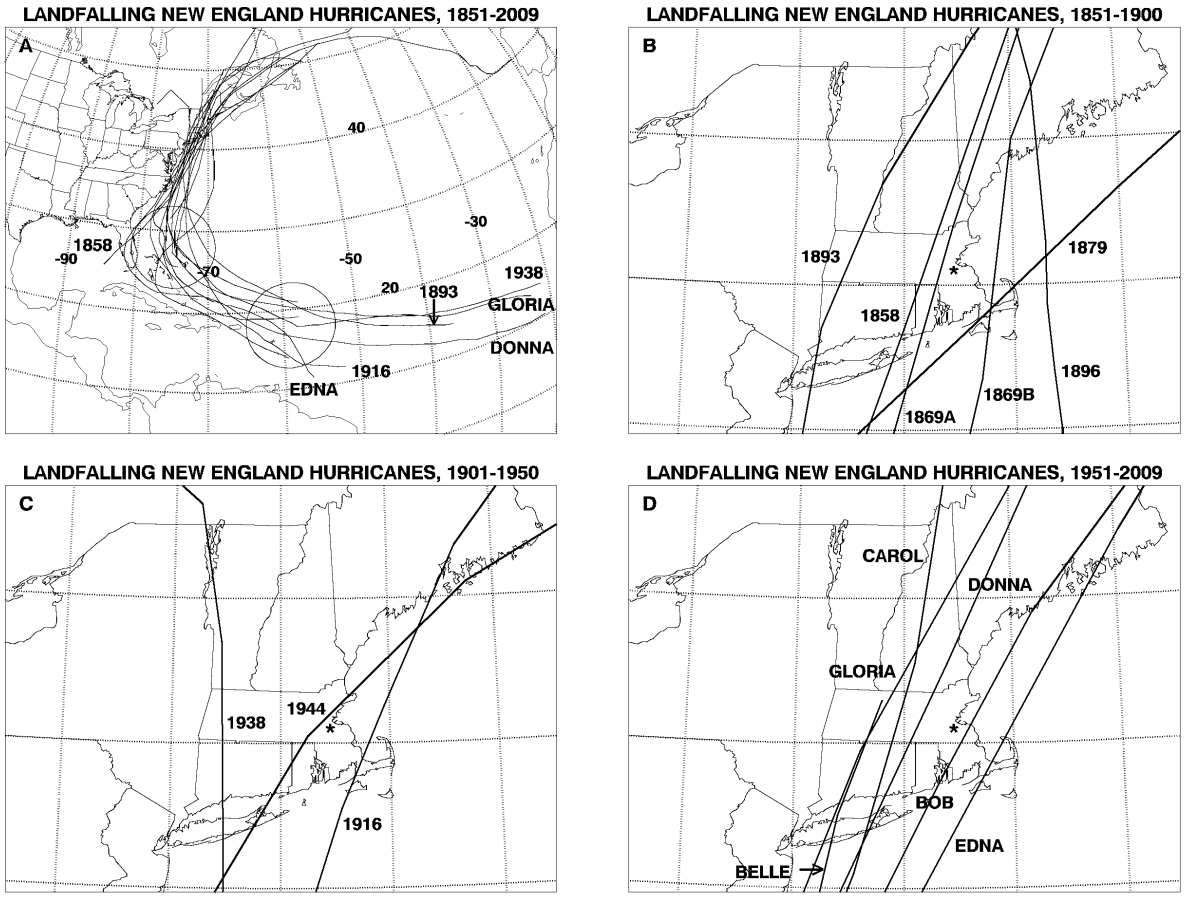


**Figure 3**: Storm tracks of all 15 hurricanes that have made direct landfall in New England or Long Island since 1851 are shown over the entire Atlantic basin (a) and over New England for three multi-decade intervals, (b) 1851-1900, (c) 1901-1950, and (d) 1951-2009. The large circles in (a) indicate the formation areas for the eight hurricanes that are not labeled on the plot and are identified in the text. The asterisk ('*') shows the location of the Blue Hill Observatory.

## New England Landfalling Hurricanes, 1851-2009

| Date | Name | Intensity Category | Forward Speed (mph) | BHO Rainfall (inches) | BHO Peak Gust (mph) | Track with respect to BHO |
|---|---|---|---|---|---|---|
| 9/16/1858 | 1858 | 1 | 35 | - | - | W |
| 9/8/1869 | 1869A | 3 | 47 | - | - | O |
| 10/5/1869 | 1869B | 2 | 36 | - | - | E |
| 8/19/1879 | 1879 | 1 | 31 | - | - | E |
| 8/24/1893 | 1893 | 1 | 23 | 0.31 | N/A | W |
| 9/10/1896 | 1896 | 2 | 10 | 4.37 | N/A | E |
| 7/21/1916 | 1916 | 1 | 14 | 0.66 | N/A | E |
| 9/21/1938 | 1938 | 3/ET | 50 | 0.13 | 186 S | W |
| 9/15/1944 | 1944 | 3 | 29 | 3.67 | 96 E* | O |
| 8/31/1954 | CAROL | 3 | 34 | 2.46 | 125 SE | W |
| 9/11/1954 | EDNA | 3 | 45 | 5.23 | 101 NW | E |
| 9/12/1960 | DONNA | 2 | 24 | 2.79 | 140 SSE | W |
| 8/10/1976 | BELLE | 1 | 20 | 2.72 | 88 S* | W |
| 9/27/1985 | GLORIA | 2 | 44 | 0.40 | 100 SSE | W |
| 8/19/1991 | BOB | 2 | 31 | 2.58 | 78 ENE | O |

**Table 2**: Descriptive information for all 15 Type I hurricanes to make direct landfall in New England since 1851. Intensity at landfall is based on the Saffir-Simpson scale of hurricane intensity, and forward speed of storm center is at landfall (Vallee, 2000). Storm total precipitation recorded at Blue Hill is listed for hurricanes since 1885, and extreme wind gusts are listed since 1938 (gusts marked with '*' were estimated from available records). Location of storm track relative to Blue Hill, i.e. passing either west (W), east (E), or overhead within 20 miles (O), is also shown.

plot) shows a double-peaked distribution, with one peak during the last half of August and a larger one during mid-September, though these peaks may in part be artifacts of the relatively small sample size. Only one tropical cyclone is missing from the lower plot in Figure 2, since it arrived outside the time period shown. This system developed over the western Caribbean, crossed southern Florida, moved northward along the East Coast as a tropical storm, and made landfall in New England as an extra-tropical storm (bringing a relatively warm rainfall and moderate winds) on February 4, 1952.

**Tropical Cyclones at Blue Hill**

There are several favored formation areas for hurricanes that have made landfall in New England, and all 15 Type I hurricanes examined here followed very similar paths along the East Coast. Figure 3 is a four-panel plot that demonstrates both of these features. The entire Atlantic basin is shown in Figure 3a to illustrate the complete paths of each hurricane. One common tropical cyclone formation area is the eastern Atlantic, which spawns the so-called Cape Verde hurricanes. The storms of 1893, 1938, Donna, and Gloria all developed in this area. The large circles in Figure 3a highlight two other common formation areas. One is near the Windward Islands, where the hurricanes of 1879, 1896, 1916, 1944, and Edna first developed. Another area near the Bahamas was the birthplace for both storms of 1869 as well as hurricanes Carol, Belle, and Bob. Only a single hurricane, which made a New England landfall in 1858, formed in the eastern Gulf of Mexico. Note that all 15 hurricanes passed or formed north of the Caribbean and then moved along the coastline either over or just east of Cape Hatteras, North Carolina.

None of these storms came into New England from the southeast or east. The remaining panels in Figure 3 show close-up views of the hurricane tracks over New England for three multi-decade periods. Eight storms made landfall on Long Island and Connecticut, two in Rhode Island, four in Massachusetts and one on the coast of Maine. Interestingly, of the four hurricanes that struck Massachusetts, the storm center of all four passed very close to Martha's Vineyard. Finally, although the center or eye of several hurricanes passed within 20 miles of Blue Hill, none has passed directly over the summit.

Observations at Blue Hill during the passage of these hurricanes through New England provide a glimpse into their behavior at this site. Although precipitation measurements at Blue Hill began when the Observatory was founded in 1885, peak wind gusts were not recorded regularly until about 1940. Table 2 summarizes information on the 15 Type I hurricanes as well as the Blue Hill rainfall and wind gust measurements during their passage. Five of the hurricanes were Category 3 on the Saffir-Simpson scale (sustained winds of 111-130 mph) at landfall. The Great New England Hurricane of 1938 maintained the strength of a Category 3 hurricane at landfall, though it was technically in transition to an extra-tropical storm as it approached the coast. On average, hurricanes make landfall in New England with an average forward speed of 32 mph, though speeds vary greatly from 10 to 50 mph.

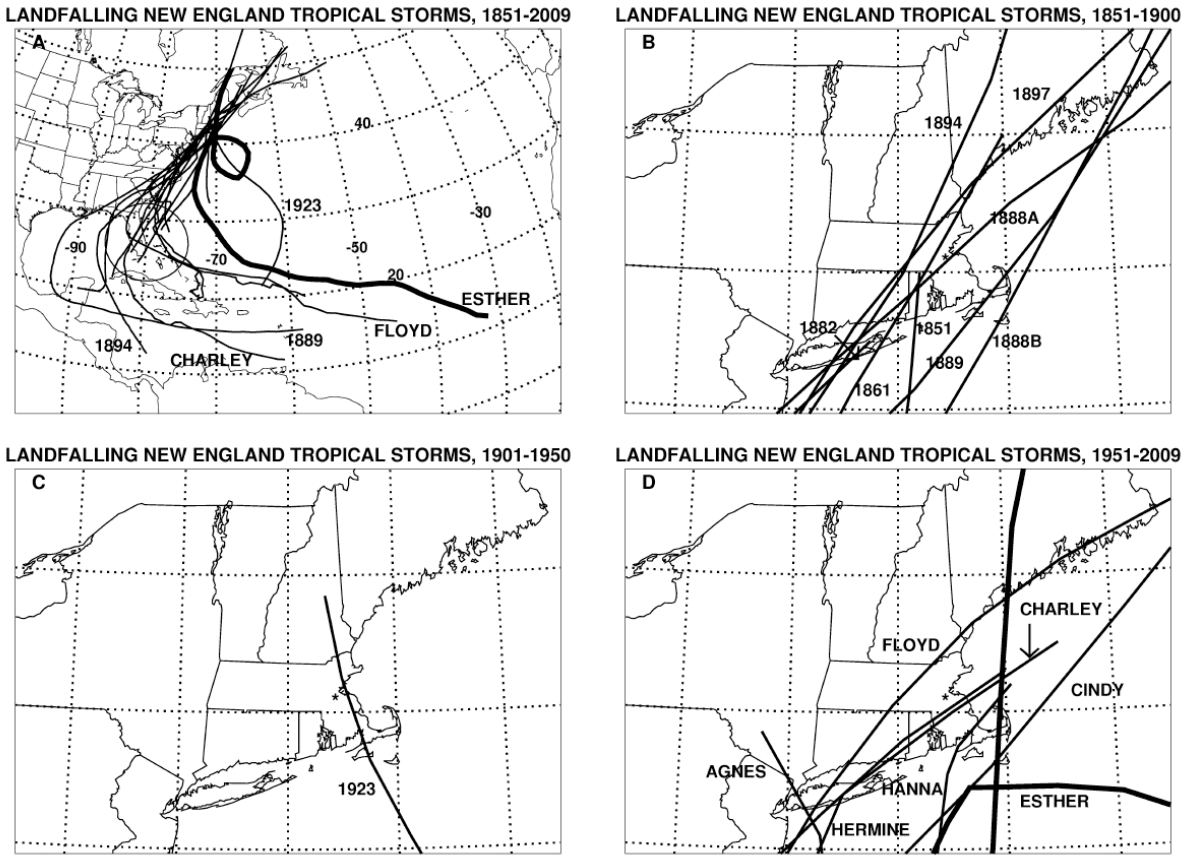


**Figure 4**: Storm tracks of all 16 tropical storms that have made direct landfall in New England or Long Island since 1851 are shown over the entire Atlantic basin (a) and over New England for three multi-decade intervals, (b) 1851-1900, (c) 1901-1950, and (d) 1951-2009. The large circle in (a) indicates the formation area for the eight tropical storms that are not labeled on the plot and are identified in the text. The '*' shows the location of the Blue Hill Observatory.

For cyclones making landfall in New England, the area to the west of the storm track typically receives more rainfall than the eastern sector due to orographic enhancement (*Vallee*, 2000), while higher winds occur to the right of the storm track (due to the effect of adding the storm's forward speed to its circulation). Blue Hill was in the eastern sector during the hurricanes that brought the least rainfall there (1938, 1893, and Gloria) and produced the highest peak wind gusts (1938, Donna, and Carol). The three wettest storms (1896, 1944, and Edna) and two of the least windy (1944 and Bob) passed near or east of Blue Hill, putting the Observatory in the western sector of the storm. Finally, a few miscellaneous facts are apparent from Table 2. The longest period of time without a hurricane landfall is 22 years, from 1916-1938. Other long stretches are 20 years (1896-1916), 18 years (1991-2009), 16 years (1960-1976), and 14 years (1879-1893). Two hurricanes making landfall in New England during the same season happened only twice since the mid-19$^{th}$ century, in 1869 and 1954.

**New England Landfalling Tropical Storms, 1851-2009**

| Date | Name | Speed/Dir (mph) | BHO Prec. (inches) | BHO Peak Gust (mph) | Track from BHO |
|---|---|---|---|---|---|
| 10/19/1851 | 1851 | 20 N | - | - | W |
| 11/3/1861 | 1861 | 22 NE | - | - | O |
| 9/24/1882 | 1882 | 26 NE | - | - | O* |
| 9/12/1888 | 1888A | 19 NE | 0.35 | 25 SW | O |
| 9/26/1888 | 1888B | 27 NE | 3.84 | 69 N | E |
| 9/25/1889 | 1889 | 36 NE | 0.22 | N/A | E |
| 10/10/1894 | 1894 | 35 NNE | 1.37 | N/A | W |
| 9/24/1897 | 1897 | 21 NE | 0.89 | N/A | W |
| 10/19/1923 | 1923 | 15 NNW | 0.70 | N/A | O |
| 7/11/1959 | CINDY | 26 NE | 1.96 | 39 N | E |
| 9/26/1961 | ESTHER | 25 N | 2.74 | 46 SW | E |
| 6/22/1972 | AGNES | 21 NW | 0.92 | 63 SE | W |
| 9/16/1999 | FLOYD | 27 NNE | 4.62 | 60 NW | W |
| 8/15/2004 | CHARLEY | 30 NE | 1.57 | 28 ENE | O |
| 8/31/2004 | HERMINE | 28 NNE | 0.63 | 24 NNW | E |
| 9/7/2008 | HANNA | 30 NE | 1.71 | 44 SE | O |

**Table 3**: Descriptive information for all 16 Type I tropical storms to make direct landfall in New England since 1851. Forward speed and direction of storm center at landfall is shown. Storm total precipitation recorded at Blue Hill is listed for tropical storms since 1885, and extreme wind gusts are listed where available. Location of storm track relative to Blue Hill, i.e. passing either west (W), east (E), or overhead within 20 miles (O), is also shown. A '*' denotes an estimated storm track.

In contrast to hurricanes, tropical storms that have made landfall in New England have more varied formation areas and storm tracks. Figure 4 illustrates the paths of all 16 tropical storms to strike New England following the same format as Figure 3. Six of these are labeled in Figure 4a and formed in the Caribbean or out in the Atlantic Ocean. The remaining ten, which developed near Florida or the Bahamas in or close to the large circle in Figure 4a, include the tropical storms of 1851, 1861, 1882, both storms of 1888, 1897, Cindy, Agnes, Hermine, and Hanna. The most unusual tracks belong to Esther (dark solid line) and the storm of 1923, which is the only tropical cyclone of at least tropical storm intensity to enter New England from the southeast. The remaining panels in Figure 4 show the tropical

storm paths over the Northeast for the three multi-decade periods. The first storm of 1888 passed very close to the Observatory on September 12 with minimal rain and wind. In 1923, the lone tropical storm during the first 50 years of the 20th century also passed very close to Blue Hill where it produced under an inch of rain and little wind. Specific data for the 16 Type I tropical storms are listed in Table 3. The average speed of tropical storms making landfall in New England is 25 mph, which is slower than hurricanes, and the fastest speeds are about 35 mph. Landfalling tropical storms bring less rainfall than hurricanes, though three of the four wettest storms (Cindy, Esther, and Floyd) were all formerly hurricanes before striking New England as weaker cyclones. There is no apparent correlation between tropical storm rainfall at Blue Hill and whether the storm passed west or east of the Observatory.

Several hurricane seasons stand out as the most prolific for tropical cyclones in New England. The greatest number in one season is six, which occurred in 1893 and 1996. The six tropical cyclones in 1893 included five hurricanes, one that made landfall in New England, two that made landfall elsewhere in the United States, and two that remained offshore. The cyclones of 1996 included two offshore hurricanes that had small impact, and two systems that crossed New England, Tropical Storm Bertha, and Extra-tropical Storm Josephine that both produced about three inches of rain. The 1888 season brought five tropical cyclones, including two landfalling tropical storms. Interestingly, the last storm that year, an offshore hurricane that brought over three inches of rain on November 26-27, 1888 was preceded by eight inches of snow at Blue Hill on November 25. This was also the latest hurricane to affect New England. About one in five years brings no tropical activity to New England, though 2001 was the first season since 1987 to be completely inactive in the northeastern United States.

## Tropical Cyclone Precipitation Measured at Blue Hill (1885-2009)

| | Average Precipitation (inches) | | | Extreme Precipitation (inches) | | |
|---|---|---|---|---|---|---|
| | H | TS | TD/ET | H | TS | TD/ET |
| Type I | 2.30 (11) | 1.65 (13) | 1.61 (12) | 5.23 (Edna, 9/1954) | 4.62 (Floyd, 9/1999) | 4.11 (9/1904) |
| Type II | 0.55 (3) | 2.65 (11) | 1.01 (34) | 1.15 (10/1893) | 12.77 (Diane, 8/1955) | 3.22 (Ivan, 9/2004) |
| Type III | 1.29 (44) | 0.97 (33) | 1.20 (22) | 6.03 (Esther, 9/1961) | 3.82 (Carrie, 9/1972) | 5.76 (10/1991) |
| All Types | 1.45 (58) | 1.45 (57) | 1.15 (68) | 6.03 (Esther, 9/1961) | 12.77 (Diane, 8/1955) | 5.76 (10/1991) |

**Table 4**: Average and highest precipitation in inches measured at Blue Hill since 1885 for various tropical cyclone categories. Numbers in parentheses after average rainfall amounts are the number of storms in the average. For extreme precipitation events, the specific storm and date are identified. Storm types are as listed in Table 1.

Tropical cyclone statistics based on Blue Hill precipitation measurements are listed in Table 4. Data are shown as averages as well as the highest recorded for each of the storm types, which are separated into the three intensity categories and three location categories. The number in parentheses next to the average precipitation in Table 4 is the number of storms included in the average. Eleven Type I (landfalling) hurricanes for which Blue Hill observations are available dropped 2.30 inches of

precipitation on average, while tropical storms and tropical depressions have brought less. For Type II events, tropical storms have brought the most precipitation, 2.65 inches on average, though this number is highly skewed by the extreme amount of 12.77 inches dropped by Tropical Storm Diane, which made landfall as a hurricane in North Carolina before it slowly moved across the southern New England coastline on August 18-19, 1955 and caused the greatest flooding event of the 20th century in this area. Excluding this storm, the ten remaining Type II tropical storms averaged only 1.64 inches and the 56 remaining tropical storms of all types averaged 1.25 inches. This illustrates the impact of a small sample size on these averages, and this must be kept in mind when interpreting these statistics. The averages for all types show only slight correlation between storm intensity and precipitation amount, varying from a high of 1.45 inches for hurricanes and TS to 1.15 inches for the TD/ET category. It's interesting to note that none of the extreme amounts for each intensity type were caused by storms that made direct landfall in New England. Hurricane Esther brought over six inches of rain and a 62 mph NE wind gust during its initial pass offshore in 1961 (it brought an additional 2.74 inches when it made landfall as a tropical storm five days later; see Table 3). Tropical Storm Diane, of course, holds the record for that storm type. For tropical depressions and extra-tropical storms, the Great Halloween Gale of October, 1991 ranks highest with a rainfall total of 5.76 inches over two days, which occurred during its closest approach to the coast as it moved westward offshore a day or two before it briefly reached hurricane intensity further out to sea.

Average and extreme wind gust measurements for tropical cyclones at Blue Hill since 1938 are listed in Table 5. Not surprisingly, hurricanes produce the highest average peak wind gusts among all storms that make landfall or remain offshore. The eight landfalling hurricanes for which wind data are available brought an average peak gust of 114 mph, while gusts for the 27 hurricanes that remained offshore average 41 mph. A 5-minute average wind speed of 121 mph from the south was derived from the chart record of a large 3-cup anemometer that survived the 1938 hurricane at Blue Hill. The peak wind gust for that storm of 186 mph was calculated from this 5-minute wind speed and has an error of 30-

**Tropical Cyclone Wind Gusts Measured at Blue Hill (1938-2009)**

| | Average Peak Wind Gust (mph) | | | Extreme Peak Wind Gust (mph) | | |
|---|---|---|---|---|---|---|
| | H | TS | TD/ET | H | TS | TD/ET |
| Type I | 114 (8) | 43 (7) | 40 (7) | 186 S (9/1938) | 63 SE (Agnes, 6/1972) | 61 NE (Josephine, 10/1996) |
| Type II | - (0) | 58 (9) | 44 (22) | - | 87 SSE (Doria, 8/1971) | 78 SSE (David, 9/1979) |
| Type III | 41 (27) | 36 (22) | 38 (13) | 67 NNE (Wilma, 10/2005) | 60 ENE (10/1942) | 60 NE (10/1991) |
| All Types | 58 (35) | 43 (38) | 41 (42) | 186 S (9/1938) | 87 SSE (Doria, 8/1971) | 78 SSE (David, 9/1979) |

**Table 5**: Average and extreme wind gusts in mph measured at Blue Hill since 1938 for various tropical cyclone categories. Numbers in parentheses after average gusts are the number of storms in each average. For extreme wind gust events, the month and year of the specific storm and its name (since 1950) are identified. Storm types are as listed in Table 1.

40 mph. Tropical Storm Doria produced a peak gust of 87 mph from the SSE at Blue Hill in late August, 1971, which is the highest gust for a storm in that category. Doria made landfall as tropical storm over coastal North Carolina before taking an inland track over western New England. Finally, the strongest wind gust at Blue Hill for the TD/ET category was 78 mph from the SSE by the extra-tropical remains of former Hurricane David in September, 1979. This Cape Verde storm became one of the largest and most powerful hurricanes ever to form in the Atlantic Ocean before making landfall in the Dominican Republic and near Savannah, Georgia and later crossing NY state and northern New England.

**Summary**

New England weather is renowned for its wide variety due to its proximity to continental polar air to the northwest and marine air to the south, the jet stream high in the atmosphere and the Gulf Stream in the ocean offshore. On occasion, these factors interact in such a way to allow tropical weather to move far northward. Over the last 159 years, nearly 250 tropical cyclones have affected New England ranging in impact from infrequent devastating storms to more typical, smaller cyclones that provide an interesting contrast to the cold snowstorms of winter. Activity peaks in September, but tropical systems have affected our weather as early as May and as late as February. Periods of greater frequency of tropical cyclones occurred in the late 19$^{th}$ century and the mid-20$^{th}$ century. A new resurgence began in the mid-1990s, and fluctuating sea surface temperatures apparently contribute to this cyclical pattern. While storms typically bring 1-2 inches of rain, total precipitation from tropical cyclones has contributed roughly four percent of all rainfall measured at Blue Hill since 1885. In the Atlantic Ocean, tropical storms and hurricanes have been given names for the last fifty years, and New England cyclone names have varied from 'Able' to 'Opal'. In fact, Hurricane Able, which dropped over three inches of rain at Blue Hill as it swirled well east of Cape Cod on August 20, 1950, was the first named storm in the Atlantic.

Tropical cyclones provide plenty of opportunity for further research for those interested. For example, little attempt was made in this article to analyze the mid-latitude weather conditions that may have interacted with tropical cyclones to direct them toward New England or to enhance local rainfall. Although space does not permit providing here the complete list of all 247 tropical cyclones that have affected New England since 1851, this list is available to members of the Observatory on request to the author by email at ‘miacono@bluehill.org’. Whether a warming Earth or changing ocean currents create more tropical cyclones during the coming decades or not, these storms will on occasion certainly influence the sometimes destructive but endlessly fascinating weather of New England.

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