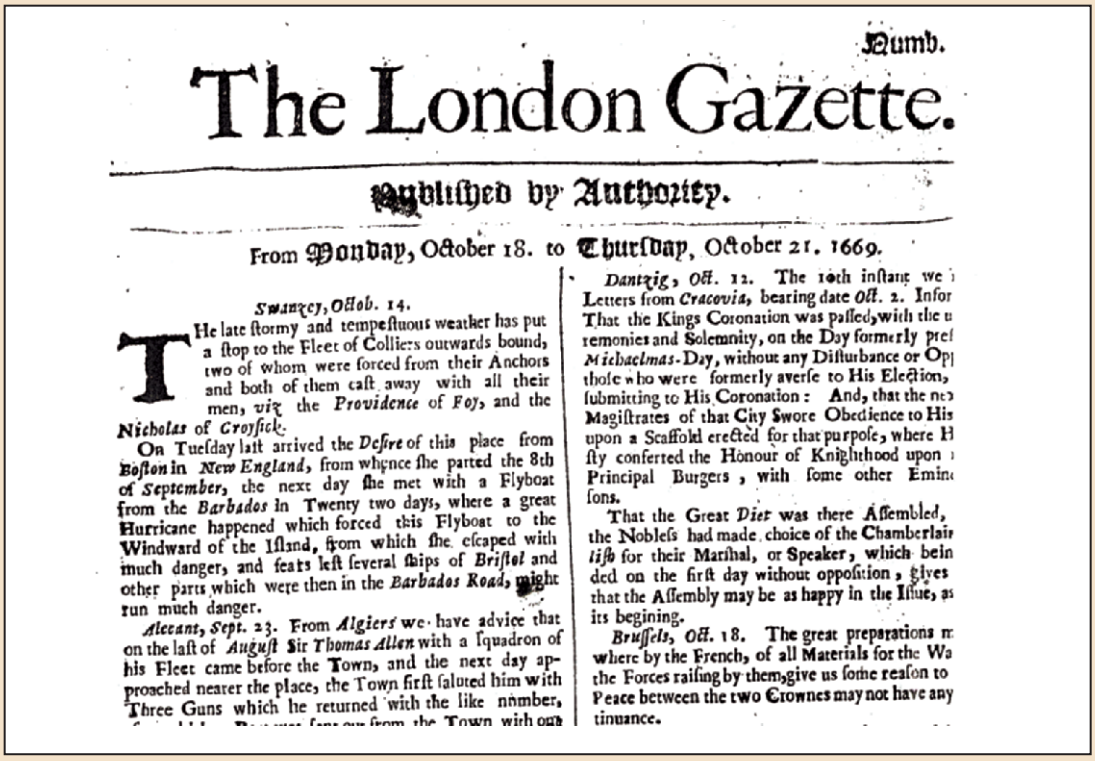
A PIONEER IN TROPICAL METEOROLOGY

William Sharpe's Barbados Weather Journal, April–August 1680

BY M. CHENOWETH, J. M. VAQUERO, R. GARCÍA-HERRERA, AND D. WHEELER

The first barometer in the Western Hemisphere provides new insight into the history of the barometer and the world's first measurement of atmospheric pressure within the circulation of a hurricane.



Numb.

The London Gazette.

Published by Authority.

From Monday, October 18. to Thursday, October 21. 1669.

Swanzey, Octob. 14.

THe late ſtormy and tempeſtuous weather has put a ſtop to the Fleet of Colliers outwards bound, two of whom were forced from their Anchors and both of them caſt away with all their men, *viz.* the *Providence* of *Foy*, and the *Nicholas* of *Croyſick*.

On Tueſday laſt arrived the *Deſire* of this place from *Boſton* in *New England*, from whence ſhe parted the 8th of *September*, the next day ſhe met with a Flyboat from the *Barbados* in Twenty two days, where a great Hurricane happened which forced this Flyboat to the Windward of the Iſland, from which ſhe eſcaped with much danger, and ſeats left ſeveral ſhips of *Briſtol* and other parts which were then in the *Barbados Road*, might run much danger.

Alecant, Sept. 23. From *Algiers* we have advice that on the laſt of *Auguſt* Sir *Thomas Allen* with a ſquadron of his Fleet came before the Town, and the next day approached nearer the place, the Town firſt ſaluted him with Three Guns which he returned with the like number,

Dantzig, Oct. 12. The 10th inſtant we Letters from *Cracovia*, bearing date *Oct.* 2. Infor That the Kings Coronation was paſſed, with the u remonies and Solemnity, on the Day formerly pref *Michaelmas*-Day, without any Diſturbance or Opp thoſe who were formerly averſe to His Election, ſubmitting to His Coronation: And, that the ne Magiſtrates of that City Swore Obedience to His upon a Scaffold erected for that purpoſe, where H ſty conferred the Honour of Knighthood upon Principal Burgers, with ſome other Emin ſons.

That the Great *Diet* was there Aſſembled, the Nobleſs had made choice of the Chamberlain *liſh* for their Marſhal, or Speaker, which bein ded on the firſt day without oppoſition, gives that the Aſſembly may be as happy in the Iſſue, as its begining.

Bruſſels, Oct. 18. The great preparations m where by the French, of all Materials for the Wa the Forces raiſing by them, give us ſome reaſon to Peace between the two Crownes may not have any tinuance.

University of Maryland (College Park) Early English Newspaper Collection

An account of the effects of a hurricane on a ship that put out from Barbados on 29 August 1669 (corrected to the modern calendar) as reported in The London Gazette (see the second paragraph of the first column). This is a typical example of 17th century English newspaper reporting of tropical cyclones.

"I believe, there might be excellent use made of the Barometer for predicting of Hurricanes, and other Tempests, especially at sea; since I am credibly informed, that a person of quality, who lives by the sea-side . . . can by the Barometer almost infallibly foretell any great tempest for several hours before it begins."

This statement, from Bohun (1671) is one of the earliest suggestions in scientific literature, if not the earliest, of using the barometer for detecting and forecasting tropical cyclones. Interest in the hurricane was partly due to the destruction of an English invasion fleet off of Guadeloupe in 1666 (*London Gazette,* 3 and 13 December 1666), and a spate of storms from 1666 to 1671 in New England, Virginia, Bermuda, Newfoundland, and the Lesser Antilles [*London Gazette,* 21 November 1667, 20 September 1669, 21 October 1669, 2 December 1669, 2 February 1670, 19 December 1670, 22 December 1670, 9 January 1671; Ludlum (1963); Teachout (1982)], which led Bohun to write of hurricanes as being ▶

"subjects of our Gazets; and scarce a year passes but we have Accounts from the American Plantations, of the Damages they have sustain'd by the Hurricanes" (Bohun 1671).

Bohun, a fellow of the Royal Society of London, wrote an extensive treatise on the nature of winds and was knowledgeable of the work done by other Royal Society members, particularly Robert Hooke, in experiments with barometers (Middleton 1964). The Royal Society, founded in 1660, had from its beginning sent letters to travelers to the Americas instructing them to gather empirical data on all manner of natural phenomena. Such natural phenomena could range across a variety of topics as different as comets and hurricanes (Jankovic 2001), and gathering and exchanging empirical information about such phenomena was at the heart of the Royal Society's activities (Gribbin 2007). A list of questions, including several about hurricanes, was provided to the newly appointed governor of Jamaica in 1670 (Stearns 1970).

Prior to 1660, the barometer was an instrument used to investigate theories about vacuums in nature and whether the mercury in the instrument was supported by the weight of the air. By the early 1660s, two Royal Society members, Robert Boyle and Robert Hooke, discovered through investigation of the hypothesized roles of the moon on lunar tides that atmospheric variations in weather had some relation to the level of the barometer. Boyle and Hooke coined the terms barometer and baroscope, respectively (Golinski 1999). Daily diaries of the state of the weather and barometer further assisted in demonstrating associated changes in the weather with atmospheric pressure fluctuations and the realization of the barometer's potential for weather forecasting (Vogel 2002). Increased interest in and use of barometers had, by 1670, led to their commercial production (Middleton 1964), although details prior to the early 1680s are scant (Golinski 1999; Vogel 2002). The confluence of new instrumentation, scientific inquiry and philosophical theorizing and large monetary losses incurred by government and merchants as a result of hurricanes are likely motivating factors behind Bohun's hypothesis of using the barometer in their forecasting.

In August 1674, Dr. Thomas Townes wrote to Dr. Martin Lister, a fellow of the Royal Society, about "great damage" done on the island of Barbados by a hurricane that "whirled us about like a top from all points of the compass" soon after his arrival on 17 August (Stearns 1970). Lister and other Royal Society members very likely read the following year's press accounts of a "very violent hurricane" at Barbados on 10 September that threw down over 300 houses, killed about 200 persons, and cast away eight ships and five ketches with the loss of life of most of the seamen (*London Gazette,* 6 December 1675).

The timing of the storms coincided with preparations for the observation of the transit of mercury at the South Atlantic island of St. Helena, where Edmund Halley made barometric observations during his stay from February 1677 to May 1678 (Lister 1684). The two hurricanes at Barbados (the most prosperous of the English colonies at this time) and the desire of the Royal Society to have scientific contacts in the American colonies made Barbados a logical choice for inquiry and the Royal Society made arrangements for barometers to be shipped to interested correspondents. By December 1677 a number of barometers were reported shipped to Barbados "to examine whether they would be of any use for the [*sic*] foretelling the seasons and mutations of the weather as they are found to do here, especially concerning hurricanes" (Stearns 1970). The immediate disposition of these barometers upon arriving in Barbados is unknown. If they were used and the data were preserved, they probably would not have recorded dramatic changes in barometer readings because there were no storms felt at Barbados in 1677 (Mulcahy 2006) and no evidence exists of any storms in the area in 1678 or 1679. However, the year 1680 provided the first hurricane in the area since 1675 and by then a barometer was in place to make the first known measurements of atmospheric pressure in a tropical cyclone.

COLONEL WILLIAM SHARPE'S LETTER TO THE ROYAL SOCIETY. In late 1680, the Royal Society received a letter from Colonel William Sharpe of Barbados. The cover letter was dated 26 August 1680 and came with an appended set of daily barometer readings and wind and weather observations from 18 April to 24 August 1680, which Sharpe called a "barometrical calendar." Sharpe acknowledged

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receipt of a letter from the Royal Society and the accompanying barometer. Sharpe's letter provides answers to questions that are similar in nature to those posed to the governor of Jamaica in 1670.

Sharpe was one of the leading planters in 17th-century Barbados (Dunn 1972) and the Speaker of the Barbados House of Assembly in 1676–78 and 1682–83. It seems likely that the original shipment of barometers to Barbados in 1677 did not reach him until 1680, as the wording in his letter suggests he received the barometer only shortly before he set it up in April 1680. He addresses the interest in "foretelling the weather" so the barometer and letter may have passed through several unwilling or uncomprehending hands before it reached Sharpe. Sharpe refers to ". . . my own ignorance and not having the conversation of any one man of experience here . . ." (Sharpe 1680), which supports such a scenario.

One of the other barometers originally shipped to Barbados in 1677 may have made its way to the English colony at St. Christopher's (St. Kitts) in the northern Leeward Islands about the same time. The Royal Society received a letter some months after Sharpe's from a "Mr. Crisp," dated 20 November 1680, who wrote he had difficulty with the instrument. Crisp wrote that he had set up the barometer according to instructions but found it ". . . never alters where it first fixt [*sic*] at that degree opposite to Stormy for 3 months together although ye weather changed 100 times in that time" (Stearns 1970). Crisp's experience was a common one; problems with barometers are documented elsewhere in the New World (e.g. Lizárraga 2001).

Neither Crisp nor Sharpe provide a diagram or description of the barometer, but Sharpe's barometer was a mercury barometer and likely a cistern type that was commonly manufactured at the time (Middleton 1964). The barometer was graduated in inches and tenths. The location of the barometer is assumed to be at Sharpe's plantation located in the northeast part of the island at about 13°13′N, 59°34′W on the rolling east-facing slopes east of the central highland of Barbados. The highest elevation of Barbados is over 1100 feet above sea level in the region west of Sharpe's plantation.

Sharpe's comments on the forecasting of the weather with the barometer follow:

> Thus far Sir you have my weak conjectures & I will be less confident to acquaint you with the few observations this little time hath furnished me with, and because the notice of a storm's continuance may be as beneficial as that of its approach I was solicitous to find out some marks that might direct to it, and having observed upon an unusual & remarkable depression of the mercury (not the little dippings commonly which the later end of a fair day usually produce) the exact time of that depression the continuance of the mercury's descending even to the time of its apparent ascending which happens some hours before the storm, I have thereupon hither found that the continuance of the violence of the storm that happens after is full a long as the time from the descending to the ascending of the mercury. Sir you may also perceive by the account I have sent that the motions of the mercury are very minute here which I attribute to the constancy and certainty of the winds in this climate, where Nature hath for the most part limited it within few points and also the small narrow and broken clouds that fall here, of whose weight the Aire can be but little sensible, and I have delayed this account the longer that it might enter into that season whereunto the tempestuous weather (if any in the whole year happen) is generally confined . . . . I have inserted in my calendar some other hours than you appointed but have not omitted that & in some places have divided a 1/10 into 4 parts because I found less than 1/10 to denote a considerable alteration (Sharpe 1680).

Sharpe's letter is of substantial interest for historians of tropical meteorology and the history of science. He observed the diurnal cycle of pressure, noticed strong winds continued with both the falling and rising of pressure associated with a tropical cyclone, attributed the small variation in pressure values to the constancy of the wind direction, has an interesting description of the appearance and shape of trade wind cumulus clouds at a time when no systematic classification of cloud types existed, patiently awaited the hurricane season to check the barometer's performance during the passage of a tropical cyclone, and closely observed pressure fluctuations at a finer level of precision than the instrument was marked, rightly noting that these small variations were significant.

Also of note is the reference by Crisp in his November 1680 letter to the barometer "at that degree opposite to Stormy," which is an apparent reference to notations on the instrument, opposite of the scale, indicating expected weather. Middleton (1964) could not date when such weather indicators were first used and no firm dates before 1683 are known (Vogel 2002) for notations on barometers, but Crisp's offhand remark indicates that the Royal Society's barometers were marked in just this way. This would suggest that Hooke may have been responsible for such notations in the first place because he made detailed daily observations and associated, in a general sense, such

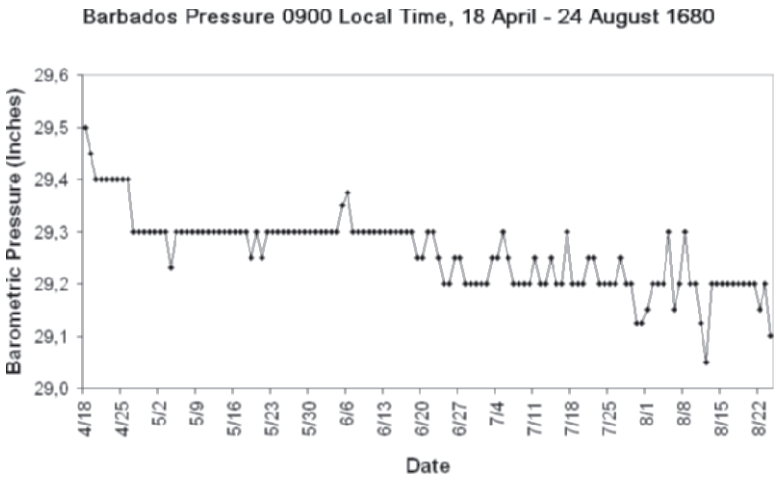


Fig. 1. Daily barometer readings made at 0900 local time on the island of Barbados from 18 Apr to 24 Aug 1680.

Table 1. List of wind force terms and their frequency of use by William Sharpe in his Barbados weather record for Apr to Aug 1680. Index values increase from lighter to stronger winds but are not calibrated with any specific wind speed.

Wind force term	N	index value
Calm	2	0
Almost calm	1	0
Little wind	17	1
Small winds	1	1
Gentle wind	5	1
Soft wind	6	1
Moderate wind	4	2
Windy	17	2
Much wind	2	2
Strong wind	30	2
Very strong wind	1	3
Great wind	15	3
Fierce wind	1	4
Storm	2	4
Most violent storm	1	4
More wind	3	2
Less wind	5	2
Wind more moderate	3	2
Wind stronger	2	2
Storm more violent	1	4
Storm well ceased	1	2
Gusts	1	2
Gusts of wind	1	2
Some gusts	3	2
Great gusts	2	3

N = the number of times the word or phrase was used.

terms with the level of the mercury. In 1677, Hooke was reported to have said ". . . whenever the quicksilver was observed to fall suddenly very low, it had always been a forerunner of a very great storm suddenly to follow . . ." (Vogel 2002). This is at the same time that the barometers were shipped to Barbados by the Royal Society. The weather indicators by Hooke may have been retained and adopted in commercial production to assist the purchaser in interpreting the instruments readings and enhance its conversational and aesthetic value.

THE PRESSURE SERIES, WINDS, AND RAINFALL, APRIL–AUGUST 1680. How reliable is Sharpe's weather record? Figure 1 presents the daily pressure values, recorded at 0900 local time each morning by Sharpe from 18 April to 24 August 1680. The record indicates evidence of two steplike declines in pressure, the first from 18 to 26 April of 0.2 in. and the other in the second half of June of 0.1 in. We can only speculate on the causes of these declines, but the formation of air bubbles in the mercury column is possible. These changes in pressure do not seem to have otherwise affected the performance of the barometer. The average pressure for the entire 129 days is 29.26 in. There are 40 days with a 4 P.M. observation added by Sharpe. In 12 instances there is a pressure fall from 9 A.M. of 0.1 in., in 12 instances a fall of 0.05 in., and in one instance a fall of 0.025 in. The average fall in pressure from 9 A.M. is 0.07 in. By applying this average difference, the average daily pressure from the mean of 9 A.M. and 4 P.M. is 29.23 in.

Station pressure and sea level pressure data for Barbados Grantley Adams Airport for 1961–2000 were obtained from the National Climatic Data Center, Asheville, North Carolina. Assuming that sea level pressure for the months of April through August is approximately the same today as in 1680 because of the relative invariance of pressure near the equator, the elevation of Sharpe's barometer can be approximated by using modern data to calculate the difference between station pressure and sea level pressure at the known elevation of the modern site and applying this difference between Sharpe's station pressure (29.23 in.) and the assumed sea level pressure of 29.96 in., which gives

a difference of 0.73 in. This gives us an estimated elevation of 708 ft above sea level, which is consistent with the location of his plantation relative to sea level and the central highland of the island. Due to the uncertainty caused by the steplike drops in pressure, the estimate has a margin of error on the order of tens of feet.

Wind direction is consistent with what would be expected in the Tropics—a persistent easterly wind flow. Sharpe's wind force terms are of interest given the nonstandard force descriptors he used. The frequency of individual wind force terms, and their total frequency, is included in Table 1. Sharpe used 14 distinct wind force terms, four terms for wind gusts, and six wind force "change in strength" terms relative to the preceding observation. Three of his 14 wind force terms and one of his gust terms are used only during the hurricane of 12–13 August. His terms have similarity with terminology in use by contemporary mariners (Lamb and Frydendahl 1991; Chenoweth 2006), but there is no obvious correspondence with a set list of terms in use at the time.

Four wind force terms, "little wind (or "wind little")," "windy," "strong wind," and "great wind" account for 79 of the 135 wind force terms in the Sharpe record and probably correspond, along with "much wind" and "very strong winds," to the most common range of trade wind speeds (very roughly, on the order of 5 to 25 kt). Other terms clearly indicate light wind speeds ("almost calm," "small winds," "gentle winds," "soft winds," and "moderate winds"). The three gust terms "gusts," "gusts of wind," and "some gusts" are unremarkable in apparent intensity.

The remaining wind force terms and gusts coincide with the August hurricane and the lowest pressure of July 1680. "Great gusts" occur on 30–31 July, with the lowest pressures of that month and may be associated with a tropical cyclone of unknown intensity passing to the south of Barbados. The remaining terms "fierce wind," "storm," and "(storm) most violent" occur with the August hurricane. August featured very light winds, other than from the hurricane, unlike the steadier and stronger winds of the previous three months (Fig. 2).

Table 2 lists the rainfall terms and their frequency of use. The number of rain days per month ranges from 3 in August (first 24 days only) to 13 in June. August was notably drier than the other months with the only significant rains coming in the hurricane (Fig. 3).

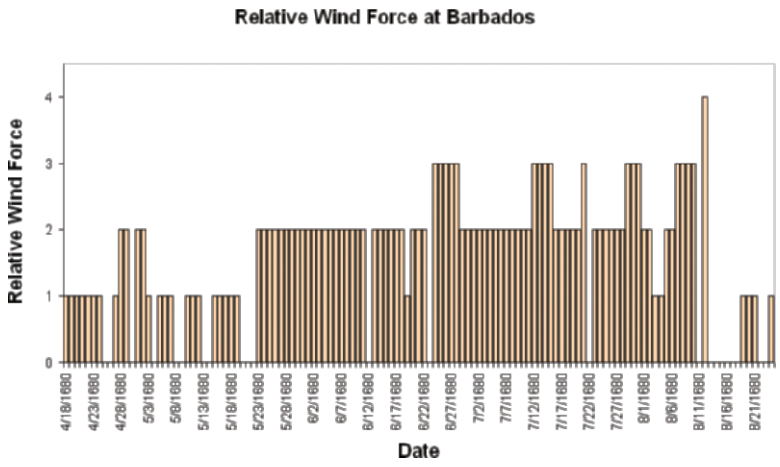


Fig. 2. Daily wind force terms represented in an arbitrary index from zero (calm) to four (storm) for the island of Barbados from 18 Apr to 24 Aug 1680. The index values are not calibrated to a specific wind speed, but instead indicate higher (lower) wind speeds at higher (lower) values of the index.

Table 2. Rainfall terminology, their frequency of use, and the number of days with rain at Barbados for Apr to Aug 1680. Index values increase from lighter to heavier rainfall amounts but are not calibrated with any specific rainfall amount.

Rainfall term	N	index value
Rain	4	1
Showers	18	1
Some showers	9	1
Frequent showers	1	2
(Thunder) storm	1	2
Much rain	12	2
Many showers	3	2
Great showers	1	3
Most violent rain	1	4

N = number of times the word or phrase was used.

Sharpe's observations, with respect to the climatology of Barbados, show signs of being reliable and accurate as his perceptions, scientific ability, and instrumentation allowed. There was a drop in pressure that is inconsistent with the rise in wind speed from April through July. This can be explained as probably being due to an air bubble(s) in the mercury column. The diurnal variability appears to have been unaffected. This is a weather record that can be trusted and valued.

THE HURRICANE OF AUGUST 1680. Sharpe's patience in waiting for "tempestuous weather" paid off and during the night of 12–13 August, a hur-

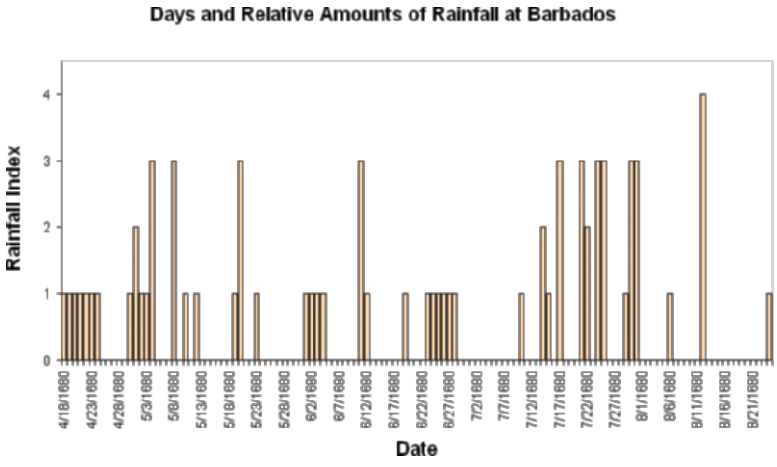
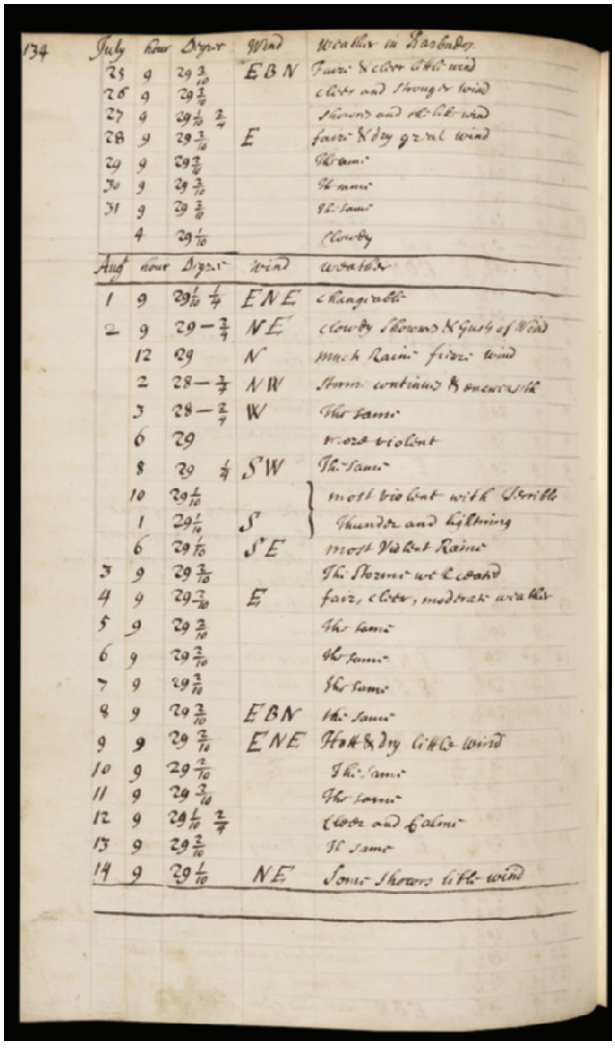


Fig. 3. Daily rainfall represented in an arbitrary index from zero (no rain) to four (very heavy rains) for the island of Barbados from 18 Apr to 24 Aug 1680. The index values crudely approximate rainfall from lighter to heavier amounts from lower to higher values of the index.



ricane passed north of Barbados. Sharpe has the distinction of making the first measurement of pressure within the circulation of a tropical cyclone yet documented for anywhere in the world (Bartolache 1772; Stearns 1970; North 1979; McClellan 1992). Sharpe's record affirmed Bohun's suggestion of the usefulness of the barometer in detecting and forecasting a hurricane.

Sharpe's observations for 11–14 August are reproduced in Fig. 4 (note that the dates in the figure are the original Julian dates, which are 10 days earlier than the modern calendar). The interpretation of the readings is complicated by Sharpe's apparent failure to record the "tenths" value at readings of 29.0 in. and less. The values from noon to 6 P.M. [approximately 1700 to 2300 coordinated universal time (UTC)] on 2 August (where "29" and "28 ¾" is taken as equivalent to "29 0/10 0/4" and "28 9/10 ¾," respectively) are assumed to be 29.00 and 28.975 in., indicating pressure falls of up to −0.225 in. below July and August afternoon readings in his record. Such an interpretation is consistent with his use elsewhere in the record. The weather comments indicate stormy weather that grew worse after the wind shift to the southwest (possibly indicating intensification of the hurricane) and that continued into 13 August before gradually improving.

Sharpe makes no comments on damage done in the storm. The lowest barometer reading, if we assume a correction of +0.73 in. for elevation (see "The pressure series, winds, and rainfall, April–August 1680"), then gives a lowest pressure, using +0.73 in. as the correction, to be 29.71 in. Using the pressure–wind speed relationship for the Tropics for low latitudes (from Table 3 of Landsea et al. 2004) to estimate wind speed from a peripheral pressure data point in a tropical cyclone gives a wind speed of 34 kt (17 m s^{-1}). Given the location of the hurricane to the north of Barbados, the weaker sector of the storm, moving west by north or west-northwest, gives a wind speed estimate at the threshold of 34 kt for a tropical storm, indicating minimal tropical storm force sustained winds. This

Fig. 4. Detail of the Sharpe weather record showing his record of the hurricane passing north of Barbados on 12–13 Aug 1680. The dates listed in the figure are 10 days behind the modern calendar. Reprinted with permission by The Royal Society, London.

is consistent with government accounts from Barbados found in the Calendar of State Papers, CO 1/46 No. 5 (Public Record Office 2000), in which officials report the storm was not violent at Barbados and make no mention of storm damage on the island. These same reports mention that stormy weather was felt at St. Kitts (St. Christopher) on 13 August and that ships put to sea and two shallops were wrecked in the harbor "more by the sea than by the wind." Furthermore, at Martinique the most violent hurricane ever known there to that time was reported to have knocked down all the houses, forts, and churches and hardly a tree or plant was left upright. Over 20 ships were lost in the cul-de-sac, including two English ships. Judging from the Barbados weather record, the storm struck Martinique during the early morning hours of 13 August between about 0600 and 1200 UTC (Fig. 5).

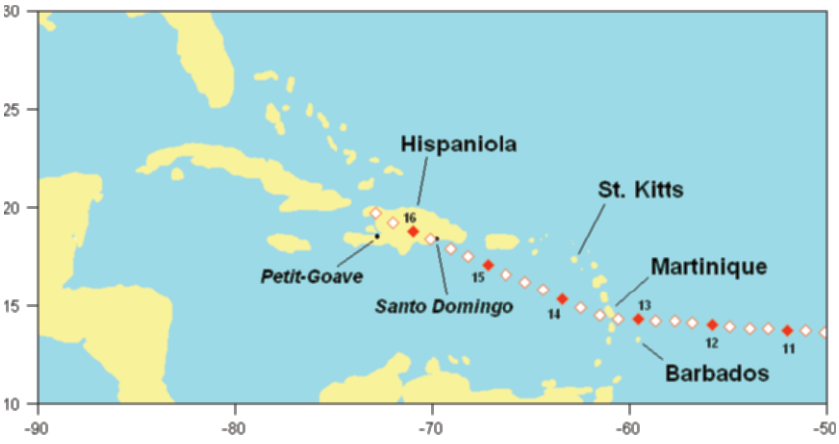


Fig. 5. Track of the hurricane of 10–16 Aug 1680. Positions are 6-hourly plots with the 0000 UTC position indicated by the filled red diamond.

This storm continued on its course to the island of Hispaniola, where it was felt severely at Santo Domingo (Anonymous 1680) and also destroyed French shipping on the western side of the island (D'Estrées 1680). There is no trace of the storm yet to be found in Cuba, Florida, or the English colonies. There is a possibility that this storm made no further landfalls and a complete account of the storm's track and its impact will be reported in another paper.

AFTER THE HURRICANE. Sharpe's letter arrived in London in 1680 during a hiatus in the publication of the *Philosophical Transactions of the Royal Society* (hereafter *Transactions*), which did not resume until 1681. In 1685, the first journal of barometer readings, made in England in 1684, was published (Plot 1685). Had the *Transactions* been actively publishing in 1680, it is likely that Sharpe's record would have been the world's first published barometer journal. The use of the barometer in understanding the relationship of atmospheric pressure to changes in weather and winds in the temperate and trade wind zones, which took place from the 1660s to 1680s, is discussed in Vogel (2002).

In the mid-1680s, two papers (one in England and the other in France) initiated a debate about the nature and origin of the trade winds that was then taken up by Edmond Halley in the *Transactions* in 1686 (Persson 2006). Halley had access to Sharpe's letter and almost certainly read it in preparing his paper as had Lister (1684) in his paper on the barometer and its connection with weather fluctuations. Halley makes reference to "the true reason of the rising and falling of the mercury, upon the change of weather" and the "very low" descent of mercury during hurricanes (Halley 1686) and cites his own observations on St. Helena and others at Barbados. Although Sharpe is not named, there is no other source that could have supplied information on the state of the barometer during a hurricane. Also, Vogel (2002) mentions that Halley had examined newly received data from Barbados, along with his own data from St. Helena, and observed the small variation in the Tropics as compared to temperate zones. Here is an example of the contribution of "colonial science" in a major philosophical debate in Europe. Sharpe's record can now be identified as the Barbados source for Halley in establishing empirical distinctions between the Tropics and temperate zone.

On 21 November 1680, the Royal Society *Journal Book* indicates that a thermometer was sent to Sharpe (Stearns 1970). The shipment of the thermometer was doubtless in hopes of his continued observations of the barometer and thermometer and recognition of his success in performing cutting-edge empirical work with a new technology in a remote environment. Unfortunately, there is no further correspondence with Sharpe in the Royal Society archives. Sharpe continued to serve at various times in the Barbados colonial government and as acting governor in 1714–15. Sharpe may have considered his duty to science accomplished, having provided his answers to the Royal Society's letter, and ceased his observations. Although the record apparently ended in 1680, we can acknowledge

Sharpe as a previously unrecognized pioneer in the history of tropical meteorology, the history of the barometer, and the history of science and recognize and appreciate his contributions.

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