NATIONAL HURRICANE CENTER TROPICAL CYCLONE REPORT

HURRICANE HUMBERTO

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13–19 September 2019

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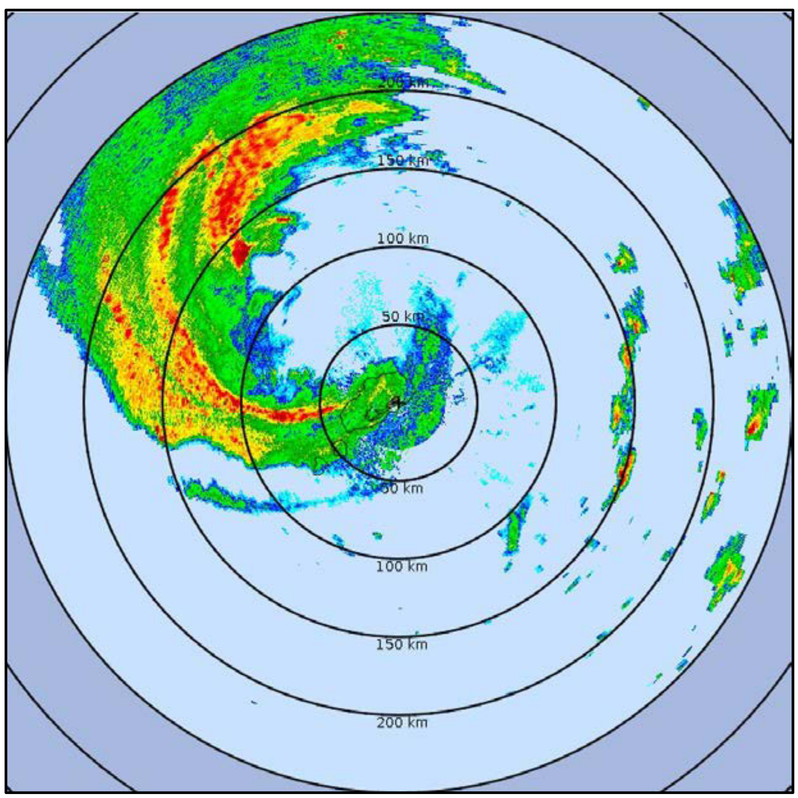

LAST BERMUDA RADAR REFLECTIVITY IMAGE AT 2249 UTC 18 SEPTEMBER 2019 WHEN HUMBERTO WAS MAKING ITS CLOSEST POINT OF APPROACH TO BERMUDA AS A MAJOR HURRICANE, JUST PRIOR TO A COMMUNICATIONS FAILURE.

Humberto was a category 3 hurricane (on the Saffir-Simpson Hurricane Wind Scale) that skirted the extreme eastern portions of the Bahamas before raking Bermuda with sustained hurricane-force winds for several hours that caused significant island-wide damage. The hurricane also produced large ocean swells and rip currents along the southeastern coast of the United States that resulted in two fatalities.

Hurricane Humberto

13–19 SEPTEMBER 2019

SYNOPTIC HISTORY

A weak tropical wave moved off the west coast of Africa on 27 August, accompanied by little convection. The disturbance continued on a westward track across the deep tropical Atlantic for the next several days before it began to interact with a mid- to upper-level trough a few hundred n mi east of the Lesser Antilles on 4 September. The westward motion of the northern portion of the wave was impeded by the southwesterly flow on the east side of the trough, which caused the wave to fracture. By 6 September, the northern portion of the wave turned slowly toward the north-northwest while the southern portion of the wave continued to move quickly westward toward the southern Windward Islands.

Little change to the northern wave's structure occurred over the next few days while associated shower activity was minimal as the wave and the upper-level trough moved in tandem toward the northwest. By 10 September, the disturbance was located just north of Hispaniola near the Turks and Caicos, moving slowly northwestward and parallel to the easternmost Bahamas archipelago. Over the next 72 h, anticyclonic flow on the east side of the now negatively tilted upper-level trough steadily increased, which aided in slow but steady development and organization of deep convection along and east of the wave axis. The associated thunderstorm activity pulsed during this time, with a distinct increase in convection noted during the nighttime period, followed by weakening during the daylight hours. Convection persisted despite its pulsing nature, with scatterometer wind data indicating that a broad surface low pressure system had formed near the southeastern Bahamas by 1200 UTC 12 September. By early on 13 September, thunderstorms had organized into a narrow curved band in the northeastern quadrant of the system, and nearby ship and surface observations from the Bahamas indicated that the low-level circulation center (LLCC) had also become better-defined. Based on these data, it is estimated that a tropical depression formed by 1800 UTC that day about 75 n mi east of the central Bahamian island of Eleuthera. The cyclone strengthened into a tropical storm just 6 h later. The "best track" chart of the tropical cyclone's path is given in Fig. 1, with the wind and pressure histories shown in Figs. 2 and 3, respectively. The best track positions and intensities are listed in Table 1[1].

Tropical Storm Humberto turned northwestward early on 14 September and maintained that motion for the next 48 h, accompanied by a slow forward speed of 3–7 kt due to the cyclone moving through a narrow break in the Bermuda-Azores ridge. Despite moderate southwesterly to westerly 850–500-mb vertical wind shear (Fig. 4), slow-moving Humberto steadily strengthened during that time, attaining hurricane status by 0000 UTC 16 September when the cyclone briefly

[1] A digital record of the complete best track, including wind radii, can be found on line at ftp://ftp.nhc.noaa.gov/atcf. Data for the current year's storms are located in the *btk* directory, while previous years' data are located in the *archive* directory.

stalled about 150 n mi east-northeast of Cape Canaveral, Florida. The broad deep-layer trough located to the northwest of Humberto nudged the tropical cyclone east-northeastward at forward speeds of less than 10 kt for the next 48 h. During this time, the hurricane continued to steadily strengthen despite strong vertical wind shear of near 30 kt and sharply decreasing mid-level humidity values (Fig. 4), with Humberto reaching major hurricane status by 0000 UTC 18 September. Thereafter, only slight strengthening occurred through 0000 UTC 19 September when Humberto passed about 55 n mi northwest of Bermuda with maximum sustained winds of 110 kt. Later that morning after passing to the north of Bermuda, Humberto began accelerating northeastward ahead of a broad trough and its associated cold front, with forward speeds increasing from 15 kt to near 25 kt throughout the day. During this time, the hurricane also began a steady weakening trend due to increasing south-southwesterly vertical wind shear exceeding 50 kt and entrainment of very dry mid-level air, despite the otherwise favorable sea-surface temperatures in excess of 27°C (Fig. 4).

By early on 20 September, the hurricane finally succumbed to the strong vertical shear conditions and became devoid of any deep convection, causing Humberto to become an extratropical cyclone when it was located about 500 n mi south-southwest of Cape Race, Newfoundland. However, the expansive extratropical low continued to produce hurricane- and gale-force winds over a large area until the system merged with a larger extratropical low and frontal system by 1800 UTC that day more than 300 n mi south-southwest of Cape Race.

METEOROLOGICAL STATISTICS

Observations in Humberto (Figs. 2 and 3) include subjective satellite-based Dvorak technique intensity estimates from the Tropical Analysis and Forecast Branch (TAFB) and the Satellite Analysis Branch (SAB), objective Advanced Dvorak Technique (ADT) estimates and Satellite Consensus (SATCON) estimates from the Cooperative Institute for Meteorological Satellite Studies/University of Wisconsin-Madison. Observations also include flight-level, stepped frequency microwave radiometer (SFMR), and dropwindsonde observations from 10 flights by the 53rd Weather Reconnaissance Squadron of the U.S. Air Force Reserve Command and 4 flights by the NOAA Aircraft Operations Center (AOC), including 3 Tail Doppler Radar (TDR) missions, which resulted in a total of 27 center fixes and 7 center fixes, respectively. Data and imagery from NOAA polar-orbiting satellites including the Advanced Microwave Sounding Unit (AMSU), the NASA Global Precipitation Mission (GPM), the European Space Agency's Advanced Scatterometer (ASCAT), and Defense Meteorological Satellite Program (DMSP) satellites, among others, were also useful in constructing the best track of Humberto.

Selected ship and buoy reports of tropical-storm-force winds, plus other pertinent marine observations, associated with Humberto are given in Table 2. Selected land-based surface observations are given in Table 3.

Winds and Pressure

Humberto's estimated maximum intensity of 110 kt between 1800 UTC 18 September and 0300 UTC 19 September is based on an average of a reconnaissance aircraft 700-mb flight-level wind of 121 kt (which equates to an equivalent surface wind speed of 109 kt), SFMR surface wind speeds of 110–113 kt (Fig. 5), dropwindsonde WL150- and MBL-surface equivalent wind speed estimates of 105 and 103 kt, respectively, and UW-CIMSS SATCON satellite intensity estimates of 112–116 kt. The reconnaissance and dropwindsonde data were collected within a narrow band of convection in the southern eyewall where SFMR rain rate estimates were 11–15 mm/h (0.43–0.59 in/h).

The highest wind speed measured by a dropwindsonde during Humberto's lifetime was 138 kt at the 890-mb level at 0249 UTC 19 September (Fig. 6a). This dropwindsonde was released and remained in Humberto's remnant southern eyewall until the splash time of 0249 UTC 19 September (Fig. 6a). The instrument traversed the convection from west to east based on the positions of the release and splash points being aligned perfectly along a 270-degree (true) direction. Although the sonde measured a surface wind speed of 114 kt, that value is an 'instantaneous' 2-second sample, which is more representative of a wind gust rather than a 1-min sustained wind.

The estimated minimum central pressure of 950 mb from 1800 UTC 18 September to 0300 UTC 19 September is based on aircraft dropwindsonde eye reports of pressures of 951–952 mb, which were accompanied by surface wind speeds of 10–20 kt. This pressure estimate is consistent with earlier pressure values of 954–955 mb measured by NOAA Buoy 40148, located about 240 n mi west of Bermuda, when the center of Hurricane Humberto passed approximately 6 n mi southeast of the buoy. At 0930 UTC 18 September, a minimum pressure value of 954.2 mb was reported, along with a coincident wind speed of 27 kt (4 m ASL), which indicates that the central pressure at that time was likely around 951 mb (Table 3; Fig. 7).

It should be noted that the steady pressure of 950–951 mb from 1800 UTC to 0300 UTC (Fig. 3) suggests that Humberto's peak tangential winds likely remained steady at around 105 kt based on various pressure-wind relationship equations. Radar data from Bermuda (Fig. 8) indicate that the eyewall was eroding quickly after 1800 UTC 18 September, and that the peak winds measured by reconnaissance aircraft and dropwindsonde at 0248 UTC 19 September likely occurred in a very narrow eyewall, which is not indicative of an intensifying tropical cyclone, especially one that is approaching category 4 intensity. The additional increase in intensity as measured by reconnaissance aircraft was likely due to baroclinic forcing that produced a low-level jet that may have had some characteristics similar to a "sting jet" that occurs in association with some deepening extratropical low pressure systems (Browning 2004; Hart et al. 2017).

By 1800 UTC 18 September, Humberto had moved into the right-rear entrance region of an upper-level jet stream wind maximum (Fig. 9, left panel), where an existing transverse circulation (i.e., combined vertical and horizontal circulations; Fig. 9, right panel) was present (Bjerknes 1951). The rapid warming of the air column on the equatorward (southeast) side of the jet stream induced by Humberto's intense warm core would have resulted in a sharp increase in the strength of both the jet stream and the transverse circulation (Fig. 10), causing an acceleration of the low-level winds. This enhanced wind phenomenon can be seen in a time series plot of surface observations from the Bermuda airport (Fig. 11) late on 18 September where a peak

10-min average wind speed of 71 kt and a gust to 101 kt occurred in conjunction with a sharp temperature decrease of at least 7°C (12°F) between 2328–2331 UTC. The much cooler air was likely caused by cold downdrafts created by rain evaporating into dry air that was entrained into Humberto's southern eyewall. This 'sting jet' phenomenon may have persisted for several more hours based on the 'onion-shaped' temperature-dewpoint vertical profile shown in the 0249 UTC 19 September dropwindsonde data (Fig. 6b) where drier air is noted in the 950–850-mb layer. Typically, the surface temperature in tropical cyclones is warmer than the air aloft unless the surface layer has been modified by drier and cooler air that descends in convective downdrafts.

The highest official wind speeds observed on Bermuda occurred late on 18 September. On the southwestern end of the island at Pearl Island, a 1-min sustained wind of 87 kt and a gust to 107 kt were measured at 2319 UTC 18 September. A 10-min average wind speed of 71 kt and a gust to 101 kt were measured on the northeastern end of the island at the L.F. Wade International Airport (TXKF) at 2328 UTC and by the AviMet-12 weather sensor located near the west end of the runway at 2331 UTC, respectively. At the Bermuda Maritime Operations Centre (MAROPS) located on the north end of the island, a 1-min sustained wind of 94 kt and a gust of 125 kt were measured at an elevation of 290 ft (88 m) at 2324 UTC. Reducing that sustained wind to a standard 10-m elevation yields an equivalent 1-min wind speed of approximately 78 kt.

There was an unofficial report of a 1-min sustained wind of 97 kt and a gust to 145 kt observed by a private anemometer located on the roof of the Commissioner's House at Commissioner's Point (Fig. 12, left panel) at an elevation of 115 ft ASL (35 m). However, there is some uncertainty in the validity of this wind report due to the anemometer being located close to the top of the building with a hipped-roof, which could cause winds flowing over the structure to be accelerated by the Bernoulli Effect. Assuming that the wind data are valid, the 97-kt wind speed would reduce to 89 kt at 10-m elevation.

The Crescent Marine Navigation Aid (NAVAID) located offshore along the reef line about 8 n mi northwest of Bermuda, measured a 10-min average wind speed of 82 kt and a gust to 113 kt at an elevation of 6 m ASL at 2313 UTC (Fig. 12, right panel). Increasing the wind speed to about 87 kt for a 10-m height (using a logarithmic vertical wind profile), and then adjusting that value to a 1-min wind speed for an open marine exposure yields an equivalent wind speed of approximately 96 kt.

The lowest reliable pressures on Bermuda occurred on the north end of the island at the airport when Humberto made its closest approach. A pressure of 978.8 mb was measured at 2321 UTC 18 September by the AviMet-12 weather sensor, while a pressure of 979.3 mb was observed at the same time by the Bermuda (TXKF) airport official weather observing system (Table 4).

Storm Surge[2]

Storm surge values along the east coast of Florida (Table 4) were generally around 1.0 to 1.5 ft, resulting in saltwater inundation levels of around 1 ft. On Bermuda, storm surge values were around 3 ft, mainly on the west-facing beaches.

Rainfall and Flooding

Rainfall amounts on Bermuda were relatively light compared to most tropical cyclones. A storm total rainfall of 1.57 inches was measured at the L.F. Wade International Airport (TXKF) on 18–19 September. Rainfall amounts across the central and northwestern Bahamas, and the east coast of Florida, were less than one inch.

CASUALTY AND DAMAGE STATISTICS

Hurricane Humberto was responsible for two direct deaths[3] in the United States. A 22-year old man disappeared after going for a swim in the ocean off St. Augustine Beach, Florida, on 15 September. According to St. Johns County Fire-Rescue, the young man was last seen in the water about 4 p.m. EDT that day, and was presumed to have drowned. The rough surf and strong rip currents also resulted in 21 water rescues along the St. Johns County coast during the weekend of 14–15 September, with three people requiring hospitalization. Farther north along the U.S. coast on 18 September, a 62-year old man drowned in Humberto-induced rip currents at Topsail Beach, North Carolina.

Humberto caused widespread damage and power outages on Bermuda. Powerful wind gusts exceeding 100 kt across all of the island knocked down trees and power lines. Around 28,000 customers, or more than 80% of the island's subscribers, were without power at some point during the storm, which included a prolonged communications outage between the Bermuda Weather Service and its Doppler weather radar system. The Bermuda Emergency Management office reported that Humberto's effects caused three structural fires and briefly forced the closure

[2] Several terms are used to describe water levels due to a storm. **Storm surge** is defined as the abnormal rise of water generated by a storm, over and above the predicted astronomical tide, and is expressed in terms of height above normal tide levels. Because storm surge represents the deviation from normal water levels, it is not referenced to a vertical datum. **Storm tide** is defined as the water level due to the combination of storm surge and the astronomical tide, and is expressed in terms of height above a vertical datum, i.e. the North American Vertical Datum of 1988 (NAVD88) or Mean Lower Low Water (MLLW). **Inundation** is the total water level that occurs on normally dry ground as a result of the storm tide, and is expressed in terms of height above ground level. At the coast, normally dry land is roughly defined as areas higher than the normal high tide line, or Mean Higher High Water (MHHW).

[3] Deaths occurring as a direct result of the forces of the tropical cyclone are referred to as "direct" deaths. These would include those persons who drowned in storm surge, rough seas, rip currents, and freshwater floods. Direct deaths also include casualties resulting from lightning and wind-related events (e.g., collapsing structures). Deaths occurring from such factors as heart attacks, house fires, electrocutions from downed power lines, vehicle accidents on wet roads, etc., are considered indirect" deaths.

of “The Causeway”, a road that connects the L.F. Wade International Airport in northern Bermuda to the population centers in southern Bermuda, due to possible structural integrity issues.

Information obtained from the Aon Re-Insurance Company’s (Aon.com) 2019 Annual Summary indicate that damage losses on Bermuda caused by Hurricane Dorian, including damage to the new airport, exceed $25 million (USD).

FORECAST AND WARNING CRITIQUE

The genesis of Humberto was adequately forecast. The wave from which Humberto developed was first introduced in the Tropical Weather Outlook 198 h prior to genesis with a low probability of formation (<40%) in both the 48- and 120-h forecast periods (Table 2). However, the disturbance was dropped from the 48-h forecast period (hours shown in parentheses in Table 2) when it became apparent that strong vertical wind shear was going to prevent genesis from occurring in the short term. The system was re-introduced into the 48-h period with a low probability of genesis 72 h before Humberto formed. The genesis probabilities for the disturbance were increased to the medium category (40–60%) 48 h and 66 h before genesis for the 48- and 120-h forecast periods, respectively. The genesis forecasts reached the high category (>60%) 30 h and 42 h before genesis occurred for the 48- and 120-h forecast periods, respectively.

A verification of NHC official track forecasts for Humberto is given in Table 5a. Official forecast track errors (OFCL) were lower than the mean official errors for the previous 5-yr period, especially at 96 and 120 h where OFCL errors were about 45% and 30% better than average, respectively. Prior to Humberto being declared a tropical cyclone, Potential Tropical Cyclone (PTC) advisories were issued from 2100 UTC 12 September until 1800 UTC 13 September in anticipation of the disturbance producing tropical-storm-force winds across the northwestern Bahamas and the Florida east coast. The OFCL forecasts were poor during the PTC stage, with the first few advisories predicting landfall in the central and northwestern Bahamas and along the east coast of the Florida peninsula (Fig. 13). However, moderate southwesterly vertical wind shear (Fig. 4) during the PTC stage kept most of the deep convection displaced into the northeastern portion of the circulation, resulting in the LLCC redeveloping to the east of the forecast tracks. Since the early OFCL forecasts were anticipating landfall, which would cause Humberto to weaken and become a shallow cyclone, they did not expect the storm to move through a weakness in the subtropical ridge situated off the southeastern coast of the United States. However, once Humberto became a tropical cyclone, track forecasts improved significantly, including accurately predicting the pronounced decrease in forward speed and sharp turn toward the northeast when Humberto moved through a break in the ridge axis by early 16 September. As a result, cross-track errors were small and no NHC forecasts took the center of the hurricane across Bermuda.

A homogeneous comparison of the official track errors with selected guidance models is given in Table 5b. NHC official track forecasts outperformed all of the guidance models at 96 h, and were bested only slightly by the dynamical models EGRI (UKMET) and HMNI (HMON) at other time periods. The consensus models HCCA, FSSE (Florida State Superensemble), TVCA, TVCX, and TVDG had slightly lower track errors compared to OFCL at 12–48 h, but they were significantly lower, by nearly 50%, at 120 h. The EMXI (ECMWF) had uncharacteristically large errors at all times, especially at the 72-, 96-, and 120-h periods, which were primarily due to along-track errors caused by a positive (fast) forward speed bias.

A verification of NHC official intensity forecasts for Humberto is given in Table 6a. Official forecast intensity errors were lower than the mean official errors for the previous 5-yr period in 12–72 h and were greater than the mean errors at the 96- and 120-h periods. The larger-than-average errors at days 4 and 5 were due to a negative (low) intensity bias preceding Humberto's peak intensity, as forecasts did not anticipate Humberto's continued strengthening in the face of extremely hostile vertical wind shear conditions (Fig. 4) when the hurricane approached Bermuda. A positive (high) intensity bias later occurred due to forecasts not capturing the rapid weakening trend after Humberto peaked in intensity while passing to the northeast of Bermuda (Fig. 14).

A homogeneous comparison of the official intensity errors with selected guidance models is given in Table 6b. NHC official intensity errors were lower than all of the dynamical models at all times, except for the EGRI and HWFI models, which bested OFCL at 12, 72, 96, and 120 h. The corrected-consensus models HCCA and FSSE were equal to or better than OFCL at all times. The global and regional models performed quite well by forecasting continued deepening of Humberto, likely in response to strong baroclinic forcing when the hurricane was expected to encounter very unfavorable vertical wind shear conditions. However, the deepening process did not equate to an increase in the eyewall pressure gradient and resultant increase in Humberto's intensity, owing to the models' baroclinic-induced pressure falls occurring over a relatively large area both inside and outside the hurricane's eye.

Watches and warnings associated with Humberto are given in Table 7.

A Tropical Storm Warning was issued for the northwestern Bahamas on the first PTC advisory (2100 UTC 12 September) and a Tropical Storm Watch was issued for portions of the Florida east coast on the second PTC advisory (0300 UTC 13 September). Due to Humberto's actual path keeping the cyclone east of rather than through the Bahamas, the Tropical Storm Warning for the northwestern Bahamas did not verify. Similarly, the Tropical Storm Watch for the Florida east coast did not verify even though sustained winds of 32 kt along with wind gusts to 35 kt (Table 4) occurred approximately 20 h after the Watch was issued.

For Bermuda, the Tropical Storm Watch, Tropical Storm Warning, Hurricane Watch, and Hurricane Warning were issued with lead times of approximately 48 h, 32 h, 32 h, and 26 h, respectively, before the arrival of tropical-storm-force winds on the island.

References

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Acknowledgements

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Table 1. Best track for Hurricane Humberto, 13–19 September 2019.

Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Stage
12 / 1200	23.0	74.2	1010	25	low
12 / 1800	23.4	74.3	1010	25	"
13 / 0000	23.8	74.3	1009	25	"
13 / 0600	24.2	74.4	1009	25	"
13 / 1200	24.7	74.5	1008	30	"
13 / 1800	25.2	74.7	1008	30	tropical depression
14 / 0000	25.6	75.2	1007	35	tropical storm
14 / 0600	26.0	75.9	1006	35	"
14 / 1200	26.5	76.5	1004	40	"
14 / 1800	27.0	77.0	1003	45	"
15 / 0000	27.5	77.3	998	50	"
15 / 0600	28.0	77.6	997	50	"
15 / 1200	28.6	77.9	995	55	"
15 / 1800	29.1	78.1	993	60	"
16 / 0000	29.2	77.8	987	65	hurricane
16 / 0600	29.5	77.3	982	70	"
16 / 1200	29.8	76.7	979	75	"
16 / 1800	30.1	76.1	975	75	"
17 / 0000	30.3	75.4	966	80	"
17 / 0600	30.5	74.7	964	85	"
17 / 1200	30.7	73.8	961	90	"
17 / 1800	30.9	72.9	956	95	"
18 / 0000	31.2	71.6	952	100	"
18 / 0600	31.5	70.3	951	105	"
18 / 1200	32.0	68.8	951	105	"
18 / 1800	32.5	67.2	950	110	"
19 / 0000	33.2	65.0	950	110	"
19 / 0300	33.8	64.0	950	110	"
19 / 0600	34.5	62.9	951	105	"
19 / 1200	36.0	60.8	955	95	"
19 / 1800	37.7	59.3	961	80	"
20 / 0000	39.1	58.5	967	70	extratropical
20 / 0600	40.4	58.0	972	60	"
20 / 1200	41.5	57.5	977	50	"
20 / 1800					dissipated
18 / 1800	32.5	67.2	950	110	minimum pressure and maximum intensity

Table 2. Number of hours in advance of formation associated with the first NHC Tropical Weather Outlook forecast in the indicated likelihood category. Note that the timings for the "Low" category do not include forecasts of a 0% chance of genesis. Hours in parentheses ( ) indicates lead time system was first mentioned in the outlook before being removed and then re-entered.

	Hours Before Genesis	
	48-Hour Outlook	**120-Hour Outlook**
Low (<40%)	(198) 72	198
Medium (40%-60%)	48	66
High (>60%)	30	42

Table 3. Selected ship and buoy reports during the PTC, tropical, and extratropical stages with winds of at least 34 kt, except for significant observations, for Hurricane Humberto during the period 13–19 September 2019.

Date/Time (UTC)	Ship call sign	Latitude (°N)	Longitude (°W)	Wind dir/speed (kt)	Pressure (mb)
13 / 0300	3FOC5	26.8	79.4	050 / 37	1013.7
13 / 0900	3FZO8	24.4	74.3	040 / 35	1011.4
13 / 1500	H3VU	26.8	79.1	070 / 35	1018.0
13 / 2200	C6FV9	28.0	80.2	050 / 37	1014.3
13 / 2300	HPYE	27.9	80.0	050 / 40	1014.2
14 / 0100	3FZO8	26.3	78.9	050 / 40	1015.6
14 / 0100	C6FV9	27.4	79.7	050 / 37	1013.9
14 / 0300	HPYE	27.1	79.3	050 / 37	1014.1
14 / 0800	HPYE	26.0	78.3	020 / 45	1011.0
14 / 2200	H3GR	30.1	81.0	050 / 35	1016.8
15 / 0000	H3GR	29.8	80.7	050 / 35	1015.8
15 / 0200	3FZO8	28.7	78.5	050 / 35	1014.9
15 / 0300	3FZO8	28.8	78.2	050 / 35	1013.8
15 / 0400	VRNY4	27.9	74.2	130 / 35	1014.0
15 / 0500	3FZO8	28.9	77.5	090 / 43	1012.9
15 / 0600	3FZO8	29.0	77.2	100 / 40	1013.0
15 / 1200	3FZO8	29.4	75.7	130 / 45G56	1015.2
15 / 1340	Buoy 41010	28.9	78.5	*** / 37	1003.4
15 / 1350	41010	28.9	78.5	*** / 35	1003.1
15 / 1400	41010	28.9	78.5	*** / 37	1002.2
15 / 1410	41010	28.9	78.5	*** / 43G50	1001.8
15 / 1420	41010	28.9	78.5	*** / 43G52	1001.6
15 / 1430	41010	28.9	78.5	*** / 43	1001.4
15 / 1440	41010	28.9	78.5	*** / 44	1000.9

15 / 1450	41010	28.9	78.5	*** / 45G55	1000.8
15 / 1500	41010	28.9	78.5	*** / 41G56	1000.8
15 / 1510	41010	28.9	78.5	*** / 37	1000.9
15 / 1520	41010	28.9	78.5	*** / 35	1001.1
15 / 1920	41010	28.9	78.5	310 / 35	998.7
15 / 1930	41010	28.9	78.5	310 / 37	998.5
15 / 1940	41010	28.9	78.5	300 / 39	998.4
15 / 1950	41010	28.9	78.5	310 / 37	998.5
15 / 2000	41010	28.9	78.5	300 / 37	998.1
15 / 2010	41010	28.9	78.5	310 / 39	998.6
15 / 2020	41010	28.9	78.5	310 / 37	998.8
15 / 2030	41010	28.9	78.5	300 / 37	998.6
15 / 2040	41010	28.9	78.5	300 / 37	999.0
15 / 2050	41010	28.9	78.5	310 / 35	999.3
15 / 2100	41010	28.9	78.5	300 / 35	999.1
15 / 2110	41010	28.9	78.5	290 / 37	998.4
15 / 2120	41010	28.9	78.5	300 / 39	998.2
15 / 2130	41010	28.9	78.5	310 / 39	998.7
15 / 2140	41010	28.9	78.5	320 / 35	999.0
15 / 2150	41010	28.9	78.5	320 / 37	999.2
15 / 2200	41010	28.9	78.5	320 / 35	999.5
15 / 2320	41010	28.9	78.5	320 / 35	1001.4
15 / 2330	41010	28.9	78.5	320 / 35	1001.5
16 / 0200	3FFL8	25.9	78.0	180 / 38	1013.9
16 / 0200	3FOC5	27.4	79.3	280 / 35	1011.4
16 / 0400	C6FM8	25.6	76.1	220 / 35	1011.0
16 / 2100	WDD612	30.6	79.6	010 / 35	1011.5
17 / 0150	Buoy 41002	31.9	74.9	070 / 35	1006.3
17 / 0240	41002	31.9	74.9	070 / 35	1006.2

17 / 0250	41002	31.9	74.9	070 / 35	1006.3
17 / 0350	41002	31.9	74.9	070 / 35	1006.2
17 / 0450	41002	31.9	74.9	060 / 37	1005.5
17 / 0610	41002	31.9	74.9	060 / 35	1003.6
17 / 0620	41002	31.9	74.9	060 / 37	1003.3
17 / 0630	41002	31.9	74.9	060 / 35	1003.4
17 / 0640	41002	31.9	74.9	060 / 35	1003.3
17 / 0650	41002	31.9	74.9	060 / 37	1003.1
17 / 0700	41002	31.9	74.9	060 / 37	1002.9
17 / 0710	41002	31.9	74.9	070 / 39	1002.7
17 / 0720	41002	31.9	74.9	060 / 39	1002.8
17 / 0730	41002	31.9	74.9	060 / 37	1002.8
17 / 0740	41002	31.9	74.9	060 / 37	1002.3
17 / 0750	41002	31.9	74.9	060 / 39	1002.5
17 / 0800	41002	31.9	74.9	060 / 37	1002.0
17 / 0810	41002	31.9	74.9	060 / 37G50	1001.9
17 / 0820	41002	31.9	74.9	060 / 37	1002.1
17 / 0828	41002	31.9	74.9	060 / 47	
17 / 0830	41002	31.9	74.9	060 / 41G52	1002.2
17 / 0840	41002	31.9	74.9	050 / 37G50	1002.2
17 / 0850	41002	31.9	74.9	060 / 41G51	1002.1
17 / 0900	41002	31.9	74.9	060 / 37	1001.8
17 / 0910	41002	31.9	74.9	050 / 39	1001.9
17 / 0920	41002	31.9	74.9	050 / 37	1001.9
17 / 0930	41002	31.9	74.9	050 / 37	1002.0
17 / 0940	41002	31.9	74.9	050 / 39G52	1001.7
17 / 0950	41002	31.9	74.9	060 / 37G51	1001.7
17 / 1000	41002	31.9	74.9	060 / 39G50	1001.6
17 / 1010	41002	31.9	74.9	060 / 37	1001.6

17 / 1020	41002	31.9	74.9	060 / 37	1001.7
17 / 1030	41002	31.9	74.9	060 / 39	1001.6
17 / 1040	41002	31.9	74.9	060 / 37	1001.6
17 / 1050	41002	31.9	74.9	060 / 37G51	1001.6
17 / 1100	41002	31.9	74.9	060 / 37	1001.7
17 / 1110	41002	31.9	74.9	050 / 37	1002.2
17 / 1120	41002	31.9	74.9	050 / 37	1002.3
17 / 1130	41002	31.9	74.9	050 / 37	1002.1
17 / 1140	41002	31.9	74.9	050 / 37	1002.3
17 / 1150	41002	31.9	74.9	040 / 37	1002.6
17 / 1200	41002	31.9	74.9	040 / 35	1002.2
17 / 1210	41002	31.9	74.9	040 / 35	1002.6
17 / 1220	41002	31.9	74.9	040 / 35	1002.8
17 / 1230	41002	31.9	74.9	040 / 35	1002.9
17 / 1240	41002	31.9	74.9	040 / 35	1002.6
17 / 1300	41002	31.9	74.9	030 / 35	1003.1
17 / 1320	41002	31.9	74.9	030 / 35	1003.3
17 / 1330	41002	31.9	74.9	030 / 35	1003.3
17 / 1350	41002	31.9	74.9	030 / 35	1003.8
17 / 1400	41002	31.9	74.9	040 / 35	1003.6
18 / 0230	Buoy 41048	31.8	69.6	110 / 35	995.1
18 / 0300	41048	31.8	69.6	110 / 35	993.5
18 / 0310	41048	31.8	69.6	120 / 37	993.5
18 / 0320	41048	31.8	69.6	130 / 39	993.5
18 / 0330	41048	31.8	69.6	120 / 35	993.0
18 / 0340	41048	31.8	69.6	120 / 35	992.7
18 / 0410	41048	31.8	69.6	120 / 37	990.2
18 / 0420	41048	31.8	69.6	120 / 39	990.4
18 / 0430	41048	31.8	69.6	130 / 41	989.7

18 / 0440	41048	31.8	69.6	120 / 37	989.1
18 / 0450	41048	31.8	69.6	130 / 39	988.7
18 / 0500	41048	31.8	69.6	130 / 41	987.7
18 / 0510	41048	31.8	69.6	120 / 41	987.4
18 / 0520	41048	31.8	69.6	120 / 45	986.1
18 / 0530	41048	31.8	69.6	120 / 45	984.7
18 / 0540	41048	31.8	69.6	120 / 47	983.9
18 / 0550	41048	31.8	69.6	120 / 47G64	982.9
18 / 0600	V7A207	35.4	68.0	070 / 40	1008.5
18 / 0600	Buoy 41048	31.8	69.6	110 / 49G65	981.4
18 / 0610	41048	31.8	69.6	110 / 49G66	979.8
18 / 0620	41048	31.8	69.6	110 / 51G68	978.3
18 / 0630	41048	31.8	69.6	110 / 54G70	976.6
18 / 0640	41048	31.8	69.6	110 / 52G73	975.3
18 / 0650	41048	31.8	69.6	110 / 51G65	973.9
18 / 0700	41048	31.8	69.6	110 / 52G71	972.6
18 / 0710	41048	31.8	69.6	110 / 54G72	971.2
18 / 0717	41048	31.8	69.6	*** / 61	
18 / 0720	41048	31.8	69.6	110 / 54G73	969.2
18 / 0724	41048	31.8	69.6	*** / 66	
18 / 0730	41048	31.8	69.6	110 / 56G74	967.1
18 / 0735	41048	31.8	69.6	*** / 64	
18 / 0740	41048	31.8	69.6	110 / 58G75	964.4
18 / 0743	41048	31.8	69.6	*** / 62	
18 / 0748	41048	31.8	69.6	*** / 62	
18 / 0750	41048	31.8	69.6	110 / 58G77	963.2
18 / 0754	41048	31.8	69.6	*** / 65	
18 / 0800	41048	31.8	69.6	110 / 58G75	962.3
18 / 0802	41048	31.8	69.6	*** / 61	

18 / 0810	41048	31.8	69.6	110 / 56G75	961.0
18 / 0820	41048	31.8	69.6	100 / 54G73	960.1
18 / 0830	41048	31.8	69.6	090 / 52G70	959.0
18 / 0840	41048	31.8	69.6	090 / 49G68	957.6
18 / 0850	41048	31.8	69.6	080 / 47G60	955.9
18 / 0900	41048	31.8	69.6	080 / 41G56	955.6
18 / 0910	41048	31.8	69.6	080 / 39G55	955.0
18 / 0920	41048	31.8	69.6	070 / 32G47	954.5
18 / 0930	41048	31.8	69.6	060 / 27G38	954.2
18 / 0940	41048	31.8	69.6	060 / 30G40	955.2
18 / 0948	41048	31.8	69.6	*** / 29	
18 / 0950	41048	31.8	69.6	040 / 24G36	955.8
18 / 1000	41048	31.8	69.6	030 / 37G54	957.1
18 / 1010	41048	31.8	69.6	010 / 49G78	956.3
18 / 1020	41048	31.8	69.6	010 / 52G73	959.0
18 / 1027	41048	31.8	69.6	*** / 61	
18 / 1030	41048	31.8	69.6	360 / 58G76	961.1
18 / 1034	41048	31.8	69.6	*** / 65	
18 / 1040	41048	31.8	69.6	360 / 60G81	963.4
18 / 1046	41048	31.8	69.6	*** / 64	
18 / 1050	41048	31.8	69.6	360 / 60G80	967.4
18 / 1100	C6SE3	36.2	71.9	020 / 37	1017.0
18 / 1100	Buoy 41048	31.8	69.6	350 / 54G75	969.5
18 / 1101	41048	31.8	69.6	*** / 60	
18 / 1110	41048	31.8	69.6	350 / 54G72	971.2
18 / 1120	41048	31.8	69.6	350 / 57G76	973.0
18 / 1129	41048	31.8	69.6	*** / 66	
18 / 1130	41048	31.8	69.6	340 / 59G77	974.5
18 / 1134	41048	31.8	69.6	*** / 62	

18 / 1140	41048	31.8	69.6	340 / 58G75	976.4
18 / 1150	41048	31.8	69.6	330 / 56G74	978.0
18 / 1154	41048	31.8	69.6	*** / 63	
18 / 1200	41048	31.8	69.6	330 / 57G74	979.8
18 / 1209	41048	31.8	69.6	*** / 64	
18 / 1210	41048	31.8	69.6	330 / 58G75	980.7
18 / 1215	41048	31.8	69.6	*** / 62	
18 / 1220	41048	31.8	69.6	330 / 56G74	982.8
18 / 1230	41048	31.8	69.6	320 / 56G73	984.5
18 / 1240	41048	31.8	69.6	330 / 54G70	986.1
18 / 1250	41048	31.8	69.6	330 / 54G70	987.3
18 / 1300	3FZO8	27.3	63.3	190 / 35	1012.8
18 / 1300	Buoy 41048	31.8	69.6	330 / 52G67	988.1
18 / 1310	41048	31.8	69.6	330 / 52G65	989.4
18 / 1320	41048	31.8	69.6	340 / 49G60	990.0
18 / 1330	41048	31.8	69.6	340 / 47	990.4
18 / 1340	41048	31.8	69.6	340 / 45	990.8
18 / 1350	41048	31.8	69.6	340 / 47	991.2
18 / 1400	41048	31.8	69.6	340 / 45	991.9
18 / 1410	41048	31.8	69.6	340 / 43	992.3
18 / 1420	41048	31.8	69.6	340 / 45	992.8
18 / 1430	41048	31.8	69.6	340 / 41	993.5
18 / 1440	41048	31.8	69.6	340 / 41	993.6
18 / 1442	Buoy 41047	27.5	71.5	*** / 35	
18 / 1450	Buoy 41048	31.8	69.6	340 / 41	994.0
18 / 1500	41048	31.8	69.6	340 / 41	994.4
18 / 1510	41048	31.8	69.6	330 / 39	994.9
18 / 1520	41048	31.8	69.6	330 / 39	995.6
18 / 1530	41048	31.8	69.6	330 / 37	996.1

18 / 1540	41048	31.8	69.6	320 / 37	996.7
18 / 1550	41048	31.8	69.6	310 / 39	997.0
18 / 1600	3FZO8	26.8	64.1	190 / 35	1012.5
18 / 1600	V7WS4	32.8	74.5	030 / 38	1019.4
18 / 1600	Buoy 41048	31.8	69.6	310 / 41	997.7
18 / 1610	41048	31.8	69.6	320 / 41	998.0
18 / 1620	41048	31.8	69.6	310 / 39	998.6
18 / 1630	41048	31.8	69.6	320 / 41	998.7
18 / 1640	41048	31.8	69.6	330 / 39	999.2
18 / 1650	41048	31.8	69.6	320 / 37	999.6
18 / 1700	3FZO8	26.6	64.3	190 / 35	1012.0
18 / 1700	Buoy 41048	31.8	69.6	330 / 39	999.7
18 / 1710	41048	31.8	69.6	330 / 41	999.6
18 / 1720	41048	31.8	69.6	330 / 37	999.8
18 / 1730	41048	31.8	69.6	330 / 37	1000.2
18 / 1740	41048	31.8	69.6	330 / 37	1000.2
18 / 1750	41048	31.8	69.6	330 / 35	1000.3
18 / 1800	VRSK6	36.0	73.7	350 / 37	1014.0
18 / 1800	V7A207	37.3	70.3	040 / 50	1011.5
18 / 1800	Buoy 41048	31.8	69.6	330 / 35	1000.6
18 / 1810	41048	31.8	69.6	330 / 37	1000.9
18 / 1820	41048	31.8	69.6	330 / 37	1001.2
18 / 1830	41048	31.8	69.6	330 / 35	1001.3
18 / 1840	41048	31.8	69.6	330 / 35	1001.5
19 / 0400	KABP	40.1	62.4	050 / 35	1016.5
19 / 0500	KABP	40.0	63.0	040 / 40	1016.3
19 / 0600	KABP	40.0	63.4	040 / 40	1015.3
19 / 0900	DCPI2	39.3	56.0	090 / 37	
19 / 1200	DCPI2	39.5	54.8	070 / 40	1011.4

19 / 1500	DCPI2	39.7	53.5	090 / 40	1010.4
19 / 1800	DCPI2	39.9	52.3	080 / 36	1013.3
20 / 1200	9VKQ2	38.9	50.2	060 / 38	1019.0
20 / 1800	44139	44.2	57.1	050 / 35	1002.0

*** = wind direction not available

G = wind gust

Buoy averaging periods are 10 minutes; 1-minute average wind denoted by no wind direction (***).

Buoys 41010 and 41048 anemometer height = 4.1 m above sea level

Buoy 41002 anemometer height = 3.8 m above sea level

Table 4. Selected surface observations for Hurricane Humberto, 13–19 September 2019.

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Estimated Inundation (ft)[e]	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)				
Bermuda									
International Civil Aviation Organization (ICAO) Sites									
L.F. Wade IAP (TXKF) (32.36N 64.68W – elev. 59 ft)	18/1955	990.9	18/1955	34 10 m/10 min	48				
	18/2019	989.8	18/2019	37 10 m/10 min	56				
	18/2055	989.2	18/2055	35 10 m/10 min	54				
	18/2142	985.1	18/2142	45 10 m/10 min	62				
	18/2155	985.0	18/2155	46 10 m/10 min	64				
	18/2220	984.1	18/2220	48 10 m/10 min	71				
	18/2255	982.1	18/2255	58 10 m/10 min	75				
	18/2309	982.0	18/2309	50 10 m/10 min	72				
	18/2321	979.3							
	18/2328	980.0	18/2328	71 10 m/10 min	97				
	18/2331	980.0	18/2331	70 10 m/10 min	101				
	18/2355	981.0	18/2355	63 10 m/10 min	95				
	19/0012	986.1	19/0012	53 10 m/10 min	75				
	19/0058	990.9	19/0058	44 10 m/10 min	64				
	19/0155	994.9	19/0155	40 10 m/10 min	53				1.57
AWOS									
Airport AviMet-12 32.366N 64.696W	18/2321	978.8	18/2330	71 10 m/10 min	101				
			18/2331	71 10 m/10 min	101				
			18/2332	70 10 m/10 min	101				
			18/2327	70 10 m/10 min	97				
Airport AviMet-30 32.361N 64.666W	18/2335	981.3	18/2331		100				

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Estimated Inundation (ft)[e]	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)				
			18/2333	69 10 m/10 min	100				
			18/2337	71 10 m/10 min	86				
			18/2339	71 10 m/10 min	89				
Crescent (offshore) Marine NAVAID 32.42N 64.82W			18/2313	82 6 m/10 min	101				
			18/2316	80 6 m/10 min	102				
			18/2300	79 6 m/10 min	113				
			18/2319	79 6 m/10 min	98				
			18/2303	78 6 m/10 min	97				
			18/2308	78 6 m/10 min	97				
			18/2309	78 6 m/10 min	100				
			18/2355	78 6 m/10 min	103				
			18/2248	77 6 m/10 min	105				
			18/2307	77 6 m/10 min	93				
			18/2320	77 6 m/10 min	96				
			18/2331	76 6 m/10 min	101				
			18/2315	75 6 m/10 min	101				
			18/2254	74 6 m/10 min	101				
			18/2322	74 6 m/10 min	108				
			18/2337	73 6 m/10 min	103				
			18/2311	73 1m/10 min	102				
			18/2343	70 6 m/10 min	106				
ESSO Pier, St. Georges Is. 32.37N 64.70W	18/2324	980.2	18/2242	73 4 m/2 min		3.0			
			18/2154	72 4 m/2 min					
			18/2212	70 46 m/2 min					

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Estimated Inundation (ft)[e]	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)				
Heliport [f] 32.36N 64.70W			18/2019	53 10 m/1 min	68				
			18/2022	52 10 m/1 min	77				
			18/2016	52 10 m/1 min	63				
			18/2018	52 10 m/1 min	75				
			18/2023	51 10 m/1 min	74				
Maritime Operations Centre (MAROPS) 32.38N 64.68W (elev. 290 ft)	18/2352	980.0	18/2324	94 /1 min	125				
			18/2327		118				
			18/2330		117				
			18/2326		116				
			18/2358		116				
			18/2332		115				
			18/2347		115				
			18/2355		115				
			18/2350		114				
Pearl Island (near shore) 32.29N 64.84W			18/2319	87 10 m/1 min	107				
			18/2322	85 10 m/1 min	95				
			18/2316	84 10 m/1 min	98				
			18/2310	83 10 m/1 min	94				
			18/2321	81 10 m/1 min	107				
			18/2317	73 10 m/1 min	105				
			18/2319	87 10 m/1 min	102				
			18/2320	78 10 m/1 min	102				
			18/2328	80 10 m/1 min	99				
			18/2316	84 10 m/1 min	98				

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Estimated Inundation (ft)[e]	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)				
Unofficial									
Commissioner's House, National Museum of Bermuda, Dockyard *WindGuru.cz* elev. 115 ft (32.33N 64.83W)			18/2322	97 /1 min	145				
			18/2318	97 /1 min	145				
			18/2320	97 /1 min					
			18/2330	97 /1 min					
Bahamas									
International Civil Aviation Organization (ICAO) Sites									
Grand Bahama IAP (MYGF) (26.56N 78.70W – elev. 10 ft)	14/2100	1010.8	13/1816	25 10 m/10 min					
Coastal-Marine Automated Network (C-MAN) Sites									
Settlement Point GBI (SPGF1) 26.70N 79.00W	15/0800	1010.7	13/2350	24 7 m/2 min	32				
Florida									
International Civil Aviation Organization (ICAO) Sites									
Daytona Beach IAP (KDAB) 29.18N 81.06W	15/1955	1011.8	15/0351	25 10 m/2 min	32				
Mayport Naval Base (KNRB) 30.39N 81.42W	16/0752	1013.2	15/1150	24 10 m/2 min	30				
National Ocean Service (NOS) Sites									
Blount Island Command (BLIF1) 30.39N 81.52W	16/2248	1014.9	15/1524	20 9 m/6 min	33				
Dames Point (DMSF1) 30.40N 81.43W	16/2248	1014.9				1.02	2.45	1.1	
Fernandina Beach (FRDF1) 30.67N 81.47W	16/2218	1014.3	15/2030	15 7 m/6 min	24	1.76	3.47	0.7	

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Estimated Inundation (ft)[e]	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)				
Lake Worth Pier (LWKF1) 26.61N 80.03W	15/2100	1012.3	13/2306	28 6 m/6 min	35	1.28	1.58	1.0	
Mayport (Bar Pilots Dock) (MYPF1) 30.40N 81.43W	16/2236	1014.2	15/1200	25 6 m/6 min	32	1.34	2.93	1.0	
Southbank Riverwalk, St. Johns River (MSBF1) 30.32N 81.66W						0.98	1.78	1.1	
South Port Everglades (PEGF1) 26.08N 80.12W	15/2042	1011.4	13/2224	32 6 m/6 min	35	0.87	1.52	1.0	
Trident Pier, Prt Canaveral (TRDF1) 28.41N 80.59W	15/2012	1012.6	14/1736	21 7 m/6 min	28	1.32	2.22	1.1	
Virginia Key, Biscayne Bay (VAKF1) 25.73N 80.16W	15/2100	1011.2	13/1936	23 10 m/6 min	31	0.91	1.38	1.2	

[a] Date/time is for sustained wind when both sustained and gust are listed.
[b] Except as noted, sustained wind averaging periods for C-MAN and land-based reports are 2 min.
[c] Storm surge is water height above normal astronomical tide level.
[d] For most locations, storm tide is water height above the North American Vertical Datum of 1988 (NAVD88). Storm tide is water height above Mean Lower Low Water (MLLW) for NOS stations in Puerto Rico, the U.S. Virgin Islands, and Barbados.
[e] Estimated inundation is the maximum height of water above ground. For some USGS storm tide pressure sensors, inundation is estimated by subtracting the elevation of the sensor from the recorded storm tide. For other USGS storm tide sensors and USGS high-water marks, inundation is estimated by subtracting the elevation of the land derived from a Digital Elevation Model (DEM) from the recorded and measured storm tide. For NOS tide gauges, the height of the water above Mean Higher High Water (MHHW) is used as a proxy for inundation.
[f] Data not available after 2024 UTC 18 September 2019.

Table 5a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) track forecast errors (n mi) for Hurricane Humberto, 13–19 September 2019. Mean errors for the previous 5-yr period are shown for comparison. Official errors that are smaller than the 5-yr means are shown in boldface type.

	Forecast Period (h)						
	12	24	36	48	72	96	120
OFCL	**17.5**	**29.2**	**44.6**	**58.8**	**93.2**	**75.5**	**122.8**
OCD5	36.3	79.3	132.4	190.6	287.9	359.5	424.9
Forecasts	23	21	19	17	13	9	5
OFCL (2014-18)	23.6	35.5	47.0	61.8	96.0	136.0	179.6
OCD5 (2014-18)	44.8	97.6	157.4	220.1	340.7	446.6	536.6

Table 5b. Homogeneous comparison of selected track forecast guidance models (in n mi) for Hurricane Humberto, 13–19 September 2019. Errors smaller than the NHC official forecast are shown in boldface type. The number of official forecasts shown here will generally be smaller than that shown in Table 5a due to the homogeneity requirement.

Model ID	Forecast Period (h)						
	12	24	36	48	72	96	120
OFCL	15.5	21.7	38.9	50.6	92.7	82.1	150.0
OCD5	29.2	52.8	96.9	153.0	295.9	393.0	522.4
GFSI	16.6	30.6	49.7	77.0	143.8	136.4	191.9
EMXI	17.6	30.6	54.6	80.2	170.3	264.2	328.8
EGRI	11.7	**18.4**	**30.1**	**37.4**	**63.5**	86.0	182.0
CMCI	18.8	36.0	66.8	101.5	210.9	275.8	200.3
NVGI	26.6	40.6	63.9	90.4	228.9	436.1	613.6
AEMI	17.5	28.7	45.7	69.0	140.4	158.2	344.6
HWFI	25.1	41.1	61.5	83.0	126.2	139.4	335.8
HMNI	17.3	23.1	**35.8**	**45.5**	**77.9**	140.8	260.9
HCCA	**13.8**	**19.3**	**31.8**	**44.1**	98.3	129.1	**127.1**
FSSE	**13.0**	**15.4**	**30.5**	**41.5**	**87.9**	113.5	163.1
TVCA	**14.7**	**20.5**	**34.6**	51.5	96.3	84.0	**79.4**
TVCX	**14.4**	**19.8**	**35.0**	**49.7**	98.8	88.6	**68.9**
TVDG	**13.5**	**17.6**	**32.7**	**45.9**	**90.3**	83.0	**57.6**
GFEX	16.0	25.7	47.9	73.1	154.3	199.5	255.6
TABD	19.4	**20.7**	40.6	73.6	189.1	462.7	911.8
TABM	27.4	48.5	82.2	115.6	187.9	220.1	253.0
TABS	47.7	111.0	191.1	276.9	437.6	670.1	1021.8
Forecasts	10	10	10	10	9	6	3

Table 6a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) intensity forecast errors (kt) for Hurricane Humberto, 13–19 September 2019. Mean errors for the previous 5-yr period are shown for comparison. Official errors that are smaller than the 5-yr means are shown in boldface type.

	Forecast Period (h)						
	12	24	36	48	72	96	120
OFCL	**5.2**	**6.2**	**5.3**	**8.5**	**10.8**	17.2	21.0
OCD5	8.1	12.1	15.7	19.9	29.2	41.0	40.0
Forecasts	23	21	19	17	13	9	5
OFCL (2014-18)	5.3	7.9	9.9	11.2	13.3	14.4	14.2
OCD5 (2014-18)	6.9	10.9	14.3	17.4	20.9	22.0	22.8

Table 6b. Homogeneous comparison of selected intensity forecast guidance models (in kt) for Hurricane Humberto, 13–19 September 2019. Errors smaller than the NHC official forecast are shown in boldface type. The number of official forecasts shown here will generally be smaller than that shown in Table 6a due to the homogeneity requirement.

Model ID	Forecast Period (h)						
	12	24	36	48	72	96	120
OFCL	4.0	3.5	4.0	9.0	10.6	15.8	11.7
OCD5	4.9	9.7	15.2	20.6	28.9	40.0	34.0
GFSI	**3.4**	5.7	9.2	12.1	15.9	22.0	11.7
EMXI	4.9	10.4	19.8	27.5	33.4	37.3	25.0
EGRI	**3.5**	6.0	8.8	9.3	**9.2**	**6.8**	**7.0**
CMCI	6.0	9.8	14.2	15.3	22.0	22.0	**11.0**
NVGI	6.3	9.8	16.2	19.4	31.0	34.3	21.0
AEMI	9.1	14.6	19.9	23.1	29.8	33.5	29.7
HMNI	6.0	9.8	14.6	16.1	17.7	16.5	16.0
HWFI	**3.2**	4.1	7.2	**8.6**	**7.6**	**7.3**	14.3
HCCA	**3.2**	**3.3**	4.7	**6.3**	10.9	**13.8**	**6.7**
FSSE	**3.2**	3.5	4.8	**6.9**	**5.8**	**7.8**	**7.0**
DSHP	4.1	7.1	12.4	15.7	18.1	23.3	12.7
LGEM	4.4	5.9	9.2	12.3	18.6	26.0	18.0
ICON	**3.8**	5.6	9.3	11.9	13.2	18.0	15.3
IVCN	**3.6**	4.9	9.0	12.2	14.1	18.2	13.3
IVDR	**3.3**	5.0	9.1	11.6	14.2	16.8	12.3
Forecasts	10	10	10	10	9	6	3

Table 7. Watch and warning summary for Hurricane Humberto, 13–19 September 2019.

Date/Time (UTC)	Action	Location
12 / 2100	Tropical Storm Warning issued	Northwestern Bahamas
13 / 0300	Tropical Storm Watch issued	Jupiter Inlet to Volusia/Brevard County Line, Florida
13 / 0900	Tropical Storm Watch modified to	Jupiter Inlet to Volusia/Brevard County Line, Florida
14 / 0300	Tropical Storm Watch discontinued	All
14 / 2100	Tropical Storm Warning discontinued	All
16 / 2100	Tropical Storm Watch issued	Bermuda
17 / 1200	Tropical Storm Watch changed to Tropical Storm Warning	Bermuda
17 / 1500	Hurricane Watch issued	Bermuda
17 / 2100	Tropical Storm Warning changed to Hurricane Warning	Bermuda
17 / 2100	Hurricane Watch discontinued	Bermuda
19 / 0300	Hurricane Warning changed to Tropical Storm Warning	Bermuda
19 / 0600	Tropical Storm Warning discontinued	Bermuda

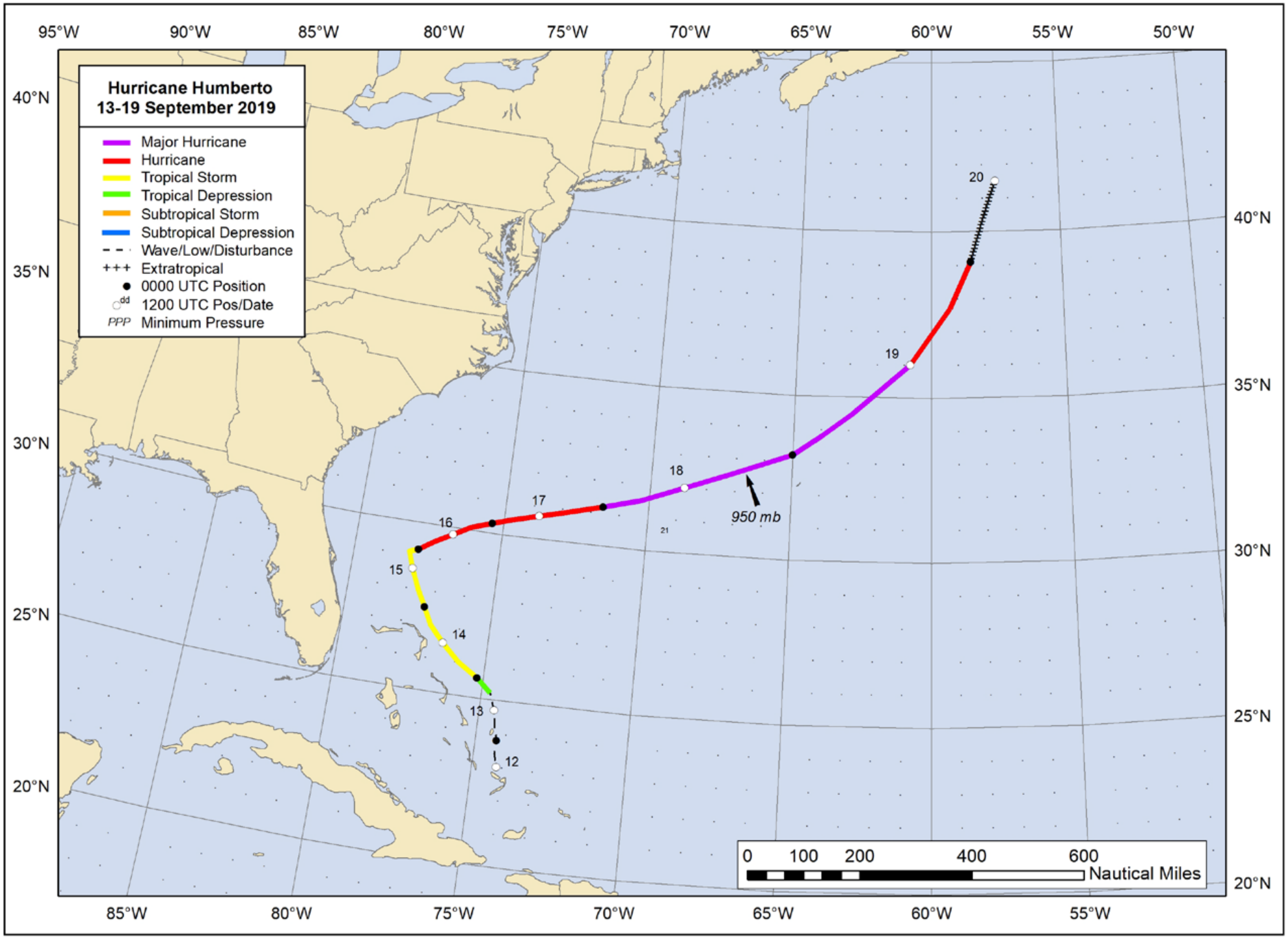

Figure 1. Best track positions for Hurricane Humberto, 13–19 September 2019. The track during the extratropical stage is partially based on analyses from the NOAA Ocean Prediction Center.

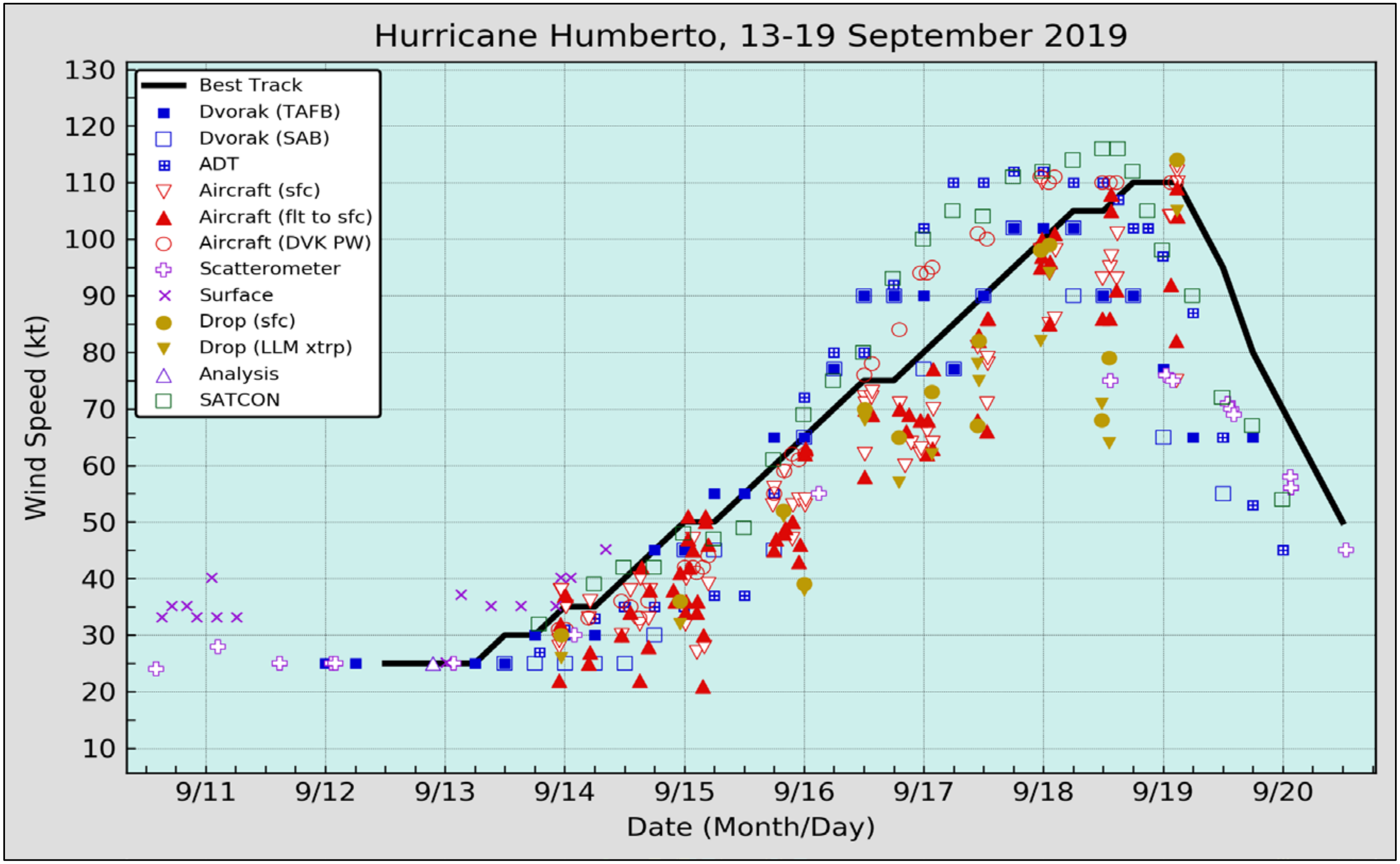

Figure 2. Selected wind observations and best track maximum sustained surface wind speed curve for Hurricane Humberto, 13-19 September 2019. Aircraft observations have been adjusted for elevation using 90%, 83%, and 80% adjustment factors for observations from 700 mb, 800 mb, and 850 mb, respectively. Dropwindsonde observations include actual 10-m winds (sfc), as well as surface estimates derived from the mean wind over the lowest 150 m of the wind sounding (LLM). Advanced Dvorak Technique estimates represent the Current Intensity at the nominal observation time. SATCON intensity estimates are from the Cooperative Institute for Meteorological Satellite Studies. Dashed vertical lines correspond to 0000 UTC.

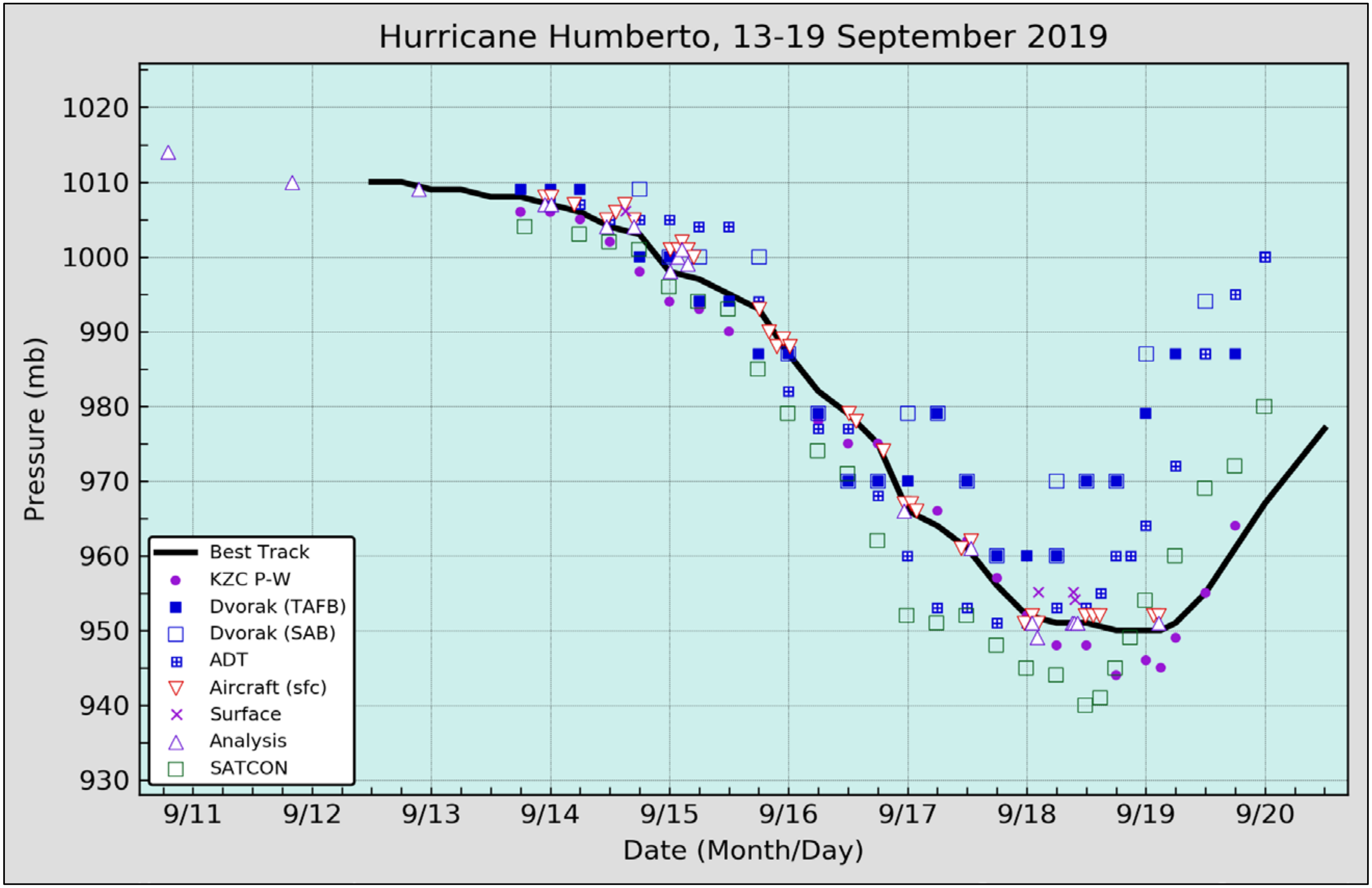

Figure 3. Selected pressure observations and best track minimum central pressure curve for Hurricane Humberto, 13-19 September 2019. Advanced Dvorak Technique estimates represent the Current Intensity at the nominal observation time. SATCON intensity estimates are from the Cooperative Institute for Meteorological Satellite Studies. KZC P-W refers to pressure estimates derived using the Knaff-Zehr-Courtney pressure-wind relationship. Dashed vertical lines correspond to 0000 UTC.

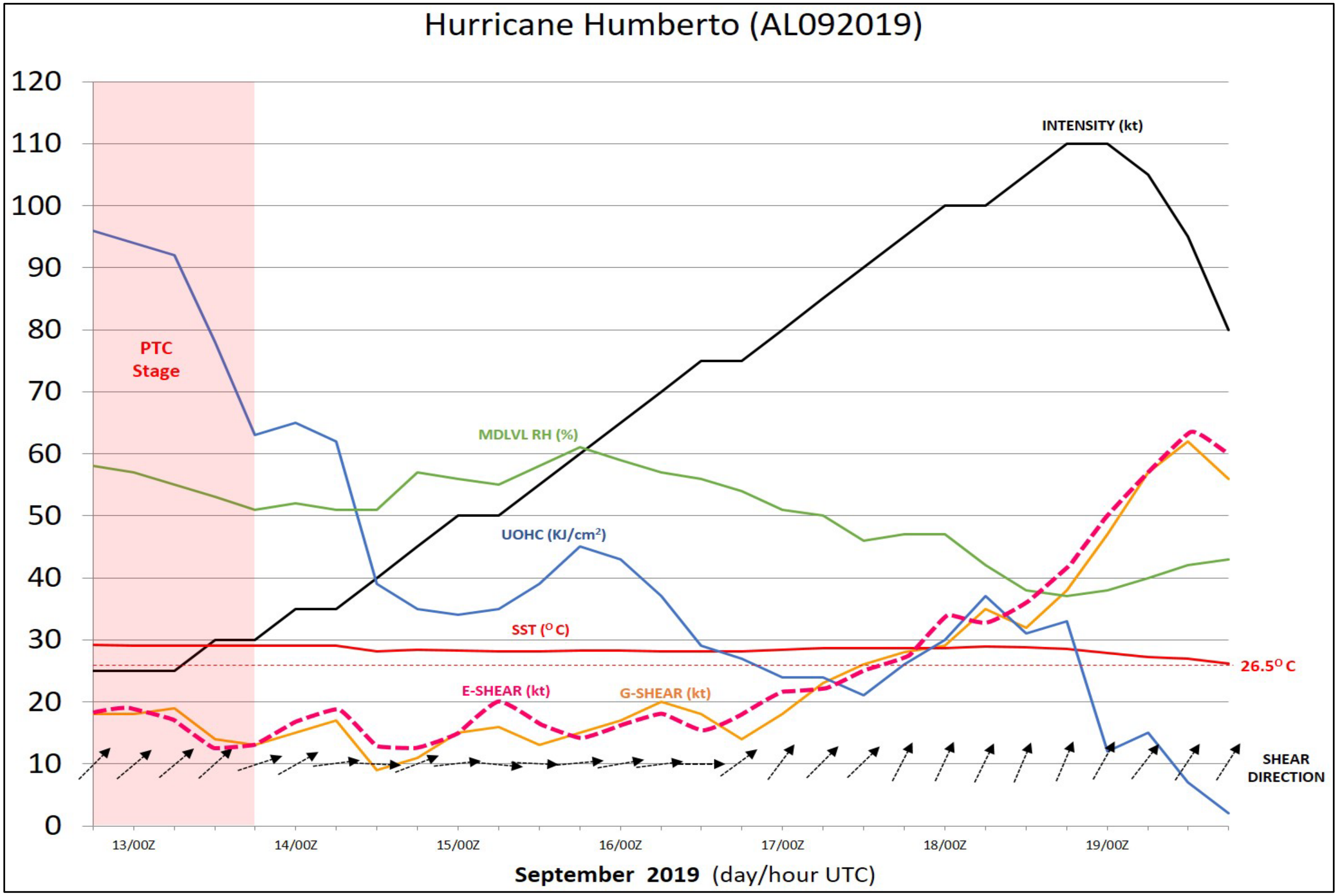

Figure 4. Time series of Hurricane Humberto's actual intensity versus GFS-based SHIPS model analyzed environmental parameters: 850−200-mb vertical wind shear (**G-SHEAR - kt**), sea-surface temperature (**SST - °C**), upper-ocean heat content (**UOHC – kJ cm^{-2}**), and 700−500-mb average relative humidity (**MDLVLRH - %**). Direction of vertical wind shear vectors (black dashed arrows) is relative to true north, with north being at the top of the page. Time period covered is from 1200 UTC 30 August to 1200 UTC 15 September 2018, which includes Humberto's Potential Tropical Cyclone stage (red shading). For comparison, the ECMWF-based SHIPS model vertical wind shear values (**E-SHEAR - kt**) have been included (pink-dashed line).

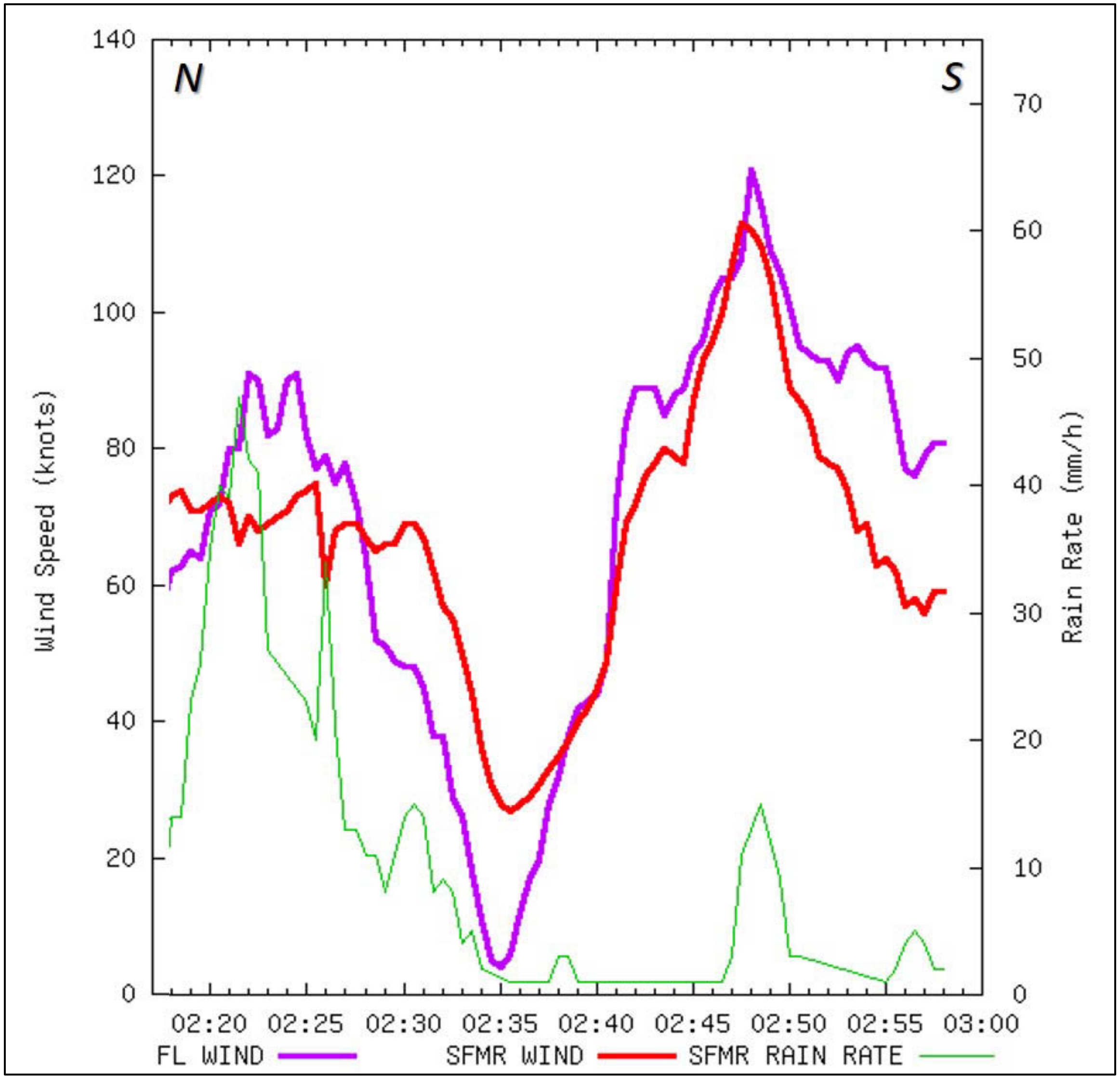

Figure 5. Time series plot of Air Force Reserve reconnaissance aircraft flight-level wind speed (kt), SFMR-derived surface wind speed (kt), and SFMR-derived rain rate (mm/h) data collected from 0218-0258 UTC 19 September 2019 while traversing Humberto's eye and eyewall from north to south. A maximum flight-level wind speed of 121 kt and a peak SFMR-derived wind speed of 113 kt were sampled at 0248 UTC in the remnant southern eyewall.

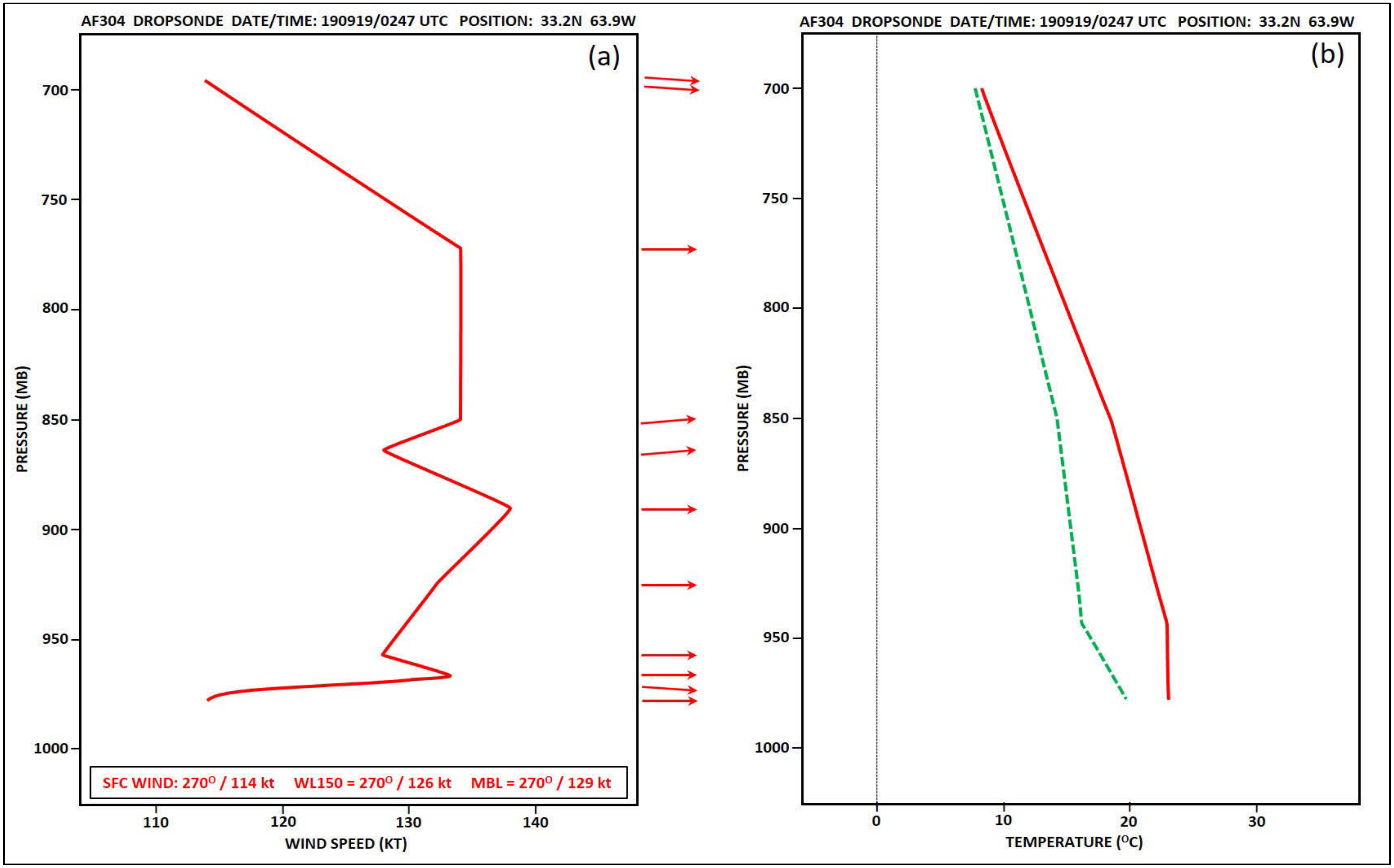

Figure 6. Vertical wind profile (a) and temperature-dewpoint profile (b) from a dropsonde released in the southern eyewall of Hurricane Humberto at 0249 UTC 19 September 2019. Solid red line indicates wind speed and red arrows indicate wind direction relative to true north (top of page); solid blue line is the ambient temperature and dashed green line is the dewpoint temperature. WL150 and MBL are computed from the mean wind speed (kt) in lowest 150 m and lowest 500 m of the dropsonde, respectively.

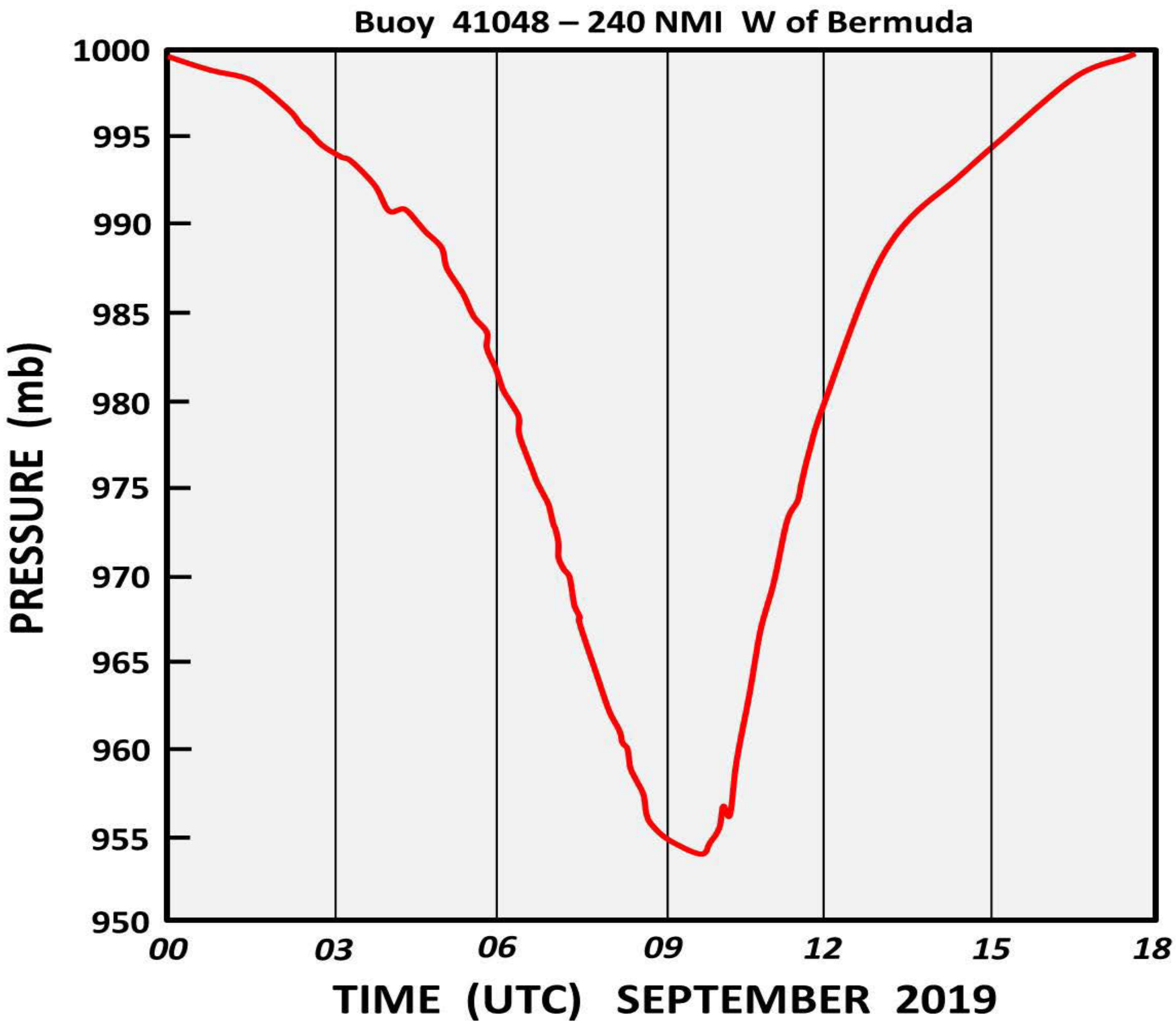

Figure 7. Time series plot of surface pressure data (mb) between 0000 UTC and 1800 UTC 18 September 2019 from NOAA Buoy 40148, located 240 n mi west of Bermuda. The center of Hurricane Humberto passed approximately 6 n mi southeast of the buoy around 0930 UTC 18 September, when a minimum pressure of 954.2 mb was measured.

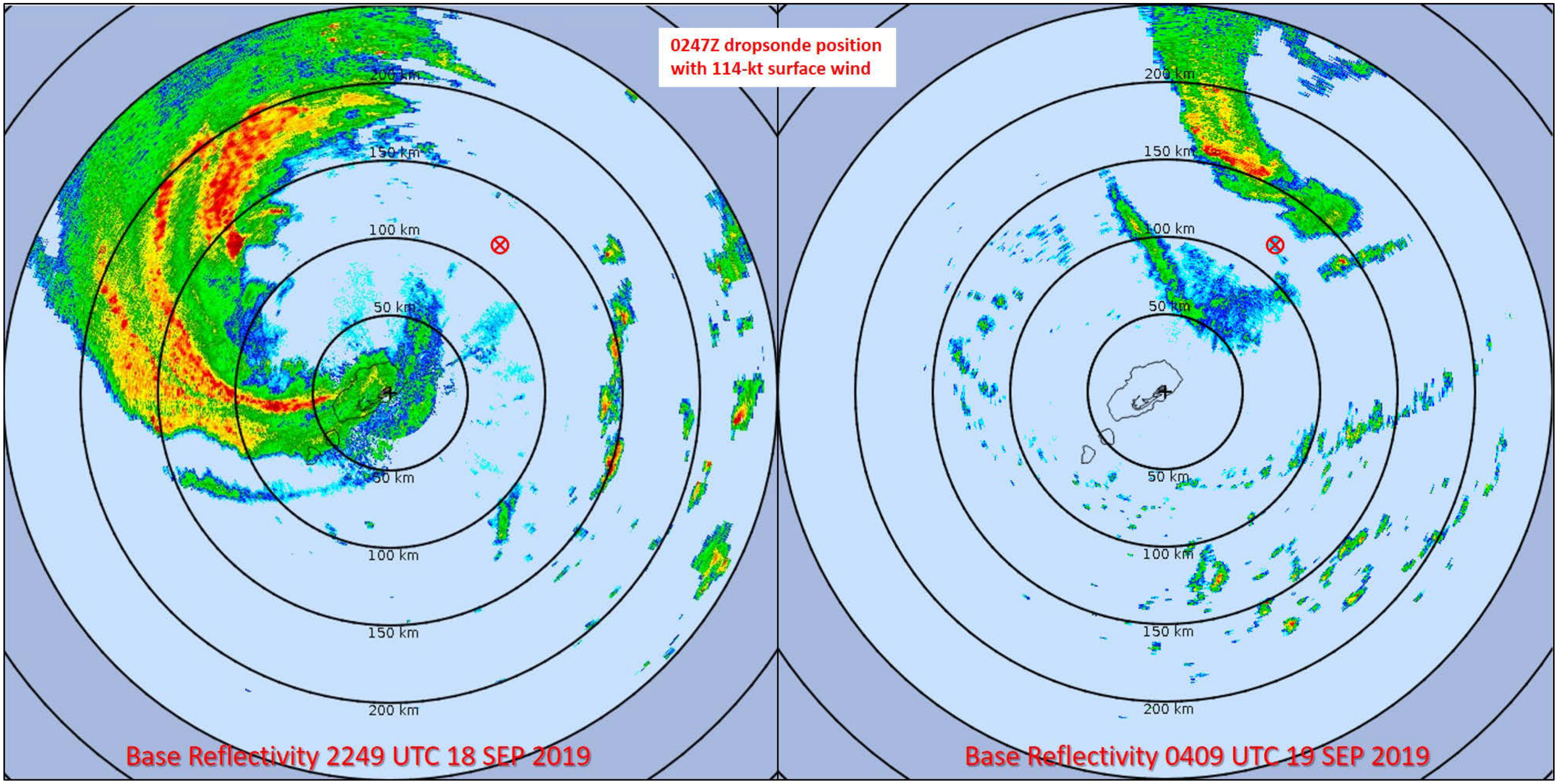

Figure 8. Bermuda Weather Service Doppler weather radar reflectivity images (0.5°elevation) at 2249 UTC 18 September (left panel) and 0409 UTC 19 September 2019 (right panel); images are the last and first radar data, respectively, surrounding a prolonged communications outage on the island caused by Hurricane Humberto. The splash location of a 0247 UTC 19 September dropsonde is indicated by the red circled-X. An Air Force Reserve reconnaissance aircraft flew through the same location and measured moderate rain rates, an indication that the dropsonde passed through the eroding remnant southern eyewall.

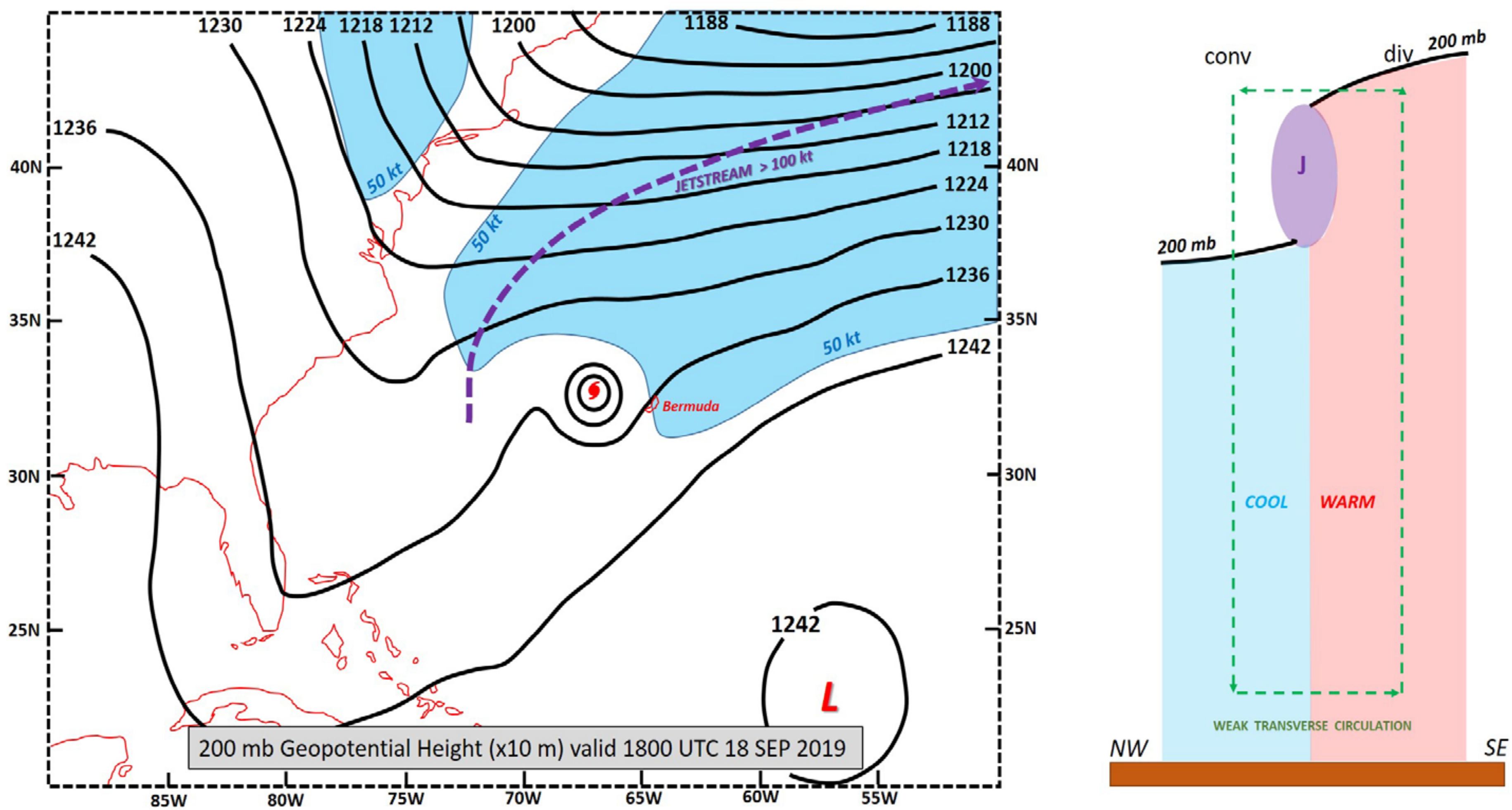

Figure 9. GFS model analysis of the 200-mb height field (dm) at 1800 UTC 18 September 2019; Purple-dashed arrow indicates axis of maximum jetstream wind speeds and blue-shaded area depicts region of wind speeds $\geq$50 kt (left panel); cross-sectional schematic diagram (oriented NW-SE through Humberto) illustrating the associated transverse circulation as Humberto approached the right-rear jetstream entrance region (right panel).

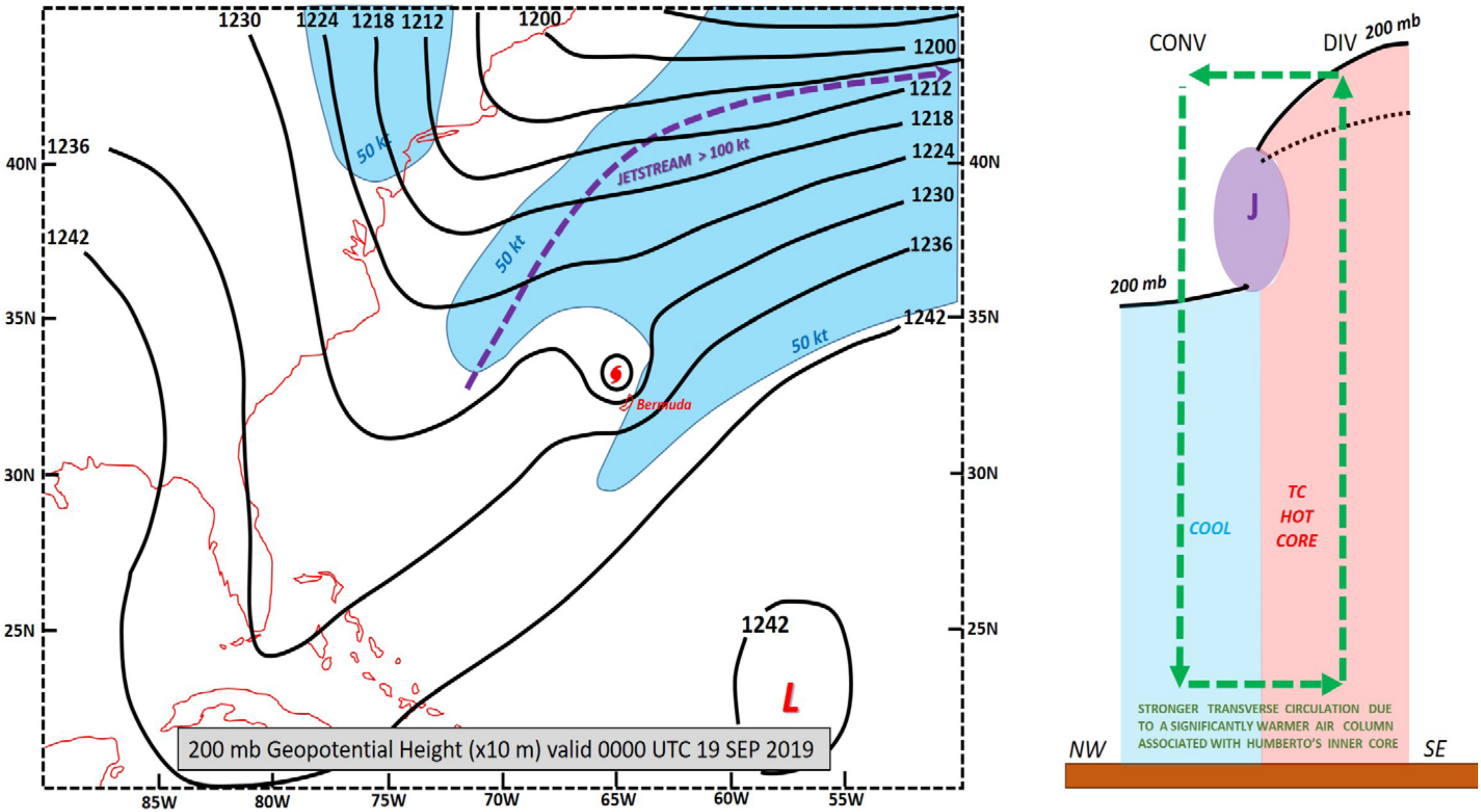

Figure 10. GFS model analysis of the 200-mb height field (dm) at 0000 UTC 19 September 2019; Purple-dashed arrow indicates axis of maximum jetstream wind speeds and blue-shaded area depicts region of wind speeds $\geq$50 kt (left panel); cross-sectional schematic diagram (oriented NW-SE through Humberto) illustrating the enhanced/increased transverse circulation due to Humberto's intense warm core superimposed onto the right-rear jetstream entrance region (right panel). Enhancement of the low-level westerly branch of the transverse circulation likely produced a 'sting jet' type wind phenomenon that helped to increase Humberto's maximum wind during the time the cyclone's eyewall was eroding and weakening.

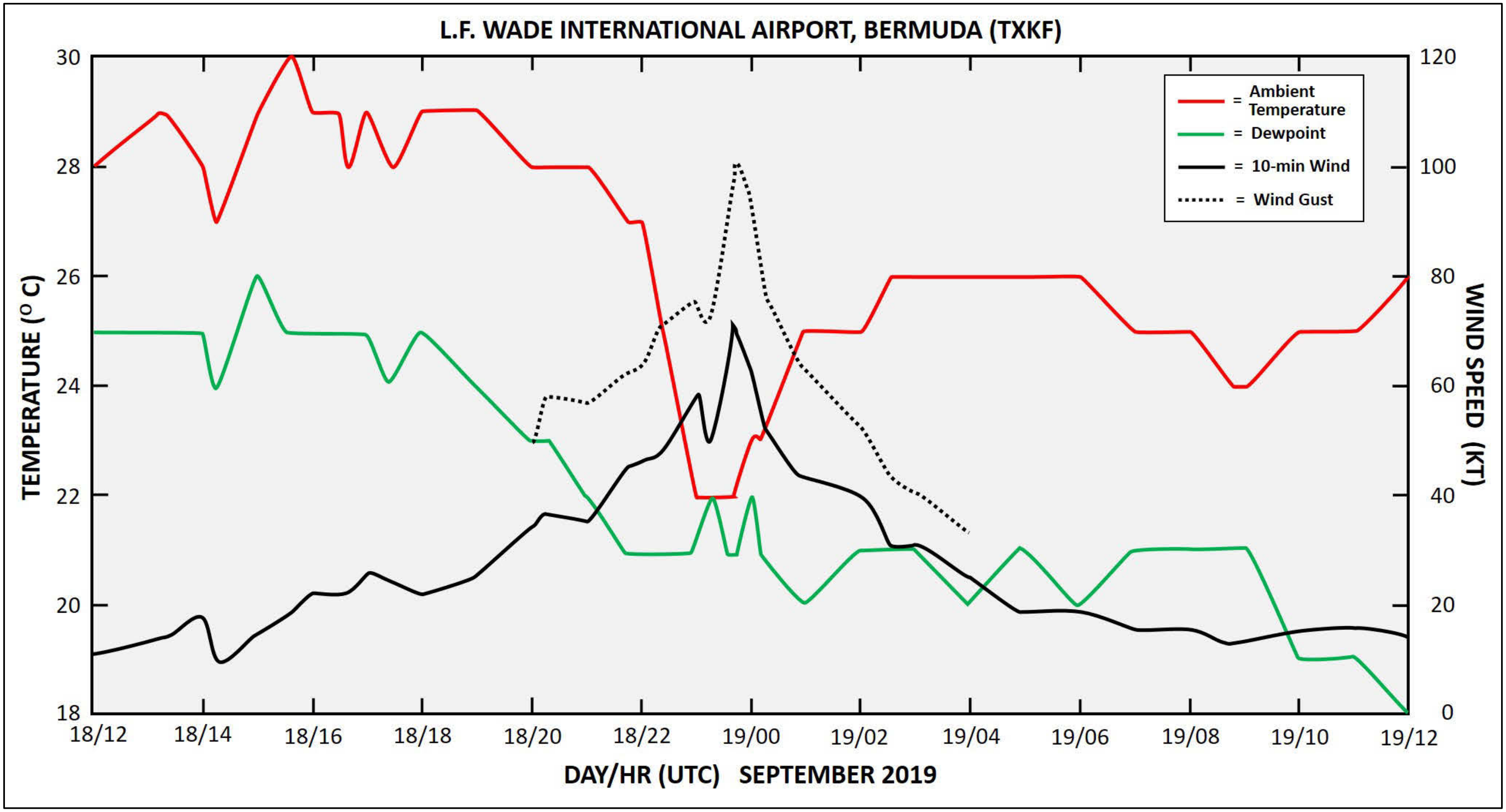

Figure 11. Time series plot of selected surface observation data from L.F. Wade International Airport, Bermuda (TXKF), during the 48-h period 1200 UTC 18 September to 1200 UTC September 2019 during the passage of the southern eyewall of Hurricane Humberto over the island. Note the occurrence of the peak winds (10-min average and gusts) coincident with a sharp drop in the ambient temperature around 2230 UTC 18 September, indicative of cold downdrafts that are driven by strong evaporative cooling.

Figure 12. Commissioner's Point, Bermuda, observation location viewing west (left panel). Anemometer equipment located on the top of the roof could have produced accelerated and unrepresentative wind speeds due to the Bernoulli Effect created by air flowing over the hipped-roof on the Commissioner's House structure. Crescent Beacon NAVAID (right panel) located approximately 8 n mi northwest of Bermuda.

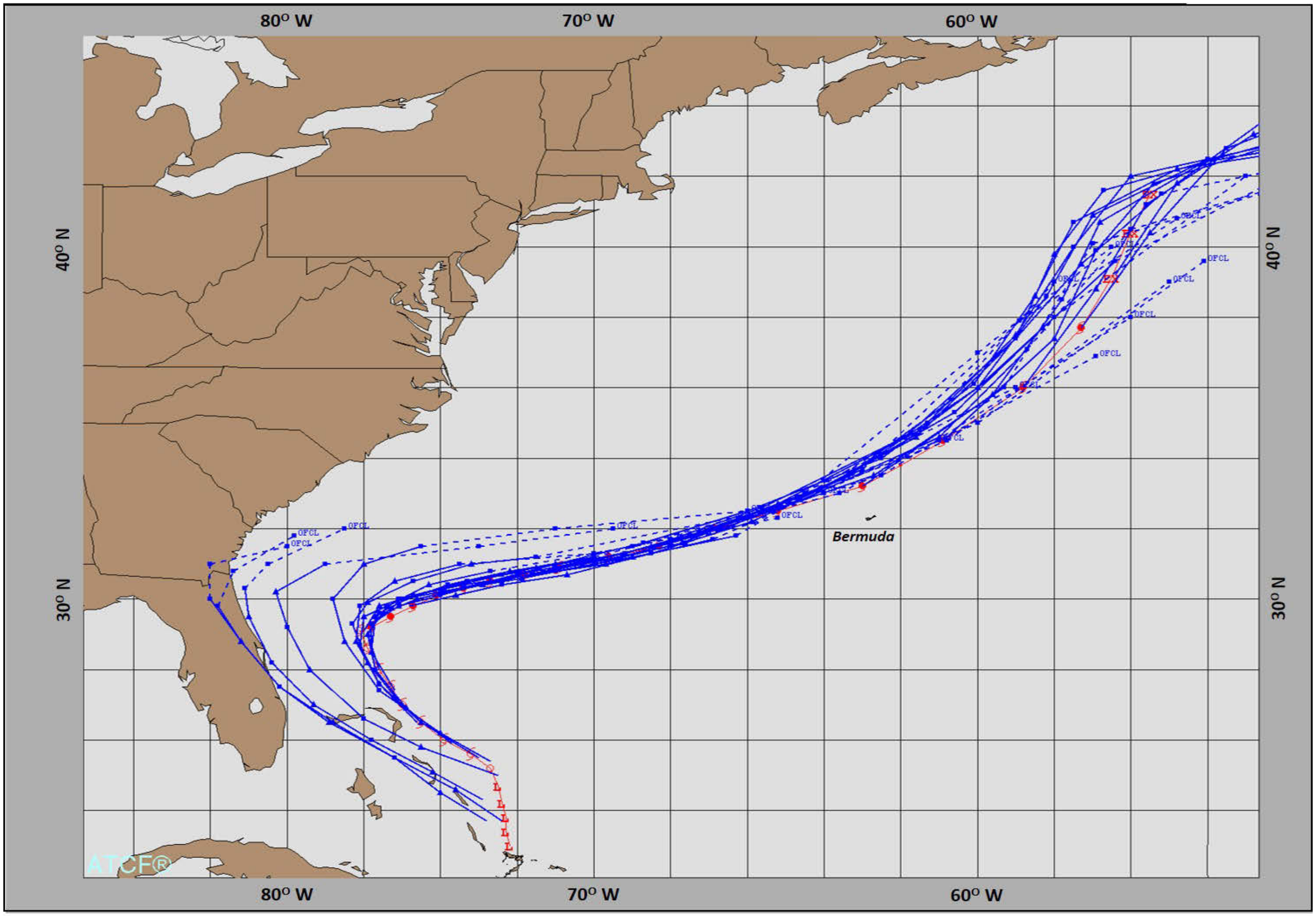

Figure 13. Selected official track forecasts (solid and dashed blue lines, with 0, 12, 24, 36, 48, 72, 96, and 120 h positions indicated), including the PTC stage, for Hurricane Humberto, 13–19 September 2019. The best track is given by the solid red line with positions given at 6-h intervals.

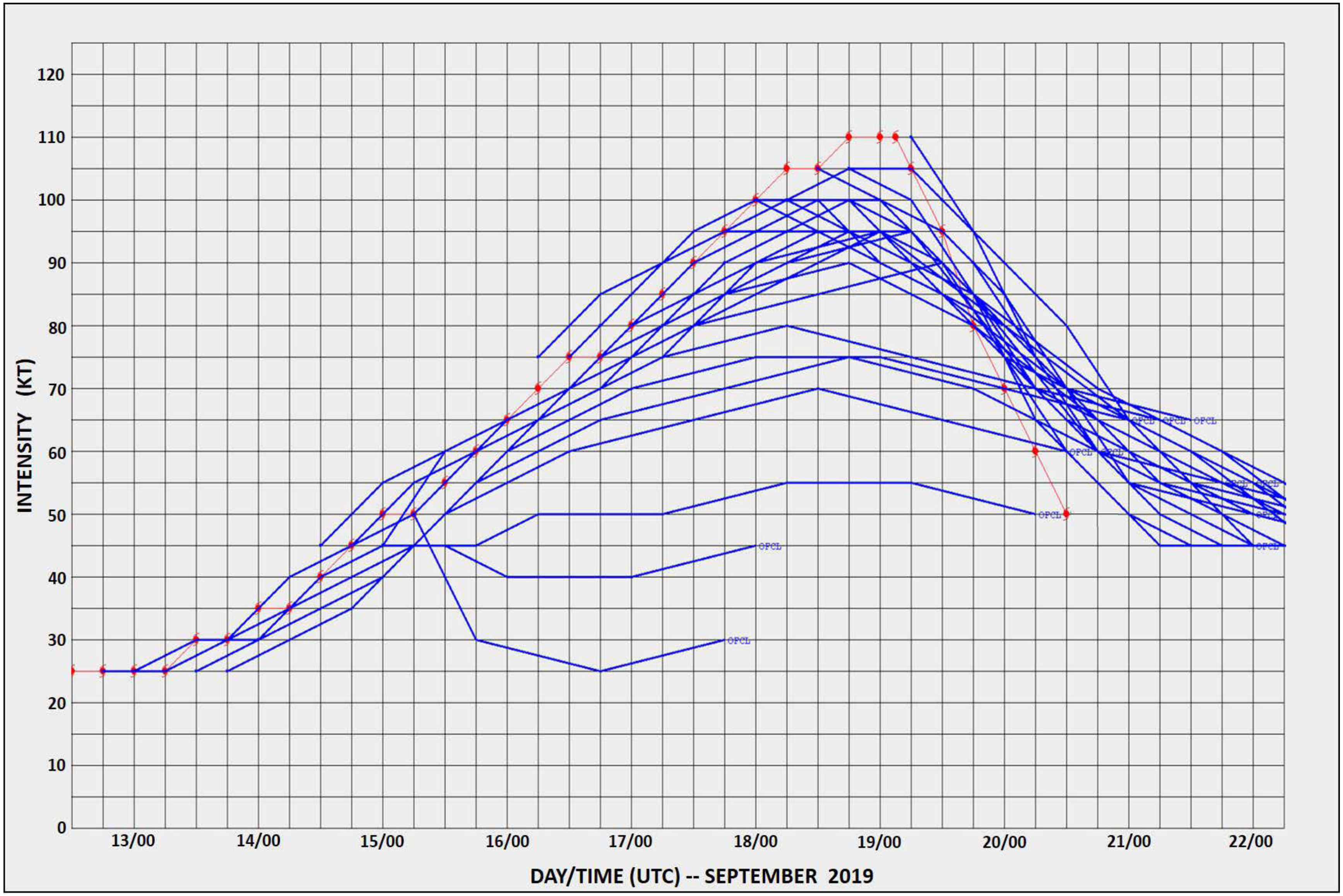

Figure 14. Selected official intensity forecasts (kt, solid blue lines, in 24-h increments) for Hurricane Humberto, 13-19 September 2019. The best track intensity (kt) is denoted by the solid red line with hurricane symbols at 6-h intervals. Intensity forecasts from 1800 UTC 12 September until 1200 UTC 13 September were during the PTC stage.