

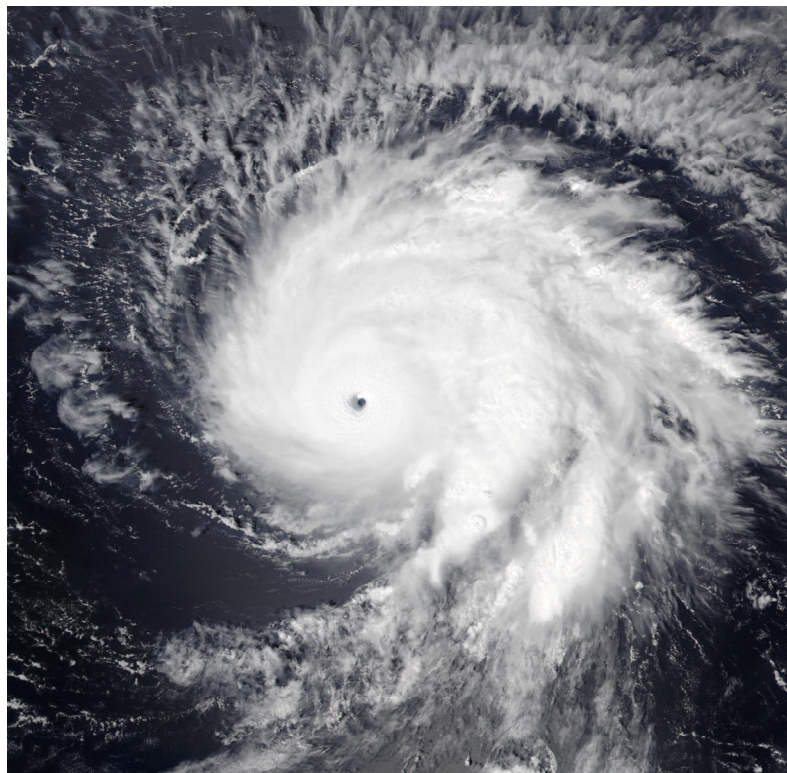


NATIONAL HURRICANE CENTER TROPICAL CYCLONE REPORT

HURRICANE SAM (AL182021)

22 September–5 October 2021

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National Hurricane Center
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GOES-16 VISIBLE SATELLITE IMAGE OF HURRICANE SAM AT 1625 UTC SEPTEMBER 26 2021. IMAGE COURTESY OF NASA.

Sam was a long-lived intense Cape Verde hurricane that reached the high end of category 4 intensity (on the Saffir-Simpson Hurricane Wind Scale) and, although the outer circulation of Sam brushed by Bermuda, its core remained east of the island, well out to sea. Sam was a major hurricane for over a week.

Hurricane Sam

22 SEPTEMBER–5 OCTOBER 2021

SYNOPTIC HISTORY

Sam formed from a well-defined tropical wave that moved off the west coast of Africa late on 19 September. A fairly concentrated westward-moving area of showers and thunderstorms associated with the wave passed to the south of the Cabo Verde Islands on 20 September, and curved convective banding features gradually became more evident during the ensuing couple of days. By 1800 UTC 22 September, the system had acquired enough convective organization and developed a sufficiently well-defined low-level circulation to warrant its designation as a tropical depression while centered about 575 n mi west-southwest of the southernmost Cabo Verde Islands. 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 1¹.

The depression soon strengthened into a tropical storm by 0600 UTC 23 September. While continuing to move over warm waters (28–29°C) and through an environment of very low vertical shear, Sam rapidly intensified and became a hurricane around 0600 UTC 24 September while centered about 1100 n mi east of the Windward Islands. The hurricane veered slightly from a westward to a west-northwestward heading as it moved along the southern side of a mid-tropospheric anticyclone over the eastern Atlantic, and its pace of strengthening briefly slowed. However, another period of rapid intensification soon began late on the 24th, and Sam’s maximum winds increased by 45 kt over the 24-h periods beginning at 1800 UTC 24 September and 0000 UTC 25 August. Sam strengthened to an intensity of 130 kt by 0000 UTC 26 September. At the onset of this rapid intensification period, Sam had developed a very compact inner core with a 10-n mi diameter eye. The hurricane strengthened a little more on the 26th, and reached its peak intensity of 135 kt around 1800 UTC that day, with its well-defined eye located about 600 n mi east of the Lesser Antilles. The eye of the intense hurricane contracted to a diameter of near 7 n mi late on 26 September while the central pressure dropped to near 927 mb.

Around the time it reached its maximum strength on 26 September, the hurricane turned toward the northwest in response to a weakness in the subtropical ridge near 60°W longitude. An eyewall replacement and a slight, but temporary, increase in southwesterly shear induced a weakening trend beginning around 0000 UTC 27 September. Sam weakened to 105 kt by 1200 UTC that day, and more or less maintained that intensity until early on 28 September when it re-

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 *bt* directory, while previous years’ data are located in the *archive* directory.

intensified to 115 kt as the eyewall replacement cycle completed. The hurricane continued its northwestward motion for the next several days, well to the east and northeast of the Leeward Islands, while remaining on the southwest side of a mid-level ridge. Sam restrengthened a little more on 30 September and 1 October while exhibiting a well-defined eye of a little over 25 n mi in diameter and moving over waters of surface temperatures near 29°C. The hurricane attained a secondary peak of intensity of 130 kt by 0600 UTC 1 October. On that day, the mid-level ridge to the northeast of the tropical cyclone retreated eastward while a large trough moved over the northeastern U.S., which caused Sam to turn toward the north-northwest and north with some increase in forward speed. Early on 2 October, the hurricane veered from a northward to a north-northeastward heading with an additional increase in forward speed as the northeast U.S. trough shifted eastward into Atlantic Canada, and the center of Sam passed to the southeast and east of Bermuda. At its closest approach, Sam's center passed within about 185 n mi east-southeast of Bermuda at 0300 UTC 2 October. By this time, the hurricane's outer circulation had expanded, so its fringe winds near tropical-storm force brushed that island.

Later on 2 October, the hurricane moved away from Bermuda while turning northeastward on the south side of the low near Atlantic Canada. Sam finally dropped below major hurricane status around 0600 UTC 3 October. For the next couple of days, Sam moved east-northeastward to northeastward, and then northward, with increasing forward speed along the southeastern and eastern side of the low while gradually weakening but maintaining hurricane-force winds. By 0600 UTC 5 October, the system's cloud pattern became highly asymmetric and elongated which indicated that Sam had become an extratropical cyclone. The post-tropical low rotated cyclonically around the Atlantic Canada low that day. On 6 October through early 7 October, the system moved generally northeastward in the mid-latitude westerlies. The post-tropical cyclone merged with another extratropical low over the north Atlantic after 0600 UTC 7 October.

METEOROLOGICAL STATISTICS

Observations in Sam (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 flights of the 53rd Weather Reconnaissance Squadron of the U.S. Air Force Reserve Command and WD-P3 aircraft of the NOAA Aircraft Operations Center. 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 Sam.

A blend of adjusted 700-mb flight-level and SFMR-observed surface winds from a NOAA Hurricane Hunter aircraft around 0000 UTC 26 September supports an intensity of 130 kt at that time. A peak surface wind of 162 kt was measured by dropsonde at about 0000 UTC 26 September, but this was likely a gust since an average of the mean boundary-layer wind and

lowest 150-m layer wind from that dropsonde was 130 kt, which also supports the 130-kt intensity estimate at that time. Objective Dvorak T-numbers reached a maximum of 6.6 at 1800 UTC 26 September, when no aircraft was in the storm and based on this, it is assumed that Sam was slightly stronger, 135 kt, at that time.

A NOAA Hurricane Hunter aircraft measured a pressure of 932 mb by dropsonde in the eye with 30 kt surface winds at 2237 UTC on 26 September, which corresponds to a minimum central pressure estimate of 929 mb. Sam's central pressure was apparently rising at that time, since a dropsonde-based pressure observed a couple of hours later was significantly higher. Therefore, the overall estimated minimum central of Sam is set, perhaps conservatively, to 927 mb at 1800 UTC 26 September which is also around the time of the highest objective T-number.

Sam was a major hurricane for 7.75 days, which made it the longest-lived Atlantic major hurricane since Ivan of 2004, and tied it for the ninth longest-lived major hurricane on record in the Atlantic basin.

Table 2 lists buoy and saildrone reports associated with Sam. The saildrone, which encountered the northeastern eyewall of the hurricane and came within about 17 n mi east-northeast of the center on 30 September, measured maximum 1-minute sustained winds of 79 kt at 1512 UTC with a gust to 110 kt at 1514 UTC at an elevation of 3 m, with a maximum significant wave height of 46 feet and individual waves as high as 82 feet. A minimum pressure of 970.1 mb was measured by the saildrone at 1521 UTC. NOAA data buoys 41044 and 41049, with anemometers at a height of 4 m, measured peak gusts of 86 kt and 62 kt, respectively, and buoy 41044 measured maximum significant wave heights of nearly 40 ft.

Sustained winds of 22 to 38 kt were measured across Bermuda but all sustained winds of tropical-storm-force were observed at elevated sites. A maximum sustained wind of 33 kt was observed at the Bermuda Heliport, next to the airport, at 0335 UTC 2 October at a height of 12 m, and a maximum sustained wind of 38 kt was measured at the Maritime Operations Centre at St. George's (near the northern end of Bermuda) at an elevation of 290 ft (88 m) above sea level at 0729 UTC 2 October. Wind gusts of 31 to 46 kt were observed across Bermuda, with most of the tropical-storm-force gusts measured at elevated sites. A gust to 46 kt was measured at an elevation of 150 feet above sea level at the National Museum of Bermuda at 0232 UTC 2 October.

The minimum pressure in Bermuda was 1012.3 mb, observed at the airport at 0603 UTC 2 October.

Little or no rain fell in Bermuda in association with Sam.

CASUALTY AND DAMAGE STATISTICS

There were no casualties associated with Sam. No significant impacts on Bermuda due to Sam were noted.

FORECAST AND WARNING CRITIQUE

The genesis of Sam was well predicted. It was first mentioned in the Tropical Weather Outlook (TWO) 78 h prior to Sam's genesis that a tropical wave, with some potential for development, was forecast to emerge from Africa. In that TWO, the system was given a low chance for development within 5 days (Table 3). The system was first given a low (<40%) chance for development within 2 days in the TWO 60 h before formation. The 5-day and 2-day genesis probabilities were moved into the medium (40%-60%) categories 72 and 42 h before development, respectively, and these probabilities were boosted to high (>60%) 54 and 18 h prior to formation, respectively.

A verification of NHC official track forecasts for Sam is given in Table 4a. The official track forecasts were excellent, with mean errors that were well below the mean official errors for the previous 5-yr period at all lead times. A homogeneous comparison of the official track errors with selected guidance models is given in Table 4b. In general, the NHC track forecasts outperformed the deterministic model guidance, with only the GFS (GFSI) having a slightly lower mean track error at 36 h. Some of the consensus aids, such as TVCA and TVDG, also had slightly lower errors than the mean official forecasts at some periods. The NHC forecasts were also quite consistent in depicting a future track that would curve away well to the east of the United States (Fig. 4).

A verification of NHC official intensity forecasts for Sam is given in Table 5a. Official intensity forecast errors were generally a little lower than the mean official errors for the previous 5-yr period. A homogeneous comparison of the official intensity errors with selected guidance models is given in Table 5b. Only the HMNI and HCCA forecast aids had lower mean errors than the NHC forecasts at some forecast intervals. The NHC forecasts mostly underpredicted Sam's intensity during the first few days of the hurricane's lifetime (Fig. 5). While a period of rapid intensification was explicitly forecast by NHC between 24–26 August, these forecasts did not fully capture the total magnitude of rapid intensification that occurred over that time span.

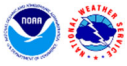
Watches and warnings associated with Sam are given in Table 6. A Tropical Storm Watch was issued for Bermuda by the Bermuda Weather Service at 0900 UTC 30 September and a Tropical Storm Warning was issued for Bermuda at 2100 UTC 30 September, about 38 h and 26 h before the first occurrence of sustained tropical-storm-force winds (at elevation) on the island, respectively.

ACKNOWLEDGMENTS

Ian Currie of the Bermuda Weather Service supplied observations from Bermuda. Dawn Petraitis of the NOAA National Data Buoy Center provided buoy data. Greg Foltz of the NOAA Atlantic Oceanographic and Meteorological Laboratory's Physical Oceanography Division helped with the saildrone observations. John P. Cangialosi produced the track map.

Table 1. Best track for Hurricane Sam, 22 September–5 October 2021.

Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Stage
22 / 1800	10.0	33.1	1008	30	tropical depression
23 / 0000	10.2	34.4	1008	30	"
23 / 0600	10.4	36.0	1006	35	tropical storm
23 / 1200	10.7	37.6	1003	45	"
23 / 1800	10.9	39.0	1000	50	"
24 / 0000	11.1	40.3	997	60	"
24 / 0600	11.4	41.6	993	65	hurricane
24 / 1200	11.6	43.0	993	65	"
24 / 1800	11.9	44.3	989	70	"
25 / 0000	12.3	45.4	982	85	"
25 / 0600	12.6	46.3	973	95	"
25 / 1200	12.8	47.2	960	105	"
25 / 1800	13.1	48.1	950	115	"
26 / 0000	13.4	48.8	943	130	"
26 / 0600	13.6	49.4	943	130	"
26 / 1200	13.8	50.0	939	130	"
26 / 1800	14.1	50.3	927	135	"
27 / 0000	14.5	50.6	940	130	"
27 / 0600	15.0	51.1	948	115	"
27 / 1200	15.4	51.7	955	105	"
27 / 1800	15.9	52.3	958	105	"
28 / 0000	16.5	52.9	955	105	"
28 / 0600	16.9	53.5	952	115	"
28 / 1200	17.3	54.1	952	115	"
28 / 1800	17.7	54.7	947	115	"
29 / 0000	18.1	55.3	947	115	"
29 / 0600	18.6	55.9	952	115	"
29 / 1200	19.1	56.6	952	115	"
29 / 1800	19.7	57.3	945	115	"
30 / 0000	20.3	58.0	940	125	"
30 / 0600	21.0	58.8	937	125	"



Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Stage
30 / 1200	22.0	59.6	937	125	"
30 / 1800	23.0	60.4	941	125	"
01 / 0000	24.3	61.0	938	125	"
01 / 0600	25.8	61.6	936	130	"
01 / 1200	27.4	61.9	936	130	"
01 / 1800	29.2	61.9	937	130	"
02 / 0000	30.8	61.5	940	125	"
02 / 0600	32.1	61.0	945	120	"
02 / 1200	33.4	60.1	948	115	"
02 / 1800	34.7	59.1	950	110	"
03 / 0000	35.8	57.9	954	100	"
03 / 0600	36.7	56.6	960	90	"
03 / 1200	37.3	55.4	964	85	"
03 / 1800	38.0	53.9	964	85	"
04 / 0000	38.7	52.2	957	90	"
04 / 0600	39.9	49.9	957	90	"
04 / 1200	41.4	47.1	960	85	"
04 / 1800	43.8	43.6	965	80	"
05 / 0000	46.5	40.5	965	75	"
05 / 0600	49.4	39.7	965	70	extratropical
05 / 1200	52.2	39.6	966	65	"
05 / 1800	50.6	42.1	966	65	"
06 / 0000	49.9	38.9	967	60	"
06 / 0600	50.5	35.5	968	55	"
06 / 1200	51.5	32.4	969	50	"
06 / 1800	53.1	29.0	971	45	"
07 / 0000	55.2	25.4	973	45	"
07 / 0600	58.1	22.3	976	40	"
07 / 1200					merged
26 / 1800	14.1	50.3	927	135	maximum winds and minimum pressure

Table 2. Selected buoy and vessel (saildrone) reports with winds of at least 34 kt for Hurricane Sam, 22 September–5 October 2021.

Date/Time (UTC)	Buoy/Vessel ID	Latitude (°N)	Longitude (°W)	Wind dir/speed (kt)	Pressure (mb)
30 / 0801	41044	21.6	58.6	--- / 68 (4m)	979.0
01 / 1206	41049	27.5	62.9	--- / 50 (4m)	998.8
30 / 1521	SD1045	22.8	59.9	79 (3m)	970.1

Table 3. 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 Before Genesis	
	48-Hour Outlook	120-Hour Outlook
Low (<40%)	60	78
Medium (40%-60%)	42	72
High (>60%)	18	54

Table 4a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) track forecast errors (n mi) for Hurricane Sam, 22 September–5 October 2021. 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	60	72	96	120
OFCL	17.0	25.3	33.1	41.4	50.8	57.9	77.6	105.5
OCD5	34.4	78.6	118.4	153.8	192.4	226.7	335.1	399.5
Forecasts	48	46	44	42	40	38	34	30
OFCL (2016-20)	23.9	36.3	49.1	63.9	79.0	94.1	128.1	169.7
OCD5 (2016-20)	45.1	97.2	157.2	216.7	271.1	325.4	414.4	490.0

Table 5a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) intensity forecast errors (kt) for Hurricane Sam, 22 September–5 October 2021. 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	60	72	96	120
OFCL	6.1	7.5	8.8	11.0	11.2	12.0	11.5	10.2
OCD5	7.7	12.4	16.2	18.9	20.5	22.2	22.2	27.2
Forecasts	48	46	44	42	40	38	34	30
OFCL (2016-20)	5.4	8.0	9.6	10.9	11.5	12.1	13.3	14.5
OCD5 (2016-20)	7.0	11.0	14.3	16.8	18.3	19.7	21.7	23.0

Table 6. Watch and warning summary for Hurricane Sam, 22 September–5 October 2021.

Date/Time (UTC)	Action	Location
30 / 0900	Tropical Storm Watch issued	Bermuda
30 / 2100	Tropical Storm Watch changed to Tropical Storm Warning	Bermuda
2 / 1200	Tropical Storm Warning discontinued	All

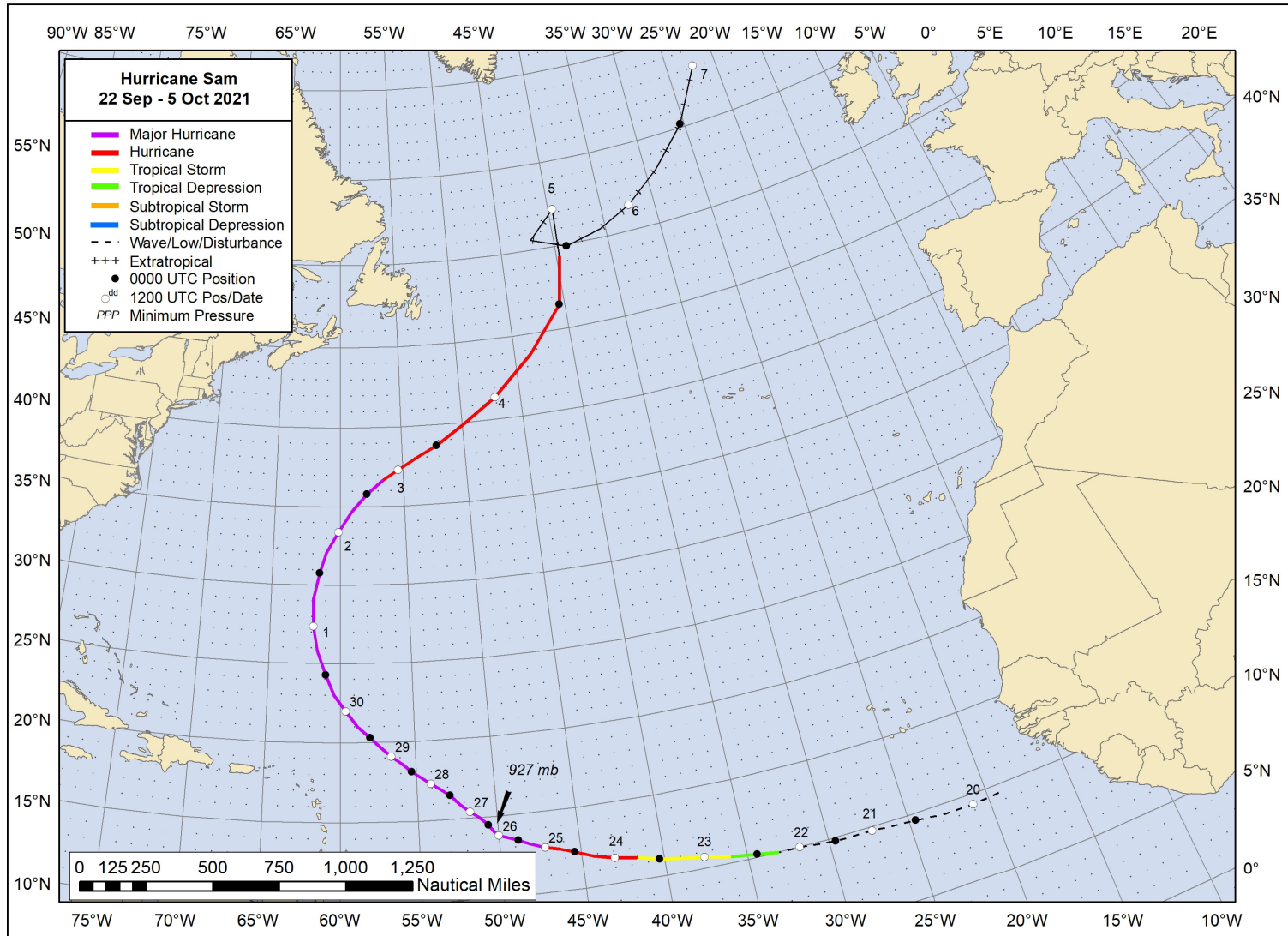


Figure 1. Best track positions for Hurricane Sam, 22 September–5 October 2021. Track during the extratropical stage is partially based on analyses from the NOAA Ocean Prediction Center.

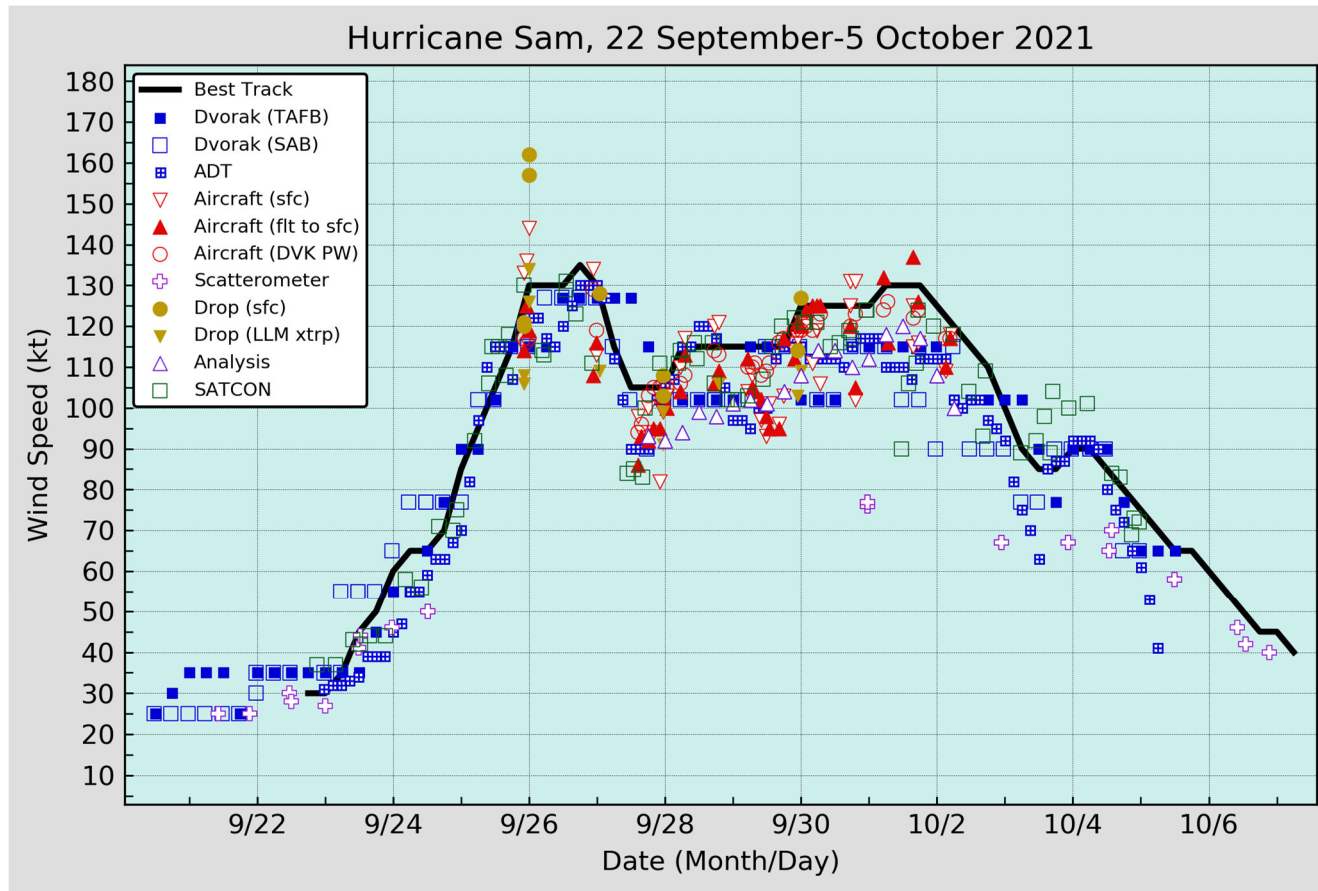


Figure 2. Selected wind observations and best track maximum sustained surface wind speed curve for Hurricane Sam, 22 September–5 October 2021. Aircraft observations have been adjusted for elevation using 90%, 80%, and 80% adjustment factors for observations from 700 mb, 850 mb, and 1500 ft, respectively. 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.

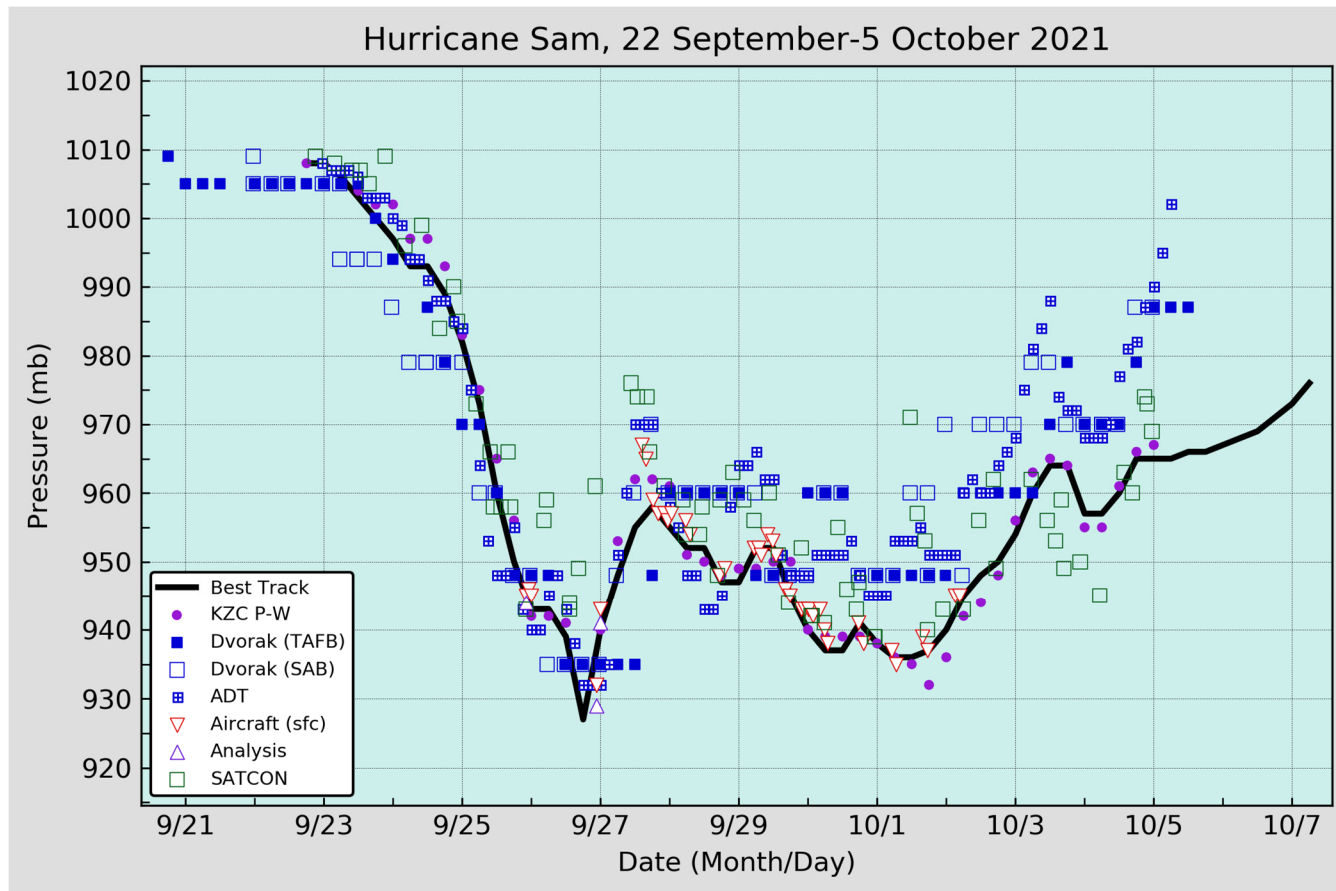


Figure 3. Selected pressure observations and best track minimum central pressure curve for Hurricane Sam, 22 September–5 October 2021. Advanced Dvorak Technique estimates represent the Current Intensity at the nominal observation time. SATCON intensity estimates are from the Cooperative Institute for 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.

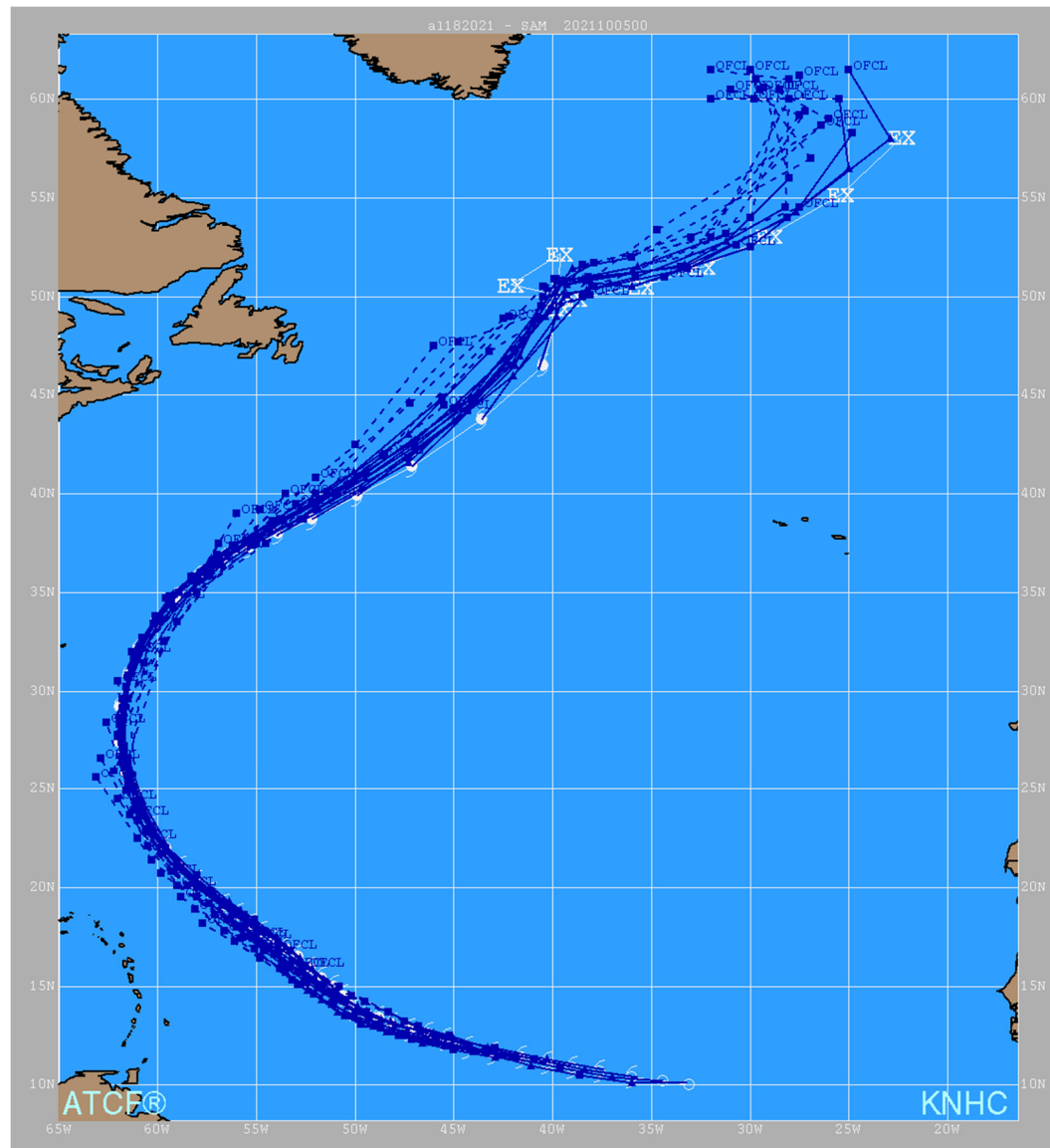


Figure 4. Official track forecasts (blue lines) for Hurricane Sam, 1800 UTC 22 September through 0000 UTC 5 October. The best track is shown in white.

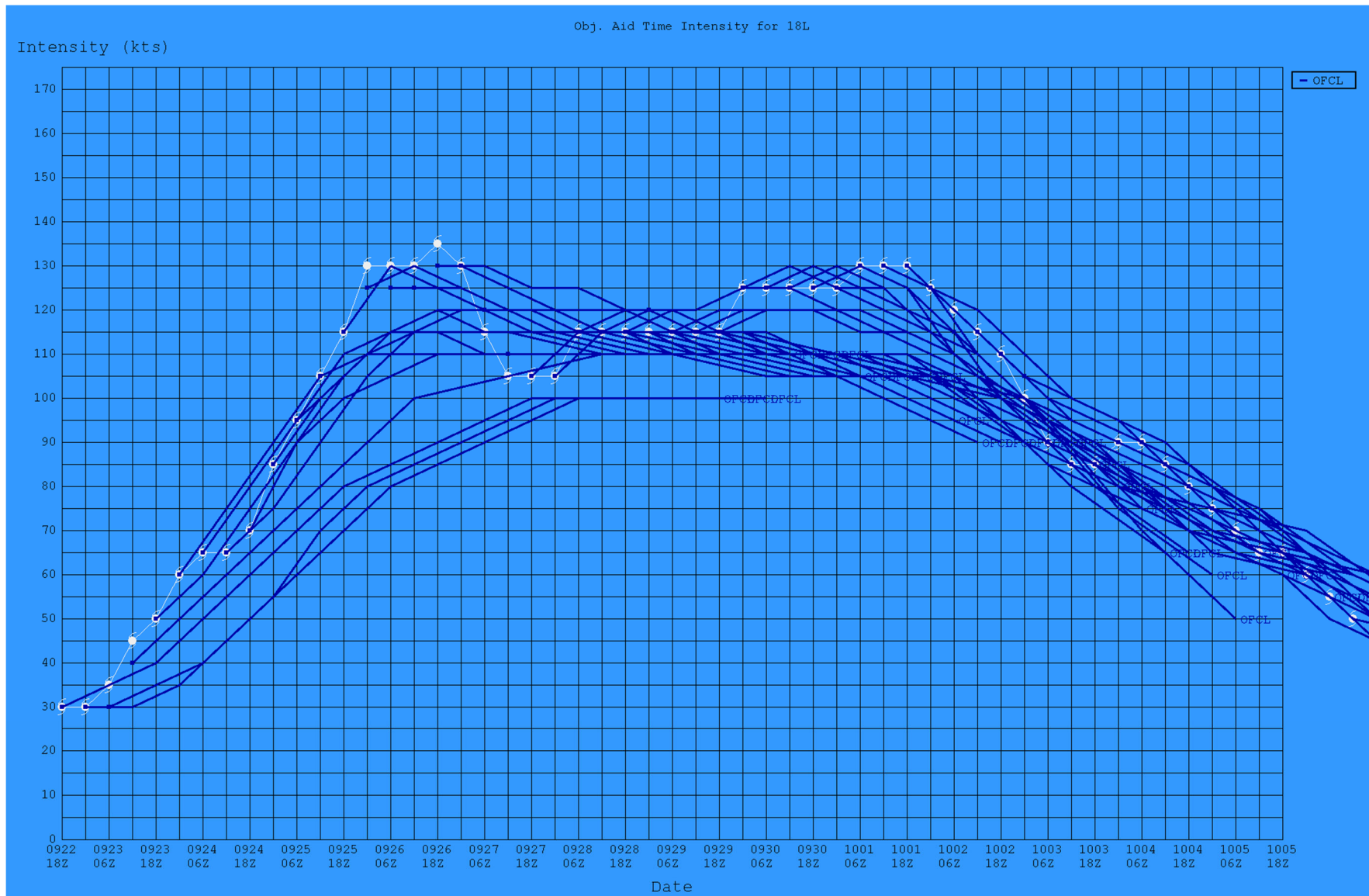


Figure 5. Official intensity forecasts (blue lines, kt) for Hurricane Sam, 1800 UTC 22 September through 0000 UTC 5 October. The best track intensity (kt) is shown in white.