NATIONAL HURRICANE CENTER
TROPICAL CYCLONE REPORT

TROPICAL STORM KAREN

(AL122019)

22–27 September 2019

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GOES-16 NATURAL-COLOR VISIBLE SATELLITE IMAGE OF TROPICAL STORM KAREN AT 1800 UTC 24 SEPTEMBER WHEN ITS CENTER WAS JUST SOUTH OF VIEQUES, PUERTO RICO. IMAGE COURTESY OF NOAA/RAMMB.

Karen was a tropical storm that formed over the southeastern Caribbean Sea and produced significant flooding across portions of the Windward Islands. The storm moved northward and made landfall on Vieques and Culebra, Puerto Rico, before dissipating over the central Atlantic a couple of days later.

Tropical Storm Karen

22–27 SEPTEMBER 2019

SYNOPTIC HISTORY

Karen originated from a tropical wave that moved off the west coast of Africa on 14 September (Fig. 1). The wave produced a concentrated area of showers and thunderstorms as it moved westward across the Cabo Verde Islands on 16 September, but the activity became less organized during the following few days when the wave moved across the tropical eastern Atlantic. A broad area of low pressure formed along the wave axis by early 21 September when it was located about 500 n mi east-southeast of the southern Windward Islands. The showers and thunderstorms gradually increased, and deep convection became sufficiently organized around a well-defined center to classify the system as a tropical depression by 0000 UTC 22 September when it was located about 100 n mi east of Tobago in the Windward Islands. The cyclone strengthened to a tropical storm 6 h later. The "best track" chart of Karen's path is given in Fig. 2, with the wind and pressure histories shown in Figs. 3 and 4, respectively. The best track positions and intensities are listed in Table 1[1].

Around the time of genesis, Karen was moving west-northwestward, steered by the southwestern periphery of an Atlantic subtropical ridge. The tropical storm moved through the southern Windward Islands later on 22 September with maximum winds of 35 kt, and then moved over the southeastern Caribbean Sea. The convective pattern became less organized by early 23 September when a combination of strong northeasterly vertical wind shear and dry air began to affect the cyclone, and Karen weakened back to a tropical depression by 0600 UTC that day as it turned northwestward. The low-level center was exposed to the north of a pulsing area of deep convection for much of the day, but by 0600 UTC 24 September, the shear relaxed and thunderstorms re-developed over Karen's center. Accordingly, the cyclone strengthened back to a tropical storm at that time when it was located about 100 n mi south-southwest of Vieques, Puerto Rico. During that time, Karen slowed down and turned northward around the western periphery of the ridge.

In slightly more favorable environmental conditions, Karen slowly strengthened and reached its first peak intensity of 40 kt by 1800 UTC 24 September when it was located just south of Vieques (cover image). The storm maintained that intensity as it moved across the islands of Vieques and Culebra during the next several hours. Karen then moved northward to north-northeastward on 25 September over the central Atlantic Ocean, and dry air caused the thunderstorms to decrease and the cyclone to weaken. The weakening was short lived, however, and Karen re-intensified slightly to 40 kt again by 1200 UTC 26 September when another burst of

[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.

deep convection formed over its center. This second peak intensity occurred when the storm was located about 400 n mi south of Bermuda.

Karen turned northeastward later on 26 September as it moved in the flow between the ridge and a mid- to upper-level low over the Bahamas. This motion continued while Karen again weakened. This time, however, the weakening persisted with the thunderstorm activity decreasing and the low-level circulation becoming increasingly stretched due to strong southwesterly shear and the interaction with a surface trough trailing from former Hurricane Jerry to its north. Karen weakened to a tropical depression by 1200 UTC 27 September and dissipated shortly thereafter when it was located over the central Atlantic Ocean, about 300 n mi southeast of Bermuda.

METEOROLOGICAL STATISTICS

Observations in Tropical Storm Karen (Figs. 3 and 4) include subjective satellite-based Dvorak technique intensity estimates from the Tropical Analysis and Forecast Branch (TAFB) and the Satellite Analysis Branch (SAB), and 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 six flights (26 center fixes) by the 53rd Weather Reconnaissance Squadron of the U.S. Air Force Reserve Command. 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 Karen. The National Weather Service WSR-88D radar from San Juan, Puerto Rico, and the Caribbean radar composite were also helpful in tracking Karen across the Caribbean region.

Winds and Pressure

The first peak intensity of Karen of 40 kt from 1800 UTC 24 September to 0600 UTC 25 September is based on a blend of the Air Force reconnaissance data of a maximum 850-mb flight-level wind of 53 kt, which reduces to a 40–45 kt surface wind, and 33–38 kt SFMR winds during that time period. The second peak intensity of 40 kt at 1200 and 1800 UTC 26 September is based on ASCAT data that showed peak winds between 35 and 42 kt.

The estimated minimum pressure of 1003 mb at 0000 and 0600 UTC 25 September is based on a 1004-mb dropsonde report with 6 kt of wind, which adjusts to 1003 mb, from the Air Force Hurricane Hunters.

There were three unofficial reports of sustained tropical-storm-force winds in the British and U.S. Virgin Islands as Karen moved through that area late on 24 September and early on 25 September (Table 2).

Rainfall and Flooding

Karen produced a widespread area of 2 to 4 inches of rain across Puerto Rico with isolated amounts of around 5 inches in higher terrain (Fig. 5). Similar rainfall amounts occurred in Trinidad and Tobago, and slightly lower rainfall amounts occurred over the Virgin Islands.

CASUALTY AND DAMAGE STATISTICS

There were no deaths reported in association with Tropical Storm Karen. Karen produced flooding on Trinidad and Tobago (Fig. 6), and the Tobago Emergency Management Agency reported that there was significant damage to roads and utility poles and several uprooted trees in Tobago. In addition, in the town of Plymouth on Tobago, several boats were damaged due to the rough seas. Similar damage occurred in Puerto Rico, where several roads were impassible during the storm due to excessive runoff and mudslides from the heavy rains. The roads were most affected in the Barranquitas, Cayey, and Guayama municipalities. In Dorado, emergency managers rescued two people that were trapped at their house. In Vieques, two piers were washed out due to the large waves and rough seas. High seas also caused coastal damage along the southern coast of mainland Puerto Rico.

FORECAST AND WARNING CRITIQUE

Genesis

The disturbance from which Karen developed was introduced into the Tropical Weather Outlook at 0600 UTC 18 September (90 h prior to genesis) with a low chance (<40%) of formation during the next 5 days (Table 3). The 5-day formation chance was raised to the medium category (40–60%) 30 h before genesis, and it failed to reach the high category prior to genesis. The system was first given a low chance of development in the next 2 days 54 h before formation, and this chance was raised to the medium category 24 h before genesis. Part of the challenge in predicting Karen's genesis was the generally unfavorable environmental conditions in the eastern Caribbean. Although these conditions limited the amount of strengthening, they were not hostile enough to hinder genesis.

Track

A verification of NHC official track forecasts for Karen is given in Table 4a. Official track forecast errors were lower than the mean official errors for the previous 5-yr period at 48 and 72 h, but higher than the mean errors at other verifying forecast times. The climatology and persistence errors (OCD5) errors were much higher than their 5-yr means at 72–120 h, indicating that Karen's track was more difficult to predict than average and NHC forecasts were quite skillful at those time ranges. A homogeneous comparison of the official track errors with selected guidance models is given in Table 4b. The best-performing models were the weighted consensus aids FSSE and HCCA, which beat the official forecasts at most verifying times. The HWFI and HMNI were among the models with the largest errors. The official forecasts had a westward bias for the portion of Karen's track over the southwestern North Atlantic, as many of the long-range

forecasts expected Karen to turn westward, which did not occur (Fig. 7). Instead, Karen weakened and moved east-northeastward before dissipating.

Intensity

A verification of NHC official intensity forecasts for Karen is given in Table 5a. Official intensity forecast errors were notably lower than the mean official errors for the previous 5-yr period at all forecast times, except at 120 h. The OCD5 errors were also generally below their 5-yr means, indicating that Karen's intensity was easier to predict than average. A homogeneous comparison of the official intensity errors with selected guidance models is given in Table 5b. The only model that consistently beat the NHC forecasts was EMXI. This result is not surprising since the global models often perform better than the standard intensity guidance for weak systems like Karen. Several of the other models beat the official forecasts at some forecast times. The NHC intensity forecasts had a high bias overall, and some of the forecasts incorrectly predicted that Karen would be near hurricane strength (not shown).

Watches and Warnings

Tropical storm watches and warnings associated with Karen are shown in Table 6. A tropical storm watch was issued for Puerto Rico and the U.S. Virgin Islands at 1500 UTC 22 September. The watch was upgraded to a tropical storm warning at 0900 UTC 23 September. The tropical storm watch provided about 56 h of lead time before tropical-storm-force winds began, while the warning provided roughly 38 h of lead time.

Impact-Based Decision Support Services (IDSS) and Public Communication

The NHC began providing direct support to emergency managers on 23 September when Karen was a tropical storm over the southeastern Caribbean Sea, which continued through 25 September as Karen pulled north away from Puerto Rico and the U.S. Virgin Islands. This decision support included calls and briefings coordinated through the FEMA Hurricane Liaison Team, embedded at NHC. The briefings included video teleconferences with Puerto Rico, the U.S. Virgin Islands, FEMA Headquarters, FEMA Region 2 staff, and U.S. Coast Guard District 7.

ACKNOWLEDGMENTS

Data in Table 2 were compiled from a Post Tropical Cyclone Report issued by the NWS Weather Forecast Office in San Juan, Puerto Rico. Tiffany O'Conner and Christopher Landsea contributed to the IDSS section.

Table 1. Best track for Tropical Storm Karen, 22–27 September 2019.

Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Stage
22 / 0000	11.5	58.8	1007	30	tropical depression
22 / 0600	11.8	59.9	1007	35	tropical storm
22 / 1200	12.1	61.1	1007	35	"
22 / 1800	12.5	62.2	1007	35	"
23 / 0000	13.0	63.2	1007	35	"
23 / 0600	13.7	64.1	1007	30	tropical depression
23 / 1200	14.4	64.8	1007	30	"
23 / 1800	15.1	65.4	1007	30	"
24 / 0000	15.7	65.7	1007	30	"
24 / 0600	16.4	65.8	1006	35	tropical storm
24 / 1200	17.0	65.8	1006	35	"
24 / 1800	17.7	65.6	1004	40	"
24 / 2200	18.1	65.4	1004	40	"
24 / 2300	18.3	65.3	1004	40	"
25 / 0000	18.5	65.2	1003	40	"
25 / 0600	19.7	65.0	1003	40	"
25 / 1200	21.0	64.8	1004	35	"
25 / 1800	22.3	64.5	1004	35	"
26 / 0000	23.6	64.2	1004	35	"
26 / 0600	24.8	64.0	1004	35	"
26 / 1200	25.9	63.7	1004	40	"
26 / 1800	26.9	63.1	1005	40	"
27 / 0000	27.7	62.3	1005	35	"
27 / 0600	28.3	61.2	1005	35	"
27 / 1200	28.8	60.0	1006	30	tropical depression
27 / 1800					dissipated
25 / 0000	18.5	65.2	1003	40	minimum pressure
24 / 2200	18.1	65.4	1004	40	Landfall on Vieques, Puerto Rico
24 / 2300	18.3	65.3	1004	40	Landfall on Culebra, Puerto Rico

Table 2. Selected surface observations for Tropical Storm Karen, 22–27 September 2019.

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)	Storm tide (ft)	Estimated Inundation (ft)	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)				
U.S. Virgin Islands									
St. Thomas (TIST) 18.34N 64.97W	24/2353	1007	24/2325	31	37				
St. Croix (TISX) 17.70N 64.80W	24/0853	1008	24/2200	23	31				
Non-Metar									
Two Brothers (XBRO) 18.34N 64.82W	24/2338	1006	24/2330	35	43				
Rupert Rock (XRUP) 18.33N 64.93W	24/2332	1005	24/2317	32	41				
Buck Island (XBUK) 18.28N 64.89W	24/2252	1002	25/0052	31	40				
Cape Air (ISTTHOMA6) 18.34N 64.89W	24/2319	1005	24/2339		51				
British Virgin Islands									
Hansen Bay (155747) 18.34N 64.67W			25/0130	36	47				
Quart-A-Nancy (155750) 18.39N 64.51W	25/0932	1005	24/1718	36	38				1.38
Puerto Rico									
Roosevelt Roads (TJNT) 18.24N 65.62W	24/2253	1007	24/1853	21	28				
San Juan (TJSJ) 18.44N 66.00W	24/1956	1007	24/1700	17	21				
Non-Metar									
Culebrita Island (XCUL) 18.31N 65.23W	24/2350	994	24/1745	37	43				
Coamo (COIP4) 18.08N 66.35W									5.00
Rio Lajas (TOAP4) 18.41N 66.26W									4.84
Barranquitas (USAP4) 18.16N 66.41W									4.63
Pastos (ALPP4) 18.13N 66.26W									4.40
Cayuco (UTHP4) 18.27N 66.79W									3.50
Levittown (LTBP4) 18.44N 66.17W									3.46

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)	Storm tide (ft)	Estimated Inundation (ft)	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)				
San Juan (PR-SJ3) 18.41N 66.07W									3.46
Rafael Capo (CMAP4) 18.40N 66.82W									3.43
Jobos (MELP4) 17.98N 66.15W									3.38
Villalba (VILP4) 18.21N 66.48W									3.25
Lares (LARP4) 18.32N 66.87W									3.17
Marueno (PRNP4) 18.04N 66.62W									3.00
Buoys									
41043 NE of Puerto Rico 21.12N 64.83W	25/1150	1008	25/1501	33 4 m, 1 min	37				
41049 South Bermuda 27.49N 62.94W	26/2140	1006	26/2223	33 4 m, 1 min	41				

[a] Date/time is for sustained wind when both sustained and gust are listed.
[b] Sustained wind averaging periods are 10 min unless otherwise noted.
[l] Incomplete data.

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%)	54	90
Medium (40%-60%)	24	30
High (>60%)	-	-

Table 4a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) track forecast errors (n mi) for Tropical Storm Karen, 22–27 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	29.3	41.5	47.3	**54.7**	**84.1**	218.8	330.0
OCD5	45.7	91.8	158.3	258.1	493.1	786.3	1082.3
Forecasts	20	18	16	14	10	6	2
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 4b. Homogeneous comparison of selected track forecast guidance models (in n mi) for Tropical Storm Karen, 22–27 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 4a due to the homogeneity requirement.

Model ID	Forecast Period (h)						
	12	24	36	48	72	96	120
OFCL	28.9	36.4	41.8	56.7	82.7	250.9	374.4
OCD5	44.5	81.7	139.9	230.8	512.4	761.4	1140.9
GFSI	32.9	47.8	54.0	63.8	**55.6**	**145.3**	**293.9**
HMNI	35.5	47.5	58.9	96.9	207.8	390.6	379.5
HWFI	**27.1**	42.7	50.2	71.0	170.5	367.3	376.5
EMXI	30.6	38.3	46.7	63.6	**76.3**	252.2	478.7
NVGI	49.3	71.6	89.0	93.1	**54.4**	**166.5**	**248.2**
AEMI	30.9	41.6	51.3	72.3	105.9	**208.6**	**237.9**
HCCA	**26.8**	37.2	**41.6**	57.9	**53.7**	**169.8**	**313.7**
FSSE	**26.0**	36.5	46.4	59.2	**40.5**	**154.7**	**271.3**
TVCX	**27.2**	37.3	42.3	58.7	**78.5**	**224.4**	416.6
GFEX	30.7	39.6	46.9	61.7	**61.8**	**197.4**	380.2
TVCA	**26.0**	38.1	43.2	58.7	**81.9**	**225.7**	404.4
TVDG	**27.7**	39.2	43.1	58.6	**65.9**	**195.3**	395.9
TABD	38.0	80.3	130.1	181.8	336.8	537.1	697.5
TABM	30.3	49.6	73.4	93.9	130.8	271.0	427.8
TABS	32.1	44.9	63.1	81.9	**53.6**	**101.1**	**144.0**
Forecasts	14	12	10	9	5	3	1

Table 5a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) intensity forecast errors (kt) for Tropical Storm Karen, 22–27 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	**4.2**	**4.7**	**6.9**	**8.6**	**10.0**	**12.5**	22.5
OCD5	5.7	10.0	11.7	15.0	15.5	18.0	40.0
Forecasts	20	18	16	14	10	6	2
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 5b. Homogeneous comparison of selected intensity forecast guidance models (in kt) for Tropical Storm Karen, 22–27 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	5.0	4.2	7.0	9.4	11.0	15.0	25.0
OCD5	6.7	11.2	13.4	17.2	17.2	16.3	43.0
HWFI	5.1	7.4	**5.6**	**4.7**	13.8	32.7	**3.0**
HMNI	9.1	5.2	**5.0**	**9.0**	**5.6**	17.0	**2.0**
HCCA	6.4	5.1	**4.8**	**6.1**	**8.8**	**14.0**	**6.0**
FSSE	7.0	7.8	7.7	**9.2**	12.0	15.7	**16.0**
IVCN	6.4	5.4	**4.8**	**6.1**	**6.2**	**13.7**	**16.0**
GFSI	**4.3**	4.3	8.0	10.2	13.0	**14.7**	**7.0**
EMXI	**4.3**	**2.2**	**5.4**	**6.6**	**5.0**	**14.7**	**8.0**
DSHP	5.9	6.8	8.5	**9.2**	14.0	16.7	33.0
LGEM	5.5	5.4	**6.5**	**7.8**	**7.6**	**10.0**	28.0
Forecasts	14	12	10	9	5	3	1

Table 6. Watch and warning summary for Tropical Storm Karen, 22–27 September 2019.

Date/Time (UTC)	Action	Location
22 / 0900	Tropical Storm Watch issued	St. Vincent and the Grenadines
22 / 0900	Tropical Storm Warning issued	Trinidad, Tobago, and Grenada
22 / 1200	Tropical Storm Watch changed to Tropical Storm Warning	St. Vincent and the Grenadines
22 / 1500	Tropical Storm Watch issued	Puerto Rico
22 / 1500	Tropical Storm Watch issued	U.S. and British Virgin Islands
22 / 1800	Tropical Storm Warning discontinued	Trinidad and Tobago
23 / 0000	Tropical Storm Warning discontinued	St. Vincent and the Grenadines
23 / 0300	Tropical Storm Warning discontinued	Grenada
23 / 0900	Tropical Storm Watch changed to Tropical Storm Warning	Puerto Rico
23 / 0900	Tropical Storm Watch discontinued	U.S. and British Virgin Islands
23 / 0900	Tropical Storm Watch issued	British Virgin Islands
23 / 0900	Tropical Storm Warning issued	U.S. Virgin Islands
23 / 1500	Tropical Storm Watch changed to Tropical Storm Warning	British Virgin Islands
25 / 0900	Tropical Storm Warning discontinued	All

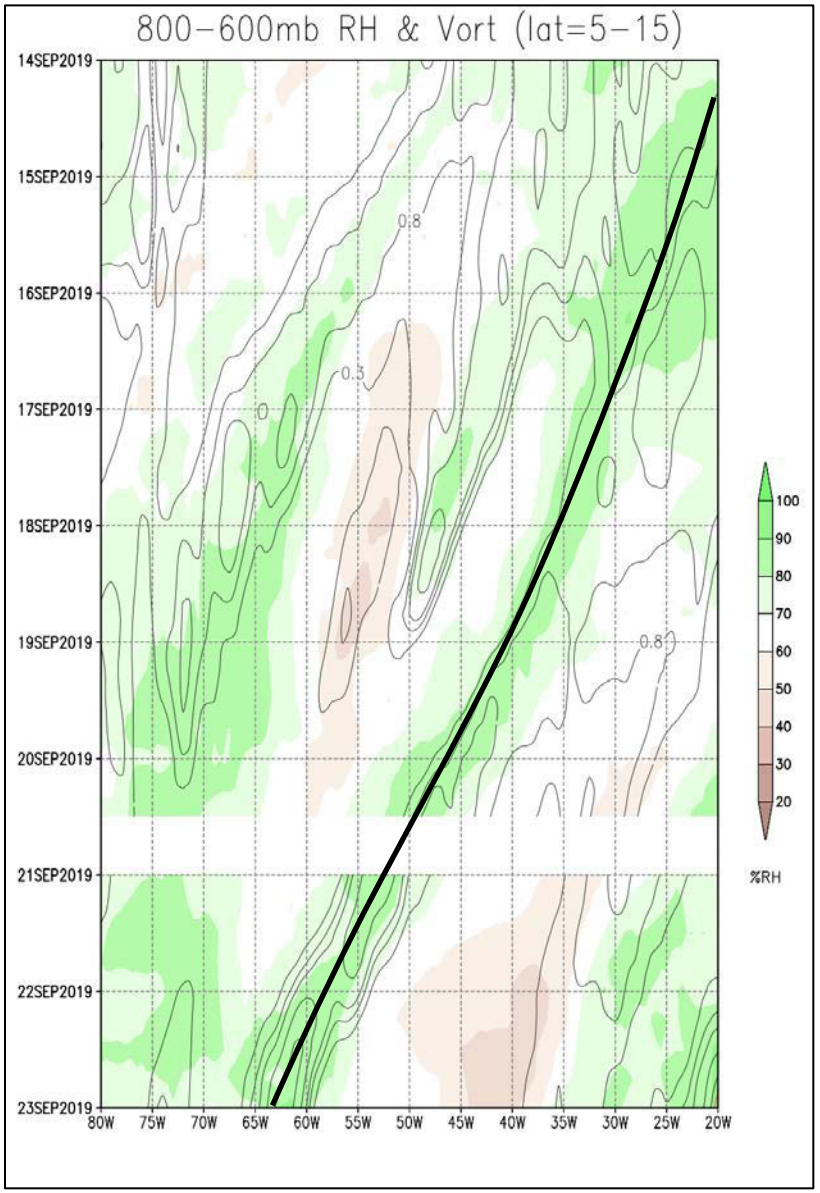

Figure 1. 800–600-mb relative humidity (shading) and relative vorticity (contours) from GFS analysis fields from 0000 UTC 14 to 0000 UTC 23 September 2019. The black line indicates the track of the tropical wave that led to the formation of Karen.

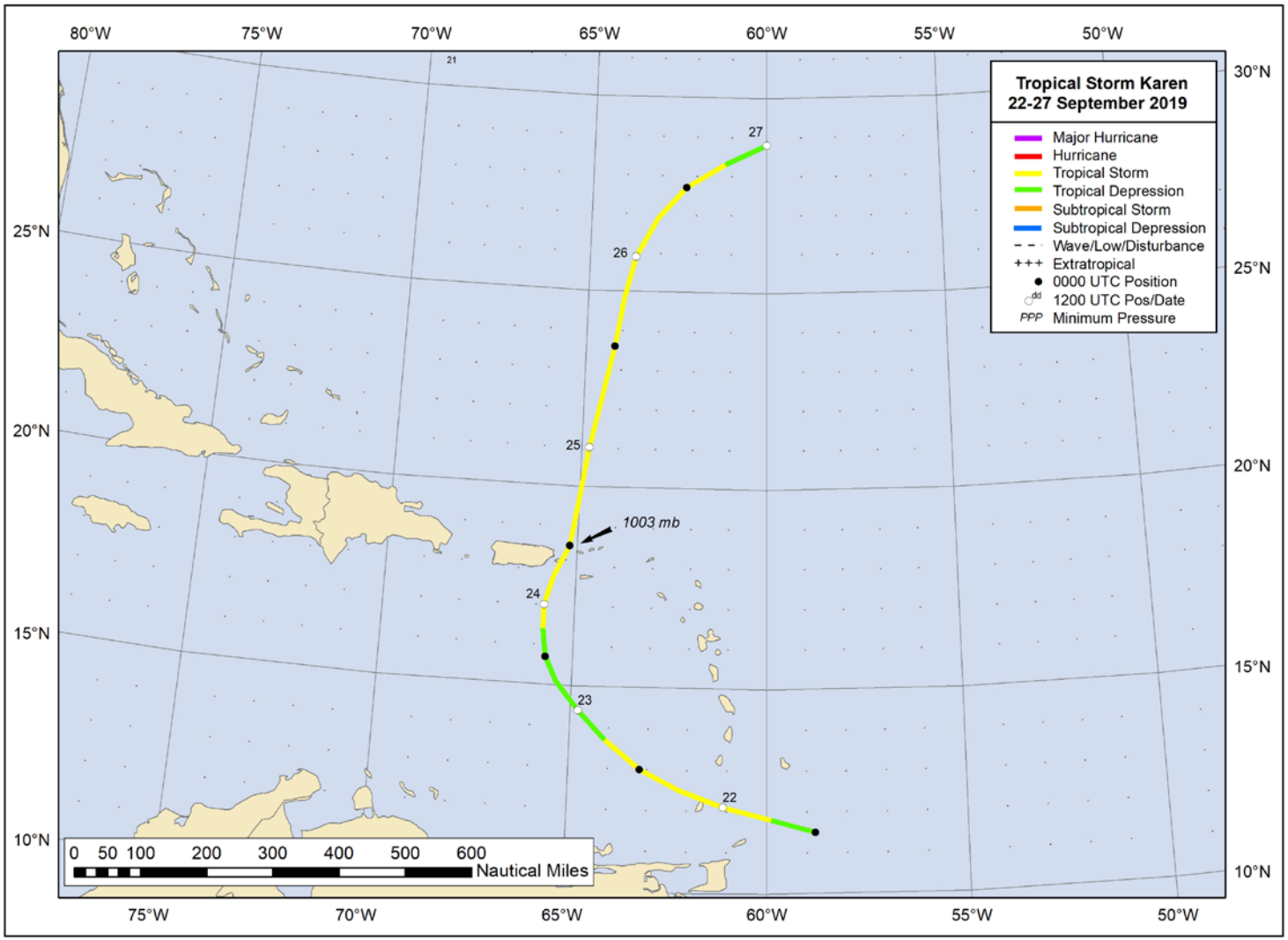

Figure 2. Best track positions for Tropical Storm Karen, 22–27 September 2019.

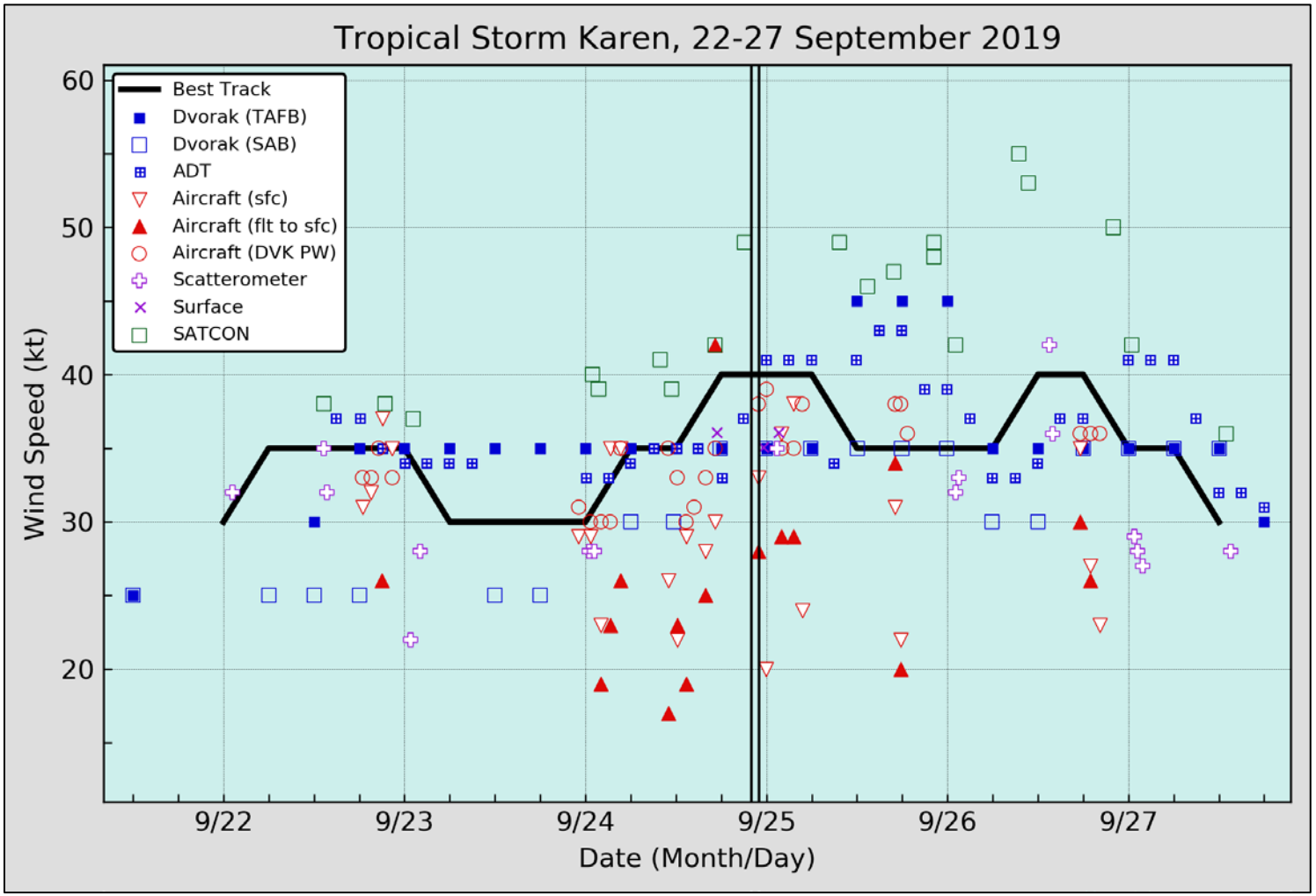

Figure 3. Selected wind observations and best track maximum sustained surface wind speed curve for Tropical Storm Karen, 22–27 September 2019. Aircraft observations have been adjusted for elevation using an 80% adjustment factor for observations from 850 mb. Advanced Dvorak Technique estimates represent 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, and the solid vertical lines corresponds to landfalls.

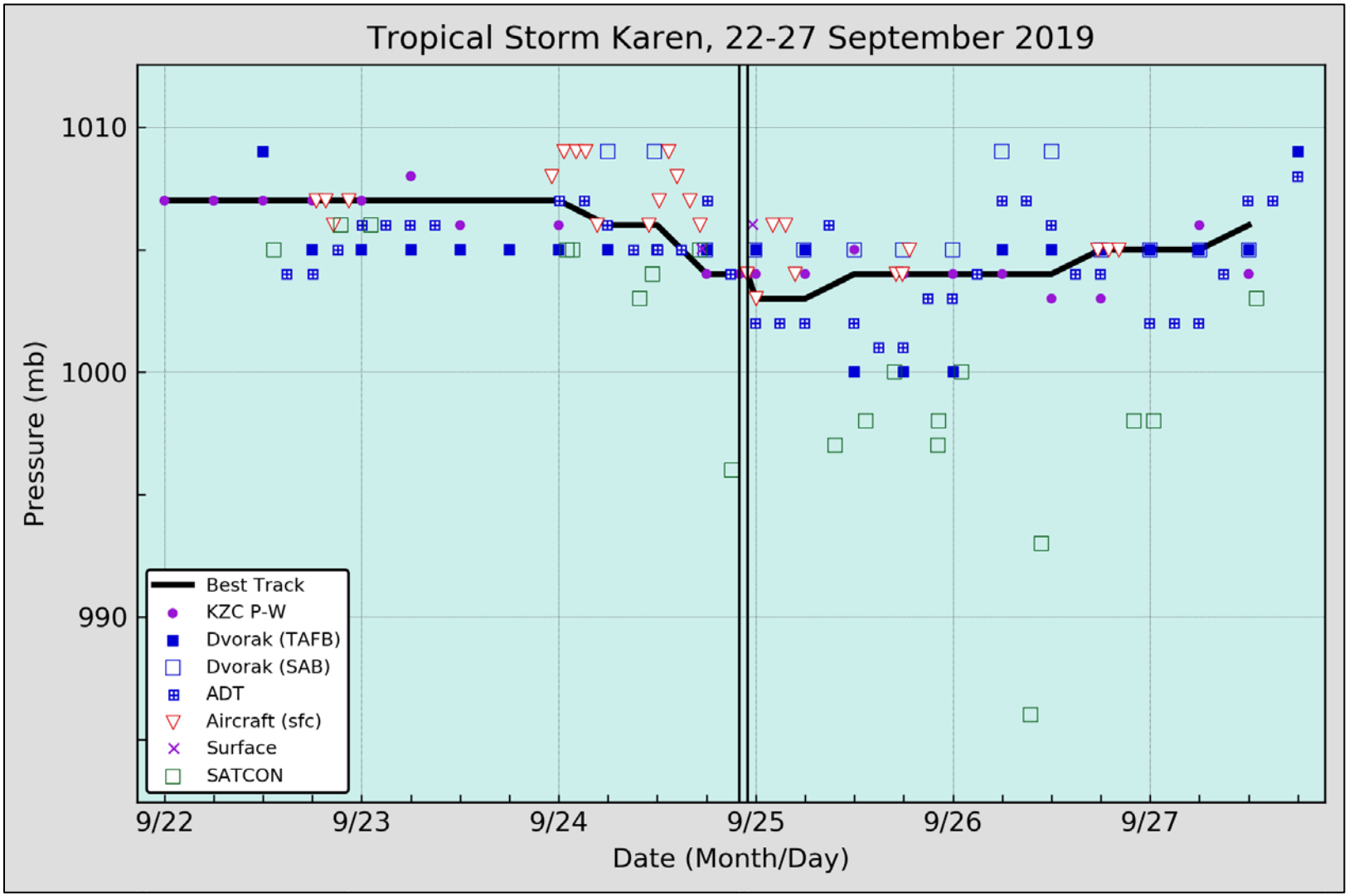

Figure 4. Selected pressure observations and best track minimum central pressure curve for Tropical Storm Karen, 22–27 September 2019. Advanced Dvorak Technique estimates represent the Current Intensity at the nominal observation time. The one SATCON intensity estimate is from the Cooperative Institute 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, and the solid vertical lines corresponds to landfalls.

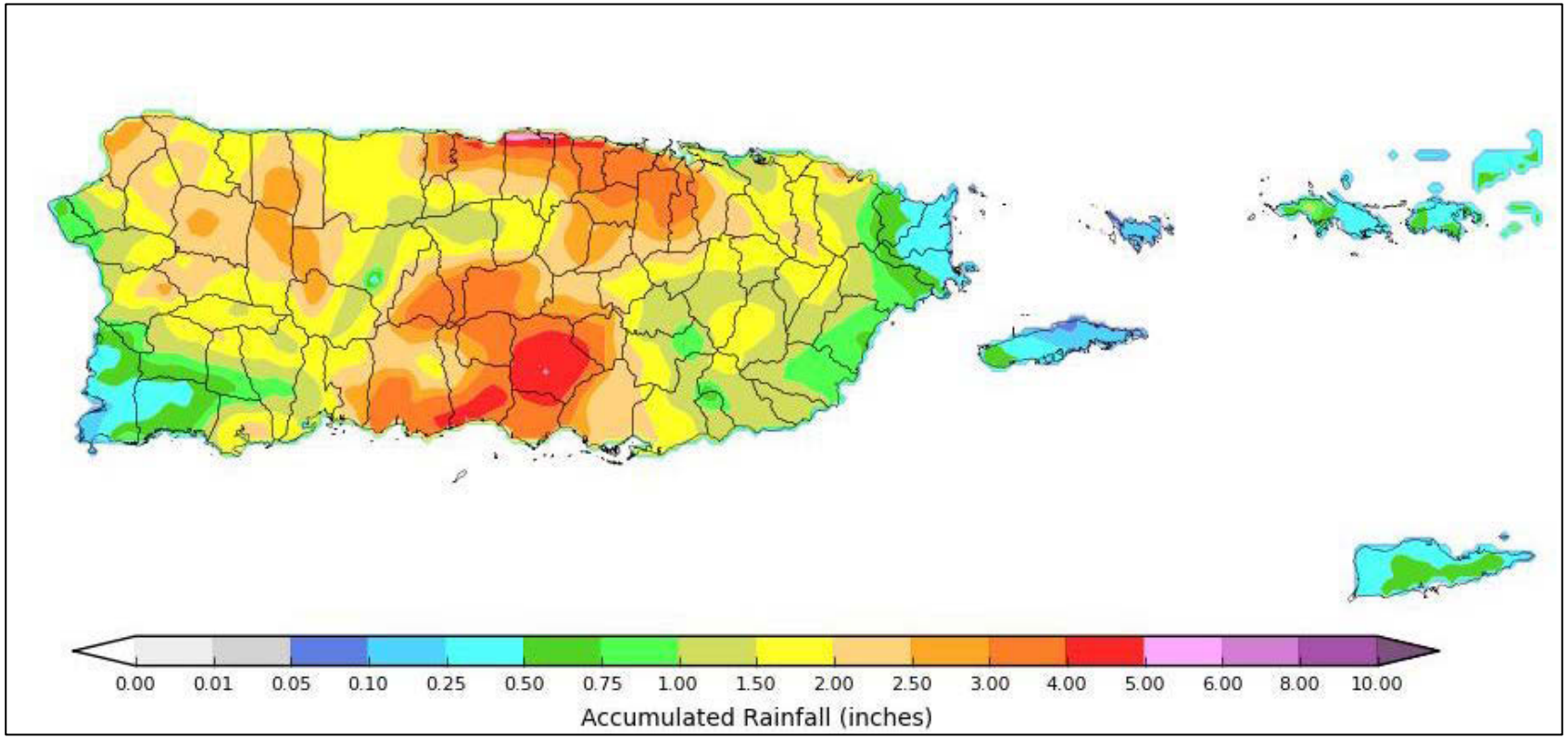

Figure 5. Estimated rainfall totals (in.) from the WSR-88D radar and rain gauges for Puerto Rico and the U.S. Virgin Islands during Tropical Storm Karen. Figure courtesy of the NWS San Juan Weather Forecast Office.

Figure 6. Flooding in Lowlands, Tobago, during Tropical Storm Karen. Picture is courtesy of the Tobago Emergency Management Agency.

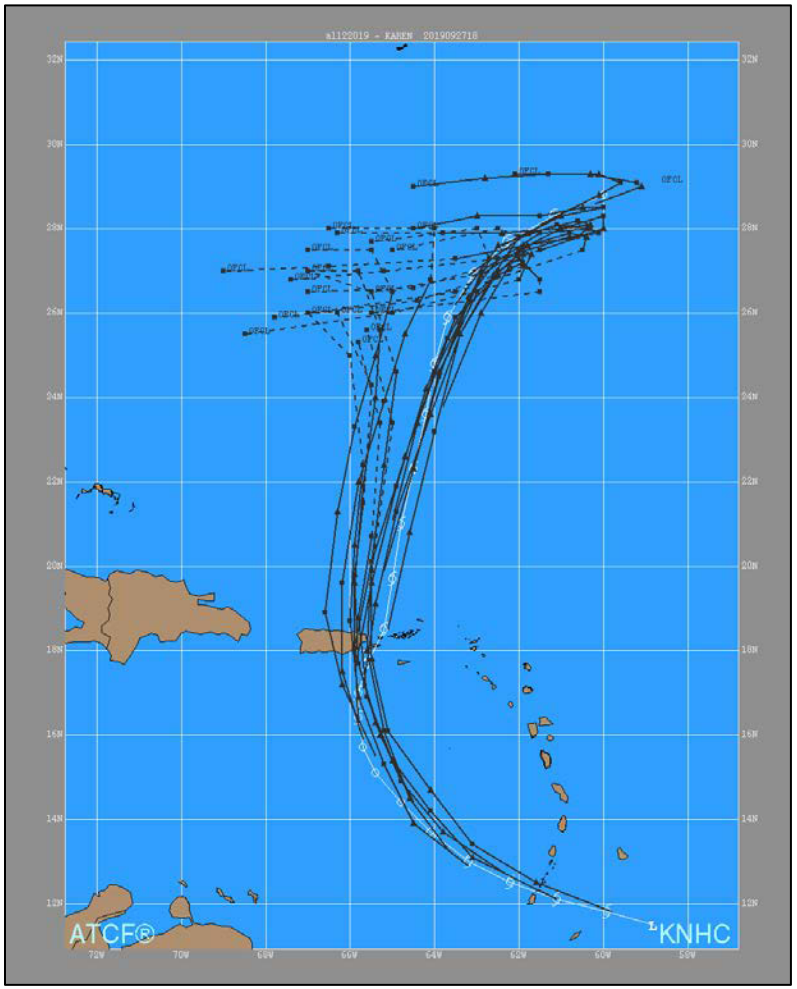

Figure 7. Selected official track forecasts (dark gray lines, with 0, 12, 24, 36, 48, 72, 96, and 120 h positions indicated) for Tropical Storm Karen from 0600 UTC 22 September to 1200 UTC 27 September. The best track is given by the white line with positions shown at 6 h intervals.