NATIONAL HURRICANE CENTER TROPICAL CYCLONE REPORT

TROPICAL STORM KARL

(AL142022)

11 – 14 October 2022

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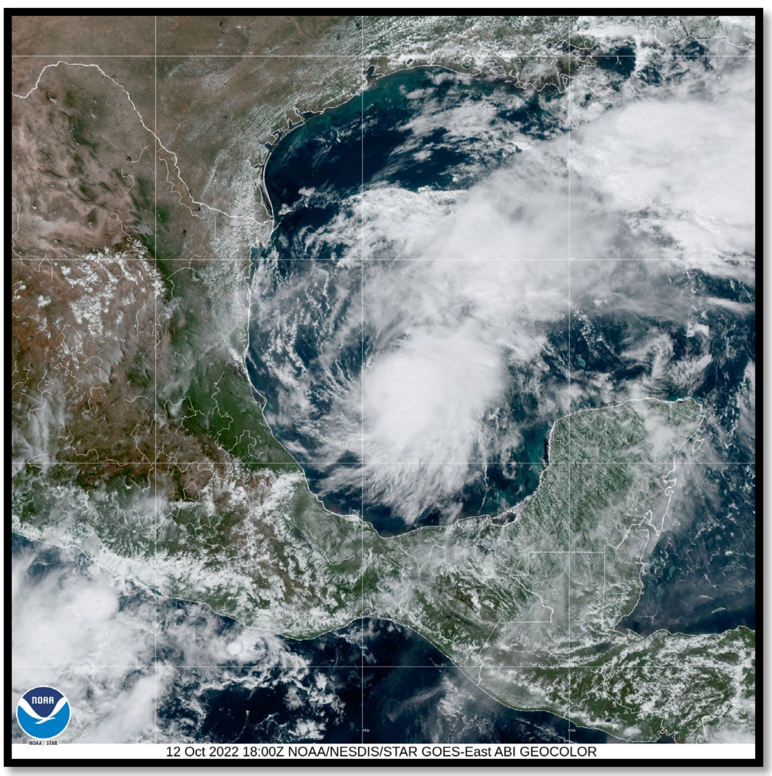
31 January 2023



GOES-16 GEOCOLOR SATELLITE IMAGE OF TROPICAL STORM KARL OVER THE SOUTHWESTERN GULF OF MEXICO AT 1800 UTC 12 OCTOBER 2022, AT THE TIME IT REACHED ITS PEAK INTENSITY (IMAGE COURTESY OF NOAA/NESDIS/STAR)

Karl was a tropical storm that partially originated from the remnants of Hurricane Julia and meandered over the southwestern Gulf of Mexico. Karl degenerated into a remnant low before it skirted the coast of the Mexican state of Tabasco. Three people died due to flooding in the state of Chiapas.

Tropical Storm Karl

11 – 14 OCTOBER 2022

SYNOPTIC HISTORY

Karl partially formed from the remnants of Hurricane Julia, which made landfall along the Caribbean coast of Nicaragua early on 9 October, crossed Central America, and dissipated near the Pacific coast of Guatemala on 10 October. A disturbance which formed within the northern part of Julia's broad low-level circulation on 10 October moved across the Yucatan Peninsula and southern Mexico and emerged over the Bay of Campeche early on 11 October. A well-defined surface circulation quickly developed, and deep convection was sufficiently organized for the system to become a tropical depression by 1200 UTC 11 October while located about 60 n mi north-northeast of Coatzacoalcos, Mexico. The depression strengthened into a tropical storm 6 h later. The "best track" chart of Karl'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].

A mid-tropospheric ridge extending from the southwestern Atlantic over the eastern Gulf of Mexico initially steered Karl north-northwestward and northward through 12 October. Deep-layer shear at the time was relatively low, and with warm water temperatures of 28–29°C, Karl strengthened to an estimated peak intensity of 50 kt by 1800 UTC 12 October while located about 185 n mi east of Tampico, Mexico. The mid-tropospheric ridge gave way to a deep-layer trough moving eastward across the central United States by late on 12 October, and the sudden pattern shift caused Karl to stall early on 13 October, coincident with an increase in westerly shear. Karl subsequently began to weaken gradually, and the northwesterly flow on the back side of the trough drove the cyclone south-southeastward during the next day or two, back toward the Bay of Campeche. All deep convection dissipated late on 14 October due to shear and a dry mid-level environment, and Karl degenerated into a remnant low by 0000 UTC 15 October while located about 55 n mi west-northwest of Ciudad del Carmen. Despite Karl becoming a remnant low, upslope flow over the mountainous terrain of the Isthmus of Tehuantepec, well south of Karl's center, caused significant rains over Tabasco and Chiapas during the evening of 14 October and early morning of 15 October. Later on 15 October, a re-establishment of low-level ridging over the eastern Gulf of Mexico caused the remnant low to turn west-southwestward, and the low dissipated by 0000 UTC 16 October about 40 n mi east-northeast of Coatzacoalcos while skirting the coast of the state of Tabasco.

[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.

METEOROLOGICAL STATISTICS

Observations in Karl (Figs. 2 and 3) include subjective satellite-based Dvorak technique intensity estimates from the Tropical Analysis and Forecast Branch (TAFB) and 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 seven flights of 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 Karl.

Karl's estimated peak intensity of 50 kt from 1800 UTC 12 October to 0000 UTC 13 October is based on a blend of aircraft data, buoy data, and subjective satellite intensity estimates. An Air Force Reserve Hurricane Hunter aircraft measured a maximum surface wind of 52 kt from the SFMR at 1649 UTC 12 October, while a subsequent flight measured a peak 850-mb flight-level wind of 57 kt at 0059 UTC 13 October (which equates to a surface intensity just over 45 kt). NOAA buoy 42055, located over the Bay of Campeche about 215 n mi northeast of Veracruz, Mexico, reported a maximum 1-minute sustained wind of 40 kt at 1710 UTC 12 October. Since the anemometer on the buoy is at a height of 4.1 m, the peak sustained wind converts to about 44 kt at a standard height of 10 m. In addition, subjective satellite intensity estimates of T3.0/45 kt were provided by TAFB and SAB during that period.

Surface winds as high as 40 to 45 kt were measured by the SFMR on the morning of 14 October. However, these reports are discounted as being too high since many of the measurements were flagged as unreliable, and those values did not match flight-level-reduced winds nor ASCAT data from around the same time.

The estimated minimum pressure of 997 mb is based on data from a dropsonde released from an Air Force Reserve reconnaissance flight on the morning of 14 October. The dropsonde measured a surface pressure of 999 mb with 18-kt winds. Karl's minimum pressure occurred a day and a half after the storm reached its peak intensity, due to the cyclone moving southward toward the coast of Mexico into an area of lower environmental pressures.

There were no ship reports of winds of tropical storm force associated with Karl. However, as stated above, NOAA buoy 42055 reported a maximum 1-minute sustained wind of 40 kt (44 kt at standard 10-meter height) with a gust to 47 kt at 1710 UTC 12 October. Sustained tropical-storm-force winds were not reported in Mexico despite Karl's proximity to land, although a gust to 37 kt was measured at Ciudad del Carmen at 1510 UTC 14 October.

Karl produced areas of heavy rain over portions of southern Mexico (Fig. 4). According to Mexico's Servicio Meteorológico Nacional, a maximum five-day total of 15.50 inches (393.7 mm) of rain fell at Camoapa, Tabasco, between 11 and 15 October. During the same period, 13.93 inches (353.8 mm) of rain was measured at Chapultenango, Chiapas, and 13.68 inches (347.4 mm) was reported at Rio de Janeiro, Chiapas. A significant majority of the rain fell during the 12-h period after Karl had degenerated into a remnant low due to upslope flow over the terrain of the Isthmus of Tehuantepec, from the evening of 14 October through the morning of 15 October. In fact, nearly 99% of the rain reported at Camoapa and Rio de Janeiro (15.27 inches/387.9 mm and 13.48 inches/342.4 mm, respectively) fell during the 24-h period from 1200 UTC 14 October through 1200 UTC 15 October. The heavy rains caused several rivers to overflow their banks, including the Pichucalco River, which flooded the town of Pichucalco with as much as 10 ft (3 m) of water.[2]

CASUALTY AND DAMAGE STATISTICS

Karl took the lives of three people in the Mexican state of Chiapas due to flooding. Two workers transporting humanitarian aid in the municipality of Juárez died when strong currents caused their boat to capsize in floodwaters. A 65-year-old person also died due to complications after being trapped in their home by rising floodwaters in the town of Pichucalco.[2,3] More than 1,000 people attending a religious event were forced to evacuate, and a young boy was rescued after he was swept away by floodwaters. Flooding and landslides elsewhere across southern Mexico destroyed bridges, roads, and other structures.

FORECAST AND WARNING CRITIQUE

Karl's genesis was poorly forecast since it was not apparent that a part of Hurricane Julia's broad circulation would split off and move over the Bay of Campeche. Table 2 provides the number of hours in advance of formation with the first NHC Tropical Weather Outlook (TWO) forecast in each likelihood category. A low (<40%) chance of genesis during the next 2 and 5 days was first indicated in the TWO at 1200 UTC 10 October, only 24 h before Karl formed. The 2-day chance of genesis was raised to medium (40-60%) only 6 h before genesis. One forecast for a high (>60%) chance of genesis was issued by NHC, but it was released after Karl is estimated to have formed in the post-analysis. Figure 5 shows that Karl's location of genesis fell within all of the potential genesis areas depicted in NHC's Graphical Tropical Weather Outlook, albeit for a small number of forecasts (5).

A verification of NHC official track forecasts for Karl is given in Table 3a. Official track forecast errors were as much as two to three times higher than the mean official errors for the previous 5-year period. Climatology-persistence (OCD5) errors were near or slightly higher than their respective 5-year means, suggesting that Karl's track was more atypical than that of most Atlantic tropical cyclones over the past 5 years. As shown in Fig. 6, the first four official NHC

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[2] Davies, R. "Mexico—1 Dead, Hundreds Evacuated after Tropical Storm Karl Dumps 380 mm of Rain." October 16, 2022. https://floodlist.com/america/mexico-floods-tropical-storm-karl-october-2022 Retrieved December 14, 2022.
[3] "Aumentan a 3 los muertos por la tormenta Karl en Chiapas" [Deaths from storm Karl in Chiapas increase to 3]. *Forbes Mexico* (in Spanish). October 17, 2022. https://www.forbes.com.mx/aumentan-a-3-los-muertos-por-la-tormenta-karl-en-chiapas/ Retrieved December 13, 2022.

track forecasts for Karl contributed to most of the forecast error, especially at 48–72 h, because they incorrectly showed the cyclone turning west and southwest into Mexico. Instead, the storm moved farther north and east than initially expected before stalling and moving back toward the south. Even after the southward turn, most official forecasts did not show Karl moving as far to the east as it did.

A homogeneous comparison of the official track errors with selected guidance models is given in Table 3b and Fig. 7. Most deterministic and consensus models had much lower errors than the NHC official forecasts, particularly at 48 and 60 h, and the Florida State Superensemble (FSSE) had the lowest errors by far. An inspection of individual model trends (not shown) indicates that most of the guidance showed a significant eastward shift on the 0600 UTC 12 October forecast cycle. This shift proved to be accurate, but due to NHC's operational consistency protocols, it took the official forecasts a cycle or two to trend in the direction of the shift, which likely led to their higher overall track errors compared to the models.

A verification of NHC official intensity forecasts for Karl is given in Table 4a. Official intensity errors were lower than the mean official errors for the previous 5-year period at all forecast times. However, OCD5 errors were higher than their respective 5-year means at all forecast times, suggesting that Karl's intensity was actually less predictable than for a typical Atlantic tropical cyclone over the past 5 years.

A homogeneous comparison of the official intensity errors with selected guidance models is given in Table 4b and Fig. 8. The NHC official intensity forecasts were outperformed by the consensus aids (e.g., ICON, HCCA, and FSSE) through 36 h but then generally performed better than the guidance at 48 and 60 h.

Coastal watches and warnings issued in association with Karl are shown in Table 5. A larger-than-normal area of watches and warnings was issued due to Karl's erratic behavior and large uncertainty in its forecast track.

Table 1. Best track for Tropical Storm Karl, 11–14 October 2022.

Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Stage
11 / 1200	19.0	94.1	1007	30	tropical depression
11 / 1800	19.6	94.5	1006	35	tropical storm
12 / 0000	20.2	94.8	1005	35	"
12 / 0600	20.9	94.9	1004	35	"
12 / 1200	21.5	94.8	1002	40	"
12 / 1800	22.0	94.6	1000	50	"
13 / 0000	22.4	94.3	1000	50	"
13 / 0600	22.4	94.3	1000	45	"
13 / 1200	21.9	94.0	1000	45	"
13 / 1800	21.3	93.6	999	40	"
14 / 0000	20.9	93.0	998	40	"
14 / 0600	20.3	92.6	997	35	"
14 / 1200	19.8	92.6	997	35	"
14 / 1800	19.4	92.6	999	35	"
15 / 0000	19.0	92.7	1004	30	low
15 / 0600	18.7	92.9	1007	25	"
15 / 1200	18.5	93.3	1009	20	"
15 / 1800	18.4	94.0	1010	20	"
16 / 0000					dissipated
12 / 1800	22.0	94.6	1000	50	maximum winds
14 / 0600	20.3	92.6	997	35	minimum pressure

Table 2. Number of hours in advance of formation associated with the first NHC Tropical Weather Outlook (TWO) 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%)	24	24
Medium (40%-60%)	6	6
High (>60%)	-	-

Table 3a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) track forecast errors (n mi) for Tropical Storm Karl, 11–14 October 2022. 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	25.7	53.2	86.4	135.9	209.4	250.4		
OCD5	52.7	123.5	216.3	278.2	294.9	226.2		
Forecasts	11	9	7	5	3	1		
OFCL (2017-21)	23.6	35.5	47.6	61.4	78.2	91.3	125.6	172.1
OCD5 (2017-21)	45.5	98.3	156.7	213.7	252.4	316.9	403.6	484.6

Table 3b. Homogeneous comparison of selected track forecast guidance models (in n mi) for Tropical Storm Karl, 11–14 October 2022. 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 3a due to the homogeneity requirement.

Model ID	Forecast Period (h)							
	12	24	36	48	60	72	96	120
OFCL	22.9	45.4	73.9	113.1	175.5			
OCD5	52.2	132.6	262.3	370.2	422.2			
GFSI	23.0	**29.6**	**50.8**	**76.4**	**107.8**			
EMXI	**21.1**	**41.8**	**60.3**	**90.4**	**124.5**			
EGRI	24.6	47.7	79.3	**87.5**	**61.4**			
CMCI	28.7	50.9	76.1	117.0	**163.3**			
NVGI	23.0	**40.5**	**73.2**	**112.1**	221.4			
HWFI	31.2	55.9	75.0	118.1	**157.3**			
HMNI	**22.4**	**31.5**	**53.8**	**78.9**	**126.9**			
CTCI	24.9	**43.6**	**67.0**	**83.7**	**84.9**			
AEMI	23.5	**35.4**	**55.4**	**82.4**	**100.0**			
HCCA	**21.8**	**37.5**	**51.5**	**76.1**	**105.2**			
FSSE	**19.8**	**23.6**	**34.5**	**58.0**	**82.0**			
GFEX	**18.7**	**34.8**	**54.4**	**82.6**	**108.2**			
TVCA	**22.2**	**40.7**	**62.4**	**85.7**	**103.5**			
TVCX	**21.6**	**40.2**	**61.9**	**85.7**	**102.6**			
TVDG	23.0	**38.7**	**60.8**	**80.1**	**98.0**			
TABD	32.9	53.3	76.7	**83.1**	**90.9**			
TABM	29.2	**40.8**	**58.1**	114.4	213.0			
TABS	45.5	97.9	165.5	239.3	313.5			
Forecasts	9	7	5	3	1			

Table 4a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) intensity forecast errors (kt) for Tropical Storm Karl, 11–14 October 2022. 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	**4.5**	**5.6**	**5.0**	**3.0**	**0.0**	**10.0**		
OCD5	7.3	11.9	20.3	25.4	23.7	28.0		
Forecasts	11	9	7	5	3	1		
OFCL (2017-21)	5.4	8.0	9.5	10.9	11.0	12.1	13.1	14.7
OCD5 (2017-21)	7.0	11.1	14.5	17.1	18.0	20.2	21.9	22.1

Table 4b. Homogeneous comparison of selected intensity forecast guidance models (in kt) for Tropical Storm Karl, 11–14 October 2022. 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	60	72	96	120
OFCL	4.5	5.6	5.8	3.8	0.0			
OCD5	7.0	12.8	21.0	25.8	19.0			
HWFI	**3.6**	5.6	6.5	4.0	10.0			
HMNI	5.1	6.1	**5.2**	**1.2**	5.0			
CTCI	6.3	7.8	**5.5**	**3.5**	7.0			
DSHP	5.1	6.5	8.2	8.5	0.0			
LGEM	5.5	7.2	8.2	6.8	4.0			
ICON	**4.0**	**4.9**	**5.7**	4.8	5.0			
IVCN	**4.4**	**5.4**	**5.5**	4.5	2.0			
IVDR	**4.2**	**5.0**	**4.8**	3.8	3.0			
HCCA	**4.3**	**4.8**	**5.3**	5.2	0.0			
FSSE	**4.0**	**4.4**	**5.0**	4.2	5.0			
GFSI	4.6	6.2	6.2	6.0	7.0			
EMXI	5.4	7.8	7.2	5.5	4.0			
Forecasts	10	8	6	4	1			

Table 5. Watch and warning summary for Tropical Storm Karl, 11–14 October 2022.

Date/Time (UTC)	Action	Location
11 / 2100	Tropical Storm Watch issued	Cabo Rojo to Puerto Veracruz
12 / 0300	Tropical Storm Watch extended	Puerto Veracruz to Roca Partida
12 / 1500	Tropical Storm Watch extended	Roca Partida to Frontera
12 / 1500	Tropical Storm Watch discontinued	North of Tuxpan to Cabo Rojo
13 / 1500	Tropical Storm Warning issued	Alvarado to Ciudad del Carmen
13 / 1500	Tropical Storm Watch discontinued	North of Alvarado to Tuxpan
14 / 0300	Tropical Storm Warning extended	Ciudad del Carmen to Sabancuy
14 / 1500	Tropical Storm Warning discontinued	West of Coatzacoalcos to Alvarado
15 / 0300	Tropical Storm Warning discontinued	All

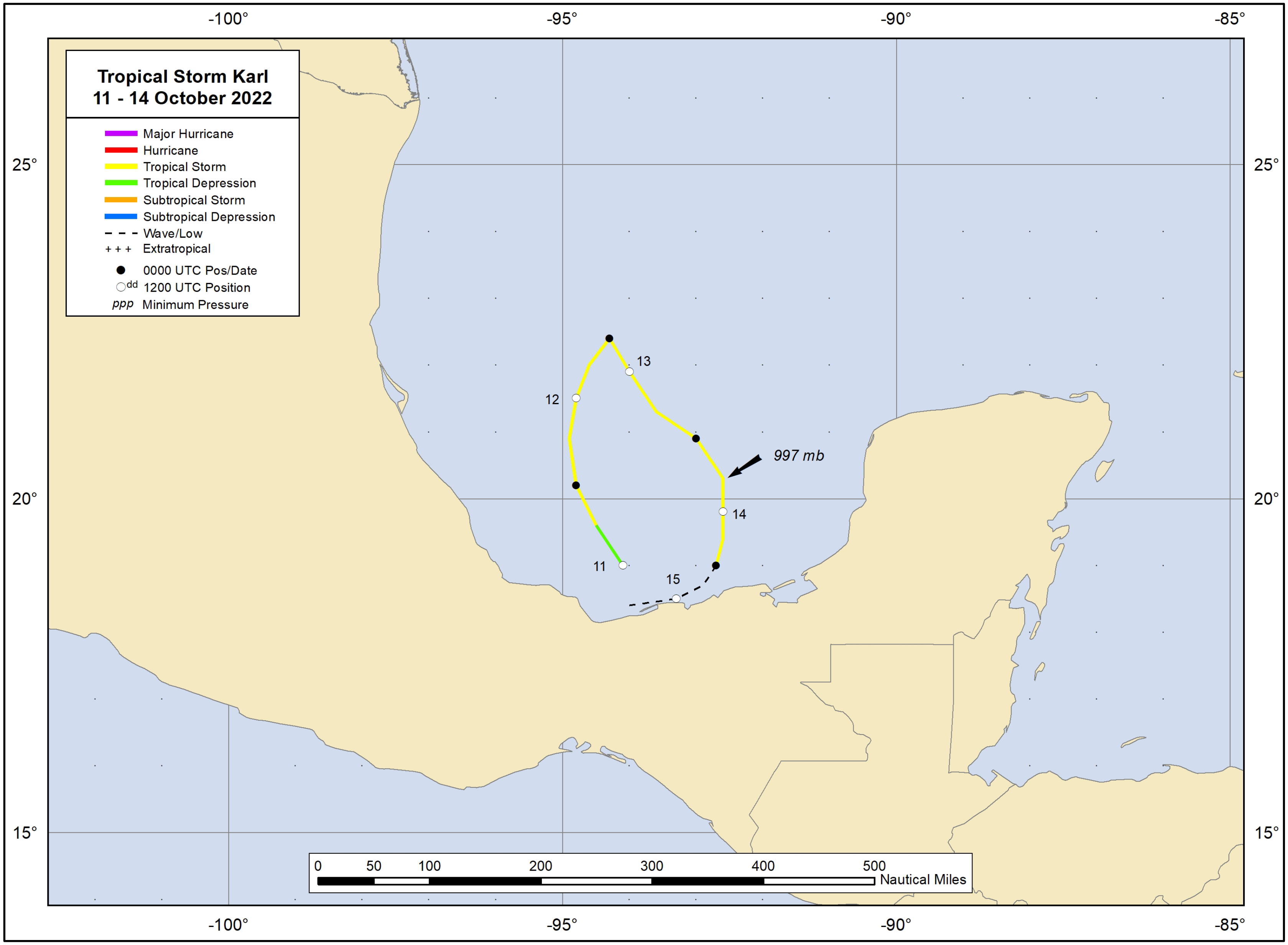

Figure 1. Best track positions for Tropical Storm Karl, 11–14 October 2022.

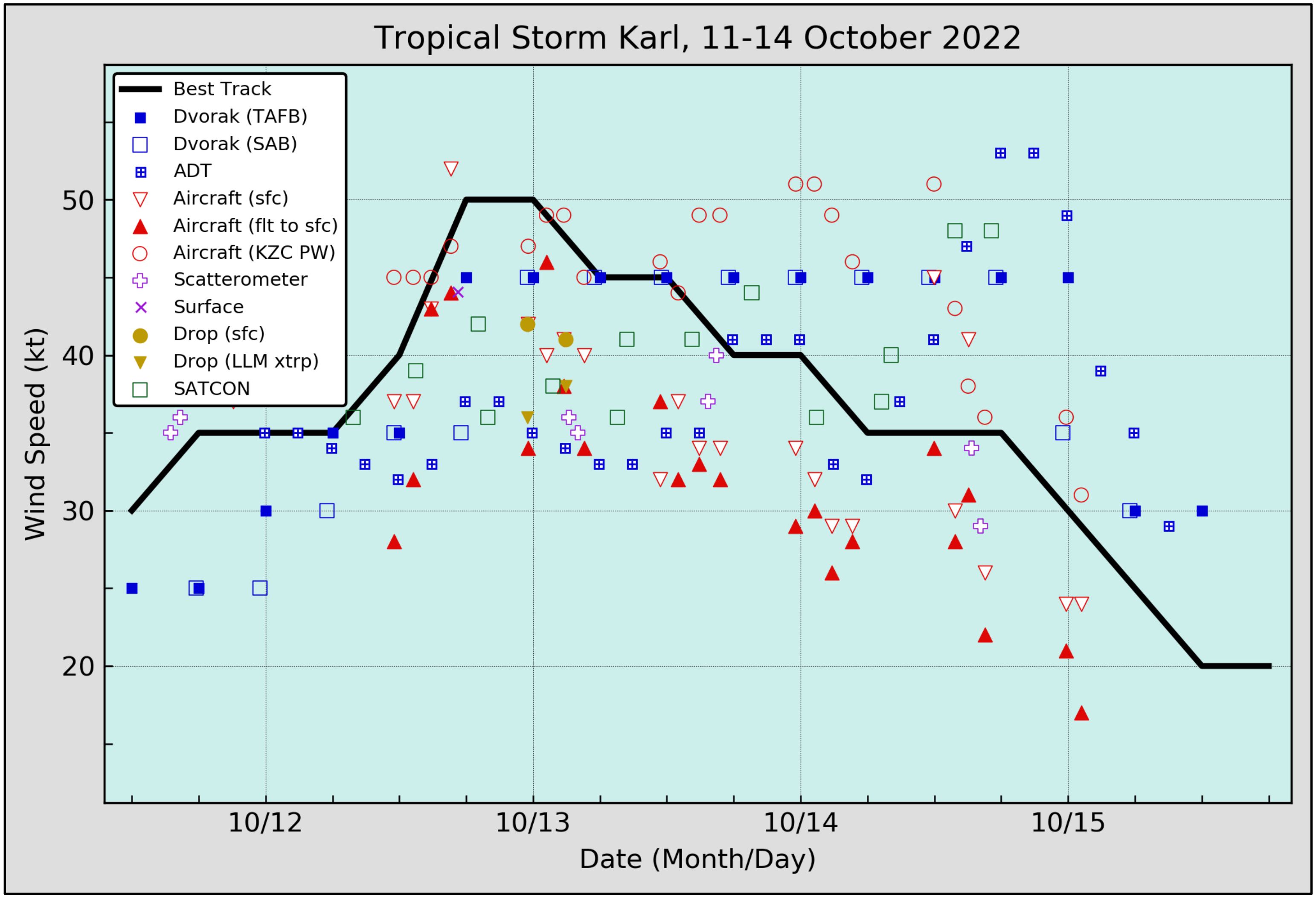

Figure 2. Selected wind observations and best track maximum sustained surface wind speed curve for Tropical Storm Karl, 11–14 October 2022. Aircraft observations have been adjusted for elevation using 80% and 75% adjustment factors for observations from 850 mb and 925 mb, respectively. Dropwindsonde 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.

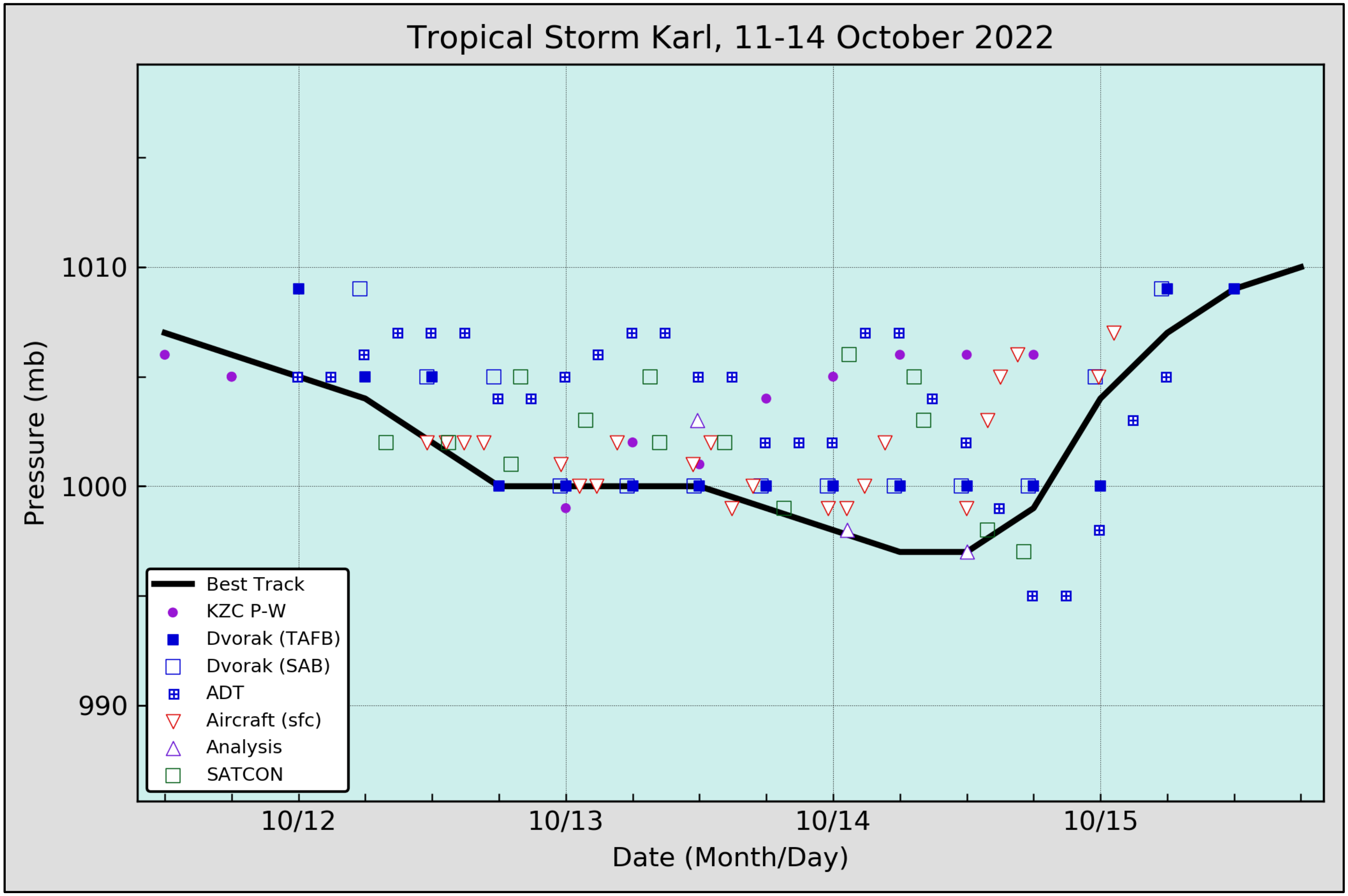

Figure 3. Selected pressure observations and best track minimum central pressure curve for Tropical Storm Karl, 11–14 October 2022. Advanced Dvorak Technique estimates represent the Current Intensity at the nominal observation time. SATCON intensity estimates are from the Cooperative Institute for Meteorological 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.

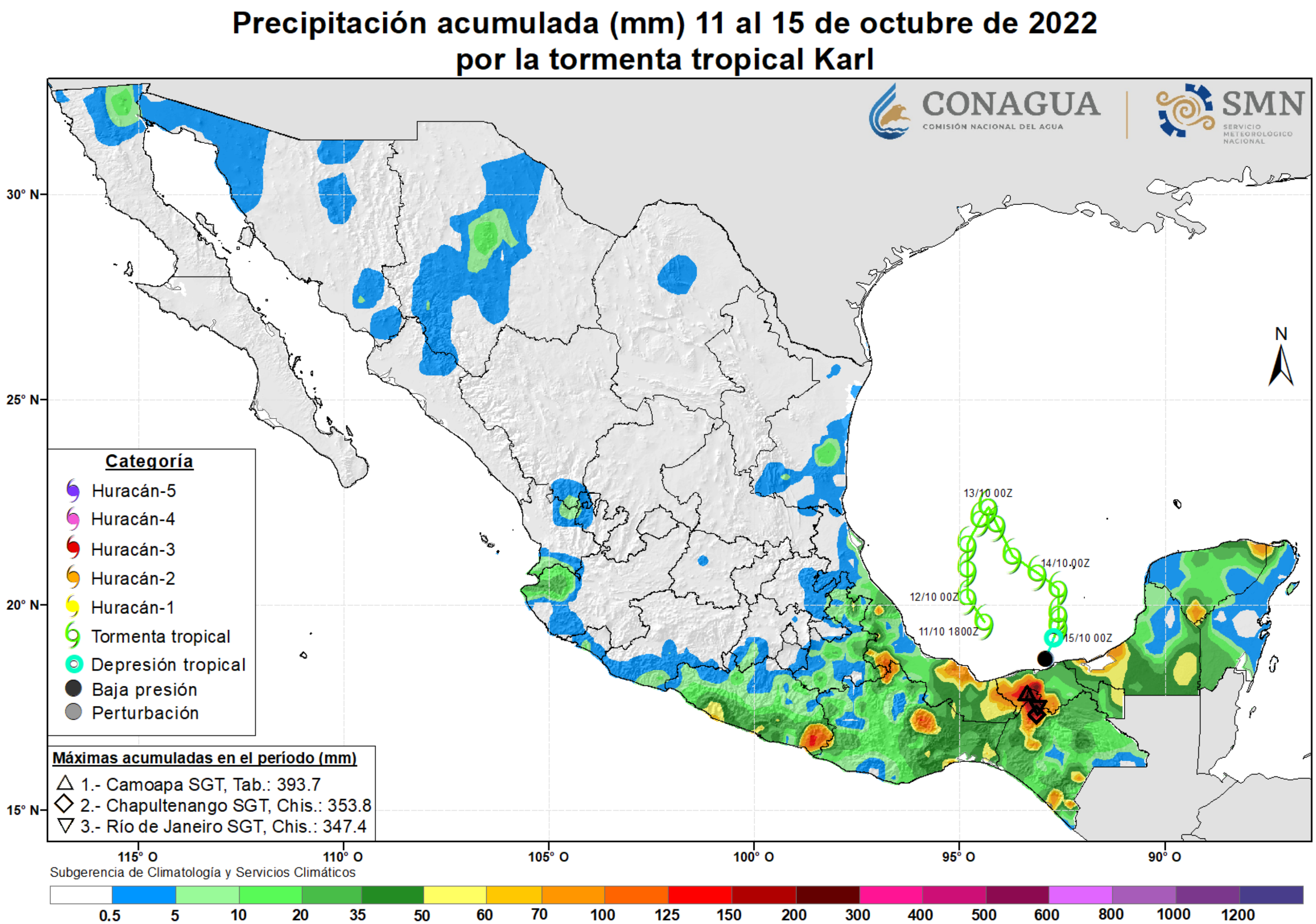

Figure 4. Rainfall totals (mm) in Mexico from 11 to 15 October 2022, the period encompassing Tropical Storm Karl's impacts in southern Mexico. Image courtesy of Mexico's Servicio Meteorológico Nacional.

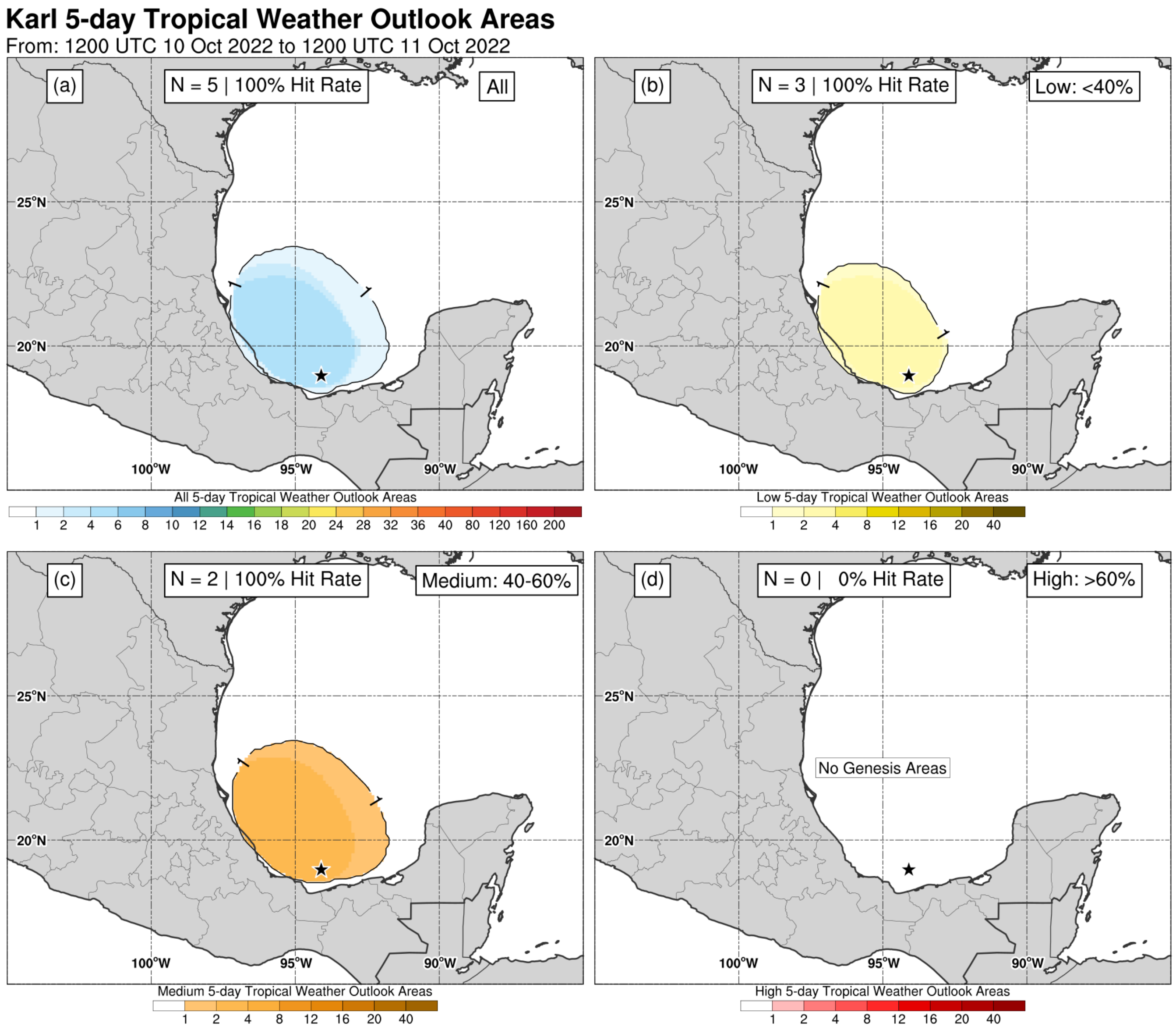

Figure 5. Composites of 5-day tropical cyclone genesis areas depicted in NHC's Tropical Weather Outlooks prior to the formation of Tropical Storm Karl for (a) all probabilistic genesis categories, (b) the low (<40%) category, (c) medium (40–60%) category, and (d) high (>60%) category. Karl's location of genesis is indicated by the black star.

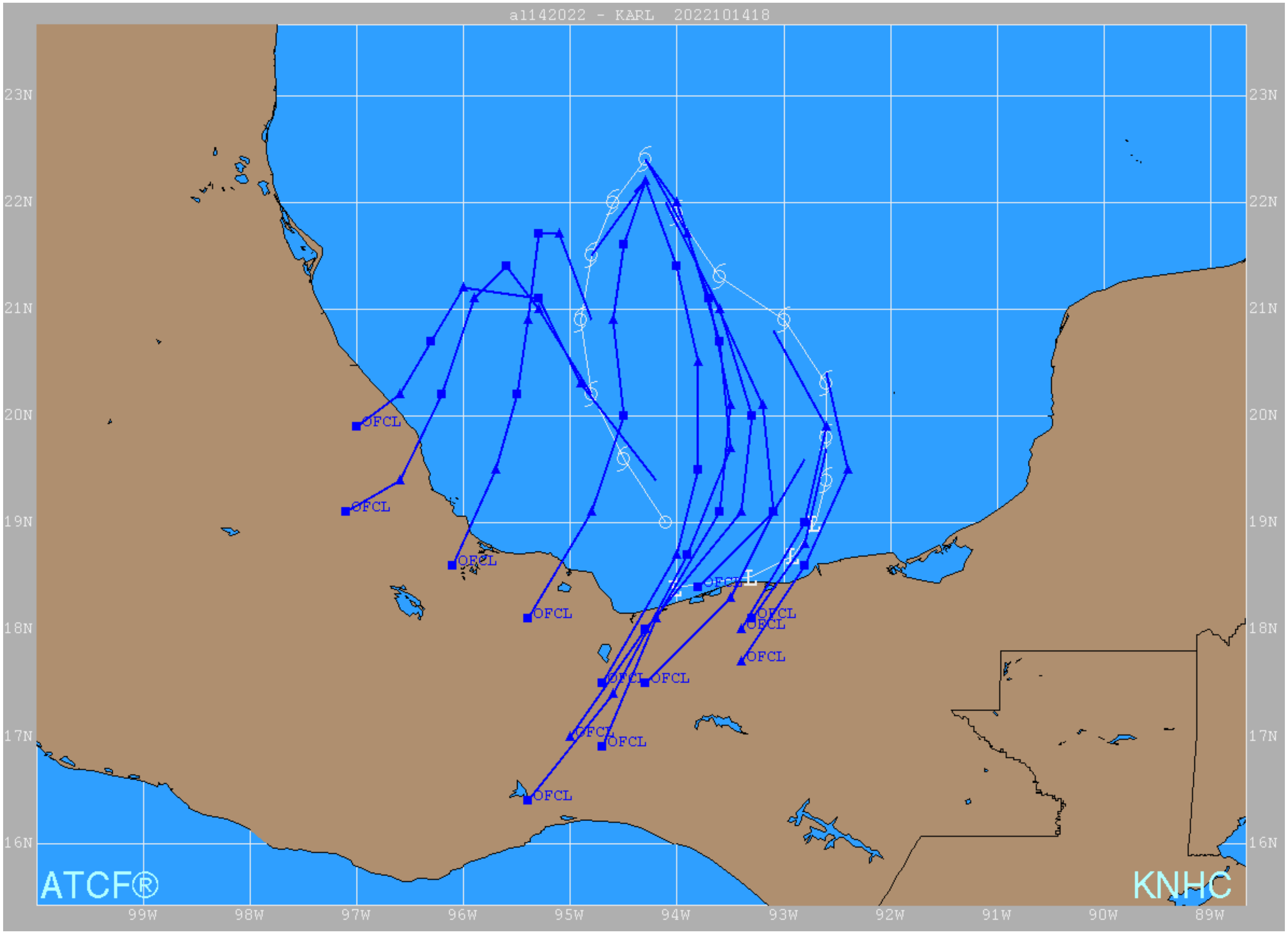

Figure 6. NHC official track forecasts for Tropical Storm Karl issued from 1800 UTC 11 October through 1800 UTC 14 October (dark blue lines) and Karl's best track (white line).

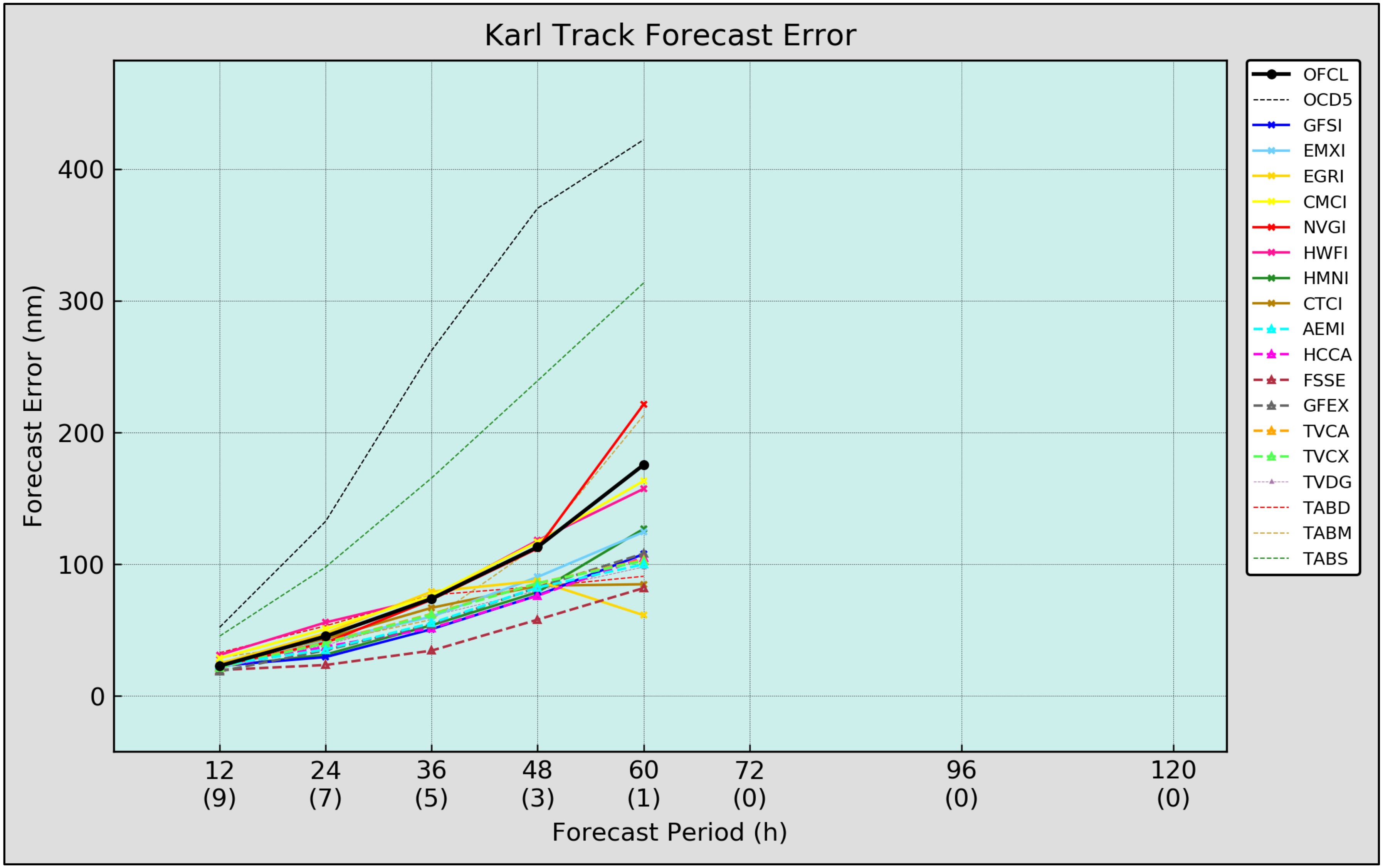

Figure 7. Homogeneous comparison of selected track forecast guidance model errors (in n mi) for Tropical Storm Karl, 11–14 October 2022. Official NHC track errors are denoted by the thick black line.

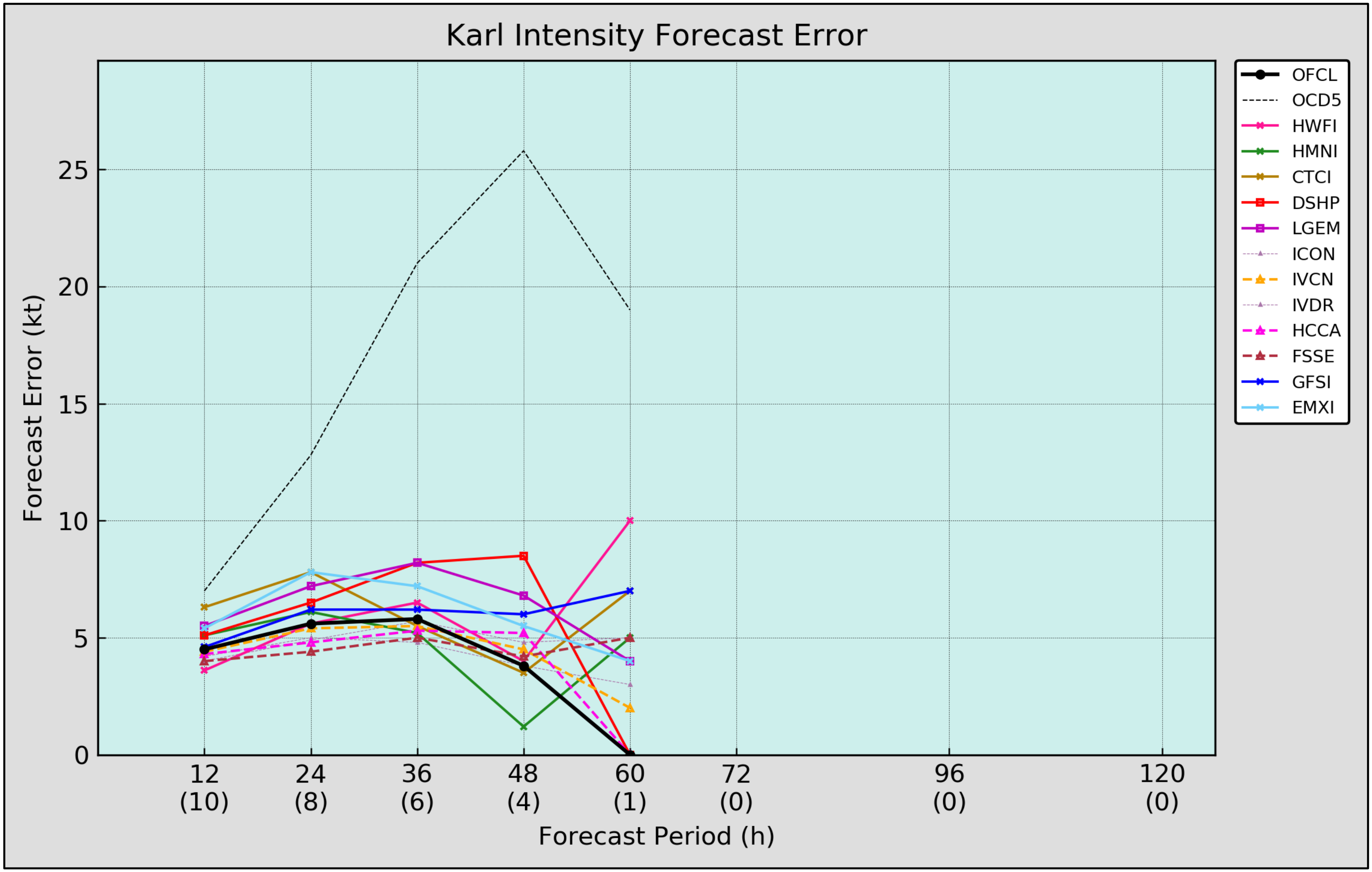

Figure 8. Homogeneous comparison of selected intensity forecast guidance model errors (in kt) for Tropical Storm Karl, 11–14 October 2022. Official NHC intensity errors are denoted by the thick black line.