NATIONAL HURRICANE CENTER TROPICAL CYCLONE REPORT[1]

HURRICANE CALVIN

(EP032023)

11–19 July 2023

Philippe P. Papin
National Hurricane Center
Jeff Powell
Central Pacific Hurricane Center
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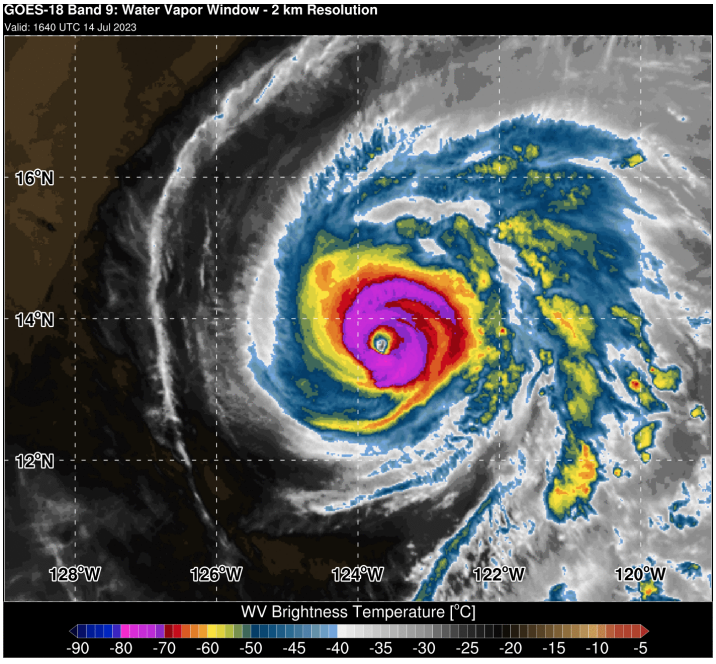

GOES-18 WATER VAPOR IMAGE AT 1640 UTC 14 JULY 2023, SHOWING HURRICANE CALVIN NEAR ITS PEAK INTENSITY. DATA USED TO CREATE THIS SATELLITE IMAGE COURTESY OF THE NOAA BIG DATA PROJECT

Calvin was a category 3 hurricane (on the Saffir-Simpson Hurricane Wind Scale) that originated in the eastern Pacific and crossed into the central Pacific basin as a tropical storm. Calvin passed about 60 n mi south of the Big Island of Hawaii as a weakening tropical storm before transitioning to a post tropical remnant low.

[1] Original report released 28 February 2024. Updated 11 June 2024 to include best track analysis, map, summary, and verification from the Central Pacific Hurricane Center.

Hurricane Calvin

11–19 JULY 2023

SYNOPTIC HISTORY

Calvin's origins appear to be related to a convectively active monsoon trough in the eastern Pacific basin that was also assisted by a low-latitude tropical wave that slowly crossed Central America between 4–6 July. While the northern portion of this wave axis moved into the Gulf of Mexico, the southern part of this wave axis interacted with the monsoon trough between 6–8 July, producing a large area of showers and thunderstorms in the eastern Pacific to the south of Central America. This convective activity was also enhanced by an eastward-propagating convectively coupled Kelvin Wave (Fig. 1) that was moving through the region during this time. The system slowly became better organized, with scatterometer data indicating a well-defined center had formed along the area of low pressure by 0600 UTC 10 July. It took an additional day and one more large convective burst persisting into the early morning hours of 11 July for the system to be designated as a tropical cyclone. Earlier scatterometer imagery indicated the system was already producing winds of at least 35 kt, so Tropical Storm Calvin formed by 0600 UTC 11 July about 390 n mi to the south-southwest of Zihuatanejo, Mexico. The "best track" chart of Calvin'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[2].

At genesis, Calvin was already embedded in an environment of low vertical wind shear, warm sea-surface temperatures, and ample deep-layer moisture, but it took another day or so for the system to develop an inner core that would take advantage of the favorable conditions. Calvin was initially steered westward by a well-established deep-layer subtropical ridge to its north over northwestern Mexico, and a portion of this ridge migrated westward, maintaining the tropical cyclone's westward motion over the first few days of its life. The system began to intensify on 12 July as a prominent curved band wrapped around the southern semicircle of the tropical cyclone (Fig. 5a). Calvin became a hurricane the following day at 1200 UTC 13 July as it began rapidly intensifying, culminating in the hurricane reaching its peak intensity as a 110-kt (Category 3) hurricane by 1800 UTC 14 July, while located about 970 n mi to the west-southwest of the southern tip of the Baja California Peninsula. At peak intensity, the major hurricane had a small but well-organized inner core, as evident on both geostationary satellite (cover photo) and microwave imagery (Fig. 5b). Calvin's motion had also started to bend more west-northwestward as it moved farther along the west-southwestern periphery of the well-established mid-level ridge now centered over California.

Calvin's peak intensity was short-lived. The hurricane began to move over cooler ocean waters, while also entraining some dry air that disrupted the small inner core (Fig. 5c). After a

[2] 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.

brief recovery in Calvin's structure on 15 July (Fig. 5d), continued cooling sea-surface temperatures and an increase in westerly vertical wind shear caused the cyclone to resume weakening. Calvin dropped below hurricane intensity at 1200 UTC 16 July, with it weakening down to 45 kt as the tropical storm crossed into the central Pacific basin shortly before 1200 UTC 17 July. As the cyclone became less vertically deep, its motion gradually turned more westward with some acceleration as it became steered primarily by the low-level trade wind flow.

The Central Pacific Hurricane Center (CPHC) began issuing advisories on Calvin at 1500 UTC 17 July. Calvin's entire track within the central Pacific basin was generally westward along the southern flank of a subtropical ridge located to the north and northeast of the storm. At basin crossing, Calvin appeared as little more than a low cloud swirl, with little or no deep convection. However, by 0000 UTC July 18, deep convection began to flare along this system's northern semicircle, persisting long enough to prompt slight strengthening at 0000 UTC July 19. Sea surface temperatures of 24° C along the cyclone's track near 140°W warmed to about 26° C near the main Hawaiian Islands, possibly accounting for the slight intensity increase to 50 kt just west of 150°W. However, southerly wind shear also increased between 17–19 July, counteracting the benefits of the slightly warmer SSTs. Calvin was already weakening again as it reached the point of closest approach, about 60 n mi south of the Big Island, shortly after 0600 UTC July 19, with spin down and transition to a post-tropical/remnant low complete by 1800 UTC that day. The remnant low dissipated shortly thereafter.

METEOROLOGICAL STATISTICS

Observations in Calvin (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), the Central Pacific Hurricane Center (PHFO), and the Joint Typhoon Warning Center (JTWC), as well as 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 four 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 Calvin.

Selected surface observations from land stations and data buoys are given in Table 2. There were no ship reports of tropical-storm-force winds in Calvin.

Winds and Pressure

Calvin's peak intensity of 110 kt at 1800 UTC 14 July is based on a blend of subjective and objective satellite intensity data. Subjective intensity estimates from TAFB and SAB were both T6.0/115 kt, but ADT peaked at a lower T5.8/110 kt. SATCON, which blends ADT data with

other microwave sounder estimates, peaked at 108 kt at 2040 UTC 14 July, after the structure on satellite imagery had started to decay.

The estimated minimum pressure of 953 mb is based on the Knaff-Zehr-Courtney pressure-wind relationship, though it is worth noting that the pressure estimates made by the subjective Dvorak estimates were a few millibars lower.

In the Hawaiian Islands, sustained 34-kt winds were briefly observed on land at Bradshaw Army Air Field, located at high elevation along the western slopes of Mauna Kea on the Big Island, as Calvin passed about 60 n mi south of that island. However, this location was noticeably outside the forecast tropical-storm-force wind radius. This wind observation from Bradshaw has been attributed to local channeling effects associated with terrain rather than directly from the tropical cyclone wind field. Lower elevation stations closer to the tropical storm reported lower sustained wind speeds.

Rainfall and Flooding

As Calvin's center moved to the south of the Big Island of Hawaii, heavy rainfall moved over the island on 18–19 July, producing rainfall totals of 4–8 inches.

CASUALTY AND DAMAGE STATISTICS

There were no reports of damage or casualties associated with Calvin. However, periods of heavy rainfall caused flooding across much of the main Hawaiian Island chain on 18–19 July. In particular, heavy rainfall forced brief road closures on the Big Island of Hawaii during the morning and early afternoon of 19 July.

FORECAST AND WARNING CRITIQUE

The genesis of Calvin was well anticipated with more than 5 days of lead time in the 7-day outlook (Table 3). The feature from which Calvin developed was introduced in the low category (< 40%) in the Tropical Weather Outlook 138 h prior to genesis. The probabilities were increased to the medium (40–60%) category 114 h and then high (>60%) 90 h before the system developed. In the 2-day probabilities, a low chance was also introduced 90 h before Calvin formed, though there was more uncertainty on the precise timing of development. The disturbance was given medium and high changes of forming only 24 h and 6 h before genesis, respectively. The location of Calvin's genesis was also well forecast (Fig. 6), with every 7-day area capturing Calvin's correct location of genesis.

A verification of NHC official track forecasts (OFCL) for Calvin is given in Table 4a. Official track forecast errors were lower than the mean official errors for the previous 5-yr period at all forecast times, likely related to the well-established steering flow pattern during the majority of Calvin's lifespan. A homogeneous comparison of the official track errors with selected guidance models is given in Table 4b. OFCL outperformed the vast majority of the deterministic guidance,

though several of the simple and corrected consensus aids did better at differing forecast lead times. HCCA performed a little better than OFCL at shorter forecast lead times from 12–24 h and 48–60 h, while TVCE performed better at longer lead times between 60–120 h, though most of these track improvements were only 6 n mi or less compared to OFCL.

A verification of NHC official intensity forecasts (OFCL) for Calvin is given in Table 5a. Official intensity forecast errors were lower than the mean official errors for the previous 5-yr period for all forecast lead times after 12 h. A homogeneous comparison of the official intensity errors with selected guidance models is given in Table 5b. Once again, OFCL outperformed most of the deterministic guidance for all forecast lead times except 120 h, a feat made more impressive given the period of rapid intensification Calvin underwent between 13–14 July. The only guidance aid that consistently outperformed OFCL (albeit barely) was HCCA, which had 1-kt or lower intensity errors compared to OFCL from 12–60 h.

A verification of CPHC official track forecasts for Calvin is given in Table 6a. A homogenous comparison of the CPHC track errors with selected guidance models is given in Table 6b. CPHC track error was less than the five-year average only at 12 hours. CPHC performance was better than the NVGI global and/or regional dynamic model but was only on par with GFEX. CPHC was outperformed by CMCI and EMXI. CPHC performed better than trajectory models like TABD, TABM, and TABS. Ensemble and consensus models like HCCA and TVCE performed well against CPHC, with FSSE and EGRI performing best.

A verification of CPHC official intensity forecasts for Calvin is given in Table 7a. A homogeneous comparison of the CPHC intensity errors with selected guidance models is given in Table 7b. CPHC intensity error for this system was smaller than the five-year average at all forecast times. CPHC performed better than CMCI, LGEM, ICON, and DSHP while performing poorly against IVDR and FSSE.

Coastal watches and warnings issued by CPHC in association with Calvin are given in Table 8. Calvin moved toward the west quite rapidly, presenting a challenge to forecasters as it posed a near-term threat to the main Hawaiian Islands as a tropical storm immediately after crossing into the basin. A Tropical Storm Watch was issued for the Big Island of Hawaii with the first full forecast package from the CPHC at 1500 UTC 17 July, followed by a Tropical Storm Warning for that island 12 hours later (see Table 6). The center of Calvin passed just south of the main Hawaiian Island chain, or about 60 n mi south of the Big Island, as a 40-kt tropical storm shortly after 1200 UTC 19 July along a steady west track. By then, Calvin was nearing the end of its life cycle. Deep convection collapsed and organization became sufficiently ill-defined and Calvin became a post-tropical cyclone in the best track by 1800 UTC.

ACKNOWLEDGEMENTS

Data in Table 2 were compiled from Post Tropical Cyclone Reports and Public Information Statements issued by the Honolulu NWS Forecast Office.

Table 1. Best track for Hurricane Calvin, 11–19 July 2023.

Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Stage
10 / 0600	10.4	98.0	1009	20	low
10 / 1200	10.5	99.4	1008	25	"
10 / 1800	10.7	101.0	1008	30	"
11 / 0000	11.2	102.5	1008	30	"
11 / 0600	11.7	104.2	1006	35	tropical storm
11 / 1200	12.1	105.8	1006	35	"
11 / 1800	12.3	107.2	1006	35	"
12 / 0000	12.4	108.5	1005	35	"
12 / 0600	12.4	109.8	1004	40	"
12 / 1200	12.4	111.3	1002	45	"
12 / 1800	12.4	112.8	998	55	"
13 / 0000	12.4	114.3	995	60	"
13 / 0600	12.3	115.4	995	60	"
13 / 1200	12.5	116.6	993	65	hurricane
13 / 1800	12.7	118.0	990	70	"
14 / 0000	13.0	119.7	976	85	"
14 / 0600	13.1	121.3	966	95	"
14 / 1200	13.4	122.6	959	105	"
14 / 1800	13.7	123.9	953	110	"
15 / 0000	14.0	125.3	962	100	"
15 / 0600	14.4	126.7	969	90	"
15 / 1200	14.6	128.2	971	90	"
15 / 1800	14.9	129.7	973	90	"
16 / 0000	15.2	131.2	977	80	"
16 / 0600	15.5	132.6	982	75	"
16 / 1200	15.7	134.0	990	65	"
16 / 1800	16.0	135.6	993	60	tropical storm
17 / 0000	16.4	137.2	995	55	"

Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Stage
17 / 0600	16.6	138.8	998	50	"
17 / 1200	16.7	140.5	1000	45	"
17 / 1800	17.0	142.4	1000	45	"
18 / 0000	17.2	144.4	1002	40	"
18 / 0600	17.3	146.5	1002	40	"
18 / 1200	17.4	148.5	1002	40	"
18 / 1800	17.6	150.4	1002	45	"
19 / 0000	17.8	152.3	1000	50	"
19 / 0600	17.7	154.3	1000	45	"
19 / 1200	17.7	155.9	1003	40	"
19 / 1800	17.9	157.7	1005	35	low
20 / 0000					dissipated
14 / 1800	13.7	123.9	953	110	maximum wind and minimum pressure

Table 2. Selected surface observations for Hurricane Calvin, 11–19 July 2023. This information will be updated once the Central Pacific Hurricane Center completes its post-analysis.

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)				
Hawaii									
International Civil Aviation Organization (ICAO) Sites									
Bradshaw Army Air Field (PHSF) (19.78°N 155.55°W)			19/1353	34	39				
Kahului Airport (PHOG) (20.89°N 156.44°W)	19/1341	997.0	18/1813	19	35				
Hilo International Airport (KHTO) (19.72°N 155.06°W)	19/1353	998.0	19/1510	14	22				
Keahole Airport Kona (KHKO) (19.74°N 156.05°W)	19/1253	989.0	18/1813	21	28				
Lanai City Airport (PHSF) (20.79°N 156.95°W)	19/1349	998.0	18/2156	27	35				
Honolulu International Airport (PHNL) (21.33°N 157.94°W)	19/0253	997.0	19/0953	24	31				
Lahiani West Maui (PHJH) (20.96°N 156.67°W)	19/1254	993.0	19/2154	27	36				
Molokai Airport Kaunakakai (PHMK) (21.15°N 157.10°W)	19/0354	995.0	19/0454	22	36				
Kamuela/Waimea (PHMU) (20.00°N 155.67°W)			19/1059	31	41				
Hydrometeorological Automated Data System (HADS) Sites (NWS)									
Kulani NWR (KNWH1) (19.55°N 155.31°W)									6.63
Laupohoehoe (LPHH1) (19.99°N 155.24°W)									6.16
Waiakea Uka (WKAH1) (19.66°N 155.13°W)									5.92
Papaikou Well (PPWH1) (19.79°N 155.13°W)									5.81
Mountain View (MTVH1) (19.55°N 155.11°W)									5.29
Glennwood (GLNH1) (19.51°N 155.17°W)									5.00
Remote Automated Weather Stations (RAWS)									
Kealakomo #2 (KMOH1) (19.29°N, 155.11°W)			18/2144	30	50				
Waikoloa (WKVH1) (19.92°N 155.79°W)			18/2035	26	47				

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)				
Kohala Ranch (KHRH1) (20.09°N 155.83°W)			18/2135	24	43				
Puu Mali (PMLH1) (19.92°N 155.42°W)			19/0800	23	44				
Lanai 1 (LHIH1) (20.87°N 157.01°W)			18/2337	29	42				
Hakalau (HKUH1) (19.55°N 155.33°W)									7.02
Nene Cabin (NENH1) (19.26°N 155.61°W)									5.18
US Geological Survey (USGS)									
Honolii Stream (NLIH1) (19.76°N 155.15°W)									7.24
Saddle Quarry (SDQH1) (19.69°N 155.29°W)									7.12
Kawainui Stream (KWSH1) (20.09°N 155.68°W)									5.87
West Wailuaiki (WWKH1) (20.81°N 156.14°W)									5.46
Puu Kukui (PKKH1) (20.89°N 156.59°W)									4.35
Offshore									
NOAA Buoys									
Southeast Hawaii (51004) (17.54°N 152.23°W)	19/0200	1005.4	18/2350	28	33				
Western Hawaii (51003) (19.29°N 160.57°W)	20/0300	1012.6	20/0600	25	33				

[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; buoy averaging periods are 8 min.

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	**168-Hour Outlook**
Low (<40%)	90	138
Medium (40%-60%)	24	114
High (>60%)	6	90

Table 4a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) track forecast errors (n mi) for Calvin in the eastern Pacific. 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	**16.2**	**20.8**	**24.8**	**28.1**	**37.6**	**45.6**	**63.4**	**70.8**
OCD5	28.4	54.6	90.3	131.7	174.3	212.2	305.3	409.0
Forecasts	23	23	23	23	22	20	16	12
OFCL (2018-22)	22.1	34.0	45.4	56.0	70.9	78.7	100.5	117.8
OCD5 (2018-22)	36.7	73.4	114.0	156.9	193.2	244.5	317.0	376.0

Table 4b. Homogeneous comparison of selected track forecast guidance models (in n mi) for Calvin in the eastern Pacific. Errors smaller than the NHC official forecast are shown in boldface type.

Model ID	Forecast Period (h)							
	12	24	36	48	60	72	96	120
OFCL	16.2	20.8	24.8	28.1	37.6	45.6	63.4	70.8
OCD5	28.4	54.6	90.3	131.7	174.3	212.2	305.3	409.0
GFSI	**15.1**	24.8	33.6	46.2	61.1	72.3	97.6	118.7
EMXI	**15.7**	22.7	26.8	32.4	43.4	58.4	81.7	86.5
CMCI	20.7	30.3	35.5	42.4	53.1	62.6	85.1	95.1
NVGI	28.8	43.2	50.9	62.9	87.7	114.1	163.4	201.9
HFAI	18.2	24.6	31.5	37.1	43.0	48.9	71.7	88.6
HFBI	17.5	25.9	30.1	38.6	51.1	64.1	96.9	121.1
HWFI	19.5	28.2	31.5	38.1	46.7	57.4	77.3	88.1
HMNI	**15.9**	25.7	33.3	42.0	49.9	57.4	**62.9**	89.8
CTCI	19.4	29.7	37.1	46.1	53.3	61.2	72.3	88.5
HCCA	**15.6**	**20.1**	24.9	**27.6**	**35.6**	49.4	82.4	118.7
TVCE	**14.5**	21.7	**24.7**	28.7	**35.3**	**41.5**	**58.0**	**66.7**
TVDG	**14.6**	21.4	24.8	28.3	**33.3**	**40.0**	**58.5**	**66.0**
TVCX	**14.8**	20.9	**24.5**	28.6	**34.7**	**40.9**	**56.6**	**67.0**
AEMI	17.1	28.3	32.9	40.5	49.4	54.3	73.0	85.6
GFEX	**14.4**	**20.6**	26.3	36.7	49.5	60.6	80.6	92.1
TABS	23.8	41.3	57.5	71.2	83.8	95.1	117.9	161.6
TABM	23.2	36.9	48.9	68.8	87.2	103.5	138.1	182.5
TABD	23.3	44.5	75.9	116.0	154.3	181.0	237.1	289.5
Forecasts	23	23	23	23	22	20	16	12

Table 5a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) intensity forecast errors (kt) for Calvin in the eastern Pacific. 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	6.5	**7.8**	**7.8**	**11.1**	**11.1**	**9.0**	**6.6**	**6.2**
OCD5	9.4	12.7	14.4	18.3	19.7	18.1	17.4	12.8
Forecasts	23	23	23	23	22	20	16	12
OFCL (2018-22)	5.4	8.9	11.0	12.8	14.3	15.8	17.0	17.6
OCD5 (2018-22)	6.9	12.1	15.9	18.6	18.7	21.0	22.3	22.1

Table 5b. Homogeneous comparison of selected intensity forecast guidance models (in kt) for Calvin in the eastern Pacific. Errors smaller than the NHC official forecast are shown in boldface type.

Model ID	Forecast Period (h)							
	12	24	36	48	60	72	96	120
OFCL	6.5	7.8	7.8	11.1	11.1	9.0	6.6	6.2
OCD5	9.4	12.7	14.4	18.3	19.7	18.1	17.4	12.8
HFAI	7.3	10.9	10.6	12.3	14.0	13.7	**6.5**	**4.2**
HFBI	7.2	9.9	10.2	12.3	13.8	11.9	7.1	**6.0**
HWFI	9.9	10.6	12.0	13.4	13.4	12.6	8.8	**5.1**
HMNI	7.7	11.0	11.8	13.2	13.5	12.4	10.3	6.9
CTCI	8.8	10.5	10.8	12.3	13.6	14.3	14.6	12.8
DSHP	7.6	8.8	9.4	11.3	12.2	10.9	8.2	9.2
LGEM	8.1	9.4	11.0	13.3	13.6	11.8	8.8	**4.8**
HCCA	**6.0**	**6.1**	**6.7**	**10.1**	**10.9**	10.2	7.8	7.3
IVCN	7.2	8.5	9.4	11.7	12.0	10.5	7.1	**3.8**
ICON	7.7	8.6	9.9	11.6	11.9	10.4	7.1	**3.8**
IVDR	7.0	8.6	9.9	11.9	12.0	10.8	7.3	**5.1**
GFSI	7.0	8.8	12.0	14.3	15.0	13.1	8.8	7.7
EMXI	9.4	14.0	17.9	20.3	19.5	16.9	8.1	6.3
Forecasts	23	23	23	23	22	20	16	12

Table 6a. CPHC official (OFCL) and climatology-persistence skill baseline (OCD5) track forecast errors (n mi) for Tropical Storm Calvin, 17–19 July 2023. 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.

Model ID	Forecast Period (h)							
	12	24	36	48	60	72	96	120
OFCL	**21.1**	42.6	57.8	62.0				
Forecasts	7	5	3	1				
OFCL (2018-2022)	22.2	33.9	42.3	51.2				
OCD5 (2018-2022)	38.0	84.1	139.5	202.9				

Table 6b. Homogeneous comparison of selected track forecast guidance models (in n mi) for Tropical Storm Calvin, 17 – 19 July 2023. Errors smaller than the CPHC official forecast are shown in boldface type.

Model ID	Forecast Period (h)							
	12	24	36	48	60	72	96	120
OFCL	21.1	42.6	57.8	62.0				
TABS	22.2	36.8	59.3	87.6				
TABM	37.3	91.6	151.5	205.9				
TABD	59.2	145.3	236.1	316.8				
TVDG	**19.7**	**37.8**	58.5	**53.8**				
TVCE	**19.4**	**32.1**	**53.2**	**50.0**				
GFEX	**17.3**	**36.2**	66.3	62.0				
TVCX	**19.4**	**34.0**	**55.4**	**50.0**				
FSSE	**16.0**	**27.2**	**55.4**	**50.8**				
HCCA	**13.6**	**27.1**	**41.0**	**30.0**				
AEMI	**19.4**	**37.8**	61.5	65.4				
NVGI	29.7	50.0	75.5	103.4				
CMCI	**11.8**	**17.3**	**27.4**	67.0				
EMXI	**19.5**	**37.8**	61.6	**29.5**				
EGRI	**14.7**	**17.6**	**23.1**	**12.0**				
HWFI	21.4	**27.7**	**48.8**	75.5				
HMNI	24.9	**30.9**	**35.8**	**38.8**				
GFSI	**19.3**	**41.6**	73.0	99.2				
Forecasts	7	5	3	1	0	0	0	0

Table 7a. CPHC official (OFCL) and climatology-persistence skill baseline (OCD5) intensity forecast errors (kt) for Tropical Storm Calvin, 17–19 July 2023. 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.

Model ID	Forecast Period (h)							
	12	24	36	48	60	72	96	120
OFCL	**2.9**	**6.0**	**6.7**	**5.0**				
Forecasts	7	5	3	1				
OFCL (2018-2022)	5.6	8.3	11.0	12.5				
OCD5 (2018-2022)	7.8	12.8	17.4	21.8				

Table 7b. Homogeneous comparison of selected intensity forecast guidance models (in kt) for Tropical Storm Calvin, 17–19 July 2023. Errors smaller than the CPHC official forecast are shown in boldface type.

Model ID	Forecast Period (h)							
	12	24	36	48	60	72	96	120
OFCL	2.9	6.0	6.7	5.0				
IVDR	4.4	**4.8**	**6.0**	**3.0**				
IVCN	4.7	**5.2**	7.0	**4.0**				
ICON	5.4	8.2	11.0	8.0				
LGEM	6.6	11.6	15.7	14.0				
DSHP	6.3	9.8	12.7	12.0				
FSSE	4.9	**5.2**	**6.0**	**4.0**				
HCCA	4.9	**4.0**	**5.0**	6.0				
CMCI	5.6	8.2	11.0	7.0				
EMXI	4.0	**4.4**	6.7	**4.0**				
EGRI	4.3	6.2	8.0	5.0				
HWFI	5.0	6.8	8.0	**0.0**				
HMNI	4.4	**5.4**	8.0	6.0				
GFSI	4.9	6.6	7.7	**3.0**				
Forecasts	7	5	3	1	0	0	0	0

Table 8. Watch and warning summary for Hurricane Calvin, 11–19 July 2023.

Date/Time (UTC)	Action	Location
17/1500	Tropical Storm Watch Issued	Island of Hawaii
18/0300	Tropical Storm Watch changed to a Tropical Storm Warning	Island of Hawaii
19/2100	Tropical Storm Warning discontinued	Island of Hawaii

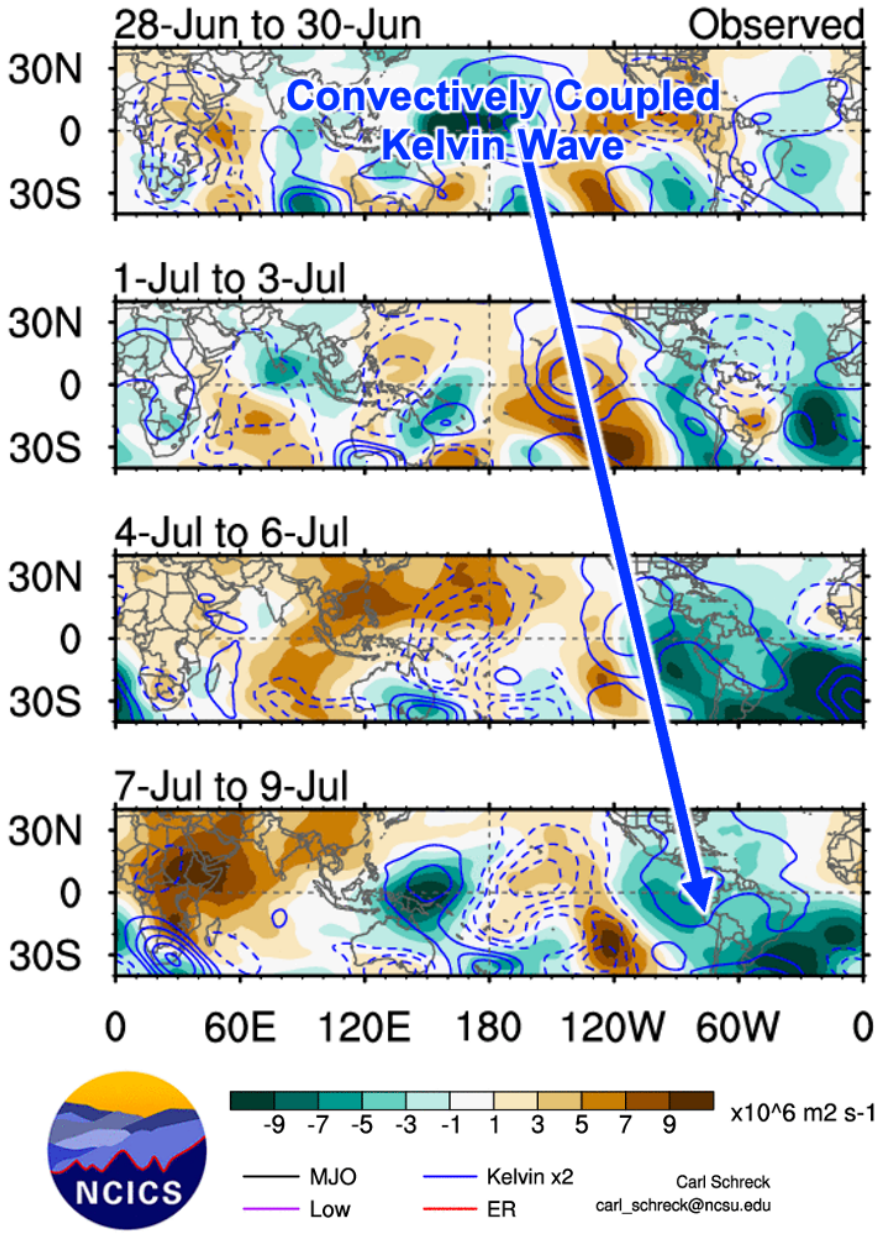

Figure 1. CFS model analysis unfiltered Velocity Potential Anomalies at 200 mb (shaded, $x10^6$ m^2 s^{-1}) over the globe covering the eastern Pacific from 28 June–9 July 2023, where green (brown) shading shows areas of upward (downward) motion favored by the upper-level velocity potential field. Blue solid (dashed) contours indicate where the velocity potential has been filtered for upward (downward) motion associated with Kelvin Waves, with annotations highlighting where a convectively coupled Kelvin Wave that moved eastward and enhanced upward vertical motion near the pre-Calvin disturbance. Image has been adapted from Carl Schreck of North Carolina Institute for Climate Studies, accessible at https://ncics.org/portfolio/monitor/mjo.

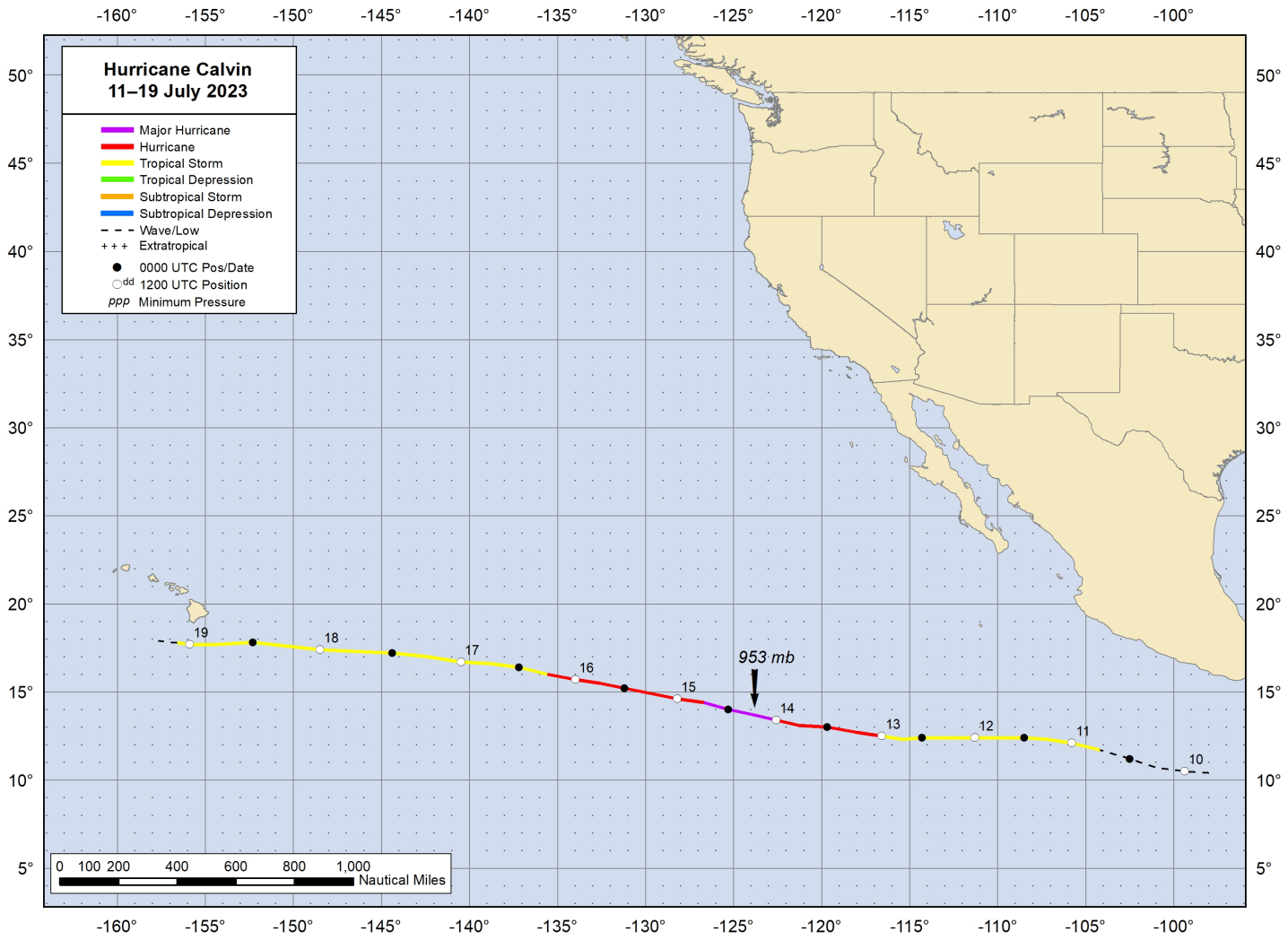

Figure 2. Best track positions for Hurricane Calvin, 11–19 July 2023.

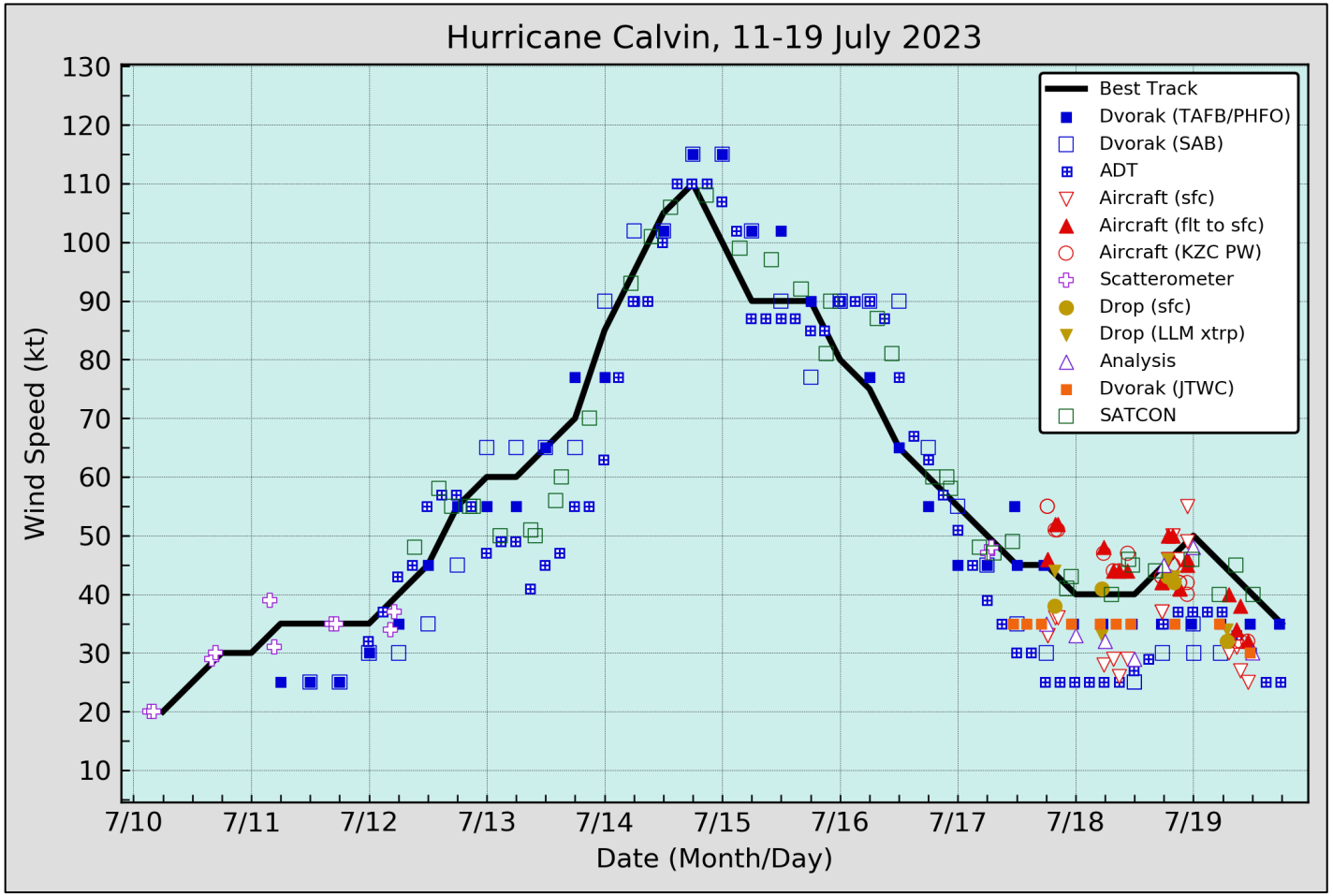

Figure 3. Selected wind observations and best track maximum sustained surface wind speed curve for Hurricane Calvin, 11–19 July 2023. Aircraft observations have been adjusted for elevation using 90%, 80%, and 75% adjustment factors for observations from 700 mb, 850 mb, and 925 mb, respectively. Dropwindsonde 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.

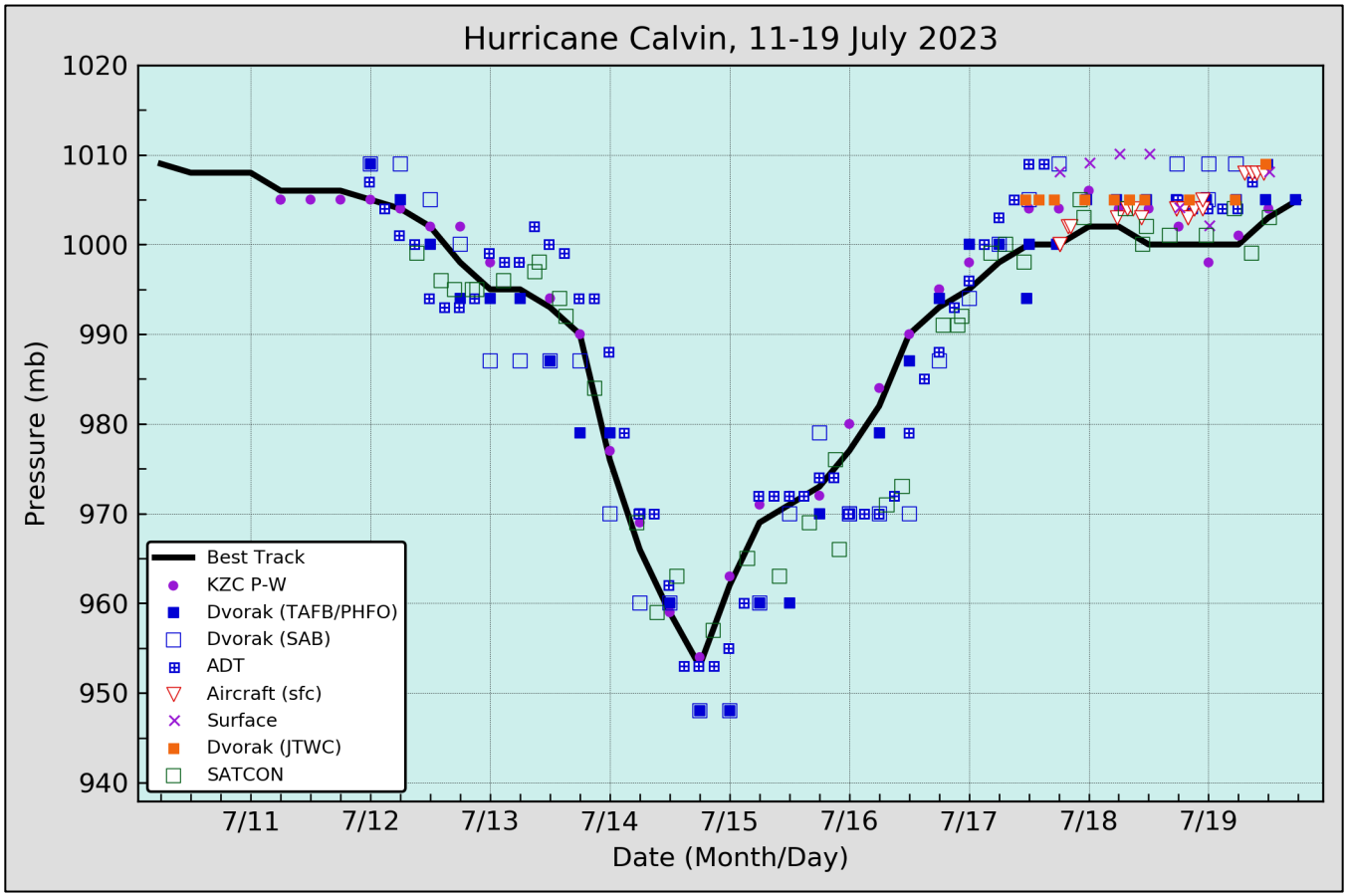

Figure 4. Selected pressure observations and best track minimum central pressure curve for Hurricane Calvin, 11–19 July 2023. Advanced Dvorak Technique estimates represent the Current Intensity at the nominal observation time. SATCON intensity estimates are from the Cooperative Institute for Meteorological 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.

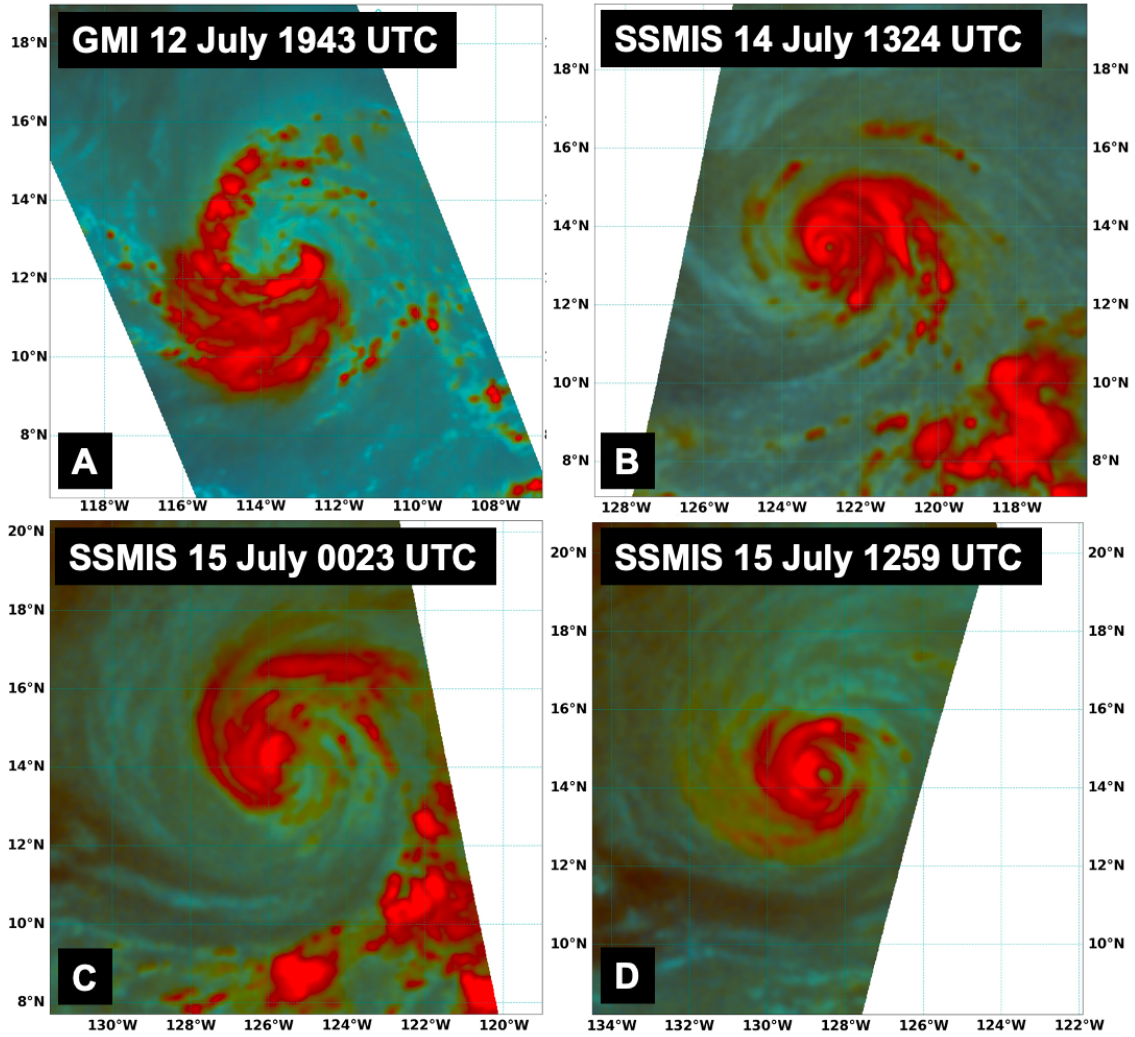

Figure 5. Passive microwave satellite 89–91-GHz color composite imagery showing Calvin's structural evolution from 12–15 July 2023. (a) 1943 UTC 12 July GMI pass showing Calvin as an intensifying tropical storm. (b) 1324 UTC SSMIS pass depicting Calvin near peak intensity with a small eye and eyewall. (c) 0023 UTC 15 July SSMIS pass showing Calvin weakening as dry air was entrained into its inner core. (d) 1259 UTC 15 July SSMIS pass showing Calvin attempting to reorganize with a nearly closed eyewall.

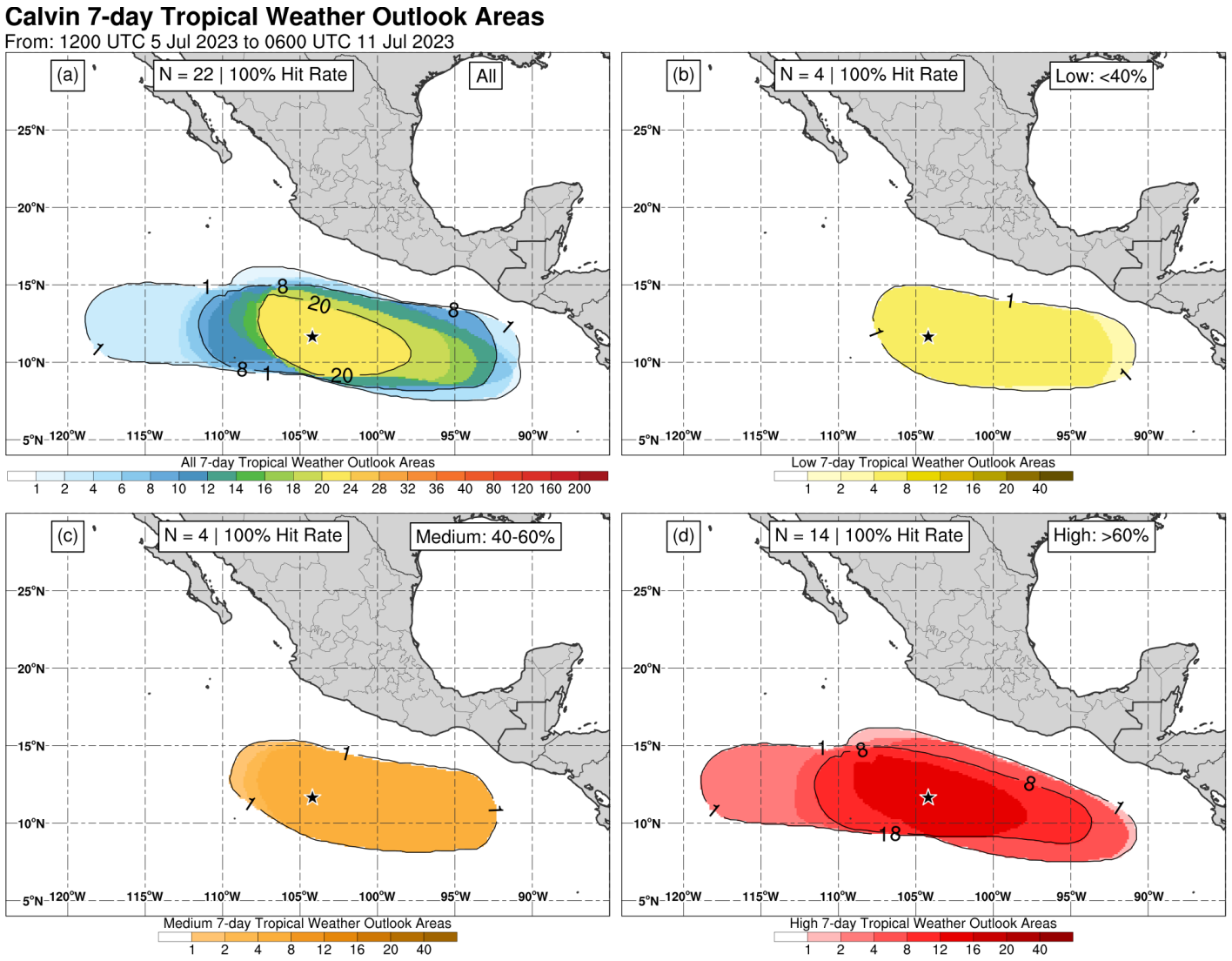

Figure 6. Composites of 7-day tropical cyclone genesis areas depicted in NHC's Tropical Weather Outlooks prior to the formation of Calvin for (a) all probabilistic genesis categories, (b) the low (<40%) category, (c) medium (40–60%) category, and (d) high (>60%) category. The location of genesis is indicated by the black star.