NATIONAL HURRICANE CENTER
TROPICAL CYCLONE REPORT

HURRICANE OLAF

(EP152021)

7–11 September 2021

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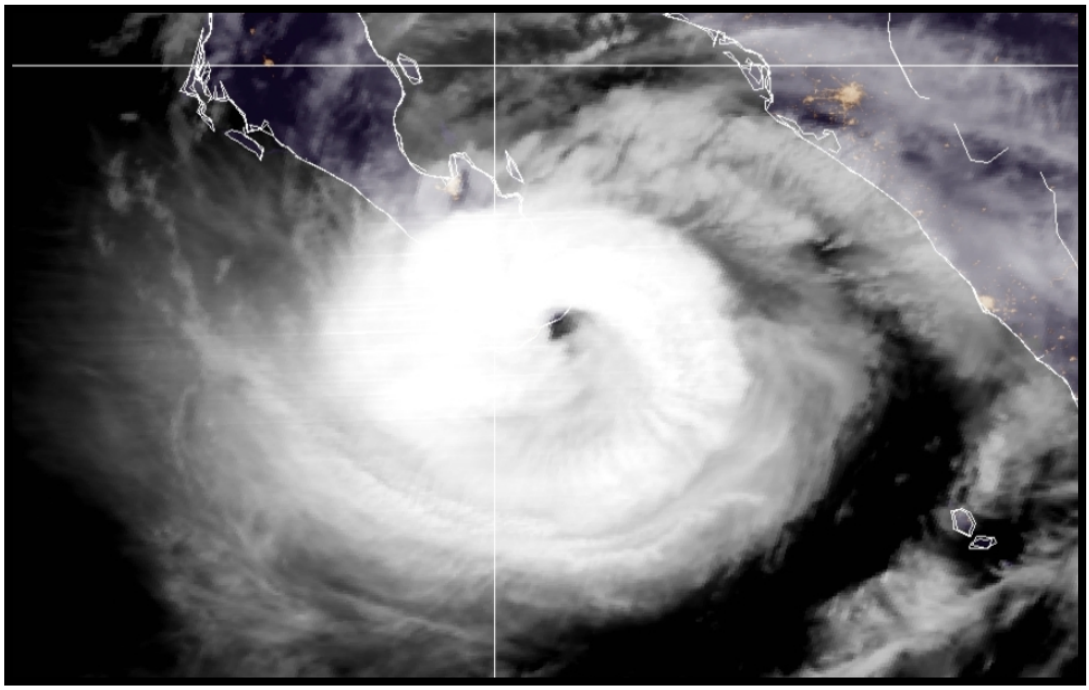


GOES-WEST GEOCOLOR IMAGE OF HURRICANE OLAF AT 0257 UTC 10 SEPTEMBER 2021 AS IT MADE LANDFALL OVER THE SOUTHERN BAJA CALIFORNIA PENINSULA OF MEXICO. IMAGE COURTESY OF NOAA/NESDIS/STAR.

Olaf was a category 2 hurricane (on the Saffir Simpson Hurricane Wind Scale) that made landfall in the southern Baja California peninsula, bringing torrential rains, strong winds, and high surf to portions of that region. The heavy rainfall resulted in one fatality in mainland Mexico.

[1] Original report dated 10 January 2022. This version adjusts the landfall pressure (and lowest pressure) in the text, Table 1, and Figures 1 and 3.

Hurricane Olaf

7–11 SEPTEMBER 2021

SYNOPTIC HISTORY

Olaf originated from a vigorous tropical wave that emerged off the west coast of Africa on 22 August. This wave was accompanied by a broad area of low pressure as it crossed the eastern and central Atlantic through 26 August. The wave fractured on 27 August, and the broad low along with the northern portion of the wave turned northwestward. This northern portion would become a tropical depression, the precursor to Tropical Storm Kate[2], over the central tropical Atlantic on 28 August. Meanwhile, the southern portion of the wave continued westward, reaching the Windward Islands on 28–29 August, Central America by 1 September, and the eastern Pacific by 2 September. A portion of this wave's low-level vorticity separated on 1 September over the Gulf of Honduras and eventually spawned Atlantic-basin Tropical Storm Mindy over the Gulf of Mexico several days later. The parent wave moved slowly west-northwestward equatorward of southern Mexico from 2–4 September, generating disorganized deep convection. By 5 September, satellite images indicated that a broad area of low pressure had formed a couple of hundred miles southwest of the coast of southwestern Mexico. The low became well-defined in satellite images on 6 September, and by 1800 UTC 7 September, the associated convection had become sufficiently organized to designate the system a tropical depression while located 200 n mi west-southwest of Manzanillo, Mexico. The depression strengthened that night as a large, curved convective band wrapped more than half-way around the center of the cyclone. By 1200 UTC 8 September, the depression became a tropical storm while centered about 185 n mi west of Manzanillo. The "best track" chart of Olaf'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[3].

For the first 18 h or so after genesis, the cyclone drifted northward within weak steering currents, with the primary feature steering the system being a mid-level low west of the Baja California peninsula. In a favorable environment of low vertical wind shear within a moist air mass while over warm waters, Olaf began to rapidly intensify once it became a tropical storm. The inner core of the cyclone became well established by early on 9 September (Fig. 4), and Olaf became a hurricane by 1200 UTC that day about 130 n mi southeast of Cabo San Lucas, Mexico. During that time, the cyclone's forward motion increased, and the hurricane turned north-northwestward and then northwestward toward the southern tip of the Baja California peninsula as a strong mid-tropospheric ridge built southeastward over northern Mexico. Olaf continued to rapidly strengthen

[2] Tropical Storm Kate's report is available at www.nhc.noaa.gov/data/tcr/AL102021_Kate.pdf

[3] 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.

and reached its peak intensity of 90 kt as it made landfall along the coast of the southern Baja California peninsula at 0250 UTC 10 September near San Jose del Cabo (cover photo, Fig. 5).

Olaf weakened when it crossed the Baja peninsula early that morning, but the system remained a hurricane as it moved offshore near Todos Santos around 0600 UTC that day. The cyclone began to rapidly lose strength over cooler waters while it moved northwestward, just offshore southern Baja California Sur. Olaf weakened to a tropical storm by 1200 UTC, when centered about 70 n mi southeast of Cabo San Lazaro. Later that day, Olaf turned west-northwestward away from the coast and began to move into a more stable thermodynamic environment, causing the deep convection to quickly decay. The cyclone turned westward early on 11 September and degenerated into a remnant low by 0600 UTC that day about 60 n mi west of Cabo San Lazaro. The low moved westward over the next 24 h and opened into a trough of low pressure by 0600 UTC 12 September when it was located about 200 n mi west of the southern Baja California peninsula.

METEOROLOGICAL STATISTICS

Observations in Olaf (Figs. 2 and 3) include subjective satellite-based Dvorak technique intensity estimates from the Tropical Analysis and Forecast Branch (TAFB), subjective Dvorak technique estimates from 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. 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, as well as radar imagery from Los Cabos, Mexico were also useful in constructing the best track of Olaf.

There were no ship or buoy reports of tropical-storm-force winds associated with Olaf.

Winds and Pressure

At 0000 UTC 10 September, about three hours prior to landfall, Olaf's intensity of 85 kt is based on an ADT estimate of T4.8/85 kt. As Olaf approached the coast, its inner-core cloud tops continued to cool, and Cabo San Lucas radar data (Fig. 5) showed an increase in organization of the hurricane's eyewall. The last ADT intensity estimate at 0250 UTC as the eye moved onshore was T5.6/105 kt, while the SATCON estimate at 0251 UTC was 89 kt. In addition, a post-analysis subjective Dvorak estimate (Fig. 6) revealed that Olaf's data T-number had increased to 5.0 (90 kt) by 0250 UTC. Therefore, it is assumed that further intensification occurred after 0000 UTC which supports a 90-kt peak intensity by the 0250 UTC landfall.

The estimated minimum pressure of 975 mb at landfall at 0250 UTC 10 September is based on an in-situ pressure of 976.7 mb that was measured inside the western portion of the eye by Josh Morgerman of the iCyclone storm chasing team, located in San Jose del Cabo. An

eyewitness report by the team indicated that the winds were nearly calm at the time the observation was taken within Olaf's eye.

Many of the observing stations near where Olaf made landfall in southern Baja California peninsula lost power during the hurricane's passage. In El Zacatal, a few miles inland of where the hurricane made landfall, a wind gust to 43 kt was reported at 2310 UTC 9 September, nearly 4 h before the center of Olaf reached that location. The Cabo San Lucas area experienced the western eyewall of Olaf. A mesonet station at the Cabo San Lucas Marina reported a sustained wind of 41 kt at 0210 UTC 10 September, and a gust to 70 kt at 0310 UTC. Farther north on the east coast of Baja California Sur in La Ventana, a WeatherFlow station measured a wind gust to 37 kt. On the west coast of the peninsula at Cerritos Beach, near where the center of Olaf emerged over the eastern Pacific waters, a sustained wind of 52 kt and a gust to 81 kt were reported at 0331 UTC, about the time that the northwestern eyewall was crossing the area. This station also stopped transmitting data at the time of this observation. Olaf quickly weakened as it slowly moved away from the west coast of the peninsula, and the center of the tropical storm passed about 20 n mi south of a Mexican Navy observing station at Puerto Cortes, producing peak sustained winds of 38 kt and a gust to 46 kt.

Rainfall and Flooding

Localized rainfall amounts to 4 inches (~100 mm) occurred in the western portion of the state of Jalisco in mainland Mexico as the center of Olaf passed west of the region (Fig. 7). This rainfall produced localized flooding and at least one landslide. Across the far southern portion of the Baja California peninsula, widespread rainfall amounts greater than 4 inches occurred. The highest rainfall amounts reported were 9.27 inches (235.5 mm) observed at El Triunfo, 9.05 inches (229.8 mm) at Li Rebera, and 7.68 inches (195 mm) at San Antonio. These rains resulted in localized flooding.

CASUALTY AND DAMAGE STATISTICS

Olaf caused 1 direct death[4] in Jalisco due to a mudslide caused by the heavy rains (Fig. 8). The cyclone caused damage to hotels, downed trees and power lines, and flooding in the southern portion of the Baja California peninsula. At the height of the storm, more than 190,000 customers lost power. According to a media report, an estimated $10 million USD (200 million pesos) in damage occurred, primarily in La Paz and Los Cabos.

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

FORECAST AND WARNING CRITIQUE

Olaf's genesis was well forecast. Table 2 provides the number of hours in advance of formation associated with the first NHC Tropical Weather Outlook (TWO) forecast in each likelihood category. The tropical wave from which Olaf formed was first introduced in the TWO and given a low (<40%) chance of genesis during the next 5 days 114 h before tropical cyclone formation occurred. The 5-day chance of genesis was raised to the medium (40–60%) and high (>60%) categories 90 h and 66 h before formation, respectively. A 2-day probability of genesis was first introduced in the low category 54 h before formation occurred. These chances were then raised to the medium and high categories 42 h and 24 h before formation, respectively.

A verification of NHC official track forecasts (OFCL) for Olaf is given in Table 3a. Official forecast track errors were above the mean official errors for the previous 5-yr period at all forecast times. Climatology and persistence model (OCD5) errors were also above their respective means through 60 h, suggesting that Olaf's track was more difficult than normal to forecast at shorter time frames. A homogeneous comparison of the official track errors with selected guidance models is given in Table 3b. The OFCL forecasts were outperformed by the individual models GFSI, HMNI, and CTCI, and the consensus TVCE at all time frames. However, OFCL track forecasts consistently outperformed EGRI and HWFI at all verifying forecast times. Figure 9a illustrates the left-of-track bias that the NHC track forecasts exhibited during the first 48 h of the cyclone's existence. Figure 9b shows that the larger-than-normal errors were at least partially due to a multi-model bias that indicated the center of Olaf would remain offshore of the Baja California peninsula. By 1200 UTC 8 September, forecast models suggested that a stronger system would likely track farther northeast compared to a weaker tropical cyclone (Fig. 10).

A verification of NHC official intensity forecasts for Olaf is given in Table 4a. Official forecast intensity errors were higher than the mean official errors for the previous 5-yr period through 36 h and lower than the means at 48–72 h. A homogeneous comparison of the official intensity errors with selected guidance models is given in Table 4b. Several models performed better than OFCL at all verifying forecast times. However, at 12–60 h, the difference in intensity errors between the best-performing intensity guidance and OFCL was only a few kt. The two models with the strongest solutions just over 36 h prior to landfall were the interpolated COAMPS-TC (CTCI) and GFSI, which performed best for the track forecast for Olaf as a result (Fig. 9).

Coastal watches and warnings associated with Olaf are given in Table 5.

Table 1. Best track for Hurricane Olaf, 7–11 September 2021.

Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Stage
06 / 1800	17.1	105.8	1009	25	low
07 / 0000	17.4	106.3	1009	25	"
07 / 0600	17.6	106.7	1009	25	"
07 / 1200	17.9	107.1	1007	30	"
07 / 1800	18.1	107.2	1007	30	tropical depression
08 / 0000	18.3	107.2	1007	30	"
08 / 0600	18.5	107.2	1006	30	"
08 / 1200	18.8	107.3	1005	35	tropical storm
08 / 1800	19.2	107.5	1002	40	"
09 / 0000	19.7	107.6	1000	45	"
09 / 0600	20.2	107.8	993	55	"
09 / 1200	20.9	108.1	987	65	hurricane
09 / 1800	21.8	108.6	981	75	"
10 / 0000	22.7	109.3	977	85	"
10 / 0250	23.0	109.7	975	90	"
10 / 0600	23.4	110.2	982	75	"
10 / 1200	24.0	111.2	990	60	tropical storm
10 / 1800	24.5	112.2	997	45	"
11 / 0000	24.7	113.0	1003	35	"
11 / 0600	24.6	113.6	1005	30	low
11 / 1200	24.5	114.1	1006	30	"
11 / 1800	24.4	114.5	1008	25	"
12 / 0000	24.3	114.8	1008	25	"
12 / 0600					dissipated
10 / 0250	23.0	109.7	975	90	maximum winds, minimum pressure, and landfall near San Jose del Cabo, Mexico

Table 2. Number of hours in advance of formation associated with the first NHC Tropical Weather Outlook forecast in the indicated likelihood category. Note that the timings for the "Low" category do not include forecasts of a 0% chance of genesis.

	Hours Before Genesis	
	48-Hour Outlook	**120-Hour Outlook**
Low (<40%)	54	114
Medium (40%-60%)	42	90
High (>60%)	24	66

Table 3a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) track forecast errors (n mi) for Hurricane Olaf, 7–11 September 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	27.3	49.8	74.2	89.6	91.8	88.3		
OCD5	46.4	106.6	171.6	225.3	265.3	203.2		
Forecasts	12	10	8	6	4	2		
OFCL (2016-20)	21.3	33.1	44.0	54.6	65.3	76.0	95.9	116.6
OCD5 (2016-20)	33.1	69.4	107.8	147.0	183.4	219.7	280.2	342.0

Table 3b. Homogeneous comparison of selected track forecast guidance models (in n mi) for Hurricane Olaf, 7–11 September 2021. 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	25.0	48.2	73.3	82.4	83.2			
OCD5	41.9	106.8	181.7	246.3	329.7			
GFSI	**20.0**	**39.8**	**54.1**	**53.1**	**18.9**			
HWFI	26.1	52.3	83.4	85.4	91.5			
HMNI	**20.9**	**36.6**	**56.5**	**64.4**	**72.6**			
EGRI	28.3	55.7	90.3	119.7	138.3			
EMXI	**24.3**	57.2	97.2	138.8	156.2			
NVGI	36.5	67.3	73.5	**79.3**	**81.7**			
CTCI	**20.6**	**34.1**	**36.0**	**39.8**	**49.3**			
CMCI	25.6	50.9	**63.2**	**70.2**	96.1			
AEMI	**19.7**	**40.9**	**61.3**	**62.9**	**53.2**			
HCCA	**22.4**	**47.2**	75.4	92.8	89.9			
TVCE	**22.4**	**45.8**	**68.5**	**81.1**	**80.8**			
TVCX	**22.4**	**46.1**	**72.1**	90.8	91.4			
TVDG	**22.4**	**45.8**	**71.6**	88.2	86.5			
TABS	29.2	61.1	97.3	111.8	104.5			
TABM	25.7	**46.1**	**64.5**	**61.2**	**37.8**			
TABD	32.7	68.4	105.9	132.7	160.8			
Forecasts	10	8	6	4	2			

Table 4a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) intensity forecast errors (kt) for Hurricane Olaf, 7–11 September 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	8.3	12.5	13.8	**12.5**	**8.8**	**15.0**		
OCD5	10.9	19.2	23.1	23.0	13.5	8.5		
Forecasts	12	10	8	6	4	2	0	0
OFCL (2016-20)	5.6	9.0	10.9	12.6	14.0	15.3	16.0	16.7
OCD5 (2016-20)	7.2	12.0	15.3	17.6	19.0	20.4	21.2	20.8

Table 4b. Homogeneous comparison of selected intensity forecast guidance models (in kt) for Hurricane Olaf, 7–11 September 2021. 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	8.3	12.5	13.8	12.5	8.8	15.0		
OCD5	10.9	19.2	23.1	23.0	13.5	**8.5**		
HWFI	**7.3**	**9.4**	**10.1**	**12.3**	8.8	**6.0**		
HMNI	**7.9**	12.6	**13.4**	15.5	**8.2**	**8.5**		
CTCI	**8.2**	**7.8**	**8.6**	**9.8**	**6.5**	15.0		
DSHP	11.2	16.8	20.6	18.0	9.5	24.0		
LGEM	12.0	18.8	23.5	23.8	13.8	**4.5**		
HCCA	8.4	**10.0**	**12.0**	**10.8**	**8.2**	16.0		
IVCN	**8.2**	**11.5**	14.2	15.3	**7.2**	**11.0**		
IVDR	**7.9**	**10.7**	**12.2**	13.3	**6.8**	**11.5**		
ICON	8.7	12.9	15.9	17.3	**8.0**	**10.0**		
GFSI	9.4	**10.0**	**10.2**	**11.3**	9.0	20.0		
EMXI	12.1	19.3	22.0	23.2	17.2	**4.0**		
Forecasts	12	10	8	6	4	2	0	0

Table 5. Wind watch and warning summary for Hurricane Olaf, 7–11 September 2021.

Date/Time (UTC)	Action	Location
8 / 0300	Tropical Storm Watch issued	Los Barriles to Todos Santos
8 / 0900	Tropical Storm Watch modified to	Los Barriles to Santa Fe
8 / 2100	Tropical Storm Watch changed to Tropical Storm Warning	Los Barriles to Santa Fe
8 / 2100	Hurricane Watch issued	Cabo San Lucas to Todos Santos
9 / 0900	Tropical Storm Warning changed to Hurricane Warning	Los Barriles to Santa Fe
9 / 0900	Tropical Storm Warning issued	Santa Fe to Cabo San Lazaro
9 / 0900	Tropical Storm Warning issued	Los Barriles to San Evaristo
9 / 0900	Hurricane Watch discontinued	All
9 / 2100	Tropical Storm Warning modified to	Cabo San Lazaro to Puerto San Andresito
9 / 2100	Tropical Storm Warning modified to	Los Barriles to Loreto
9 / 2100	Hurricane Warning modified to	Los Barriles to Cabo San Lazaro
10 / 0900	Tropical Storm Warning modified to	Todos Santos to Loreto
10 / 0900	Hurricane Warning modified to	Todos Santos to Cabo San Lazaro
10 / 1500	Tropical Storm Warning modified to	Puerto San Andresito to Loreto
10 / 1500	Hurricane Warning discontinued	All
10 / 2100	Tropical Storm Warning modified to	Puerto San Andresito to Santa Fe
11 / 0300	Tropical Storm Warning discontinued	All

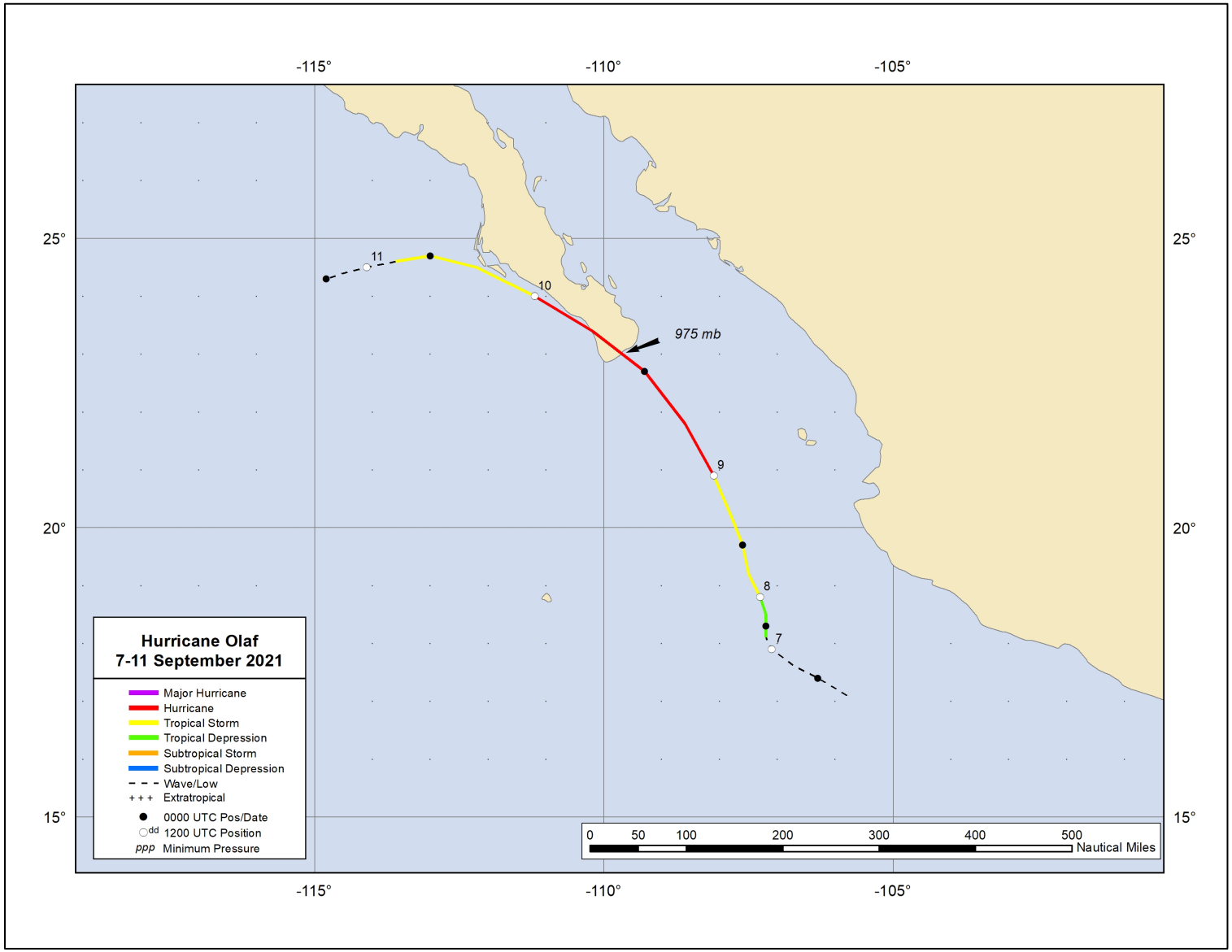


Figure 1. Best track positions for Hurricane Olaf, 7–11 September 2021.

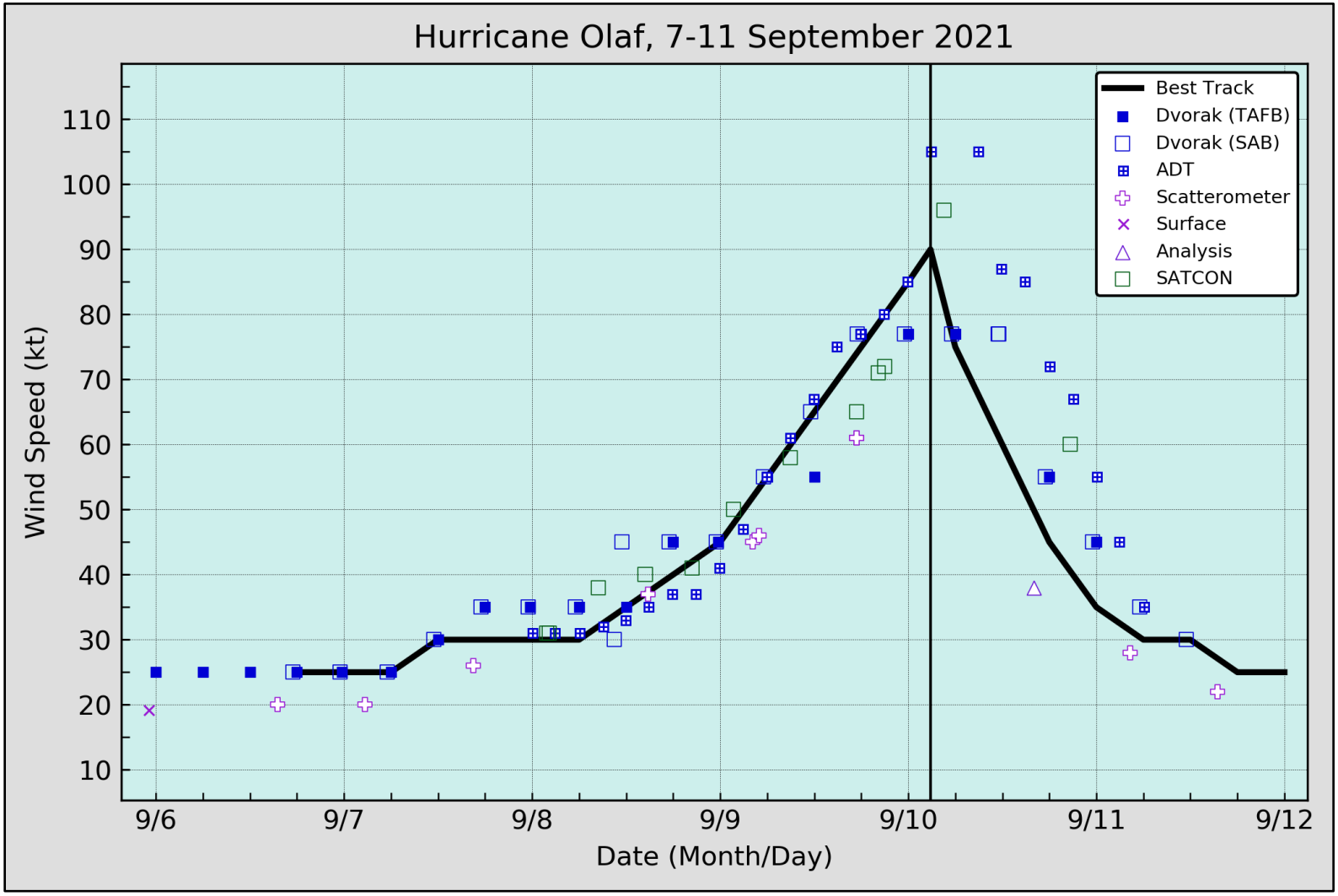


Figure 2. Selected wind observations and best track maximum sustained surface wind speed curve for Hurricane Olaf, 7–11 September 2021. Advanced Dvorak Technique estimates represent the Current Intensity at the nominal observation time. SATCON intensity estimates are from the Cooperative Institute for Meteorological Satellite Studies. Dashed vertical lines correspond to 0000 UTC. The solid vertical line corresponds to landfall.

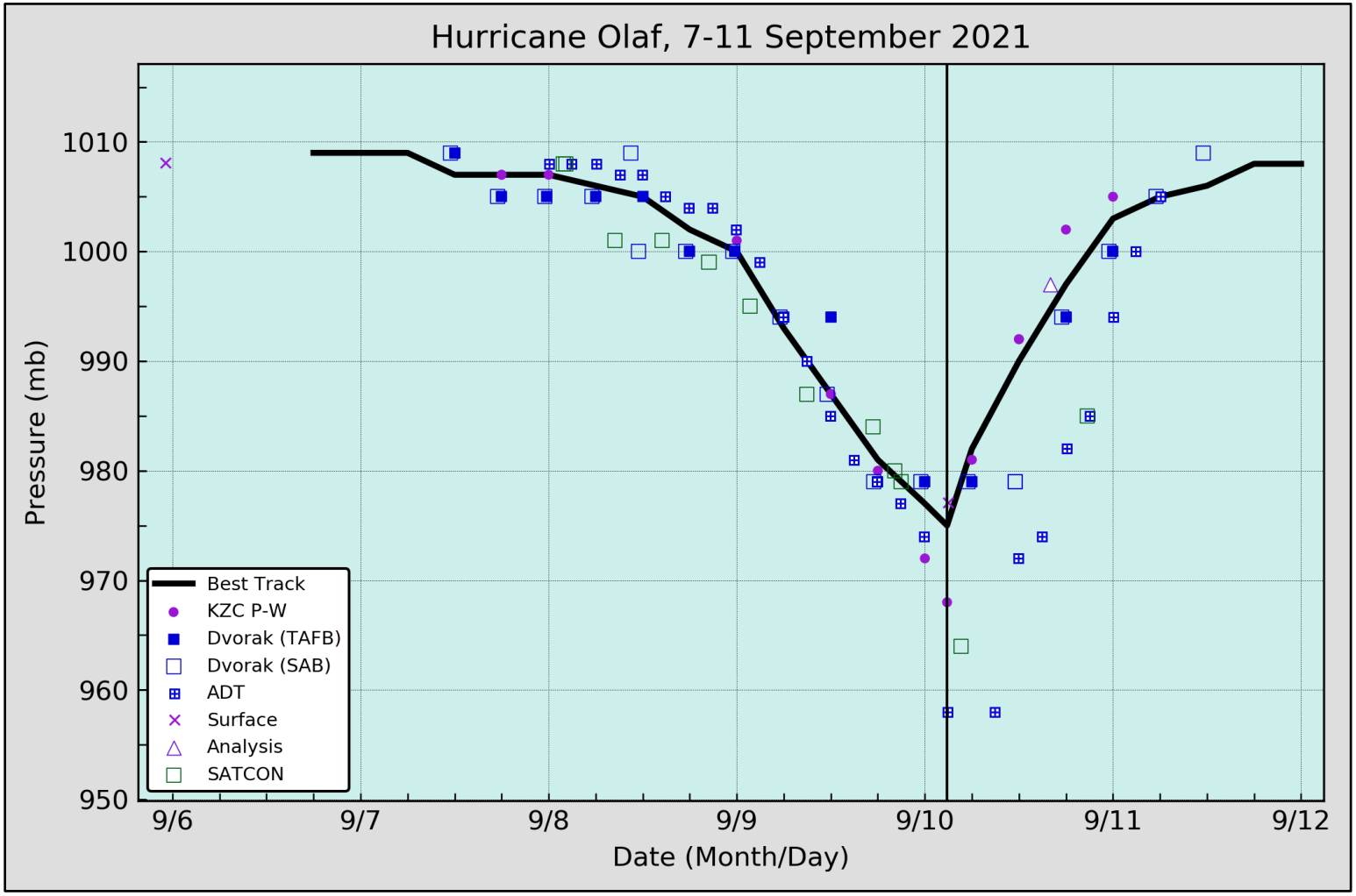


Figure 3. Selected pressure observations and best track minimum central pressure curve for Hurricane Olaf, 7–11 September 2021. Advanced Dvorak Technique estimates represent the Current Intensity at the nominal observation time. SATCON intensity estimates are from the Cooperative Institute for Meteorological 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. The solid vertical line corresponds to landfall.

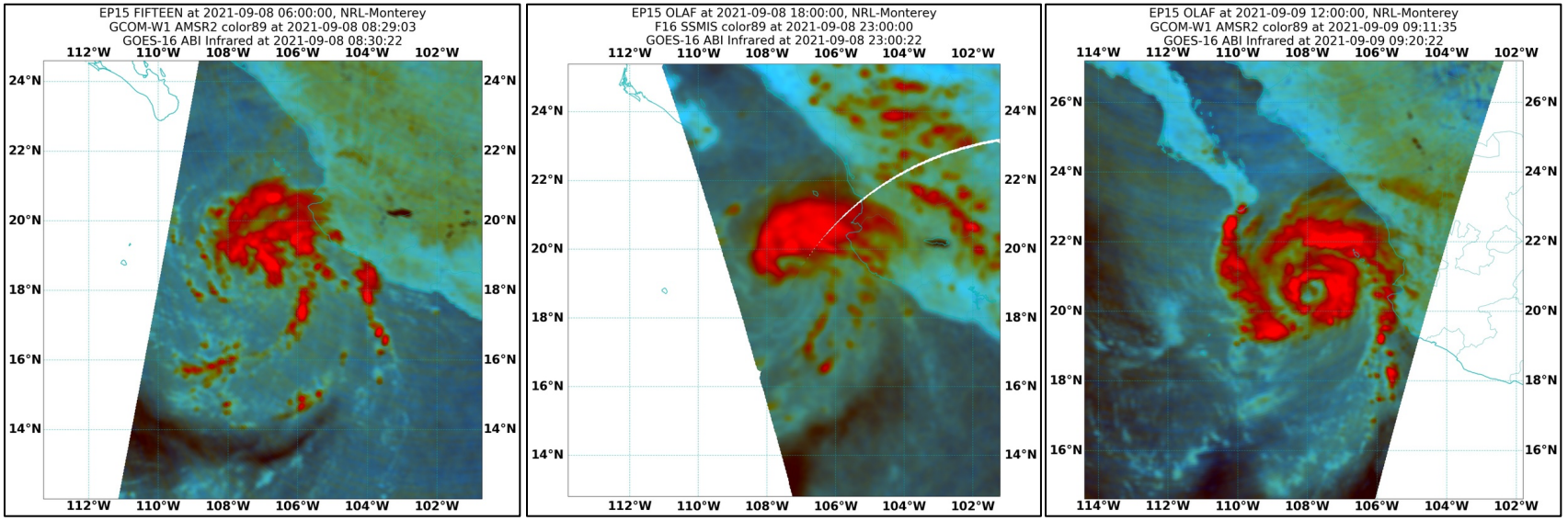


Figure 4. Series of microwave images spanning about 24 h, during the time that Olaf's inner core became better defined. The images on the left and right are AMSR2 89-GHz color composite images from 0829 UTC 8 September and 0911 UTC 9 September, respectively. The middle image is an 89-GHz color composite image from the F-16 SSMIS satellite at 2300 UTC 8 September.

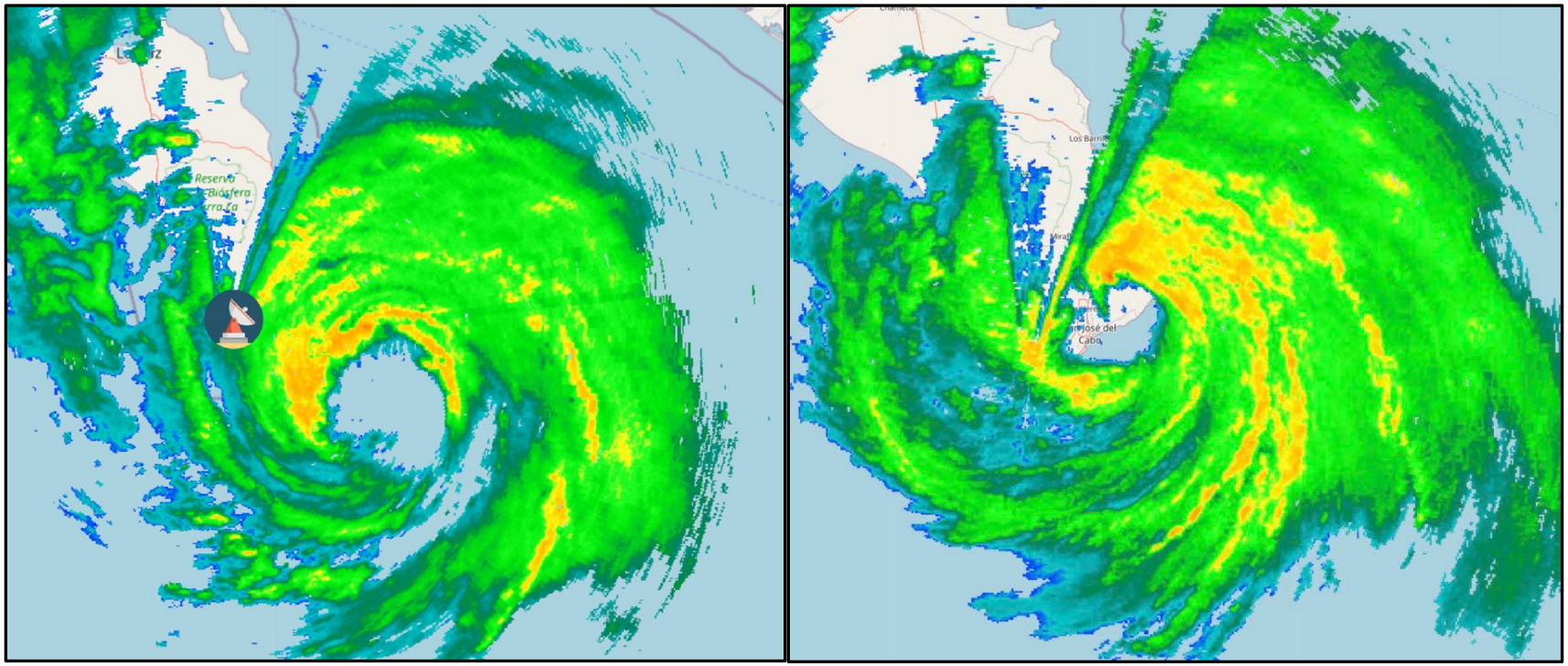


Figure 5. Los Cabos radar reflectivity image around 0000 UTC 10 September as Olaf was approaching Baja California Sur (left) and at 0249 UTC near the time of landfall (right). Images courtesy of CONAGUA – Commison Nacional del Agua.

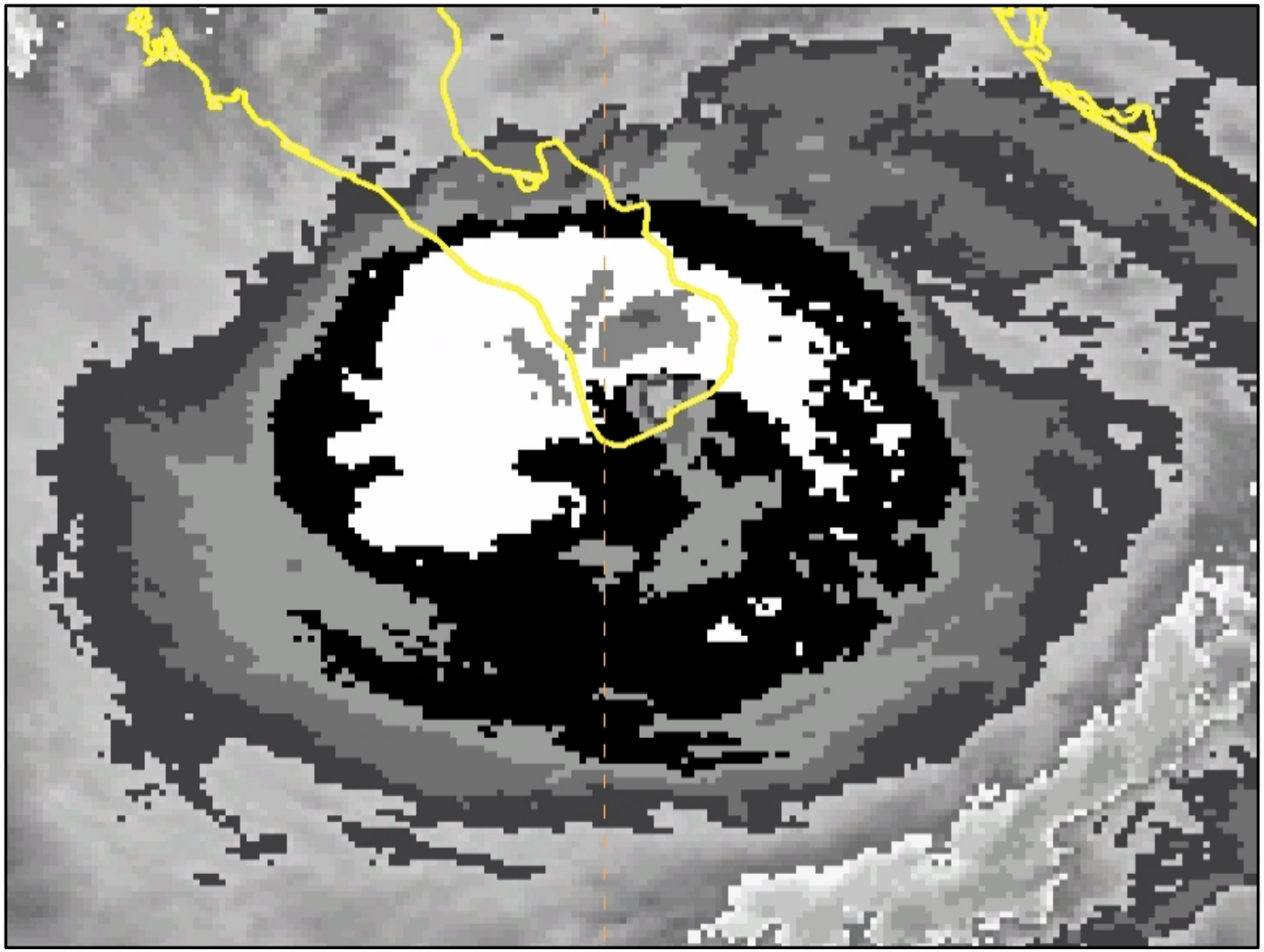


Figure 6. GOES-16 infrared image of Olaf at landfall (0250 UTC 10 September). The Dvorak BD enhancement curve was applied to the image to perform the subjective Dvorak intensity estimate.

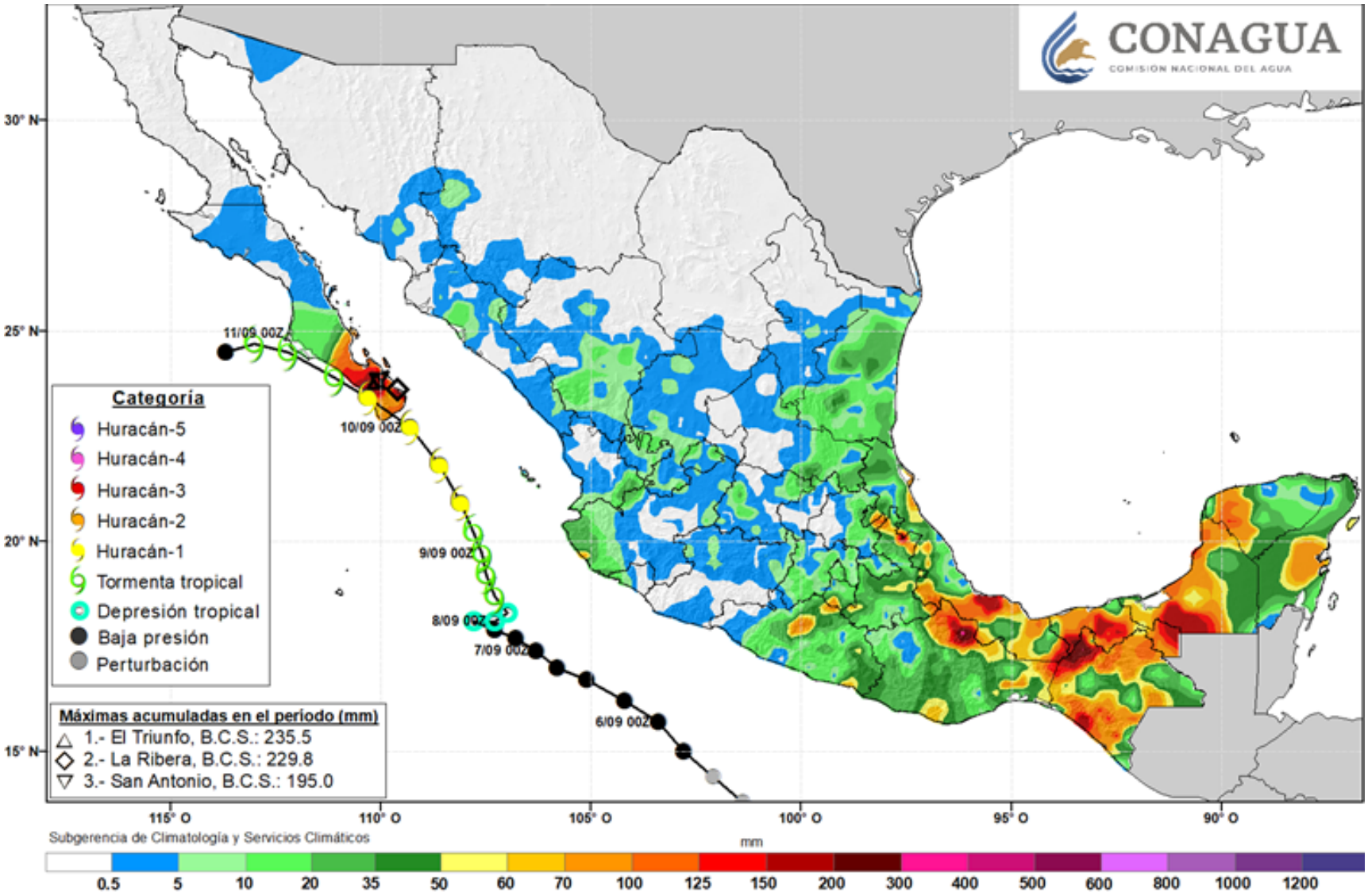


Figure 7. Total rainfall (mm) during the period 8–11 September 2021. Map courtesy of CONAGUA. Track is based on the operational best track prior to re-analysis.

Figure 8. A mudslide in Jalisco caused by Olaf's heavy rainfall resulted in one fatality. Image courtesy of *LATINUS*.

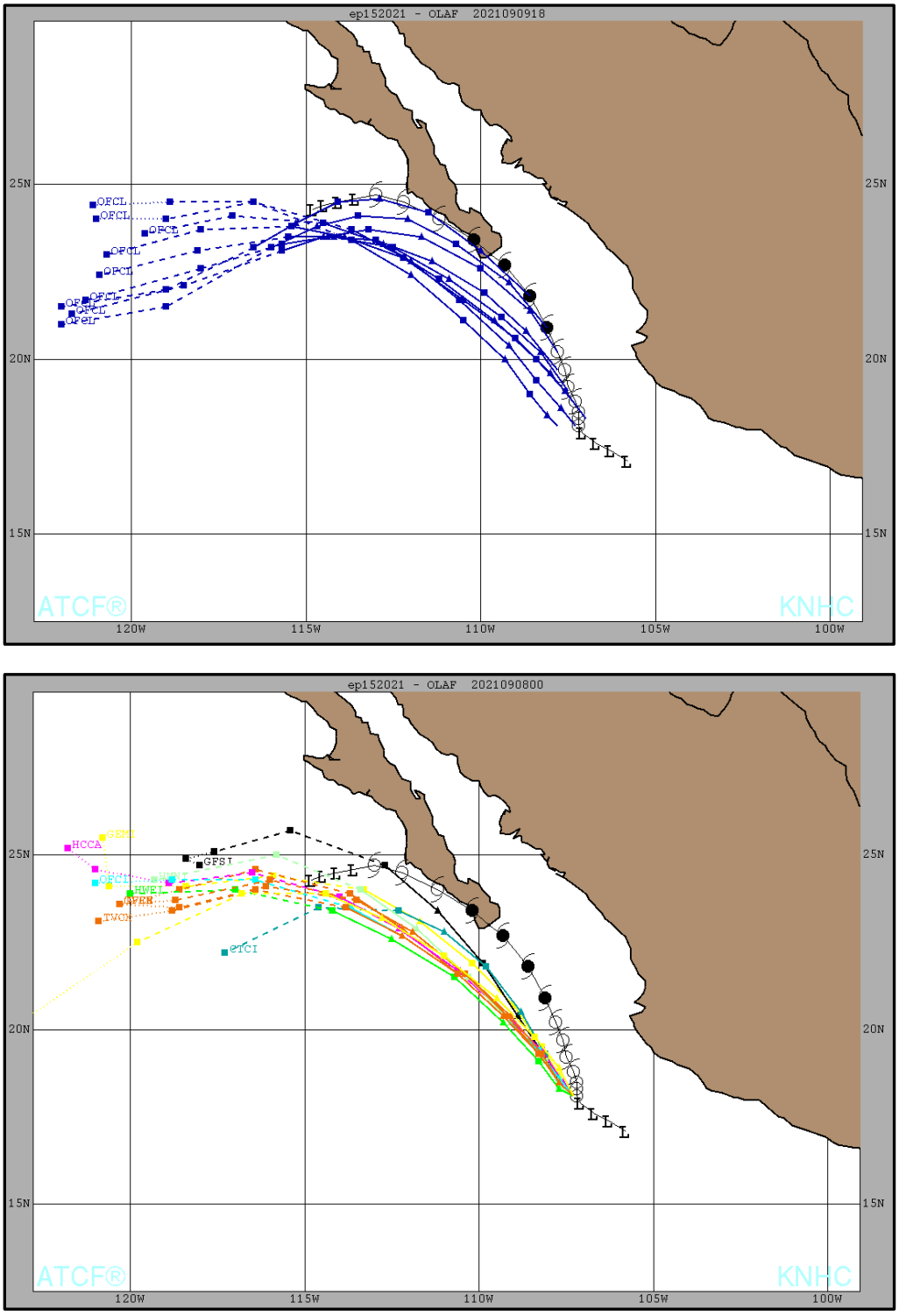
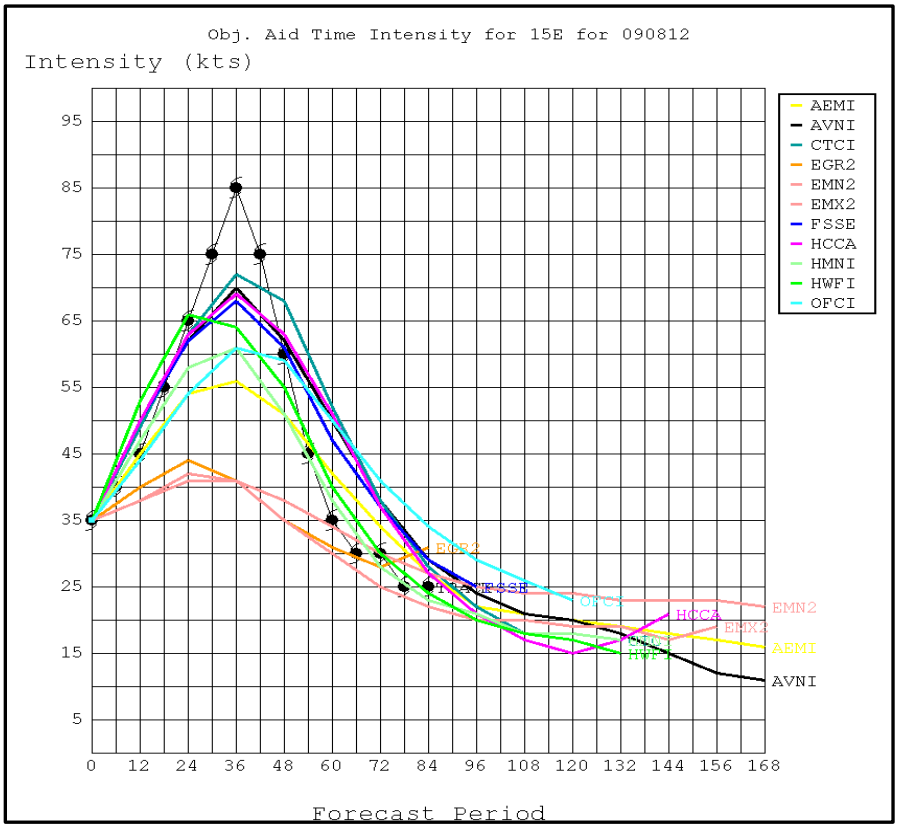


Figure 9. (a) All NHC official five-day track forecasts (blue lines) for Olaf from 1800 UTC 07 September through 1800 UTC 9 September. Olaf's best track is indicated by the black line and symbols. (b) Five-day selected track models for Hurricane Olaf from the 0000 UTC 8 September forecast cycle.



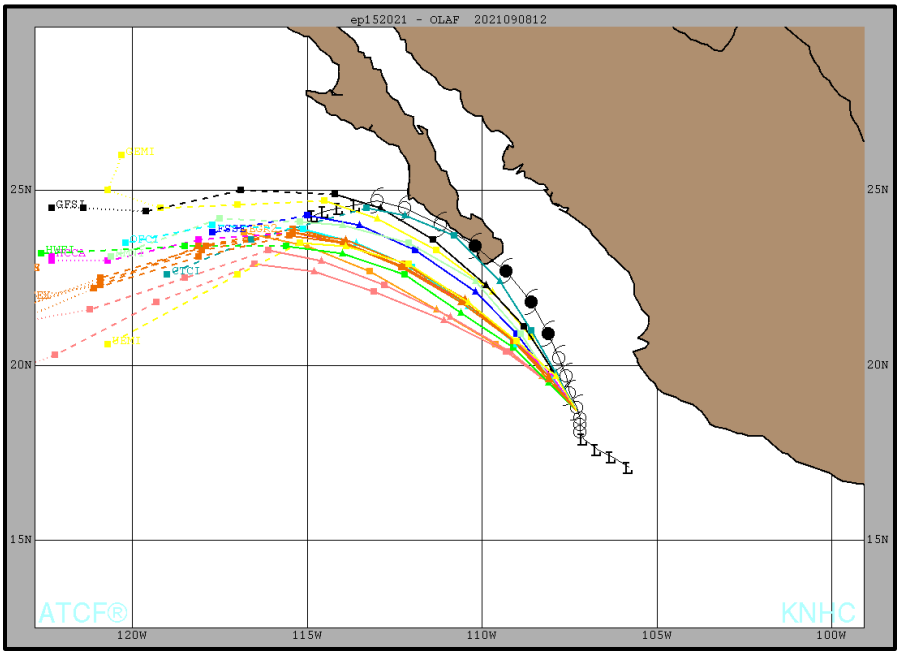


Figure 10. (a) Selected model intensity forecasts for Olaf from the 1200 UTC 8 September forecast cycle. Olaf's verifying intensity is indicated by the black line and symbols. (b) Selected five-day track models for Hurricane Olaf from the 1200 UTC 8 September forecast cycle. Note CTCI (green line) and GFSI (black line) forecasting a stronger cyclone with a track closer to the coast of southern Baja California.