NATIONAL HURRICANE CENTER TROPICAL CYCLONE REPORT

HURRICANE LARRY

(AL122021)

31 August–11 September 2021

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HURRICANE LARRY AS SEEN FROM THE INTERNATIONAL SPACE STATION ON 4 SEPTEMBER 2021.
PHOTO CREDIT NASA ASTRONAUT MEGAN MCARTHUR/@ASTRO_MEGAN/TWITTER.

Larry was a classic, long-lived Cape Verde hurricane that reached category 3 intensity (on the Saffir-Simpson Hurricane Wind Scale) over the central tropical Atlantic. Larry passed east of Bermuda before making landfall in southeastern Newfoundland as a category 1 hurricane. The storm produced extensive power outages and tree damage in Newfoundland, and swells from the storm caused 5 direct fatalities on the east coast of the United States, and in Puerto Rico and the U.S. Virgin Islands.

Hurricane Larry

31 AUGUST–11 SEPTEMBER 2021

SYNOPTIC HISTORY

Larry originated from a strong tropical wave that emerged off the west coast of Africa on 30 August. The wave was accompanied by a broad area of low pressure and corresponding 24-h pressure falls of 4 to 6 mb when it exited the west coast of Africa. Deep convection quickly began to increase around the eastern portion of the broad circulation while it moved generally westward over the far eastern tropical Atlantic early on 31 August. By 1800 UTC that day, the convective organization increased enough for the system to be designated as a tropical depression when it was located about 280 n mi south-southeast of the Cabo Verde Islands. The system strengthened into a tropical storm 6 h later. The “best track” chart of Larry’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].

Located within favorable atmospheric and oceanic conditions consisting of low vertical wind shear, abundant low- to mid-level moisture, and sea surface temperatures of 27–28°C, Larry steadily strengthened over the next few days while moving generally westward at 17–20 kt to the south of a strong mid-level ridge. Microwave satellite data indicated that a small inner-core had developed by late on 1 September, and by 0600 UTC the next day a well-defined low- to mid-level eye feature became apparent (Fig. 4). That feature, along with subjective satellite intensity estimates indicates that Larry attained hurricane status by 0600 UTC 2 September when it was located about 425 n mi west-southwest of the westernmost Cabo Verde Islands. Later that day, Larry’s intensification briefly paused when microwave images suggested that an eyewall replacement cycle had commenced, but this cycle was disrupted by some shear and an intrusion of dry mid-level air. Larry recovered from the disruption to its inner core and the hurricane began a period of rapid strengthening by early on 3 September. An eye became apparent in visible satellite imagery shortly after 1200 UTC that day, and became better defined in both visible and infrared satellite images by late that day. It is estimated that Larry became a major hurricane (Category 3 or greater on the Saffir-Simpson Hurricane Wind Scale) by 0000 UTC 4 September, and reached its first peak intensity of 110 kt (Category 3) 6 h later when it was located about 1000 miles east of the Leeward Islands. By that time, Larry turned west-northwestward and slowed down a bit as it neared the western portion of the mid-level ridge.

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[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.

Shortly after Larry reached its peak intensity, another eyewall replacement cycle occurred, resulting in the original 15–20 n-mi-wide eye doubling in size to 30–40 n mi in diameter by 1800 UTC 4 September. This changing inner-core structure was accompanied by a slight decrease in intensity, but Larry remained at category 3 strength. By the next morning, the large eye (now 40–50 n mi in diameter) became even better defined and the surrounding cloud tops cooled. This resulted in slight re-strengthening and Larry is estimated to have reached an intensity of 110 kt for a second time (Fig. 5) when it was centered about 725 n mi east of the Leeward Islands. Although Larry weakened slightly early on 6 September, it maintained an annular hurricane-like structure with a large 40–50 n-mi-wide eye and few outer banding features. Larry remained a major hurricane until 1200 UTC 7 September when reconnaissance aircraft data indicated that the hurricane's intensity had dropped to 95 kt. Around that same time, the hurricane reached the western extent of the subtropical ridge and turned northwestward over the central Atlantic.

Larry maintained category-2 intensity while moving northwestward on 8 September, and during this time that a further expansion of the wind field occurred. By late that day, scatterometer data indicated that the tropical-storm-force wind radii extended as far as 200 n mi from the center over the eastern semicircle of the storm. Gradually decreasing sea surface temperatures along the path of the hurricane resulted in slow weakening, and Larry's intensity declined to 80 kt by 0600 UTC 9 September. The hurricane then turned north-northwestward and made its closest approach to Bermuda, with the large eye passing about 130 n mi east-northeast of the island late on 9 September.

Early the next day, Larry turned northward and began to accelerate ahead of an approaching mid-latitude trough. Increasing southwesterly vertical wind shear and cooler sea surface temperatures caused the large hurricane to continue gradually weaken, and by 1200 UTC 10 September, Larry's intensity decreased to 70 kt. Shortly thereafter, the hurricane turned north-northeastward with its forward speed increasing to more than 30 kt as it passed a little less than 200 n mi southeast of the coast of Nova Scotia that afternoon. By 0000 UTC 11 September, the center of Larry approached the southeastern coast of Newfoundland while its forward speed increased to nearly 40 kt. The center of the fast-moving hurricane passed very close to Marticut Island, Newfoundland, before making landfall with an estimated intensity of 70 kt around 0330 UTC along the coast of Great Bona Cove, Newfoundland. Larry weakened, but remained a 65-kt hurricane at 0600 UTC 11 September after passing north of Newfoundland. Over the next 6 h, the cyclone quickly transformed into a large and powerful 60-kt extratropical cyclone by 1200 UTC 11 September, when it was located about 320 n mi north-northeast of St. John's, Newfoundland. The extratropical storm weakened slightly before it was absorbed by 0000 UTC 12 September by a larger extratropical cyclone that was moving eastward over the Labrador Sea. Moisture from the remnants of Larry combined with the extratropical low that absorbed the cyclone to produce up to 4 ft of snow and hurricane-force wind gusts across interior portions of Greenland.

METEOROLOGICAL STATISTICS

Observations in Larry (Figs. 2 and 3) include subjective satellite-based Dvorak technique intensity estimates from the Tropical Analysis and Forecast Branch (TAFB) and the Satellite Analysis Branch (SAB), objective Advanced Dvorak Technique (ADT) estimates and Satellite Consensus (SATCON) estimates from the Cooperative Institute for Meteorological Satellite Studies/University of Wisconsin-Madison. Observations also include flight-level, stepped frequency microwave radiometer (SFMR), and dropwindsonde observations from 7 reconnaissance aircraft missions into the hurricane. This includes 5 flights of the U.S. Air Force Reserve Command's 53rd Weather Reconnaissance Squadron's WC-130 aircraft and 2 research missions by the NOAA WP-3D Orion aircraft. These missions provided a total of 15 center fixes for Larry on 6–9 September. There were also 3 synoptic surveillance flights of the NOAA G-IV aircraft that provided information on Larry's surrounding environment on 5–7 September.

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 Larry. Surface observations from Newfoundland provided by Environment Canada, and land-based radar imagery from Bermuda as well as Nova Scotia and Newfoundland were also helpful in tracking Larry when it passed near those areas.

Ship reports of winds of tropical storm force associated with Larry are given in Table 2, and selected surface observations from land stations and data buoys are given in Table 3.

Winds and Pressure

Larry's estimated peak intensity of 110 kt is based on various subjective and objective satellite estimates. The first 110-kt peak from 0600–1200 UTC 4 September is based on UW/CIMSS ADT Current Intensity numbers of T5.8 (110 kt) from 0420–1050 UTC 4 September, and SATCON estimates of 111–116 kt just prior to 0600 UTC that day. The second 110-kt peak intensity from 1200 UTC 5 September to 0000 UTC 6 September is based on a blend of subjective Dvorak classifications of T6.0 (115 kt) from TAFB and SAB, and UW-CIMSS ADT and SATCON estimates of 103–106 kt. Although the subjective Dvorak T-numbers at 1200 UTC 5 September suggest Larry could have been slightly stronger, the thickness of the coldest ring of cloud top temperatures barely met the criteria for a Dvorak T-number of 6.0 (115 kt). In addition, the cloud pattern supporting those higher T-numbers was very transient with the cloud top temperatures within the surrounding ring oscillating over the next several hours. Dvorak data T-numbers from both SAB and TAFB fell below T6.0 just 6 h later even though the CI-numbers remained at 115 kt due to constraints in the Dvorak technique.

SFMR and dropwindsonde data from reconnaissance aircraft missions on 7–9 September indicate that as the hurricane moved northward and the wind field expanded, it was less efficient than typical (90% of the 700-mb flight-level winds) in transporting winds aloft to the surface. Therefore, a blend of the higher 700-mb flight-level reduced winds and lower SFMR and dropwindsonde-supported surface winds was used to estimate Larry's intensity during that time (Fig. 2). The highest 700-mb flight-level wind measured by reconnaissance aircraft was 118 kt at 1106 UTC 8 September, which occurred during the period when the higher flight-level winds did not appear to be efficiently mixing to the surface. The highest SFMR winds reported on that mission were 75 kt. The peak 700-mb flight-level winds from that flight may have also been associated with a transient embedded mesocyclone.

Satellite intensity estimates, scatterometer surface wind data, and surface observations from Newfoundland indicate that Larry made landfall in southeastern Newfoundland as a hurricane with an estimated intensity of 70 kt around 0330 UTC 11 September. Larry was the first hurricane landfall in Newfoundland since Igor in 2010. The highest sustained wind measured in Newfoundland was at an unofficial reporting station at Cape St. Mary's Lighthouse that reported 69-kt sustained winds and a gust to 98 kt. This site is on an elevated rocky cliff near the southwestern portion of the Avalon Peninsula. A wind gust to 80 kt was also reported at the Cape Pine Lighthouse on the southeastern part of the peninsula. Sustained winds of 59 kt with a gust to 78 kt were reported at Cape Race, and winds of 52 kt with a gust to 74 kt were observed at St. John's International Airport. Many locations to the right of the track of Larry's center over southeastern Newfoundland experienced hurricane-force wind gusts (Fig. 6, Table 3).

During Larry's closest approach to Bermuda, the large hurricane brought sustained tropical-storm-force winds to the island. An automated observing site at the Marine Operations Centre on Bermuda reported a peak 1-minute wind of 40 kt with a gust to 46 kt, and sustained winds of 37 kt with a gust to 45 kt were reported at the National Museum.

According to media reports, the powerful extratropical cyclone that Larry was absorbed by produced hurricane-force wind gusts over portions of Greenland. A wind gust of 87 kt was reported at the Kulusuk Airport along the southeastern coast of the island, and at Tasiilaq, winds of 48 kt with gusts over 78 kt were measured.

Larry's estimated minimum pressure of 953 mb from 1200 UTC 5 September through 0000 UTC 6 September is based on the Knaff-Zehr-Courtney pressure-wind relationship. The lowest pressure measured by a dropwindsonde released from reconnaissance aircraft was 956 mb, which was reported around 1918 UTC 6 September about 18 h after Larry's second estimated peak in intensity. The estimated minimum pressure of 958 mb at landfall in Newfoundland on 11 September is based on surface observations. Canadian buoy 44139 (44.24°N 57.10°W) measured a minimum pressure of 962 mb at 2300 UTC 10 September with 47-kt winds. A surface station at St. Lawrence measured a minimum pressure of 960.8 mb with 6-kt winds and a station at Terra Nova measured 960.7 mb with 13-kt winds.

Storm Surge[2]

Water levels rose quickly along the southern coast of Newfoundland as the center of Larry approached the area late on 10 September. The hurricane made landfall around the time of high tide resulting in a peak storm tide of 3.65 m (12.0 ft) above the local chart datum at a tide gauge at Argentia early on 11 September (Fig. 7), which broke the record highest storm tide at that gauge set on 25 December 1983. Subtracting the predicted astronomical tide, a storm surge of 1.51 m (5.0 ft) occurred at that location. A tide gauge at St. Lawrence measured a storm tide of 3.64 m (11.9 ft) above the local chart datum and a storm surge of 1.48 m (4.9 ft). Using Higher High Water Large Tide (HHWLT), which is equivalent to Mean Higher High Water (MHHW) in the United States, as a proxy for inundation on normally dry ground along the immediate coastline, there was approximately 1 m (3.3 ft) of storm surge inundation at the coastline at those locations (Fig. 7). Storm surge amounts of 0.48 to 0.65 m (1.6 to 2.1 ft) above normal tide levels were also reported at Port-Aux-Basques, St. John's, and Bonavista in Newfoundland (Table 3).

The storm surge was accompanied by large waves along portions of the immediate coast of southeastern Newfoundland, which caused coastal damage and road overwash (see damage section below). Canadian buoy 44139, located well offshore of the southwest coast of Newfoundland, measured significant wave heights[3] of 9.8 m (32.2 ft) and a peak wave height of 20.8 m (68.2 ft). Closer to the coast, a buoy at the mouth of the Placentia Bay measured significant wave heights of 8.1 m (26.6 ft) and a peak wave height of 13.8 m (45.3 ft) and buoy AZMP-STA27, located a little less than 2 miles east-northeast of the coast near Cape Spear Lighthouse, reported significant wave heights of 5.3 m (17.4 ft) and a peak wave height of 7.6 m (25.6 ft).

Rainfall and Flooding

Larry's fast motion across southeastern Newfoundland limited rainfall accumulations across that area. The highest reported rainfall total were 38 mm (1.48 inches) at Port Rexton, 35 mm (1.38 inches) at Mount Pearl, and 32 mm (1.25 inches) near St. John's (Table 3).

The powerful extratropical cyclone that Larry was absorbed by produced blizzard conditions and up to 4 ft of snow accumulation in portions of Greenland.

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[2] Several terms are used to describe water levels due to a storm. **Storm surge** is defined as the abnormal rise of water generated by a storm, over and above the predicted astronomical tide, and is expressed in terms of height above normal tide levels. Because storm surge represents the deviation from normal water levels, it is not referenced to a vertical datum. **Storm tide** is defined as the water level due to the combination of storm surge and the astronomical tide, and is expressed in terms of height above a vertical datum. **Inundation** is the total water level that occurs on normally dry ground as a result of the storm tide, and is expressed in terms of height above ground level. At the coast, normally dry land is roughly defined as areas higher than the normal high tide line, or Higher High Water Large Tide (HHWLT) in Canada.

[3] Significant wave height is defined as the average height, from trough to crest, of the highest one-third of the waves.

CASUALTY AND DAMAGE STATISTICS

Although there were no reports of deaths[4] associated with Larry's landfall in Canada, the hurricane's large wind field generated swells that impacted beaches across the western portion of the Atlantic basin including the Leeward Islands, Greater Antilles, Bahamas, Turks and Caicos, Bermuda, the east of coast of the United States, and Canada (Fig. 8). The swells produced rough surf and rip current conditions that caused 5 direct fatalities. A female swimmer drowned in a rip current at Annaly Bay on St. Croix in the U.S. Virgin Islands on 7 September, and a 24-year-old man died in a rip current at a beach in Puerto Rico on 11 September. Along the east coast of the United States between 8–11 September, a 68-year-old man drowned at North Myrtle Beach, South Carolina, a 69-year-old man drowned at Jetty Park in Cape Canaveral, Florida, and a 23-year-old man died in a rip current at Dam Neck Beach in Virginia.

Media reports indicate that an emergency beacon on a sailboat that had been allegedly stolen from a yacht club in Halifax, Nova Scotia, activated and transmitted a position near the center of Larry late on 10 September. It is assumed that the boat sank in the hurricane, but it is not known if anyone was onboard.

Larry produced significant wind impacts over much of southeastern Newfoundland and caused storm surge and wave impacts along much of the south-facing coastline of that island. There were reports of numerous downed trees and power lines, as well as some roof damage across the area. At the peak of the storm, nearly 61,000 customers were without power, primarily on the Avalon Peninsula of Newfoundland. Figure 9 illustrates wind damage at an elementary school in St. John's. Exposed roads along the south-facing coastline of southeastern Newfoundland were impacted by overwash and washouts due to storm surge and pounding surf (Figs. 10 and 11). The community of Little Bay on the Burin Peninsula was evacuated due to rising water.

According to a report released on 27 October 2021 from Catastrophe Indices and Quantification Inc. (CATIQ), Larry caused an estimated 25 million in Canadian dollars in insured loss in southeastern Newfoundland.

FORECAST AND WARNING CRITIQUE

The genesis of Larry was well forecast, especially for a system that developed only about a day after the incipient disturbance departed the west coast of Africa. The potential for tropical cyclone formation was first noted in the Tropical Weather Outlook at 1800 UTC 27 August with a

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[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.

low (<40%) chance of development over the next five days (Table 4). This provided 96 h of lead time before development occurred. The 5-day chance of genesis was raised to the medium (40–60%) category 84 h before formation, and the high (>60%) category 66 h before development occurred. The 2-day probabilities also provided reasonable lead time on genesis. The system was assigned a low 2-day probability of formation 60 h before development and the probabilities reached the medium and high categories 42 and 24 h before formation, respectively.

A verification of NHC official track forecasts for Larry is given in Table 5a. Official forecast track errors were much lower than the mean official errors for the previous 5-yr period and the errors from 48 to 120 h were 45–50% less than the long-term average. However, the OCD5 errors were also lower than their 5-year means, suggesting that the forecasts for Larry were easier than average. A homogeneous comparison of the official track errors with selected guidance models is given in Table 5b. The ECMWF model (EMXI) had the lowest mean errors of any of the individual dynamical models and was the only individual model to beat the NHC forecast at any verifying period. The NHC forecasts had lower mean track errors than the remainder of individual models at every forecast lead time. Several of the consensus aids exhibited lower errors than the official forecast, with the TVCA, TVCX, and TVDG aids besting the official forecast at each verifying lead time. The TVCX (variable consensus comprised of the GFSI, HWFI, CTCI, EGRI, and double-weighted EMXI) and TVDG (corrected consensus comprised of double weighted GFSI, EMXI, and EGRI, and single weighted CTCI and HWFI) generally had the lowest mean errors of the entire guidance suite. Figure 12 shows all of the NHC official forecasts for Larry along with the storm's best track. The NHC forecasts accurately predicted the hurricane's re-curvature over the west-central Atlantic, but they exhibited a right-of-track bias for the portion of Larry's track northeast of Bermuda through landfall in Newfoundland. The dynamical model guidance generally exhibited a similar bias (not shown).

A verification of NHC official intensity forecasts for Larry is given in Table 6a. The official intensity forecast errors were lower than the long-term means. The OCD5 errors were also lower than their long-term means, suggesting that the intensity forecasts for Larry were less difficult than average. A homogeneous comparison of the official intensity errors with selected guidance models is given in Table 6b. The HWRF (HWFI) was the only dynamical model that consistently exhibited lower mean errors than the official forecast, besting it at all time periods. The simple consensus aids ICON, IVCN, and IVDR also performed better than the official forecasts at nearly all lead times. Each of those intensity aids had mean errors of less than about 10 kt at each verifying lead time. The NHC intensity forecasts were consistent in predicting significant strengthening of Larry – for example, the first NHC forecast predicted that the tropical cyclone would become a hurricane within 60 h and reach category 2 intensity within 4–5 days. Beginning with the third NHC advisory issued at 0900 UTC 1 September, the intensity forecasts called for Larry to become a major hurricane (category 3 or greater) within 72 h. While these forecasts were generally accurate, the storm did strengthen somewhat faster than anticipated, becoming a hurricane within 36 h of genesis, and a major hurricane only 78 h after tropical cyclone development occurred. Beginning on 6 September (5 days before landfall in Canada), the NHC intensity forecasts were also consistent in showing Larry passing near or over southeastern Newfoundland as a category 1 hurricane (Fig. 13).

Watches and warnings associated with Larry are given in Table 7. Tropical Storm Watches and Warnings were issued for Bermuda by the Bermuda Weather Service, and Tropical Storm and Hurricane Watches and Warnings were issued by the Canadian Hurricane Centre for portions of southeastern Newfoundland.

IMPACT-BASED DECISION SUPPORT SERVICES (IDSS)

NHC provided a briefing for the leadership of FEMA Regions 1, 2, and 3 on 5 September when Larry was a major hurricane east of the northern Leeward Islands. This briefing provided confidence that Larry would not be a direct threat to the United States and allowed emergency managers to remain focused on recovery from flooding impacts experienced from Hurricane Ida.

ACKNOWLEDGEMENTS

Data in Table 3 and Figures 6 and 7 were compiled from post-storm reports provided by the Bermuda Weather Service and the Canadian Hurricane Centre. David Roth of the NOAA Weather Prediction Center provided additional rainfall reports and analysis. Deanna Spindler of the NOAA Environmental Modeling Center provided the GFS Wave graphic in Figure 8.

Table 1. Best track for Hurricane Larry, 31 August–11 September 2021.

Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Stage
31 / 1800	11.5	20.6	1006	30	tropical depression
01 / 0000	11.9	22.5	1005	35	tropical storm
01 / 0600	12.2	24.5	1004	40	"
01 / 1200	12.4	26.5	1003	45	"
01 / 1800	12.5	28.4	999	55	"
02 / 0000	12.7	30.0	996	60	"
02 / 0600	13.0	31.6	991	65	hurricane
02 / 1200	13.3	33.3	987	70	"
02 / 1800	13.6	35.0	987	70	"
03 / 0000	13.9	36.7	985	75	"
03 / 0600	14.1	38.4	983	80	"
03 / 1200	14.4	40.0	980	80	"
03 / 1800	14.7	41.4	973	90	"
04 / 0000	15.2	42.7	964	100	"
04 / 0600	15.8	44.0	956	110	"
04 / 1200	16.4	45.3	956	110	"
04 / 1800	17.0	46.5	958	105	"
05 / 0000	17.7	47.5	958	105	"
05 / 0600	18.4	48.5	958	105	"
05 / 1200	19.2	49.4	953	110	"
05 / 1800	20.0	50.3	953	110	"
06 / 0000	20.7	51.2	953	110	"
06 / 0600	21.2	52.0	956	105	"
06 / 1200	21.6	52.7	956	105	"
06 / 1800	22.1	53.5	956	105	"
07 / 0000	22.7	54.2	956	105	"
07 / 0600	23.3	54.8	960	100	"
07 / 1200	24.0	55.4	963	95	"
07 / 1800	24.7	56.0	965	95	"

Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Stage
08 / 0000	25.4	56.5	966	95	"
08 / 0600	26.2	57.1	966	95	"
08 / 1200	27.2	57.9	966	90	"
08 / 1800	28.2	58.9	967	90	"
09 / 0000	29.1	59.9	968	85	"
09 / 0600	30.1	60.8	968	80	"
09 / 1200	31.3	61.5	966	80	"
09 / 1800	32.8	62.1	966	80	"
10 / 0000	34.4	62.3	966	80	"
10 / 0600	36.5	62.2	964	75	"
10 / 1200	38.9	61.1	961	70	"
10 / 1800	41.9	59.5	958	70	"
11 / 0000	45.1	56.6	958	70	"
11 / 0330	47.3	54.6	958	70	"
11 / 0600	48.8	53.3	959	65	"
11 / 1200	52.5	49.7	963	60	extratropical
11 / 1800	55.3	46.8	967	55	"
12 / 0000					absorbed by larger extratropical low
05 / 1200	19.2	49.4	953	110	maximum winds and minimum pressure
11 / 0330	47.3	54.6	958	70	landfall near Great Bona Cova, Newfoundland, Canada

Table 2. Selected ship reports with winds of at least 34 kt for Hurricane Larry, 31 August–11 September 2021.

Date/Time (UTC)	Ship call sign	Latitude (°N)	Longitude (°W)	Wind dir/speed (kt)	Pressure (mb)
02 / 0700	9V8838	14.6	35.0	050 / 35	1009.7
02 / 1100	9V8838	15.4	35.9	050 / 37	1015.6
02 / 1800	9V8838	17.0	37.8	060 / 35	1012.2
03 / 0500	9V8838	19.0	40.1	060 / 37	1013.5
10 / 0600	9V9404	33.1	63.6	250 / 35	

Table 3. Selected surface observations for Hurricane Larry, 31 August–11 September 2021.

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Estimated Inundation (ft)[e]	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)				
Bermuda									
L.F. Wade Intl. Airport (32.36°N 64.67°W)	09/2035	1004.3	9/2029	29	37				
L.F. Wade Intl. Aiport Heliport (32.36°N 64.67°W)			10/0017	28[f]	42				
Pearl Island AWOS (32.37°N 64.70°W)			9/1904	36[f]	40				
The Crescent (32.41°N 64.82°W)			9/2024	32[g]	39				
Marine Ops Centre MAROPS (32.38°N 64.68°W)			9/2019	40[f]	46				
National Museum Bermuda (32.33°N 64.83°W)			9/2122	37	45				
Canada									
Cape St. Mary's Lighthouse (46.823°N 54.195°W)			11/0300	69[i]	98[i]				
Cape Pine Lighthouse (46.618°N 53.533°W)					80[i]				
St. John's Airport (47.619°N 52.752°W)	11/0500	979.9	11/0600	52	74	1.6	5.6		0.83
Cape Race (46.66°N 53.076°W)	11/0400	980.4	11/0400	59	78				
Bell Island (47.655°N 52.916°W)					77[i]				
Green Island (46.880°N 56.084°W)					76[i]				
Bay Roberts (47.613°N 53.224°W)					74[i]				
Grates Cove (48.172°N 52.939°W)	11/0600	977.9	11/0600	58	74				
Long Harbour (47.424°N 53.766°W)					71				
Bishop's Cove (47.07°N 53.02°W)					70				

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Estimated Inundation (ft)[e]	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)				
Cape Bonavista Lighthouse (48.700°N 53.085°W)					70				
Robin Hood Bay (47.605°N 52.671°W)					69				
St Mary's (46.91°N 53.57°W)					67				
Bonavista (48.667°N 53.114°W)	11/0700	977.6	11/0700	43	66	2.0	4.6		1.24
St. John's West (47.513°N 52.783°W)	11/0600	982.5	11/0500	33	62				0.99
St. Lawrence (46.917°N 55.383°W)	11/0300	960.8	11/0200	35	52	4.9	11.9	3.2	1.08
Winterland (47.136°N 55.328°W)	11/0500	965.8	11/0500	34	47				1.03
Terra Nova (48.557°N 53.974°W)	11/0500	960.7	11/0800		60				
Argentia (47.290°N 53.992°W)						5.0	12.0	3.2	
Port-Aux Basques (47.573°N 59.153°W)						1.6	7.2		
Port Rexton (48.39°N 53.33°W)									1.48
Mount Pearl (47.520°N 52.828°W)									1.38
St. John's (4.3 NNE) (47.595°N 52.687°W)									1.25
L'Anse Au Loup (51.520°N 56.837°W)									1.03
Harcourt (48.2N 53.87W)									1.02
Twillingate (49.683°N 54.8°W)									0.95
Lethbridge (48.35°N 53.9°W)									0.91
St. Anthony (51.383°N 56.1°W)									0.89
Salmonier (47.05°N 55.21°W)									0.83
Gander (2.7 NW) (48.95°N 54.567°W)									0.75
Lewisporte (49.244°N 55.065°W)									0.71
Grand Falls-Windsor (48.931°N 55.653°W)									0.69

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Estimated Inundation (ft)[e]	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)				
Offshore									
Buoy 44139 (44.24°N 57.10°W)	10/2300	962.0	10/2200	48	62				
Buoy 44137 (44.26°N 62.03°W)	10/1700	994.7	10/2200	26	35				
Mouth of Placentia (46.974°N 54.695°W)	11/0400	971.0	11/0400	45	56				
Fortune Bay (47.261°N 55.503°W)	11/0300	971.8	11/0300	37	48				
AZMP-STA27 (47.538°N 52.588°W)	11/0500	977.5	11/0500	45	76				
Hibernia Rig, Grand Banks (46.750°N 48.783°W)	11/1200	1008.3	11/1200	51					
Hebron Rig, Grand Banks (46.544°N 48.498°W)	11/1200	1007.3	11/1200	45					

[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.
[c] Storm surge is water height above normal astronomical tide level.
[d] Storm tide is water height above the local chart datum.
[e] Estimated inundation is the maximum height of water above ground. For Canada, the height of the water above Higher High Water Large Tide (HHWLT), which is equivalent to Mean Higher High Water (MHHW) in the United States, is used as a proxy for inundation.
[f] 1-minute average
[g] 10-minute average
[i] Incomplete

Table 4. Number of hours in advance of formation associated with the first NHC Tropical Weather Outlook forecast in the indicated likelihood category. Note that the timings for the "Low" category do not include forecasts of a 0% chance of genesis.

	Hours Before Genesis	
	48-Hour Outlook	**120-Hour Outlook**
Low (<40%)	60	96
Medium (40%-60%)	42	84
High (>60%)	24	66

Table 5a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) track forecast errors (n mi) for Hurricane Larry, 31 August–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	**17.4**	**22.8**	**28.8**	**35.3**	**43.3**	**50.1**	**63.7**	**87.0**
OCD5	39.1	84.0	122.6	155.8	180.3	202.2	228.8	204.5
Forecasts	41	39	37	35	33	31	27	23
OFCL (2016-20)	23.9	36.3	49.1	63.9	83.7	94.1	128.1	169.7
OCD5 (2016-20)	45.1	97.2	157.2	216.7	257.6	325.4	414.4	490.0

Table 5b. Homogeneous comparison of selected track forecast guidance models (in n mi) for Hurricane Larry, 31 August–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 5a due to the homogeneity requirement.

Model ID	Forecast Period (h)							
	12	24	36	48	60	72	96	120
OFCL	16.2	21.2	26.3	31.5	37.5	43.4	54.9	78.7
OCD5	34.2	72.4	119.0	150.7	173.8	195.8	221.3	194.9
GFSI	16.7	26.6	39.0	51.6	62.4	71.8	85.6	122.2
HMNI	16.3	22.0	35.1	44.0	52.2	56.6	71.8	126.5
HWFI	19.1	29.0	37.9	49.8	62.6	79.9	112.7	150.2
EGRI	18.4	28.1	38.8	47.8	57.1	71.0	112.8	175.9
EMXI	**14.3**	21.2	29.0	36.1	44.7	50.7	70.3	85.1
CMCI	18.5	30.9	44.8	55.1	66.4	78.6	88.5	79.4
NVGI	22.0	36.3	56.1	67.4	81.1	97.7	117.8	142.2
CTCI	16.9	24.6	36.1	45.9	52.4	59.7	85.3	136.4
AEMI	16.9	28.1	37.6	46.5	56.5	67.8	90.7	111.5
HCCA	**15.1**	21.6	28.5	32.9	**37.3**	**43.2**	**54.1**	**76.4**
FSSE	16.7	**20.3**	26.7	**28.9**	**32.5**	**42.9**	59.3	88.9
TVCX	**14.1**	**18.1**	**23.3**	**27.4**	**32.4**	**39.0**	**50.3**	**68.3**
GFEX	**14.7**	**19.7**	27.2	33.5	38.8	44.8	56.1	79.6
TVCA	**14.7**	**18.7**	**23.7**	**29.2**	**33.2**	**41.2**	**53.4**	**72.9**
TVDG	**14.6**	**18.1**	**22.6**	**26.8**	**31.7**	**38.2**	**48.9**	**69.7**
TABD	21.5	37.4	59.4	84.6	111.7	135.0	188.3	221.9
TABM	24.3	35.7	51.3	69.0	87.1	106.8	125.8	144.1
TABS	27.2	41.0	61.0	79.9	100.5	120.5	144.5	152.2
Forecasts	38	36	35	33	31	29	25	21

Table 6a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) intensity forecast errors (kt) for Hurricane Larry, 31 August–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	**4.8**	**7.7**	**7.8**	**8.9**	**9.7**	**11.1**	**13.1**	**12.8**
OCD5	5.9	8.5	9.8	11.6	11.8	12.7	13.3	15.9
Forecasts	41	39	37	35	33	31	27	23
OFCL (2016-20)	5.4	8.0	9.6	10.9	11.5	12.1	13.3	14.5
OCD5 (2016-20)	7.0	11.0	14.3	16.8	18.5	19.7	21.7	23.0

Table 6b. Homogeneous comparison of selected intensity forecast guidance models (in kt) for Hurricane Larry, 31 August–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 6a due to the homogeneity requirement.

Model ID	Forecast Period (h)							
	12	24	36	48	60	72	96	120
OFCL	4.9	7.8	7.8	8.9	9.7	11.1	13.1	12.8
OCD5	6.1	8.6	9.8	11.6	11.8	12.7	13.3	15.9
GFSI	6.8	9.3	10.9	12.0	13.2	13.4	**12.6**	13.4
HMNI	5.3	**7.7**	9.8	12.7	14.7	13.9	14.6	14.0
HWFI	5.8	**7.5**	9.0	9.3	**9.3**	**10.0**	**9.4**	**8.6**
CTCI	5.7	**6.4**	**7.6**	10.3	12.3	13.6	17.5	15.5
EMXI	9.9	16.1	18.5	19.9	18.9	16.5	**13.0**	**8.8**
DSHP	6.3	9.3	10.3	11.1	10.0	**9.8**	**11.3**	12.9
LGEM	6.7	9.6	11.7	12.1	10.6	**10.5**	13.8	15.1
ICON	5.1	**6.4**	**7.5**	**7.9**	**8.4**	**8.4**	**8.7**	**7.3**
IVCN	4.9	**5.9**	**6.3**	**5.9**	**5.5**	**6.2**	**7.0**	**7.0**
IVDR	5.0	**5.9**	**6.6**	**6.3**	**6.1**	**6.0**	**5.7**	**5.0**
HCCA	5.4	**7.1**	**6.8**	**4.9**	**4.7**	**6.3**	**10.7**	**12.0**
Forecasts	40	38	37	35	33	31	27	23

Table 7. Watch and warning summary for Hurricane Larry, 31 August–11 September 2021.

Date/Time (UTC)	Action	Location
7 / 1500	Tropical Storm Watch issued	Bermuda
8 / 1200	Tropical Storm Watch changed to Tropical Storm Warning	Bermuda
9 / 0600	Hurricane Watch issued	St. Schotts to Pouch Cove
9 / 0600	Tropical Storm Watch issued	Lamaline to St. Schotts
9 / 0600	Tropical Storm Watch issued	Pouch Cove to Bonavista
9 / 2100	Hurricane Warning issued	Arnold's Cove to Jones Harbour
9 / 2100	Tropical Storm Warning issued	Lamaline to Arnold's Cove
9 / 2100	Tropical Storm Warning issued	Jones Harbour to Bonavista
9 / 2100	Hurricane Watch discontinued	All
9 / 2100	Tropical Storm Watch discontinued	All
10 / 0000	Tropical Storm Warning discontinued	Bermuda
10 / 0900	Tropical Storm Warning modified to	Francois to Arnold's Cove
10 / 0900	Tropical Storm Warning modified to	Jones Harbour to Fogo Island
11 / 0600	Tropical Storm Warning discontinued	Francois to Arnold's Cove
11 / 0900	Hurricane Warning discontinued	All
11 / 0900	Tropical Storm Warning discontinued	All

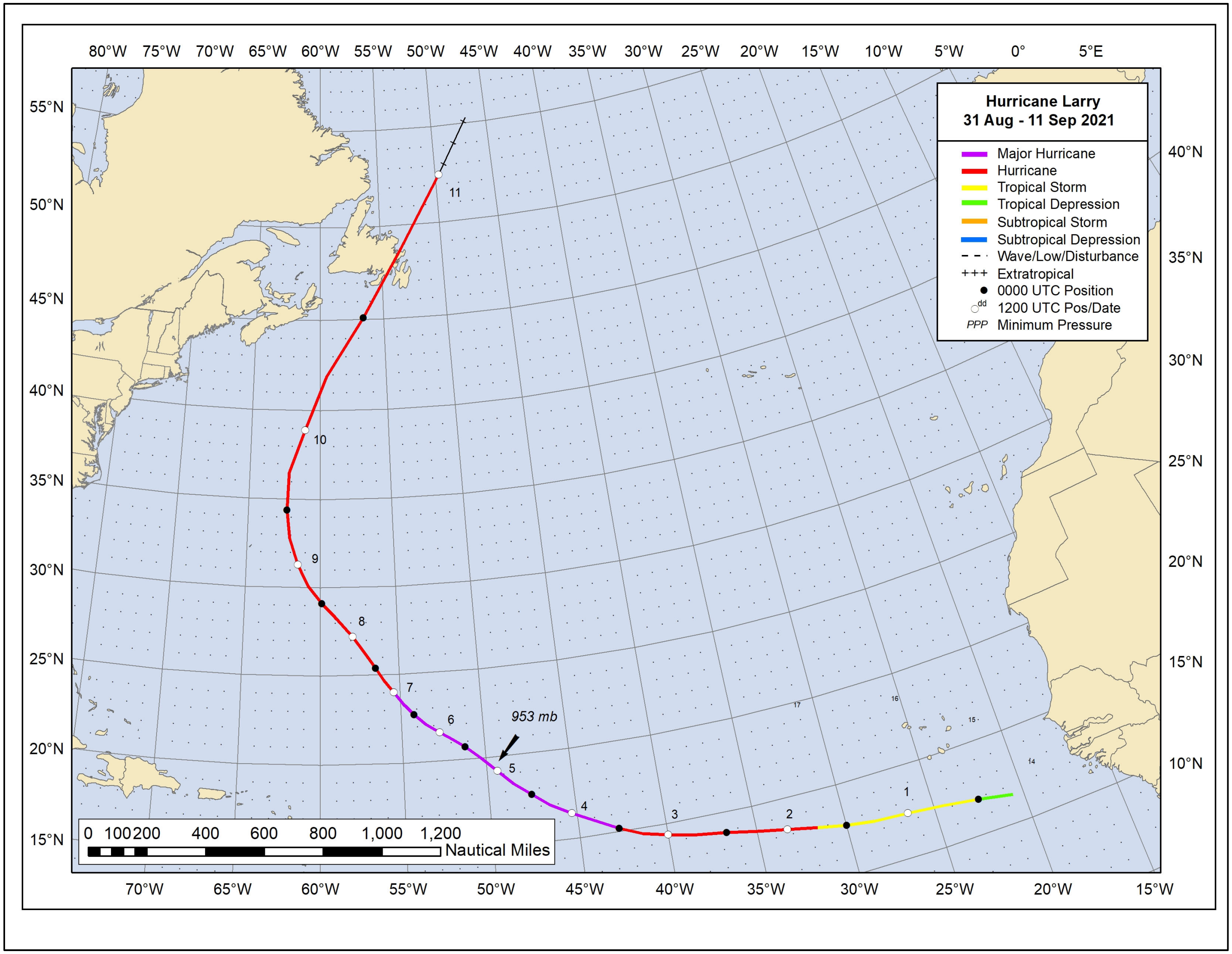


Figure 1. Best track positions for Hurricane Larry, 31 August–11 September 2021. Track during the extratropical stage is partially based on analyses from the NOAA Ocean Prediction Center.

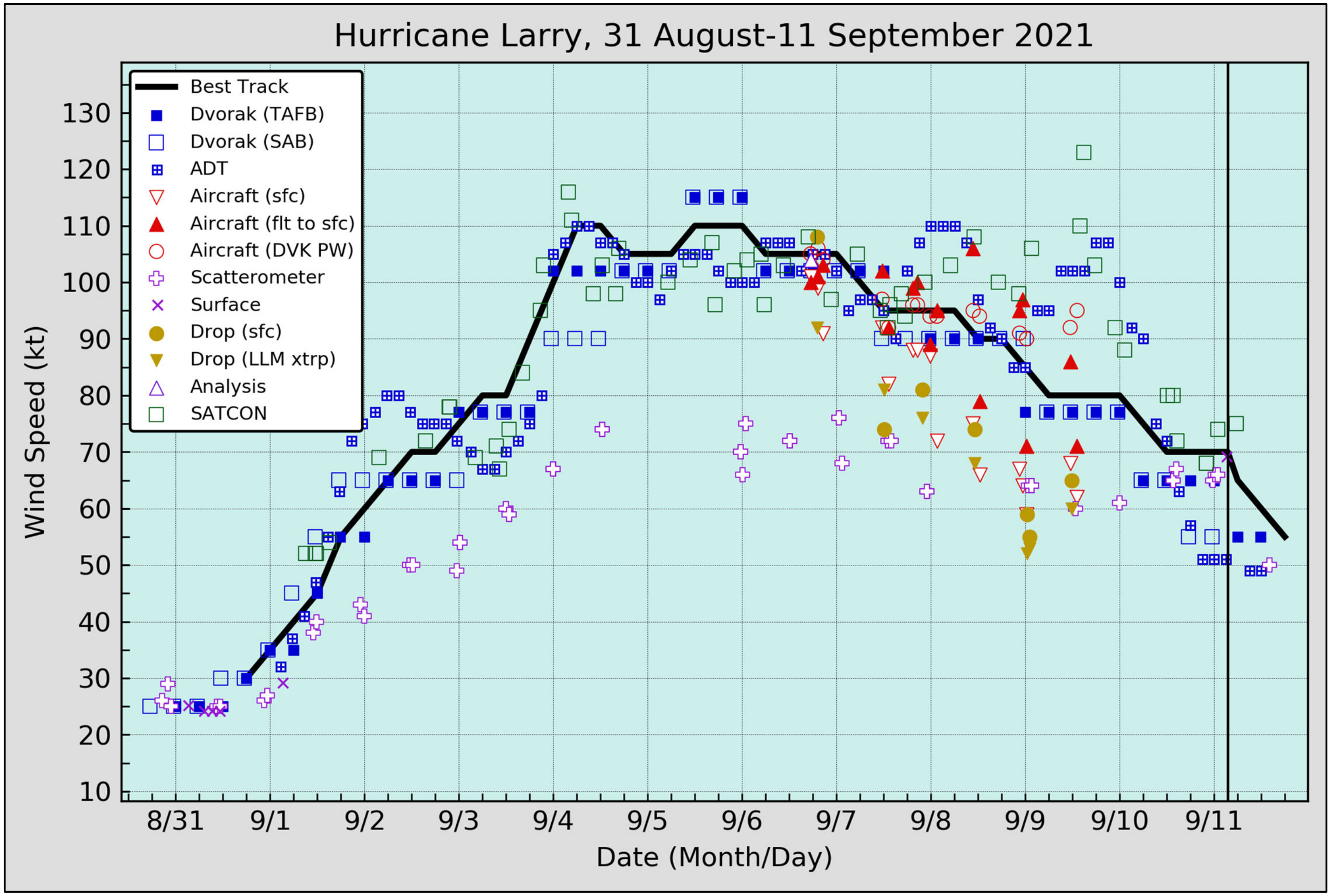


Figure 2. Selected wind observations and best track maximum sustained surface wind speed curve for Hurricane Larry, 31 August–11 September 2021. Aircraft observations have been adjusted for elevation using 90%, 80%, and 80% adjustment factors for observations from 700 mb, 850 mb, and 1500 ft, respectively. Dropwindsonde observations include actual 10 m winds (sfc), as well as surface estimates derived from the mean wind over the lowest 150 m of the wind sounding (LLM). Advanced Dvorak Technique estimates represent the Current Intensity at the nominal observation time. SATCON intensity estimates are from the Cooperative Institute for Meteorological Satellite Studies. Dashed vertical lines correspond to 0000 UTC, and the solid vertical line corresponds to landfalls.

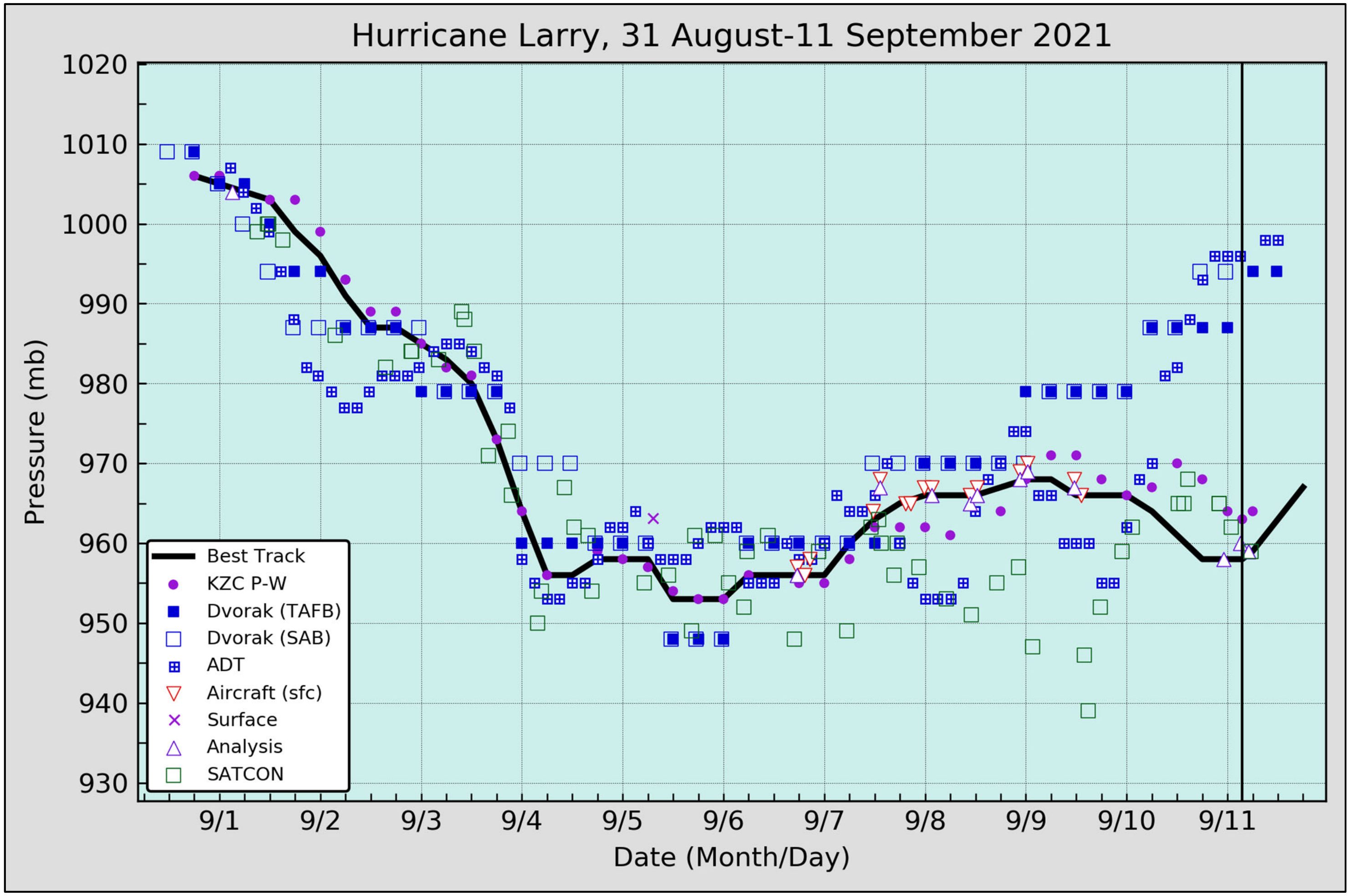


Figure 3. Selected pressure observations and best track minimum central pressure curve for Hurricane Larry, 31 August–11 September 2021. Advanced Dvorak Technique estimates represent the Current Intensity at the nominal observation time. SATCON intensity estimates are from the Cooperative Institute for 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, and the solid vertical line corresponds to landfalls.

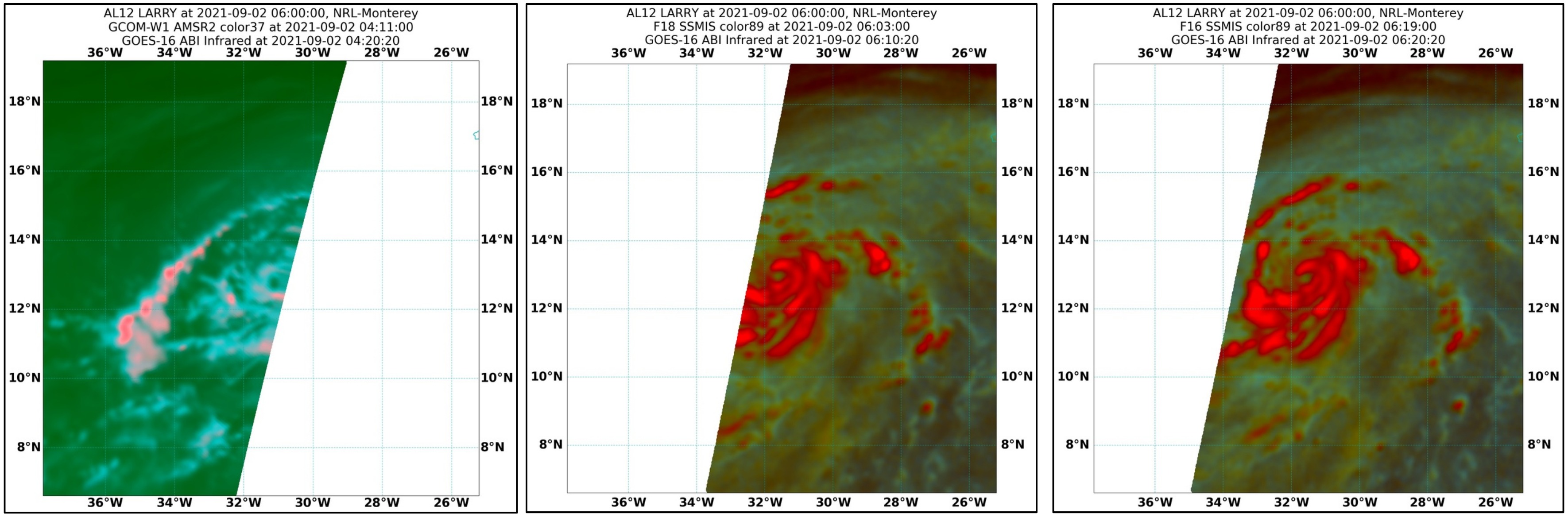


Figure 4. Series of microwave images of Larry around the time the tropical cyclone is estimated to have reached hurricane strength. The image on the left is a AMSR2 37-GHz color composite image from 0420 UTC 2 September that revealed a tight inner core and low-level ring. The middle and right images are 89-GHz color composite images from F-18 and F-16 SSMIS satellites at 0610 UTC and 0620 UTC 2 September, respectively. Those images showed the presence of a well-defined mid-level eye feature.

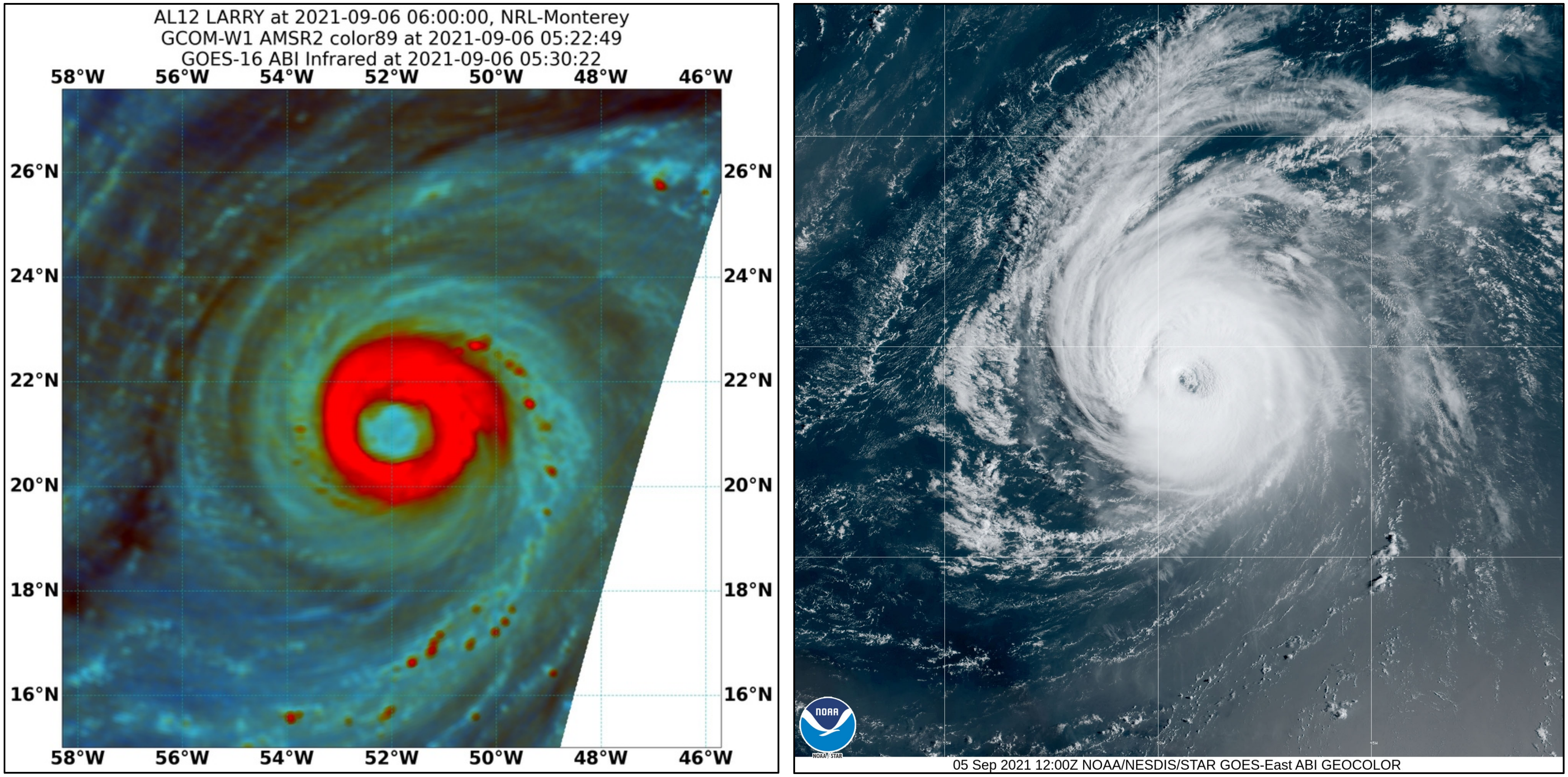


Figure 5. AMSR2 89-GHz color composite microwave image of Hurricane Larry at 0522 UTC 6 September (left) and GOES-16 Geocolor image of the hurricane at 1200 UTC the same day. Larry is estimated to have reached it second peak intensity of 110 kt by 1200 UTC that day. Note the 40–50 n-mi-wide eye and lack of outer banding, features that denote the annular hurricane characteristics of Larry at that time.

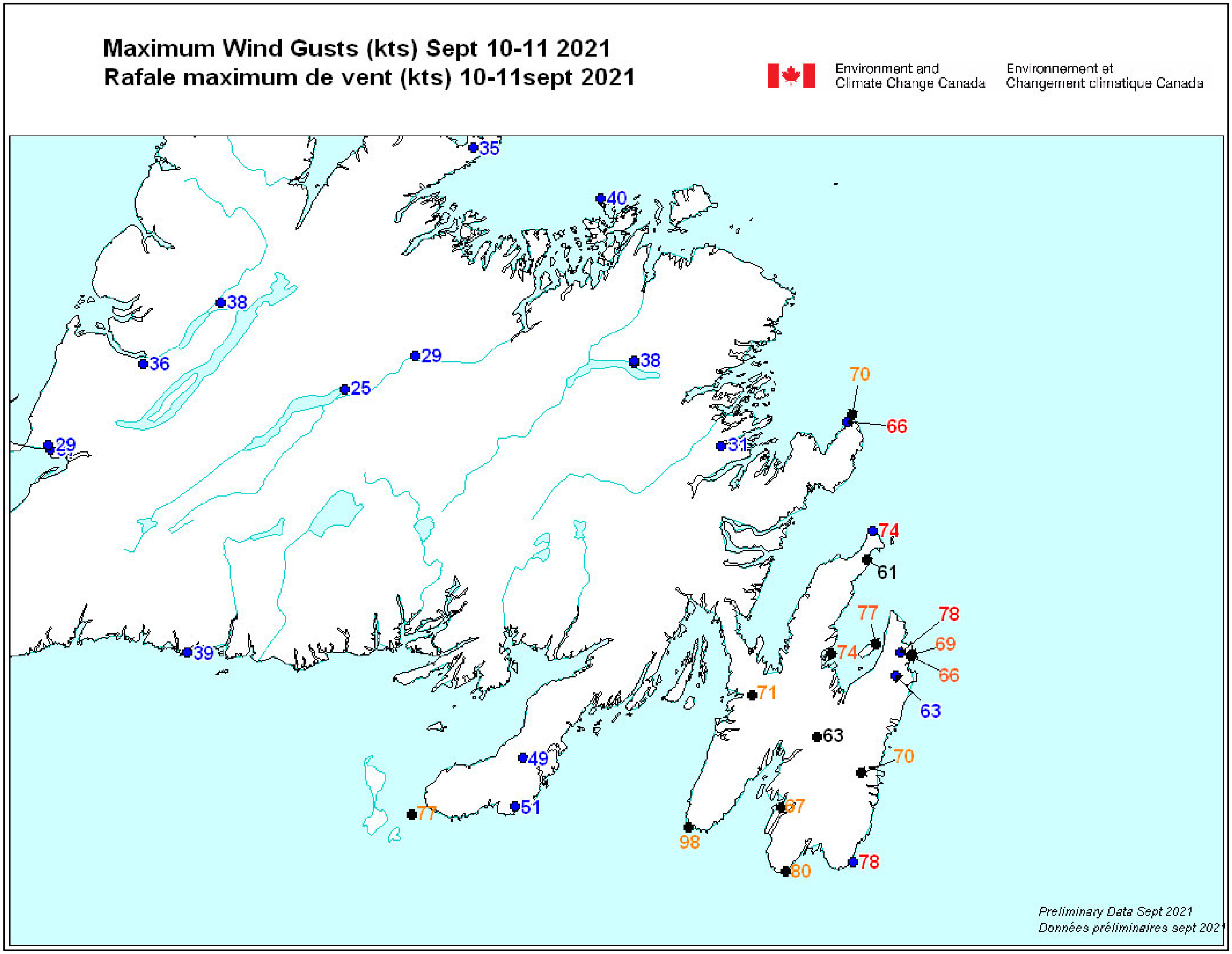
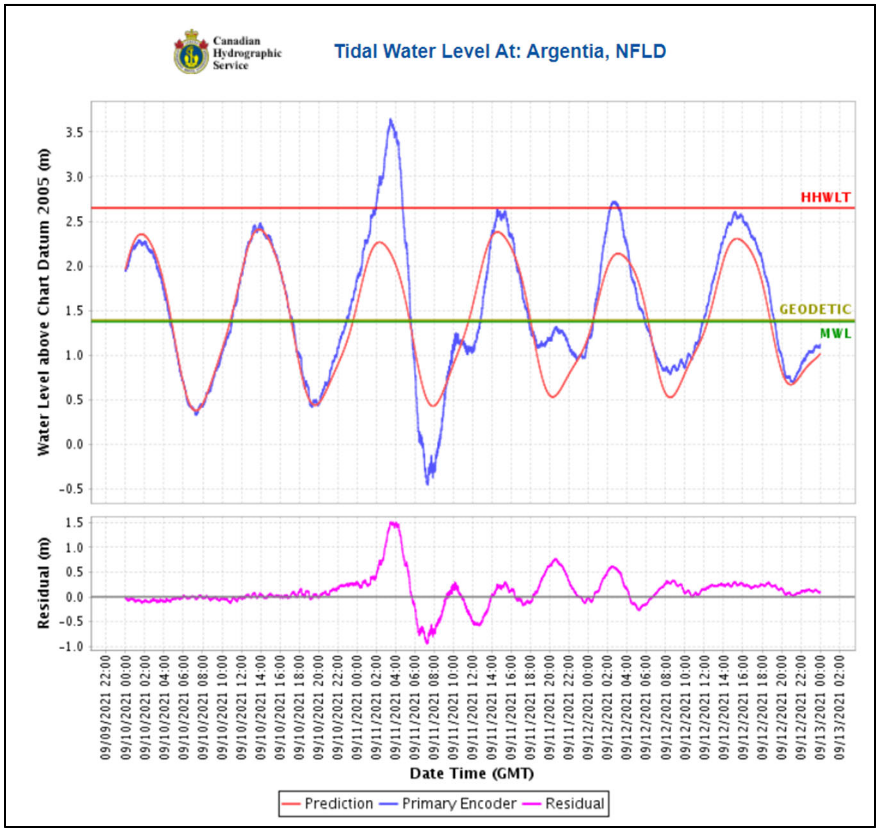


Figure 6. Map of peak wind gusts (kt) across Newfoundland in association with Hurricane Larry on 10–11 September 2021. Map courtesy of Environment and Climate Change Canada.



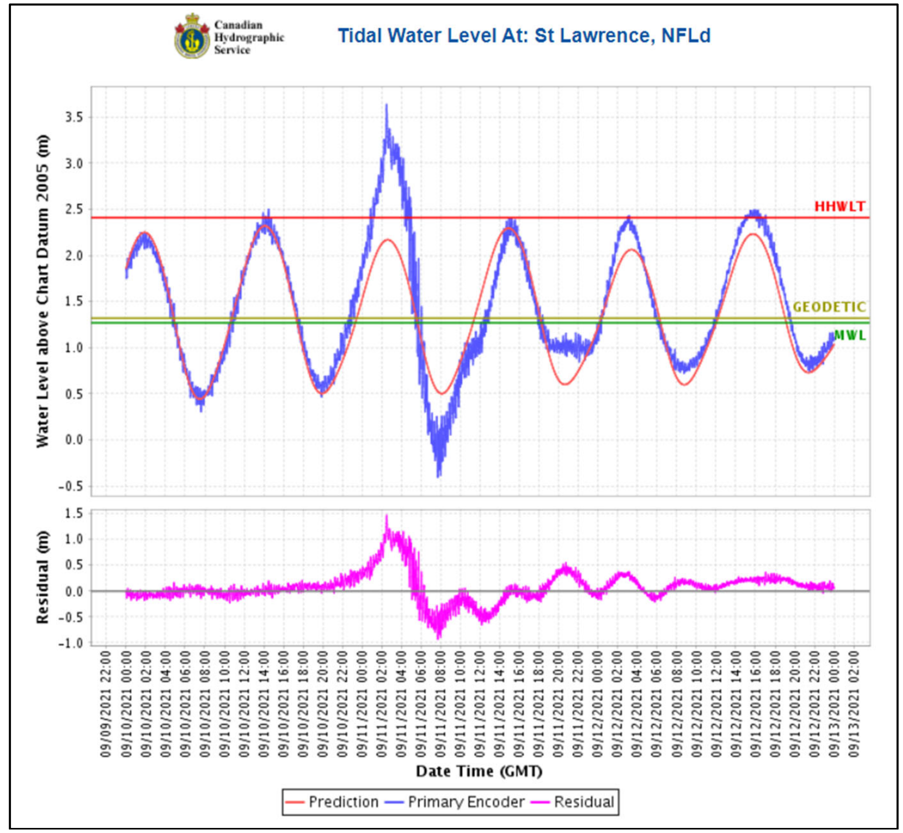


Figure 7. Water levels (m, blue lines) in Newfoundland, Canada, at Argentia (left) and St. Lawrence (right) from 9 to 13 September. Note the sharp rise in water levels beginning late on 10 September as the center of Larry approached the coastline. The bottom graphic in both figures (magenta lines) shows the residual or storm surge values relative to normal time levels at each location. The red line on the top graph represents Higher High Water Large Tide (HHWLT) which is a proxy for inundation on normally dry ground and is equivalent to Mean Higher High Water (MHHW) in the United States.

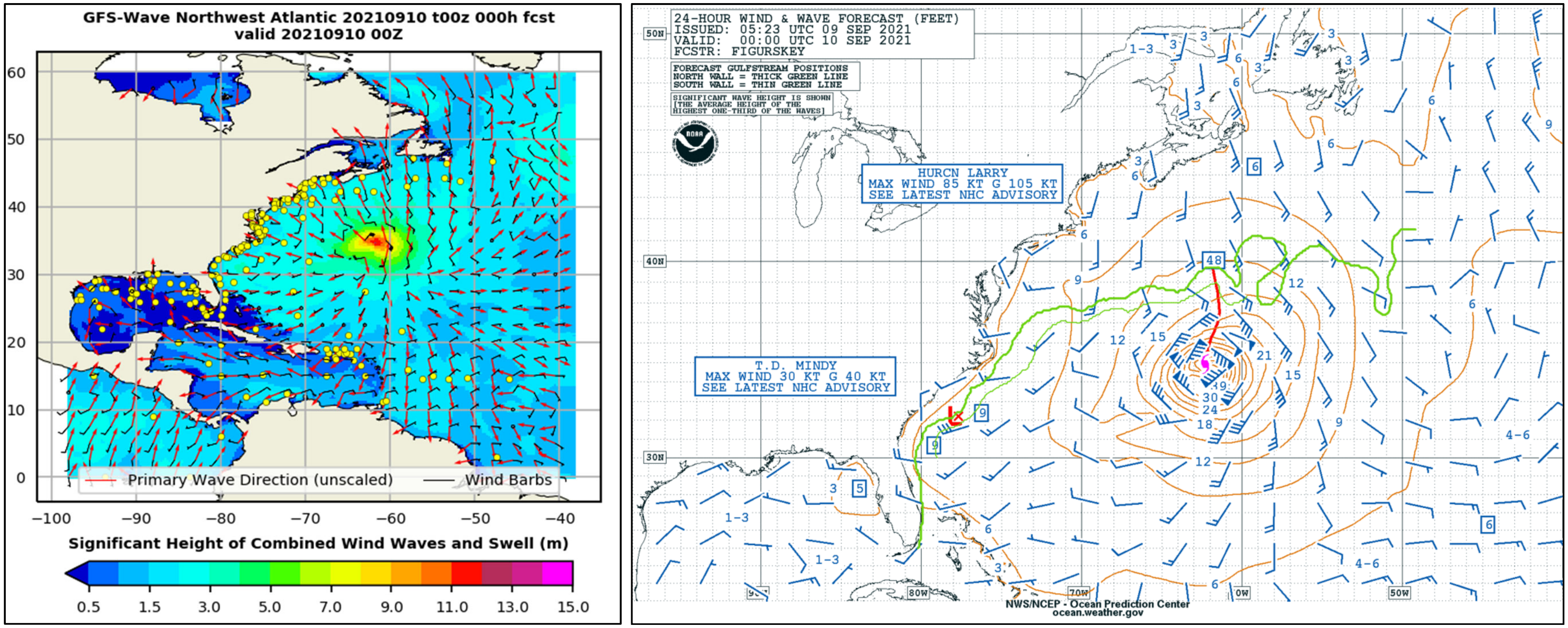


Figure 8. GFS-Wave significant wave height model analysis (m, left) and NOAA Ocean Prediction Center wind and wave 24-h forecast (ft, right) valid at 0000 UTC 10 September. Note the large wave and swell field (red arrows in left image) extending from Hurricane Larry that covers most of the western Atlantic. The swells were responsible for high surf and rip currents along many of the western Atlantic beaches and resulted in 5 direct drowning fatalities.

Figure 9. Wind damage at the Mary Queen of Peace Elementary School in St. John’s, Newfoundland. Photo courtesy Josh Gushue/CBC via the Canadian Hurricane Centre.

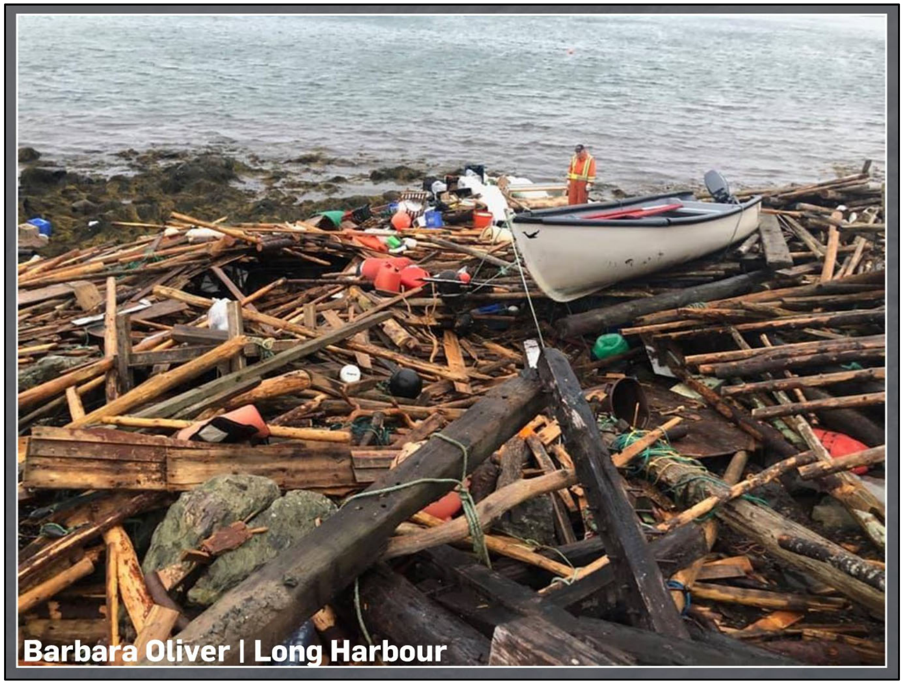


Figure 10. Flooding from storm surge (left) at Fortune on the Burin Peninsula, Newfoundland and damage from wave action and storm surge (right) at Long Harbour. Storm surge flooding photo (left) courtesy Matt Woodland via Facebook and the Canadian Hurricane Center. Wave action damage photo (right) courtesy Barbara Oliver via the Canadian Hurricane Centre.

Figure 11. Examples of overwash, damage, and debris along low-lying roads along the south-facing coastline of the Avalon Peninsula in Newfoundland after the passage of Hurricane Larry. The top two pictures are along on Route 90 at St. Vincent's and the bottom photos are of Route 92-10 (Lower Road North Harbour). Photos courtesy of the Government of Newfoundland and Labrador.

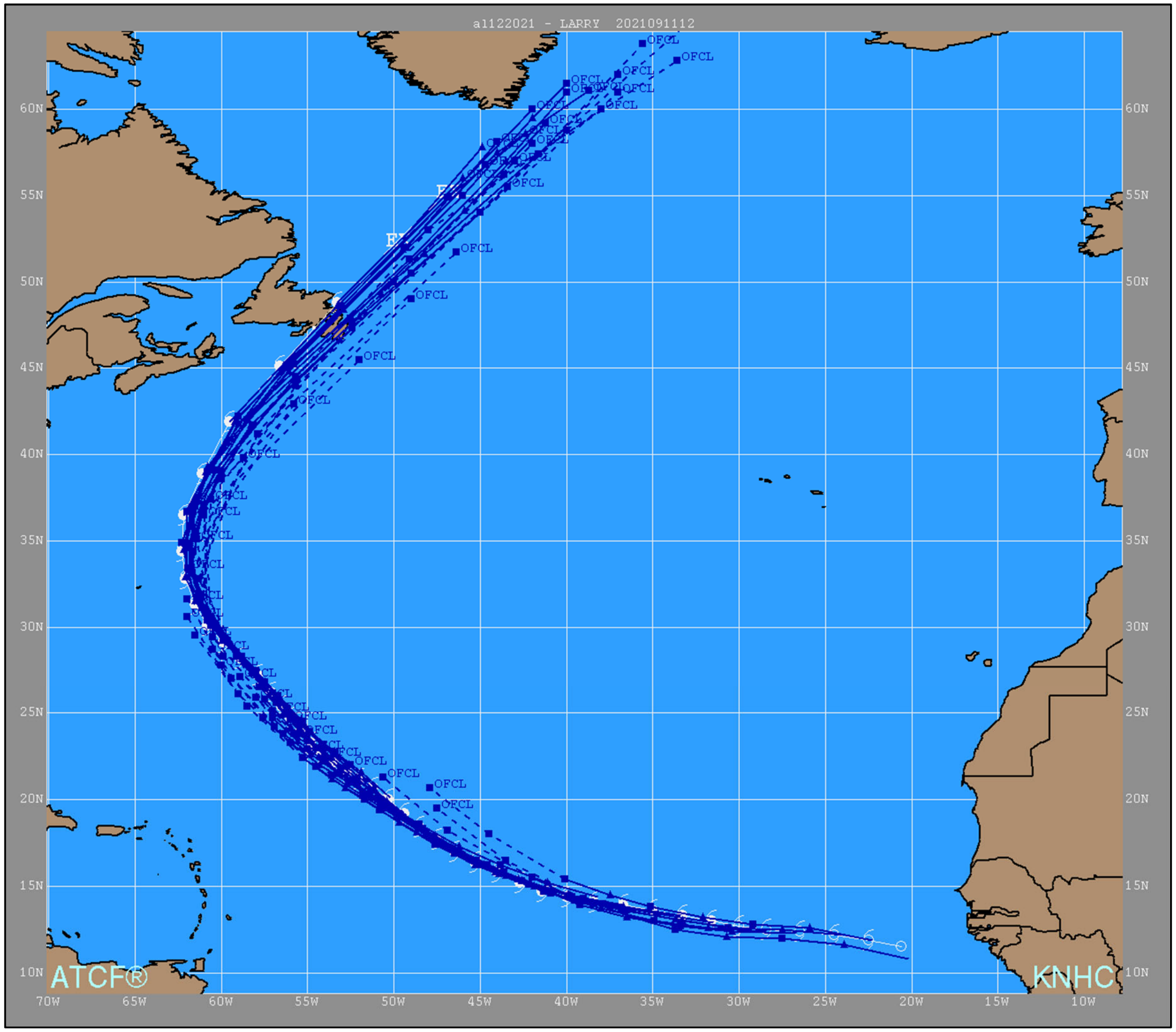


Figure 12. NHC official forecasts (dark blue lines) for Hurricane Larry, 31 August–11 September 2021. Larry's actual track is denoted by the white tropical storm and hurricane symbols plotted at 6-h intervals.

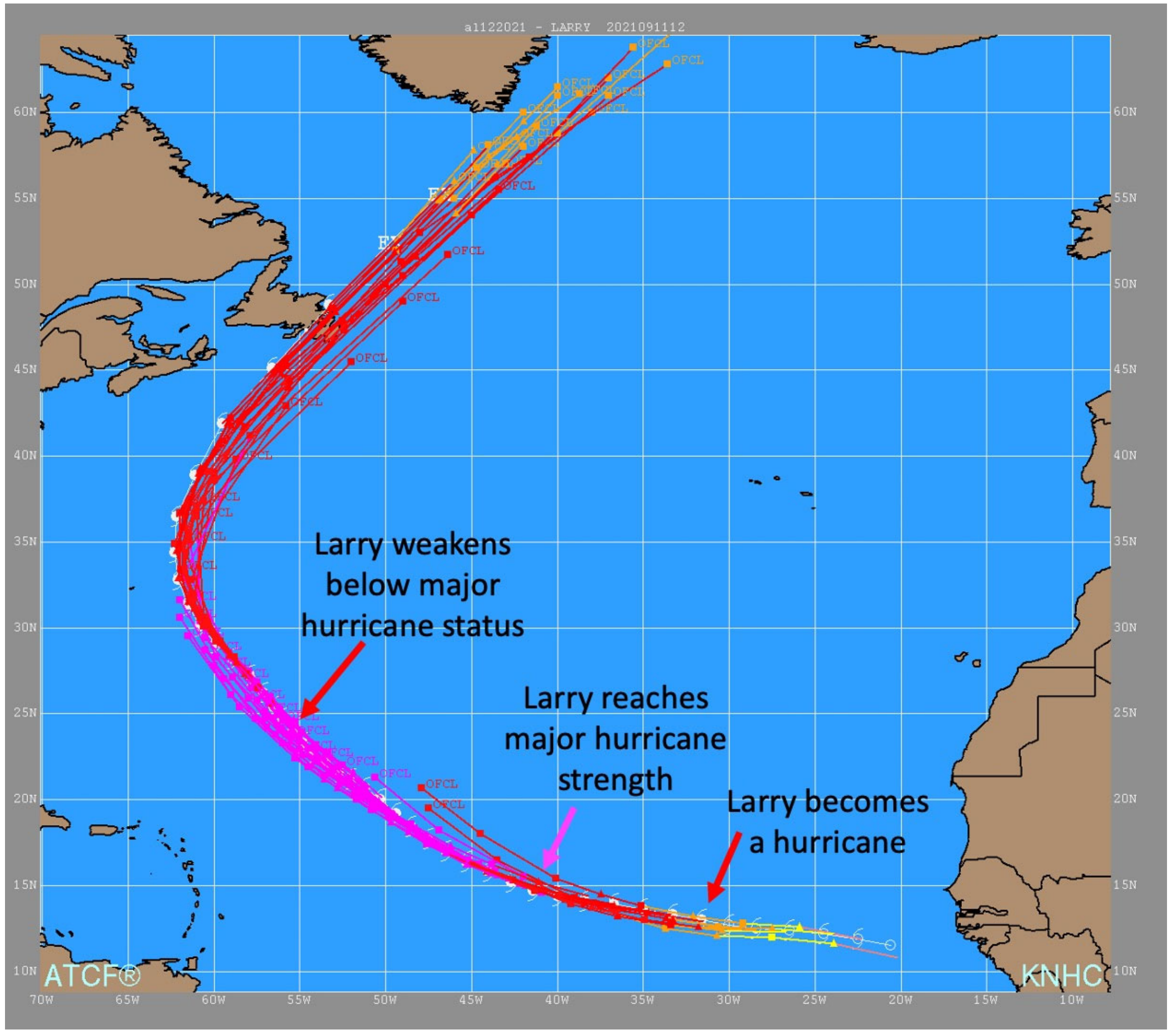


Figure 13. Same as figure 12, but color coded by forecast intensity (yellow – tropical storm, red – category 1 and 2 hurricanes, magenta – major hurricane).