NATIONAL HURRICANE CENTER TROPICAL CYCLONE REPORT

HURRICANE LEE

(AL132023)

5–16 September 2023

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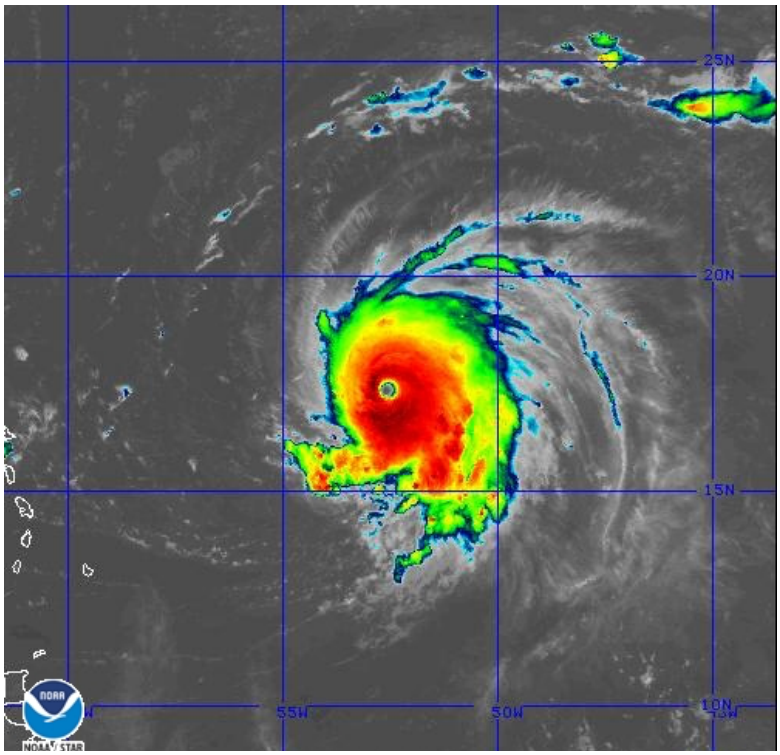

GOES-16 INFRARED IMAGE OF HURRICANE LEE AT 0400 UTC 8 SEPTEMBER 2023 NEAR THE TIME OF PEAK INTENSITY. IMAGE COURTESY OF NOAA/NESDIS STAR.

Lee was a classical September Cabo Verde hurricane that formed over the tropical Atlantic. It explosively intensified into a category 5 hurricane, but moved north of the Leeward Islands and avoided land as a hurricane. Lee became post tropical before making landfall over Nova Scotia with some wind, storm surge and rainfall impacts. Although overall damage was relatively minor, four direct deaths were noted, all in the United States.

Hurricane Lee

5–16 SEPTEMBER 2023

SYNOPTIC HISTORY

Lee formed from a strong tropical wave that moved off the west coast of Africa late on 1 September with a large area of disorganized showers and thunderstorms. While the associated deep convection waned the next day, a mid-level circulation formed on 3 September due to a resurgence of mostly diurnal convection a few hundred miles southwest of the Cabo Verde Islands. A broad surface low pressure area was noted near the mid-level center on 4 September, and a concentrated area of deep convection formed overnight on 5 September. Satellite and scatterometer data indicated that the surface low had become well-defined by 1200 UTC 5 September, marking the formation of a tropical depression about midway between the Windward Islands and the coast of west Africa. The depression became a tropical storm 6 h later. The "best track" chart of Lee'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].

Lee intensified quickly, at times rapidly, over the ensuing 36 h or so in an environment of low-to-moderate shear, high mid-level moisture and warm SSTs. In fact, Lee became a hurricane just 24 h and a major hurricane 48 h after it became a tropical storm, respectively. Early on 7 September, the vertical wind shear diminished while the hurricane moved over even warmer water, promoting a period of explosive intensification with Lee strengthening about 70 kt in 24 h. This resulted in Lee becoming a category 5 hurricane (on the Saffir-Simpson Hurricane Wind Scale) with a peak intensity of 145 kt at 0600 UTC 8 September (cover) as the hurricane continued to move west-northwestward several hundred miles east of the Leeward Islands. An increase in southwesterly shear caused the cyclone to rapidly weaken later on 8 September, and Lee gradually weakened on 9 September below major hurricane strength, still moving west-northwestward but a bit slower. The eyewall convection of Lee became more solid on 10 September, and Lee re-intensified while also becoming quite a bit larger. Lee reached a second peak intensity of 105 kt early on 11 September, and it began a series of eyewall replacement cycles, as shown by aircraft reconnaissance data and synthetic-aperture-radar (SAR) imagery (Fig. 4), while it moved about midway between Puerto Rico and Bermuda. Although the minimum central pressure changed little for a day or two, Lee continued to grow in size with only a slight decrease in maximum winds. Aircraft data showed that hurricane-force winds extended up to 110 n mi away from the center by early on 13 September.

The environment around Lee was changing on 13 September, with the tropical cyclone finding a break in the now-weak west Atlantic subtropical ridge, causing Lee to turn northward as a large trough moved across the northeastern United States. Increasing westerly shear and

[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.

upwelling of cooler waters under the large hurricane contributed to gradual weakening while Lee moved slowly northward over the next couple of days. Another shortwave trough in the northeastern United States dove down the west side of Lee on 15 September, initiating extratropical transition, along with increasingly southerly environmental shear bringing in drier air near the cyclone. Lee became a hurricane-force extratropical cyclone near 0600 UTC 16 September, a few hundred miles south of southwestern Nova Scotia. The post-tropical cyclone gradually weakened while it moved north of the Gulf Stream over cooler waters and within high shear, making landfall on Long Island, in southwestern Nova Scotia, later that day around 2000 UTC with maximum sustained winds of about 55 kt well east of the center. Lee then moved across the Bay of Fundy, New Brunswick, and Prince Edward Island during the next 18 h or so, crossing the Gulf of St. Lawrence while continuing to gradually weaken. The cyclone moved across northern Newfoundland and then out in the open North Atlantic on 18 September before eventually merging with another extratropical low by 0000 UTC 19 September, several hundred miles east of Labrador.

METEOROLOGICAL STATISTICS

Observations in Lee (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 30 flights of the 53rd Weather Reconnaissance Squadron (WRS) of the U.S. Air Force Reserve Command and NOAA's Aircraft Operations Center (flight paths and 69 center fixes are shown in Fig. 5). 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 Lee.

Ship reports of winds of tropical storm force associated with Lee are given in Table 2, and selected Canadian surface observations from land stations are given in Table 3. A supplemental file containing a larger selection of surface and buoy observations is available for download on the NHC website at https://www.nhc.noaa.gov/data/tcr/supplemental/lee.zip. This file also contains rainfall reports from National Weather Service Cooperative (COOP) stations and the Community Collaborative Rain, Hail and Snow Network (CoCoRaHS) sites.

Winds and Pressure

Lee's peak intensity of 145 kt was based on a blend of 700-mb flight-level winds of 153 kt near 0454 UTC 8 September (reducing to about 140 kt at the surface using the standard reduction factor from that level) and peak corrected SFMR values of 145-150 kt (based on recent research showing a 5-10 kt high bias of SFMR data at high wind speeds).

Lee's estimated minimum pressure of 926 mb was based on dropsonde data, with 928 mb and 20 kt of wind recorded near 0455 UTC 8 September. Notably, there was a rise from 928 mb at 1025 UTC 8 September to 940 mb just 76 minutes later -- quite a remarkable filling over open water in such a short period of time.

At Lee's landfall in Nova Scotia as an extratropical cyclone, the intensity of 55 kt was based on earlier scatterometer data with the central pressure of 970 mb extrapolated from previous aircraft data and estimates from the Canadian Hurricane Centre.

Across Canada, sustained tropical-storm-force winds (mostly as Lee was a post-tropical cyclone) occurred with some gusts near hurricane force. The peak measured wind gust report was 63 kt at Halifax Airport (Table 3), though some unofficial reports near Longs Eddy Point, Grand Manan, New Brunswick were near 80 kt.

In Bermuda, LF Wade International Airport (TXKF) reported 10-min sustained winds of 47 kt at 2346 UTC 14 September with a peak wind gust of 65 kt recorded 8 minutes earlier, and a minimum pressure of 997.8 mb.

For the United States, sustained tropical-storm-force winds (as a post-tropical cyclone) occurred across much of the immediate coast of New England from southeastern Massachusetts northward to Downeast Maine. The highest sustained wind from a land-based United States station was 40 kt, recorded both at Eastport, Maine, and Hatch Beach, Massachusetts, with peak gusts to about 55 kt. A full table of U.S. wind and pressure observations is located at https://www.nhc.noaa.gov/data/tcr/supplemental/lee.zip.

Storm Surge[2]

Across Canada, the Canadian Hurricane Centre reported storm surge of 3 to 5 ft above mean water levels from Lee as a post-tropical cyclone across coastal communities in southwestern Nova Scotia. The storm surge along with high astronomical tide and significant wave action caused impacts in coastal communities. A Canadian Hydrographic Service tide gauge in Halifax, Nova Scotia, measured 4.8 ft above mean water level and 2.4 ft above Higher High Water Mean Tide (HHWMT; a tidal datum similar to MHHW).

The combination of Lee's storm surge and tides produced inundation of 1 to 2 ft above ground level (AGL) along portions of the New England coast from Narragansett, Rhode Island, to Newburyport, Massachusetts, including Nantucket and Martha's Vineyard. Fig. 6 provides the peak storm surge observations from various National Ocean Service (NOS) tide gauges and

[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, i.e. the North American Vertical Datum of 1988 (NAVD88) or Mean Lower Low Water (MLLW). **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 Mean Higher High Water (MHHW).

United States Geological Survey (USGS) stream gauges referenced as feet above Mean Higher High Water (MHHW), which is used as a proxy for inundation on normally dry ground along the immediate coastline. Lee's highest measured water levels were 1.62 ft above MHHW at the NOS tide station in Chatham, Massachusetts, and 1.58 ft above MHHW at the USGS stream gauge in Provincetown, Massachusetts. The NOS tide gauge on Nantucket Island recorded 1.43 ft above MHHW. Other notable water levels measured along the Providence River include 1.18 ft MHHW from the NOS tide gauges at Providence and Conimicut Light, Rhode Island.

Due to the large wind field from Lee, storm surge inundation levels of 1 to 2 ft AGL also occurred along the north shore of Long Island and the Connecticut coast, with minor storm surge impacts extending as far north as Portland, Maine.

Rainfall and Flooding

Lee brought a widespread area of 3 to 5 inches of rain to eastern Maine and New Brunswick, Canada (Fig. 7). The maximum rainfall (6.50”) was reported near Steuben, Maine, and the highest Canadian total (5.56”) was near Hanwell, New Brunswick. Road closures were reported due to flash flooding across eastern Maine and a number of basements flooded in Lubec. Isolated flooding was also reported in Fredericton and Saint John, New Brunswick. A full spreadsheet of rainfall totals is at https://www.nhc.noaa.gov/data/tcr/supplemental/lee.zip.

Tornadoes

There were no tornadoes reported.

CASUALTY AND DAMAGE STATISTICS

There were four direct deaths[3] reported from Lee. One drowning of a 15-year-old boy was reported in Fernandina Beach, Florida, due to a rip current; a large tree limb fell on a 51-year-old man as he was driving near Searsport, Maine; a 21-year-old male died when his family’s boat capsized near Manasquan Inlet, New Jersey; and a 66-year-old male drowned in Poza del Obispo, Puerto Rico, due to a rip current. Three injuries were reported: one due to a tree falling through a moving vehicle in Maine, and two occurring when a lobster boat capsized offshore Maine due to a rogue wave. Additionally, a commercial whale watching vessel broke its mooring, creating a HAZMAT incident that released 1,800 gallons of diesel fuel into the ocean offshore of Maine.

[3] 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.

Heavy rainfall led to flash flooding and multiple road closures, and strong wind gusts led to many downed trees and power lines, especially across coastal Maine, Nova Scotia and New Brunswick. Power outages peaked around 200,000 in the U.S., with similar totals in Nova Scotia. The majority of U.S. outages were in coastal Maine with only a small portion in New Hampshire or near Cape Cod, Massachusetts. Farther east in Canada, some roadways in the Lawrencetown area and the Eastern Shore in the Halifax region were destroyed by a combination of high waves and storm surge, including the boardwalk in Rissers Beach Provincial Park.

Minor damage was reported in Bermuda from wave action at the Royal Naval Dockyard, with power outages of about 12,000 customers reported, and the island's main airport closed for a couple of days.

No official damage estimates are available from Lee, but the firm AON estimated total damage of $50 million.

FORECAST AND WARNING CRITIQUE

Genesis

The genesis forecasts of Lee were moderately skillful, especially at shorter range. The system from which Lee developed was introduced in the Tropical Weather Outlook 114 h prior to genesis (Table 4). The 7-day probabilities were raised to the medium (40-60%) and high (>60%) categories 102 and 78 hours before genesis, respectively. A 2-day chance of formation was introduced into the outlook 84 hours before formation, and the 2-day probabilities were raised to the medium and high categories 48 and 24 hours before development, respectively. Lee's location of formation was reasonably well anticipated as every NHC genesis area drawn captured the formation location, although the off-center genesis location to the east suggests that Lee formed a little sooner than expected (Fig. 8). times.

Track

A verification of NHC official track forecasts (OFCL) for Lee is given in Table 5a. Official track forecast errors were exceptionally low through 72 h, and below the previous 5-year period means through 120 h. Even though the OCD5 (climatology/persistence) errors were low as well, suggesting an easier-than-normal set of forecasts, the 72-h NHC errors for Lee were lower than the 36-h mean 5-year error. A homogeneous comparison of the official track errors with selected guidance models is given in Table 5b. Even though the NHC forecast had quite low errors, some of the models and a few consensus aids were even a bit better (such as the GFS and HMON models, especially at long range). Fig. 9a shows all the NHC track forecasts in comparison to the GFS model (Fig. 9b) – note the consistency of the track forecasts, and the very low spread in the GFS (yielding a remarkably low 120-h error of only 48 n mi for 20 forecasts). The poorest-performing track models were the United Kingdom global model (EGRI), the ECMWF model, and the HAFS suite.

It should be noted that a few forecasts were made when Lee was an extratropical cyclone over the western Atlantic due to existing tropical storm watches/warnings that were issued for US/Canada. These forecasts were not included in the verification statistics since the standard rules of NHC verification require the cyclone to be a tropical cyclone at both the initial and forecast verifying times.

Intensity

A verification of NHC official intensity forecasts for Hurricane Lee is given in Table 6a. Official intensity forecast errors were larger than the official 5-year mean errors at all forecast time frames, even though the OCD5 tended to be below the long-term means. The NHC forecasts had a low bias early in the hurricane's lifecycle, and the forecasts were too high later on (Fig. 10a) as Lee's wind field grew larger rather than stronger peak winds. It is worth noting that NHC forecasters from the very first advisory well anticipated the storm's rapid intensification, although it occurred earlier than expected. Additionally, the NHC forecasters correctly anticipated extratropical transition and weakening before reaching Canada. A homogeneous comparison of the official intensity errors with selected guidance models is given in Table 6b. The official forecasts, except at 12 h, were beaten by much of the guidance, although most of the guidance could not outperform OCD5 (the no-skill model). The HWRF had a particularly good performance for Lee (Fig. 10b), along with the GFS model. The HAFS suite (Figs. 10c/d) and the DSHP/LGEM statistical-dynamical models were much poorer than average for Lee.

Wind Watches and Warnings

Coastal wind watches and warnings associated with Hurricane Lee are given in Table 7.

For the United States, a Tropical Storm Watch was issued for much of the northeastern coastline from eastern Massachusetts northward at 2100 UTC 13 September, and generally the northeastern portion of the watch was upgraded to a warning 18 h later. With sustained tropical-storm-force (or gale-force) winds arriving around 0600 UTC 16 September, these watches provided a maximum lead time of about 57 h before the arrival of tropical-storm-force winds, and warnings provided a maximum lead time of about 39 h.

Storm Surge Watches and Warnings

In the United States, a Storm Surge Watch was first issued at 2100 UTC 13 September from Chatham to Sagamore Beach, Massachusetts, including Cape Cod Bay and Nantucket. The peak storm surge forecast was 2 to 4 ft AGL. Figure 6 illustrates the maximum extent of the storm surge watch area. The Storm Surge Watch was discontinued 24 h later, at 2100 UTC 14 September, due to the forecast confidence in the center and track of Lee passing well offshore of Downeast Maine. At the time of the discontinuation of the Storm Surge Watch, the peak storm surge forecast was 1 to 3 ft AGL for the New England coast, given the expansive wind field from Lee.

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

The NHC began communication with emergency managers on Friday 8 September, as Lee was in the Central Atlantic. Fourteen decision support briefings were provided to emergency managers and coordinated through the Federal Emergency Management Agency (FEMA) Hurricane Liaison Team embedded at the NHC. The briefings were video-teleconferences with FEMA HQ, FEMA Regions 1, 2, and 3, and the states of Virginia, New Jersey, New York, Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, and Maine. These briefings continued through Saturday 16 September, until Lee moved inland over Atlantic Canada. The Tropical Analysis and Forecast Branch (TAFB) of NHC provided six live briefings for the United States Coast Guard District 7 from 6–11 September.

NHC Director Dr. Michael Brennan provided daily briefings to Congressional Stakeholders, FEMA, and Florida's Emergency Managers. The briefings were coordinated with the Congressional Affairs Team. In print and broadcast media, Lee generated about 39,000 mentions from 7–16 September. NHC provided 10 live stream broadcasts via YouTube and Facebook Live. The total viewership on YouTube was 407,300 and on Facebook 117,600 for a total reach on NHC social media platforms of 524,900. In addition to the general public, the videos were used by news agencies and local broadcast TV stations. In addition to the live streams, social media posts were included at least once a day on the NHC Facebook page. Key Messages were also included on every NHC advisory from 5–17 September.

Acknowledgments

Much of the data in this report came from Post Tropical Cyclone (PSH) Reports issued by NWS Weather Forecast Offices (WFOs) in Boston, Gray and Caribou. David Roth of the NOAA Weather Prediction Center produced the rainfall map and spreadsheet, Chris Fogarty of the Canadian Hurricane Centre provided the Canadian wind reports and Ian Currie of the Bermuda Weather Service provided the Bermuda information. Data from the National Data Buoy Center, NOS Center for Operational Oceanographic Products and Services, United States Geological Survey, and the NOAA Storm Prediction Center were also used in this report. The authors would like to thank those at NHC for their contributions to this report: Matthew Green from FEMA supplied the IDSS briefing information; Dr. Chris Landsea supplied the TAFB briefing information; Maria Torres provided the media information; Dr. Philippe Papin generated the genesis figure; Dr. Lisa Bucci provided the track and intensity verification figures plus reconnaissance flights; John Cangialosi made the GIS track map; Dr. Cody Fritz and the Storm Surge Unit contributed to the storm surge analysis and figures; and the Hurricane Specialist Unit peer reviewed the report.

Table 1. Best track for Hurricane Lee, 5–16 September 2023.

Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Stage
05 / 1200	12.2	39.6	1008	30	tropical depression
05 / 1800	12.9	41.1	1006	35	tropical storm
06 / 0000	13.2	42.5	1003	45	"
06 / 0600	13.5	43.9	997	55	"
06 / 1200	14.0	45.0	994	60	"
06 / 1800	14.6	46.1	991	65	hurricane
07 / 0000	15.1	47.1	989	70	"
07 / 0600	15.6	48.2	986	75	"
07 / 1200	16.1	49.4	980	85	"
07 / 1800	16.6	50.7	961	105	"
08 / 0000	17.0	51.8	933	135	"
08 / 0600	17.5	53.0	926	145	"
08 / 1200	17.9	54.1	940	135	"
08 / 1800	18.5	55.1	941	125	"
09 / 0000	19.0	56.0	958	105	"
09 / 0600	19.5	57.0	963	100	"
09 / 1200	20.0	57.9	954	100	"
09 / 1800	20.4	58.8	958	95	"
10 / 0000	20.8	59.5	960	85	"
10 / 0600	21.2	60.2	960	90	"
10 / 1200	21.5	60.8	956	95	"
10 / 1800	21.9	61.4	954	105	"
11 / 0000	22.3	61.9	950	105	"
11 / 0600	22.8	62.5	950	105	"
11 / 1200	23.2	63.2	948	105	"

Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Stage
11 / 1800	23.5	63.9	948	100	"
12 / 0000	23.7	64.5	948	100	"
12 / 0600	23.9	65.1	948	100	"
12 / 1200	24.1	65.7	948	100	"
12 / 1800	24.5	66.2	946	100	"
13 / 0000	24.9	66.6	946	100	"
13 / 0600	25.3	66.9	948	100	"
13 / 1200	26.0	67.2	950	95	"
13 / 1800	26.8	67.6	951	90	"
14 / 0000	27.6	67.8	951	90	"
14 / 0600	28.5	68.0	953	85	"
14 / 1200	29.8	68.2	955	80	"
14 / 1800	31.1	68.3	955	75	"
15 / 0000	32.1	67.8	955	75	"
15 / 0600	33.6	67.6	957	75	"
15 / 1200	35.1	67.1	962	75	"
15 / 1800	37.1	66.7	962	75	"
16 / 0000	38.7	65.9	963	75	"
16 / 0600	40.9	66.0	965	70	extratropical
16 / 1200	42.7	66.3	965	65	"
16 / 1800	43.8	66.4	968	55	"
16 / 2000	44.3	66.3	970	55	"
17 / 0000	44.7	66.2	979	55	"
17 / 0600	45.9	64.8	986	50	"
17 / 1200	47.3	63.0	989	40	"
17 / 1800	48.6	60.1	989	40	"

Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Stage
18 / 0000	50.7	57.9	994	35	"
18 / 0600	51.7	53.2	994	35	"
18 / 1200	52.6	48.6	993	40	"
18 / 1800	53.0	42.0	993	40	"
19 / 0000					dissipated
08 / 0600	17.5	53.0	926	145	minimum pressure and maximum winds
16 / 2000	44.3	66.3	970	55	extratropical landfall on Long Island in SW Nova Scotia

Table 2. Selected ship reports with winds of at least 34 kt for Hurricane Lee, 5–16 September 2023 (all reports but the first were from Lee as an extratropical cyclone).

Date/Time (UTC)	Ship call sign	Latitude (°N)	Longitude (°W)	Wind dir/ speed (kt)	Pressure (mb)
15 / 2000	ZCDW9	42.3	71.0	010 / 43	1018.4
16 / 0800	C6PZ8	39.6	57.7	160 / 50	1007.5
17 / 0200	C6PZ8	40.5	61.9	220 / 37	1008.5
17 / 0200	C6CX3	48.2	59.5	160 / 35	1008.2
17 / 0500	C6PZ8	40.8	62.7	230 / 40	1005.5
17 / 0600	C6CX3	47.1	59.5	200 / 35	1003.1
17 / 0800	PDAN	47.5	59.6	170 / 35	1004.9
17 / 0900	C6CX3	46.3	60.2	100 / 40	1002.1
17 / 0900	PDAN	47.7	59.7	160 / 35	1005.9
17 / 1000	PDAN	47.9	59.7	160 / 35	997.8
17 / 1100	PDAN	48.0	59.7	160 / 35	997.8
17 / 1400	C6CX3	46.5	60.1	210 / 38	999.1
17 / 2000	9HA507	42.3	60.6	230 / 35	1010.5

Table 3. Selected Canadian surface observations for Lee in the post-tropical stage, 16–17 September 2023. A detailed list of United States wind and pressure observations can be found at: https://www.nhc.noaa.gov/data/tcr/supplemental/lee.zip.

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)				
Canada									
Nova Scotia									
Halifax Airport					63				
Beaver Island					60				
Brier Island					59				
Lunenburg					59				
Baccaro Point					58				
New Brunswick									
Saint John					46				
Grand Manan					45				
Prince Edward Island									
Harrington					46				
Charlottetown					45				

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	**168-Hour Outlook**
Low (<40%)	84	114
Medium (40%-60%)	48	102
High (>60%)	24	78

Table 5a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) track forecast errors (n mi) for Hurricane Lee, 5–16 September 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.

	Forecast Period (h)							
	12	24	36	48	60	72	96	120
OFCL	**12.8**	**14.2**	**17.5**	**23.3**	**33.4**	**47.3**	**88.9**	**134.2**
OCD5	23.8	50.1	82.5	113.4	149.2	180.6	232.0	291.4
Forecasts	41	39	37	35	33	31	27	23
OFCL (2018-22)	23.8	35.7	47.8	61.4	76.1	90.5	125.7	172.1
OCD5 (2018-22)	46.4	99.2	157.4	215.0	254.9	321.2	405.1	486.6

Table 5b. Homogeneous comparison of selected track forecast guidance models (in n mi) for Hurricane Lee, 5–16 September 2023. 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	12.5	14.3	16.6	22.4	34.0	46.3	88.2	130.1
OCD5	25.0	52.2	85.0	116.4	154.3	184.4	253.5	318.4
GFSI	14.1	19.6	24.6	27.6	34.4	**39.1**	**41.9**	**48.0**
HMNI	13.3	18.0	22.3	**21.0**	**24.8**	**31.4**	**50.7**	**77.1**
HWFI	15.2	20.8	26.6	29.7	38.4	53.2	105.0	147.8
HFAI	12.7	17.3	21.9	31.1	47.4	62.5	105.9	138.1
HFBI	14.8	21.3	31.0	46.4	67.3	84.2	138.3	190.9
EGRI	12.6	18.1	26.3	36.1	51.4	65.6	127.3	199.4
EMXI	13.5	19.0	26.7	38.0	54.5	66.3	111.3	172.7
CMCI	14.0	24.6	33.5	44.7	59.2	72.9	103.6	135.9
NVGI	16.1	27.1	38.1	49.5	59.2	73.7	116.2	140.2
CTCI	14.2	19.5	23.2	27.2	39.6	57.1	112.8	193.9
AEMI	12.9	18.1	24.7	30.1	37.9	48.1	**72.1**	**101.3**
HCCA	**11.4**	**14.2**	17.5	25.4	40.2	57.4	101.8	153.0
FSSE	**11.5**	**14.0**	16.9	22.5	35.3	**42.2**	**73.5**	**127.4**
TVCX	**11.8**	15.6	**16.4**	**21.7**	**33.8**	**44.4**	88.4	136.8
GFEX	13.0	17.2	19.7	23.1	**31.1**	**37.7**	**64.4**	**104.8**
TVCA	**11.9**	15.2	17.0	**20.8**	**33.1**	**44.4**	**87.1**	135.2
TVDG	**12.1**	15.0	**16.4**	**20.3**	**31.5**	**42.3**	**82.7**	130.6
TABD	18.8	39.8	66.4	91.5	113.3	130.8	153.7	153.9
TABM	19.7	31.6	38.2	46.3	55.9	67.4	**80.3**	**78.9**
TABS	35.8	68.6	91.8	105.4	117.1	128.3	138.4	**117.5**
Forecasts	36	34	32	30	28	26	24	20

Table 6a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) intensity forecast errors (kt) for Hurricane Lee, 5–16 September 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.

	Forecast Period (h)							
	12	24	36	48	60	72	96	120
OFCL	8.0	12.7	16.4	18.3	19.2	18.7	19.1	18.0
OCD5	9.2	14.3	16.5	18.0	17.2	12.6	11.6	11.7
Forecasts	41	39	37	35	33	31	27	23
OFCL (2018-22)	5.1	7.6	8.9	10.1	10.7	11.5	13.3	15.5
OCD5 (2018-22)	6.8	10.7	13.9	16.5	18.3	20.2	22.9	23.4

Table 6b. Homogeneous comparison of selected intensity forecast guidance models (in kt) for Hurricane Lee, 5–16 September 2023. 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	8.1	12.8	16.5	18.4	18.1	18.0	19.2	17.7
OCD5	9.1	14.2	**16.4**	**17.5**	**15.3**	**10.6**	**10.7**	**11.1**
HMNI	9.9	13.4	**15.3**	**15.4**	**14.5**	**13.9**	**14.7**	**14.2**
HWFI	9.0	**10.8**	**13.3**	**12.6**	**10.5**	**8.8**	**8.2**	**8.5**
HFAI	9.8	17.9	23.5	25.3	21.0	19.5	20.5	19.2
HFBI	9.6	15.2	20.3	21.8	19.0	21.5	24.8	20.0
CTCI	9.4	15.1	18.7	22.5	20.3	**17.4**	**15.2**	**13.8**
DSHP	9.4	14.4	**16.4**	18.9	19.2	18.6	22.1	25.0
LGEM	9.0	12.9	**16.2**	18.4	19.0	19.3	22.3	21.0
ICON	8.4	**11.3**	**13.9**	**14.7**	**13.8**	**13.2**	**15.2**	**15.6**
IVCN	8.4	**12.1**	**15.2**	**16.6**	**15.1**	**14.8**	**16.3**	**14.3**
IVDR	8.5	**12.3**	**15.3**	**16.4**	**14.4**	**13.8**	**14.8**	**11.8**
HCCA	8.7	12.9	**16.1**	19.4	**16.5**	**15.3**	**15.7**	**10.4**
FSSE	8.5	**12.6**	**14.9**	**17.6**	**16.7**	**17.5**	22.2	20.3
GFSI	9.5	14.2	**15.8**	**15.9**	**13.9**	**9.3**	**5.5**	**3.9**
EMXI	10.1	15.5	19.8	20.1	18.6	**16.8**	**11.0**	**10.0**
Forecasts	40	38	36	34	32	30	26	22

Table 7. Coastal wind watch and warning summary for Hurricane Lee, 5–16 September 2023.

Date/Time (UTC)	Action	Location
12 / 1500	Tropical Storm Watch issued	Bermuda
13 / 0300	Tropical Storm Watch changed to Tropical Storm Warning	Bermuda
13 / 2100	Tropical Storm Watch issued	Watch Hill to Stonington
13 / 2100	Tropical Storm Watch issued	Block Island
13 / 2100	Tropical Storm Watch issued	Martha's Vineyard
13 / 2100	Tropical Storm Watch issued	Nantucket Island
13 / 2100	Hurricane Watch issued	Stonington to US/Can Border
14 / 0300	Tropical Storm Watch issued	Point Lepreau to Fort Lawrence
14 / 0300	Tropical Storm Watch issued	Fort Lawrence to Digby
14 / 0300	Tropical Storm Watch issued	Medway Harbour to Porter's Lake
14 / 0300	Hurricane Watch issued	Digby to Medway Harbour
14 / 1500	Tropical Storm Watch changed to Tropical Storm Warning	Martha's Vineyard
14 / 1500	Tropical Storm Watch changed to Tropical Storm Warning	Nantucket Island
14 / 1500	Tropical Storm Watch modified to	Watch Hill to Woods Hole
14 / 1500	Tropical Storm Warning issued	Woods Hole to Hull
14 / 2100	Tropical Storm Watch discontinued	Watch Hill to Woods Hole
14 / 2100	Tropical Storm Watch discontinued	Hull to Stonington
14 / 2100	Tropical Storm Watch discontinued	Block Island
14 / 2100	Tropical Storm Watch modified to	Medway Harbour to Point Tupper
14 / 2100	Tropical Storm Warning issued	Westport to US/Can Border
15 / 0300	Tropical Storm Watch discontinued	All

Date/Time (UTC)	Action	Location
15 / 0300	Tropical Storm Warning issued	Fort Lawrence to Point Tupper
15 / 0900	Hurricane Watch modified to	Petit Manan Point to US/Can Border
15 / 1500	Tropical Storm Warning modified to	US/Can Border to Fort Lawrence
15 / 1500	Hurricane Watch modified to	US/Can Border to Point Lepreau
15 / 1500	Hurricane Watch modified to	Digby to Ecum Secum
15 / 1800	Tropical Storm Warning discontinued	Bermuda
15 / 1800	Tropical Storm Warning modified to	Westport to US/Can Border
15 / 2100	Tropical Storm Watch issued	Point Tupper to Tidnish
15 / 2100	Tropical Storm Watch issued	Shediac to Belledune
15 / 2100	Tropical Storm Watch issued	Prince Edward Island
15 / 2100	Tropical Storm Watch issued	Magdalen Islands
15 / 2100	Tropical Storm Warning issued	Shediac to Tidnish
16 / 1500	Tropical Storm Watch changed to Tropical Storm Warning	Prince Edward Island
16 / 1500	Tropical Storm Watch changed to Tropical Storm Warning	Magdalen Islands
16 / 1500	Tropical Storm Watch discontinued	All
16 / 1500	Tropical Storm Warning modified to	Portsmouth to US/Can Border
16 / 1500	Tropical Storm Warning discontinued	Martha's Vineyard
16 / 1500	Tropical Storm Warning discontinued	Nantucket Island
16 / 1500	Tropical Storm Warning discontinued	Fort Lawrence to Point Tupper
16 / 1500	Tropical Storm Warning discontinued	Shediac to Tidnish
16 / 1500	Tropical Storm Warning issued	Nova Scotia
16 / 2100	Tropical Storm Warning modified to	Cape Elizabeth to US/Can Border
16 / 2100	Hurricane Watch discontinued	All
17 / 0000	Tropical Storm Warning modified to	Stonington to US/Can Border
17 / 0300	Tropical Storm Warning discontinued	Stonington to US/Can Border

Date/Time (UTC)	Action	Location
17 / 0300	Tropical Storm Warning discontinued	US/Can Border to Belledune
17 / 0300	Tropical Storm Warning discontinued	Nova Scotia
17 / 0300	Tropical Storm Warning issued	Fundy National Park to Fort Lawrence
17 / 0300	Tropical Storm Warning issued	Tidnish to Shediac
17 / 0300	Tropical Storm Warning issued	Fort Lawrence to Avonport
17 / 0300	Tropical Storm Warning issued	Lower East Pubnico to Tidnish
17 / 0600	Tropical Storm Warning discontinued	Fundy National Park to Fort Lawrence
17 / 0600	Tropical Storm Warning discontinued	Tidnish to Shediac
17 / 0600	Tropical Storm Warning discontinued	Fort Lawrence to Avonport
17 / 0600	Tropical Storm Warning discontinued	Lower East Pubnico to Tidnish
17 / 0600	Tropical Storm Warning discontinued	Prince Edward Island
17 / 0600	Tropical Storm Warning issued	Brule to Hubbards
17 / 0600	Tropical Storm Warning issued	Lower Darnley to Victoria PEI
17 / 0900	Tropical Storm Warning discontinued	Brule to Hubbards
17 / 0900	Tropical Storm Warning discontinued	Lower Darnley to Victoria PEI
17 / 0900	Tropical Storm Warning issued	Lismore to Porters Lake
17 / 0900	Tropical Storm Warning issued	Savage Harbor to Wood Islands PEI
17 / 1500	Tropical Storm Warning discontinued	All

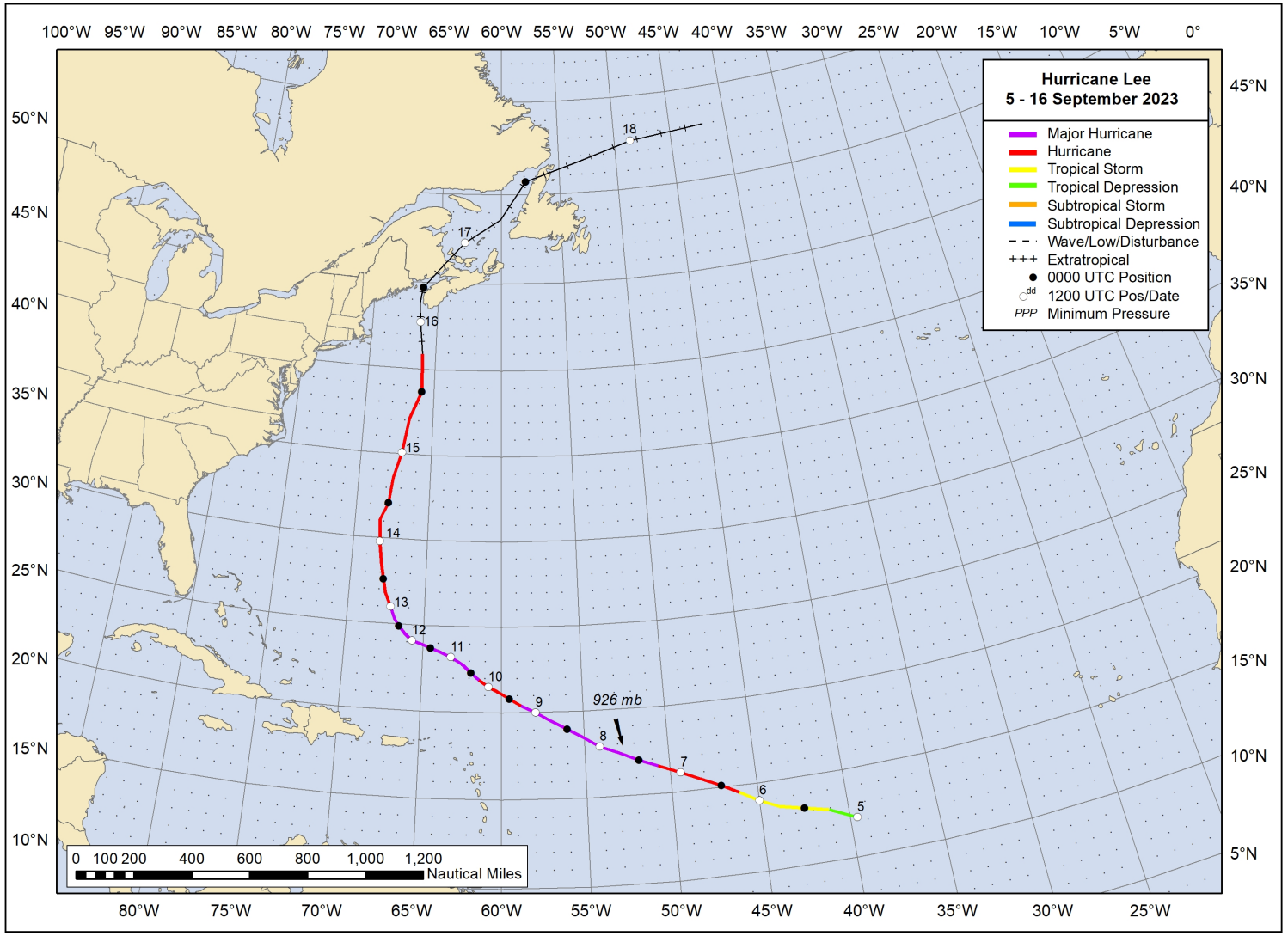

Figure 1. Best track positions for Hurricane Lee, 5–16 September 2023. Tracks over Canada and/or during the extratropical stage are partially based on analyses from the NOAA Weather Prediction Center and Ocean Prediction Center.

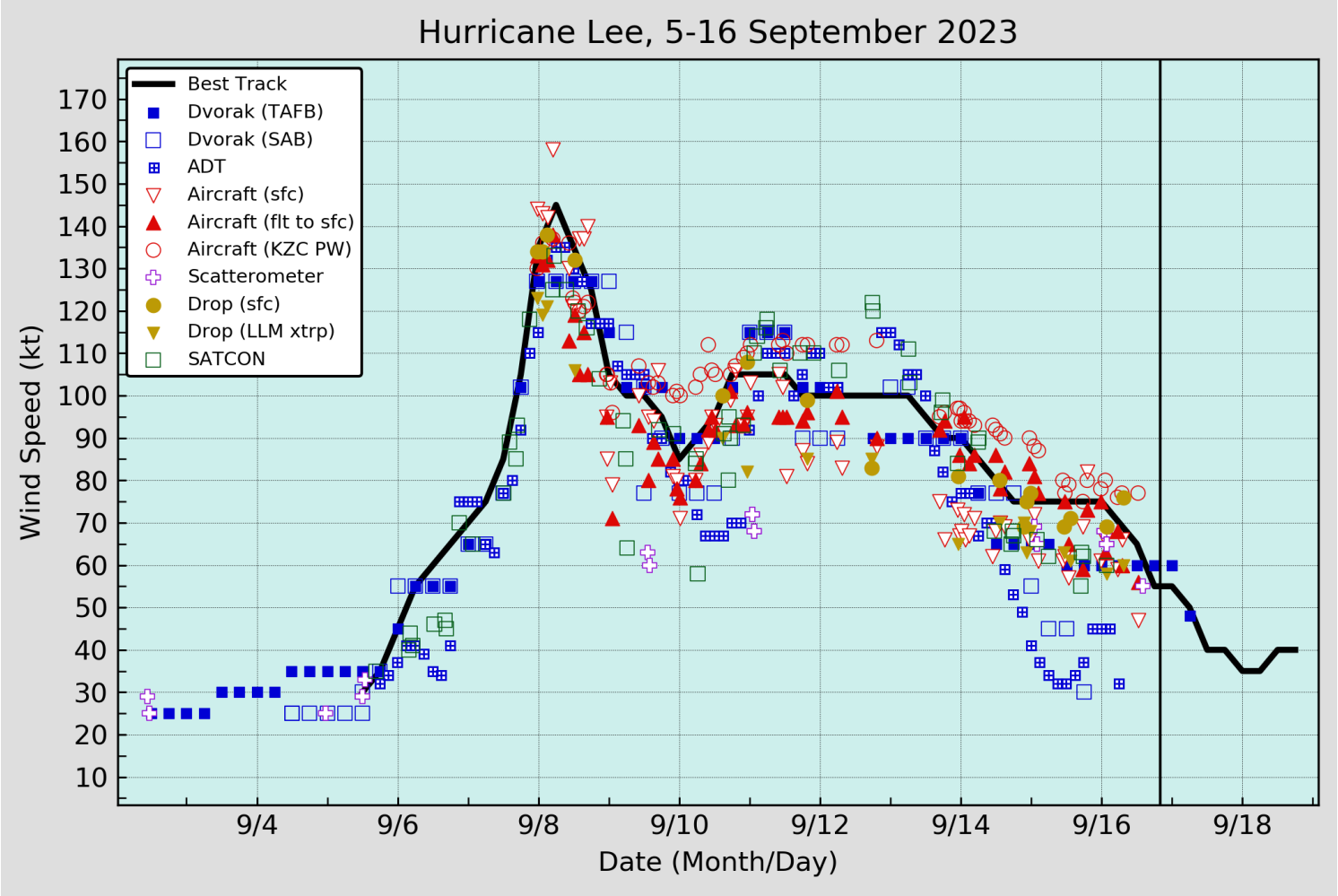

Figure 2. Selected wind observations and best track maximum sustained surface wind speed curve for Hurricane Lee, 5–16 September 2023. Aircraft observations have been adjusted for elevation using 90%, 80%, and 75% adjustment factors for observations from 700 mb, 850 mb, and 925 mb, respectively. Dropwindsonde 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, and solid vertical lines correspond to landfall.

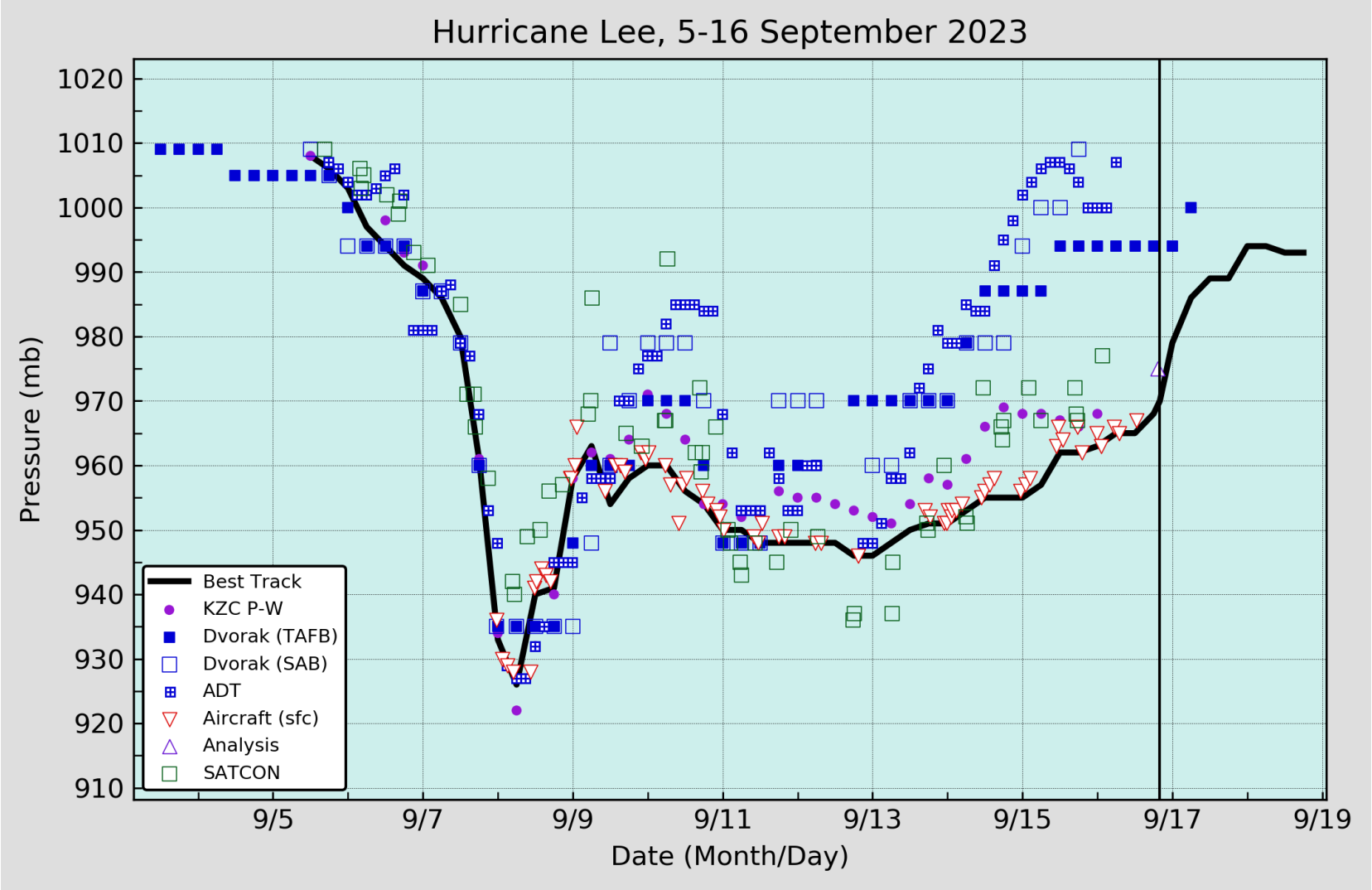

Figure 3. Selected pressure observations and best track minimum central pressure curve for Hurricane Lee, 5–16 September 2023. Advanced Dvorak Technique estimates represent the Current Intensity at the nominal observation time. SATCON intensity estimates are from the Cooperative Institute for Meteorological 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, and solid vertical lines correspond to landfall.

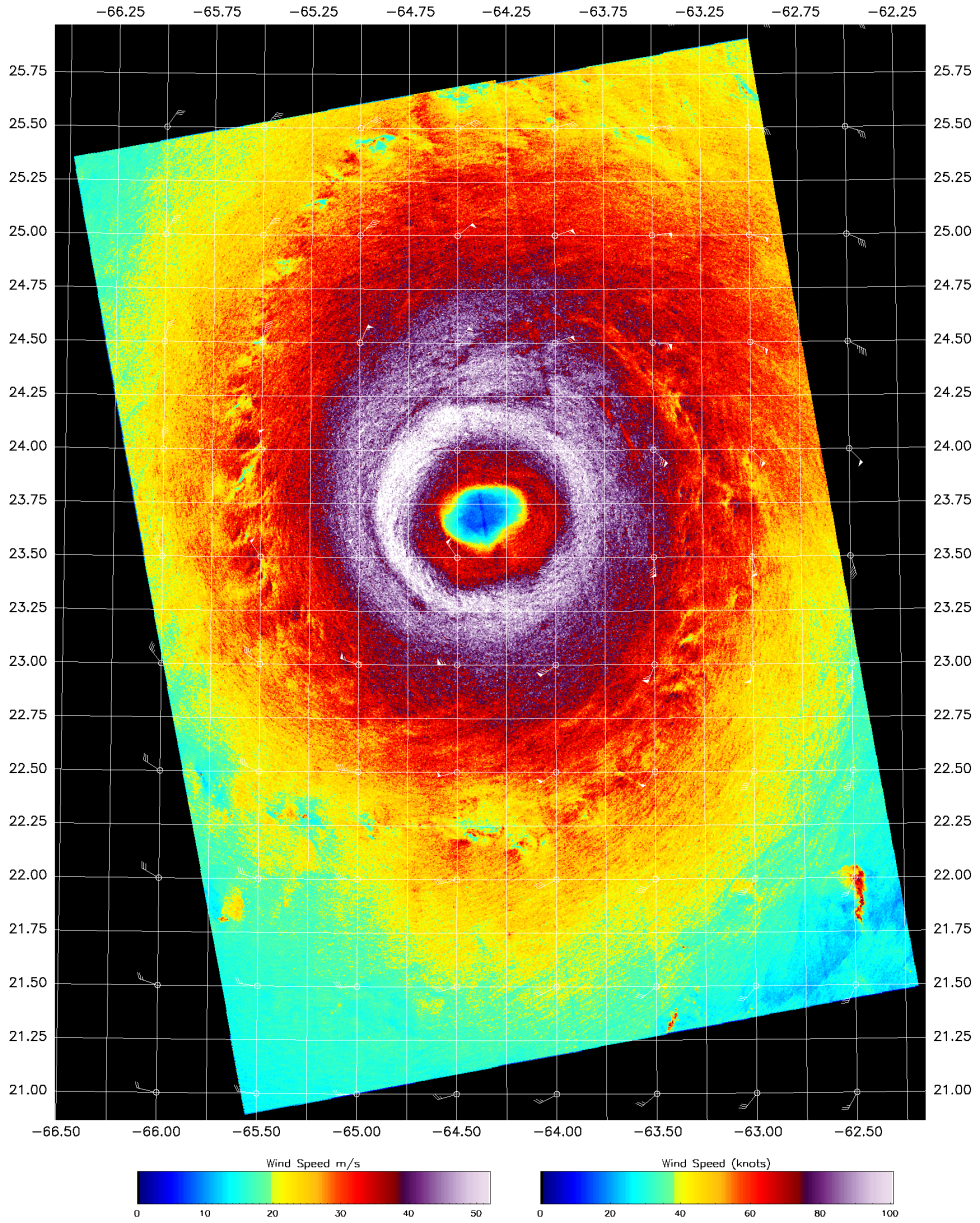

Figure 4. Synthetic aperture radar data of Lee from RCM-1 at 2222 UTC 11 September 2023. Imagery courtesy NESDIS.

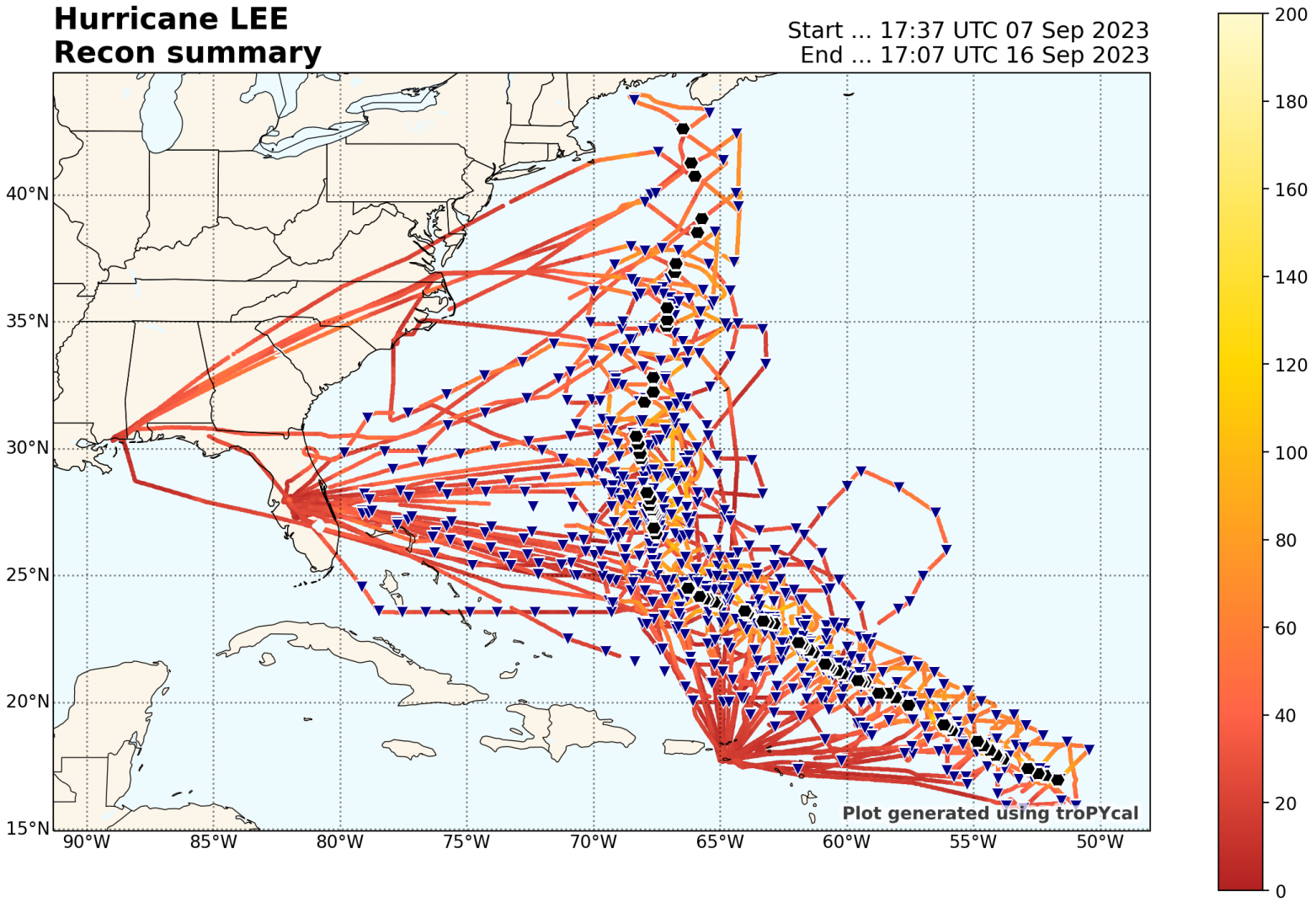

Figure 5. Air Force Reserve and NOAA Hurricane Hunter aircraft flight tracks (red) from reconnaissance missions into Hurricane Lee from 7–16 September 2023. The black markers denote center fixes, and the blue triangles indicate dropsonde locations. The color coding of the flight tracks is based on the observed flight-level wind speed with the color legend to the right of the map representing the color associated with the various wind speeds in knots.

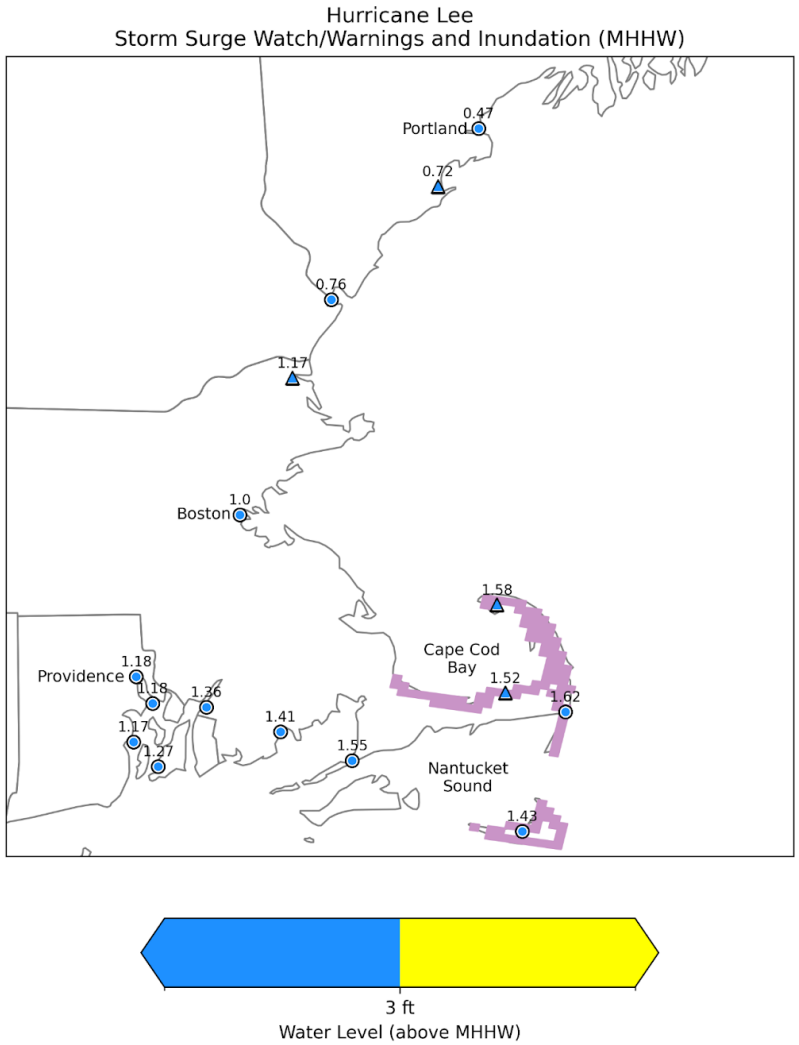

Figure 6. Maximum water levels measured during Hurricane Lee from NOS tide gauges (circles) and USGS stream gauges (triangles), as well as areas covered by storm surge watches (lavender) issued at 2100 UTC 13 September. Water levels are referenced as feet above Mean Higher High Water (MHHW), used as a proxy for inundation (above ground level) on normally dry ground along the immediate coastline.

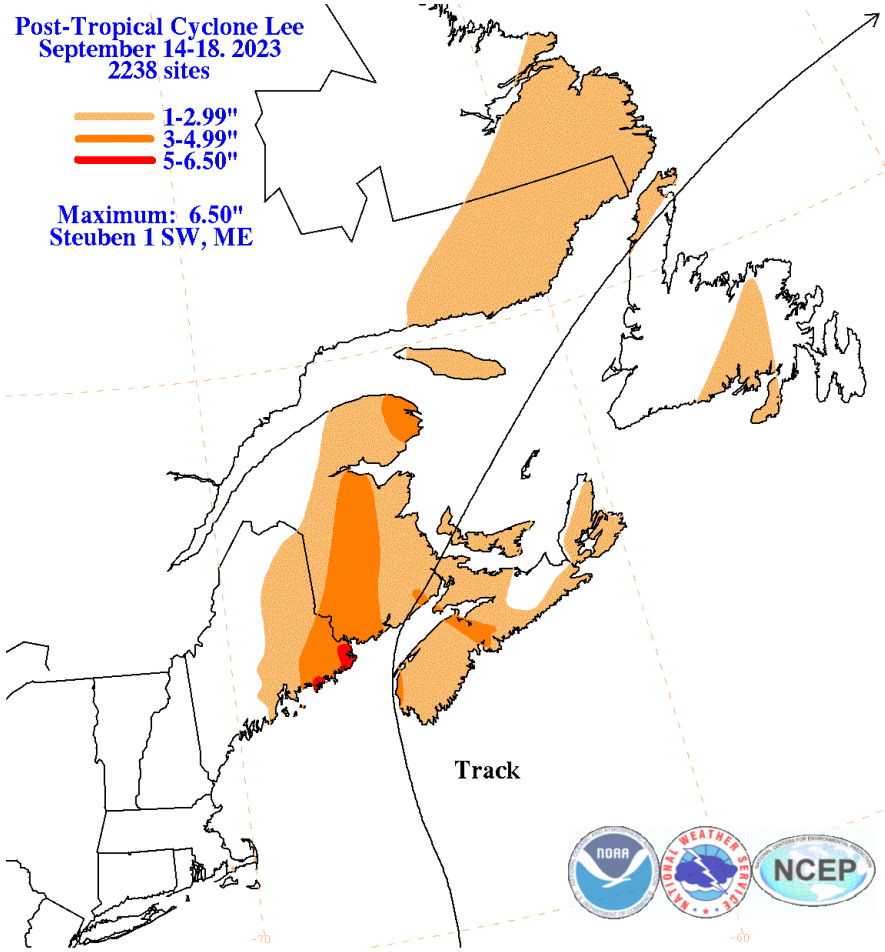

Figure 7. Rainfall from Post-Tropical Cyclone Lee, 14–18 September 2023. Map courtesy David Roth, Weather Prediction Center. The track shown is from operational estimates only.

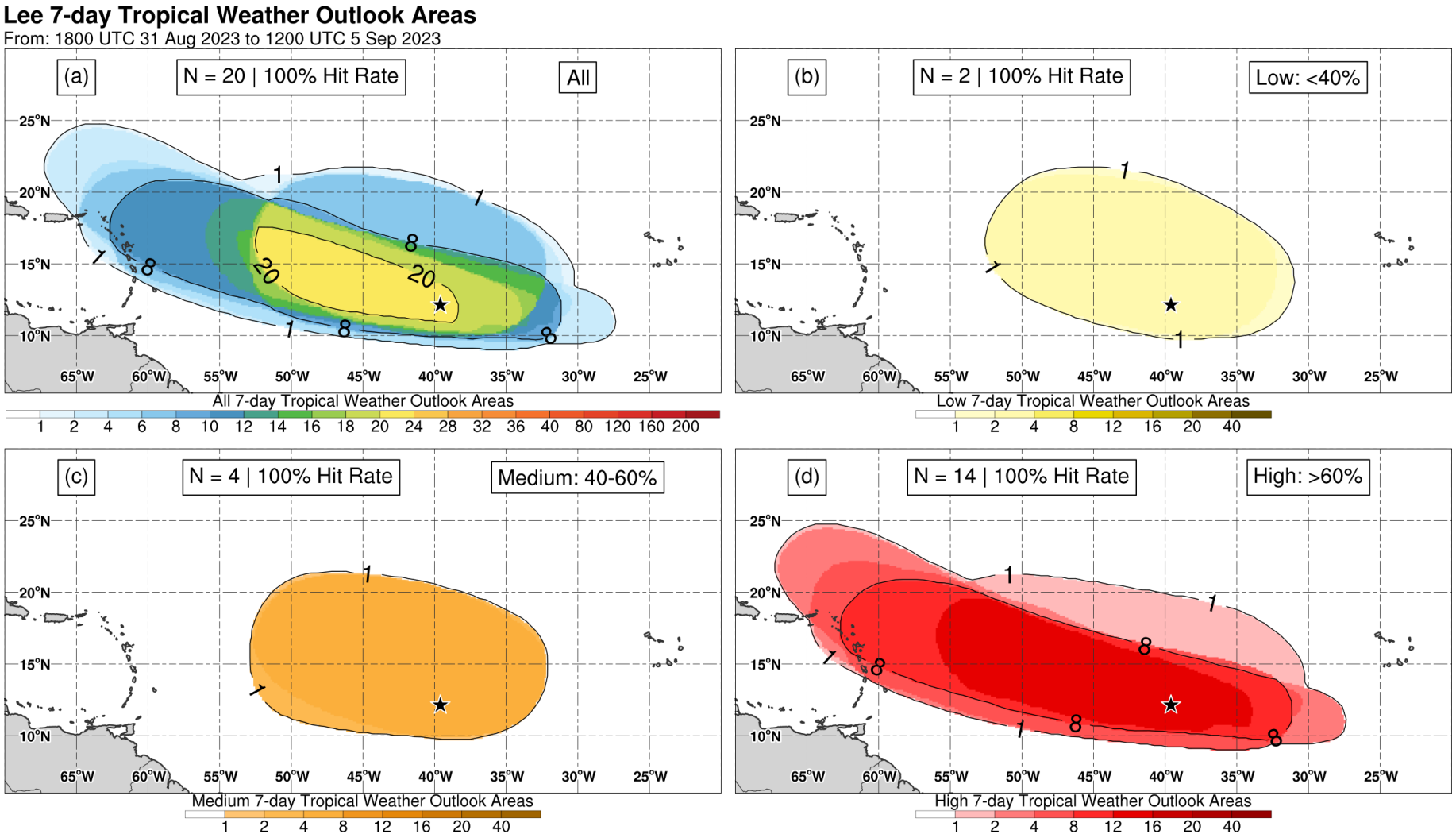

Figure 8. Composites of 7-day tropical cyclone genesis areas depicted in NHC's Tropical Weather Outlooks prior to formation for (a) all probabilistic genesis categories, (b) the low (<40%) category, (c) medium (40–60%) category, and (d) high (>60%) category. The location of genesis is indicated by the black star.

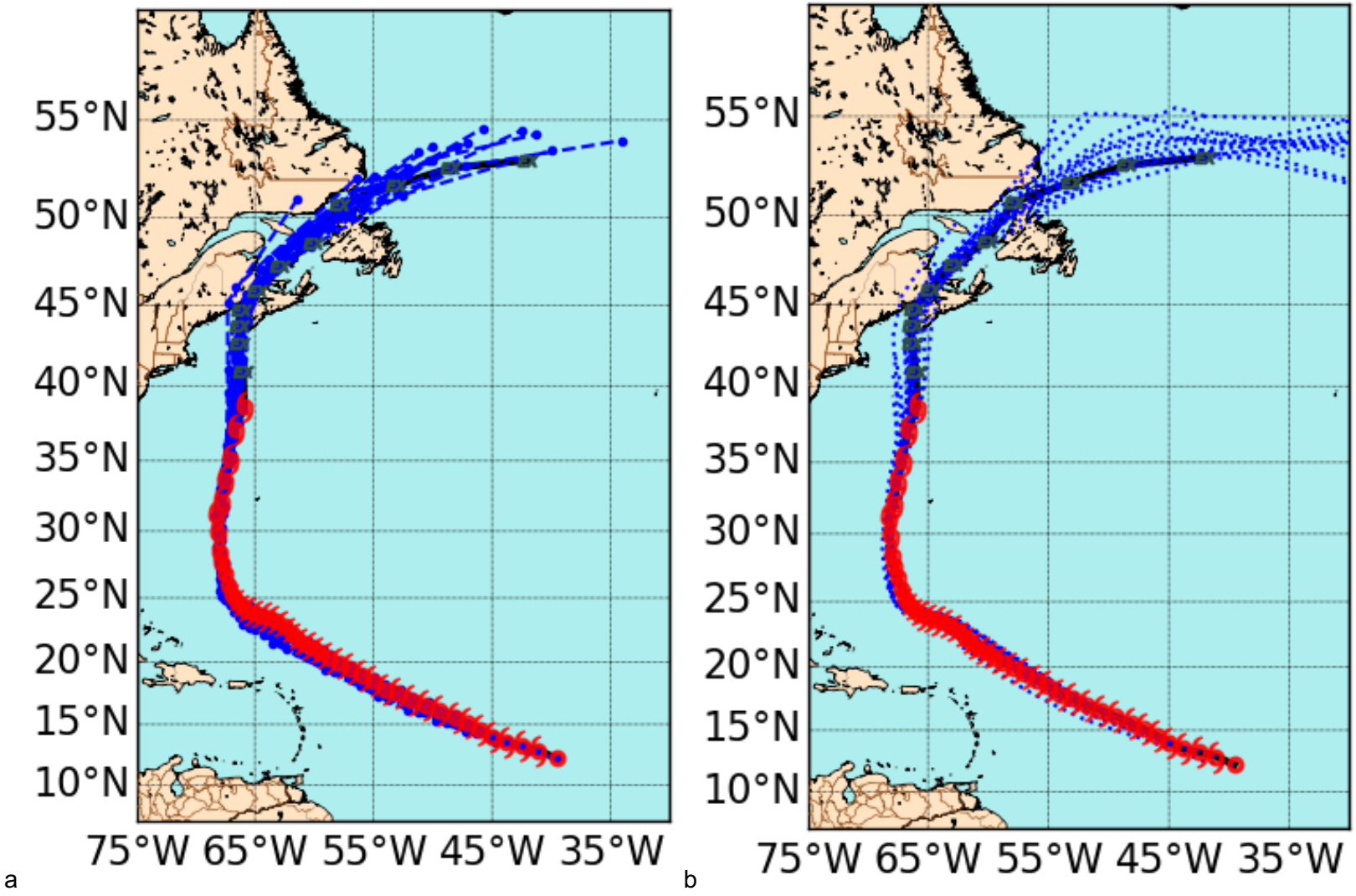

Figure 9. Selected track forecasts (blue lines) for Hurricane Lee, 5–16 September 2023. The best track is given by the red and black symbols. Panel a) is the official track forecasts (OFCL) and panel b) is the GFS model.

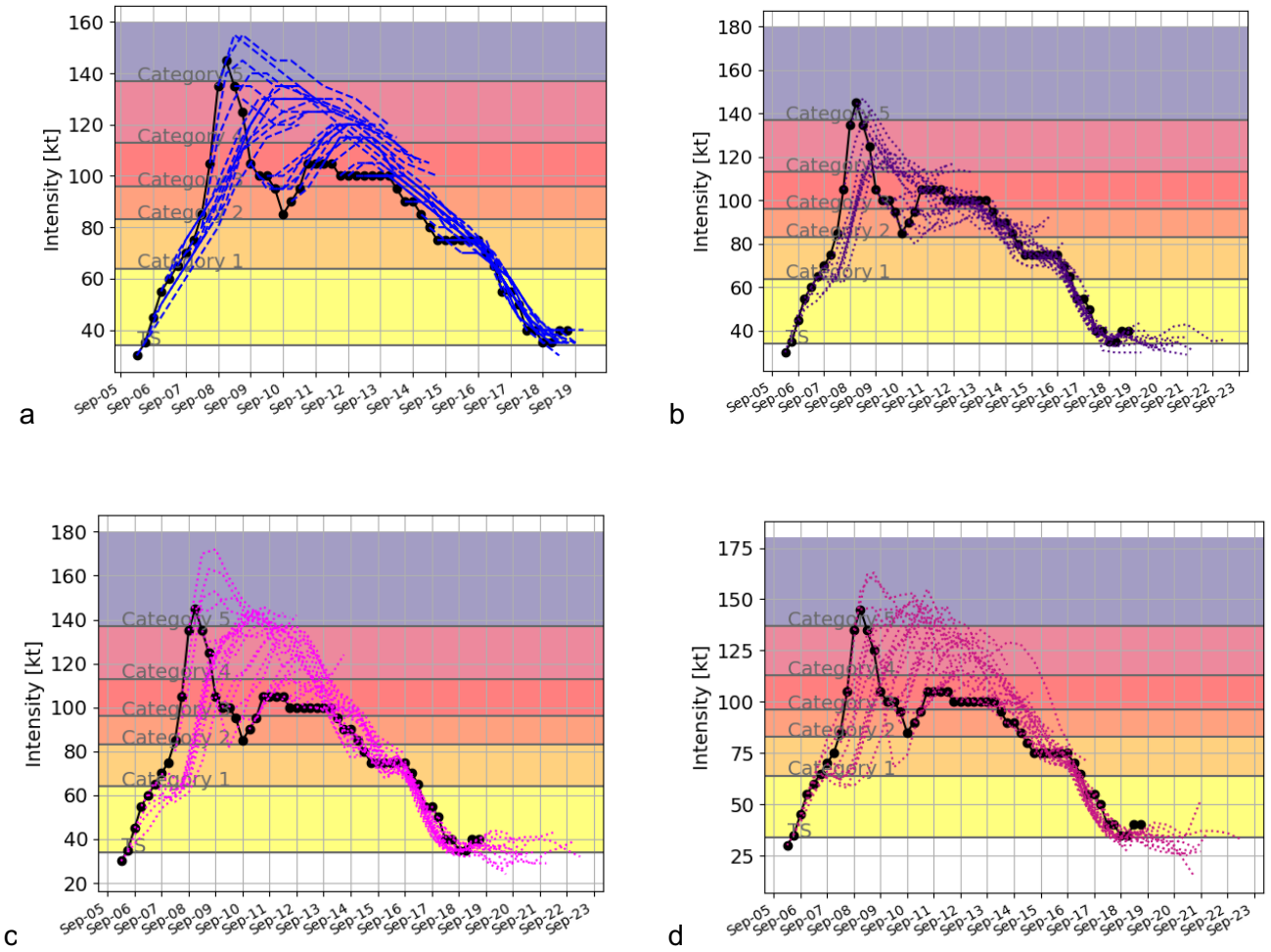

Figure 10. Intensity forecasts for Hurricane Lee, 5–16 September 2023. The colored lines are the individual forecasts, with the black solid line the verifying values. Panel a) is the official forecast (OFCL), b) the HWRF model, c) HAFS-A and d) HAFS-B.