Tropical Cyclone Report
Hurricane Earl
(AL072010)
25 August - 4 September 2010

John P. Cangialosi
National Hurricane Center
13 January 2011

Updated 25 February 2011 to amend Table 3
Updated 27 January 2011 to fix typo

Earl was a Cape Verde hurricane that caused damage in the northern Leeward Islands and made landfall as a Category 1 hurricane (on the Saffir-Simpson Hurricane Wind Scale) in Nova Scotia, Canada. It reached its peak intensity as a Category 4 hurricane over the western Atlantic.

a. Synoptic History

Earl originated from a strong tropical wave that departed the west coast of Africa on 23 August. A closed-surface circulation developed along the wave axis by 0000 UTC 24 August and the associated thunderstorm activity became organized as the low moved south of the Cape Verde Islands later that day. By early 25 August, the low acquired sufficient convective organization to be considered a tropical depression by 0600 UTC, when centered about 200 n mi west-southwest of the Cape Verde Islands. The convective curved banding expanded and became better organized later that day, and the system strengthened to a tropical storm by 1200 UTC. The "best track" chart of Earl'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].

Strong subtropical ridging over the eastern Atlantic steered Earl westward to west-northwestward at a forward speed, between 15-20 kt, for the next few days. Meanwhile, the tropical storm strengthened gradually over sea surface temperature of 28°-29° C and in an environment of light to moderate shear. Data from an Air Force Reserve reconnaissance aircraft indicate that Earl became a hurricane by 1200 UTC 29 August, when centered about 220 n mi east of the northern Leeward Islands. Around that time, the cyclone neared a weakness in the subtropical ridge caused by Hurricane Danielle to its west, and Earl slowed and gradually turned northwestward. During this process, the hurricane experienced rapid intensification. A banded-type eye became apparent in radar imagery from Guadeloupe and St. Maarten around 0000 UTC 30 August, and Earl strengthened to a Category 3 hurricane about 12 h later when it was located very near the northern Leeward Islands.

Data from both NOAA and Air Force hurricane hunter aircraft, along with satellite imagery, indicate that Earl intensified by 40-kt over 24 h, becoming a Category 4 hurricane by

[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.

1800 UTC 30 August. Shortly after reaching that status, Earl began a concentric eyewall replacement cycle that was well observed in both the San Juan Doppler radar and aircraft flight-level wind data (Fig. 4). This cycle halted the intensification process and Earl remained a 115-kt hurricane for the next 24 h. Southwesterly shear increased late on 31 August, which resulted in Earl weakening back to a Category 3 hurricane by 0000 UTC 1 September. Earl weakened a little more during the morning hours of 1 September while passing directly over NOAA buoy 41046, which reported a minimum pressure of 943 mb around 0700 UTC, and a sustained wind of 71 kt with a gust to 87 kt immediately prior to the minimum pressure report. However, by that afternoon the eye became more distinct and deep convection increased and gained symmetry, presumably due to a decrease in shear. Earl re-intensified to category 4 strength by 1800 UTC 1 September and reached its peak intensity of 125 kt 12 h later, when it was located about 380 n mi southeast of Wilmington, North Carolina. An infrared satellite image of Earl near its peak intensity is shown in Fig. 5.

Earl then rapidly weakened as it turned northward and fell below major hurricane status by 0000 UTC 3 September. The rapid weakening was likely due to the combination of another concentric eyewall replacement cycle, an increase in south-southwesterly shear, cooler waters, and a drier environmental air mass. Earl weakened to a Category 1 hurricane later on 3 September while passing offshore of the mid-Atlantic and northeast United States coastline. The cyclone passed about 75 miles east of Cape Hatteras, North Carolina and 70 miles west of NOAA buoy 41001, which reported a sustained wind of 52 kt and a gust to 64 kt around 0900 UTC 3 September. Air Force reconnaissance data indicate that Earl weakened to a tropical storm by 0000 UTC 4 September, while centered about 130 n mi south-southeast of the eastern tip of Long Island, New York.

Microwave imagery suggested that an increase in organization occurred after the plane departed the cyclone (Fig. 6) and Earl re-strengthened to a hurricane as it accelerated to a forward speed of about 30 kt by 1200 UTC 4 September. Earl made landfall as a 65-kt hurricane about 3 h later near Liverpool, Nova Scotia in Canada and as a 60-kt tropical storm on Prince Edward Island around 1900 UTC 4 September.

Earl became extratropical by 0000 UTC 5 September in the Gulf of St. Lawrence, as it interacted with an upper-level low; this interaction also caused the system to slow down and turn toward the north. Meanwhile, the cyclone steadily weakened and is estimated to have merged with another low by 0600 UTC 6 September over the Labrador Sea.

b. Meteorological Statistics

Data sources for Earl (Figs. 2 and 3) include satellites, aircraft, airborne and ground-based radars, conventional land-based surface and upper-air observing sites, Coastal Marine Automated Network (CMAN) stations, National Ocean Service (NOS) stations, ocean buoys, and ships. Ship reports of winds of tropical storm force or greater associated with Earl are given in Table 2, and selected surface observations from land stations and data buoys are given in Table 3.

Satellite-based observations include subjective Dvorak technique intensity estimates from the Tropical Analysis and Forecast Branch (TAFB) and the Satellite Analysis Branch (SAB), and objective Dvorak estimates from the Cooperative Institute for Meteorological Satellite Studies/University of Wisconsin-Madison (UW-CIMSS). Microwave data and imagery from National Oceanic and Atmospheric Administration (NOAA), Defense Meteorological Satellite Program (DMSP), and National Aeronautics and Space Administration (NASA), including the Tropical Rainfall Measuring Mission (TRMM), and the European Space Agency's Advanced Scatterometer (ASCAT) were useful in constructing the best track of Earl.

Aircraft observations include flight-level, SFMR, and dropwindsonde observations, as well as 48 center fixes from 12 operational missions into Earl by the 53rd Weather Reconnaissance Squadron of the U. S. Air Force Reserve Command. In addition, the NOAA Aircraft Operations Center WP-3D aircraft flew 11 missions into Earl as part of the tri-agency PREDICT-IFEX-GRIP field project and released a total of 381 dropwindsondes. These were mainly for research purposes but still provided important data for operational use. The NOAA G-IV jet flew seven synoptic surveillance missions around Earl.

National Weather Service WSR-88D radars from San Juan, Puerto Rico, and portions of the mid-Atlantic coastline were used to make center fixes, observe the storm's structure, and obtain velocity data while Earl was near those areas.

The analyzed maximum wind speed of 125 kt at 0600 UTC 2 September is based on a 700 mb flight-level of 140 kt at 0710 UTC 2 September, and a 3-h average objective satellite intensity estimate of T6.4 or 125 kt from UW-CIMSS at 0600 UTC 2 September. The estimated minimum pressure of 927 mb at 0600 UTC 2 September is based on a dropwindsonde report of 929 mb with 25 kt of wind at 0708 UTC 2 September.

The landfall intensity near Liverpool, Nova Scotia at 1500 UTC 4 September is based mainly on surface observations. Maximum 10-min sustained wind reports of 56 kt were received from McNabs Island and Beaver Island, and 55 kt from Osbourne Head. Applying a 1.11 gust factor (Harper 2009) to these values yields a maximum 1-min surface wind of 61 to 62 kt.[2] Although the aircraft data only supported an intensity of about 60 kt 12 h earlier, the increase in organization observed in microwave imagery after that time suggest that winds could have increased before landfall. Based on the 62 kt (adjusted) observations from McNabs Island and Beaver Island, the increase in organization that occurred in the hours prior to landfall, and the assumption that higher winds were occurring at locations other than at the few available surface sites, Earl is estimated to have been a hurricane at landfall in Nova Scotia.

Earl produced a widespread area of 3 to 5 inches of rainfall across the northern Leeward Islands, with Antigua receiving nearly 8 inches. Rainfall totals in the 3 to 5 inch range were also common over far eastern North Carolina, southeastern Massachusetts, and much of eastern Maine.

[2] Harper, B.A., J.D. Kepert, and J.D. Ginger, 2009: Guidelines for Converting Between Various Wind Averaging Periods in Tropical Cyclone Conditions. World Meteorological Organization, 52 pp

The highest storm surge value reported was 4.27 ft at Hatteras Village, North Carolina. Earl produced a surge of up to 3 ft across a large portion of the U.S. coast from North Carolina to Maine. Storm tide values around 19 ft were reported in Maine, but these were dominated by tidal effects.

c. Casualty and Damage Statistics

Five casualties were caused by Hurricane Earl. Two of these occurred offshore of New Jersey, where two men, aged 20 and 23, drowned in rough surf. A 7-year-old girl was swept out to sea in large waves at Acadia National Park in Maine, a 54-year-old man drowned while trying to swim ashore in Blind Bay, Nova Scotia, and a 14-year-old girl died due to the high surf in northeastern Florida.

The hurricane produced high waves over a large portion of the western Atlantic basin for several days. According to media reports, Earl caused flooding from surge and high waves in low-lying areas and damaged homes and buildings in portions of the northern Leeward Islands. Antigua and Barbuda suffered the most damage totaling about 12.5 million USD. In North Carolina, numerous homes along the coast were flooded by storm surge. Hyde and Dare counties were among the hardest hit in the state with monetary damage estimates over 2 million and one half million dollars, respectively. In eastern Massachusetts, there were reports of downed trees and power lines. Similar damage was reported in Nova Scotia and western Newfoundland, Canada. The total damage estimate associated with Earl is around 45 million USD, of which about 18 million USD of damage occurred in the U.S.

d. Forecast and Warning Critique

The genesis of Earl was very well anticipated. The tropical wave from which Earl originated was introduced with a low probability of formation (less than 30%) in the Tropical Weather Outlook at 1200 UTC 23 August, 42 h prior to formation. At this time, the tropical wave was emerging into the eastern Atlantic. The probability was raised to medium (30-50%) just 6 h later and then to the high category (greater than 50%) 6 h after that, which was 30 h before the tropical cyclone developed. Several of the global models had shown this system developing even while it was located well inland over Africa.

A verification of NHC official track forecasts for Earl is given in Table 4a. Official forecast track errors were lower than the mean official errors for the previous 5-yr period at all times. The climatology and persistence model (OCD5) errors were also lower than mean errors for that model during the previous 5-yr period, which indicates that Earl was easier than average to forecast. A homogeneous comparison of the official track errors with selected guidance models is given in Table 4b. The multi-model consensus models TVCN and GUNA performed better than the official forecast through 36 h. The GFS (GFSI) was the best performing model at and beyond 36 h and bested the official forecast during that time period. While Earl was over the central Atlantic, many of the models and the official forecast had a pronounced rightward bias (Fig. 7).

A verification of the NHC official intensity forecasts for Earl is given in Table 5a. Official errors for Earl were lower than the mean official errors for the previous 5-yr period at every forecast time, except 12 h. The climatology and persistence model (OCD5) errors were near the previous 5-yr average at the 12 h, 24 h, and 36 h time periods, and larger than the average errors at 48 h and beyond. A homogeneous comparison of the official intensity errors with selected guidance models is given in Table 5b. The intensity errors were generally similar to those of the guidance models available for Earl. The corrected consensus (IVCN) was the only model that consistently outperformed the official forecast through 72 h.

Watches and warnings associated with Earl are given in Table 6. A tropical storm watch was issued for the U.S. Virgin Islands and Puerto Rico at 2100 UTC 28 August, and a tropical storm warning was issued for that area 15 h later. This resulted in a lead time for Earl's closest approach of about 48 h for the watch and 33 h for the warning. Hurricane and tropical storm watches were issued for the North Carolina and southern Virginia coastlines at 2100 UTC 31 August. The watches were upgraded to warnings at 1500 UTC 1 September. This provided lead times of 48 h for the watches and 30 h for the warnings.

e. Acknowledgments

National Weather Service Forecast offices in Puerto Rico and from North Carolina to Maine provided many of the observations listed in this report. Jay Titlow of Weatherflow contributed several observations that were helpful in preparing the best track. Paul Fanelli of the Center for Operational Oceanographic Products and Services sent marine observations along the U.S. east coast. Surface observations from Canada were provided by Environmental Canada's Hurricane Center. NOAA buoy observations are from the National Data Buoy Center. The Hurricane Specialist Unit at the National Hurricane Center provided extensive insight and guidance in the writing of this report.

Table 1. Best track for Hurricane Earl, 25 August – 4 September 2010.

Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Stage
24 / 0000	12.4	19.3	1009	25	low
24 / 0600	12.8	20.9	1009	25	"
24 / 1200	13.2	22.6	1008	30	"
24 / 1800	13.6	24.3	1008	30	"
25 / 0000	13.9	26.0	1008	30	"
25 / 0600	14.1	27.8	1007	30	tropical depression
25 / 1200	14.3	29.7	1006	35	tropical storm
25 / 1800	14.5	31.5	1006	35	"
26 / 0000	14.7	33.0	1006	35	"
26 / 0600	14.9	34.5	1004	40	"
26 / 1200	15.1	36.0	1004	40	"
26 / 1800	15.3	37.7	1004	40	"
27 / 0000	15.5	39.4	1004	40	"
27 / 0600	15.7	41.2	1004	40	"
27 / 1200	15.8	43.1	1004	40	"
27 / 1800	15.9	45.0	1004	40	"
28 / 0000	16.0	47.0	1000	45	"
28 / 0600	16.1	49.0	996	50	"
28 / 1200	16.2	51.0	996	50	"
28 / 1800	16.3	53.0	996	50	"
29 / 0000	16.5	54.8	991	55	"
29 / 0600	16.7	56.5	991	55	"
29 / 1200	17.0	58.0	985	65	hurricane
29 / 1800	17.3	59.3	978	75	"
30 / 0000	17.7	60.6	971	85	"
30 / 0600	18.1	61.9	967	95	"
30 / 1200	18.5	63.1	965	105	"
30 / 1800	19.0	64.2	954	115	"
31 / 0000	19.6	65.3	938	115	"
31 / 0600	20.2	66.4	931	115	"
31 / 1200	20.9	67.5	935	115	"
31 / 1800	21.6	68.4	940	115	"
01 / 0000	22.5	69.4	940	110	"

Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Stage
01 / 0600	23.6	70.5	941	105	"
01 / 1200	24.7	71.6	942	110	"
01 / 1800	25.9	72.7	941	115	"
02 / 0000	27.2	73.5	932	120	"
02 / 0600	28.6	74.3	927	125	"
02 / 1200	30.1	74.8	935	115	"
02 / 1800	31.7	75.1	943	100	"
03 / 0000	33.0	74.9	949	90	"
03 / 0600	34.5	74.2	955	85	"
03 / 1200	36.1	73.4	959	75	"
03 / 1800	37.6	72.2	960	70	"
04 / 0000	39.1	70.6	961	60	tropical storm
04 / 0600	40.7	68.4	961	60	"
04 / 1200	43.0	65.7	961	65	hurricane
04 / 1500	44.3	64.5	962	65	"
04 / 1800	45.5	63.2	965	65	"
04 / 1900	46.0	62.7	967	60	tropical storm
05 / 0000	48.4	60.2	971	55	extratropical
05 / 0600	50.6	57.5	978	50	"
05 / 1200	52.4	55.4	987	45	"
05 / 1800	54.0	54.1	992	40	"
06 / 0000	55.7	53.5	994	35	"
06 / 0600					absorbed
04 / 1500	44.3	64.5	962	65	landfall near Liverpool, Nova Scotia
04 / 1900	46.0	62.7	967	60	landfall in Prince Edward Island
02 / 0600	28.6	74.3	927	125	minimum pressure and maximum wind

Table 2. Selected ship reports with winds of at least 34 kt for Hurricane Earl, 25 August – 4 September 2010.

Date/Time (UTC)	Ship call sign	Latitude (°N)	Longitude (°W)	Wind dir/speed (kt)	Pressure (mb)
31 / 0600	KIRH	18.5	67.2	310 / 37	1000.9
31 / 1500	WPGK	18.7	67.2	220 / 35	1005.0
03 / 1200	3FFR4	30.5	78.4	260 / 35	1015.0
03 / 1500	WKAB	37.2	76.0	310 / 37	1002.5
03 / 1800	9VVK	35.6	74.9	240 / 38	1004.0
03 / 1800	C6TX6	35.7	74.7	250 / 37	998.0
03 / 2100	PHEO	34.0	67.0	190 / 35	1018.3
04 / 0100	PHEO	34.4	67.7	240 / 42	1018.1
04 / 0200	PHEO	34.6	68.0	220 / 37	1017.2
04 / 0400	PHEO	34.9	68.3	220 / 45	1017.0
04 / 1000	PHEO	35.8	69.1	240 / 43	1014.3
04 / 1200	9HJC9	38.5	64.3	230 / 45	1007.4
04 / 1500	C6TQ6	42.0	69.8	250 / 40	998.0
04 / 1500	CG3029	44.7	63.6	140 / 41	973.8
04 / 1800	C6TQ6	41.0	69.1	250 / 37	1003.0
04 / 1800	VCRG	47.3	61.8	080 / 40	983.7
04 / 2100	WKAW	44.5	55.8	190 / 41	1005.8
04 / 2100	VCRG	47.3	61.8	220 / 41	969.0
04 / 2100	VOCJ	47.6	59.1	140 / 35	987.2

Table 3. Selected surface observations for Hurricane Earl, 25 August – 4 September 2010.

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)			
United States								
North Carolina								
International Civil Aviation Organization (ICAO) Sites								
Beaufort (KMRH)	03/0656	1000.6	03/0510	32	41			0.82
Frisco (KHSE)	03/0300	990.1	03/0507	34	57			
Manteo (KMQI)			03/1002	38	61			3.98
Kill Devil Hills (KFFA)			03/0801	30	51			4.47
Cherry Point (KNKT)	03/0400	1001.7	03/0400	26	36			
Weather Flow Observations								
Alligator Rive Bridge	03/0950	997.6	03/0719	43	51			
KHK Resort	03/0730	990.5	03/1111	50	60			
Oregon Inlet	03/0925	988.2	03/1300	46	63			
Avon Sound	03/0710	988.1	03/1136	49	63			
Ocracoke Sound	03/0530	993.4	03/0708	48	63			
Pamlico Sound	03/0740	992.3	03/0912	54	65			
Marine Observations								
Duck Pier (DUCN7)	03/1000	993.3	03/0948	44	59			
Cape Lookout (CLKN7)	03/0500	999.5	03/1000	38	46			
ORIN7	03/0906	991.9	03/0600	41	71			
Hatteras Village						4.27	4.70	
Duck						2.65	5.19	
Beaufort	03/0748	1001.3	03/0206	25	36	1.08	4.51	
CO-OPS								
Wrightsville Beach	03/0618	1004.9	02/1706	26	32	0.95	5.42	
Public/Other								
Cedar Island	03/0550	1000.0	03/0750	41	51	2.00	2.00	
Stumpy Point	03/0800	996.0	03/0900	47	53			
South Oregon Inlet			03/1106	56[e]	74[e]			

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)			
Virginia								
ICAO Sites								
Oceana (KNTU)	03/1156	1001.3	03/1156	29	42			0.90
Norfolk (KORF)	03/1251	1002.5	03/1051	20	36			0.21
Marine Observations								
Cape Henry (CHYV2)	03/1242	1000.2	03/1218	37	44			
Kiptopeke (KPTV2)			03/1224	28	38	1.50	4.14	
Chesapeake Light Station (CHLV2)	03/1300	999.7	03/1140	29	49			
Rappahannock Light Tower (RPLV2)	03/1424	1000.6	03/1342	35	39			
Sewells Point	03/1212	1003.2				1.75	3.84	
CO-OPS								
Lewisetta (8635750)	03/2224	1002.7	04/1606	18	23	1.23	2.78	
Chesapeake Bay Bridge (8638863)	03/1200	1001.8	03/1248	35	41	1.90	4.11	
Weather Flow Observations								
Third Island Chesapeake Bay Bridge Tunnel	03/1250	997.0	03/1245	43	50			
Silver Beach	03/1440	1000.9	03/1232	31	35			
Tangier Island	03/1435	1000.0	03/1240	27	34			
Onancock	03/1536	1000.5	03/1305	32	37			
Willoughby Degaussing Range			03/1324	26	31			
Norfolk Terminal			03/0930	25	31			
Maryland								
Marine Observations								
Ocean City Inlet	03/1906	999.5	03/1512	25	34	1.65	3.54	
CO-OPS								
Snow Hill (8571359)						1.85	2.64	
Bishops Head (8571421)	03/2306	1002.2	04/0348	21	25	1.71	3.20	
Mc Creadys Creek (871559)						1.79	3.52	
Vienna (8571773)						1.93	3.42	
Baltimore (8574680)	03/2200	1001.4	04/1712	14	20	1.22	2.75	

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)			
Annapolis (8575512)	03/2112	1001.4				1.20	2.52	
New Jersey								
Marine Observations								
Brant Beach (BRBN4)	03/2218	999.7	03/1548	27	31			
Atlantic City Marina (ACMN4)			03/1730	25	35			
New York								
ICAO Sites								
Westhampton Beach (KFOK)	04/0253	996.5	03/2351	21	30			2.62
Marine Observations								
Lattingtown						3.33	6.00	
Inwood						2.16	4.47	
Freeport						2.05	4.01	
Montauk	04/0254	994.7				1.75	3.50	
Bergen Point	04/0254	998.8				1.62	6.19	
Point Lookout						1.61	4.07	
Lindenhurst						1.61	2.73	
Connecticut								
Marine Observations								
New London	04/0436	995.1				1.59	3.90	
New Haven	04/0318	996.7				1.55	7.62	
Bridgeport	04/0454	997.4				1.55	8.24	
Rhode Island								
CO-OPS								
Newport (8452660)	04/1918	992.4	04/0530	24	29	1.54	4.46	
Massachusetts								
ICAO Sites								
Hyannis (KHYA)			04/0535	27	41			4.47
Nantucket (KACK)			04/0625	36	47			2.29
West Tisbury (KMVY)			04/0135	29	38			
Provincetown (KPVC)			04/0655	24	35			
Marine Observations								

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)			
Nantucket Harbor (NTKM3)	04/0500	985.5	04/0618	27	39			
Horseshoe Shoal			04/0651	42	52			
Buzzards Bay (BUZM3)	04/0400	990.4	04/0330	34	43			
Chatham						2.05	2.83	
Nantucket						2.21	2.50	
Woods Hole	04/0436	990.1				1.57	2.12	
Fall River						1.55	2.49	
Boston	04/0648	992.9				1.92	3.13	
CO-OPS								
Fall River (8447386)	04/0430	993.2				1.55	5.43	
Pubic/Other								
Edgartown 41.4 N -70.5 W								6.21
Yarmouth 41.7 N -70.2 W								5.17
Wellfleet 41.9 N -70.0 W								5.06
Vineyard Haven 41.5 N -70.6 W								3.95
Chatham (KCQX) 41.7 N -70.0 W								3.51
Orleans 41.8 N -70.0 W								3.50
Chatham 41.7 N -70.0 W								3.35
Falmouth 41.6 N -70.6 W								3.18
Maine								
Marine Observations								
Mt. Desert Rock (MDRM1)			04/1400	31	35			
Eastport						1.00	18.00	
Bar Harbor						2.00	11.00	
Fort Point						1.55	5.00	
Wells	04/0942	991.7				1.30	7.97	
Portland	04/1000	991.6				1.54	6.80	
CO-OPS								

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)			
Eastport (8410140)	04/1418	983.1	04/1054	26	31	1.70	19.44	
Bar Harbor (8413320)	04/1248	987.1	04/0818	24	33	1.71	12.05	
Public/Other								
West Quoddy (QDYM1)			04/1135	24	36			
Cutler (CUTM1)			04/1506	27	34			
Millbridge (WS031) 44.6 N -67.8 W								4.93
Kenduskeag 44.9 N -68.9 W								4.40
Madawaska (AR037) 47.4 N -68.3 W								4.21
Colombia Falls (WS014) 44.7 N -67.7 W								4.19
Ashland (AR091) 46.6 N -68.4 W								3.95
Hartford (TM1) 44.4 N -70.3 W								3.81
Portage (AR062) 46.8 N -68.5 W								3.72
Harrington (ME-WS-9) 44.6 N -67.8 W								3.50
Oxbow (OXBM1) 46.4 N -68.5 W								3.49
Jonesboro (JONM1) 44.7 N -67.6 W								3.38
Old Town (OLDM1) 44.9 N -68.6 W								3.34
Bangor (KBGR) 44.8 N -68.8 W								3.28
Wilton 44.6 N -70.2 W								3.27
Orono (PN036) 44.9 N -68.7 W								3.25
Livermore Falls (RM1) 44.5 N -70.2 W								3.22
Mercer (RM1) 44.7 N -69.9 W								3.20
North Anson (NM1) 44.9 N -70.0 W								3.11
Bellmont 44.4 N -69.1 W								3.06
Puerto Rico and the U.S. Virgin Islands								

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)			
ICAO sites								
San Juan, PR (TJSJ)	30/2353	999.0	31/0014	29	39			
St. Croix,VI (TISX)	30/1924	1000.3	30/1756	32	43			
St Thomas, VI (TIST)	30/2015	992.5	30/2151	46	60			3.02
Marine Observations								
Arecibo, PR (AROP4)	30/2130	1005.2	31/0312	29	49			
San Juan, PR (SJNP4)	31/1130	1005.2	30/2142	38	44			
Fajardo, PR (FRDP4)	30/2236	998.2	30/1830	34	44			
Isabel Segunda Vieques, PR (VQSP4)			30/1312	32	42			
Charlotte Amalie Vinos, VI (CHAV3)			30/2148	39	59			
Christiansted Harbor, VI (CHSV3)	30/1812	999.5	30/1112	30	52			
Lime Tree Bay, VI (LTBV3)	30/1912	999.1	30/1848	38	47			
Penuelas, PR (PLSP4)			31/0736	31	38			
Salt River Bay, VI (SRBV3)			30/2000	30	40			
Culebra, PR (CLBP4)	30/2118	997.3	30/2054	39	53			
Esperanza Vieques, PR (ESPP4)	30/2226	998.8	30/2218	39	48			
Weather Flow Observations								
Two Brothers, VI			30/1830	52	65			
Crown Mountain, VI			30/1800	45				
Public/Other								
Naguabo (NGIP4) 18.3 N -65.8 W								5.18
Orocovis (OROP4) 18.2 N -66.5 W								5.04
Vega Baja 18.4 N -66.4 W								4.62
Carolina (TJSJ) 18.4 N -66.0 W								3.92
Utuado(ARHP4) 18.3 N -66.7 W								3.92
San Juan 18.4 N -66.1 W								3.60

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)			
Jayuya (JAYP4) 18.2 N -66.6 W								3.58
Villalba (VINP4) 18.2 N -66.5 W								3.54
Guaynabo (RPCP4) 18.4 N -66.1 W								3.45
Comerio (CMRP4) 18.2 N -66.2 W								3.44
Morovis (MORP4) 18.3 N -66.4 W								3.33
Caguas (CAKP4) 18.2 N -66.0 W								3.28
San Lorenzo (SLGP4) 18.2 N -66.0 W								3.23
Ciales (CIAP4) 18.3 N -66.5 W								3.12
Cidra (DRAP4) 18.2 N -66.1 W								3.12
Northern Leeward Islands								
Antigua (TAPA)	30/0600	998.7	30/0938	45	56			7.75
St. Eustatius (TNCE)	30/1200	997.0	30/1500	40	58			
St. Maarten (TNCM)	30/1300	986.3	30/1500	31	47			
Canada								
McNabs Island, NS	04/1600	971.6	04/1500	56[f]	70	3.8	6.1	
Beaver Island, NS	04/1700	978.9	04/1800	56[f]	73			
Osbourne Head, NS	04/1600	972.8	04/1500	55[f]	69			2.0
Halifax, NS	04/1600	971.1	04/1548	44[f]	65			
Caribou Point, NS	04/1800	971.4	04/1700	41[f]	58			
Corner Brook, NL	05/0200	985.7	05/0500	28[f]	52			0.4
Western Head, NS	04/1400	963.0	04/1300	38[f]	53			0.9
Buoys								
42060 16.5 N 63.5 W	30/0830	1003.1	30/1213	32	37			
41043 21.1 N 65.0 W	31/0526	998.9	31/0714	55	72			
41046 23.8 N 70.9 W	01/0714	942.6	01/0640	71	87			
41047 27.5 N 71.5 W	01/2123	999.5	01/2250	54	64			

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)			
41001 34.7 N 72.7 W	03/0850	986.3	03/0830	52	64			
44025 40.3 N 73.2 W	03/2250	995.5	03/2140	26	33			
44017 40.7 N 72.0 W	04/0250	992.9	03/2230	28	37			
44018 41.3 N 69.3 W			04/0920	31	39			
44008 40.5 N 69.2 W			04/0810	40	52			
44009 38.5 N 74.7 W	03/2050	997.0	03/1550	29	36			
44020 41.4 N 71.2 W			04/0610	35	45			
44024 42.3 N 65.9 W			04/1004	43	54			
42085 17.9 N 66.5 W	31/0330	1002.6	31/0200	29	37			
41053 18.5 N 66.1 W	30/2340	999.0	31/0130	31	49			

[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 ASOS reports are 2 min; buoy averaging period is 8 min.
[c] Storm surge is water height above normal astronomical tide level.
[d] Storm tide is referenced above Mean Lower Low Water (MLLW).
[e] Anemometer height 5 m.
[f] Wind averaging period 10 min.

Table 4a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) track forecast errors (n mi) for Hurricane Earl, 25 August – 4 September 2010. Mean errors for the 5-yr period 2005-9 are shown for comparison. Official errors that are smaller than the five-year means are shown in boldface type.

	Forecast Period (h)						
	12	24	36	48	72	96	120
OFCL	**23.1**	**34.8**	**49.4**	**69.4**	**115.0**	**173.6**	**233.3**
OCD5	36.1	74.4	121.3	174.7	289.3	406.8	535.0
Forecasts	40	38	36	34	30	26	22
OFCL (2005-9)	31.8	53.4	75.4	96.8	143.8	195.6	252.1
OCD5 (2005-9)	46.9	97.3	155.4	211.6	304.8	387.9	467.8

Table 4b. Homogeneous comparison of selected track forecast guidance models (in n mi) for Hurricane Earl, 25 August – 4 September 2010. Errors smaller than the NHC official forecast are shown in boldface type. The number of official forecasts shown here will generally be smaller than that shown in Table 4a due to the homogeneity requirement.

Model ID	Forecast Period (h)						
	12	24	36	48	72	96	120
OFCL	21.3	34.7	52.9	73.0	116.6	172.0	247.7
GFSI	23.5	38.2	**52.0**	**71.3**	**113.5**	**157.4**	**216.0**
GHMI	29.7	51.0	64.5	76.3	117.7	**168.9**	274.5
HWFI	32.6	56.2	72.5	92.4	147.9	206.0	275.1
GFNI	21.5	45.4	68.5	94.9	139.3	209.8	339.4
NGPI	**18.1**	41.7	69.6	102.0	185.7	266.6	415.3
EGRI	23.8	41.5	63.2	91.4	150.1	206.3	**219.4**
EMXI	22.7	41.4	65.2	91.4	159.7	249.2	386.9
AEMI	24.0	38.7	59.7	88.3	160.1	222.5	305.2
TVCN	**17.5**	**32.9**	**49.8**	73.2	126.1	180.6	269.3
TVCC	23.0	42.0	62.6	87.3	142.5	205.7	291.6
TCON	**20.6**	36.2	54.1	75.8	130.8	185.5	256.0
TCCN	25.6	45.4	65.9	89.3	141.5	199.2	252.4
GUNA	**18.9**	**33.3**	**50.9**	74.1	128.9	183.2	255.7
CGUN	24.5	43.4	64.2	87.9	139.2	198.1	248.3
LBAR	33.0	57.6	86.2	109.8	150.8	206.2	**224.8**
BAMS	42.6	86.7	129.5	158.5	200.8	215.3	**237.5**
BAMM	35.9	69.2	100.0	122.4	156.5	**169.9**	**203.9**
BAMD	37.6	67.8	95.6	126.4	173.1	220.8	285.8
Forecasts	28	28	28	27	23	21	14

Table 5a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) intensity forecast errors (kt) for Hurricane Earl, 25 August – 4 September 2010. Mean errors for the 5-yr period 2005-9 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	72	96	120
OFCL	7.3	**10.5**	**12.1**	**14.0**	**15.2**	**15.8**	**16.8**
OCD5	8.3	12.7	15.4	19.0	24.4	28.7	25.2
Forecasts	40	38	36	34	30	26	22
OFCL (2005-9)	7.0	10.7	13.1	15.2	18.6	18.7	20.1
OCD5 (2005-9)	8.6	12.5	15.8	18.2	21.0	22.7	21.7

Table 5b. Homogeneous comparison of selected intensity forecast guidance models (in kt) for Hurricane Earl, 25 August – 5 September 2010. 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	72	96	120
OFCL	7.5	10.9	12.4	13.9	16.2	16.1	17.5
GHMI	8.1	12.6	14.1	**13.8**	17.0	17.7	21.3
HWFI	9.0	13.6	16.8	17.9	19.2	23.2	25.6
GFNI	8.5	11.5	**11.6**	**12.5**	19.8	24.0	22.1
FSSE	**7.1**	**10.8**	13.2	**13.0**	16.6	22.4	27.5
DSHP	8.0	12.1	15.0	15.9	19.5	17.2	20.8
LGEM	**7.2**	**10.4**	13.1	**13.5**	17.7	**15.3**	20.4
ICON	**7.2**	11.5	13.6	**13.7**	17.1	17.0	20.1
IVCN	**7.2**	**10.7**	**12.0**	**12.1**	**15.3**	17.3	20.2
Forecasts	34	34	34	32	26	23	18

Table 6. Watch and warning summary for Hurricane Earl, 25 August – 4 September 2010.

Date/Time (UTC)	Action	Location
27 / 1600	Tropical Storm Watch issued	Saint Martin and Saint Barthelemy
28 / 0900	Tropical Storm Watch issued	Antigua, Barbuda, Montserrat, Saint Kitts, Nevis, and Anguilla
28 / 2100	Tropical Storm Watch changed to Tropical Storm Warning	Antigua, Barbuda, Montserrat, Saint Kitts, Nevis, Anguilla, St. Maarten, Saba, and St. Eustatius
28 / 2100	Tropical Storm Watch issued	British and U.S. Virgin Islands
29 / 0000	Tropical Storm Watch changed to Tropical Storm Warning	French Saint Martin and Saint Barthelemy
29 / 0300	Tropical Storm Warning changed to Hurricane Warning	Antigua, Barbuda, Montserrat, Saint Kitts, Nevis, Anguilla
29 / 0300	Tropical Storm Watch discontinued	All
29 / 0300	Hurricane Watch issued	St. Maarten, Saba, and St. Eustatius, British and U.S. Virgin Islands, and Puerto Rico
29 / 0900	Tropical Storm Warning changed to Hurricane Warning	St. Maarten, Saba, and St. Eustatius
29 / 0900	Hurricane Watch discontinued	St. Maarten, Saba, and St. Eustatius
29 / 1200	Tropical Storm Warning issued	British Virgin Islands
29 / 1500	Tropical Storm Warning issued	U.S. Virgin Islands and Puerto Rico
29 / 2100	Hurricane Warning issued	British Virgin Islands
30 / 0900	Hurricane Warning issued	U.S. Virgin Islands
30 / 1500	Tropical Storm Watch issued	Turks and Caicos Islands
30 / 1500	Hurricane warning changed to Tropical Storm Warning	Antigua, Barbuda, Montserrat, Saint Kitts, Nevis, Anguilla
30 / 1500	Hurricane Warning issued	Culbera and Vieques
30 / 1700	Tropical Storm Warning discontinued	Antigua, Barbuda, Montserrat, Saint Kitts, Nevis
30 / 1900	Hurricane Warning changed to Tropical Storm Warning	Anguilla
30 / 2100	Tropical Storm Watch changed to Tropical Storm Warning	Turks and Caicos
30 / 2100	Hurricane Watch discontinued	Puerto Rico
30 / 2100	Hurricane Warning changed to Tropical Storm Warning	British and U.S. Virgin Islands
30 / 2100	Tropical Storm Watch issued	Southeastern Bahamas
30 / 2100	Tropical Storm Warning discontinued	Anguilla
30 / 2100	Hurricane Warning discontinued	All
31 / 1100	Tropical Storm Warning discontinued	British and U.S. Virgin Islands, and Puerto Rico
31 / 2100	Tropical Storm Watch issued	Cape Fear to Surf City
31 / 2100	Hurricane Watch issued	Surf City to NC/VA border

Date/Time (UTC)	Action	Location
1 / 0900	Tropical Storm Watch discontinued	Southeastern Bahamas
1 / 0900	Tropical Storm Warning discontinued	Turks and Caicos Islands
1 / 0900	Tropical Storm Warning issued	San Salvador Island
1 / 0900	Hurricane Watch modified to	Surf City to Parramore Island
1 / 1500	Tropical Storm Watch discontinued	All
1 / 1500	Tropical Storm Warning issued	Cape Fear to Bogue Inlet
1 / 1500	Hurricane Watch discontinued	Surf City to Parramore Island
1 / 1500	Hurricane Watch issued	NC/VA border to Cape Henlopen
1 / 1500	Hurricane Warning issued	Bogue Inlet to NC/VA border
1 / 1800	Tropical Storm Warning discontinued	San Salvador Island
1 / 2100	Tropical Storm Watch issued	Sandy Hook to Woods Hole and Sagamore Beach to Merrimack River
1 / 2100	Tropical Storm Warning issued	NC/VA border to Sandy Hook
1 / 2100	Hurricane Watch issued	Woods Hole to Sagamore Beach
2 / 0900	Tropical Storm Watch modified to	Sandy Hook to Fire Island
2 / 0900	Tropical Storm Watch discontinued	Sagamore Beach to Merrimack River
2 / 0900	Tropical Storm Watch issued	Plymouth to Eastport
2 / 0900	Tropical Storm Watch issued	Port Maitland to Medway Harbour
2 / 0900	Tropical Storm Warning issued	Fire Island to Port Jefferson Harbor
2 / 0900	Hurricane Watch discontinued	Woods Hole to Sagamore Beach
2 / 0900	Hurricane Watch issued	Westport to Plymouth
2 / 1500	Tropical Storm Watch modified to	Sandy Hook to New Haven and Hull to Eastport
2 / 1500	Tropical Storm Warning issued	New Haven to Westport
2 / 1500	Hurricane Watch discontinued	Westport to Plymouth
2 / 1500	Hurricane Warning issued	Westport to Hull
2 / 1800	Tropical Storm Watch modified to	Ecum Secum to Medway Harbour
2 / 1800	Tropical Storm Watch issued	Digby to Fort Lawrence and US/Can border to Fort Lawrence
2 / 1800	Hurricane Watch issued	Medway Harbour to Digby
2 / 2100	Tropical Storm Watch modified to	Digby to Fort Lawrence
3 / 0000	Tropical Storm Warning modified to	Surf City to Bogue Inlet
3 / 0000	Tropical Storm Warning issued	Hull to Merrimack River and Stonington to Eastport
3 / 0300	Tropical Storm Watch discontinued	Hull to Eastport
3 / 0300	Tropical Storm Watch modified to	Point Tupper to Medway Harbour
3 / 0300	Tropical Storm Watch issued	Merrimack River to Stonington, Stonington to Eastport, Aulds Cove to Tidnish, and Prince Edward Island

Date/Time (UTC)	Action	Location
3 / 0300	Tropical Storm Warning modified to	Cape Fear to Bogue Inlet
3 / 0600	Tropical Storm Watch modified to	Tidnish to Shediac and Digby to Fort Lawrence
3 / 0900	Tropical Storm Watch changed to Tropical Storm Warning	Prince Edward Island
3 / 0900	Tropical Storm Watch issued	Cape Breton Island to Magdalen Islands and
3 / 0900	Tropical Storm Watch issued	Ecum Secum eastward to Lismore and Ecum Secum eastward to Lismore
3 / 0900	Tropical Storm Warning discontinued	Cape Fear to Bogue Inlet
3 / 0900	Tropical Storm Warning issued	Lismore southward to Ecum Secum
3 / 0900	Hurricane Watch discontinued	NC/VA border to Cape Henlopen
3 / 0900	Hurricane Warning modified to	Cape Lookout to NC/VA border
3 / 1500	Tropical Storm Watch discontinued	Sandy Hook to New Haven
3 / 1500	Tropical Storm Watch modified to	US/Can border to Fort Lawrence, Ocracoke to Sandy Hook
3 / 1500	Tropical Storm Watch discontinued	Point Tupper to Medway Harbour, Tidnish to Sediac
3 / 1500	Tropical Storm Warning modified to	New Haven to Woods Hole, Sagamore Beach to Hull, Fort Lawrence southward to Ecum Secum
3 / 1500	Tropical Storm Warning issued	Tidnish to Lismore
3 / 1500	Hurricane Watch modified to	Ecum Secum to Digby
3 / 1500	Hurricane Warning discontinued	Cape Lookout to NC/VA border, Westport to Hull
3 / 1500	Hurricane Warning issued	Woods Hole to Sagamore Beach
3 / 1800	Tropical Storm Warning modified to	NC/VA border to Sandy Hook
3 / 2100	Tropical Storm Watch changed to Tropical Storm Warning	US/Can border to Fort Lawrence, Magdalen Islands
3 / 2100	Tropical Storm Watch discontinued	Cape Elizabeth to Stonington, Ecum Secum eastward to Lismore
3 / 2100	Tropical Storm Watch issued	Point Escuminiac to Shediac
3 / 2100	Tropical Storm Warning discontinued	NC/VA border to Sandy Hook, Fort Lawrence southward to Ecum Secum
3 / 2100	Tropical Storm Warning modified to	Tidnish to Shediac
3 / 2100	Tropical Storm Warning issued	Nova Scotia
4 / 0300	Tropical Storm Warning discontinued	Fire Island to Port Jefferson Harbor, New Haven to Woods Hole
4 / 0300	Tropical Storm Warning modified to	Watch Hill to Hull
4 / 0300	Hurricane Warning discontinued	All
4 / 0900	Tropical Storm Warning discontinued	Watch Hill to Hull
4 / 1200	Tropical Storm Warning discontinued	Stonington to Eastport
4 / 1200	Tropical Storm Warning modified to	Fundy National Park

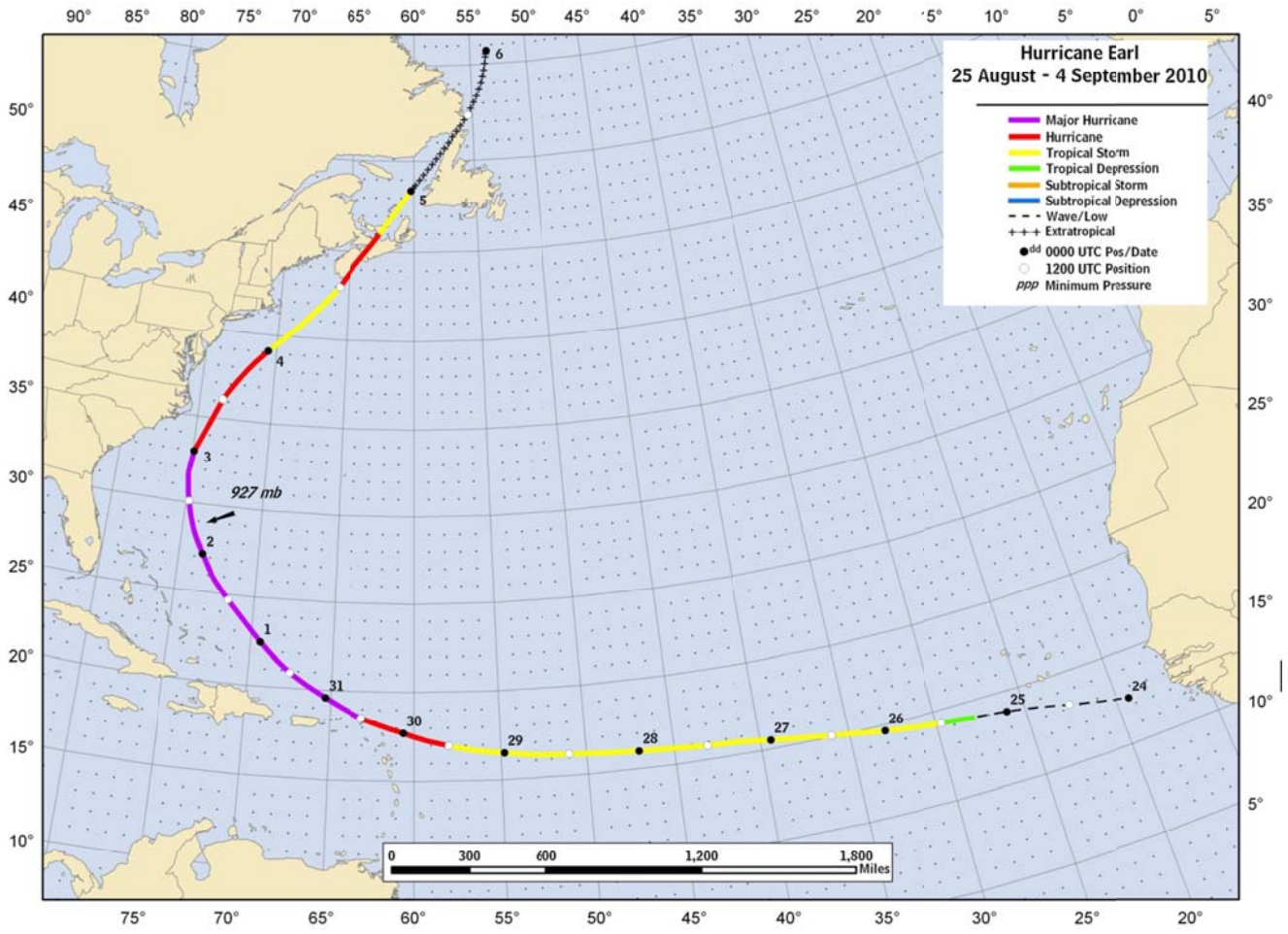


Figure 1. Best track positions for Hurricane Earl, 25 August – 4 September 2010. Track during the extratropical stage is based on analyses from the NOAA Ocean Prediction Center and the Canadian Hurricane Center.

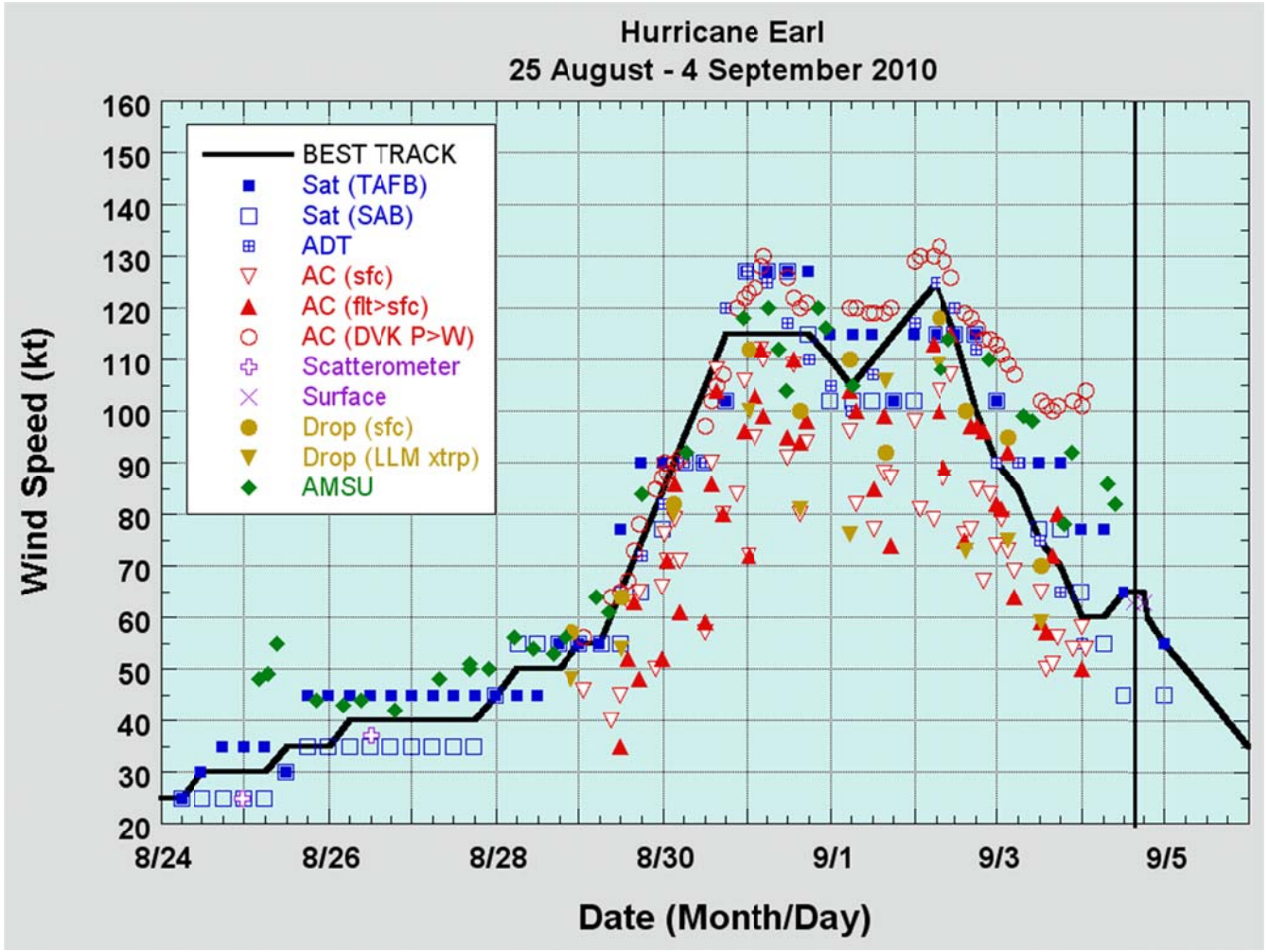


Figure 2. Selected wind observations and best track maximum sustained surface wind speed curve for Hurricane Earl, 25 August – 4 September 2010. Aircraft observations have been adjusted for elevation using 90%, 80%, and 80% reduction factors for observations from 700 mb, 850 mb, and 1500 ft, respectively. 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), and from the sounding boundary layer mean (MBL). Objective Dvorak estimates represent linear averages over a three-hour period centered on the nominal observation time. Dashed vertical lines correspond to 0000 UTC. The solid vertical line corresponds to landfall.

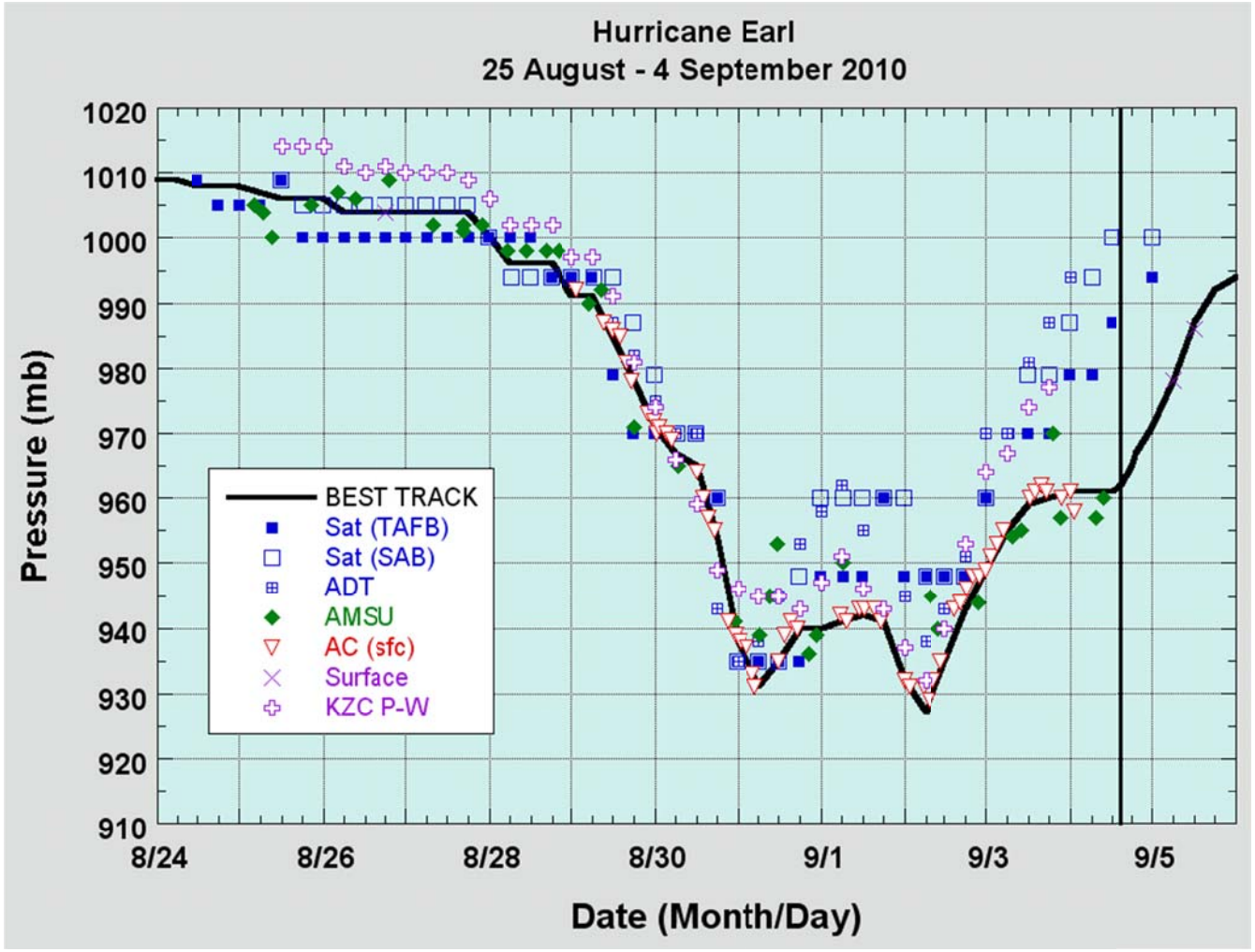
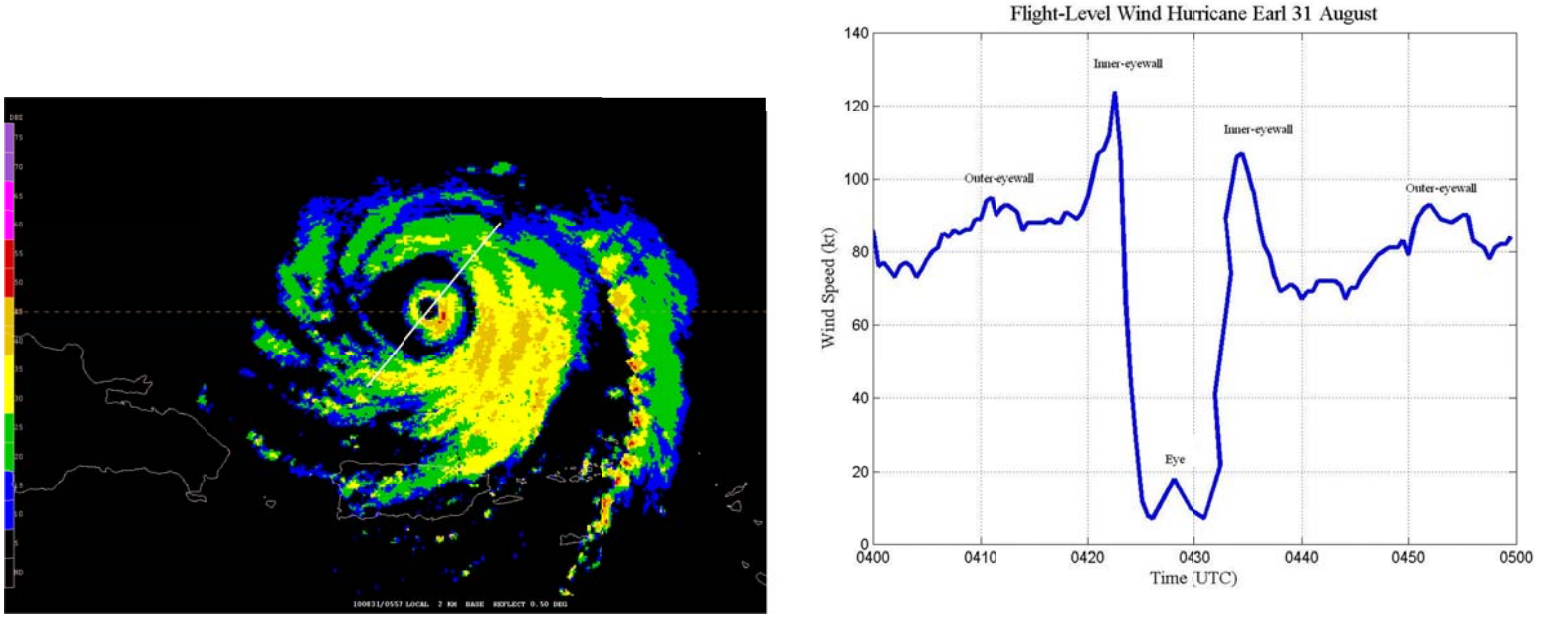


Figure 3. Selected pressure observations and best track minimum central pressure curve for Hurricane Earl, 25 August – 4 September 2010. Objective Dvorak estimates represent linear averages over a three-hour period centered on the nominal observation time. KZC P-W refers to pressure estimates derived using the Knaff-Zehr-Courtney pressure-wind relationship. Dashed vertical lines correspond to 0000 UTC. The solid vertical line corresponds to landfall.



(a) (b)

Figure 4. (a) WSR-88D San Juan radar reflectivity image of Hurricane Earl at 0557 UTC 31 August when the hurricane was passing north of the island. The white line shows a portion of the Air Force reconnaissance aircraft flight leg around the same time. (b) Flight-level winds along the flight leg shown in (a).

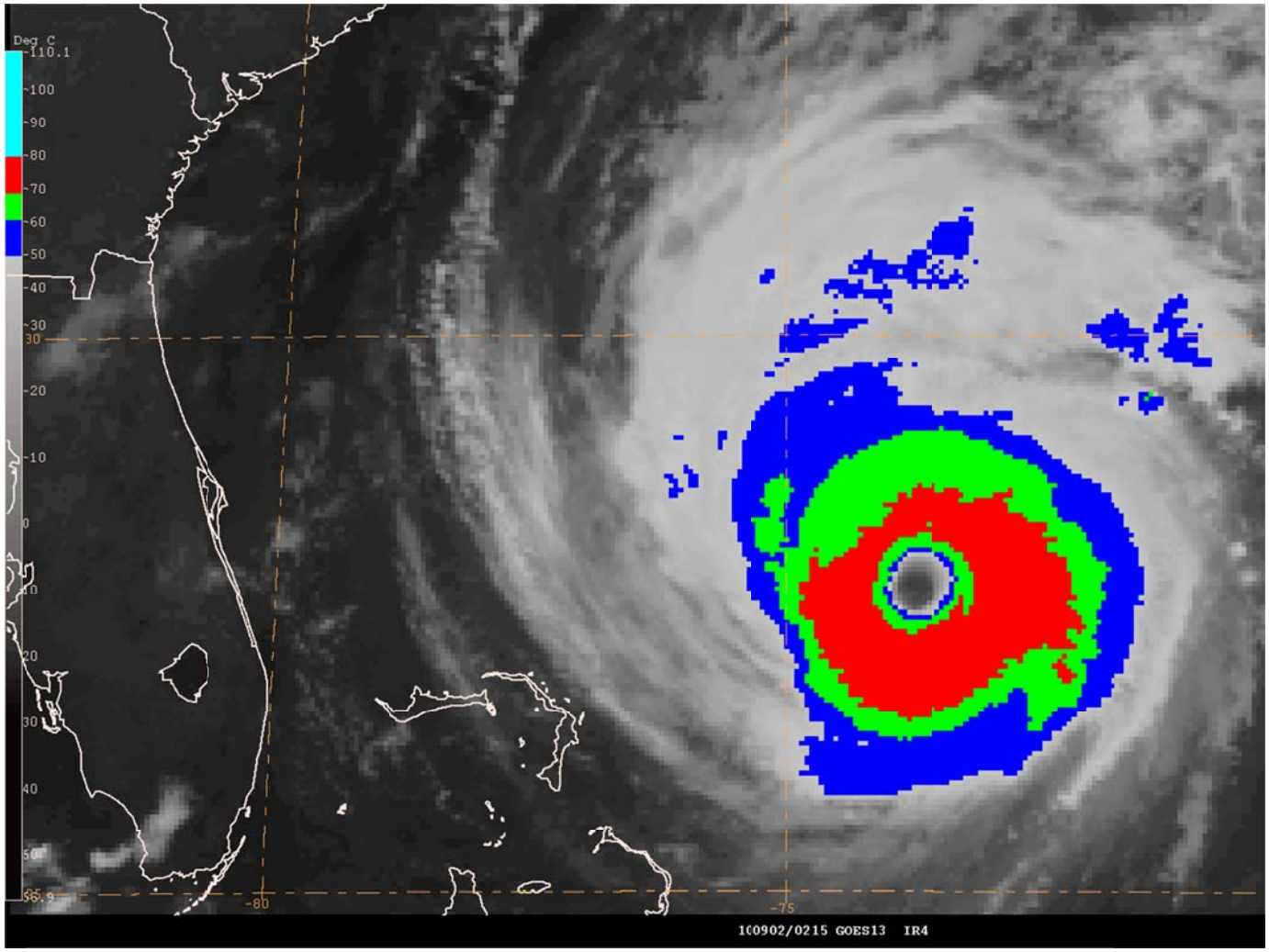
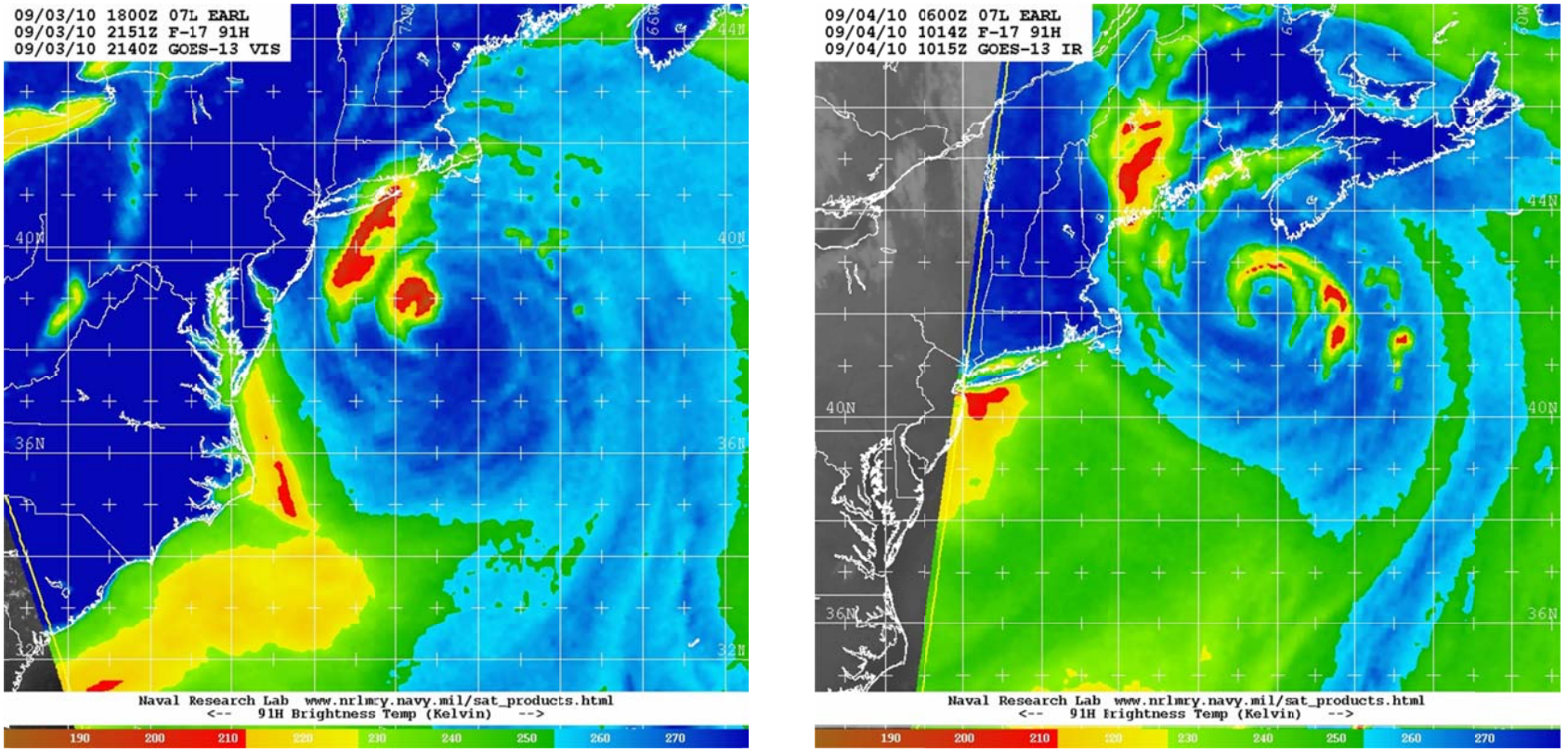
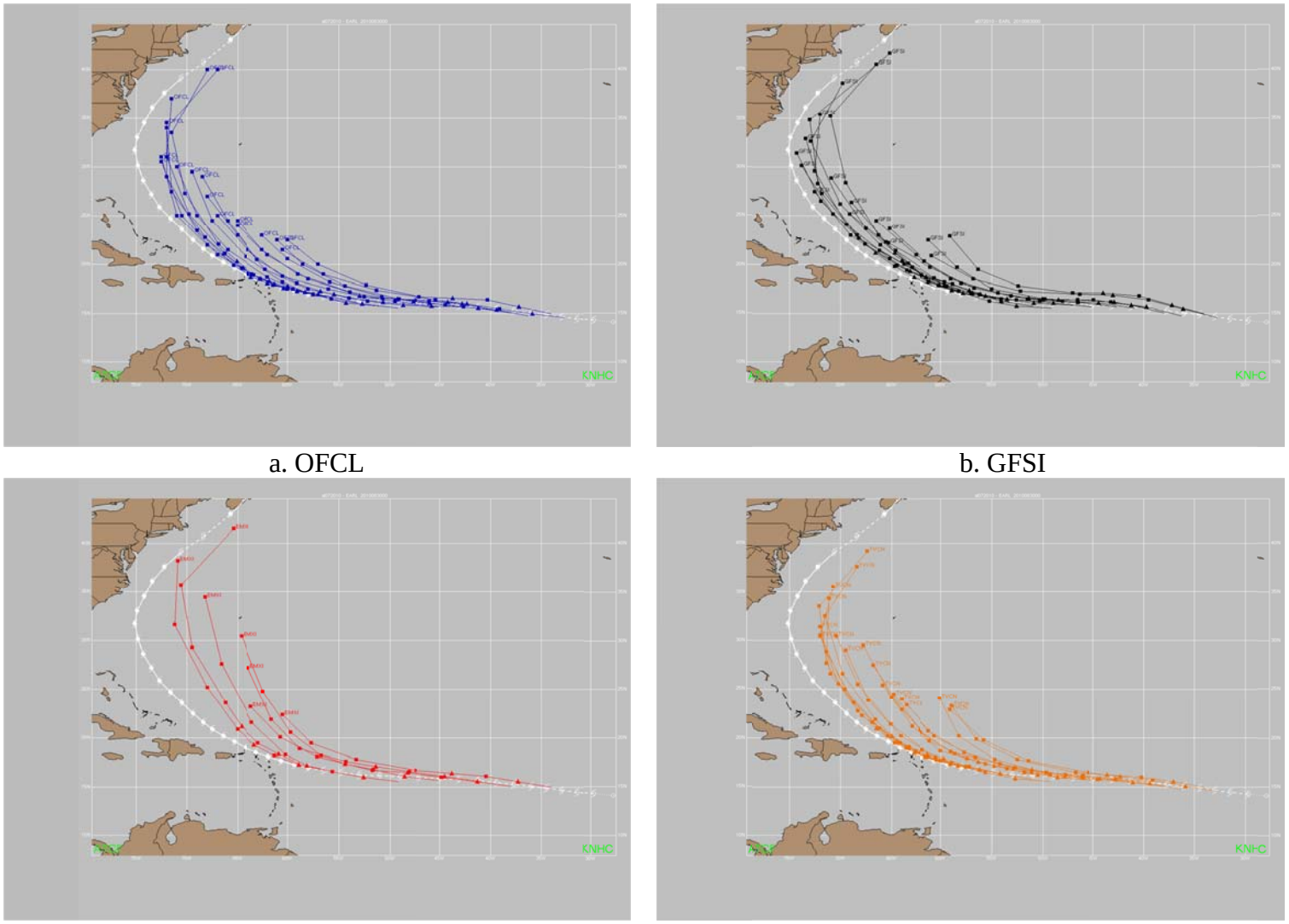


Figure 5. An infrared satellite image at 0215 UTC 2 September 2010 of Hurricane Earl near its peak intensity.



(a) (b)

Figure 6. 91-H GHz SSMI/S images at 2151 UTC 3 September 2010 (a) and at 1014 UTC 4 September (b) showing the organization in structure prior to the landfall in Canada. Images courtesy of the Naval Research Laboratory in Monterey, CA



a. OFCL b. GFSI

c. EMXI d. TVCN

Figure 7. Official NHC and interpolated model track forecasts for Earl every 6 h from 0000 UTC 26 August to 0000 UTC 30 August. Note that the official forecast and all of the model guidance shown had a pronounced rightward bias during this time.