NATIONAL HURRICANE CENTER TROPICAL CYCLONE REPORT

HURRICANE EDOUARD

(AL062014)

11 – 19 September 2014

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EDOUARD AS SEEN FROM THE INTERNATIONAL SPACE STATION ON 17 SEPTEMBER 2014. (IMAGE COURTESY OF NASA)

Edouard was a category 3 hurricane (on the Saffir-Simpson Hurricane Wind Scale) that remained over the open Atlantic Ocean during its lifetime. Edouard was the first major hurricane to develop in the Atlantic basin since Hurricane Sandy of 2012. Multiple research missions, sometimes simultaneous, were conducted in Edouard by NOAA and NASA aircraft, including the first-ever release of an unmanned aerial vehicle into an Atlantic tropical cyclone.

Hurricane Edouard

11 – 19 SEPTEMBER 2014

SYNOPTIC HISTORY

Edouard developed from a westward-moving tropical wave that exited the coast of western Africa late on 6 September. The wave was accompanied by a broad low pressure system and disorganized deep convection, which fluctuated significantly during the next four days as the disturbance moved west-northwestward over the far eastern tropical Atlantic. By late on 10 September, however, convection began to increase near the center of the surface low when the system was located well to the west of the Cape Verde Islands. By 1200 UTC 11 September, deep convection had become sufficiently organized to designate the system as a tropical depression about 720 n mi west of the Cape Verde Islands. The "best track" chart of the tropical cyclone'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].

The depression turned toward the northwest and maintained that general motion for the next five days as the cyclone moved around the southwestern periphery of a deep-layer subtropical ridge that extended across the central and eastern Atlantic Ocean along 30^{O}- 32^{O} N latitude. Upper-level winds and sea-surface temperatures were quite favorable for development, but the surrounding environment of drier-than-normal mid-level air likely inhibited the intensification process. Slow but steady strengthening occurred while the cyclone moved northwestward, with the system becoming a tropical storm early on 12 September and a hurricane early on 14 September. Edouard became a major hurricane early on 16 September, reaching its peak intensity of 105 kt at 1200 UTC that morning when it was located about 360 n mi east of Bermuda, making it the first major hurricane to develop in the Atlantic basin since Hurricane Sandy of 2012. However, Edouard's status as a major hurricane was short-lived. The inner-core deep convection eroded significantly and a weakening trend began almost immediately, likely caused by an eyewall replacement cycle (Fig. 4) and perhaps cold upwelling/mixing of at least 7^{O} C beneath the hurricane (Fig. 5).

Late on 16 September, Edouard moved northward while weakening, and then turned northeastward and accelerated on 17 September ahead of an approaching mid-latitude trough and associated frontal system. The next day, Edouard turned eastward and began to rapidly weaken as the hurricane became embedded in the mid-latitude westerlies and encountered strong westerly vertical wind shear. Edouard weakened to a tropical storm late on 18 September, and degenerated into a strong post-tropical cyclone early on 19 September about 400 n mi west of the western Azores Islands. The remnant low moved southeastward and then

[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.

southward over the next two days before merging with a frontal system early on 21 September several hundred n mi south-southwest of the Azores Islands.

METEOROLOGICAL STATISTICS

Observations in Edouard (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), and objective Advanced Dvorak Technique (ADT) estimates from the Cooperative Institute for Meteorological Satellite Studies/University of Wisconsin-Madison. Observations also include flight-level, stepped frequency microwave radiometer (SFMR), dropwindsonde observations, and Coyote unmanned aerial vehicle (UAV) flight-level data from flights conducted by the NOAA Aircraft Operations Center (AOC) WP-3D Hurricane Hunter aircraft, and dropwindsonde observations from flights conducted by the NASA AV-6 Global Hawk unmanned aircraft as part of the Hurricane and Severe Storms Sentinel (HS3) research program. Data and imagery from NOAA polar-orbiting satellites including the Advanced Microwave Sounding Unit (AMSU), the NASA Tropical Rainfall Measuring Mission (TRMM), 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 Edouard.

There were no ship reports of tropical-storm-force winds associated with Edouard while it was a tropical cyclone.

Winds and Pressure

Edouard's estimated peak intensity of 105 kt at 1200 UTC 16 September is based on a blend of satellite intensity estimates of T5.5/102 kt from TAFB and T5.7/107 kt from UW-CIMSS ADT. The minimum pressure of 955 mb at 1200 UTC 16 September is based on the Knaff-Zehr-Courtney (KZC) pressure-wind relationship corresponding to an intensity of 105 kt.

The NOAA WP-3D Hurricane Hunters aircraft conducted eight research missions into or around Hurricane Edouard during the period of 11-19 September, generally during daylight hours between 1200-2100 UTC. Those missions resulted in nine center fixes that occurred at either the 750 mb or 700 mb pressure levels (~8,000 and ~10,000 ft, respectively). Maximum flight-level winds of 115 kt and 114 kt were observed at 1622 UTC and 1722 UTC UTC, respectively, on 15 September. The strongest SFMR surface winds measured were 94 kt at 1804 UTC 15 September and 92 kt at 1620 UTC 16 September. The strongest surface winds measured by a dropwindsonde in the eyewall were 103 kt at 1804 UTC 15 September and 98 kt at 1413 UTC 16 September. The lowest pressure measured in the eye of Edouard by a NOAA dropwindsonde was 957 mb at 1652 UTC 16 September. However, the dropwindsonde also reported a surface wind of 11 kt, so the minimum central pressure at that time is estimated to be 956 mb.

The NASA AV-6 Global Hawk similarly conducted eight research missions into and around Hurricane Edouard on 11, 14, and 16-19 September. Unlike the NOAA WP-3D aircraft, the Global Hawk aircraft overflew Edouard at altitudes in excess of 60,000 ft and therefore did not make any eyewall penetrations. The unmanned aircraft did, however, release more than 340 dropwindsondes, including a few into the eye of the hurricane. During an overflight mission at 0612 UTC 17 September, a dropwindsonde was released from an altitude of about 62,000 feet into the inner edge of the southern eyewall during a south-to-north pass. The instrument rotated counter-clockwise through the eastern semicircle of the eyewall, measuring a peak wind speed of 95 kt just a few hundred feet above the surface, a surface wind speed of 90 kt, and a sea-level pressure of 963 mb (Fig. 6).

For the first time ever, an unmanned aircraft was deployed by a NOAA WP-3D manned aircraft directly into a hurricane (Figs. 7 and 8). NOAA released a total of four Coyote UAVs into Hurricane Edouard during flights conducted on 15-17 September 2014 while operating out of Bermuda (Fig. 9). The Coyotes sent back important meteorological data from both Edouard's eye and surrounding eyewall. Before the system failed after completing a counter-clockwise flight path that lasted 28 minutes on 16 September, the Coyote reported a maximum flight-level wind of 100 kt at 1432 UTC at an altitude of about 3,200 ft ASL (971 m) when the small UAV was located in the southwestern eyewall.

Additional information on missions conducted in Hurricane Edouard by NOAA AOC, including deployment of the Coyote UAV, and also by the NASA Global Hawk unmanned aircraft can be found in the References section at the end of this report.

CASUALTY AND DAMAGE STATISTICS

There were no reports of damage or casualties associated with Edouard.

FORECAST AND WARNING CRITIQUE

The genesis of Edouard was not forecast particularly well in the short term (Table 2). An area of disturbed weather was introduced into the Tropical Weather Outlook (TWO) with a 30% (medium) chance of formation in five days at 0000 UTC 6 September, 132 h prior to genesis. The system was introduced in the 48-h forecast period with a low genesis probability (<30%) and the probability was increased to the medium chance category (30-50%) 6 h later. However, the 48-h probabilities were decreased to the low chance category 36 h before genesis occurred; similarly, the 5-day genesis probabilities were also decreased to the medium chance category 36 h before genesis occurred. Although the five-day probabilities were increased back into the high category of development 30 h before Edouard formed, the 48-hour genesis probabilities never reached the high category.

A verification of NHC official track forecasts (OFCL) for Edouard is given in Table 3a. Official forecast track errors ranged from 19% - 35% lower than the mean official errors for the previous 5-yr period throughout the entire 120-h forecast period. A homogeneous comparison of the official track errors with selected guidance models is given in Table 3b. OFCL track errors were lower than or comparable to all of the available model guidance from 12-72 hours. At 96 h and 120 h, OFCL forecasts were outperformed by about 10% - 25% by the GFS-ensemble mean (AEMI), HWFI, and EGRI models, and also by the consensus track models TCON and TVCA.

A verification of NHC official intensity forecasts (OFCL) for Edouard is given in Table 4a. Official forecast intensity errors were lower than the mean official errors for the previous 5-yr period at all forecast times. A homogeneous comparison of the official intensity errors with selected guidance models is given in Table 4b. OFCL intensity errors were lower than or comparable to all of the available model guidance at all forecast times, except for the GHMI model at 72 h, which was more than 20% better than OFCL intensity forecasts.

There were no tropical cyclone watches and warnings associated with Edouard.

References

http://www.aoml.noaa.gov/hrd/emergingobtech/suave/

http://www.aoml.noaa.gov/keynotes/keynotes_0914_coyote_success.html

http://www.nasa.gov/content/goddard/nasa-hs3-mission-global-hawks-bullseye-in-hurricane-edouard/#.VGHh6slNdDQ

http://www.nasa.gov/content/goddard/nasas-hs3-looks-hurricane-edouard-in-the-eye/#.VGHxJMlNdDT

Table 1. Best track for Hurricane Edouard, 11-19 September 2014.

Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Stage
10 / 1800	13.7	33.2	1009	25	low
11 / 0000	14.2	34.4	1009	25	"
11 / 0600	14.9	35.5	1009	25	"
11 / 1200	15.8	36.5	1008	30	tropical depression
11 / 1800	16.5	37.7	1007	30	"
12 / 0000	17.2	39.2	1006	35	tropical storm
12 / 0600	17.7	40.8	1005	35	"
12 / 1200	18.3	42.3	1000	40	"
12 / 1800	18.9	43.6	999	40	"
13 / 0000	19.6	44.8	998	40	"
13 / 0600	20.4	45.7	997	45	"
13 / 1200	21.4	46.4	996	45	"
13 / 1800	22.3	47.0	995	50	"
14 / 0000	23.0	47.9	994	55	"
14 / 0600	23.7	49.0	991	60	"
14 / 1200	24.4	50.3	985	70	hurricane
14 / 1800	25.1	51.5	980	75	"
15 / 0000	25.8	52.7	975	80	"
15 / 0600	26.5	54.0	970	85	"
15 / 1200	27.0	55.1	966	90	"
15 / 1800	27.7	56.1	962	95	"
16 / 0000	28.5	56.7	960	95	"
16 / 0600	29.5	57.3	956	100	"
16 / 1200	30.6	57.8	955	105	"
16 / 1800	31.7	57.7	958	95	"
17 / 0000	32.9	57.0	959	85	"
17 / 0600	34.3	56.0	958	85	"
17 / 1200	35.7	54.5	957	80	"
17 / 1800	37.2	52.4	955	80	"
18 / 0000	38.3	49.5	958	75	"
18 / 0600	39.3	46.7	964	70	"
18 / 1200	39.9	44.1	969	70	"
18 / 1800	39.9	42.1	973	65	"
19 / 0000	39.9	40.1	980	60	tropical storm
19 / 0600	39.9	38.9	988	55	"
19 / 1200	39.5	38.1	994	45	"
19 / 1800	39.5	37.4	1001	40	low
20 / 0000	39.4	36.6	1004	35	"
20 / 0600	39.3	35.7	1006	30	"
20 / 1200	39.1	34.4	1008	30	"
20 / 1800	38.8	33.0	1010	25	"

21 / 0000	38.1	31.8	1012	25	"
21 / 0600	37.1	30.9	1013	25	"
21 / 1200	36.1	30.2	1014	25	"
21 / 1800	35.1	30.2	1014	25	"
22 / 0000	34.2	30.4	1015	25	"
22 / 0600	33.4	30.7	1015	25	"
22 / 1200					dissipated
16 / 1200	30.6	57.8	955	105	minimum pressure & maximum intensity

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

	Hours Before Genesis	
	48-Hour Outlook	**120-Hour Outlook**
Low (<30%)	108	132
Medium (30%-50%)	96	132
High (>50%)	-	102

Table 3a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) track forecast errors (n mi) for Edouard. 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	72	96	120
OFCL	**22.2**	**32.3**	**42.2**	**50.1**	**72.9**	**118.8**	**169.0**
OCD5	54.7	128.3	190.3	246.2	355.1	401.0	398.7
Forecasts	31	29	27	25	21	17	13
OFCL (2009-13)	28.8	45.5	61.2	77.8	114.5	158.4	208.2
OCD5 (2009-13)	48.2	100.1	160.2	220.8	326.6	410.7	479.4

Table 3b. Homogeneous comparison of selected track forecast guidance models (in n mi) for Edouard. Errors smaller than the NHC official forecast are shown in boldface type. The number of official forecasts shown here will generally be smaller than that shown in Table 3a due to the homogeneity requirement.

Model ID	Forecast Period (h)						
	12	24	36	48	72	96	120
OFCL	16.5	24.1	34.1	43.2	64.5	98.7	142.6
OCD5	52.7	128.8	197.5	263.7	381.8	404.8	384.3
GFSI	17.4	24.6	35.6	45.4	82.9	124.3	153.0
AEMI	19.1	27.6	38.9	47.6	66.5	**86.7**	**107.2**
GHMI	24.9	41.3	58.2	78.0	140.1	177.4	200.0
HWFI	20.1	31.4	43.1	45.8	65.8	**83.3**	160.8
GFNI	35.0	68.3	96.7	130.7	214.5	307.8	451.8
EGRI	21.7	32.0	35.0	44.6	**64.2**	**81.8**	**128.9**
EMXI	19.6	30.5	40.9	58.1	85.7	142.8	214.6
CMCI	26.2	48.3	68.5	86.6	113.4	138.9	203.1
NVGI	27.9	48.7	69.2	88.3	127.6	167.0	202.1
TCON	**15.8**	**22.4**	**31.1**	**38.4**	64.5	**94.4**	**127.6**
TVCA	16.5	**23.6**	**31.6**	**39.5**	64.5	100.5	**132.3**
FSSE	**15.7**	**23.4**	**31.4**	**40.4**	**61.9**	104.8	175.7
BAMS	42.1	77.5	98.9	109.1	128.0	175.9	231.9
BAMM	30.1	52.8	71.8	83.5	112.4	139.9	202.9
BAMD	31.6	57.0	75.3	90.6	111.6	198.0	316.7
Forecasts	26	25	23	21	17	13	9

Table 4a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) intensity forecast errors (kt) for Edouard. 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	72	96	120
OFCL	**2.7**	**5.7**	**7.2**	**8.2**	**12.6**	**12.6**	**10.0**
OCD5	4.1	6.6	10.4	12.8	20.0	22.1	16.3
NF	31	29	27	25	21	17	13
OFCL (2009-13)	6.1	10.4	13.4	14.5	15.0	16.4	16.1
OCD5 (2009-13)	7.7	12.7	16.4	18.8	20.5	20.3	20.8

Table 4b. Homogeneous comparison of selected intensity forecast guidance models (in kt) for Edouard. 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	3.0	6.1	7.6	8.7	12.4	10.3	6.8
OCD5	4.5	7.0	11.0	13.7	20.2	20.1	11.3
HWFI	6.3	9.5	11.4	12.7	**11.7**	11.6	7.1
GHMI	6.1	8.1	8.3	9.6	**10.0**	**9.4**	7.1
GFNI	6.7	10.2	11.8	13.0	18.0	19.2	19.5
DSHP	3.8	**5.9**	8.8	11.0	13.6	13.7	9.2
LGEM	4.2	**5.3**	8.4	11.0	13.8	11.3	**5.2**
ICON	4.6	6.3	8.2	10.3	**12.1**	10.3	**5.5**
IVCN	4.6	6.3	8.2	10.3	**12.1**	10.3	**5.5**
FSSE	4.4	7.8	10.0	11.6	14.1	13.6	10.5
GFSI	5.6	10.1	13.4	15.4	19.9	16.9	13.5
EMXI	5.2	9.4	14.4	22.2	30.1	29.8	26.4
Forecasts	28	27	25	23	19	15	11

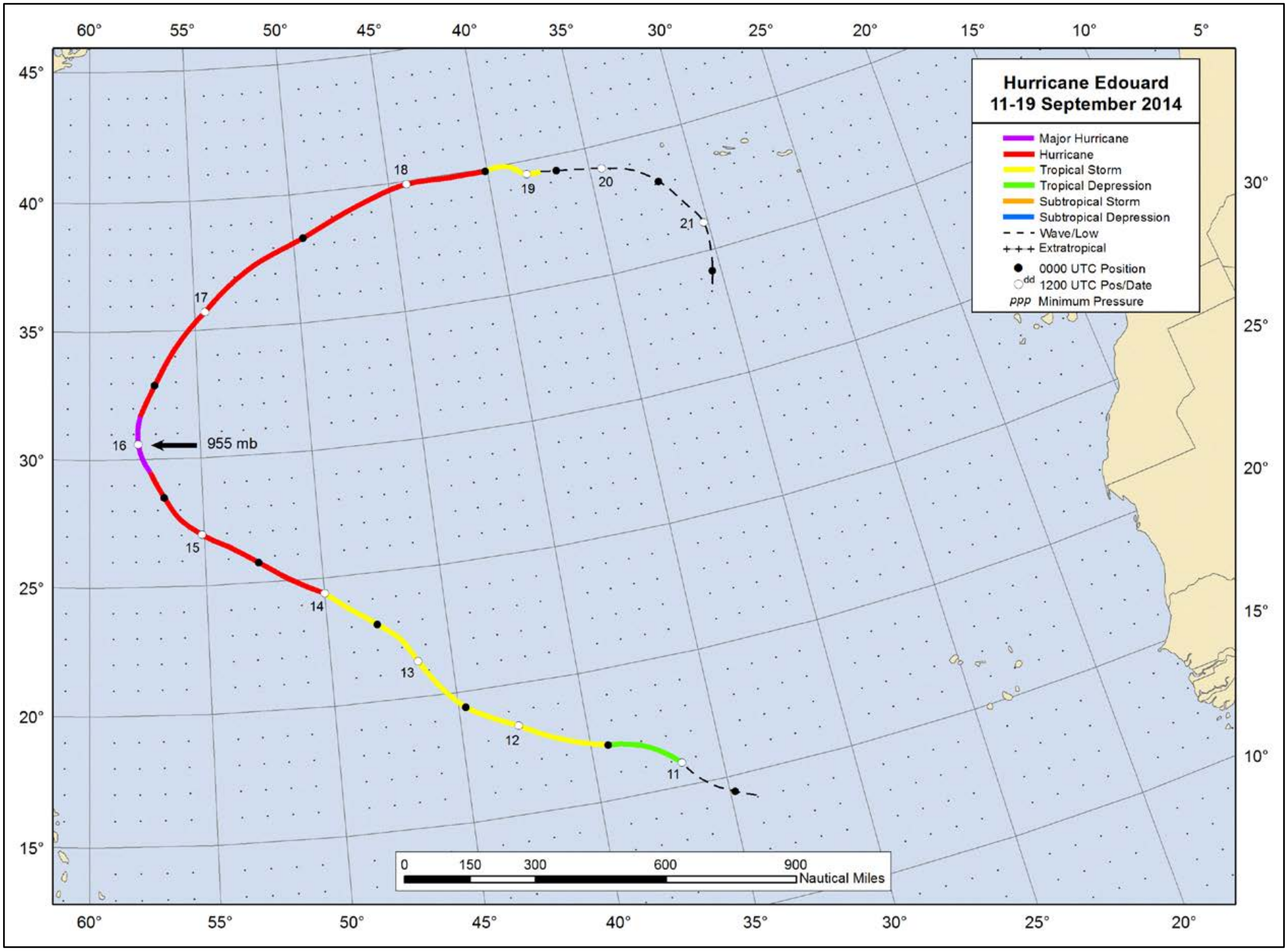

Figure 1. Best track positions for Hurricane Edouard, 11-19 August 2014. Track during the post-tropical phase is partially based on analyses from the NOAA Ocean Prediction Center.

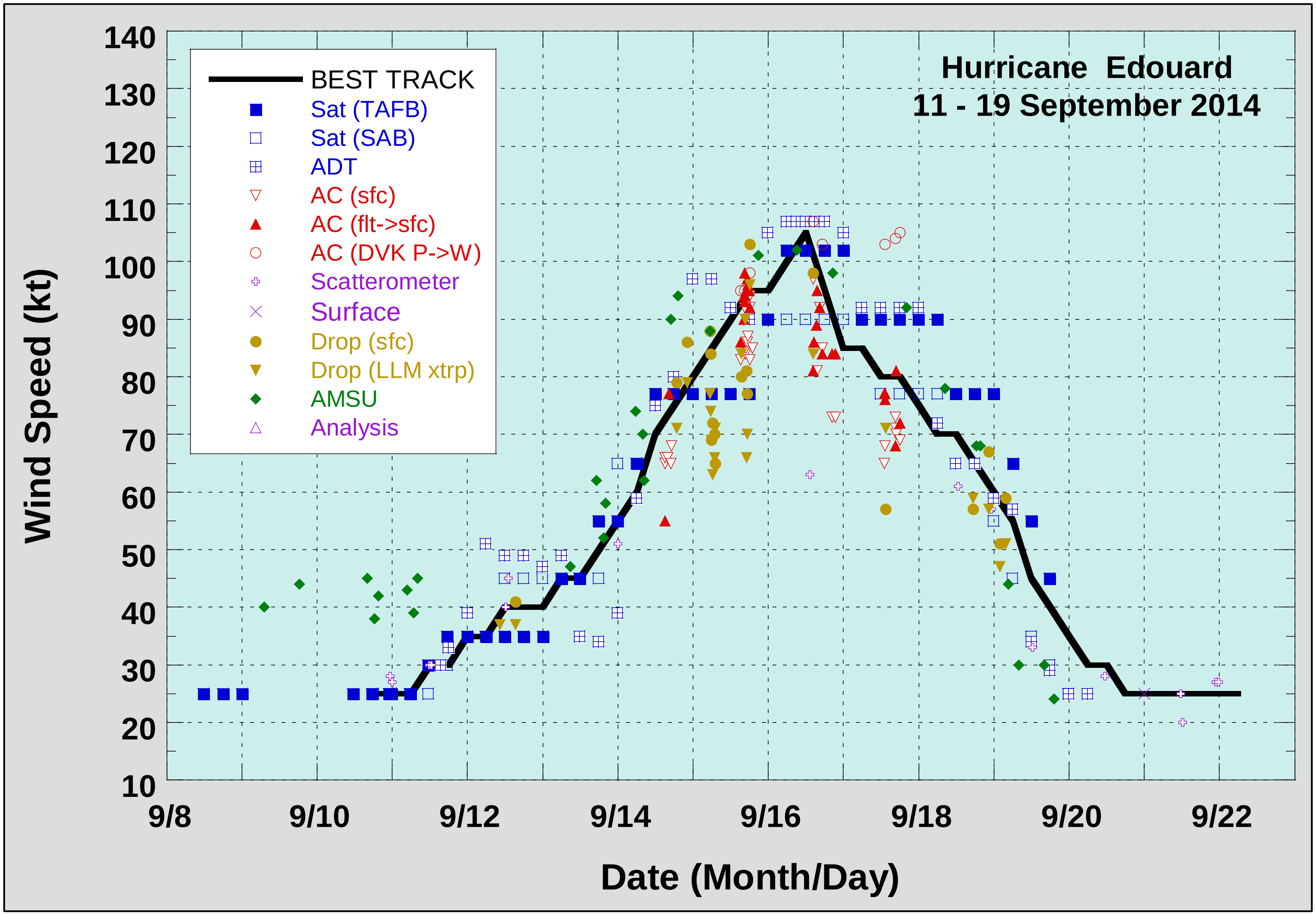

Figure 2. Selected wind observations and best track maximum sustained surface wind speed curve for Hurricane Edouard, 11-19 September 2014. Advanced Dvorak Technique estimates represent the Current Intensity at the nominal observation time. AMSU intensity estimates are from the Cooperative Institute for Meteorological Satellite Studies technique. Dashed vertical lines correspond to 0000 UTC.

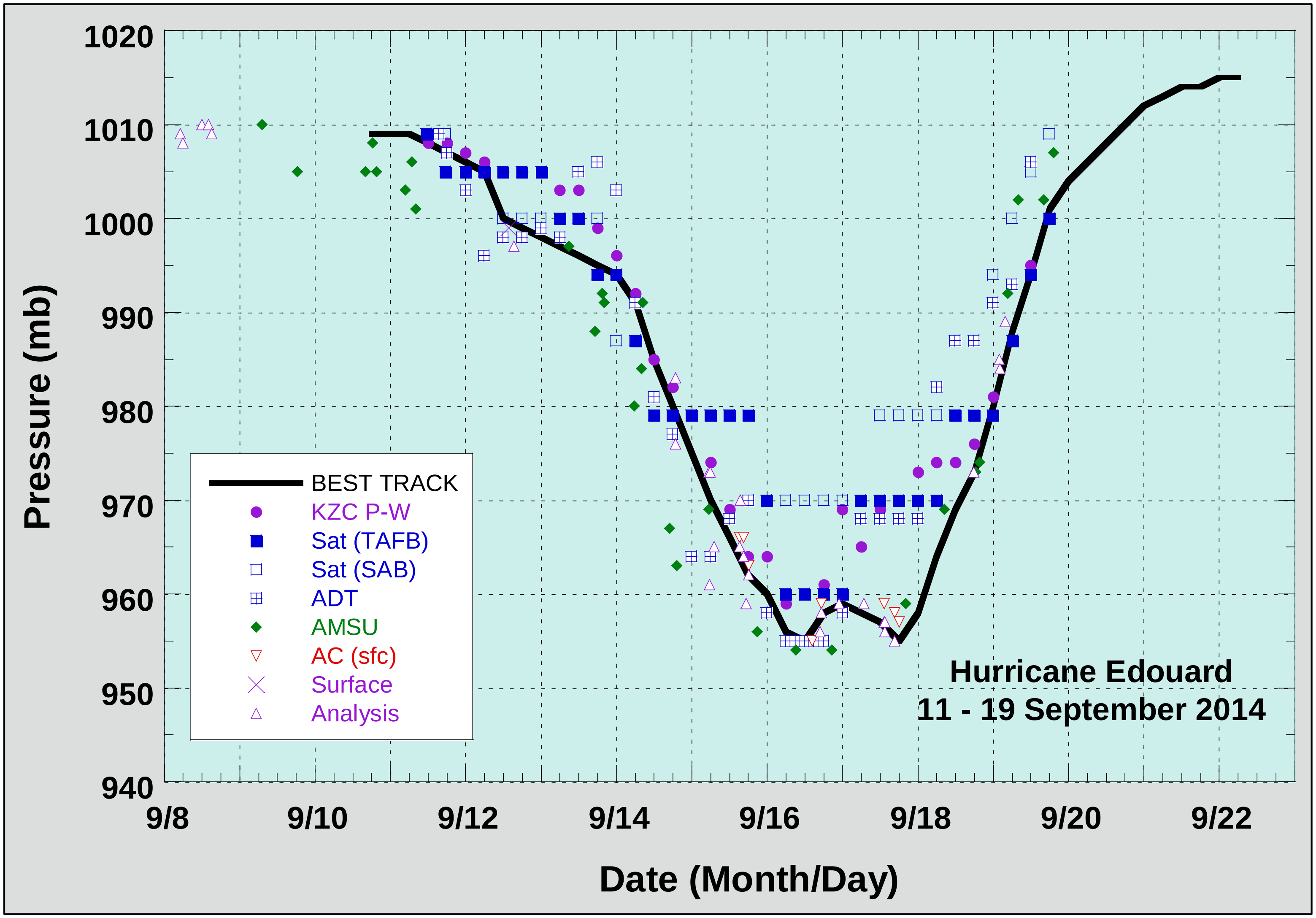

Figure 3. Selected pressure observations and best track minimum central pressure curve for Hurricane Edouard, 11-19 September 2014. Advanced Dvorak Technique estimates represent the Current Intensity at the nominal observation time. AMSU intensity estimates are from the Cooperative Institute for Meteorological Satellite Studies technique. KZC P-W refers to pressure estimates derived using the Knaff-Zehr-Courtney pressure-wind relationship. Dashed vertical lines correspond to 0000 UTC.

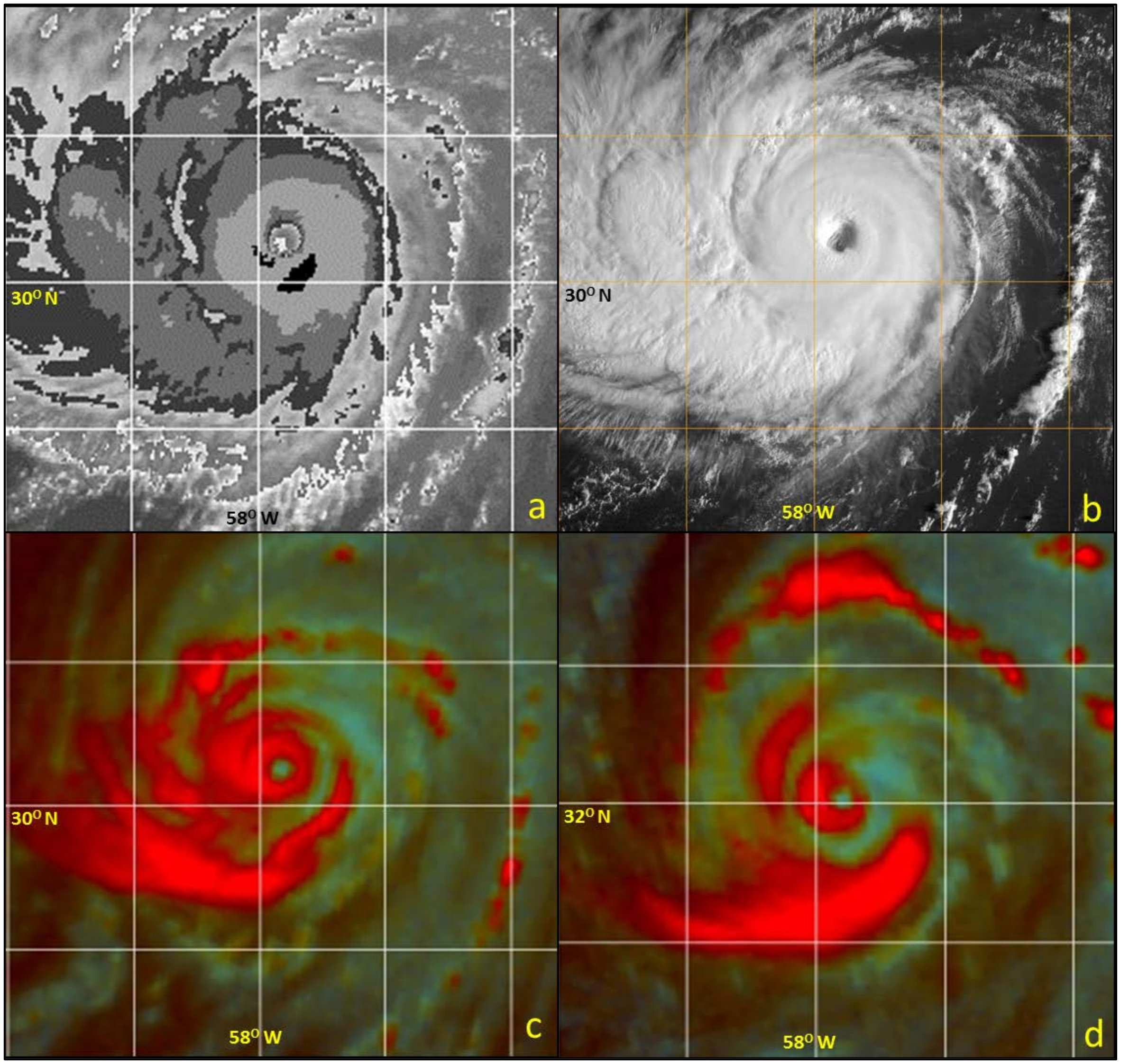

Figure 4. Multi-spectral satellite imagery of Hurricane Edouard near its peak intensity of 105 kt at 1145 UTC 16 Sep: (a) GOES-13 infrared with Dvorak enhancement curve, (b) GOES-13 visible, and (c) Special Sensor Microwave Imager/Sounder [SSMI/S]; (d) ongoing weakening due to an eyewall replacement cycle and erosion of the inner-core convection is evident in the 2017 UTC 16 September SSMI/S image. Images courtesy Naval Research Laboratory, Monterey, CA.

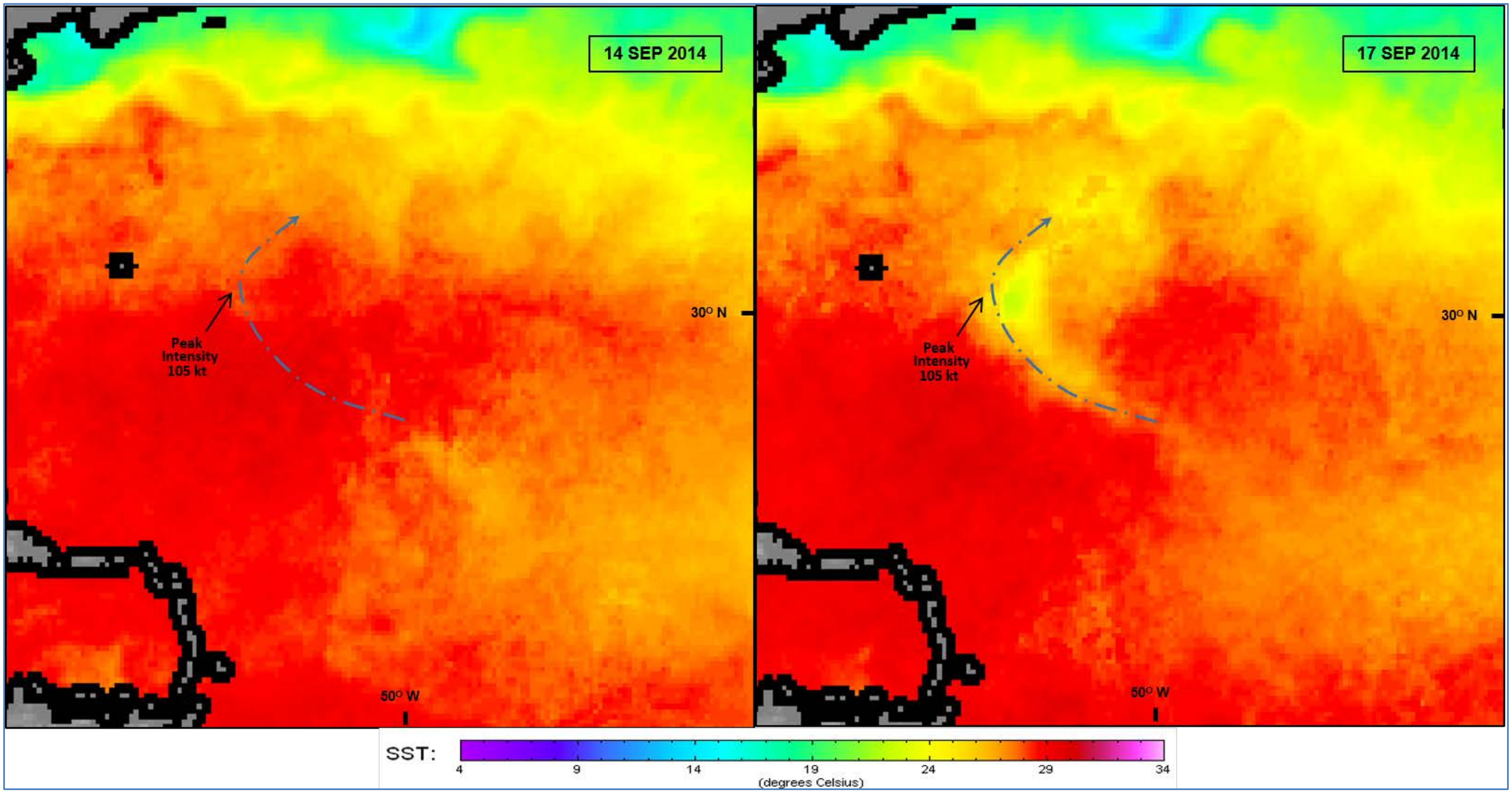

Figure 5. Sea-Surface temperature (SST) analyses valid at 1200 UTC on 14 September (left panel) and 17 September (right panel), respectively. Cold upwelling/mixing of at least 7^{O} C (green shaded area) induced by Hurricane Edouard's wind field can be seen along the storm track, especially just to the east of the location where the peak intensity of 105 kt occurred at 1200 UTC 16 September 2014. Images courtesy of REMSS, Santa Rosa, CA.

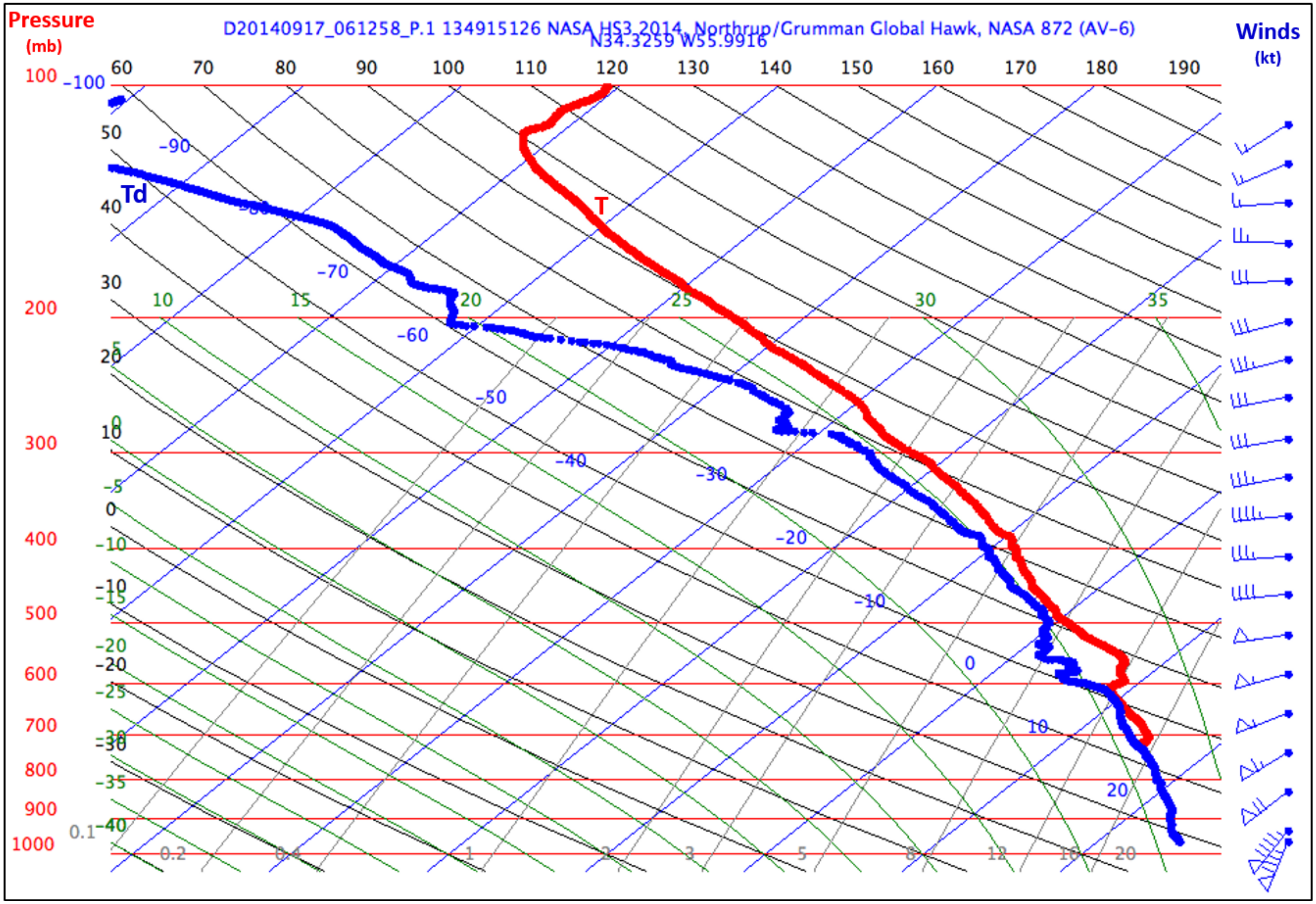

Figure 6. Vertical profile of temperature (T ^{O}C), dewpoint (Td ^{O}C), and winds (kt) from a dropwindsonde released by the NASA Global Hawk AV-6 aircraft at approximately 0612 UTC 17 September inside the eye of Hurricane Edouard. Graphic courtesy NASA.

Figure 7. Upward view from NOAA Hurricane Hunter aircraft inside the eye of Hurricane Edouard on 16 September 2014, shortly after the cyclone had reached its peak intensity. Image courtesy Kristie Twining, NOAA-AOML Hurricane Research Division.

Figure 8. Downward view from NOAA Hurricane Hunter aircraft inside the eye of Hurricane Edouard on 16 September 2014, shortly after the cyclone had reached its peak intensity. Image courtesy Kristie Twining, NOAA-AOML Hurricane Research Division.

Figure 9. Coyote UAV, a component of the Small Unmanned Aircraft Vehicle Experiment (SUAVE), is displayed in flight mode (left) and is ready to be released by NOAA WP-3D Hurricane Hunter flight crewman (right) into the eye of Hurricane Edouard on 16 September. Pictures courtesy NOAA-AOML Hurricane Research Division.