NATIONAL HURRICANE CENTER TROPICAL CYCLONE REPORT

HURRICANE GASTON

(AL072016)

22 August – 2 September 2016

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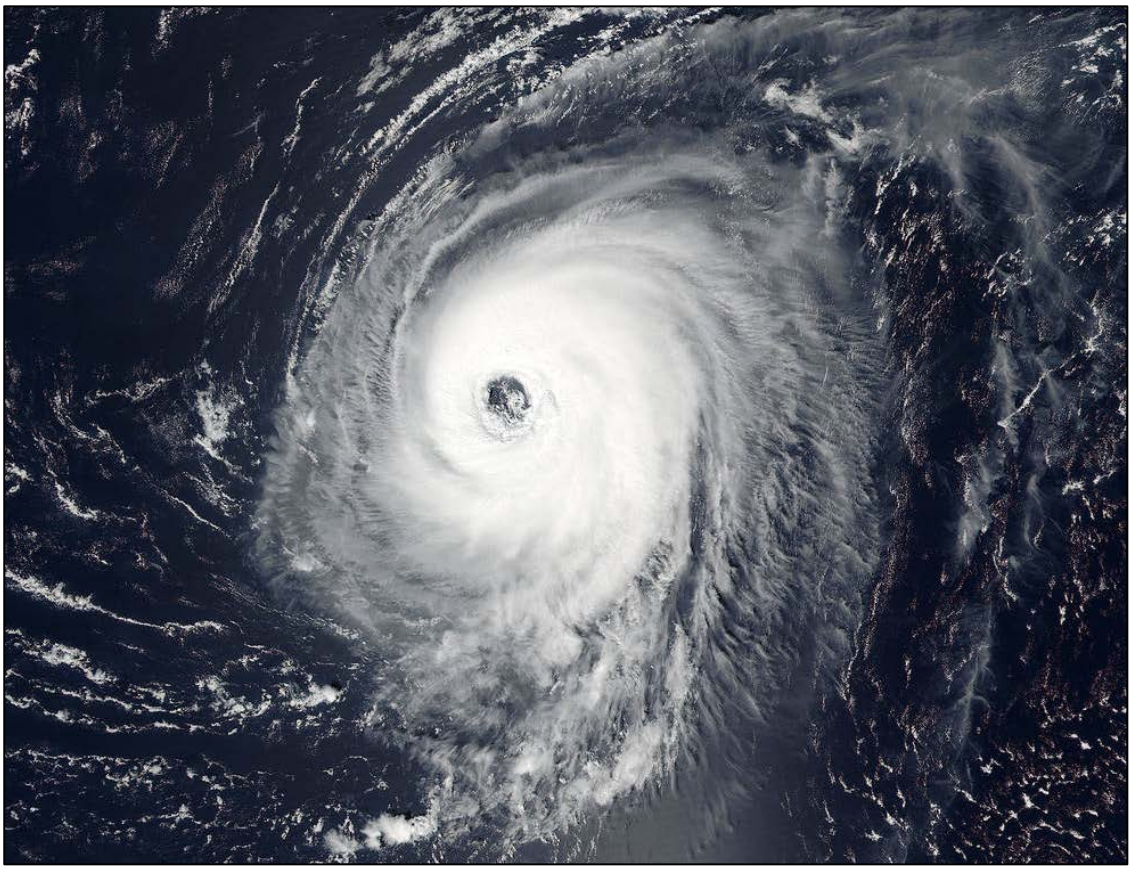

NASA-NOAA'S SUOMI NPP VISIBLE SATELLITE IMAGE OF HURRICANE GASTON AT 1625 UTC 30 AUGUST 2016. IMAGE COURTESY OF NASA GODDARD MODIS RAPID RESPONSE TEAM

Gaston was a classic Cape Verde hurricane that attained category 3 intensity (on the Saffir-Simpson Hurricane Wind Scale) over the central Atlantic. Gaston brought tropical-storm-force winds to portions of the Azores when it passed near those islands as a post-tropical cyclone.

Hurricane Gaston

22 AUGUST – 2 SEPTEMBER 2016

SYNOPTIC HISTORY

Gaston formed from a strong tropical wave that departed the west coast of Africa late on 20 August. The wave was accompanied by disorganized showers and thunderstorms and a broad low pressure area when it moved over the far eastern tropical Atlantic Ocean early the next day. Although the convective activity decreased later that day, the low pressure system became better defined. Deep convection redeveloped later on 21 August, and continued to increase and become better organized, leading to the formation of a tropical depression by 1200 UTC 22 August, about 265 n mi southwest of the southernmost Cabo Verde Islands. Within an environment of low vertical wind shear and sea surface temperatures of 27-28°C, the depression strengthened into a tropical storm 6 h later. The "best track" chart of Gaston'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].

After formation, the tropical storm moved west-northwestward to the south of a deep-layer ridge over the eastern Atlantic. During the first 24 h of Gaston's life cycle, deep convection continued to increase in organization and the tropical storm steadily strengthened. After a brief pause in the intensification late on 23 August, Gaston's inner-core structure increased in organization early the next day with a low-level ring and mid-level eye feature noted in microwave imagery (Fig. 4). The tropical cyclone continued to strengthen and Gaston became a hurricane about 835 n mi west of the Cabo Verde Islands by 1200 UTC 24 August. The hurricane then turned northwestward toward a break in the ridge caused by a large mid- to upper-level low over the central Atlantic. Strong upper-level southwesterly winds around the southeastern portion of the upper-level low caused the 850–200-mb shear over Gaston to increase to 20 to 25 kt by early on 25 August, and the tropical cyclone's winds dropped below hurricane strength by 1200 UTC that day. Gaston's cloud pattern became increasingly asymmetric and the tropical storm weakened a little more that day before the intensity leveled off at 55 kt for the next 36 hours.

Late on 26 August, the separation between Gaston and the mid- to upper-level low began to increase as the low moved southwestward, while Gaston continued to move northwestward at about 15 kt. This resulted in a gradual reduction in the shear over the storm, and Gaston began to re-strengthen when the convective structure improved. Gaston regained hurricane status by 1800 UTC 27 August, and it rapidly strengthened during the next 24 to 30 h while it was located over warm water and within a favorable upper-level wind environment. Gaston attained category 3 (on the Saffir-Simpson Hurricane Wind Scale) strength by 1800 UTC 28 August, and reached its estimated peak intensity of 105 kt 6 h later. While Gaston rapidly strengthened, the forward

[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.

speed of the hurricane slowed as a blocking mid-level ridge built to the north of the hurricane. Shortly after reaching peak intensity Gaston became nearly stationary about 490 n mi east-southeast of Bermuda, but Gaston did not remain a major hurricane for long. The slow motion of the hurricane caused upwelling of cooler waters, which, along with an eyewall replacement, resulted in Gaston weakening to category 2 intensity by late on 29 August.

After drifting northward, Gaston began moving slowly northeastward early on 30 August when a ridge became established to the southeast of the tropical cyclone. Later that day, the hurricane turned east-northeastward and its forward speed increased to about 10 kt. The hurricane moved away from the area of upwelled waters and microwave imagery (Fig. 5) indicates that the hurricane completed an eyewall replacement, which caused the eye to grow to a diameter of 35 n mi. Gaston re-strengthened and reached a second peak intensity of 105 kt at 0000 UTC 31 August. By 1200 UTC that day, increasing westerly shear and gradually decreasing sea surface temperatures caused Gaston to weaken again while it moved east-northeastward along the southern edge of the mid-latitude westerly flow. Gaston weakened below major hurricane strength around 1800 UTC 31 August, and it became a tropical storm at 1200 UTC 2 September when it was located about 90 n mi west-southwest of Flores Island in western Azores. Shortly after that, strong westerly shear and sea surface temperatures below 26°C caused the deep convection to dissipate, and Gaston became a post-tropical cyclone (with 45-kt winds) as it passed very near Flores Island at 1800 UTC 2 September. The post-tropical low continued to quickly weaken and it degenerated into a trough of low pressure a couple of hundred n mi northeast of the central Azores by 1800 UTC 3 September.

METEOROLOGICAL STATISTICS

Observations in Gaston (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 dropwindsonde observations from two flights of the NASA Global Hawk unmanned aircraft. 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 Gaston.

The 105-kt estimated peak intensity of Gaston at 0000 UTC 29 August is based on subjective Dvorak intensity estimates of 102 kt from TAFB and SAB, and an objective ADT estimate of 112 kt. The second analyzed peak intensity of 105 kt on 31 August is also based on subjective and objective Dvorak intensity estimates.

Operationally, Gaston was analyzed as a 60-kt tropical storm until dropwindsonde data from a NASA Global Hawk unmanned aircraft mission indicated that the tropical cyclone was a hurricane. A dropwindsonde launched at 0243 UTC 25 August measured a mean boundary layer wind of 80 kt and a mean wind of 77 kt over the lowest 150 m of the sounding. Both of these

observations support an intensity of 65 kt. Although four dropwindsondes from that mission reported surface winds of 64 to 69 kt, however only the 0243 UTC sonde contained mean boundary layer winds strong enough to corroborate hurricane intensity. Since the organization of Gaston appeared its best in microwave and conventional satellite data about 12 to 18 h previous to that, the best track indicates that Gaston first attained hurricane strength at 0600 UTC 24 August, shortly after a low-level eye feature was noted in microwave satellite data (Fig. 4). By the time the Global Hawk data were available, the cloud pattern had begun to deteriorate due to southwesterly shear. The dropwindsonde data also supported a minimum pressure of 988 mb, which is several mb lower than the operational estimates based on the Knaff-Zehr-Courtney pressure-wind relationship.

Although Gaston became a post-tropical cyclone when it passed near the western Azores on 2 September, the cyclone brought tropical-storm-force wind gusts to the central and western Azores Islands (Table 2). Peak wind gusts of 45 kt were reported at Flores and at the Horta Observatory on Faial Island in the Central Azores.

There were no ship reports of winds of tropical storm force in association with Gaston.

CASUALTY AND DAMAGE STATISTICS

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

FORECAST AND WARNING CRITIQUE

The genesis of Gaston was fairly well predicted, especially for a system that was first identified over Africa. The potential for tropical cyclone formation was first noted in the 5-day Tropical Weather Outlook 114 h before formation occurred (Table 3). The formation chance was raised to the medium (40-60%) and high (>60%) categories 54 h and 42 h before development, respectively. The disturbance was introduced into the 2-day Outlook at 0600 UTC 20 August while it was still located over Africa. The 2-day probabilities were increased to the medium category 30 h before development, and the high category 24 h before formation.

A verification of NHC official track forecasts for Gaston is given in Table 4a. The NHC track forecasts for Gaston were generally very good, with the average official forecast track errors about 50% lower than the previous 5-yr means. A homogeneous comparison of the official track errors with selected guidance models is given in Table 4b. The only individual dynamical model that outperformed the NHC track forecasts at any lead time was the European Center for Medium-Range Weather Forecasts model (EMXI), which bested the official forecasts through 72 h. The consensus models TVCX, GFEX, and TVCA had slightly lower mean track errors than the NHC forecasts at most times. The GFEX (GFSI and EMXI consensus) exhibited the lowest mean track errors through 48 h, and the TVCX (GFSI, EGRI, GHMI, HWFI, and double weighted EMXI) had the lowest errors at 72, 96, and 120 h.

A verification of NHC official intensity forecasts for Gaston is given in Table 5a. Official forecast intensity errors were also much lower than the long-term mean at all forecast lead times. A homogeneous comparison of the official intensity errors with selected guidance models is given in Table 5b. The NHC forecasts and numerical models performed quite well for Gaston. The NHC forecast had lower mean errors than most of the individual intensity models at nearly all lead times except for the LGEM which had lower average errors from 24 to 96 h. The IVCN and ICON consensus aids outperformed the NHC forecasts at all forecast lead times except 12 h.

Watches and warnings associated with Gaston for the Azores are given in Table 6.

Table 1. Best track for Hurricane Gaston, 22 August – 2 September 2016.

Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Stage
21 / 1200	11.0	19.4	1009	20	low
21 / 1800	11.0	21.2	1009	20	"
22 / 0000	11.0	23.0	1009	25	"
22 / 0600	11.2	24.8	1009	25	"
22 / 1200	11.5	26.5	1008	30	tropical depression
22 / 1800	12.0	28.2	1007	35	tropical storm
23 / 0000	12.5	29.9	1006	40	"
23 / 0600	13.0	31.6	1005	45	"
23 / 1200	13.5	33.4	1003	55	"
23 / 1800	13.9	35.0	1003	55	"
24 / 0000	14.2	36.5	1000	55	"
24 / 0600	14.8	37.9	997	60	"
24 / 1200	15.8	39.1	992	65	hurricane
24 / 1800	16.9	40.2	988	65	"
25 / 0000	18.0	41.4	988	65	"
25 / 0600	18.9	42.7	988	65	"
25 / 1200	19.8	44.0	992	60	tropical storm
25 / 1800	21.0	45.0	996	55	"
26 / 0000	22.3	46.0	996	55	"
26 / 0600	23.6	47.0	996	55	"
26 / 1200	24.8	47.9	996	55	"
26 / 1800	25.8	49.1	996	55	"
27 / 0000	26.7	50.3	996	55	"
27 / 0600	27.5	51.5	996	55	"
27 / 1200	28.1	52.8	992	60	"
27 / 1800	28.7	53.6	989	65	hurricane
28 / 0000	29.3	54.2	980	75	"

28 / 0600	29.9	54.5	976	80	"
28 / 1200	30.3	54.7	969	90	"
28 / 1800	30.5	55.0	962	100	"
29 / 0000	30.6	55.2	955	105	"
29 / 0600	30.7	55.3	960	100	"
29 / 1200	30.8	55.4	964	95	"
29 / 1800	31.1	55.4	967	90	"
30 / 0000	31.4	54.9	970	85	"
30 / 0600	31.7	54.4	970	85	"
30 / 1200	32.0	53.5	968	85	"
30 / 1800	32.4	52.5	963	95	"
31 / 0000	32.7	51.5	955	105	"
31 / 0600	33.1	50.5	955	105	"
31 / 1200	33.7	49.2	960	100	"
31 / 1800	34.5	47.9	965	95	"
01 / 0000	35.5	46.3	969	90	"
01 / 0600	36.3	44.3	973	85	"
01 / 1200	37.1	42.0	976	80	"
01 / 1800	37.8	39.5	981	75	"
02 / 0000	38.2	37.0	985	70	"
02 / 0600	38.5	35.0	988	65	"
02 / 1200	38.9	33.0	992	60	tropical storm
02 / 1800	39.3	31.2	1003	45	low
03 / 0000	39.7	29.5	1006	35	"
03 / 0600	40.2	27.8	1007	30	"
03 / 1200	40.9	26.1	1008	25	"
03 / 1800					dissipated
29 / 0000	30.6	55.2	955	105	minimum pressure and maximum winds

Table 2. Selected surface observations from the Azores for Gaston.

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)	Gust (kt)	
Flores	02/1800	1003.1	02/0930	26	45	0.35
Corvo	02/1810	1004.9	02/1120	31	42	
Horta (Airport)			03/0010	32	39	
Horta (Observatory)			02/2000	29	45	
Graciosa			03/0440	24	37	
Angra do Heroismo			03/0150	22	41	
Pico			02/2030	21	40	0.41

[a] Date/time is for sustained wind when both sustained and gust are listed.

Table 3. Number of hours in advance of formation associated with the first NHC Tropical Weather Outlook forecast in the indicated likelihood category. Note that the timings for the “Low” category do not include forecasts of a 0% chance of genesis.

	Hours Before Genesis	
	48-Hour Outlook	**120-Hour Outlook**
Low (<40%)	54	114
Medium (40%-60%)	30	54
High (>60%)	24	42

Table 4a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) track forecast errors (n mi) for Gaston. 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	**16.1**	**22.4**	**27.8**	**34.8**	**53.6**	**84.3**	**117.8**
OCD5	43.8	90.8	150.8	220.9	362.6	435.2	416.4
Forecasts	42	40	38	36	32	28	24
OFCL (2011-15)	28.4	45.0	60.4	77.1	113.1	157.8	210.0
OCD5 (2011-15)	48.3	101.5	161.5	222.6	329.8	412.6	483.9

Table 4b. Homogeneous comparison of selected track forecast guidance models (in n mi) for Gaston. 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	15.2	21.5	27.7	34.4	52.4	81.1	112.4
OCD5	45.1	93.1	154.7	224.8	369.4	440.1	396.6
GFSI	16.7	25.0	33.8	46.1	81.9	141.4	198.4
GHMI	22.7	38.3	49.6	54.6	66.0	101.0	201.5
HWFI	20.5	31.5	47.5	63.7	105.8	101.1	141.5
EGRI	18.8	29.9	34.3	46.5	81.4	134.2	182.8
EMXI	**14.7**	**20.2**	**23.4**	**28.2**	**49.3**	91.5	132.0
CMCI	22.7	39.6	52.7	72.6	100.0	148.0	222.3
CTCI	18.8	29.6	41.6	58.5	107.3	106.6	153.7
GFNI	31.2	55.6	83.9	107.1	148.4	180.9	201.0
AEMI	18.5	28.8	37.0	50.2	95.7	138.8	200.4
HCCA	**14.4**	22.7	32.0	46.7	72.3	87.8	158.9
FSSE	15.5	23.9	33.8	46.1	78.9	84.2	114.5
TVCX	15.3	**21.4**	**26.2**	**30.7**	**48.2**	**70.0**	**106.1**
GFEX	**13.9**	**19.4**	**22.8**	**28.3**	**51.7**	98.3	138.0
TCON	16.1	24.0	29.3	34.6	57.1	82.3	121.4
TVCA	16.1	23.0	**27.6**	**33.0**	53.6	**72.0**	**111.3**
BAMD	30.9	54.3	78.2	102.7	172.9	243.2	349.1
BAMM	32.1	54.7	75.6	90.9	113.5	199.5	335.1
BAMS	46.0	82.9	115.1	140.3	207.6	297.6	384.5
Forecasts	38	36	34	32	29	25	20

Table 5a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) intensity forecast errors (kt) for Gaston. 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	**4.9**	**7.0**	**7.8**	**7.5**	**9.7**	**11.1**	**8.3**
OCD5	7.1	10.3	13.2	16.6	20.5	19.8	17.7
Forecasts	42	40	38	36	32	28	24
OFCL (2011-15)	6.2	9.4	11.5	13.3	14.6	14.6	15.8
OCD5 (2011-15)	7.3	10.8	13.3	15.3	17.7	17.8	17.6

Table 5b. Homogeneous comparison of selected intensity forecast guidance models (in kt) for Gaston. 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	4.6	7.4	8.5	7.8	8.4	10.6	8.8
OCD5	6.6	10.0	13.4	17.3	20.9	20.3	20.5
GFSI	5.3	9.0	11.4	13.1	13.3	14.1	9.8
GHMI	6.7	10.3	11.8	10.6	8.4	**9.7**	10.2
HWFI	4.8	**7.3**	10.4	11.3	13.1	12.9	**8.3**
EMXI	7.2	11.0	14.0	16.4	19.7	24.0	16.6
GFNI	6.0	9.7	11.3	13.1	14.7	14.5	14.0
CTCI	5.1	**5.8**	**7.5**	8.9	10.8	12.1	10.6
DSHP	6.1	7.9	8.6	8.7	9.1	11.3	**6.3**
LGEM	6.0	**7.2**	**7.4**	**7.4**	**7.5**	**9.6**	9.6
ICON	5.0	**6.5**	**7.8**	8.1	**8.0**	**8.9**	**7.1**
IVCN	4.7	**5.6**	**6.6**	**7.3**	**8.1**	**9.0**	**6.3**
FSSE	4.9	**6.7**	**8.0**	**7.7**	9.8	12.4	15.3
HCCA	4.6	**6.0**	**6.8**	7.8	9.0	10.8	13.2
Forecasts	38	36	34	32	29	25	20

Table 6. Watch and warning summary for Hurricane Gaston.

Date/Time (UTC)	Action	Location
31 / 2100	Tropical Storm Watch issued	Western Azores and Central Azores
1 / 0900	Tropical Storm Watch changed to Tropical Storm Warning	Western Azores
1 / 1500	Tropical Storm Watch changed to Tropical Storm Warning	Central Azores
3 / 0600	Tropical Storm Warning discontinued	All

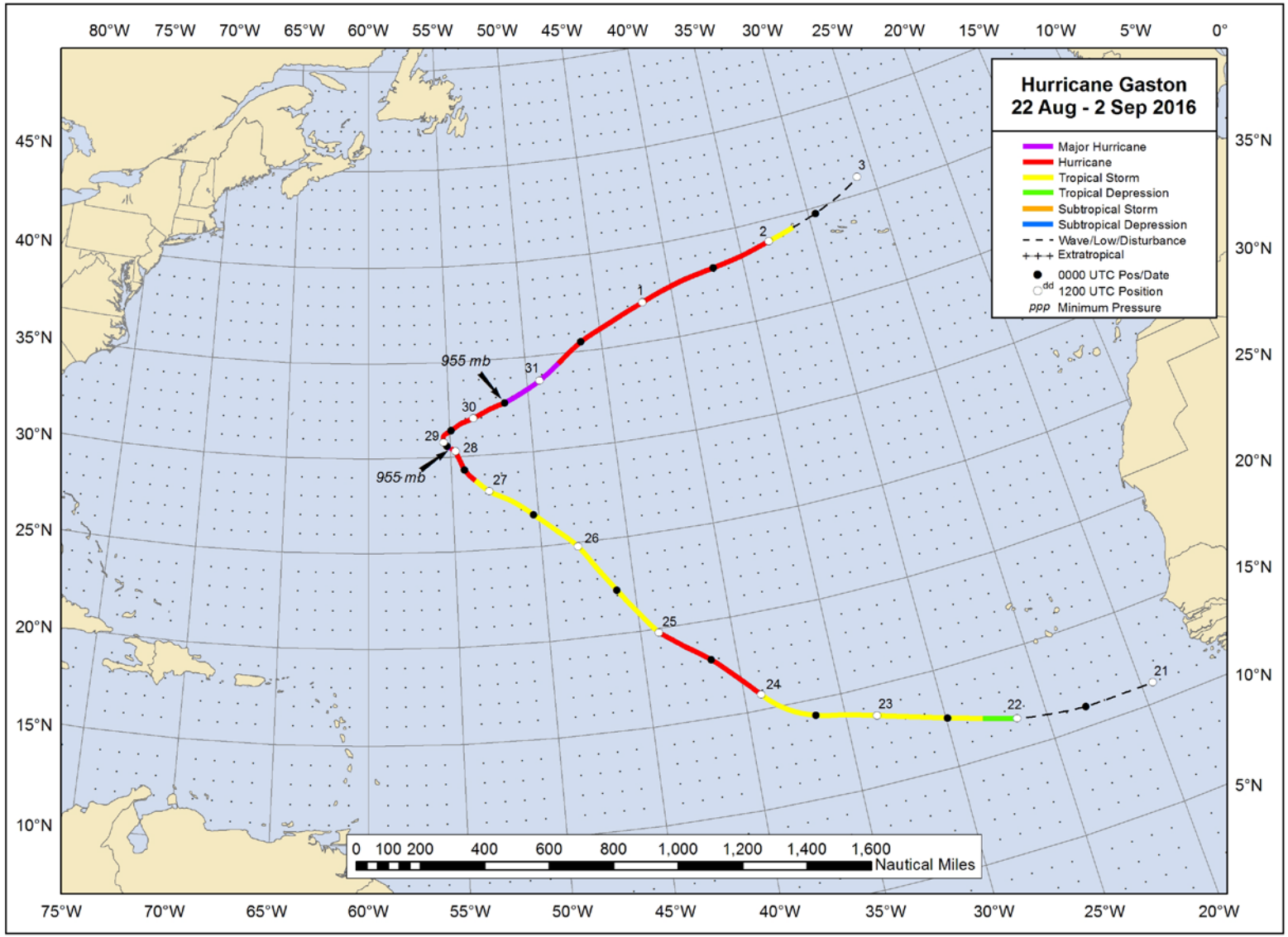

Figure 1. Best track positions for Hurricane Gaston, 22 August - 2 September 2016.

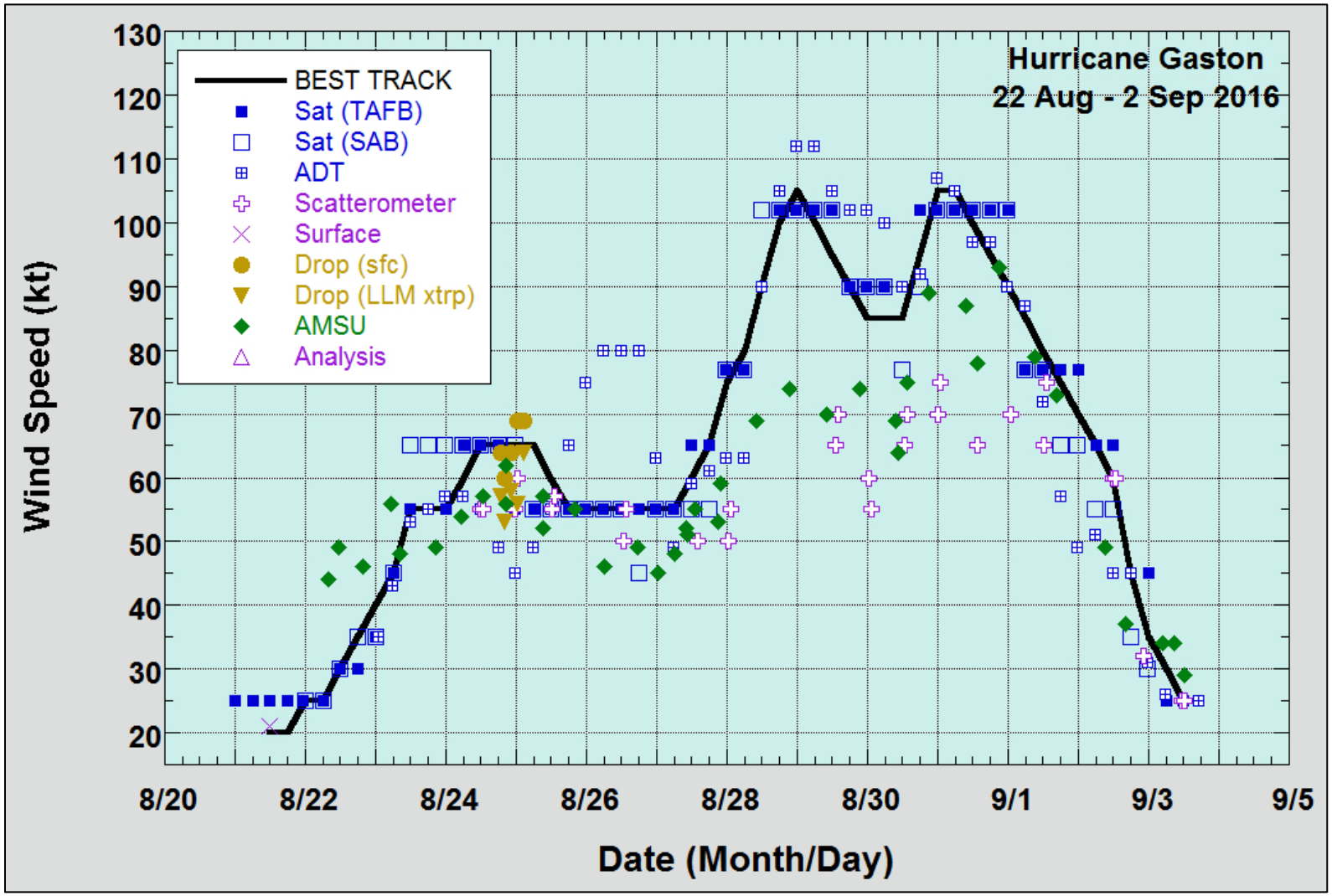

Figure 2. Selected wind observations and best track maximum sustained surface wind speed curve for Hurricane Gaston, 22 August – 2 September 2016. Dropwindsonde observations include actual 10 m winds (sfc), as well as surface estimates derived from the mean wind over the lowest 150 m of the wind sounding (LLM). Advanced Dvorak Technique estimates represent the Current Intensity at the nominal observation time. AMSU intensity estimates are from the Cooperative Institute for Meteorological Satellite Studies technique. Dashed vertical lines correspond to 0000 UTC.

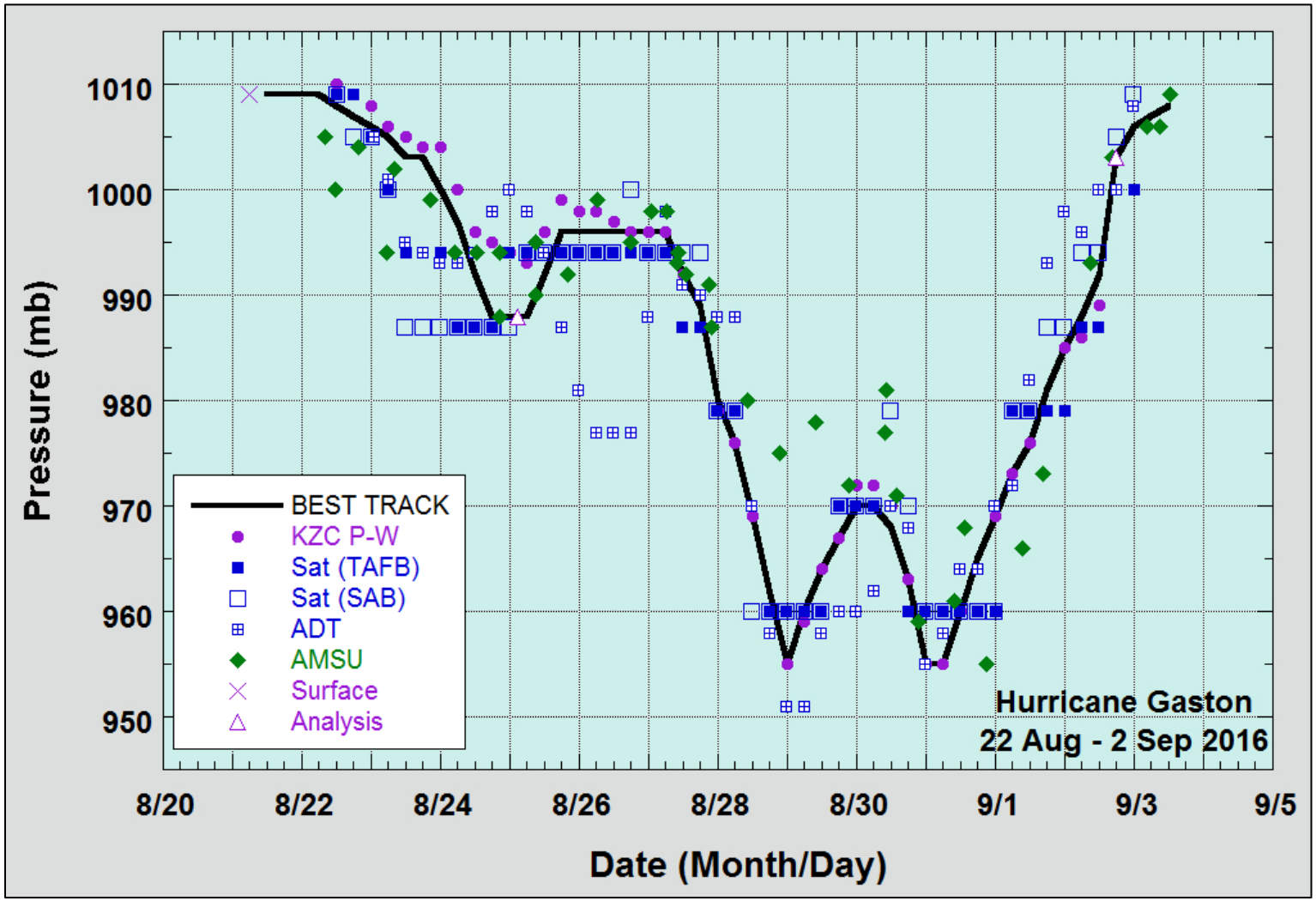

Figure 3. Selected pressure observations and best track minimum central pressure curve for Hurricane Gaston, 22 August – 2 September 2016. Advanced Dvorak Technique estimates represent the Current Intensity at the nominal observation time. AMSU intensity estimates are from the Cooperative Institute for 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.

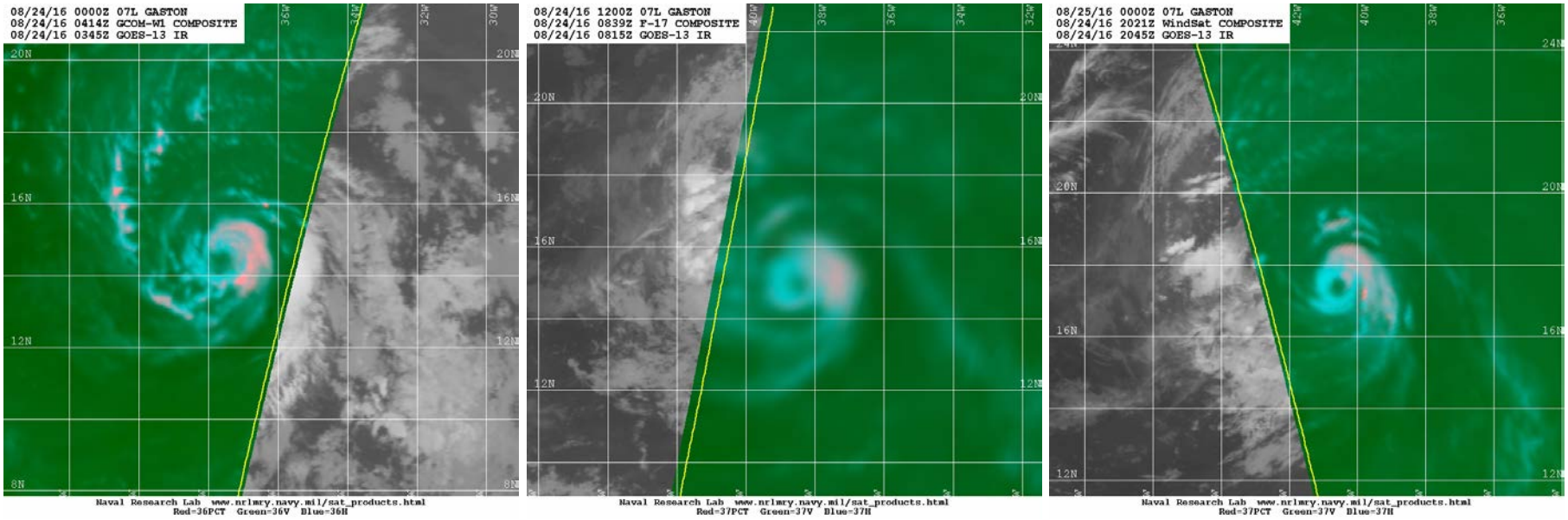

Figure 4. Series of 37-GHz color composite microwave satellite images of Gaston between 0414 UTC and 2021 UTC 24 August 2016. Note the presence of a well-defined low-level cloud ring. Gaston is estimated to have first reached hurricane strength during this time. Images courtesy of the Naval Research Laboratory.

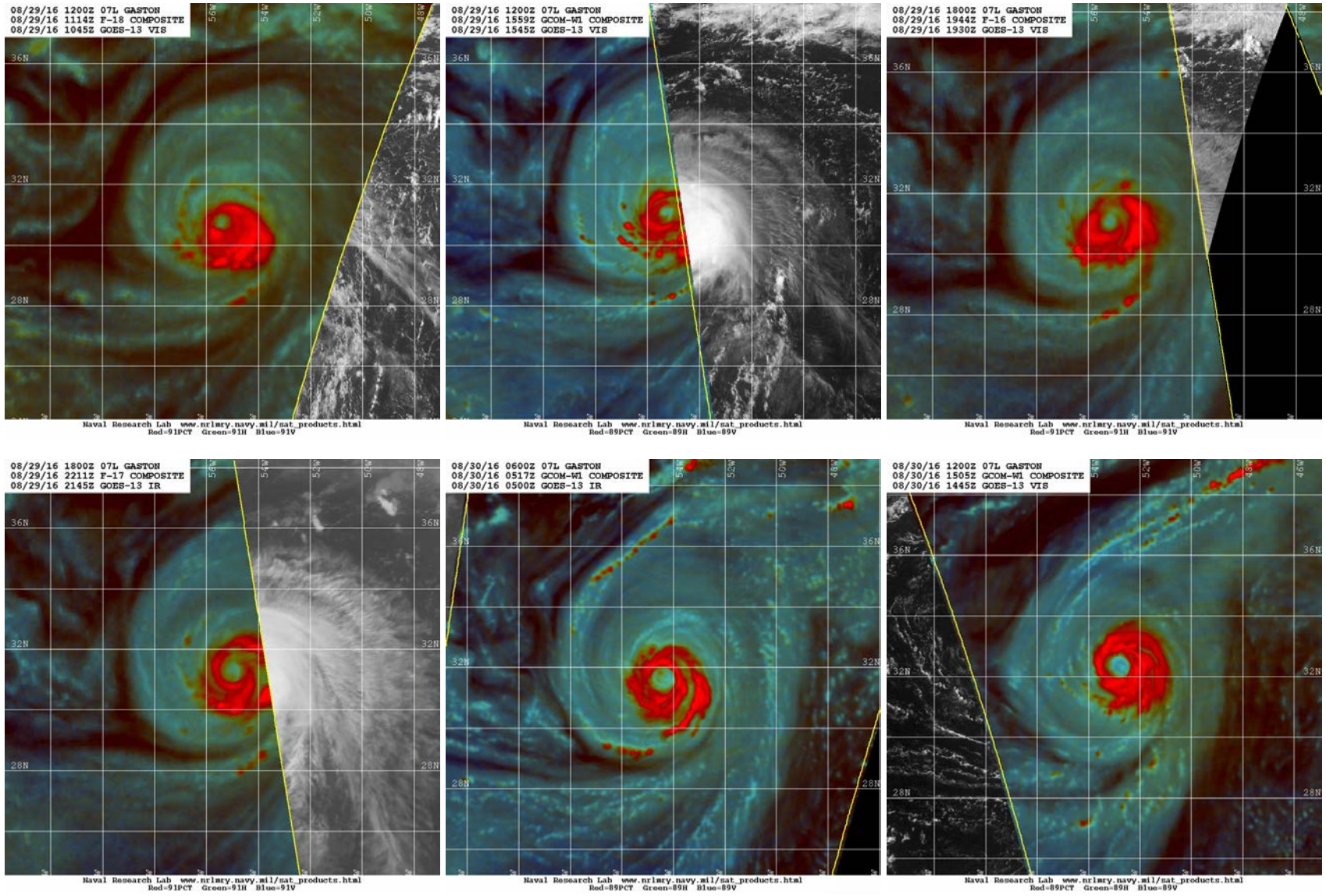

Figure 5. Series of 89- to 91-GHz color composite microwave satellite images of Gaston between 1114 UTC 29 August (top left) and 1505 UTC 30 August (bottom right) that show the evolution of the eyewall replacement cycle that occurred during that time. Note the increase in the size of the eye after the completion of the eyewall replacement.