

Tropical Cyclone Report  
Hurricane Rafael  
(AL172012)  
12-17 October 2012

Lixion A. Avila  
National Hurricane Center  
14 January 2013

Rafael moved across the northern Leeward Islands as a tropical storm and became a category 1 hurricane (on the Saffir-Simpson Hurricane Wind Scale) over the Atlantic well south of Bermuda.

a. Synoptic History

Rafael formed from a tropical wave that moved off the west coast of Africa on 5 October. The wave was accompanied by a large but disorganized area of cloudiness and thunderstorms during its westward trek across the tropical Atlantic. The shower activity increased when the wave approached the Lesser Antilles and interacted with a mid- to upper level trough located over the eastern Caribbean Sea. The wave crossed the Lesser Antilles during 11 and 12 October, and data from these islands indicated that the disturbance was already producing tropical storm force winds. However, this system did not have a closed surface circulation. The wave entered the eastern Caribbean Sea and slowed down. It then developed a closed circulation, becoming a tropical storm at 1800 UTC 12 August about 200 n mi south-southeast of St Croix in the U.S Virgin Islands. The “best track” chart of Rafael’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<sup>1</sup>.

Rafael was a disorganized cyclone with most of the thunderstorm activity located primarily to the east of the center due to moderate wind shear caused by a mid-to upper level trough. The trough weakened and shifted westward while an upper-level anticyclone developed over Rafael, resulting in less shear and gradual strengthening of the cyclone. Rafael turned to the north at a little faster forward speed, embedded within a southerly steering flow east of the upper trough.

Rafael moved northward and passed between St. Martin and St Croix around 0000 UTC 14 October with maximum winds of 45 knots. It then turned to the north-northwest over the Atlantic and slowed down again when the steering currents weakened. The cyclone had a very large area of thunderstorms, primarily in bands to the southeast of the center, and these rain bands with gusty winds continued to affect the northern Leeward Islands even though the center of the storm was over the open Atlantic as shown in Fig 4.

---

<sup>1</sup> 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 *bt* directory, while previous years’ data are located in the *archive* directory.

Rafael strengthened and became a hurricane at 0600 UTC 15 October about 650 n mi miles south of Bermuda. The cyclone began to move northward ahead of a cold front nearing the east coast of the United States, and it reached its maximum intensity of 80 kt and a minimum pressure of 969 mb at 1200 UTC 16 October about 300 n mi miles south of Bermuda. The cyclone recurved and accelerated ahead of the cold front, and became an extratropical cyclone at 1800 UTC 17 October well to the southeast of Nova Scotia. The extratropical cyclone looped around another extratropical low over the northeast Atlantic for several days and then moved southeastward and eastward while weakening. It dissipated over Portugal at 1800 UTC 26 October.

b. Meteorological Statistics

Observations in Hurricane Rafael (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), and dropwindsonde observations from flights of the 53<sup>rd</sup> Weather Reconnaissance Squadron of the U. S. Air Force Reserve Command and by the National Oceanic Administration Agency (NOAA) Aircraft Operations Center WP-3D aircraft. In addition, data from the NOAA buoy network was included in the analysis. 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 Rafael.

Rafael's estimated peak intensity of 80 kt was based on a blend of a maximum flight-level wind of 92 kt at the 700 mb-level, SFMR data of 70 to 75 kt, and both subjective and objective Dvorak numbers. In addition, the time of the peak intensity was chosen when the cloud pattern in both conventional and microwave imagery showed the best organization with the presence of an eye feature. The cloud pattern began to deteriorate after 1200 UTC 16 October.

Although most of the Lesser Antilles experienced gusty winds, the strongest winds were observed at Barbados with a maximum gust of 41 kt at 0809 UTC 12 October as the precursor wave moved through the area. Bermuda also reported a tropical-storm-force wind gust (42 kt) at 2206 UTC 16 October when the outer circulation of Rafael was moving nearby. Ship and buoy reports of winds of tropical storm force associated with Rafael are given in Table 2a and b.

c. Casualty and Damage Statistics

There was one direct death<sup>2</sup> associated with Rafael in Guadeloupe, France when the person was crossing a flooded river. There were no reports of significant damage.

d. Forecast and Warning Critique

The disturbance associated with Rafael was introduced into the Tropical Weather Outlook (TWO) at 0600 UTC 8 October with a low probability (10%) of development during the next 48 h. The chance of genesis was increased to 50% or medium at 0600 UTC 11 October, and then increased to high (70%) at 0000 UTC 12 October, about 18 h before Rafael formed.

A verification of NHC official track forecasts for Hurricane Rafael is given in Table 3a. Official forecast track errors were lower than the mean official errors for the previous 5-yr period. A homogeneous comparison of the official track errors with selected guidance models is given in Table 3b. In general, the variable consensus TVCA had the lowest errors through 48 h while the FSSE in general performed the best between 48 and 96 h. There were no 5-day forecasts to verify. Most of the track models captured the northward and then north-northwestward turn of Rafael across the northern Leeward Islands and the adjacent Atlantic, around the mid- to upper-level trough located over the eastern Caribbean Sea. The track models also clearly showed that Rafael would turn northward and northeastward over the Atlantic away from the U.S. east coast ahead of a cold front (Fig. 5).

A verification of NHC official intensity forecasts for Hurricane Rafael 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. The climatology-persistence intensity model errors, however were much larger than the official but not so if compared with the previous 5-yr period for the same model. A homogeneous comparison of the official intensity errors with selected guidance models is given in Table 4b. In this case, the DSHP model had lower errors than the official forecasts from 36 to 96 h. Both the dynamical HWFI and GHMI models performed better than the official forecasts at longer ranges. However, the number of forecast is quite small to make this a meaningful comparison.

Watches and warnings issued operationally for Hurricane Rafael are given in Table 5.

---

<sup>2</sup> 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.

Table 1. Best track for Hurricane Rafael, 12-17 October 2012.

Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Stage
12 / 1800	14.7	62.7	1006	35	tropical storm
13 / 0000	15.0	63.2	1007	35	"
13 / 0600	15.3	63.7	1006	35	"
13 / 1200	15.6	63.8	1006	35	"
13 / 1800	16.7	63.6	1004	40	"
14 / 0000	17.9	63.5	1004	45	"
14 / 0600	18.9	63.6	1003	45	"
14 / 1200	19.7	63.9	999	50	"
14 / 1800	20.4	64.3	994	55	"
15 / 0000	21.3	64.7	989	60	"
15 / 0600	22.0	65.2	986	65	hurricane
15 / 1200	22.6	65.6	983	70	"
15 / 1800	23.6	65.8	979	75	"
16 / 0000	24.6	65.6	974	80	"
16 / 0600	25.9	65.3	972	80	"
16 / 1200	27.6	64.9	969	80	"
16 / 1800	29.5	64.2	970	75	"
17 / 0000	31.6	63.1	970	75	"
17 / 0600	34.0	61.7	972	70	"
17 / 1200	36.5	60.1	972	65	"
17 / 1800	38.8	58.0	972	65	extratropical
18 / 0000	41.3	55.0	972	65	"
18 / 0600	43.4	50.7	972	60	"
18 / 1200	45.2	46.0	972	55	"
18 / 1800	47.0	41.0	973	55	"
19 / 0000	49.2	36.2	975	50	"
19 / 0600	51.0	32.5	973	50	"
19 / 1200	53.0	29.5	970	50	"
19 / 1800	55.0	30.0	968	50	"
20 / 0000	56.5	33.0	966	50	"
20 / 0600	56.0	37.0	966	50	"
20 / 1200	53.1	36.4	967	50	"
20 / 1800	50.8	34.3	970	50	"
21 / 0000	49.7	32.2	975	45	"
21 / 0600	49.2	31.1	978	40	"
21 / 1200	48.2	30.6	979	40	"
21 / 1800	47.0	30.8	982	40	"
22 / 0000	45.5	31.1	983	40	"
22 / 0600	43.9	29.8	985	40	"
22 / 1200	41.9	28.3	987	40	"
22 / 1800	40.0	27.0	989	40	"
23 / 0000	39.2	25.5	992	40	"
23 / 0600	39.5	24.5	992	40	"
23 / 1200	39.8	23.6	992	40	"
23 / 1800	40.5	22.1	992	40	"
24 / 0000	41.2	20.1	993	40	"
24 / 0600	41.6	18.8	995	40	"
24 / 1200	42.1	17.5	995	30	"

24 / 1800	41.9	16.0	995	30	"
25 / 0000	41.6	14.6	995	30	"
25 / 0600	41.3	13.3	995	30	"
25 / 1200	41.0	12.0	996	30	"
25 / 1800	40.9	11.2	997	30	"
26 / 0000	40.7	10.4	998	30	"
26 / 0600	40.3	9.1	999	30	"
26 / 1200	40.0	7.5	1002	25	"
26 / 1800					dissipated
16 / 1200	27.6	64.9	969	80	Maximum winds/minimum pressure

Table 2a. Selected ship reports with winds of at least 34 kt for Hurricane Rafael, 12-17 October 2012.

Date/Time (UTC)	Ship call sign or buoy	Latitude (°N)	Longitude (°W)	Wind dir/speed (kt)	Pressure (mb)
13 / 0200	3FFL8	17.7	63.1	070/35	1008.0
16 / 0000	3EIF9	18.9	66.5	190/39	1010.2
16 / 0600	WRAH	24.3	63.2	160/44	1003.1

Table 2b. Selected buoy reports with winds of at least 34 kt for Hurricane Rafael, 12-17 October 2012.

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)	Storm tide (ft)
	Date/time (UTC)	Press. (mb)	Date/time (UTC) <sup>a</sup>	Sustained (kt) <sup>b</sup>	Gust (kt)		
<b>Buoys</b>							
42060	13/1902	1004.3	15/1326	220/31	230/35		
41043	15/0041	991.8	14/1741	060/47	340/52		
41049	16/1233	995.1	16/1156	150/45	150/52		
41011	17/1450	997.1	17/1440	013/34	010/45		

<sup>a</sup> Date/time is for sustained wind when both sustained and gust are listed.

<sup>b</sup> Buoy averaging periods are 8 min.

Table 3a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) track forecast errors (n mi) for Hurricane Rafael. Mean errors for the 5-yr period 2007-11 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	<b>26.2</b>	<b>41.3</b>	<b>48.5</b>	<b>67.7</b>	<b>116.9</b>	<b>145.7</b>	
OCD5	55.1	131.3	203.8	248.9	351.7	731.8	
Forecasts	18	16	14	12	8	4	
OFCL (2007-11)	30.4	48.4	65.9	83.1	124.4	166.5	
OCD5 (2007-11)	46.9	95.2	151.7	211.6	316.8	404.3	

Table 3b. Homogeneous comparison of selected track forecast guidance models (in n mi) for Hurricane Rafael. 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	22.4	37.1	43.6	59.9	115.8	111.4	
OCD5	55.0	128.3	200.6	254.2	394.6	863.8	
GFSI	24.4	<b>32.8</b>	44.2	65.9	165.2	245.8	
HWFI	29.1	52.3	65.2	81.0	161.0	406.7	
UKMI	26.3	51.1	76.9	105.0	165.9	257.6	
EGRI	26.3	51.1	76.4	105.0	165.9	257.6	
EMXI	24.3	45.7	84.0	133.5	299.2	442.4	
CMCI	39.6	63.0	82.3	112.9	184.0	184.1	
AEMI	23.1	<b>34.3</b>	39.8	<b>51.5</b>	116.2	<b>84.9</b>	
FSSE	22.9	<b>32.7</b>	44.4	<b>53.0</b>	<b>70.6</b>	<b>82.4</b>	
TVCA	<b>21.4</b>	<b>29.1</b>	<b>40.9</b>	<b>53.4</b>	<b>83.9</b>	134.2	
LBAR	31.5	63.3	114.8	161.5	326.7	660.6	
BAMD	34.1	47.0	66.2	82.6	121.1	141.4	
BAMM	51.3	82.7	105.0	117.7	119.6	213.0	
BAMS	86.8	148.4	192.4	222.3	202.6	294.1	
Forecasts	15	13	11	9	5	2	0



Table 4a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) intensity forecast errors (kt) for Hurricane Rafael. Mean errors for the 5-yr period 2007-11 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	<b>4.2</b>	<b>5.3</b>	<b>6.8</b>	<b>7.5</b>	<b>11.9</b>	<b>15.0</b>	
OCD5	5.9	8.8	11.9	14.6	23.1	21.5	
Forecasts	18	16	14	12	8	4	
OFCL (2007-11)	7.1	10.8	13.0	15.0	16.9	17.1	
OCD5 (2007-11)	8.4	12.4	15.4	17.7	20.5	21.5	

Table 4b. Homogeneous comparison of selected intensity forecast guidance models (in kt) for Hurricane Rafael. 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	4.2	5.3	6.8	7.5	11.9	15.0	
OCD5	5.9	8.8	11.9	14.6	23.1	21.5	
IVCN	5.2	6.9	7.4	7.8	<b>10.5</b>	<b>6.0</b>	
ICON	5.2	6.9	7.4	7.8	<b>10.5</b>	<b>6.0</b>	
DSHP	5.1	6.8	<b>6.3</b>	<b>5.1</b>	<b>11.5</b>	<b>8.5</b>	
LGEM	5.4	9.1	13.2	16.5	23.4	27.3	
HWFI	4.8	7.4	8.9	<b>4.9</b>	<b>7.6</b>	<b>7.3</b>	
GHMI	6.4	9.7	10.4	11.8	<b>9.3</b>	<b>3.5</b>	
Forecasts	18	16	14	12	8	4	0

Table 5. Watch and warning summary for Hurricane Rafael, 12-17 October 2012.

Date/Time (UTC)	Action	Location
13 / 0000	Tropical Storm Watch issued	Puerto Rico
13 / 0000	Tropical Storm Warning issued	British Virgin Isl., Anguilla, Barbuda, St. Kitts, Nevis, Antigua and Montserrat
13 / 0000	Tropical Storm Warning issued	Saba, St. Eustatius, and St. Maartin
13 / 0000	Tropical Storm Warning issued	Guadeloupe, St. Martin, Desirade, Les Saintes, Marie Galante and Martinique
13 / 0000	Tropical Storm Warning issued	St. Lucia
13 / 0000	Tropical Storm Warning issued	U.S. Virgin Islands
13 / 0900	Tropical Storm Warning discontinued	St. Lucia
13 / 1500	Tropical Storm Warning discontinued	Martinique
13 / 1500	Tropical Storm Warning issued	Culebra and Vieques
14 / 0600	Tropical Storm Warning discontinued	Guadeloupe, St. Martin
14 / 0900	Tropical Storm Watch discontinued	All
14 / 0900	Tropical Storm Warning discontinued	British Virgin Isl., Anguilla, Barbuda, St. Kitts, Nevis, Antigua and Montserrat
14 / 0900	Tropical Storm Warning discontinued	Saba, St. Eustatius, and St. Maartin
14 / 0900	Tropical Storm Warning discontinued	St. Martin
14 / 0900	Tropical Storm Warning discontinued	U.S. Virgin Islands
14 / 0900	Tropical Storm Warning discontinued	Culebra and Vieques
14 / 1200	Tropical Storm Warning discontinued	All
14 / 1500	Tropical Storm Watch issued	Bermuda
15 / 1500	Tropical Storm Watch changed to Tropical Storm Warning	Bermuda
17 / 0300	Tropical Storm Warning discontinued	Bermuda

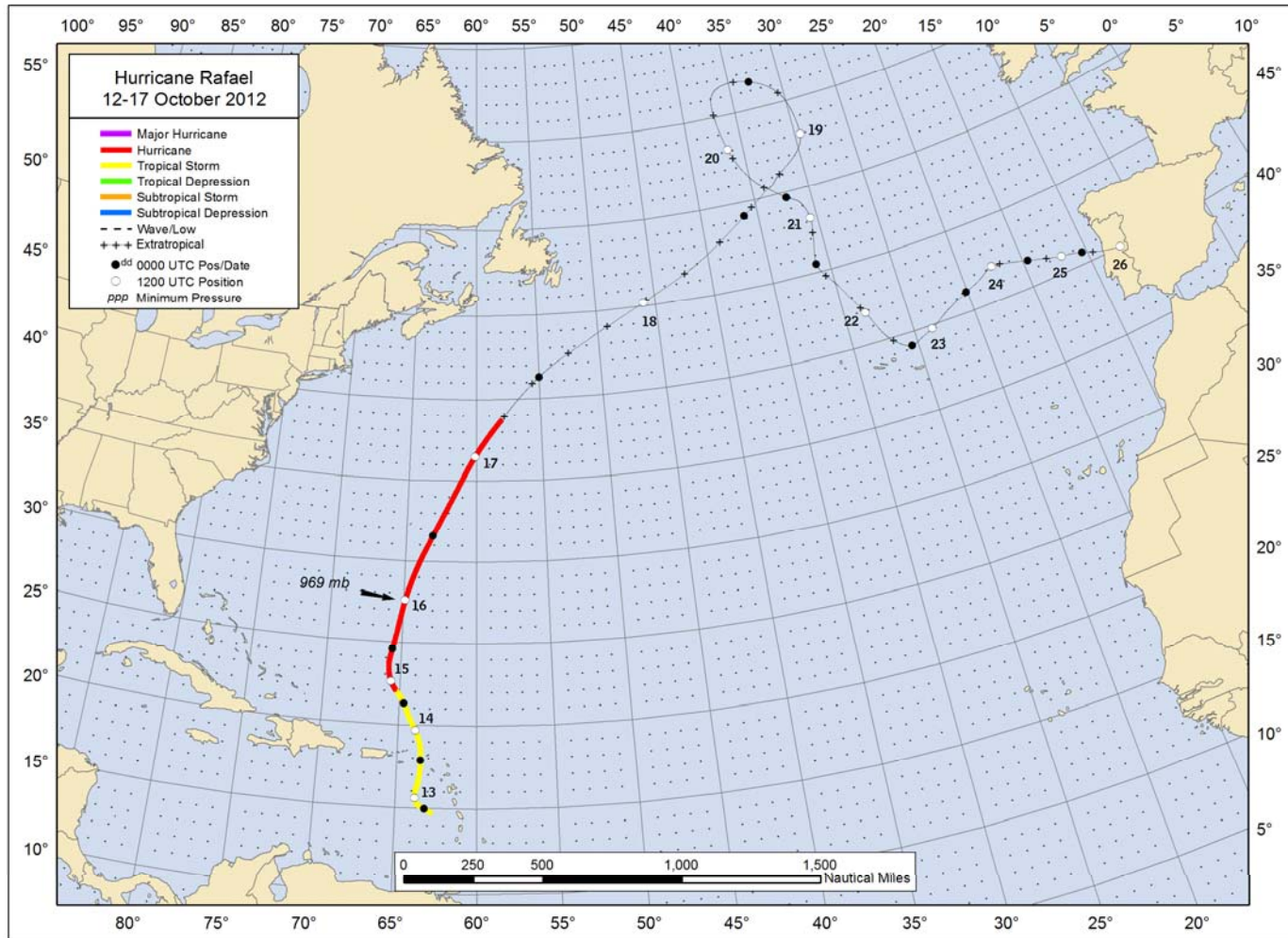


Figure 1 Best track positions for Hurricane Rafael, 12-17 October 2012. Track during the extratropical stage is mostly based on analyses from the NOAA Ocean Prediction Center.

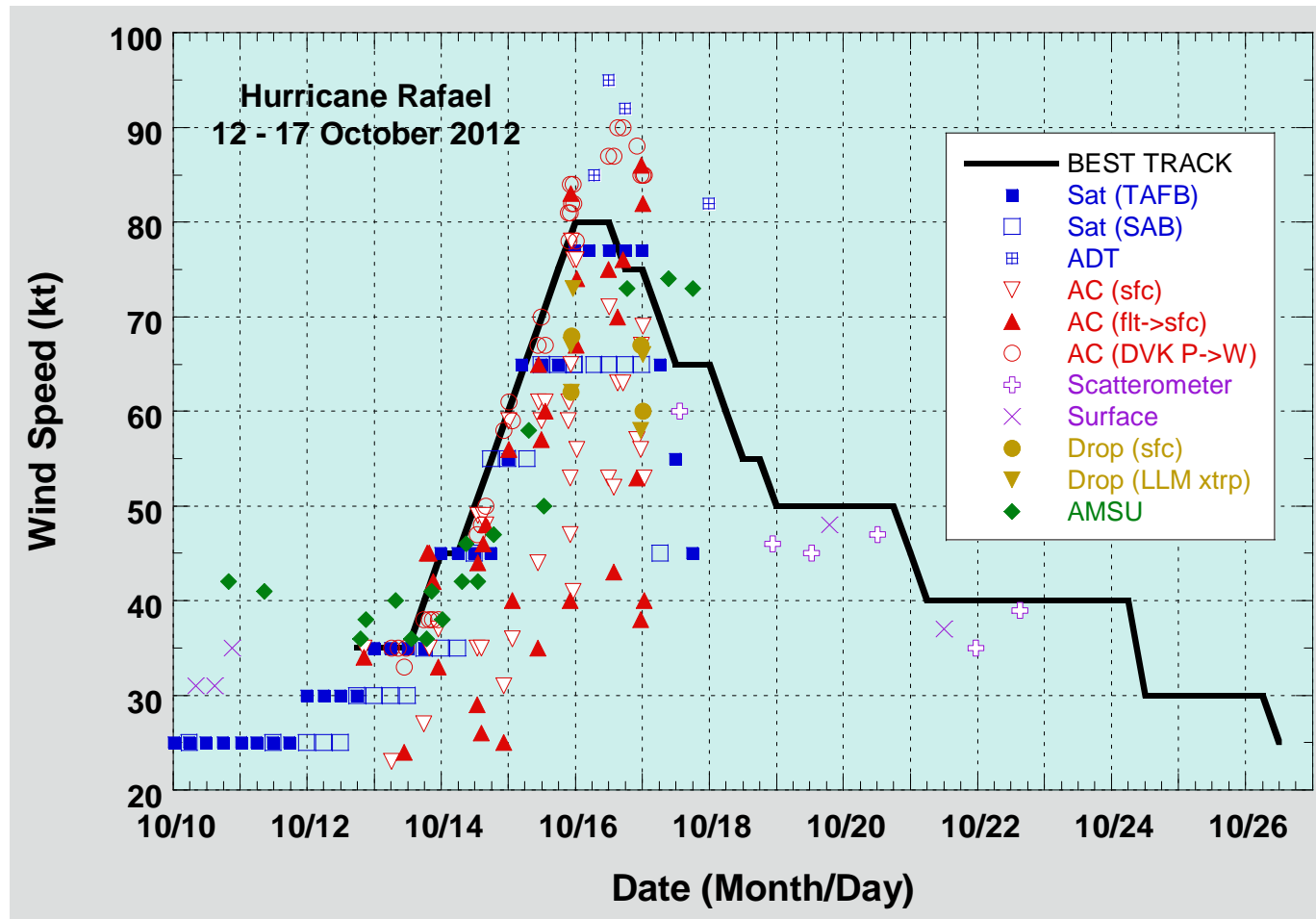


Figure 2. Selected wind observations and best track maximum sustained surface wind speed curve for Hurricane Rafael, 12-17 October 2012. Aircraft observations have been adjusted for elevation using 90%, 80%, and 80% adjustment factors for observations from 700 mb, 850 mb, and 1500 ft, respectively. Dropwindsonde observations include actual 10 m winds (sfc), as well as surface estimates derived from the mean wind over the lowest 150 m of the wind sounding (LLM). Advanced Dvorak Technique estimates represent CI numbers. AMSU intensity estimates are from the Cooperative Institute for Meteorological Satellite Studies technique. Estimates during the extratropical stage are based on analyses from the NOAA Ocean Prediction Center. Dashed vertical lines correspond to 0000 UTC.

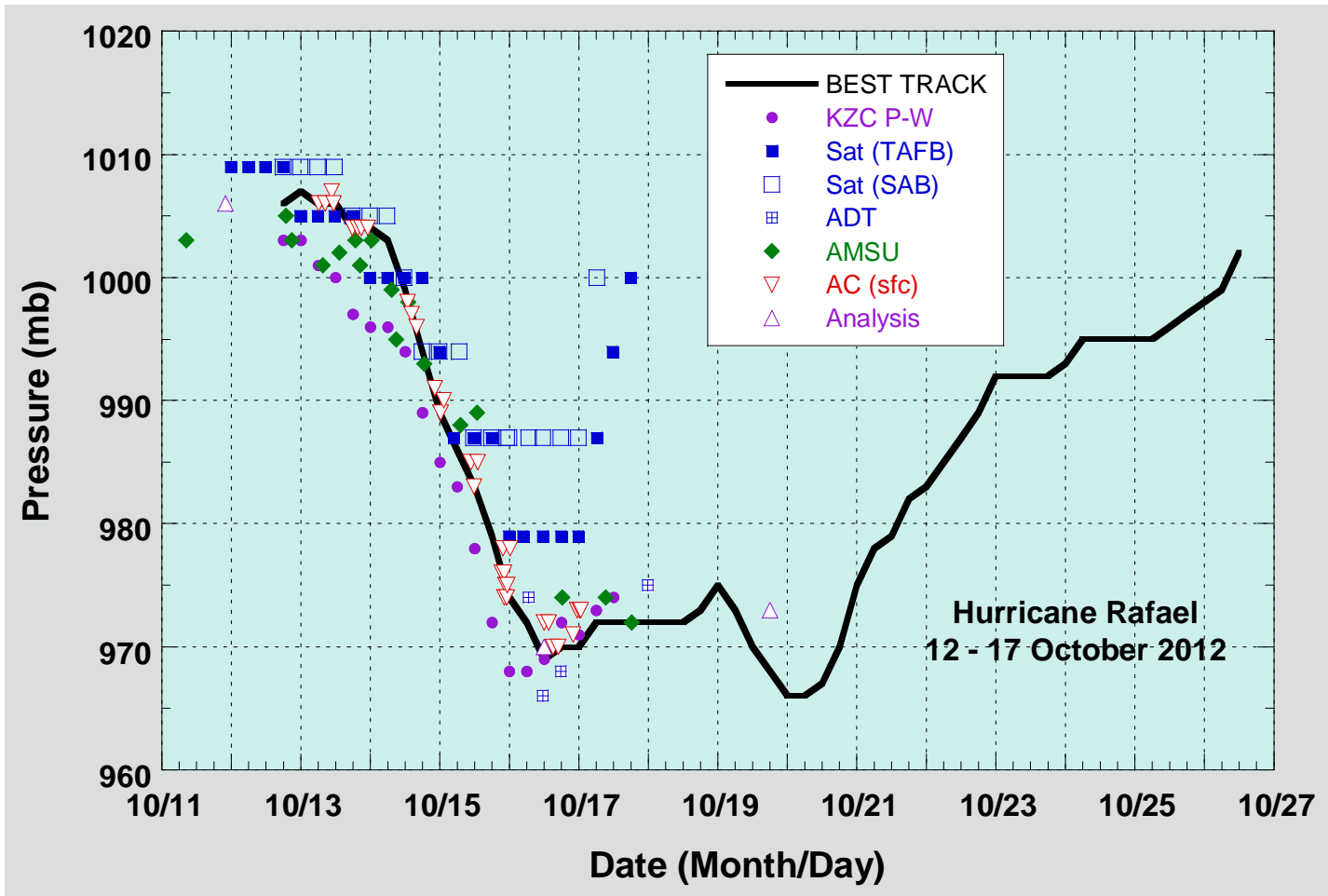


Figure 3.

Selected pressure observations and best track minimum central pressure curve for Hurricane Rafael, 12-17 October 2012. Advanced Dvorak Technique estimates represent CI numbers. AMSU intensity estimates are from the Cooperative Institute for Meteorological Satellite Studies technique. The KZC P-W values are obtained by applying the Knaff-Zehr-Courtney pressure-wind relationship to the best track wind data. Estimates during the extratropical stage are based on analyses from the NOAA Ocean Prediction Center. Dashed vertical lines correspond to 0000 UTC.

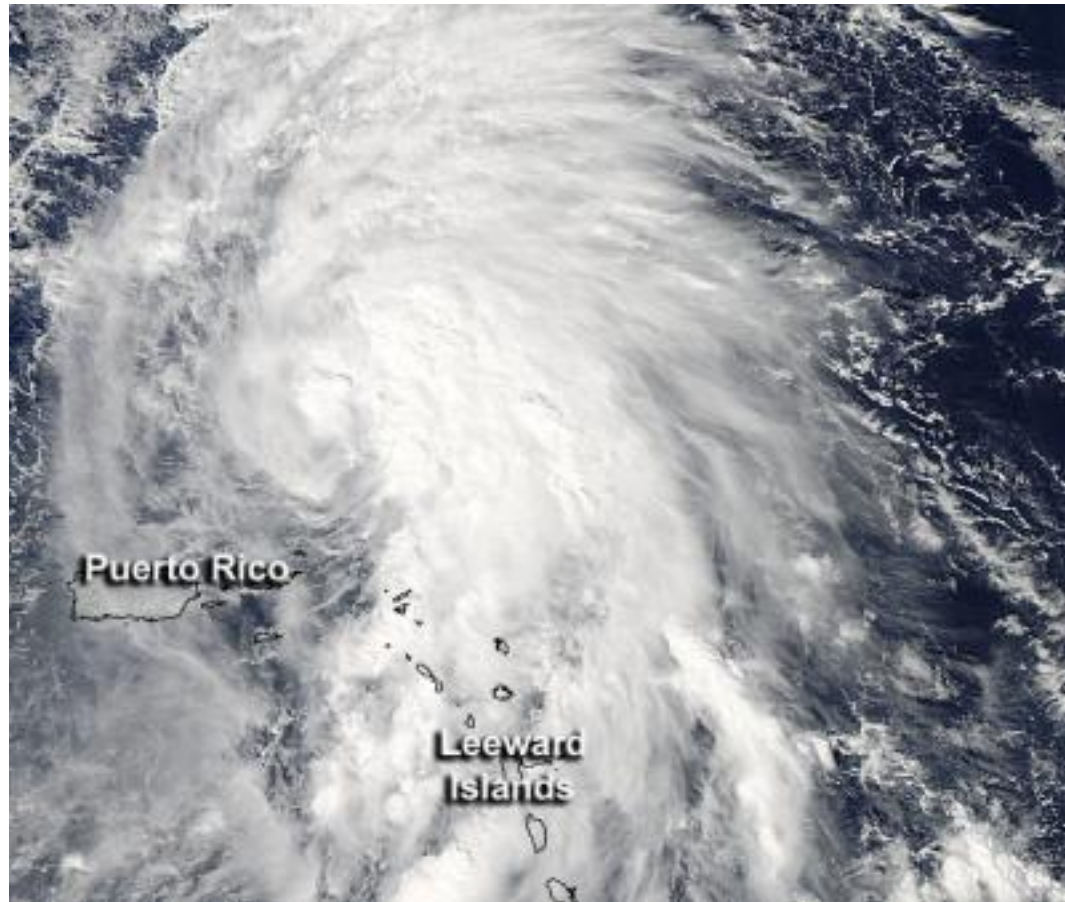
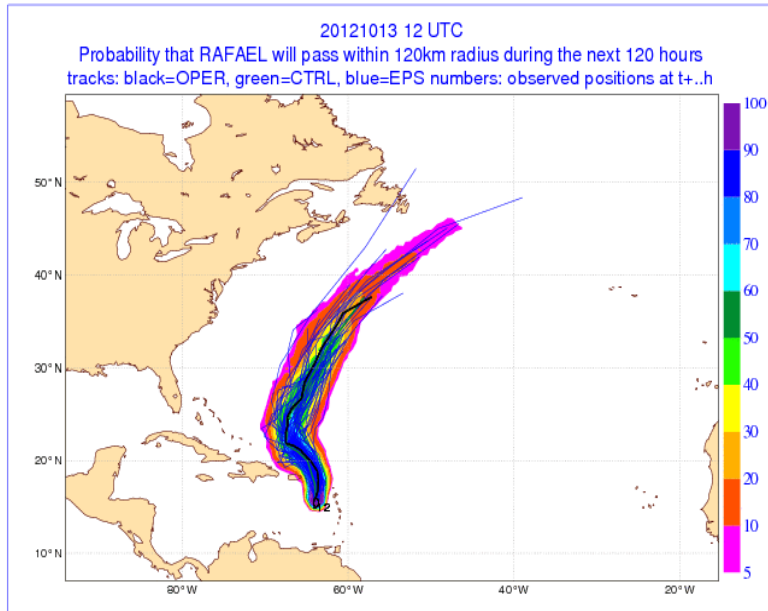


Figure 4. The MODIS instrument aboard NASA's Aqua satellite captured this visible image of Tropical Storm Rafael in the Atlantic Ocean at 1720 UTC October 14, 2012. Note that most of the showers and thunderstorms were occurring in rainbands east and south of the center of circulation affecting the Leeward Islands. Image is courtesy of NASA Goddard MODIS Rapid Response Team.

(a)



(b)

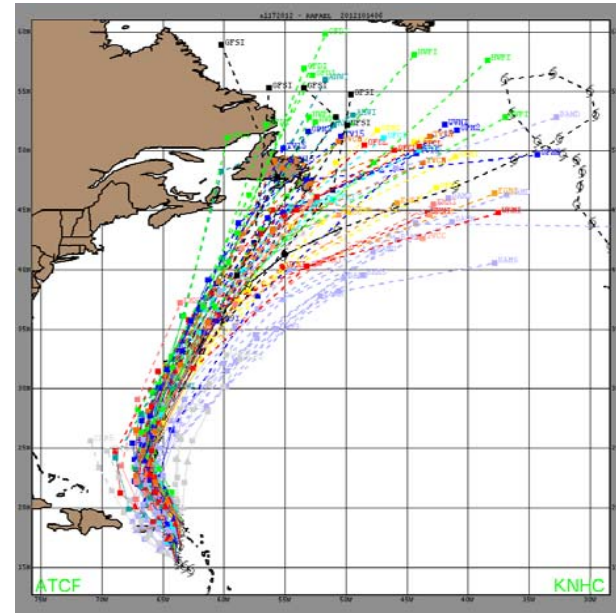


Figure 5. ECMWF ensemble member track forecast for Rafael at 1200 UTC 13 October 2012 (a). NHC track guidance for Rafael from 0600 UTC 13 October to 0600 UTC 14 October (b). Note that the models captured the initial north-northwestward turn north of Puerto Rico and the turn to the northeast over the Atlantic.