

Preliminary Report
Hurricane Floyd
7 - 17 September, 1999

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Floyd was a large and intense Cape Verde hurricane that pounded the central and northern Bahama islands, seriously threatened Florida, struck the coast of North Carolina and moved up the United States east coast into New England. It neared the threshold of category five intensity on the Saffir/Simpson Hurricane Scale as it approached the Bahamas, and produced a flood disaster of immense proportions in the eastern United States, particularly in North Carolina.

a. Synoptic History

Floyd can be traced back to a tropical wave that emerged from western Africa on 2 September. This system was not particularly impressive-looking, in terms of the organization of the convection shown on satellite images, but there was evidence of curvature in the cloud lines. Overall the system was broad and disorganized, yet easily recognizable as a synoptic-scale entity.

The wave proceeded westward across the eastern tropical Atlantic at about the normal speed of propagation, 6 degrees of longitude per day, with little apparent change, for several days. A center of circulation was estimated late on 5 September near 15°N 32.5°W but the cloud pattern lacked sufficient deep convection for a Dvorak classification. On 6 September, there was enough of a curved band of deep convection present so that the system was classified as a T1.0 on the Dvorak scale around 1200 UTC. A favorable upper-level outflow pattern existed over the area, and the cloud pattern became more consolidated and better organized on the 7th. Tropical Depression Eight formed about 1000 miles east of the Lesser Antilles by 1800 UTC that day.

A deep-layer ridge prevailed to the north of the cyclone and the associated steering current moved the system west-northwestward at 12-15 knots for a couple of days. When it reached a position about 750 n mi east of the Leeward Islands, the cloud pattern became sufficiently well organized for the system to become Tropical Storm Floyd around 0600 UTC 8 September. Even though large-scale conditions appeared conducive for strengthening, there was a lack of a well-defined inner core. This was evidenced by visible, infrared, and microwave imagery that showed no tightly curved banding features or a concentration of deep convection close to the center, a condition that probably prevented rapid intensification during the early stages of the tropical cyclone. Floyd slowly strengthened and became a hurricane by 1200 UTC 10 September while centered about 200 n mi east-northeast of the northern Leeward Islands.

As Floyd was nearing hurricane status, a mid-tropospheric trough in the vicinity of 60°-65°W longitude caused a slowing of the forward speed, and then a turn toward the northwest. The northwestward motion continued until the 11th, keeping the hurricane well to the northeast of the islands of the northeastern Caribbean. On the 11th, Floyd neared the southwest portion of the mid-Atlantic upper-tropospheric trough which was situated to the north of Puerto Rico, i.e. close to its climatological position. Historically, hurricanes have had difficulty strengthening in this area. Floyd's upper-level outflow was disrupted over the southern semicircle by the trough and an anticyclone over the eastern Caribbean. Consequently, after strengthening nearly to category three status early on the 11th, the hurricane weakened to 85 knots around 0000 UTC on the 12th. Early on the 12th, rising mid- to upper-tropospheric heights to the north of Floyd forced a turn toward the west. The westward turn also marked the beginning of a major strengthening episode (this phenomenon has also been observed with many past hurricanes, e.g. Andrew of 1992). Maximum sustained winds increased from 95 knots to 135 knots, and the central pressure fell about 40 mb from early on the 12th to early on the 13th. From 0600 to 1800 on the 13th, Floyd was at the top end of category four intensity on the Saffir/Simpson Hurricane Scale.

One potential contributor to the significant strengthening of Floyd was the presence of enhanced upper oceanic heat content along its track. Analyses from the Physical Oceanography Division of NOAA/AOML showed relatively high values of heat content just to the east of the Bahamas a day or two before Floyd passed through the area.

Floyd was aimed at the central Bahamas until late on the 13th, when the heading became west-northwestward. The eye passed just 20 to 30 n mi northeast and north of San Salvador and Cat Islands on the night of the 13th. Floyd's eyewall passed over central and northern Eleuthera on the morning of the 14th, and after turning toward the northwest, Floyd struck Abaco island on the afternoon of the 14th. By the time the hurricane hit Abaco, it had weakened somewhat from its peak, but Floyd was still a borderline category three/four hurricane.

As a mid- to upper-tropospheric trough over the eastern United States eroded the subtropical ridge over the extreme western Atlantic, Floyd continued to turn gradually to the right. The center of the hurricane paralleled the central Florida coast, passing about 95 n mi east of Cape Canaveral around 0900 UTC 15 September. By the afternoon of the 15th, Floyd was abeam of the Florida/Georgia border and headed northward toward the Carolinas.

Although there was a fluctuation in intensity, related to an eyewall replacement event discussed in the next section, overall the intensity of Floyd diminished from the 13th to the 15th. Environmental causes for intensity change are not entirely understood, but two large-scale factors probably contributed to a gradual decline: the entrainment of drier air at low levels from the northwest, and increasing south-southwesterly vertical shear. As Floyd neared the North Carolina coast late on the 15th, its maximum winds decreased below category three status.

After turning toward the north-northeast with forward speed increasing to near 15 knots, Hurricane Floyd made landfall near Cape Fear, North Carolina at 0630 UTC 16 September as a category two hurricane with estimated maximum winds near 90 knots. Floyd was losing its eyewall structure as it made landfall. Continuing to accelerate north-northeastward, Floyd's center passed over extreme eastern North Carolina on the morning of the 16th and over the greater Norfolk, Virginia area around 1500 UTC that day. Floyd then weakened to a tropical storm and moved swiftly along the coasts of the Delmarva peninsula and New Jersey on the afternoon and early evening of the 16th, reaching Long Island by 0000 UTC 17 September. By that time, the storm's forward speed had increased to near 29 knots. The system decelerated as it moved into New England.

By late on the 16th and early on the 17th, Floyd was becoming more involved with a frontal zone that existed along the Atlantic seaboard. The system took the form of a frontal low and thus became extratropical by the time it reached the coast of Maine at 1200 UTC 17 September. The cyclone turned toward the northeast and then east-

northeast, moving over the coast of New Brunswick late on the 17th, Prince Edward Island early on the 18th and Newfoundland late on the 18th and early on the 19th. Floyd's extratropical remnant merged with a large extratropical low over the north Atlantic and was no longer a distinct entity by 1800 UTC 19 September.

b. Meteorological Statistics

Table 1 lists the best track positions and intensities at six-hourly intervals. Figure 1 is a display of this track.

Figures 2(a,b) and 3 depict the best track curves of maximum one-minute average "surface" (10 meters above ground level) wind speed and minimum central sea-level pressure, respectively, as a function of time. Also plotted on Figs. 2a and 3 are aircraft reconnaissance and dropsonde data from the U.S. Air Force Reserves (the Hurricane Hunters) and NOAA, estimates from analyses of surface synoptic data, as well as Dvorak-technique estimates from the Tropical Analysis and Forecast Branch, TAFB, the Satellite Analysis Branch, SAB, and the U.S. Air Force Weather Agency (AFGWC in the figures) using satellite imagery. Figure 2b also shows the best track wind speed curve, but with only *in situ* data, i.e. flight level and dropsonde wind measurements. In both Figs. 2a and 2b the flight level winds are adjusted for elevation (90% of 700 mb wind speeds, 80% of 850 mb speeds, and 85% of 1500 ft speeds), and dropsonde wind measurements above the surface are adjusted to the 10 meter level using a mean hurricane eyewall profile determined by previous dropsonde measurements .

The peak intensity of Floyd, 135 knots, is based upon roughly 90% of the highest flight level (700 mb) winds of 149 knots at 0933 UTC 13 September. Minimum dropsonde-measured central pressure was 921 mb at 1121 UTC on that date.

Floyd is estimated to have been a 90-knot hurricane at landfall in North Carolina. There was a 10 meter anemometer measurement of sustained winds of 83 knots at 0710 UTC with gusts to 106 knots at 0716 UTC taken by University of Oklahoma meteorology professor Josh Wurman near Topsail Beach North Carolina. There were also unofficial reports of peak wind gusts to 120 knots (at 8 stories elevation) at Wrightsville Beach and 104 knots at the Wilmington Emergency Operations Center.

Table 2 lists ship reports of tropical storm force or greater wind speeds associated with Floyd. Table 3 lists a selection of surface observations from land stations and data buoys. Floyd's eye passed over NOAA data buoy 41010, located about 105 n mi east-northeast of Cape Canaveral, around 0900 UTC 15 September. That buoy

reported maximum 8-minute averaged winds of 72 knots at an anemometer height of 5 meters. At least three factors would imply a higher value for the 1-minute, 10 meter wind speed from the buoy observation: 1) going from an 8-minute to a 1-minute average; 2) going from 5 meters to 10 meters elevation; and 3) the presence of waves over 50 feet high. The best track intensity of Floyd when it passed over the buoy is near 100 knots, as indicated by dropsonde and aircraft flight level wind data. The center of the hurricane passed about 25 n mi west of the Frying Pan Shoals C-MAN station located about 30 n mi southeast of Cape Fear at 0500 UTC 16 September. This station reported winds sustained at 86 knots for a 20-minute period centered at that time, at an anemometer height of 44 meters.

On 13 September, just after Floyd reached maximum strength, there was evidence of a concentric eyewall. Figure 4 is a sequence of microwave images produced by the Naval Research Laboratory. Note that in the first image, during the deepening phase, there was a dominant inner eyewall with an eye diameter of 20 to 25 n mi. Later on, after peak intensity was reached, there was some indication of a concentric eyewall, particularly in the last image of this sequence. It is interesting to note that after this period, there was an apparent eyewall replacement, as suggested in the microwave image sequence shown in Fig. 5, and in radar imagery from NOAA/WP-3D aircraft research missions (not shown). It can be seen that the inner eyewall was dissipating while Floyd was centered near Eleuthera. This corresponded to a weakening of the hurricane to near 105 knots. The outer convective ring became the new eyewall by the time Floyd was centered over Abaco, corresponding to an eye diameter near 50 n mi. Afterwards, the new eye failed to contract significantly, while Floyd re-strengthened just slightly as it reached Abaco. After the disintegration of the inner eyewall the large-scale environment, as noted in the previous section, became less favorable. Consequently, after leaving the Bahamas, Floyd never regained its former intensity and, in fact, slowly weakened.

Heavy rainfall preceded Floyd over the mid-Atlantic states due to a pre-existing frontal zone and the associated overrunning. Hence, even though the tropical cyclone was moving fairly quickly, precipitation amounts were very large. Rainfall totals as high as 15 to 20 inches were recorded in portions of eastern North Carolina and Virginia. At Wilmington, North Carolina, the storm total of 19.06 inches included a 24-hour record of 15.06 inches. Totals of 12 to 14 inches were observed in Maryland, Delaware, and New Jersey. New records were set in Philadelphia for the most amount of rain in a calendar day, 6.63 inches. In southeastern New York, rainfall totals were generally in the 4 to 7 inch range but there was a report of 13.70 inches at Brewster. Totals of nearly 11 inches were measured in portions of New England.

Storm surge values as high as 9 to 10 feet were reported along the North Carolina coast.

A number of tornadoes were sighted in eastern North Carolina. There was a confirmed tornado in Bertie County and another in Perquimans County. The latter tornado destroyed two houses and damaged three or four others. At least ten tornadoes were reported by spotters in the Newport/Morehead City County Warning area, and these apparently caused some structural damage. Four tornadoes or funnel clouds were seen in the Wilmington area, but no damage was apparent.

c. Casualty and Damage Statistics

There were 57 deaths that were directly attributable to Floyd, 56 in the United States and 1 in Grand Bahama Island. The death toll by state is as follows: North Carolina 35, Pennsylvania 6, New Jersey 6, Virginia 3, Delaware 2, New York 2, Connecticut 1, and Vermont 1. Most of these deaths were due to drowning in freshwater flooding. Floyd was the deadliest hurricane in the United States since Agnes of 1972.

In the United States, the Property Claims Services Division of the Insurance Services Office reports that insured losses due to Floyd totaled 1.325 billion dollars. Ordinarily this figure would be doubled to estimate the total damage. However, in comparison to most hurricane landfalls, in the case of Floyd there was an inordinately large amount of freshwater flood damage, which probably alters the two to one damage ratio. Total damage estimates range from 3 to over 6 billion dollars. *Note - in 2011 the U.S. damage estimate was revised to \$6.9 billion.*

d. Forecast and Warning Critique

When averaged over the entire lifetime of the hurricane, the track forecasts for Floyd were excellent. Table 4 shows the average track errors for the official forecast and for a selection of objective guidance models. It can be seen that the average official forecast errors were substantially below the most recent ten-year averages. Also, on average, the official forecasts were better than all of the guidance except the UKMI model which had average track errors that were about equal to those of the official forecasts.

Although the *overall* average official forecast errors for Floyd were extremely low, the official forecasts were just ordinary if one considers only the period when hurricane warnings were in effect for the United States,. For example, the average

24-hour track forecast error for the latter period was roughly the same as the most recent ten-year average. Official track forecasts during the latter period also had a westward bias, and were somewhat slow. For example, the 36-hour official track forecasts during the period when hurricane warnings were in effect for the United States were an average of 104 n mi too far west and 70 n mi too far south. All of the track guidance models showed a similar westward and slow bias during this period.

Official intensity forecasts were fairly good (errors of 10 knots or less) for the first couple of days of Floyd's history. However, there were some large underforecasts of intensity, by as much as 30 to 40 knots, from 10-12 September. After Floyd reached its maximum intensity, the official forecasts did not show enough weakening. From 13 September onward, the wind speed was overpredicted in the advisories at practically every forecast time interval, by as much as 30 to 40 knots, and even 50 knots in one occasion. The Statistical Hurricane Intensity Prediction Scheme, SHIPS, performed similarly.

Table 5 is a chronology of the various watches and warnings that were issued for Floyd. A hurricane warning was issued for the northwest Bahamas more than 24 hours prior to the arrival of the eyewall at Eleuthera. For the United States, practically the entire east coast (the greater Miami area northward to Plymouth Massachusetts) was put under a hurricane warning for Floyd. To the authors' knowledge, the last time such an event occurred was during Hurricane Donna of 1960. Hurricane warnings for the southeast Florida coast proved unnecessary. However, given the forecast uncertainty and the required response times for evacuations and other preparations for such a large, severe hurricane, it was prudent to issue such warnings. The hurricane warning was issued for the coast of North Carolina at 0300 UTC 15 September. This is about 26-27 hours prior to the arrival of the eyewall in the Cape Fear area. Generally, for the coasts of South and North Carolina, hurricane warnings were issued at least 24 hours before the onset of tropical storm force winds.

According to preliminary information provided to the Federal Emergency Management agency, over 2 million people were evacuated for Floyd in the United States. This is probably the largest evacuation in U.S. history.

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Table 1. Best track, Hurricane Floyd, 7 - 17 September, 1999

Date/Time (UTC)	Position		Pressure (mb)	Wind Speed (kt)	Stage
	Lat. (°N)	Lon. (°W)			
7/1800	14.6	45.6	1008	25	tropical depression
8/0000	15.0	46.9	1007	30	“
0600	15.3	48.2	1005	35	tropical storm
1200	15.8	49.6	1003	40	“
1800	16.3	51.1	1000	45	“
9/0000	16.7	52.6	1000	45	“
0600	17.1	53.9	1003	45	“
1200	17.3	55.1	1003	50	“
1800	17.9	56.3	996	60	“
10/0000	18.3	57.2	995	60	“
0600	18.6	58.2	990	60	“
1200	19.3	58.8	989	70	hurricane
1800	20.2	59.6	975	70	“
11/0000	20.8	60.4	971	80	“
0600	21.4	61.1	963	95	“
1200	21.9	62.0	962	95	“
1800	22.5	63.0	966	90	“
12/0000	22.7	64.1	967	85	“
0600	22.8	65.2	960	95	“
1200	23.0	66.2	955	105	“
1800	23.2	67.4	940	115	“
13/0000	23.4	68.7	931	125	“
0600	23.6	70.0	922	135	“
1200	23.9	71.4	921	135	“
1800	24.1	72.9	923	125	“
14/0000	24.5	74.0	924	115	“
0600	24.9	75.3	927	105	“
1200	25.4	76.3	930	105	“
1800	26.1	77.0	930	110	“
15/0000	27.1	77.7	933	115	“
0600	28.2	78.5	935	110	“
1200	29.3	78.9	943	100	“
1800	30.6	79.1	947	95	“
16/0000	32.1	78.7	950	90	“
0600	33.7	78.0	956	90	“
1200	35.7	76.8	967	70	“
1800	38.0	75.3	974	60	tropical storm
17/0000	40.6	73.5	980	50	“

Table 1 (continued). Best track, Hurricane Floyd, 7 - 17 September, 1999

17/0600	42.1	72.1	983	50	tropical storm
1200	43.3	70.6	984	45	extratropical
1800	44.2	68.9	985	45	“
18/0000	44.8	67.3	987	40	“
0600	45.4	65.5	990	35	“
1200	46.6	63.0	992	35	“
1800	47.7	59.3	992	35	“
19/0000	48.0	56.3	992	35	“
0600	48.5	52.5	994	35	“
1200	49.5	48.0	992	40	“
1800					merged with low

13/1200	23.9	71.4	921	135	minimum pressure
14/1200	25.4	76.3	930	105	landfall near Alice Town, Eleuthera
14/1900	26.3	77.1	932	120	landfall near Cherokee Sound, Abaco
16/0630	33.8	78.0	956	90	landfall near Cape Fear, North Carolina

Table 2. Ship reports of 34 knots or higher wind speed associated with Hurricane Floyd, September 1999.

date/time (UTC)	ship call sign	latitude (°N)	longitude (°W)	wind dir/ speed(knots)	pressure (mb)
08/1500	PDYI	19.0	52.6	070/39	1011.1
09/0900	DFSO	17.2	53.7	180/37	1004.2
09/1200	DFSO	16.9	54.5	210/37	1005.2
09/1500	DFSO	16.6	55.4	180/45	1005.5
12/1500	DGOO	22.7	69.3	320/35	1001.5
12/1800	DGOO	23.5	69.5	340/37	998.5
12/1800	ZCAH3	24.9	63.1	130/58	1009.3
12/2100	DGOO	24.1	69.8	030/43	994.8
13/0000	DGOO	24.5	69.9	040/45	994.8
13/0300	DGOO	24.9	70.3	/52	997.0
13/0600	DGOO	25.6	70.5	040/52	998.5
13/0900	DGOO	26.3	70.8	060/52	999.5
13/1200	DILD	24.9	53.1	170/37	1013.9
13/1200	DGOO	27.0	71.0	090/52	1002.9
13/1800	KHRH	19.5	74.7	360/50	994.0
13/1800	WZJF	21.3	66.9	135/35	1009.5
14/0000	PPXI	30.6	74.3	070/50	1001.0
14/0900	WGJT	22.0	73.5	180/35	998.2
14/1200	PPXI	30.4	71.0	110/45	1001.0
14/1500	PEXU	26.7	70.6	120/37	1009.2
15/0300	SHIP	30.3	74.3	100/45	1006.5
15/0900	DGOS	29.3	73.8	130/38	1004.0
15/1200	DGOS	28.9	73.8	130/47	1003.5
15/1200	PFKV	30.6	74.0	120/38	1004.4
15/1800	PFKV	30.3	74.0	130/36	1003.6
16/0000	WRGQ	31.5	75.4	160/46	(898.1)
16/0300	PEXU	29.4	73.9	190/36	1008.5
16/0600	WRGQ	31.2	75.2	200/41	1001.0
16/0600	SHIP	36.8	73.0	140/36	1006.8
16/1200	WZJE	32.0	71.6	180/38	1008.5
16/1200	3ELL6	32.0	72.5	200/36	1007.2

Table 2 (continued). Ship reports of 34 knots or higher wind speed associated with Hurricane Floyd, September 1999.

date/time (UTC)	ship call sign	latitude (°N)	longitude (°W)	wind dir/ speed(knots)	pressure (mb)
16/1800	BKJO	34.7	72.2	190/60	1005.0
16/1800	WZJE	32.1	72.3	210/52	1009.6
16/2100	DEDI	40.4	70.9	130/42	998.0
16/2100	SHIP	36.6	69.5	180/47	1007.0
17/0000	DEDI	40.4	70.8	140/50	993.3
17/0000	SHIP	36.6	68.4	190/40	1009.5
17/0000	WAUU	36.0	68.5	190/46	1009.7

Table 3 (continued). Hurricane Floyd, selected surface observations, September 1999.

Location	Press. (mb)	Date/ time (UTC)	Sustained wind (kt) ^a	Peak gust (kt)	Date /time (UTC) ^b	Storm surge (ft) ^c	Storm tide (ft) ^d	total rain (in)
Maryland								
Annapolis								11.60
Cambridge							2.5	
Chestertown								14.00
Lewisetta							3.5	
Martin State Airport	989.0							
Mid-Bay Buoy				60	16/1710			
Ocean City	976.8	16/1853	31	45	16/1653			1.71
Patuxent NAS	991.0		30	36	16/1555			
Salisbury	980.4	16/1851	28	42	16/2150			5.08
Solomon's Island							3.0	
St. Inigoes	987.6							
Tall Timbers				62	16/2040			11.10
Thomas Point Light			43	49	16/1300			
Delaware								
Cape Henlopen				56	16/PM			
Greenwood								10.58
Lewes						2.6	6.76	
Vernon								12.36
Wilmington	986.0	16/2106	32	40	16/2214			
New Jersey								
American Corners								10.20
Atlantic City	980.2	16/2054	23	34	16/2345	2.0	6.22	
Caldwell/Essex Co. Airport	987.8	16/2353		38	16/2353			10.21
Cape May						2.6	7.36	
Doylestown								10.07
Federalburg								11.20
Neshanic								10.07
Newark Int'l Airport	985.1	16/2351	38	46	16/2351			6.22
Pequanock								11.04
Sandy Hook	981.0	16/2306	34	45	17/0024	1.9	6.57	
Somerville								13.34
Teterboro Airport	985.0	16/2351	24	38	16/2351			8.53
Wayne/Iflows								12.21
White House								12.98
Pennsylvania								
Philadelphia	985.0	16/2136	32	42	16/2136	2.8	9.34	
New York								
Central Park	983.8	16/2250	25	36	16/1450			5.02
Farmingdale Airport	981.6	16/2353	23	37	16/2053			3.13
HPN Airport	985.8	17/0050	25	42	16/2350			6.26
Islip/MacArthur Airport	983.4	17/0156	27	37	16/2356			
JFK Int'l Airport	982.5	16/2351	30	41	17/0051			3.27
LaGuardia Airport	983.7	16/2351	30	41	17/0051			4.94
MGJ Airport			29	44	16/2039			
MTP Airport	986.9	17/0254	22	37	17/0454			
Newburgh/Stewart Airport	992.6	17/0045	34	54	16/2245			
NWS Upton								3.50
Westhampton Airport	984.8	17/0153	28	43	17/0153			
White Plains Airport	985.8	17/0050	25	42	16/2350			
Massachusetts								
Beverly				31				

Table 3 (continued). Hurricane Floyd, selected surface observations, September 1999.

Location	Press. (mb)	Date/ time (UTC)	Sustained wind (kt) ^a	Peak gust (kt)	Date /time (UTC) ^b	Storm surge (ft) ^c	Storm tide (ft) ^d	total rain (in)
Blue Hill Observatory-Milton				40				
Boston							10.7	
Boston/Logan Airport				38				
Brewster				63	17/0545			
Buzzards Bay			47	57	17/0300			
Fox Point Hurricane Barrier						4.2		
Hadley								9.60
Hyannis				62				
Lawrence				32				
Martha's Vineyard				34				
Nantucket				32			1.3	
New Bedford Hurr. Barrier				64	17/0600	2.5		
Norwood				27				
Orange				29				
Plymouth				33				
Southwick								9.16
Taunton				38				
Westfield				37				
Worcester				30				
Rhode Island								
Block Island				39				
Newport				35			2.6	
Providence				35			5.9	
Westerly				31				
Connecticut								
Bridgeport Airport	981.8	17/0154	29	39	16/2254			
Bristol								10.80
Burlington								9.45
Danbury Airport	987.1	17/0153	15	21	17/0153			
Groton/New London Airport	986.8	17/0145	30	43	17/0045			
Hartford Airport	985.4	17/0253						
Meriden	984.5	17/0156						
MMK Airport	986.4	17/0155	20	34	17/0155			
New Haven Airport	983.8	17/0145	33					
Southington								9.14
Willimantic	985.8	17/0352		31				
Windsor Locks				37				
New Hampshire								
Manchester				28				
NOAA National Data Buoy Center buoys								
41004 (30.5°N 79.1°W)			54	72	16/0200			
41009 (28.5°N 80.2°W)	980.9	15/0900	52	70	15/1000			
41008 (31.4°N 80.9°W)			24	31	15/2100			
41010 (28.9°N 78.5°W)	939.6	15/0900	72	91	15/0700			
44009 (38.5°N 74.7°W)	976.0	16/1900	39	52	16/1800			
44014 (36.8°N 74.8°W)	981.4	16/1600	50	66	16/1615			
44025 (40.3°N 73.2°W)	980.0	17/0000	33	43	17/0600			
NOAA National Data Buoy Center C-MAN stations								
BUZM3(41.4°N 71.0°W)			47	57	17/0300			
CLKN7 (34.6°N 76.5°W)	974.9	16/0500	63	79	16/0450			
DSLN7 (31.2°N 75.3°W)	985.8	16/0730	69	82	16/0750			

Table 3 (continued). Hurricane Floyd, selected surface observations, September 1999

Location	Press. (mb)	Date/ time (UTC)	Sustained wind (kt) ^a	Peak gust (kt)	Date /time (UTC) ^b	Storm surge (ft) ^c	Storm tide (ft) ^d	total rain (in)
DUCN7 (36.2°N 75.8°W)	977.0	16/0900	67	83	16/0850			
FPSN7 (33.5°N 77.6°W)	958.7	16/0600	86	97	16/0512			
SAUF1 (29.9°N 81.3°W)	992.9	15/1200	58		15/1200			

^aASOS and C-MAN are 2 min; buoys are 8 min.

^bDate/time is for sustained wind when both sustained and gust are listed.

^cStorm surge is water height above normal astronomical tide level.

^dStorm tide is water height above National Geodetic Vertical Datum (1929 mean sea level).

Table 4.

**Preliminary forecast evaluation of Hurricane Floyd
Heterogeneous sample**

(Errors in nautical miles for tropical storm
and hurricane stages with number
of forecasts in parenthesis)

Technique	Period (hours)				
	12	24	36	48	72
CLIP	40 (35)	88 (33)	148 (31)	206 (29)	312 (25)
GFDI	36 (34)	71 (32)	97 (30)	115 (28)	153 (25)
GFDL*	31 (30)	66 (30)	96 (28)	109 (26)	155 (24)
LBAR	30 (34)	59 (32)	92 (30)	112 (28)	120 (24)
AVNI	38 (35)	77 (33)	119 (31)	141 (29)	187 (25)
BAMD	37 (34)	70 (32)	106 (30)	147 (28)	239 (24)
BAMM	50 (34)	96 (32)	137 (30)	175 (28)	243 (24)
BAMS	63 (34)	123 (32)	173 (30)	207 (28)	263 (24)
A98E	35 (33)	72 (31)	113 (29)	120 (27)	174 (24)
NGPI	39 (29)	69 (27)	101 (25)	123 (23)	146 (19)
UKMI	29 (32)	54 (30)	66 (26)	76 (24)	97 (21)
NHC OFFICIAL	28 (35)	53 (33)	73 (31)	73 (29)	104 (25)
NHC OFFICIAL 1989-1998 10-year average	48 (2005)	89 (1790)	128 (1595)	164 (1410)	242 (1107)

* GFDL output not available until after forecast issuance.

Table 5. Watch and warning summary, Hurricane Floyd, September 1999

Date/time (UTC)	Action	Location
09/2100	Tropical storm watch issued	Antigua, Barbuda, Anguilla, and Dutch Saint Maarten
09/2200	Tropical storm watch issued	French Saint Martin and Saint Barthelemy
11/0300	Tropical storm watch discontinued	Antigua, Barbuda, Anguilla and Dutch Saint Maarten
11/0300	Tropical storm watch discontinued	French Saint Martin and Saint Barthelemy
12/0900	Tropical Storm warning and hurricane watch issued	Turks, Caicos, and Southeast Bahamas
12/0900	Hurricane watch issued	Central Bahamas
13/0000	Hurricane warning issued	Central Bahamas
13/0000	Hurricane watch issued	Northwest Bahamas
13/0900	Hurricane watch upgraded to hurricane warning	Northwest Bahamas
13/0900	Hurricane watch issued	Florida: South of Flagler Beach to Hallandale
13/1500	Hurricane watch extended	South to include Miami-Dade County and north of Flagler Beach, Florida to Brunswick, Georgia
13/1800	Hurricane watch extended	Including Lake Okeechobee
13/2100	Hurricane watch upgraded to hurricane warning	Florida City, Florida to south of Brunswick, Georgia
13/2100	Tropical storm warning issued	Florida Keys, north of Seven Mile Bridge
13/2100	Hurricane watch issued	Georgia: Brunswick to Savannah
14/0300	Hurricane watch extended	North of Savannah, Georgia to Little River Inlet, South Carolina

Table 5. (continued) Watch and warning summary, Hurricane Floyd, September 1999

Date/time (UTC)	Action	Location
14/0900	Tropical storm warning discontinued	Turks and Caicos Islands
14/1500	Tropical storm warning discontinued	Southeast Bahamas
14/2100	Tropical storm warning discontinued	Florida Keys, from the Seven Mile Bridge northward
14/2100	Hurricane warning extended	Georgia and South Carolina coasts to Little River Inlet, South Carolina
14/2100	Hurricane warning downgraded to tropical storm warning	Florida: Florida City to Boca Raton
14/2100	Hurricane watch extended	North of Little River Inlet, South Carolina to Cape Charles Light, Virginia, south of New Point Comfort, including Pamlico and Albermarle sounds
15/0300	Hurricane warning extended	North of Little River Inlet, South Carolina to the North Carolina/Virginia border
15/0300	Hurricane warning discontinued	Florida: Boca Raton to Ft. Pierce
15/0300	Hurricane watch extended	North Carolina/Virginia border to Chincoteague, Virginia, including Chesapeake Bay, south of Smith Point
15/0300	Hurricane warning discontinued	Central Bahamas
15/0300	Tropical storm warning discontinued	Florida: Florida City to Ft. Pierce
15/0600	Hurricane warning discontinued	Northwest Bahamas: New Providence, Bimini, Andros, and Berry Islands

Table 5. (continued) Watch and warning summary, Hurricane Floyd, September 1999

Date/time (UTC)	Action	Location
15/0900	Tropical storm watch issued	Chincoteague, Virginia to Cape Henlopen, Delaware, including Chesapeake Bay north of Smith Point and the Potomac from Cobb Island to Smith Point
15/1200	Hurricane warning discontinued	Florida: South of Sebastian Inlet to Ft. Pierce Northwest Bahamas: Grand Bahama and Abaco Islands
15/1500	Hurricane warning discontinued	Florida: Sebastian Inlet to Titusville
15/1500	Tropical storm watch extended	North of Chincoteague, Virginia to Sandy Hook, New Jersey, including Delaware Bay
15/1700	Tropical storm watch extended	North of Sandy Hook, New Jersey to Montauk Point on Long Island, New York, including Delaware Bay
15/1900	Hurricane warning discontinued	Florida: Titusville to Fernandina Beach
15/2100	Hurricane warning extended	North of North Carolina/Virginia border to Chincoteague, Virginia, including Chesapeake Bay, south of Smith Point
15/2100	Tropical storm watch upgraded to tropical storm warning	North of Chincoteague, Virginia to Sandy Hook, New Jersey, including northern Chesapeake Bay, the Potomac Basin, and Delaware Bay

Table 5. (continued) Watch and warning summary, Hurricane Floyd, September 1999

Date/time (UTC)	Action	Location
15/2100	Tropical storm watch extended	North of Sandy Hook, New Jersey to the Merrimack River, Massachusetts, including Long Island Sound
16/0300	Hurricane warning discontinued	North of Fernandina Beach, Florida to Edisto Beach, South Carolina
16/0300	Hurricane warning extended	North of Chincoteague, Virginia to Cape Henlopen, Delaware
16/0300	Tropical storm warning extended	North of Sandy Hook, New Jersey to Plymouth, Massachusetts
16/0900	Hurricane warning extended	North of Cape Henlopen, Delaware to Manasquan Inlet, New Jersey and from Moriches Inlet, New York to Plymouth, Massachusetts
16/0900	Tropical storm warning extended	North of Plymouth, Massachusetts to Merrimack River, Massachusetts
16/1100	Hurricane warning discontinued	From South Santee River, South Carolina, southward
16/1300	Hurricane warning discontinued	South Santee River, South Carolina to Surf City, North Carolina
16/1500	Hurricane warning discontinued	North Carolina: North of Surf City to Cape Hatteras
16/1800	Hurricane warning discontinued	Cape Hatteras, North Carolina to Cape Charles Light, Virginia, including southern Chesapeake Bay

Table 5. (continued) Watch and warning summary, Hurricane Floyd, September 1999

Date/time (UTC)	Action	Location
16/2100	Hurricane warning downgraded to tropical storm warning	Cape Charles Light, Virginia to the Merrimack River, Massachusetts, including Chesapeake Bay, the Potomac Basin, Delaware Bay, and Long Island Sound
17/0300	Tropical storm warning discontinued	Cape Charles Light, Virginia to Sandy Hook, New Jersey, including Chesapeake Bay, the Potomac Basin, and Delaware Bay
17/0900	Tropical storm warning discontinued	Sandy Hook, New Jersey to the Merrimack River, Massachusetts, including Long Island Sound

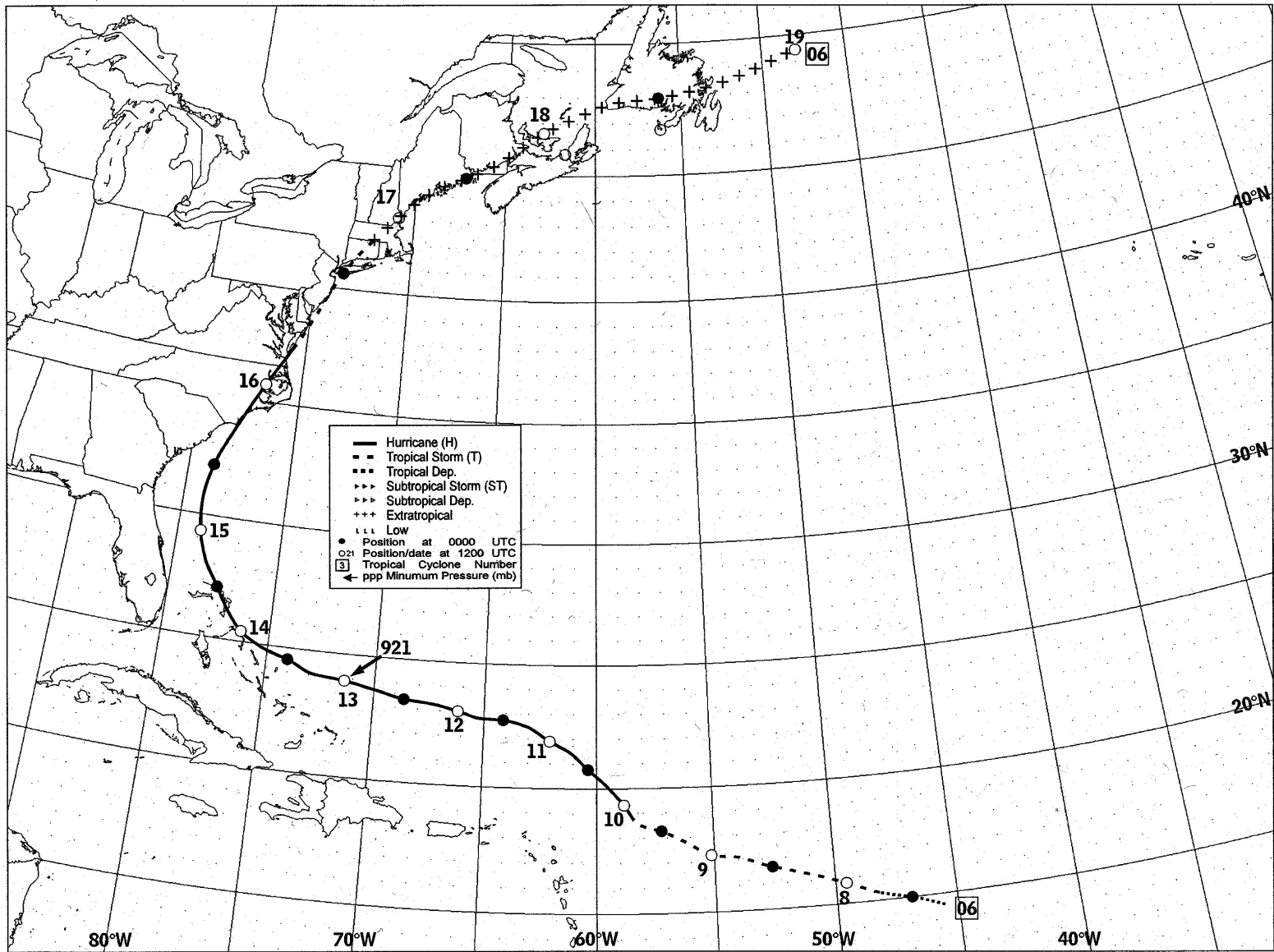


Figure 1. Best track positions for Hurricane Floyd, 07-17 September 1999.

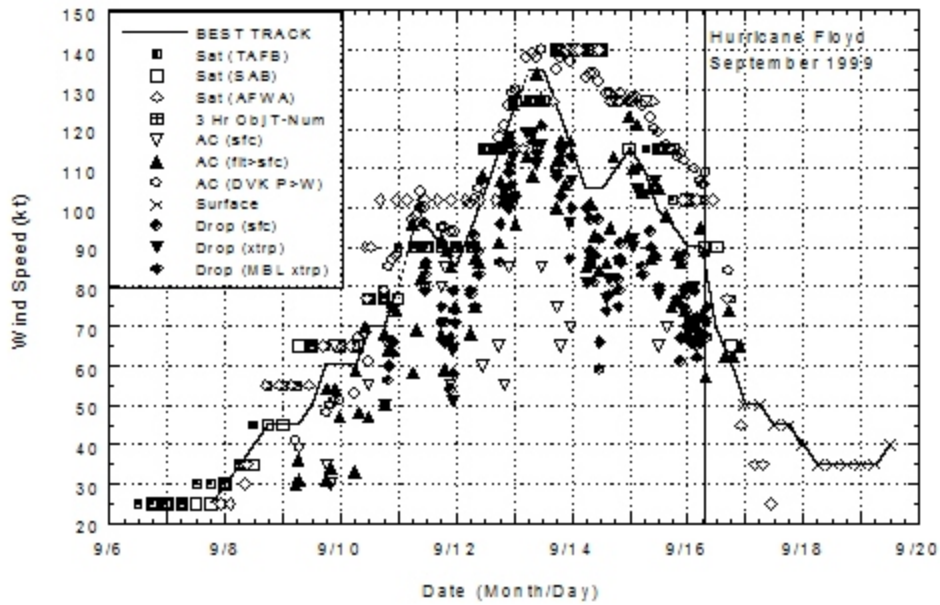


Fig. 2a. Best track maximum sustained wind speed curve for Hurricane Floyd, showing all available intensity estimates and wind observations. Aircraft wind measurements have been adjusted for elevation (90% of 700 mb wind speeds, 80% of 850 mb speeds, and 85% of 1500 ft speeds), and dropsonde wind measurements above the surface are adjusted to the 10 meter level using a mean hurricane eyewall profile determined by previous dropsonde measurements. Vertical line denotes landfall.

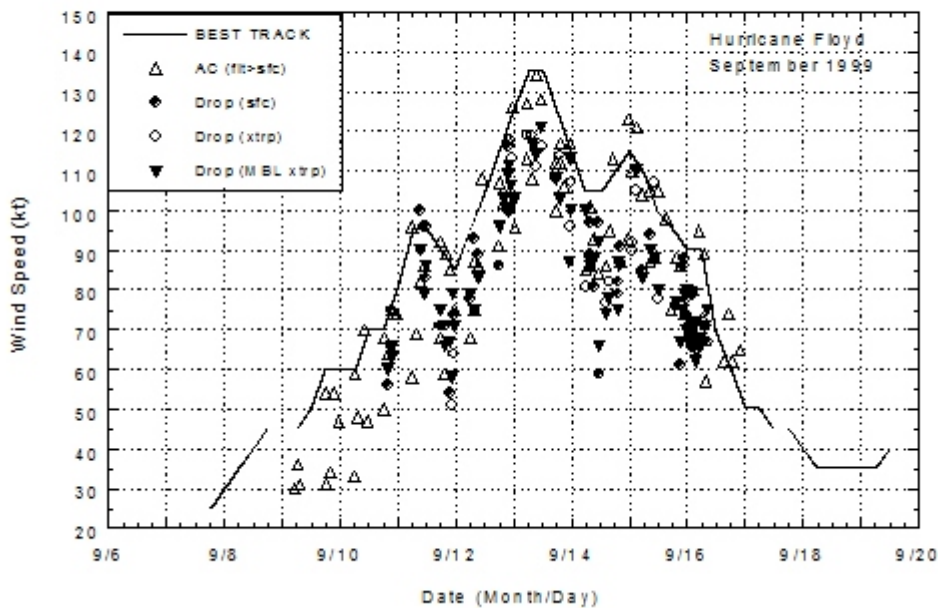


Fig. 2b. Best track maximum sustained wind speed curve for Hurricane Floyd, showing only *in situ* wind observations adjusted for elevation as indicated in Fig. 2a.

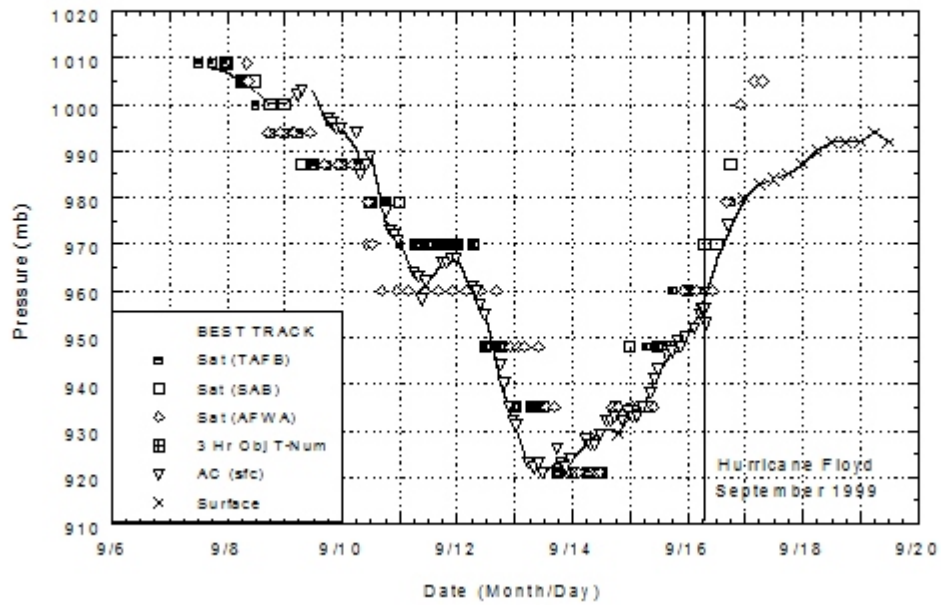


Fig. 3. Best track minimum central pressure curve and central pressure observations or estimates for Hurricane Floyd. Vertical line denotes landfall.

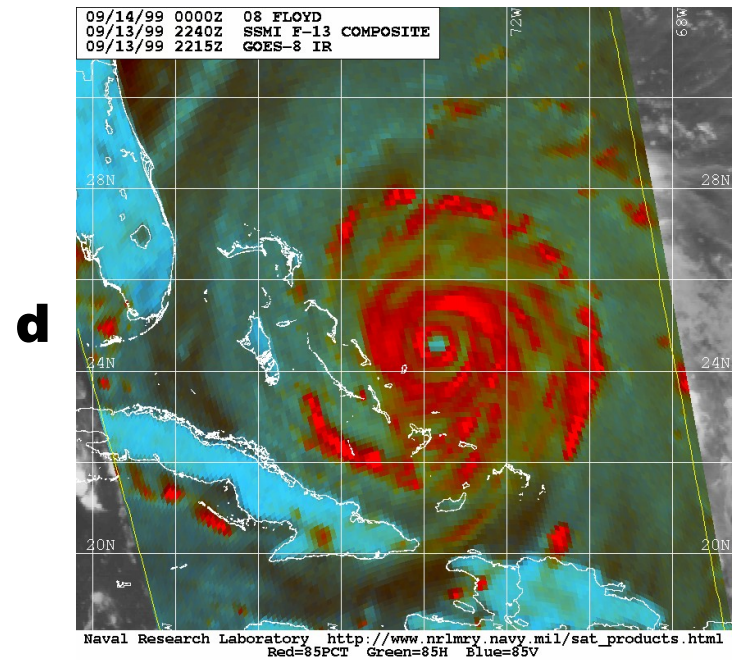
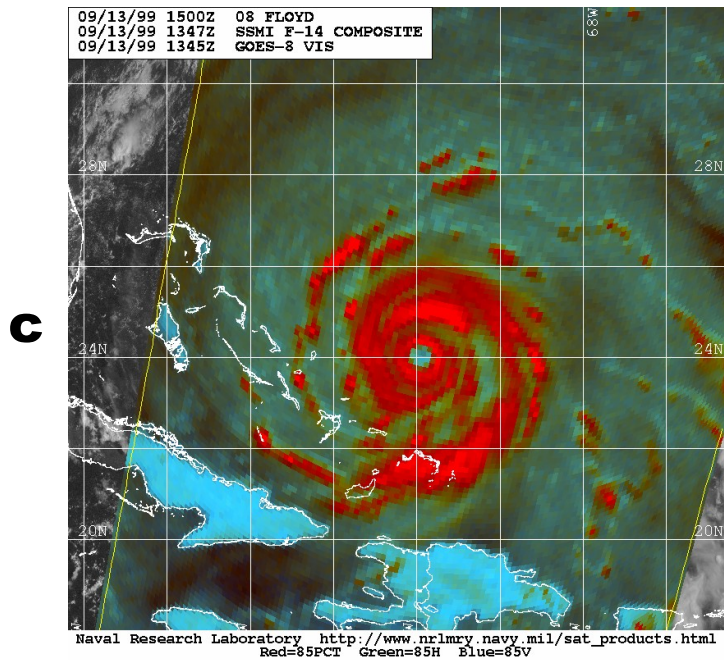
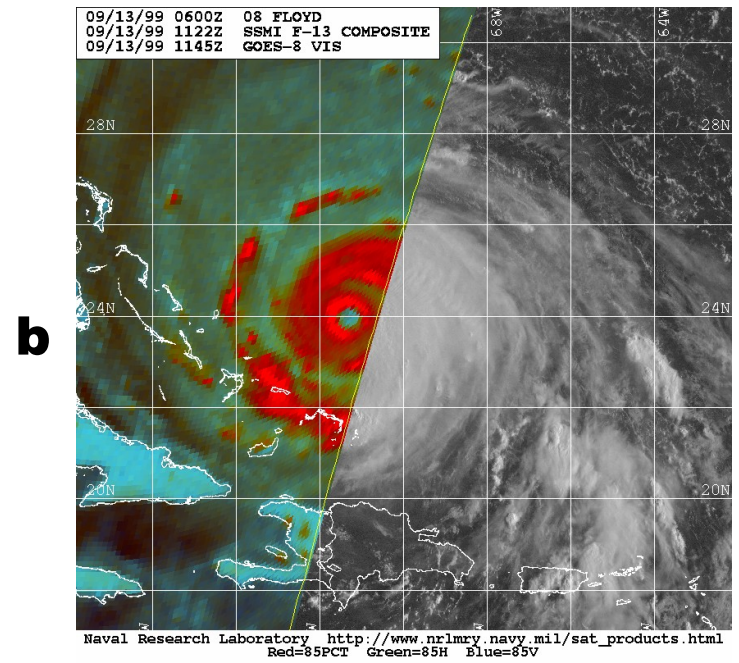
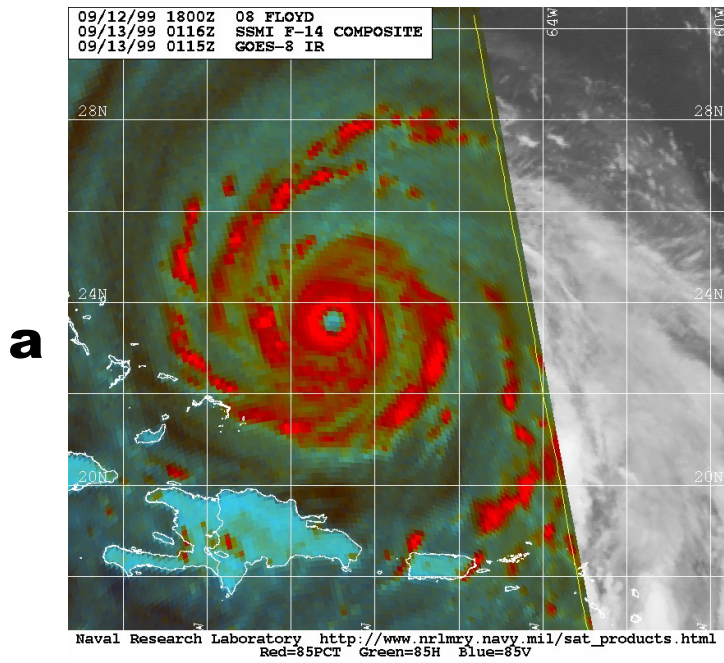


Fig. 4. Sequence of microwave images of Hurricane Floyd at: (a) 0116 UTC, (b) 1122 UTC, (c) 1347 UTC, and (d) 2240 UTC 13 September, 1999.

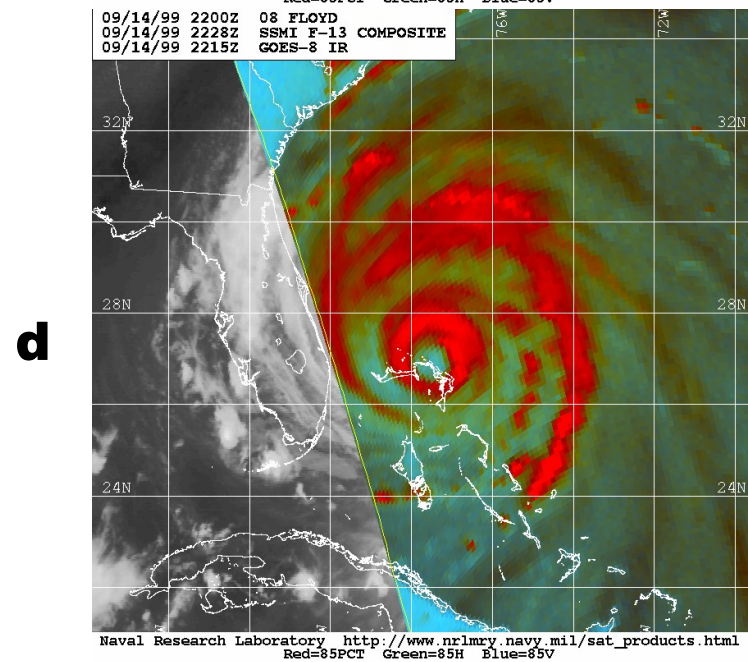
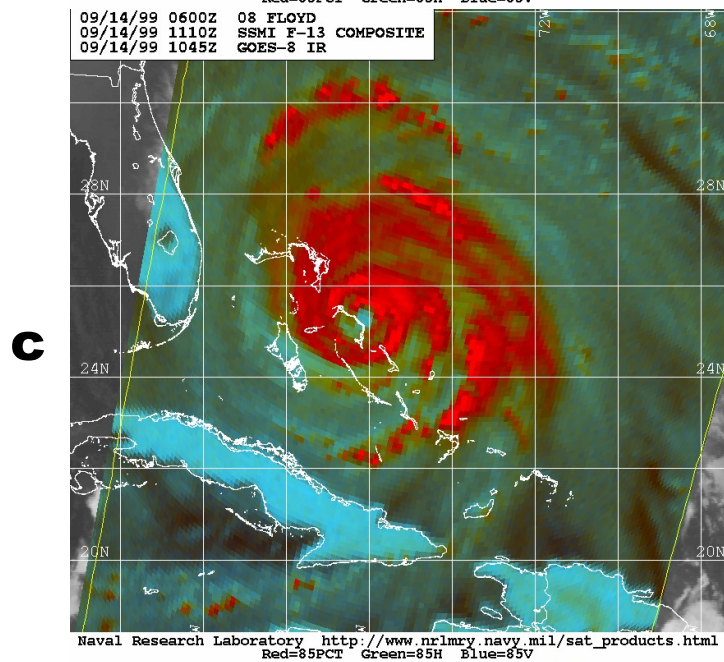
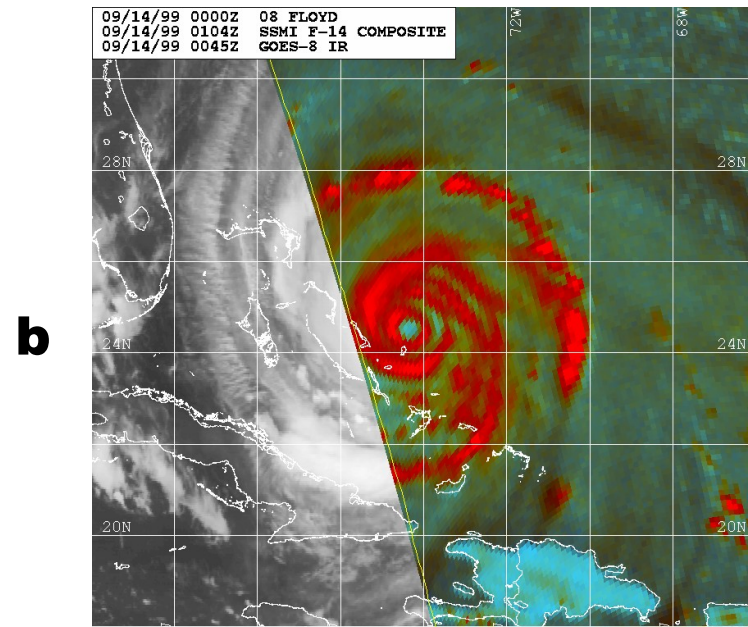
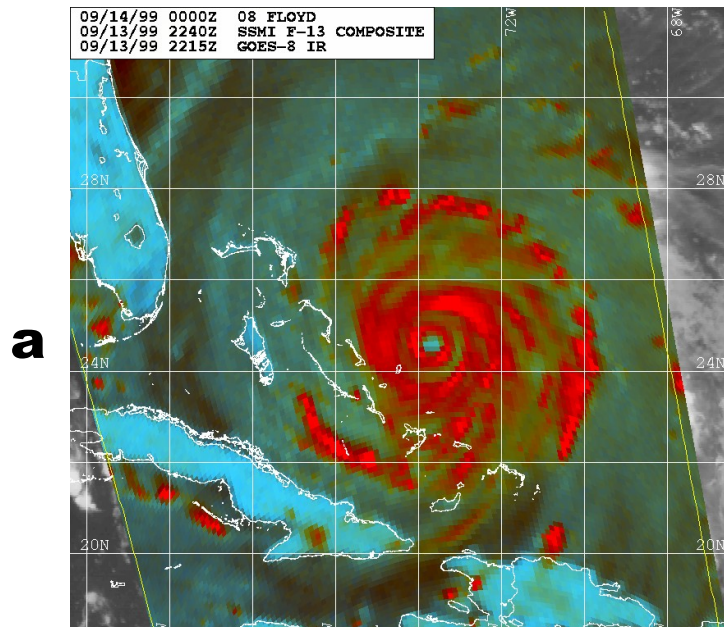


Fig. 5. Sequence of microwave images of Hurricane Floyd at: (a) 2240 UTC 13 September, (b) 0104 UTC, (c) 1110 UTC, and (d) 2228 UTC 14 September, 1999.