Preliminary Report
Hurricane Fran
23 August - 8 September

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National Hurricane Center
10 October 1996

Fran was a Cape Verde hurricane that moved across the Atlantic during the peak of the hurricane season. It made landfall on the North Carolina coast as a category three hurricane on the Saffir/Simpson Hurricane Scale, resulting in significant storm surge flooding on the North Carolina coast, widespread wind damage over North Carolina and Virginia, and extensive flooding from the Carolinas to Pennsylvania.

a. Synoptic History

Hurricane Fran formed from a tropical wave that emerged from the west coast of Africa on 22 August. Deep convection associated with the wave was organized in a banding-type pattern and animation of satellite images suggested a cyclonic circulation. Ship reports soon confirmed that the circulation was on the surface. The post-analysis "best track" in Figure 1 shows that the system became a tropical depression just southeast of the Cape Verde Islands at 1200 UTC 23 August. Best track position, central pressure and maximum one-minute sustained wind speed are listed for every six hours in Table 1.

The tropical depression moved westward near 15 knots for the next few days without significant development. This lack of development may be attributed, in part, to disrupted low-level inflow due to the large and powerful Hurricane Edouard which was centered about 750 n mi to the west-northwest. Satellite intensity estimates suggest that the depression became Tropical Storm Fran at 1200 UTC 27 August while located about 900 n mi east of the Lesser Antilles.

Fran began to track toward the west-northwest in the wake of Hurricane Edouard. Deep convection became more concentrated and Fran is estimated to have reached hurricane status at 0000 UTC 29 August while centered about 400 n mi east of the Leeward Islands. The center of Fran was about 150 n mi to the northeast of the Leeward Islands near 1200 UTC 30 August.

The tropical cyclone weakened to just below hurricane strength later on the 30th, possibly due to the low-level inflow being disrupted again by Edouard. About this time, changing steering currents caused Fran to turn toward the northwest and slow to about 5 knots.

By 1200 UTC 31 August, as Edouard moved farther away, Fran had regained hurricane strength. As Hurricane Edouard moved northward off the U.S. mid-Atlantic coast, the subtropical ridge became better established to the north of Fran, causing Fran to resume a west-northwestward motion with an increased forward speed of about 10 knots. Fran moved on a track roughly parallel to the Bahama Islands with the eye remaining a little more than 100 n mi to the northeast of the islands.

Fran strengthened to a category three hurricane by the time it was northeast of the central Bahamas on 4 September. The powerful tropical cyclone began to be influenced by a cyclonic circulation centered over Tennessee that was most pronounced in mid to upper levels of the atmosphere. Fran was steered by the resulting flow around the low over Tennessee and the western extension of the subtropical ridge over the northwest Atlantic. The hurricane gradually turned toward the northwest to north-northwest and increased in forward speed.

The minimum central pressure dropped to 946 mb and maximum sustained surface winds reached 105 knots, Fran's peak intensity, near 0000 UTC 5 September when the hurricane was centered about 250 n mi east of the Florida east coast.

Fran was moving northward near 15 knots when it made landfall on the North Carolina coast. The center moved over the Cape Fear area around 0030 UTC 6 September, but the circulation and radius of maximum winds were large and hurricane force winds likely extended over much of the North Carolina coastal areas of Brunswick, New Hanover, Pender, Onslow and Carteret counties. At landfall, the minimum central pressure is estimated at 954 mb and the maximum sustained surface winds are estimated at 100 knots. The strongest winds likely occurred in streaks within the deep convective areas north and northeast of the center.

Fran weakened to a tropical storm while centered over central North Carolina and subsequently to a tropical depression while moving through Virginia. The tropical cyclone gradually lost its warm core as it moved over the eastern Great Lakes and became extratropical near 0000 UTC 9 September while centered over southern

Ontario. The remnants of Fran were absorbed into a frontal system near 0600 UTC 10 September.

b. Meteorological Statistics

Figures 2 and 3 show the curves of minimum central sea-level pressure and maximum one-minute "surface" wind speed, respectively, as a function of time. The observations on which the curves are based are also plotted and consist of aircraft reconnaissance data and Dvorak-technique estimates using satellite imagery, as well as synoptic fixes after landfall. According to international agreements within the world meteorological community, the surface wind is actually the wind representative of 33 feet (10 meters) above the ground.

All operational aircraft reconnaissance flights into Fran were provided by the U.S. Air Force Reserves. These "Hurricane Hunters" made 71 center fixes during 17 flights. The minimum central pressure reported by aircraft was 946 mb at 2306 UTC 4 September. A circular eye with a diameter of 25 n mi was observed on aircraft radar at this time. The 946 mb minimum pressure was measured by dropsonde and was the lowest pressure reported during Fran's existence. The maximum winds of 114 knots from a flight level of 700 mb (near 10,000 feet) were measured about 6 hours prior to the 946 mb pressure report. Flight-level winds in excess of 100 knots were reported several times during the two days prior to landfall. 113-knot winds were reported from aircraft 52 n mi east of the hurricane center at 2314 UTC 5 September, and 107-knot winds were reported 41 n mi northeast of the center at the time of landfall. However, the core of the hurricane weakened somewhat on radar presentations, and a closed eyewall was not reported by aircraft during the two hours prior to the center moving onshore.

Objective intensity estimates from digital infrared satellite imagery peaked near the time that the minimum central pressure was reported by reconnaissance aircraft.

The WSR-88D (Weather Surveillance Radar - 1988 Doppler) at Wilmington, North Carolina, measured winds in excess of 120 knots aloft as the inner convective bands approached the Cape Fear area at 2130 UTC 5 September.

A ship with call sign **LAVX4** reported 85 knot winds and a pressure of 984 mb at 1800 UTC 5 September while located about 60 n mi northeast of the hurricane center.

Several other ship reports were helpful in defining the extent of tropical storm force winds, as were reports from a network of drifting buoys deployed offshore of the Carolinas in advance of Fran. Table 2 lists ship reports of at least tropical storm force winds in the vicinity of Fran.

Several wind gusts to hurricane force were measured from coastal areas in North Carolina. As usual for landfalling hurricanes, however, reports of sustained hurricane force winds are difficult to find. Table 3 lists selected U.S. surface observations. The NOAA C-MAN station at Frying Pan Shoals (about 50 n mi south-southeast of Wilmington, North Carolina) reported sustained winds of 79 knots and gusts to 108 knots from a tower about 80 feet above sea level.

Numerous pressure and wind reports from North Carolina were relayed to the NHC through amateur radio volunteers. The lowest measured pressure was 954 mb from Southport. The highest measured wind gust was 119 knots at an elevation of 30 feet (mounted on a house approximately 4 feet above the chimney) from a Davis wind instrument located on Hewletts Creek in Wilmington. A gust to 109 knots was measured in Wrightsville Beach. Although these measurements are very much desired to supplement the more official observations, they will not be listed in Table 3 until their accuracy is verified.

Several tornadoes were indicated by Doppler radar in North Carolina and Virginia. Confirmation, however, has been difficult due to the extensive nature of straight line wind damage across the region.

At the time of this report, a post-storm high water mark survey was being conducted by the U.S. Army Corps of Engineers and the U.S. Geological Survey. Many high water marks remain to be surveyed and "tied into" bench marks. The locations of the maximum values cannot be finalized until the survey is complete. However, initial survey results show an extensive storm surge along the North Carolina coast primarily southwest of Cape Lookout. Still water mark elevations on the inside of buildings, indicative of the storm surge, range from 8 to 12 feet. Outside water marks on buildings or debris lines are higher due to the effect of breaking waves.

Rainfall totals exceeding six inches were common near the path of Fran. WSR-88D radar precipitation estimates were as high as 12 inches over portions of Brunswick and Pender counties in North Carolina. Extensive flooding spread well

inland from the Carolinas into Virginia, West Virginia and Pennsylvania. Some of this flooding was considered the most severe in years. Near Washington, D.C., for example, the Old Town district of historic Alexandria was partially evacuated as the Potomac River rose, flooding streets with more than three feet of water. The next update of this report will include an analysis of rainfall along the path of Fran to be provided by the NWS Eastern Region Headquarters.

c. Casualty and Damage Statistics

According to Associated Press reports, Hurricane Fran was responsible for 34 deaths. Most of the deaths were caused by flash flooding in the Carolinas, Virginia, West Virginia and Pennsylvania. Twenty-one died in North Carolina alone. However, the total death count will likely be revised downward in the next update of this report based on data from NWS personnel to be published in Storm Data, since the NWS attempts to list deaths **directly** attributable to the weather. For example, most vehicle accidents and heart attacks from over-exertion after a hurricane are not considered direct deaths.

Storm surge on the North Carolina coast destroyed or seriously damaged numerous beachfront houses. Widespread wind damage to trees and roofs, as well as downed power lines, occurred as Fran moved inland over North Carolina and Virginia. Extensive flooding was responsible for additional damage in the Carolinas, Virginia, West Virginia, Maryland, Ohio and Pennsylvania.

Nearly a half-million tourists and residents were ordered to evacuate the coast in North and South Carolina. Press reports from Reuters News Service stated that 4.5 million people in the Carolinas and Virginia were left without power.

The Property Claim Services Division of the American Insurance Services Group reports that Fran caused an estimated $1.6 billion dollars in insured property damage to the United States. This estimate includes $1.275 billion in North Carolina, $20 million in South Carolina, $175 million in Virginia, $50 million in Maryland, $20 million in West Virginia, $40 million in Pennsylvania and $20 million in Ohio. A conservative ratio between total damage and insured property damage, compared to past landfalling hurricanes, is two to one. Therefore, the total U.S. damage estimate is $3.2 billion.

d. Forecast and Warning Critique

During Fran's life as a tropical storm or hurricane, the average official track forecast errors ranged from 66 n mi at 24 hours (37 cases) to 137 n mi at 48 hours (33 cases) to 185 n mi at 72 hours (29 cases). These errors are at least 25 percent less than the previous ten-year averages of the official track errors.

The BAMD (deep-layer Beta and Advection Model) and the GFDI (interpolated version of the Geophysical Fluid Dynamics Laboratory model) provided the best guidance in terms of the lowest track forecast errors. However, the GFDI model showed a distinct bias to the left of the actual track (Figure 4). The guidance from this model, which is generally acknowledged to be the most accurate one operationally available to the NHC, resulted in some left bias in the official forecasts near landfall.

Most NHC intensity forecast errors were 15 knots or less. All but one intensity forecast made after 2100 UTC 02 September correctly indicated a landfalling category three hurricane.

Table 4 lists the various watches and warnings that were issued. Hurricane warnings were posted for the hardest hit portions of the North Carolina coast about 27 hours prior to landfall.

Acknowledgments

Some of the information in this report was provided by NWS offices in the Eastern Region and is greatly appreciated. Stephen Baig prepared Fig. 1, and Mike Hopkins assisted with Table 3.

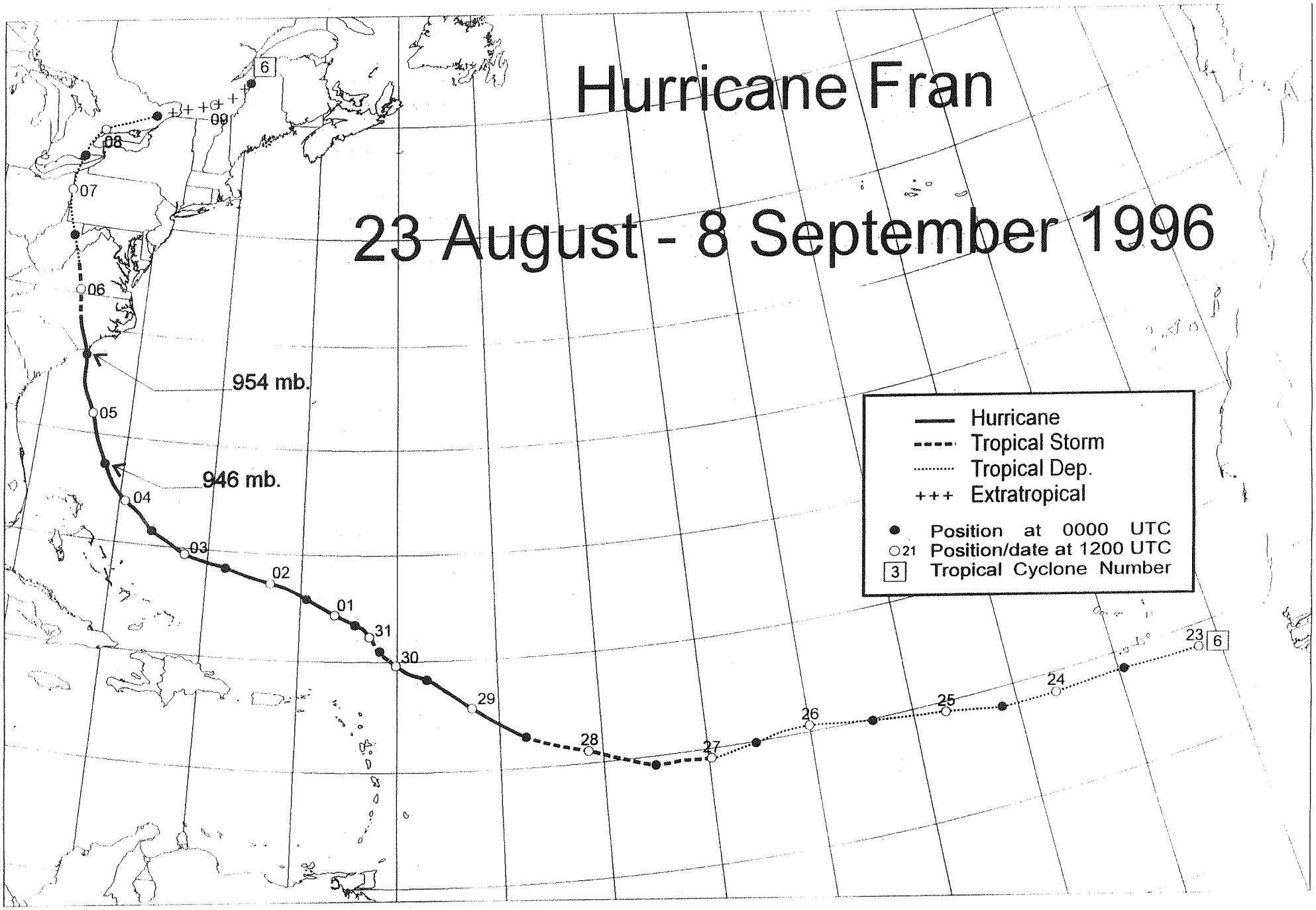

Figure 1. Best track positions for Hurricane Fran, 23 August - 8 September 1996.

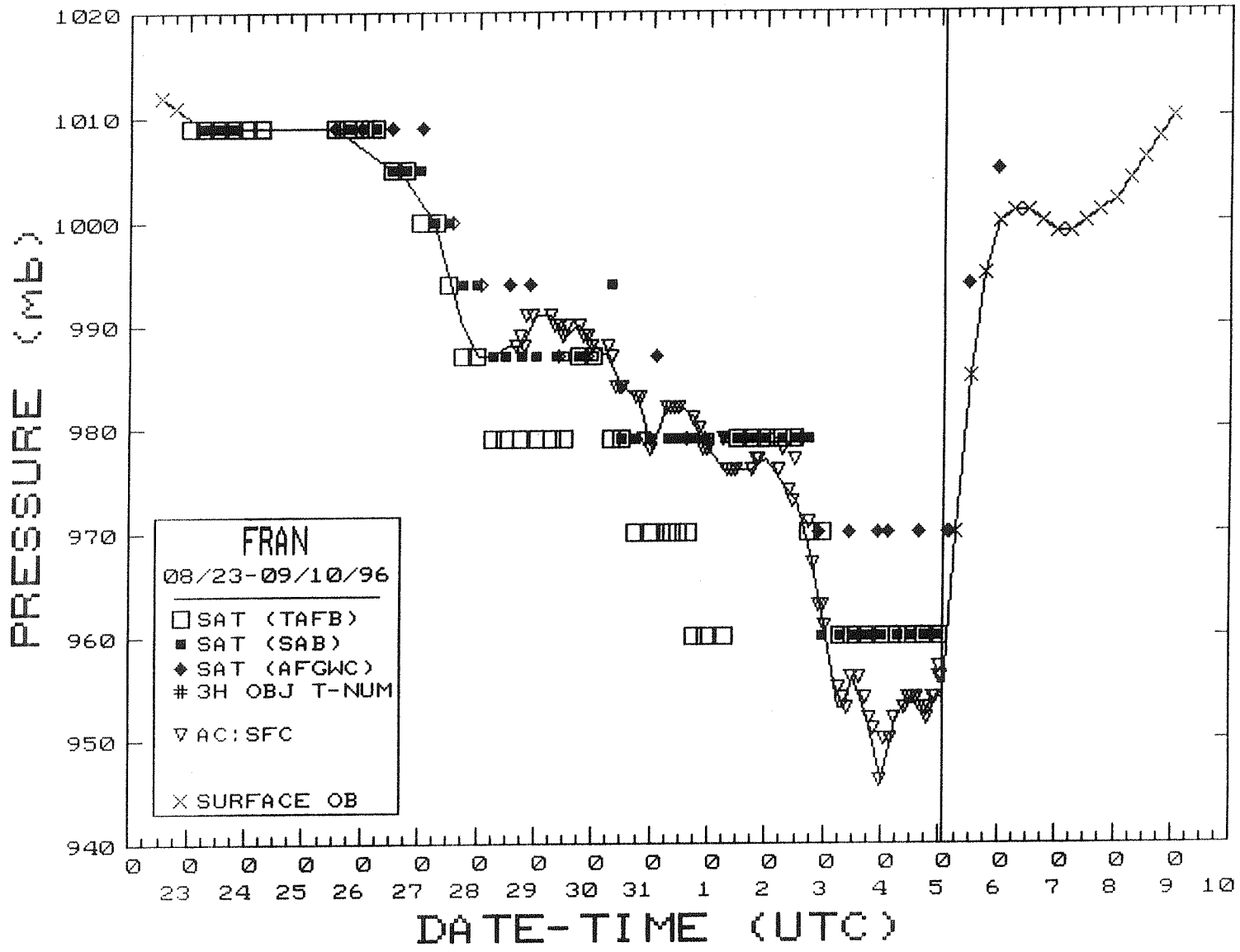

Figure 2. Best track minimum central pressure curve for Hurricane Fran. Vertical line denotes landfall. X's indicate estimates from surface analyses.

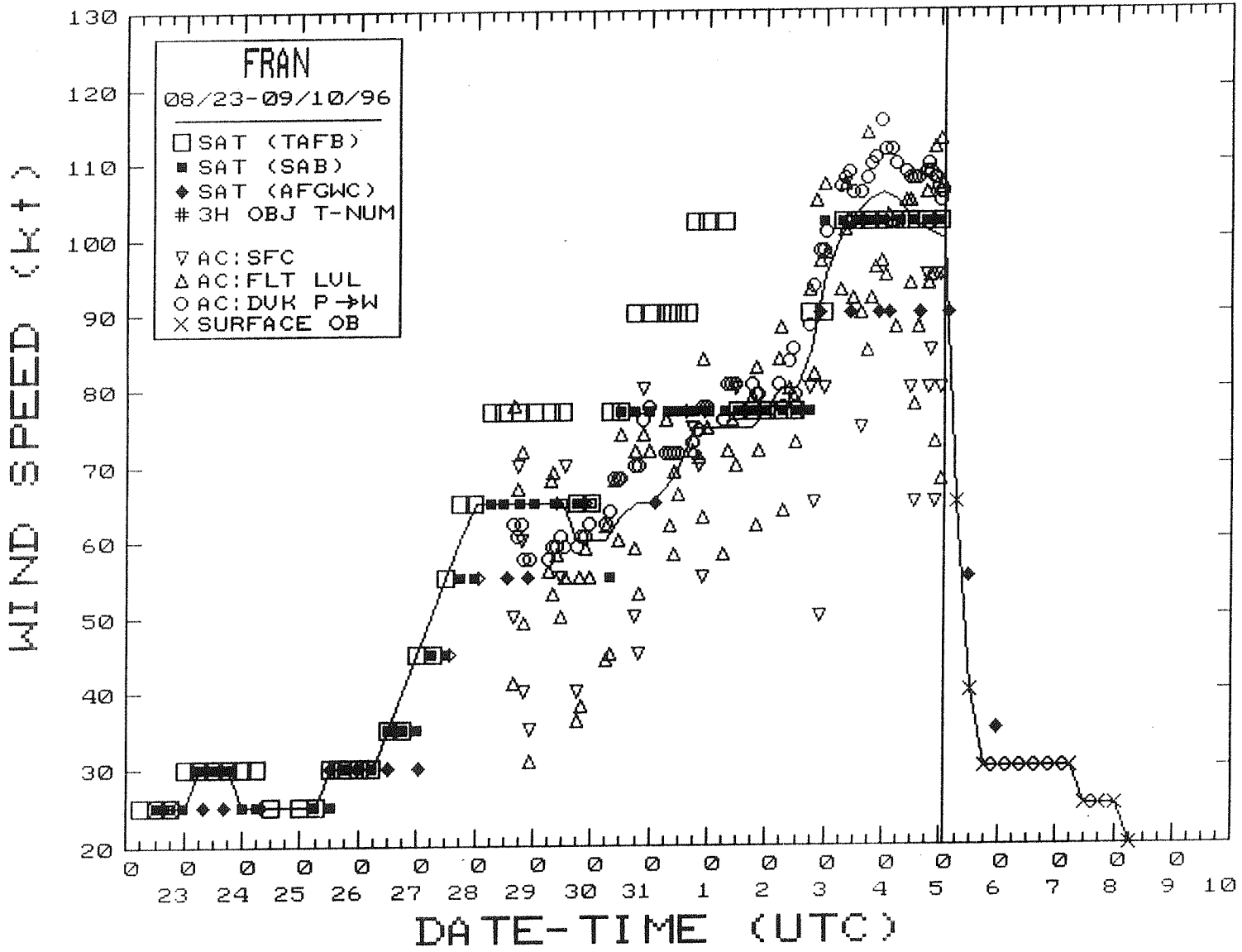

Figure 3. Best track maximum sustained wind speed curve for Hurricane Fran. Vertical line denotes landfall. Not all aircraft observations are a sampling of the maximum wind. X's indicate estimates from surface analyses.

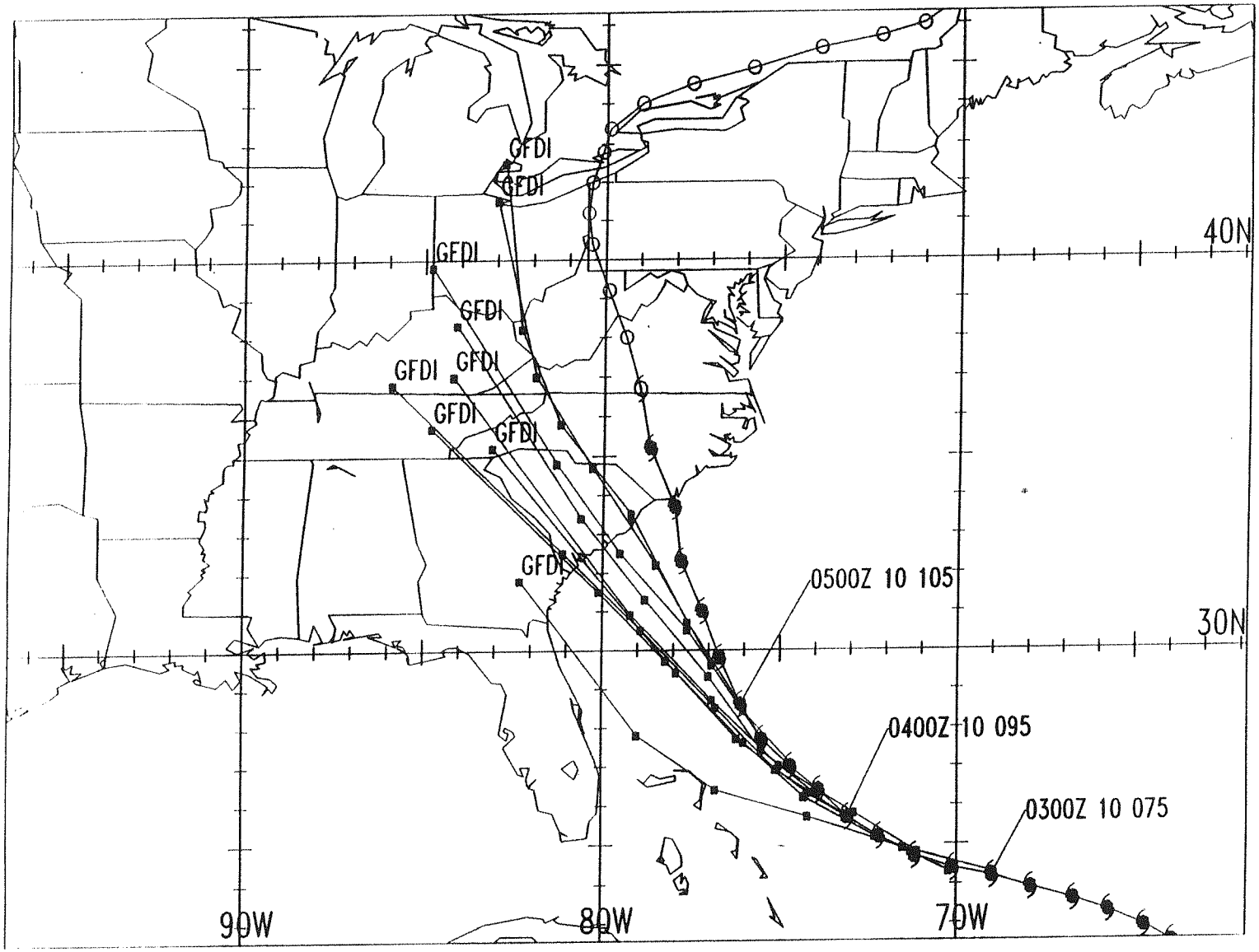

Figure 4. GFDI guidance on Hurricane Fran from 0000 UTC 3 September to 0000 UTC 5 September showing a left bias.

Table 1. Best track, Hurricane Fran, 23 August - 8 September, 1996

Date/Time (UTC)	Position		Pressure (mb)	Wind Speed (kt)	Stage
	Lat. (°N)	Lon. (°W)			
23/1200	14.0	21.0	1012	25	tropical depression
1800	14.1	22.8	1011	25	"
24/0000	14.2	24.8	1010	25	"
0600	14.2	26.6	1009	30	"
1200	14.1	28.2	1009	30	"
1800	14.1	29.6	1009	30	"
25/0000	14.1	30.8	1009	25	"
0600	14.3	32.0	1009	25	"
1200	14.6	33.4	1009	25	"
1800	14.7	35.1	1009	25	"
26/0000	14.9	37.0	1009	25	"
0600	15.1	38.6	1009	25	"
1200	15.3	40.0	1009	30	"
1800	15.2	41.4	1008	30	"
27/0000	14.9	42.7	1007	30	"
0600	14.7	43.8	1006	30	"
1200	14.6	44.9	1005	35	tropical storm
1800	14.6	46.1	1004	40	"
28/0000	14.6	47.5	1002	45	"
0600	15.0	49.1	1000	50	"
1200	15.5	50.7	995	55	"
1800	15.9	52.3	990	60	"
29/0000	16.4	53.7	987	65	hurricane
0600	17.0	55.0	987	65	"
1200	17.8	56.3	988	65	"
1800	18.6	57.5	988	65	"
30/0000	19.1	58.5	991	65	"
0600	19.4	59.4	991	65	"
1200	19.8	60.1	989	65	"
1800	20.2	60.6	990	60	tropical storm
31/0000	20.5	60.9	988	60	"
0600	20.8	61.2	987	60	"
1200	21.1	61.4	984	65	hurricane
1800	21.5	61.7	983	65	"
01/0000	21.7	62.1	978	65	"
0600	21.9	62.6	982	65	"

Table 1 (continued). Best track, Hurricane Fran, 23 August - 8 September, 1996

Date/Time (UTC)	Position		Pressure (mb)	Wind Speed (kt)	Stage
	Lat. (°N)	Lon. (°W)			
01/1200	22.2	63.2	982	70	hurricane
1800	22.5	63.9	981	75	"
02/0000	22.9	64.7	978	75	"
0600	23.3	65.7	976	75	"
1200	23.6	66.7	976	75	"
1800	23.9	67.9	976	75	"
03/0000	24.2	69.0	977	75	"
0600	24.4	70.1	975	80	"
1200	24.7	71.2	973	80	"
1800	25.2	72.2	968	85	"
04/0000	25.7	73.1	961	95	"
0600	26.4	73.9	953	100	"
1200	27.0	74.7	956	105	"
1800	27.7	75.5	952	105	"
05/0000	28.6	76.1	946	105	"
0600	29.8	76.7	952	105	"
1200	31.0	77.2	954	100	"
1800	32.3	77.8	952	100	"
06/0000	33.7	78.0	954	100	"
0600	35.2	78.7	970	65	"
1200	36.7	79.0	985	40	tropical storm
1800	38.0	79.4	995	30	tropical depression
07/0000	39.2	79.9	1000	30	"
0600	40.4	80.4	1001	30	"
1200	41.2	80.5	1001	30	"
1800	42.0	80.4	1000	30	"
08/0000	42.8	80.1	999	30	"
0600	43.4	79.9	999	30	"
1200	44.0	79.0	1000	25	"
1800	44.5	77.6	1001	25	"
09/0000	44.9	75.9	1002	25	extratropical
0600	45.4	74.0	1004	20	"
1200	45.7	72.3	1006	15	"
1800	46.0	71.1	1008	15	"
10/0000	46.7	70.0	1010	15	"
0600					absorbed by a front
05/0000	28.6	76.1	946	105	minimum pressure
06/0030	33.9	78.7	954	100	landfall near Cape Fear, NC

Table 2. Ship reports of 34 knots or higher wind speed, associated with Hurricane Fran, August-September 1996.

date/time (UTC)	ship name	latitude (°N)	longitude (°W)	wind dir/ speed(knots)	pressure (mb)
30/0000	AMAGISAN	24.7	58.1	090/47	1017.0
30/0600	AMAGISAN	23.9	57.1	090/49	1015.0
30/1200	AMAGISAN	23.1	55.9	110/35	1015.0
30/1800	AMAGISAN	22.1	54.7	090/49	1014.0
31/0000	AMAGISAN	21.2	53.5	110/35	1014.5
31/0600	AMAGISAN	20.3	52.3	100/39	1014.0
31/1200	SHIP	26.7	60.8	110/45	1014.3
03/0600	SEALAND CRUSADER	26.8	67.3	150/35	1011.0
04/0000	ELSX2	28.4	74.6	060/37	1008.5
05/1200	KAAPGRACHT	32.2	79.6	010/66	1006.5
05/1200	LAVX4	32.9	76.7	090/45	1001.0
05/1200	ELRV2	32.9	77.4	070/40	1004.0
05/1200	SUNBELT DIXIE	33.2	77.3	040/58	1004.5
05/1200	CR MARSEILLE	33.6	77.1	XXX/60	1006.5
05/1200	CRISTOFORO COLOMBO	34.7	74.2	140/40	1013.0
05/1500	LAVX4	32.8	76.8	090/53	994.5
05/1500	ELRV2	33.2	76.7	060/42	1000.5
05/1800	LAVX4	33.0	76.9	100/85	984.0
05/1800	CR MARSEILLE	34.5	75.6	090/50	1007.0
05/2100	CRISTOFORO COLOMBO	33.0	73.6	130/40	1010.0
05/2100	ZIM AMERICA	34.7	74.0	120/45	1010.0
05/2100	OOCL FIDELITY	35.8	74.0	110/34	1012.0
06/0000	COPACABANA	31.5	72.9	160/36	1013.0
06/0000	CRISTOFORO COLOMBO	32.5	74.2	140/38	1010.0
06/0000	ZIM AMERICA	34.3	74.1	140/45	1009.0
06/0000	OOCL FIDELITY	35.4	74.2	120/38	1010.0
06/0300	OOCL FIDELITY	35.0	74.7	110/40	1007.0
06/0600	LAVX4	33.3	76.2	200/43	1006.0
06/0600	CR MARSEILLE	33.9	73.5	180/40	1013.2
06/0900	ZIM AMERICA	33.6	75.4	200/45	1009.0

Table 3. Hurricane Fran selected surface observations, September, 1996.

Location	Press. (mb)	Date/ time (UTC)	Sustained wind (kts)[a]	Peak gust (kts)	Date /time (UTC)[b]	Storm surge (ft)[c]	Storm tide (ft)[d]	total rain (in)
South Carolina								
Charleston (CHS)	998.0	05/2234	27	36	05/2330			1.10
Charleston City Office			29	41	05/1850	1.1		0.87
Cheraw	992.2			56	06/0315			1.32
Cherry Grove Pier				67	05/2215			8.36
Conway				48				5.02
Dillon								4.62
Florence			30 M	56M	06/0250			2.21
Garden City Pier				64	05/2215			5.91
Loris				47				5.14
Marion								3.01
Mullins								3.98
Myrtle Beach Pavilion				66	05/2215			
Myrtle Beach Pier				65	05/2215	3.6		7.02
North Carolina								
Apex (South RDU)								6.06
Atlantic Beach				87				
Butner								6.21
Cape Lookout	987.0							
Cherry Point MCA (NKT)M	993.9	06/0255	43	66	06/0255			
Duck Pier						1.5		
Duke Marine Lab (Beaufort)				80		5.4		
Elizabeth City CG (ECG)	1005.1	06/1147	37	48	06/1255			
Fayetteville (FAY)	971.6	06/0430	55	69	06/0430			
Figure Eight Island							10-12 e	
Fort Bragg (FBG)	972.3	06/0246	38	64	06/0431			4.70
Graham								6.65
Greensboro (GSO)	984.4	06/0900	30	42	06/0537			3.91
Greenville				87				
Holden Beach				60	05/2300			
New River	982.0	05/0230		82				7.05
Newport								3.24
North Topsail Beach			65		05/0045		8-9 e	
Oregon Inlet						2.3		
Pope AFB (POB)	977.6	06/0455	43	58	06/0418			6.72
Raleigh-Durham (RDU)	977.6	06/0653	39	69	06/0453			8.80
Rocky Mount (RWI) *	980.7	06/0200	17	39	06/0445			3.68
Rougemount (Durham Co)								6.02
Seymour Johnson (GSB)	981.0	06/0555	55	70	06/0555			6.38
Southport State Pilot Office				91				
Wilmington (ILM)	961.4	06/0036	58	75	05/2349			
Wilmington Tide Gauge						5.5		
Wrightsville Beach							10-11 e	
NOAA Ship Whiting f	959.9	05/2135						
Virginia								
Charlottesville (CHO) M	998.6	06/1645	22	38	06/1045			
Danville (DAN) M	987.5	06/1151	34	46	06/0449			

Table 3(continued). Hurricane Fran selected surface observations, September 1996.

Location		Press. (mb)	Date/ time (UTC)	Sustained wind (kts)[a]	Peak gust (kts)	Date/ time (UTC)[b]	Storm surge (ft)[c]	Storm tide (ft)[d]	total rain (in)
Hot Springs (HSP)	M	1002.4	06/1400	29	48	06/1540			
Lynchburg (LYH)	M	990.6	06/1454	18	38	06/1243			
Norfolk NAS (NGU)		1004.6	06/0855	36	55	06/0805	2.6		
Richmond (RIC)		1000.8	06/1141	32	46	06/1141			
Roanoke (ROA)	M	994.7	06/1254	33	44	06/0954			
Staunton (SHD)	M	997.6	06/1840	25	43	06/1120			
Washington D.C.	g						5.6/7.3		
CMAN Stations									
Frying Pan Shoals (FPSN7)		960.6	05/2300	79	108	05/2100			
Diamond Shoals (DSLN7)		1006.6	06/0500	58	65	06/0400			
Cape Lookout (CLKN7)		996.9	06/0100	56	71	06/0300			
Folly Island (FBIS1)		997.6	05/2200	24	41	05/1900			

[a]NWS standard averaging period is 1 min; ASOS and C-MAN are 2 min; buoys are 8 min.
[b]Date/time is for sustained wind when both sustained and gust are listed.
[c]Storm surge is water height above normal astronomical tide level.
[d]Storm tide is water height above NGVD.
[e]Estimated.
[f]Docked at Wilmington State Pier.
[*]Station not reporting from 02-10Z 06 Sept.
[M]Taken directly from METAR reports.
[g]The 5.6 ft value occurred on 06 Sept at 17 UTC, and was the actual storm surge, the 7.3 ft value occurred as a much broader peak on 09 Sept at 0418 UTC, from freshwater runoff.

Table 4. Watch and warning summary, Hurricane Fran, August - September 1996.

Date/time (UTC)	Action	Location
29/0300	hurricane watch	Northeastern Leeward Islands from Antigua through St. Maartin
29/2100	hurricane watch discontinued	Northeastern Leeward Islands from Antigua through St. Maartin
02/2100	hurricane watch	Central Bahamas
02/2100	tropical storm warning	Central Bahamas
03/0900	hurricane watch	Northwestern Bahamas
03/1800	hurricane warning	Northwestern Bahamas
04/0300	hurricane watch	north of Sebastien Inlet, FL to Little River Inlet, SC
04/0900	watches and warnings discontinued	Central Bahamas
04/1500	hurricane watch extended northward	Little River Inlet, SC to Oregon Inlet, NC including Pamlico Sound
04/1800	hurricane warning downgraded to tropical storm warning	Northwestern Bahama Islands of Andros and New Providence
04/2100	hurricane warning	north of Brunswick, GA to Cape Lookout, NC
04/2100	hurricane watch	north of Cape Lookout, NC to Currituck Beach Light, NC including Pamlico and Albemarle Sounds
04/2100	tropical storm warning	Flagler Beach, FL to Brunswick, GA
04/2100	hurricane watch discontinued	south of Cape Lookout, NC
05/0300	hurricane warning extended northward	north of Cape Lookout, NC to NC/VA border including the Pamlico and Albemarle Sounds
05/0300	hurricane watch	north of NC/VA border to Chincoteague, VA including the Greater Hampton Roads area

Table 4 (continued). Watch and warning summary, Hurricane Fran, August-September 1996.

Date/time (UTC)	Action	Location
05/0300	hurricane warning downgraded to tropical storm warning	northwestern Bahama Islands of Abaco and Grand Bahama
05/0300	hurricane warning discontinued	northwestern Bahama Islands
05/0300	tropical storm warning discontinued	Andros and New Providence Islands
05/0900	tropical storm warning discontinued	Flagler Beach, FL to Brunswick, GA
05/0900	tropical storm warning discontinued	northwestern Bahama Islands of Abaco and Grand Bahama
05/1500	tropical storm warning	north of the NC/VA border to Chincoteague, VA including the Greater Hampton Roads area
05/1500	tropical storm warning	lower Chesapeake Bay
05/1500	hurricane warning downgraded to tropical storm warning	north of Brunswick, GA to just south of Edisto Beach, SC
06/0100	hurricane and tropical storm warnings discontinued	Cape Romain, SC southward
06/0300	hurricane warnings discontinued	south of Cape Fear, NC
06/0300	hurricane watch discontinued	north of the NC/SC border to Chincoteague, VA including the Greater Hampton Raods area
06/0900	hurricane warning discontinued	remainder of NC coast
06/1800	tropical storm warning discontinued	remainder of U.S. east coast