

PRELIMINARY REPORT

Hurricane Bonnie
19-30 August 1998

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Bonnie was the third hurricane to directly hit the coast of North Carolina during the past three years.

a. Synoptic History

The origin of Bonnie was a large and vigorous tropical wave that moved over Dakar, Senegal on 14 August. The wave was depicted on visible satellite imagery by a large cyclonic low- to mid-level circulation void of deep convection. The wave caused a 24-h surface pressure change of -3.5 and -4.0 mb at Dakar and Sal respectively. There was a well established 700 mb easterly jet which peaked at 50 knots just before the wave axis crossed Dakar, followed by a well marked wind-shift from the surface to the middle troposphere. The overall circulation exited Africa basically just north of Dakar where the ocean was relatively cool. However, a strong high pressure ridge steered the whole system on a west-southwest track over increasingly warmer waters and convection began to develop. Initially, there were several centers of rotation within a much larger circulation and it was not until 1200 UTC 19 August that the system began to consolidate and a tropical depression formed. Although the central area of the tropical depression was poorly organized, the winds to the north of the circulation were nearing tropical storm strength. This was indicated by ship observations and high resolution low-cloud wind vectors provided in real time by the University of Wisconsin. The depression was then upgraded to Tropical Storm Bonnie based on these winds and satellite intensity estimates at 1200 UTC 20 August. Bonnie moved on a general west to west-northwest track around the circulation of the Azores-Bermuda High toward the northern Leeward Islands.

The first reconnaissance plane reached Bonnie late on the 20th and measured a minimum pressure of 1004 mb and winds of 61 knots at 1500 feet to the northeast of the center. Bonnie skirted the Leeward Islands and most of the associated weather remained to the north over the open Atlantic. During that period, Bonnie's circulation was very asymmetric.

Under a favorable upper-level wind environment, Bonnie gradually strengthened and became a hurricane at 0600 UTC 22 August when it was located about 200 n mi north of the eastern tip of Hispaniola. At that time, the hurricane hunters found a nearly complete eyewall and flight-level peak winds of 76 knots. Bonnie moved on a general

west-northwest heading and reached maximum winds of 100 knots and a minimum pressure of 954 mb about 150 n mi east of San Salvador in the Bahamas.

The ridge to the north of Bonnie temporarily weakened and the steering currents collapsed. The hurricane then drifted northward for a period of 18 to 24 hours. Thereafter, the subtropical ridge reintensified, forcing Bonnie to move northwestward and then northward toward the coast of North Carolina while the hurricane maintained winds of 100 knots.

After a slight weakening, the eye of Bonnie passed just east of Cape Fear around 2130 UTC 26 August and then made landfall near Wilmington as a border line Category 2/3 hurricane on the Saffir/Simpson Hurricane Scale (SSHS) around 0330 UTC 27 August.

The hurricane slowed down and weakened while moving over eastern North Carolina. It was then downgraded to tropical storm status based on surface observations and WSR88-D winds. Bonnie turned northeastward over water ahead of a middle-level trough and rapidly regained hurricane strength as indicated by aircraft reconnaissance data. Thereafter, the hurricane moved on a general northeast to east track and became extratropical near 1800 UTC 30 August, about 240 n mi south southeast of New Foundland.

Bonnie's track is shown in Fig. 1. Table 1 is a listing, at six-hourly intervals, of the best-track position, estimated minimum central pressure and maximum 1-minute surface wind speed.

b. Meteorological Statistics

The best track pressure and wind curves as a function of time are shown in Figs. 2 and 3 and are primarily based on data from numerous reconnaissance flights into the hurricane. The best track also incorporates WSR-88D data, surface observations and GPS sondes in the eyewall of the hurricane. The routine satellite intensity estimates from the Tropical Analysis and Forecast Branch (TAFB), the Satellite Analysis Branch (SAB) and the Air Force Weather Agency, (AFGWC in figures) were also included. The Hurricane Bonnie event was characterized by a high density of observations. During Bonnie, the NOAA high altitude jet and P-3 deployed a very large number of sondes over a large portion of the Atlantic as a part of a major synoptic flow experiment. These observations were primarily used to initialize the numerical models.

The maximum winds measured were 116 knots at the 700-mb level at 0113 UTC 25 August and then again at 1659 UTC 26 August. These measurements were taken during the AF963 and the NOAA 43 reconnaissance missions, respectively. Table 2 displays selected surface observations during Bonnie, primarily over the area where the hurricane made landfall. There were several important and useful observations relayed to the NHC and to the local NWS

forecast offices from amateur observing reports. These include reports of peak winds of 104 knots at 0138 UTC near NC State Port and 100 knots at Wrightsville Beach at 1951 UTC 27 August. Rainfall totals of about 8 to 11 inches were recorded in portions of eastern NC.

Storm tides of 5 to 8 feet above normal were reported mainly in eastern beaches of Brunswick County NC, while a storm surge of 6 feet was reported at Pasquotank and Camdem counties in the Albemarle Sound.

A tornado was reported in the town of Edenton NC in Chowan County.

c. Casualty and Damage Statistics

Three people died as a consequence of Bonnie. A 12-year old girl was killed when a large tree fell on her home in Currituck County, NC. Another person was caught in rip currents and drowned in Rehoboth Beach, Delaware. The third person died in Cape Cod in a rowboat accident when choppy seas overturned the boat. The last one may have been indirectly related to Bonnie.

There are numerous reports of many trees down, roof and structural damage and widespread power outages primarily in eastern North Carolina and Virginia where a federal disaster was declared for several counties. The area hardest hit appears to have been Hampton Roads, Virginia, where the damage could reach well into the hundreds of millions of dollars.

The Property Claim Services Division of the American Insurance Services Group reports that Bonnie caused an estimated \$ 360 million in insured property damage to the United States. This estimate includes \$ 240 million in North Carolina, \$ 95 million in Georgia, and \$ 25 million in South Carolina. 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 \$ 720 million.

d. Forecast and Warning Critique

Figure 4 shows a sequence of numerical guidance forecast track for 1800 UTC on 22, 23 and 24 August. Note that on the 22nd, most of the models suggested that Bonnie was going to remain out to sea. Thereafter, during the 23rd and 24th, there was a significant change in the model forecasts and some of them turned the hurricane toward the west while others kept it out to sea. At that point, the forecast became very difficult and highly uncertain. Consequently, watches and warnings were required for a large portion of the southeast U.S. coast (Table 3). In spite of the model's scatter, the official forecast tracks remained basically unchanged and in the middle of the model forecast ensemble. Apparently, during the earlier runs, the models weakened the ridge to the north of the hurricane too soon and forecast a premature

recurvature.

Table 4 lists track forecast error statistics. The official forecast errors for Bonnie were in general very close to the most recent 10-year average. There was only a small improvement in the 48 and 72 hour forecast if compared to the average.

With the exception of a few 72-h forecast errors at the beginning of Bonnie's life, the NHC intensity forecasts for Bonnie were smaller than the past 10-year average errors.

Figure Captions:

- Fig. 1. Best track positions for Hurricane Bonnie, 19-30 August 1998.
- Fig. 2. Best track one-minute surface wind speed curve for Hurricane Bonnie.
- Fig. 3. Best track minimum central pressure curve for Hurricane Bonnie.
- Fig. 4 Sequence of numerical guidance output at 1800 UTC for 22, 23 and 24 August 1998.

Table 1. Best track, Hurricane Bonnie, 19- 30 August, 1998

Date/Time (UTC)	Position		Pressure (mb)	Wind Speed (kt)	Stage
	Lat. (°N)	Lon. (°W)			
19/1200	14.7	48.1	1009	25	tropical depression
1800	15.4	50.1	1009	30	“
20/0000	16.2	52.2	1009	30	“
0600	16.9	54.7	1008	30	“
1200	17.3	57.3	1007	35	tropical storm
1800	18.2	59.6	1006	35	“
21/0000	18.7	61.3	1005	40	“
0600	19.1	62.9	1002	45	“
1200	19.5	64.5	1000	50	“
1800	20.3	65.9	999	55	“
22/0000	21.1	67.3	991	65	hurricane
0600	21.8	68.7	989	70	“
1200	22.3	69.8	980	75	“
1800	23.0	70.5	970	85	“
23/0000	23.4	71.0	962	90	“
0600	23.8	71.3	960	95	“
1200	24.1	71.5	958	100	“
1800	24.4	71.7	955	100	“
24/0000	24.8	71.8	954	100	“
0600	25.2	72.1	960	100	“
1200	25.6	72.4	962	100	“
1800	26.1	72.8	963	100	“
25/0000	26.9	73.2	963	100	“
0600	27.8	73.8	962	100	“
1200	28.8	74.7	963	100	“
1800	29.8	75.6	963	100	“
26/0000	30.8	76.4	958	100	“
0600	31.7	77.3	964	100	“
1200	32.7	77.8	965	100	“
1800	33.4	77.8	962	100	“
27/0000	34.0	77.7	963	95	“
0600	34.5	77.5	965	85	“
1200	34.9	77.1	974	75	“
1800	35.4	76.6	980	60	tropical storm
28/0000	35.8	75.9	983	65	hurricane
0600	36.2	75.1	985	75	“
1200	36.7	74.3	990	65	“
1800	37.3	73.2	991	60	tropical storm
29/0000	38.3	71.4	993	45	“
0600	39.2	69.6	999	45	“
1200	40.2	67.8	999	45	“
1800	41.6	64.8	1000	45	“
30/0000	42.9	61.5	1000	45	“
0600	44.3	57.0	1000	45	“
1200	44.5	53.5	1000	45	“
1800	44.0	50.0	998	45	extratropical
31/0000	44.0	45.0	996	45	“
0600	43.0	41.0			absorbed by a front
24/0000	24.8	71.8	954	100	minimum pressure
27/0400	34.4	77.7	964	95	Landfall near Wilmington NC

Table 2. Hurricane Bonnie selected surface observations, August 1998.

Location	Press (mb)	Date/ time (UTC)	Sustaine d wind (kts) ^a	Peak gust (kts)	Date/ time (UTC) ^b	Storm surge (ft) ^c	Storm tide (ft) ^d	total rain (in)
U.S. Virgin Islands								
St. Thomas Airport	1006.	21/112	23	33	21/0851			0.29
Puerto Rico								
Ceiba	1006.	21/112	24	33	21/0156			0.51
Carolina								1.10
Grand Turk								3.50
South Carolina								
Charleston International Airport	1007.	26/185	25	33	26/2034			
Charleston City Office			25	39	26/1230			
Myrtle Beach (MYR)			38	52	26/1715			
North Carolina								
Wilmington	969.9	27/005	49	64	26/1827			9.04
Kure Beach				77	26/1630			
Florence Air.			34	44	26/2150			
Elizabeth City	995.7	28/003	51	63	28/0333			1.42
Ocracoke	990.5	27/181		66	27/1457			6.60
Oregon inlet	989.1			54	27/2015			
Emerald isle	976.9			62				
Newport	985.1	27/103		52	27/0553			9.51
Greenville				63	27/0915			8.20
Morehead City								10.70
Cherry Point			41	61	27/0114			10.93
Jacksonville				62	27/1133			11.00
Frisco			49	69	27/1109			
New Hanover							7-9	
Tide Gage on Masonboro							9.1	
Wrightsville Beach							7-	
Virginia								
Cape Henry			70	90	28/0300			
Chesapeake Light Stn.			68	81	28/0350			
Currituck County EOC				81	28/0400			
Oceana NAS	999.0		38	54	28/0357			
Langley AFB	1005.		46	58	27/2355			
Norfolk Airport (ORF)	1000.	28/002	40	56	28/0141			6.77
Porthmouth	1000.	28/010		55	28/0222			2.44
Norfolk NAS	1002.		36	48	27/2315			4.91
Sewells Point							6.0	
Coastal Pasquotank						6.0		
Chowan County						5-6		
New Jersey/Delaware								
Delaware Light	1005.	28/180	32	40	28/1700			
Reedy Point							6.28	
Cape May							6.05	
Atlantic City							4.97	
Sandy Hook							5.64	
Georges Bank bouy	990.2	29/160	35	45	29/1700			
CMAN Stations								

Frying Pan Shoals (FPSN7)	964.0	26/163	76 ^f	90	26/2130
Cape Lookout	994.2	27/130	48	75	27/1211
Diamond Shoals (DSL7)	996.8	27/220	68	79	27/2034
Duck NC	993.5	28/010	45	55	27/2000
Cheasepeake Lt. (CHLV7)	995.7	28/060	72 ^f	86	28/0532

Buoys					
41002	998.7	26/030	42 ^f	57	26/0426
41004	990.5	26/130	38	49	26/1600
44004	994.3	29/060	36 ^f	46	29/0131
44014	989.8	28/100	37	47	28/0200
44137	998.2	30/000	50		30/0300
44144	990.8	30/030	47		30/0300

^a Standard NWS ASOS and C-MAN maveraging period is 2 min; buoys are 8 min unless otherwise indicated.

^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 10 min average wind.

Table 3. Tropical Cyclone watch and warning summary for Hurricane Bonnie.

Date/Time (UTC)	Action	Location
20/0300	Tropical Storm Watch issued	Antigua, Barbuda, Anguilla, St. Maarten, Saba and St. Eustatius
20/1500	Tropical Storm Watch issued	U.S. and British Virgin Islands
20/2100	Tropical Storm Warning issued	U.S. and British Virgin Islands
20/2100	Tropical Storm Watch issued	Puerto Rico
21/0900	Tropical Storm Watch issued	Turk and Caicos and the southeastern Bahamas
21/1200	Tropical Storm Watch discontinued	Antigua, Barbuda, Anguilla, St. Maarten, Saba and St. Eustatius
21/1500	Tropical Storm Warnings and a Hurricane Watch	Turk and Caicos and southeastern Bahamas
21/1500	Hurricane watch issued	Central Bahamas
21/1500	Tropical Storm Warning discontinued	U.S. and British Virgin Islands
21/1500	Tropical Storm Watch discontinued	Puerto Rico
22/0900	Hurricane Warning issued	Central Bahamas
22/1500	Hurricane Watch issued	Northwestern Bahamas
23/0000	Hurricane Warning discontinued	Turks and Caicos
23/0000	Hurricane Warning replaced by Tropical Storm Warning	Southeastern Bahamas
24/0900	Tropical Storm Warning discontinued	Southeastern Bahamas
24/2100	Hurricane Watch issued	Savannah, Georgia to the North Carolina/Virginia border including the Pamlico and Albemarle Sounds
25/0900	Hurricane Warning issued	from Murrells Inlet, S.C. To the north Carolina Virginia border, including the Palmico and Albemarle Sounds
25/1200	Hurricane Watch issued	from North Carolina/Virginia border to Cape Henlopen, Delaware including the Chesapeake Bay southward from Windmill point.
25/1500	Tropical Storm Warning issued	from Murrels inlet to Cape Romain, S.C.
25/1800	Hurricane Warning extended northward	to Chincoteague, VA
25/2100	Hurricane Warning extended southward	to Cape Romain, S.C.
26/0600	Hurricane Warning extended southward	to Edisto Beach, S.C.
26/1500	Hurricane Warning and Watches discontinued	south of Cape Romain
26/2100	Hurricane Warnings and Watches revised. Tropical Storm Warning and Hurricane Watch issued	from North Carolina/ Virginia border to Chincoteague, Virginia and for the Chesapeake Bay from Smith Point southward
26/2100	Tropical Storm Warning issued	from Chincoteague, Virginia to Cape Henlopen, Delaware
27/0100	Hurricane warning replaced by Tropical Storm Warning	south of Murrels Inlet to Cape Romain

27/0900	Hurricane Warning replaced by Tropical Storm Warnings	south of Little River Inlet, NC to Murrels Inlet, SC
27/0900	Tropical Storm Watch issued	from north of Cape Henlopen to Sandy Hook, NJ including Delaware Bay
27/0900	Tropical Storm Warning discontinued	from south of Murrels Inlet
27/1500	Tropical Storm Warning issued	from new River Inlet, NC to Cape Henlopen, DE including Palmico and Albemarle Sounds and Chesapeake Bay southward from Smith Point
27/1500	Tropical Storm Watch issued	Chesapeake bay from Smith Point to Drum Point and for the Potomac River from Cobb Point to Smith Point
27/2100	Tropical Storm Warnings extended northward	from New River Inlet NC to watch Hill, RI including Palmico and Albemarle Sounds, Chesapeake Bay southward from Smith Point and Delaware Bay
27/2100	Tropical Storm Watch issued	from east of Watch Hill, RI to Plymouth, MA
28/0300	Tropical Storm Warning discontinued	south of Cape Lookout, NC
28/0900	Tropical Storm Warning issued	from Watch Hill to Plymouth
28/0900	Tropical Storm Warning discontinued	south of Ocracoke, NC and for the Chesapeake Bay and Potomac River north of Smith Point
28/1500	Tropical Storm Warning discontinued	south of NC/VA border including Pamlico and Albemarle Sounds and for Chesapeake and Delaware Bays
28/2100	Tropical Storm Warning discontinued	south of Watch Hill including Delaware Bay and Long Island Sound
29/0300	Tropical Storm Warning discontinued	remainder of the U.S. East coast

* Tropical Cyclone watches and warnings are issued by respectively countries in coordination with the National Hurricane Center.

Table 4

**Preliminary forecast evaluation of Hurricane Bonnie
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	60 (41)	127 (40)	196 (38)	258 (36)	318 (32)
GFDI	47 (39)	86 (38)	136 (37)	203 (36)	397 (32)
GFDL*	43 (34)	79 (34)	116 (33)	180 (33)	348 (31)
LBAR	44 (41)	89 (40)	137 (38)	213 (36)	393 (32)
AVNI	46 (41)	89 (40)	140 (37)	214 (37)	468 (30)
BAMD	40 (41)	66 (40)	87 (38)	137 (36)	183 (32)
BAMM	40 (41)	81 (40)	112 (38)	142 (36)	242 (32)
BAMS	69 (41)	124 (40)	162 (38)	194 (36)	327 (32)
NGPI	42 (34)	78 (33)	117 (31)	157 (29)	226 (25)
UKMI	46 (40)	78 (39)	117 (31)	143 (35)	214 (31)
NHC OFFICIAL	45 (41)	86 (39)	129 (37)	172 (36)	232 (32)
NHC OFFICIAL (1988-1997)	47 (1838)	88 (1633)	127 (1449)	165 (1284)	248 (1006)

* GFDL output not available until after forecast issued.

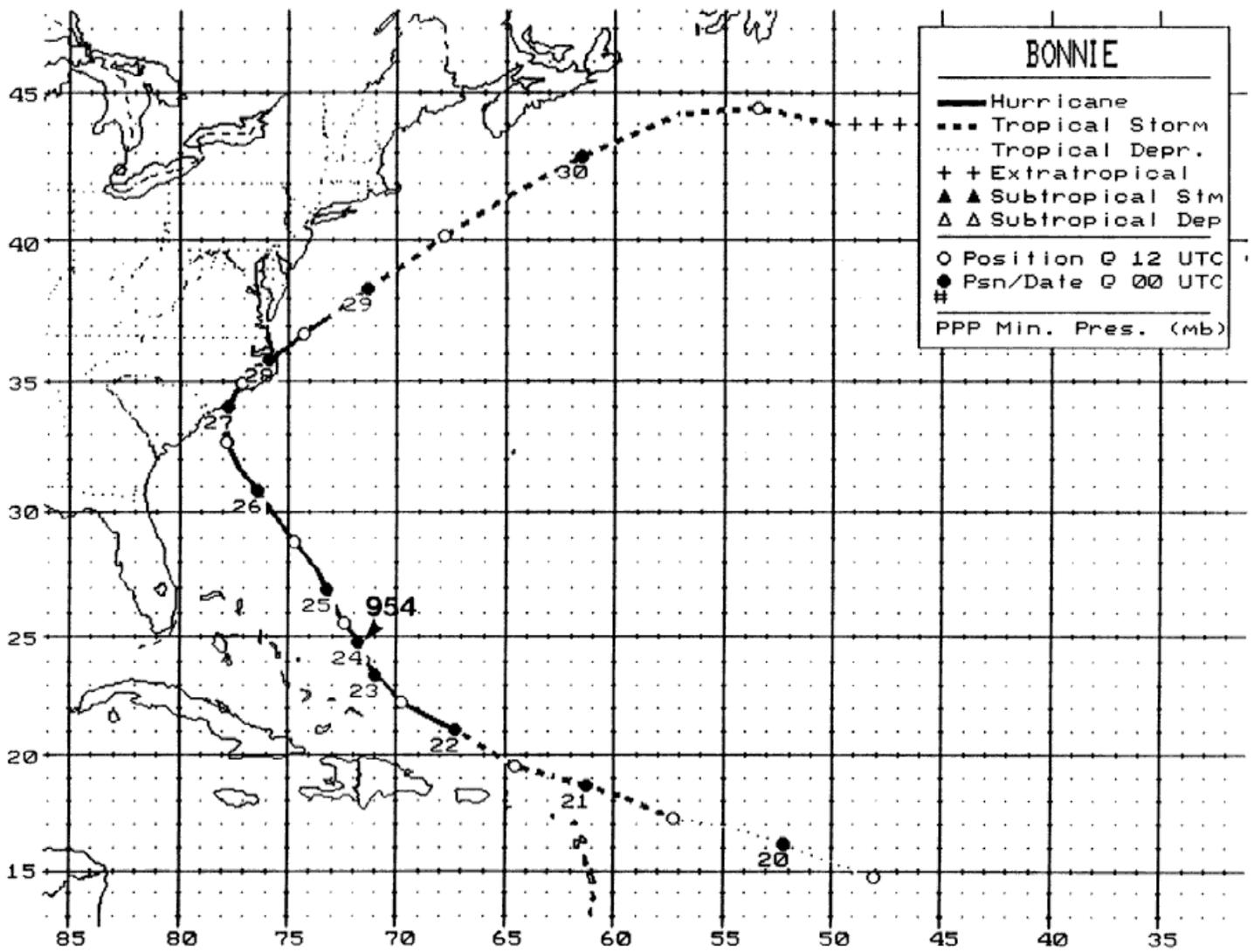


Fig. 1. Best track positions for Hurricane Bonnie, 19-30 August 1998.

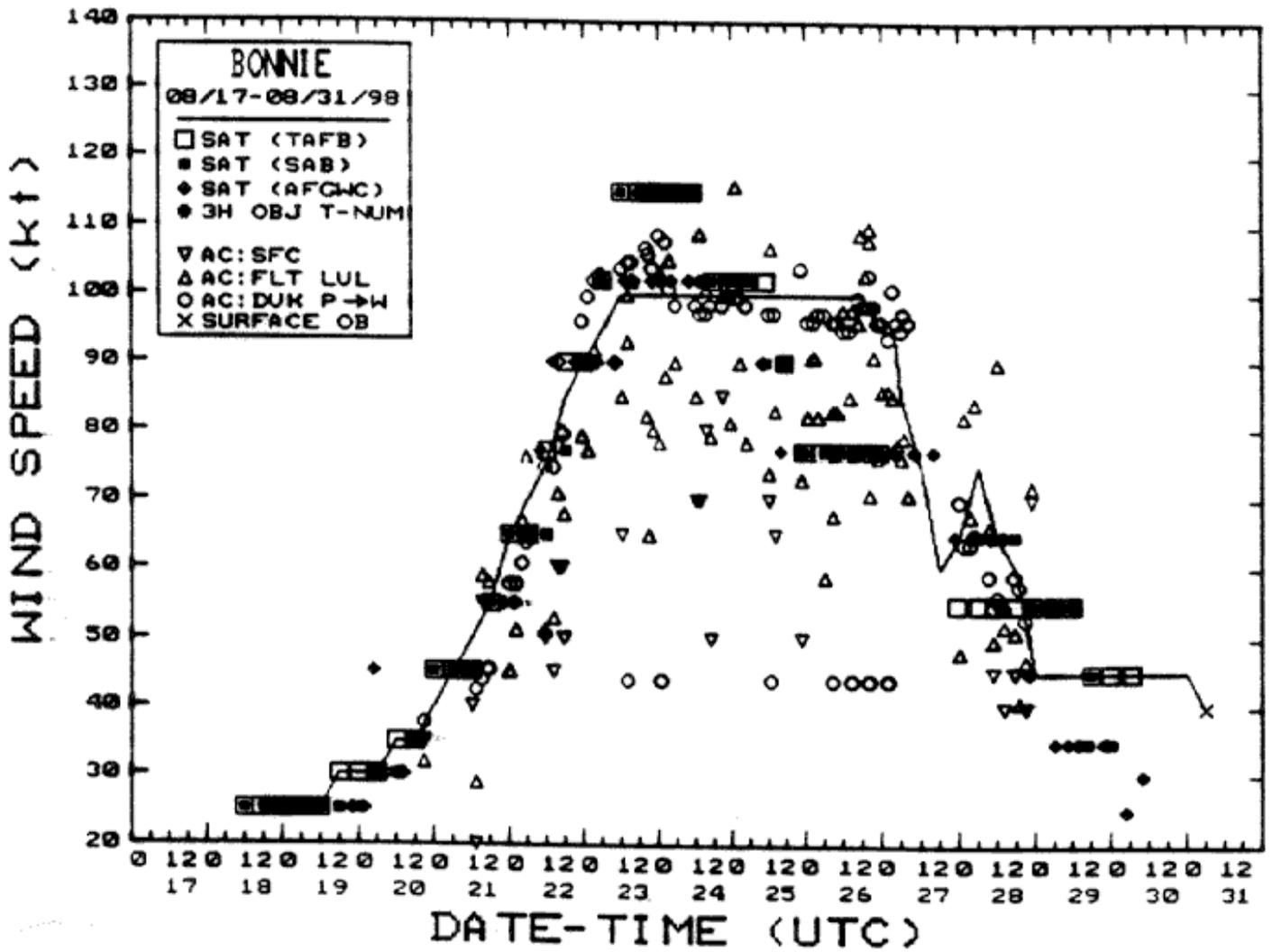


Fig. 2. Best track one-minute surface wind speed curve for Hurricane Bonnie.

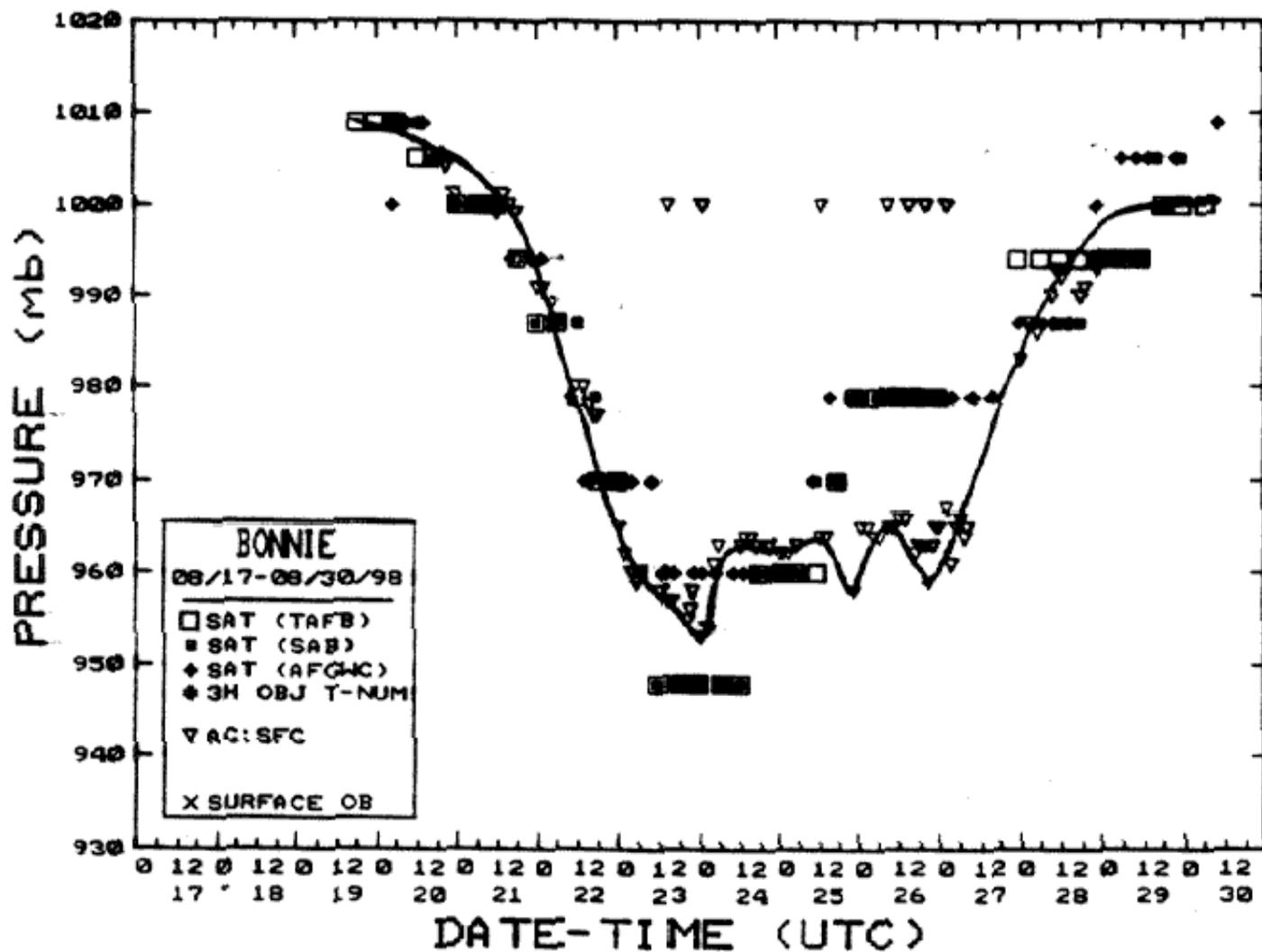


Fig. 3. Best track minimum central pressure curve for Hurricane Bonnie.

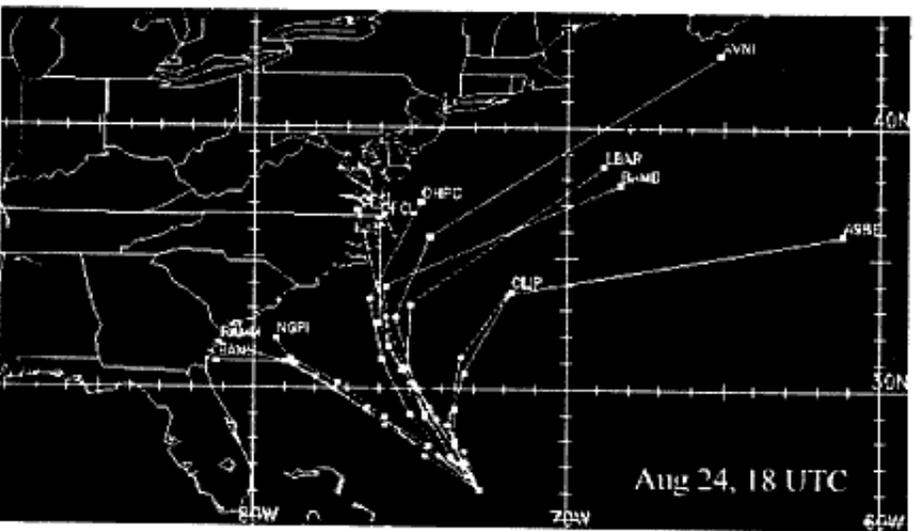
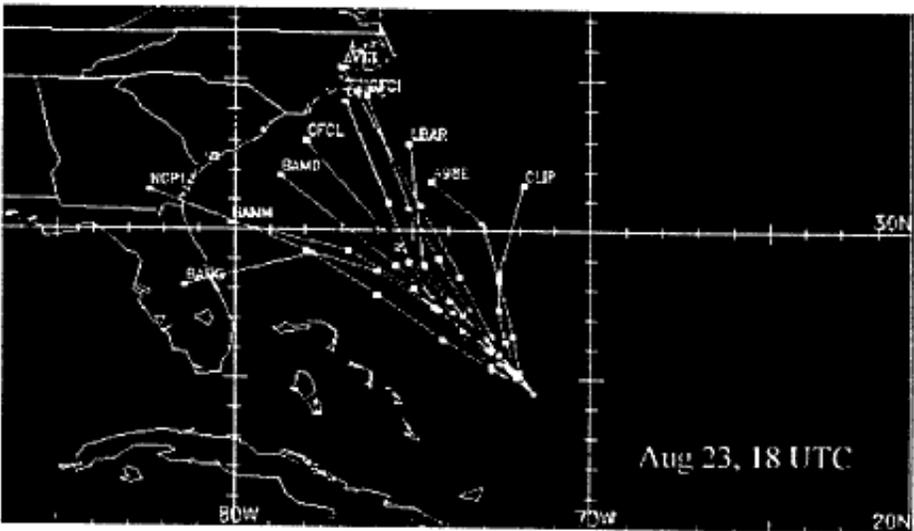
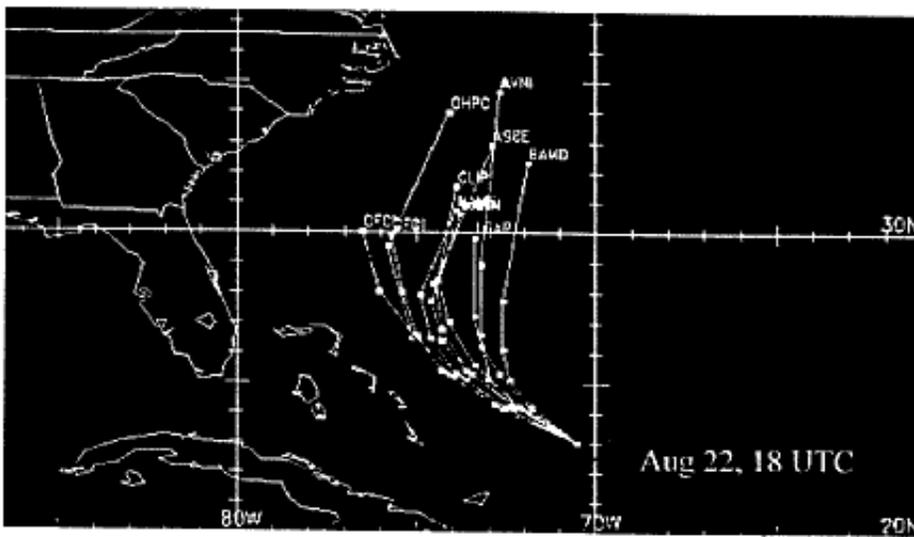


Figure 4. Sequence of model guidance for Hurricane Bonnie