Atlantic Hurricane Season of 1997

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ABSTRACT

The 1997 Atlantic hurricane season is summarized and the year's tropical storms, hurricanes, and one subtropical storm are described. The tropical cyclones were relatively few in number, short lived, and weak compared to long-term climatology. Most systems originated outside the deep Tropics. Hurricane Danny was the only system to make landfall. It produced rainfall totals to near 1 m in southern Alabama and is blamed for five deaths. Hurricane Erika was responsible for the season's two other fatalities, in the coastal waters of Puerto Rico.

1. Introduction

A sharp drop in tropical cyclone activity occurred in the Atlantic hurricane basin from 1995–96 to 1997 (Table 1). Only seven tropical storms formed in 1997, and just three of those reached hurricane strength (Table 2). This also represents a considerable reduction from the long-term averages of ten tropical storms and six hurricanes. The months of August and September were particularly quiet. On average, about six tropical storms develop during that two-month period (Neumann et al. 1993). There was just one in 1997, an occurrence last noted in 1929. Also, for the first time since 1961, no tropical cyclones formed in August.

Hurricane Danny, which formed over the Gulf of Mexico, was the only system to make landfall. Hurricane Erika brushed the northeastern Lesser Antilles and was the only cyclone to become a ''major'' hurricane, that is, to have winds of at least 96 kt (1 kt = 0.5144 m s^{-1}) over 1 min [category three or higher on the Saffir–Simpson hurricane scale; Simpson (1974)].

All but one tropical cyclone (Erika) formed in the western part of the hurricane basin at relatively high latitudes, 22°–32°N (Fig. 1). In contrast, 11 of the 13 tropical cyclones in 1996 formed south of 22°N. Most of 1997 systems originated in association with low-level frontal boundaries or upper-level disturbances. In general, these systems were rather short lived and weak, encountering strong vertical wind shear and rather cool waters after just a few days. Tropical waves contributed directly to the formation of only two named systems. This is one of the smallest contributions (by percentage) on record by tropical waves. On average, about 60% of tropical cyclones originate from tropical waves (Pasch et al. 1998).

Historically, many of the strongest Atlantic tropical cyclones develop from tropical waves between the coast of Africa and the Lesser Antilles in the August–September period. Such tropical cyclone formation appears to be related to 1) the wave's ''intrinsic'' potential for development (e.g., its observed size, cloud and circulation structure, convective nature) when it crosses the west coast of Africa, and 2) the characteristics of the eastern Atlantic atmospheric and oceanic environment that it then encounters. While satellite signatures, surface pressure analyses, and circulation features derived from rawindsonde data provide some clues about tropical waves departing Africa, a reliable quantitative measure of point 1 above remains elusive.

Some progress has been made on identifying the environmental factors influencing tropical cyclone development from tropical waves. The relatively small number of systems in 1997, their high latitude of formation, and the minor role of tropical waves are all consistent with the climatological expectations associated with an El Niño event (e.g., Gray 1984; Goldenberg and Shapiro 1996; Pasch et al. 1998), such as occurred during 1997 (Climate Prediction Center 1997). During an El Niño, stronger than normal westerly winds often occur at 200 mb over the tropical North Atlantic Ocean. These winds tend to shear the tops off of (westward moving) thunderstorms that are necessary for the formation and subsequent development of tropical cyclones. Indeed, in September 1997, anomalously strong westerly winds covered most of the Atlantic area traversed by tropical waves and only one tropical cyclone, Hurricane Erika, developed during that month (Fig. 2b).

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TABLE 1. Number of Atlantic tropical storms and hurricanes in the 1990s.

Year	Tropical storms	Hurricanes
1990	14	8
1991	8	4
1992	6	4
1993	8	4
1994	7	3
1995	19	11
1996	13	9
1997	7	3

The behavior of the tropical Atlantic atmosphere during August 1997 cannot be explained by analysis of just the upper-level circulation. Despite the ongoing El Niño, the 200-mb circulation was near normal between Africa and the Lesser Antilles that month (Fig. 2a). Nevertheless, August tropical cyclone activity was well below normal, with no tropical storms or hurricanes for the first time in 36 years. (In comparison, five named tropical cyclones formed in this area from tropical waves during the especially active August of 1995.)

The following section describes the 1997 cyclones. The meteorological analyses and poststorm ''best tracks'' (e.g., Fig. 1) were based primarily on analyses of Geostationary Operational Environmental Satellite (GOES) and polar-orbiting weather satellite imagery using the Dvorak (1984) technique and reconnaissance aircraft reports from the ''Hurricane Hunters'' of the United States Air Force Reserve. These data were supplemented by observations from surface and upper-air sites, and weather radars.

2. Storm and hurricane summaries

a. Unnumbered subtropical storm, 1–2 June

A weak and poorly organized low-level circulation formed within a cluster of thunderstorms over the Straits of Florida on 29 May 1997. Little development occurred over the following two days. During that period, the system initially drifted northeastward and then accelerated toward the north-northeast. Surface observations indicate that low pressure developed within the system by 31 May. Winds increased to 20–25 kt on the east side of the low by that day, but a well-defined closed circulation was not evident. A mid- to upper-tropospheric short-wave trough approaching from the southwest enhanced convection near the system center.

Operationally, National Weather Service (NWS) analyses and forecasts designated this system as an extratropical cyclone through its lifetime. A poststorm analysis of all data subsequently available suggests, however, that the system had a mostly subtropical structure (see, Hebert and Poteat 1975), as indicated for about a day in satellite images (e.g., Fig. 3), and that the system became a subtropical depression at about 0600 UTC 1 June.

The subtropical depression moved rapidly north-northeastward and strengthened. Near 1000 UTC on 1 June, National Oceanic and Atmospheric Administration (NOAA) data buoy 41002 reported that winds of 27 kt (8.5-min average), gusts to 35 kt, and a pressure of 1003.8 mb occurred about 25 n mi (1 n mi = 1.853 km) east of the center. A 10-min average wind of 32 kt occurred at the buoy during the following hour. Later that day, a U.S. Air Force Hurricane Hunter aircraft measured a minimum pressure of 1004 mb with maximum flight level winds of 55 kt at 450 m. These data indicate that the system reached subtropical storm strength near 1200 UTC 1 June and its maximum sustained surface winds of 45 kt 6 h later. Satellite imagery on 1 June showed a well-defined low-level center with a band of relatively shallow cumulonimbi wrapped around the south side of the center.

The cyclone turned east-northeastward on 2 June when located about 120 n mi south of the New England coast. It became extratropical around 1800 UTC that day and merged with a cold front. The remnant low dissipated by 0000 UTC 3 June.

b. Tropical Storm Ana, 30 June–4 July

Ana formed from a frontal low pressure system just off the coast of South Carolina on 30 June and moved

TABLE 2. 1997 Atlantic hurricane season statistics.

No.	Name	Class*	Dates**	Maximum 1-min wind in kt ($m\ s^{-1}$)	Minimum sea level pressure (mb)	U.S. damage ($ millions)	Direct deaths
1	—	ST	1–2 Jun	45 (23)	1003		
2	Ana	T	30 Jun–4 Jul	40 (21)	1000		
3	Bill	H	11–13 Jul	65 (33)	986		
4	Claudette	T	13–16 Jul	40 (21)	1003		
5	Danny	H	16–26 Jul	70 (36)	984	100	5
6	Erika	H	3–15 Sep	110 (57)	946		2
7	Fabian	T	4–8 Oct	35 (18)	1004		
8	Grace	T	16–17 Oct	40 (21)	999		

* ST—subtropical storm, wind speed 34–63 kt (17–32 $m\ s^{-1}$); T—tropical storm, wind speed 34–63 kt (17–32 $m\ s^{-1}$); H—hurricane, wind speed 64 kt (33 $m\ s^{-1}$) or higher.

** Dates begin at 0000 UTC and include tropical and subtropical depression stages.

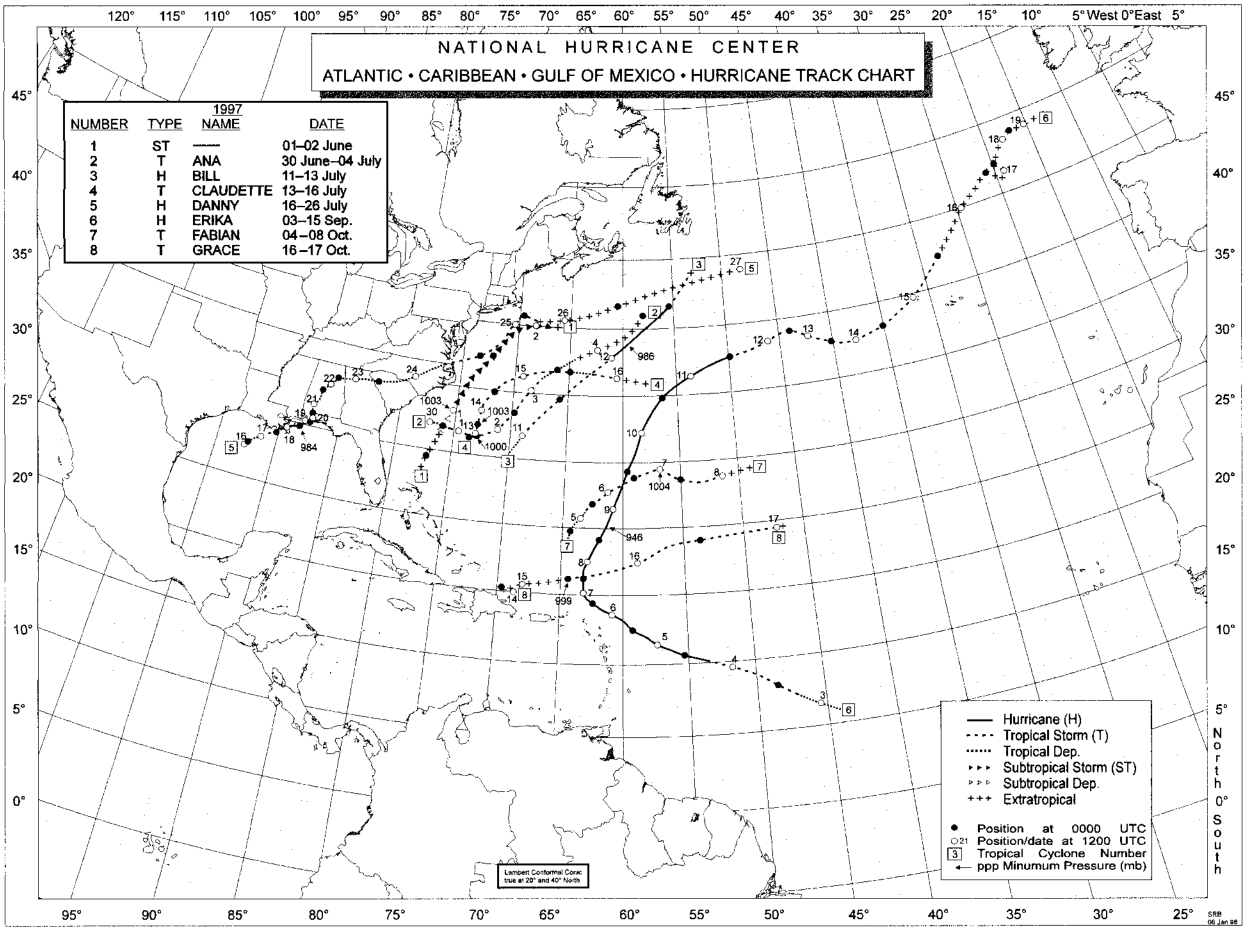

FIG. 1. Tracks of tropical storms, subtropical storm, and hurricanes in the Atlantic basin during 1997.

slowly eastward as a tropical depression. The next day it became Tropical Storm Ana, even though vertical wind shear limited convective development near the center of the low-level circulation. A reconnaissance aircraft flew into Ana on the afternoon of 1 July and measured a 54-kt wind speed in the northeast quadrant at an altitude of 450 m and a minimum surface pressure of 1000 mb. The wind data are the basis for estimating that Ana's maximum 1-min surface wind speed reached 40 kt.

A deepening mid- to upper-tropospheric short-wave trough that moved to eastern North America accelerated the storm toward the northeast on 2 and 3 July. On 4 July, Ana became extratropical after traversing relatively cold water for several days. It then dissipated.

c. Hurricane Bill, 11–13 July

Hurricane Bill developed from a large upper-level low that separated from a midoceanic trough northeast of Puerto Rico. On 7 July, satellite images indicated that cloudiness and showers associated with the upper-level low began to increase and, although surface pressures were quite high north of Puerto Rico, a small perturbation of the wind field and a trough developed at the surface. A low pressure center formed from the trough just east of the Bahamas and moved toward the west-northwest. The upper-level low, on the other hand, moved southwestward into the Caribbean Sea. These changes decreased the wind shear over the surface low.

The first indication that a tropical depression might be forming occurred while the system approached the eastern Bahamas and induced a pressure fall there of about 3 mb in 24 h. Convection then gradually became organized and it is estimated that the system became a tropical depression near 0600 UTC 11 July. The tropical cyclone was then moving northeastward ahead of a cold front over the eastern United States.

A reconnaissance plane measured 45-kt winds at an altitude of about 215 m, to the southeast of the center, early on 11 July. The minimum surface pressure was 1013 mb. This pressure is not particularly low for a tropical cyclone, but environmental pressures were high and the prevailing pressure gradient could support tropical storm force winds. The system is estimated to have become a tropical storm at 1200 UTC on 11 July.

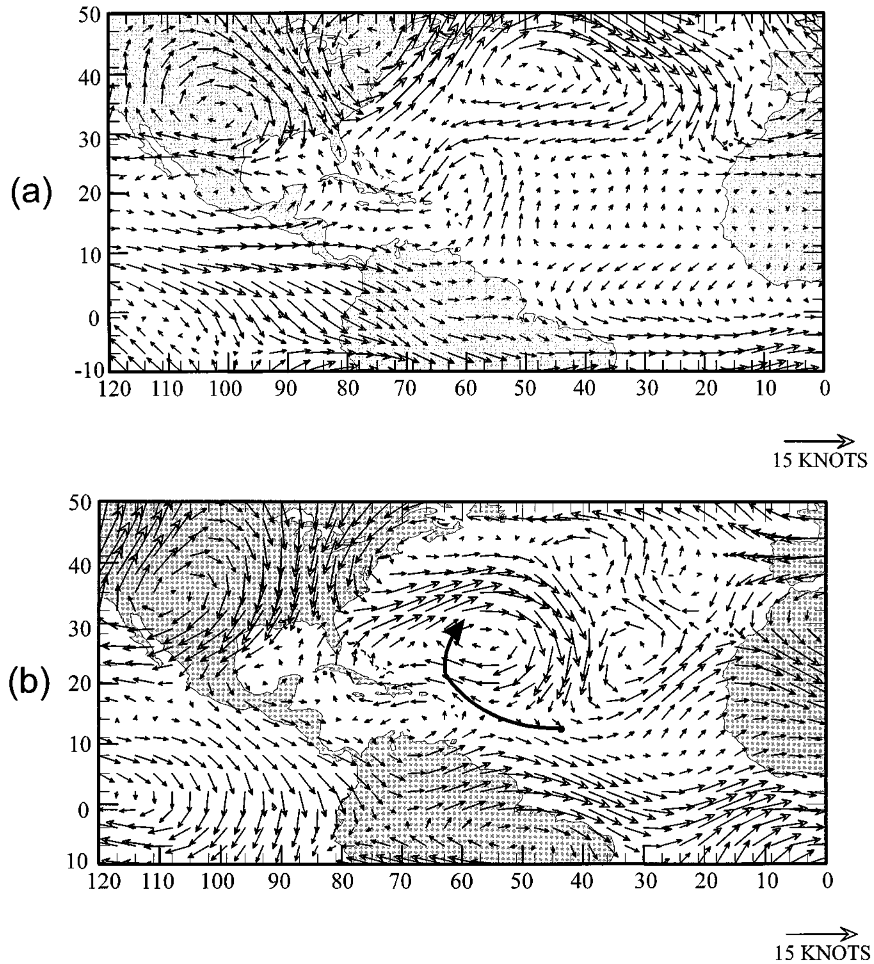

FIG. 2. Anomaly of 200 mb wind for (a) Aug 1997, and (b) Sep 1997 with origin (dot) and smoothed early part of Hurricane Erika track (line).

Bill moved toward the northeast at about 20–25 kt. On the evening of 11 July the center passed about 150 n mi to the northwest of Bermuda, where tropical storm warnings were in effect. The strongest winds associated with Bill occurred to the east of the circulation center but did not extend out far enough to bring tropical storm force winds to that island.

The northeastward track took Bill into an environment that led to strengthening, despite the presence of progressively cooler water. An eye appeared intermittently on satellite pictures starting at 0415 UTC 12 July and was clearly depicted on high-resolution visible images at 1300 UTC 12 July, suggesting that the cyclone had reached hurricane strength. A Dvorak technique analysis from the Tropical Analysis and Forecast Branch of the Tropical Prediction Center (TPC) indicated that Bill reached its peak intensity of 65 kt at 1500 UTC 12 July. The minimum pressure estimated at that time was 986 mb. Bill was then absorbed by a frontal system and could not be identified by 0600 UTC 13 July.

d. Tropical Storm Claudette, 13–16 July

The frontal system that swept Hurricane Bill northeastward across the western Atlantic also generated a frontal low a few hundred miles to the east of Georgia and South Carolina on 11 July. Over the following two days, the low moved little and gradually acquired a closed, low-level cyclonic circulation that was independent of the frontal band dissipating in its vicinity. The low is estimated to have become a tropical depression at 0600 UTC on 13 July while located about 275 n mi to the south-southeast of Cape Hatteras, North Carolina.

The depression became Tropical Storm Claudette 12 h later, based on 45–50-kt winds measured at a flight level of 250 m during the first reconnaissance aircraft mission in the system. About this time, banding of convection increased enough for Dvorak T numbers to reach 2.5 (corresponding to 35-kt maximum wind speed). This development came despite some southerly to southwesterly wind shear, which prevented Claudette from developing more than a weak anticyclone aloft.

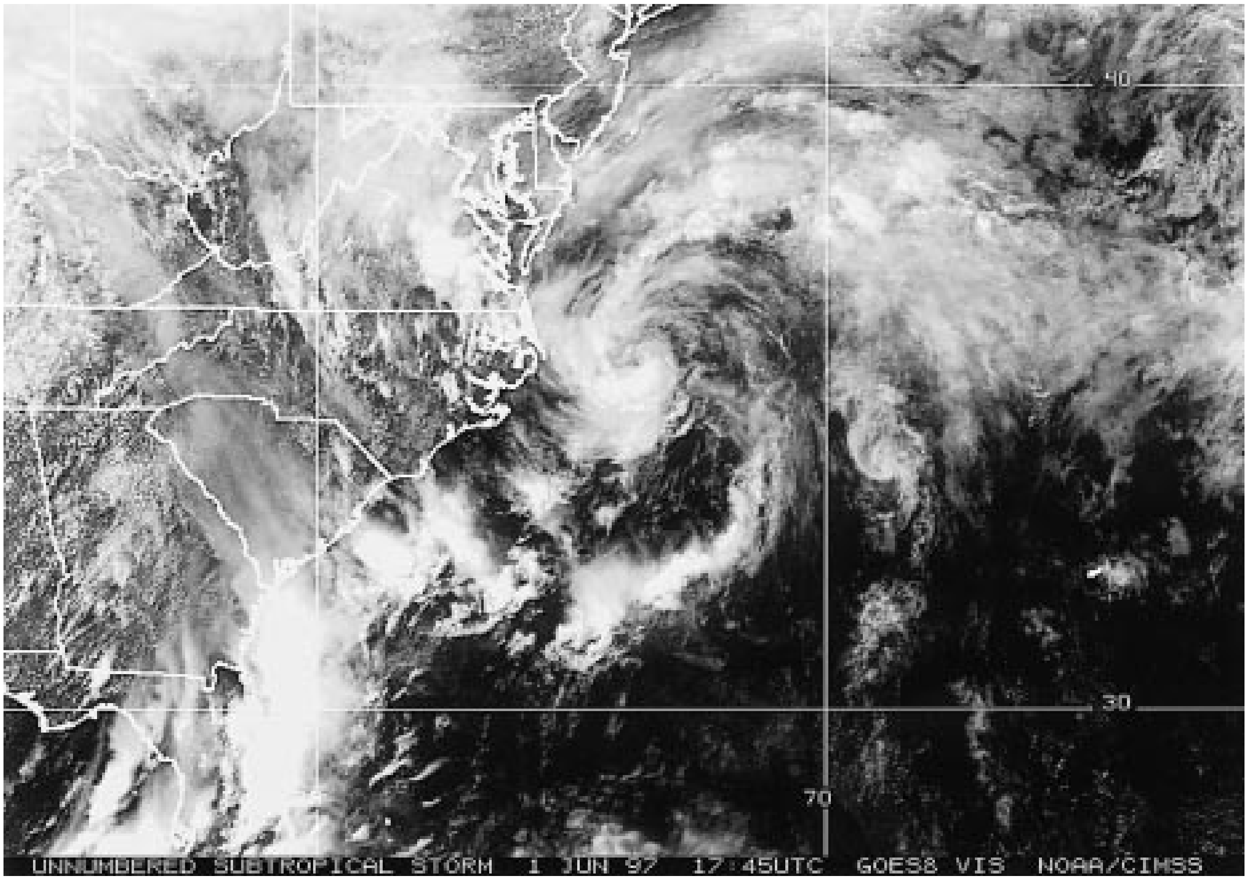

FIG. 3. *GOES-8* visible satellite image of the unnumbered subtropical storm at 1745 UTC 1 June 1997.

Deep convection was episodic with most activity occurring during the nighttime hours. Intensity estimates based on satellite pictures and reconnaissance aircraft data suggest that Claudette retained 30–40-kt winds from 13 to 16 July. During that period, Claudette initially moved northward, but then was accelerated toward the east by the flow ahead of an approaching frontal system. On 14 July, this environment was sampled by Global Positioning System (GPS) dropsondes deployed from the NOAA G-IV jet making its inaugural flight in support of tropical cyclone operations (Fig. 4). This high-altitude aircraft is expected to improve analyses and forecasts by collecting and transmitting real-time data on the three-dimensional structure of 1) the large-scale environment and, within a few years, 2) tropical cyclones (NOAA, 1994).

On 16 July, Claudette merged with the front, its center once again becoming a frontal low. The extratropical low moved generally toward the east over the following week. Satellite pictures (not shown) suggest that it dissipated near the Azores Islands on 23 July.

e. Hurricane Danny, 16–26 July

1) SYNOPTIC HISTORY

Like tropical cyclones Ana, Bill, and Claudette, Danny came from a weather system of nontropical origin. On 13 July, a broad upper-tropospheric trough over the southeastern United States helped initiate a cluster of thunderstorms over the lower Mississippi River Valley. This area of convection drifted southward over the north-central Gulf of Mexico coastal waters, and appears to have contributed to the formation of a small, weak surface low near the coast of Louisiana on 14 July. Over the next couple of days, the associated cyclonic circulation expanded somewhat over the northern Gulf. However, surface winds remained quite weak and the associated deep convection was not persistent or well organized.

By 1200 UTC on 16 July, deep convection became a little better organized near the center, the system began to resemble a tropical cyclone, and Dvorak satellite classifications were initiated. Observations from oil rigs and NOAA data buoys at the same time showed that the circulation had become well defined. These surface and near-surface data indicated that maximum surface winds were near 25 kt, and it is estimated that Tropical Depression Four formed at that time about 125 n mi south of the coast of southwestern Louisiana.

Further development of the system was rather slow until around 1200 UTC 17 July. Then, the amount and organization of deep convection quickly increased. Re-

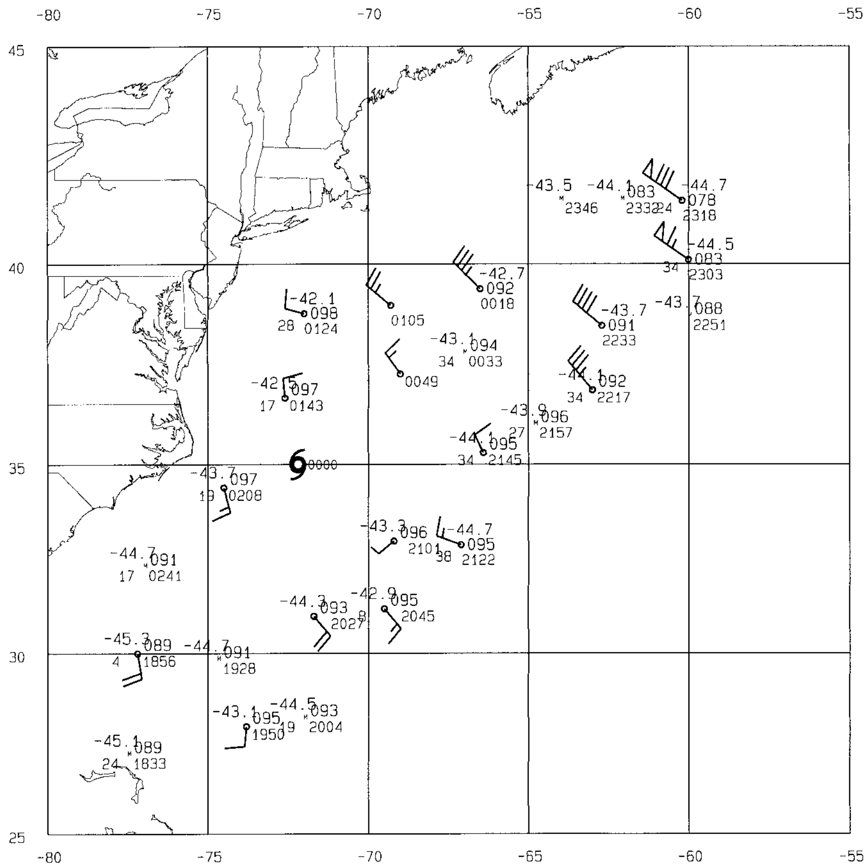

FIG. 4. GPS dropsonde data at 250 mb obtained by NOAA G-IV jet making its inaugural operational surveillance mission within the environment of an Atlantic tropical cyclone. Standard plotting convention used, with temperature (°C) and relative humidity (%) nominally shown to upper left and lower left of site, respectively, and altitude (decameters with leading ''1'' omitted) and time (UTC on 14 Jul or early on 15 Jul 1997) shown to the right. Flag for 50 kt, full barb for 10 kt, and half barb for 5 kt. Cyclone symbol indicates center position of Tropical Storm Claudette at 0000 UTC 15 Jul 1997. Figure provided by NOAA/Hurricane Research Division.

connaissance aircraft observations taken near 1500 UTC on 17 July suggested that the cyclone had reached tropical storm strength a few hours earlier. Danny continued to strengthen and was a hurricane by 0600 UTC on 18 July. By this time the center was nearing the Mississippi River delta.

While over the northern coastal region of the Gulf of Mexico, Danny was generally located on the southeast side of the axis of a very weak midtropospheric trough that was oriented from east-northeast to west-southwest. The cyclone moved quite slowly in a generally east-northeastward direction (Fig. 5). It is rather rare for Gulf of Mexico tropical cyclones to move in this direction during the month of July. At times, the center of Danny became nearly stationary.

Hurricane Danny made its first landfall just northwest of the Mississippi River delta near the Louisiana towns of Empire and Buras early on 18 July. Danny was a very small hurricane. Reports from the Hurricane Hunters indicated a radius of maximum winds of 8–9 n mi. Hurricane force winds occurred mostly in the eastern semicircle, within about 20 n mi of the center. Communities from Port Sulphur southeastward to Venice, Louisiana, probably experienced hurricane force winds. [The Venice Automated Surface Observing System (ASOS) site lost power after reporting wind gusts to 38 kt a couple of hours before the closest approach of the hurricane's center.] Tropical storm force winds extended out only about 100 n mi.

After passing over extreme southeastern Louisiana, the center of Danny was back over the Gulf of Mexico, south of the coast of Mississippi, during the day on 18 July (Fig. 6). There was a little more strengthening, and Danny reached its peak intensity of 70 kt with a minimum central pressure of 984 mb. The hurricane wobbled to the east, then north-northeastward, bringing the eye to the mouth of Mobile Bay near Fort Morgan, Alabama, just before dawn on 19 July (see Fig. 5). The eyewall and western edge of the eye passed over Dauphin Island, which experienced sustained hurricane

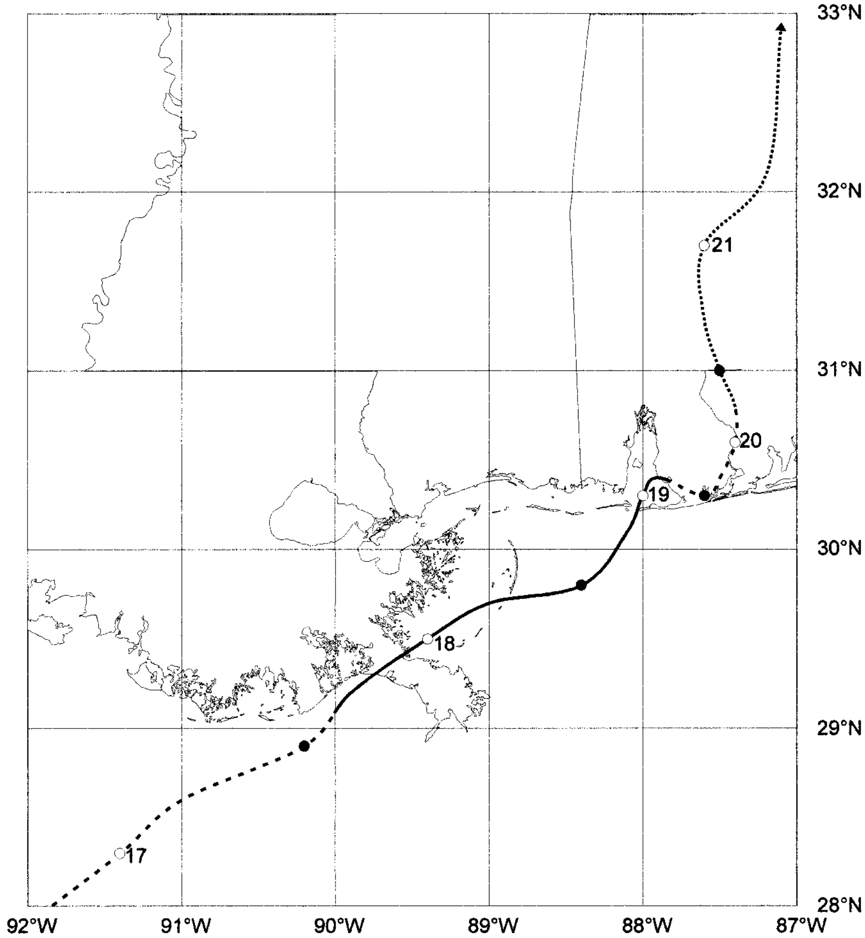

FIG. 5. As in Fig. 1 for detailed track of Hurricane Danny near U.S. Gulf of Mexico coast.

force winds and torrential rains (see Table 3). After drifting over extreme southern Mobile Bay, the center plodded eastward, practically stalled, and then crossed the coast on the southeast shore of the bay near Mullet Point, Alabama, around midday on 19 July. Danny continued to move erratically just after landfall, toward the southeast over extreme southeastern Alabama, while weakening to a tropical storm by 0000 UTC on 20 July. The cyclone then turned northward, continued weakening, and passed over the extreme northwestern Florida panhandle. Danny weakened to a tropical depression by 1800 UTC on 20 July. It moved northward to northeastward over Alabama for two days.

Although Danny was very weak at the surface on 22–23 July, satellite and radar images (not shown) indicated a well-defined cyclonic cloud and precipitation signature while the cyclone moved eastward over northern Georgia and South Carolina. The low pressure system moved east-northeastward over North Carolina on the morning of 24 July. Around midday, prior to the center reaching the Atlantic seaboard near the North Carolina–Virginia border, the cyclone began strengthening and accelerating in forward speed. The fact that Danny was reintensifying while still partially over land suggests that it was deriving energy from a baroclinic source. A front was situated just to the north of the cyclone around this time. Winds around Danny were already back to tropical storm force when the center moved back over water around 1900 UTC on 24 July.

The storm then headed north-northeastward and its forward speed dropped markedly, from 25–30 kt to nearly stationary, while Danny appeared to be drawn in toward a middle- to upper-tropospheric cyclone over the northeastern United States. This motion brought the center of Danny to about 25 n mi southeast of Nantucket Island, Massachusetts, around 0000 UTC 26 July. After buffeting southeastern Massachusetts, Danny lost its remaining tropical characteristics and turned out to sea. The cyclone was absorbed into a frontal zone over the North Atlantic around 1800 UTC on 27 July.

2) METEOROLOGICAL STATISTICS

The Hurricane Hunters flew a total of 11 missions into Danny, 10 in the northern Gulf of Mexico coastal area, and 1 in the Atlantic. Just before landfall near the

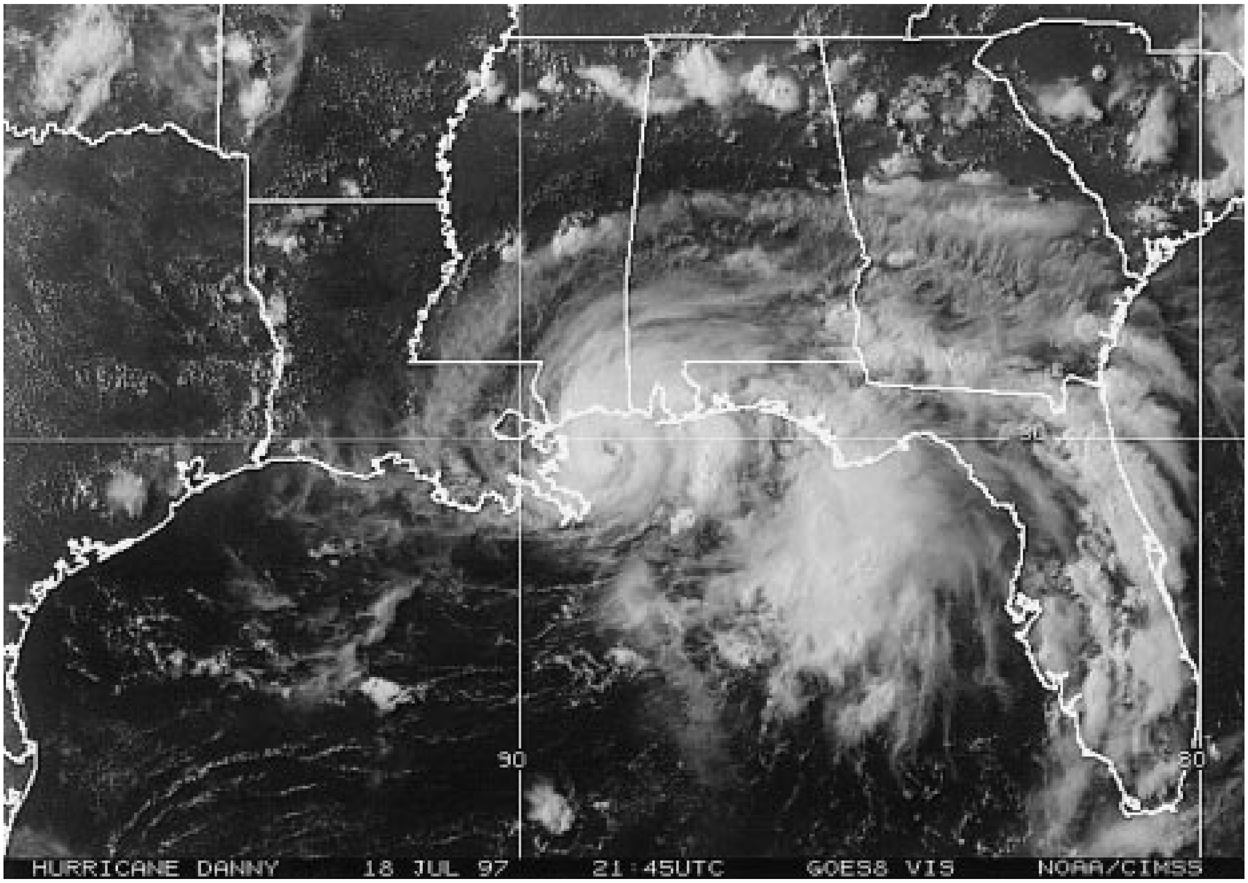

FIG. 6. *GOES-8* visible satellite image of Hurricane Danny at 2145 UTC 18 Jul 1997 when the hurricane was near its peak intensity.

mouth of the Mississippi River early on 18 July, the Hurricane Hunters reported maximum flight-level (450 m) winds of 80 kt. At about the same time, 10-min average winds of 55 kt, with gusts to 83 kt, were reported at Grand Isle, Louisiana. Maximum winds reported by the Hurricane Hunters at 450 m were 82 kt at 1449 UTC 18 July. The minimum central pressure reported from aircraft was 984 mb at 2325 UTC on 18 July, and again at 1142, 1259, and 1410 UTC on 19 July.

Table 3 lists a selection of surface observations taken during Danny. The Dauphin Island C-MAN site measured 10-min average winds of 65 kt at 1145 UTC 19 July and gusts to 88 kt 21 min earlier. The Mobile WSR-88D radar showed that around these times the strongest eyewall convection was occurring in this vicinity over the southwest quadrant of the hurricane. At 1139 UTC, aircraft reported maximum winds of 64 kt at the 850-mb flight level in the southwest quadrant. Thus, surface and flight-level winds were about the same magnitude in this highly convective regime of the hurricane.

True to form for a slow-moving hurricane, rainfall totals were very large over extreme southern Alabama. Doppler radar estimates suggested maximum storm total precipitation amounts to around 1100 mm near Dauphin Island. Recent studies show that a new relationship between reflectivity and rainfall for tropical cyclones, used with the Mobile radar, gives a rather accurate estimate of the actual precipitation (Spratt and Sharp 1997). A rainfall total of 932.4 mm (36.71 in.) was measured at the Dauphin Island Sea Lab. This is one of the largest hurricane-related totals ever measured in the United States. A new 24-h record rainfall for Alabama of 826.0 mm (32.52 in.) was established there during the period ending at 0100 UTC on 20 July (T. Ross, National Climatic Data Center, 1998, personal communication). Because rain gauges usually do not capture all of the rainfall in the high wind regime of a hurricane, this rain gauge total is probably an underestimate of the local total. Fortunately, most of the extreme precipitation amounts occurred in areas near the coast, or over water, near southwestern Mobile Bay. This helped to limit flooding, which would have been disastrous if that much rain had occurred farther inland. Nonetheless, some significant inland flooding occurred along the path of Danny, notably in Charlotte, North Carolina, where rainfall totals of 200–300 mm where recorded.

Storm tides of generally 0.5–1.5 m occurred from the Florida–Alabama border to Dauphin Island. A maximum storm tide of 2 m was reported along Highway

TABLE 3. Hurricane Danny selected surface observations, Jul 1997.

Location	Press. (mb)	Date/ time (UTC)	Sustained wind (kt)[a]	Peak gust (kt)	Date/ time (UTC)[b]	Storm surge (m)[c]	Storm tide (m)[d]	Total rain (mm)
Louisiana								
Bayou Bienvenue							1.61	
Buras								236.7
Grand Isle							1.65	
Grand Isle C-MAN			55[f]	83	18/0900			
New Orleans Intern. Airp.	1008.8	18/1023	24	29	20/0455			6.9
New Orleans Lakefr. Airp.	1008.5	18/1018	33	39	20/0446			27.7
Rigolettes							1.01	
S.W. Pass C-MAN	1005.6	18/1000	41[f]	55	18/1130			
Venice ASOS[e]	1006.4	18/0747	26	38	18/0724			
Mississippi								
Pascagoula Trent Lott Airp.	1005.1	19/1011	22	30	19/0730			
Alabama								
Alabama Port								685.8
Bayou La Batre							0.73	
Bellefontaine								635.0
Chickasaw								431.8
Coden								499.6
Daphne								597.9
Dauphin Island							0.73	
Dauphin Island C-MAN	987.7	19/0900	65[f]	88	19/1145			
Dauphin Island Sea Lab	985.8	19/1100	60	75	19/0615			932.4
Dog River								429.3
Fairhope Agric. Expt. Stn.				59	20/1353			609.6
Fairhope Treatment Plant								609.6
Gulf Beach							0.79	
Gulf Shores								762.0
Gulf Shores (5 mi west)								635.0
Gulf Shores ham radio				70	19/1930			
Gulf Shores Fishing Pier			61		19/1500			
Highway 182W[g]							1.99	
Little Dauphin Island Bay							1.52	
Malbis								838.2
Mobile (I-65 and Springhill)								407.4
Mobile Bay state docks							−0.61	
Mobile Brookley Field	1000.7	19/1104	36	46	20/1011			
Mobile Regional Airport	1004.4	19/1023	31	39	19/1736			331.2
Montrose								660.4
Orange Beach ham radio				66	19/0900			
Robertsdale								457.2
Silverhill								571.5
Spanish Fort								510.5
St. Elmo								482.6
Summerdale								546.1
Theodore								533.4
Florida								
Crestview	1009.1	20/0930	20	28	20/2008			490.2
Eglin Air Force Base	1009.9	20/0730		32	20/1755			56.4
Hurlburt Air Force Base	1009.1	20/0655	30	38	19/0900			95.5
Milton Whiting Field	1005.8		27	34	20/0239			56.6
Pensacola Naval Air Stn.	1001.1		43	55	20/0216			163.3
Pensacola Regional Airp.	1002.0	20/0552	31	41	20/0208			172.2
North Carolina								
Diamond Sh. Lt. C-MAN	1013.0	24/1900	42	51	24/2000			
Duck Pier C-MAN	1009.5	24/1900	42	51	24/2000			
Elizabeth City	1003.7	24/1846	42	55	24/1846			36.6
Rocky Mount				51				
Virginia								
Cape Henry				54				
Chesapeake Bay Br. Tunnel				54				
Chesapeake Light C-MAN	1005.6	24/2000	51[f]	61	24/2055			

TABLE 3. (*Continued*)

Location	Press. (mb)	Date/ time (UTC)	Sustained wind (kt)[a]	Peak gust (kt)	Date/ time (UTC)[b]	Storm surge (m)[c]	Storm tide (m)[d]	Total rain (mm)
Hampton Roads Br. Tunnel				39				
Langley AFB				54				
Norfolk ASOS	1007.5	24/1752	30	44	24/1817			57,7
Norfolk Naval Stn.				51				
Oceana Naval Air Stn. (V. Bch.)				43				34.5
Sewells Point							0.61	
Wakefield NWSO								76.4
Massachusetts								
Buzzards Bay C-MAN	1008.5	25/1900	42[f]	51	25/2240			
Chatham Coast Guard			38		25/1500			
Chatham upper-air site			35	40	25/1645			
Cotuit								72.4
Falmouth								66.8
Martha's Vineyard ASOS	1004.9	25/1935	33	42	25/1945			73.2
Nantucket Island						0.25		
Nantucket Island ASOS	999.5	25/1953	37	45	25/2020			105.2
Nantucket Island spotter			35	61	25/2100			114.8
Otis AFB tower, Falmouth	1006.8	25/1955	32	51	25/2155			
Plymouth ASOS			29	37	25/2212			
Vineyard Haven (Martha's Vineyard)								57.9
Wareham								82.6
NOAA NDBC buoys								
42007 (30.1°N, 88.8°W)	1001.4	18/2100	35	46	18/2300			
42040 (29.2°N, 88.3°W)	1006.2	19/0000	33[f]	42	18/1520			
44004 (38.5°N, 70.7°W)	1004.9	25/0800	32[f]	42	25/0900			
44008 (40.5°N, 69.4°W)	995.4	26/0100	30[f]	37	25/1800			
44014 (36.6°N, 74.8°W)	1003.5	24/2100	42[f]	54	24/2100			

[a] NWS standard averaging period is 1 min; ASOS and C-MAN are 2 min (except where indicated); buoys are 8 min. Elevations for C-MAN sites are as follows: Grand Isle (15.8 m), S.W. Pass (30.5 m), Dauphin Island (17.4 m), Diamond Shoals (46.6 m), Duck Pier (30.4 m), Chesapeake Light (43.3 m), Buzzards Bay (24.8 m), NDBC buoys listed are at 5 m.
[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 National Geodetic Vertical Datum.
[e] Site lost power at 0747 UTC.
[f] Ten-minute average wind.
[g] About midway between Gulf Shores and Fort Morgan, AL.

182W, about midway between Gulf Shores and Fort Morgan. A combination of storm surge and wave action could have contributed to this high water mark. In the upper part of Mobile Bay, offshore winds blew water out of the bay so that tides were about 0.5 m below normal. Observers reported that the bay had never been so low in their experience and that, except for the river channels, one could have walked across the bay.

Danny spawned tornadoes in Orange Beach and Alabama Port, Alabama. Farther inland, a severe thunderstorm cell in Danny's circulation produced five tornado touchdowns in Lexington (causing one fatality), Richland (two touchdowns), Kershaw, and Chesterfield Counties of South Carolina. A small, weak tornado was reported in Abbeville County, South Carolina. A few hours before Danny moved into the Atlantic, tornadoes touched down in the South Norfolk section of Chesapeake, Virginia, and in downtown Norfolk.

In southeastern Massachusetts, the strongest winds occurred on Nantucket Island. That area experienced sustained tropical storm force winds, with gusts to near 60 kt.

3) Casualty and damage statistics

Danny was directly responsible for five deaths. A man was killed when he was caught at sea on his sailboat, off the Alabama coast near Fort Morgan. A woman was killed by a tornado that tore apart her duplex in Lexington County, South Carolina. In Charlotte (Mecklenberg County), North Carolina, a girl drowned when floodwater swept her into a creek, and floodwaters drowned two women in cars. Five additional fatalities are indirectly associated with Danny. A man died of a heart attack while trying to secure a boat during the storm on the Alabama coast, and four people died in storm-related traffic accidents in Georgia.

According to the American Insurance Services Group, insured losses from Danny were about $60 million. The National Hurricane Center (NHC) estimates around $100 million in total damage.

4) Warnings

The NHC issued a hurricane watch for the coasts of Louisiana, Mississippi, and Alabama when the cyclone strengthened into a tropical storm at 1500 UTC 17 July. When Danny strengthened to a hurricane, this watch was upgraded to a hurricane warning at 0700 UTC 18 July, only a couple of hours before landfall in extreme southeastern Louisiana, and 27 h before the landfall on the coast of Alabama. Danny's north-northeastward jog toward southeastern Massachusetts was unexpected and the tropical storm warning for that area was issued only a couple of hours before the occurrence of sustained tropical storm force winds there.

f. Hurricane Erika, 3–15 September

1) Synoptic history

Erika moved into the eastern tropical North Atlantic Ocean on 31 August as a westbound tropical wave associated with a large area of disturbed weather. The system also showed evidence of large-scale cyclonic turning at low levels. It was not until 3 September, however, when located about 1000 n mi east of the Lesser Antilles, that deep convection and the implied surface circulation became defined well enough for it to be designated a tropical depression.

The depression strengthened to become Tropical Storm Erika on 3 September and to hurricane status on 4 September. Meanwhile, its movement was mostly west-northwestward at 15 kt or so under the steering control of a well-established subtropical high pressure ridge. Early on 4 September, infrared satellite imagery showed a warm spot embedded in the deep convection over the center, which hinted at the development of an eye. However, visible satellite imagery later showed a less ominous cloud pattern containing a partially exposed low-level center. The strengthening of Erika to a hurricane (inferred from data obtained on a drifting buoy to the east of the Lesser Antilles) occurred despite the implied shearing conditions. Deep convection soon reappeared over the center and strengthening continued. Erika was then moving toward the west-northwest.

On 5–8 September, the forward speed gradually decreased while the center of the hurricane came within about 75 n mi to the northeast of the northeasternmost Lesser Antilles Islands, just far enough away for hurricane conditions to miss these islands. By 8 September, Erika turned toward the north with a movement of only 5 kt while an amplifying trough over the western North Atlantic eroded the subtropical ridge and weakened the steering currents.

Erika reached its peak intensity of 110 kt at 1800 UTC on 8 September and retained this wind speed for about 24 h (Fig. 7). This occurred while Erika was about 300 n mi north of the Lesser Antilles and starting to accelerate northward. Reconnaissance aircraft data and satellite imagery indicated an eye diameter of about 30 n mi during this period and the hurricane's maximum radius of tropical storm force wind speeds expanded from about 175 to 250 n mi.

NOAA research aircraft released GPS dropsondes into the eyewall on 7 and 8 September, when Erika was strengthening to its maximum intensity. A vertical wind profile obtained near the eyewall showed wind speeds to be smallest, about 90 kt, at a flight level near 750 mb (Fig. 8). The winds over a deep layer below the aircraft were greater than at flight level. In fact, the wind speed in that profile was 128 kt only 40 m above the surface. A significant dropoff is shown below that altitude.

The hurricane passed about 300 n mi east of Bermuda on 10 Sepember and became embedded in midlatitude steering currents that turned Erika toward the east-northeast on 11 and 12 September. By then a combination of cool sea surface temperatures and westerly winds aloft had begun to weaken the cyclone. Winds dropped below hurricane force on 12 September. However, deep convection periodically developed near Erika's center for another 4 days and maximum wind speeds between 45 and 60 kt are estimated for the system while it moved mostly eastward over the North Atlantic Ocean. On 15 September, the center passed near the westernmost Azores Island, where tropical storm conditions were experienced. Erika then lost most of its deep convection and became extratropical by 16 September. It continued moving northeastward for several more days, followed by dissipation on 20 September while located about 200 n mi southwest of Ireland.

2) Meteorological statistics

The NOAA G-IV jet flew missions that provided data for operational analyses and computer model runs on 4 and 5 September. Supplemental data during this period were obtained from NOAA P-3 aircraft. This was when Erika was threatening the Caribbean Islands and several days before the recurvature across the North Atlantic Ocean. This dataset also provides an opportunity to evaluate the impact of high-altitude dropsonde missions that provide data over a large domain.

A NOAA drifting data buoy reported a 60-kt wind speed at 1600 UTC on 4 September, when Erika was about 500 n mi east of the Lesser Antilles. This is the basis for estimating that Erika became a hurricane at 1800 UTC, although uncertainty persists about the best application of data from these special platforms to the operational analysis of 1-min winds at the 10-m level.

No reports of tropical storm force or higher sustained surface winds came from the islands of the northeastern Caribbean in association with Erika. The highest report received was 32-kt sustained wind speed with gusts to

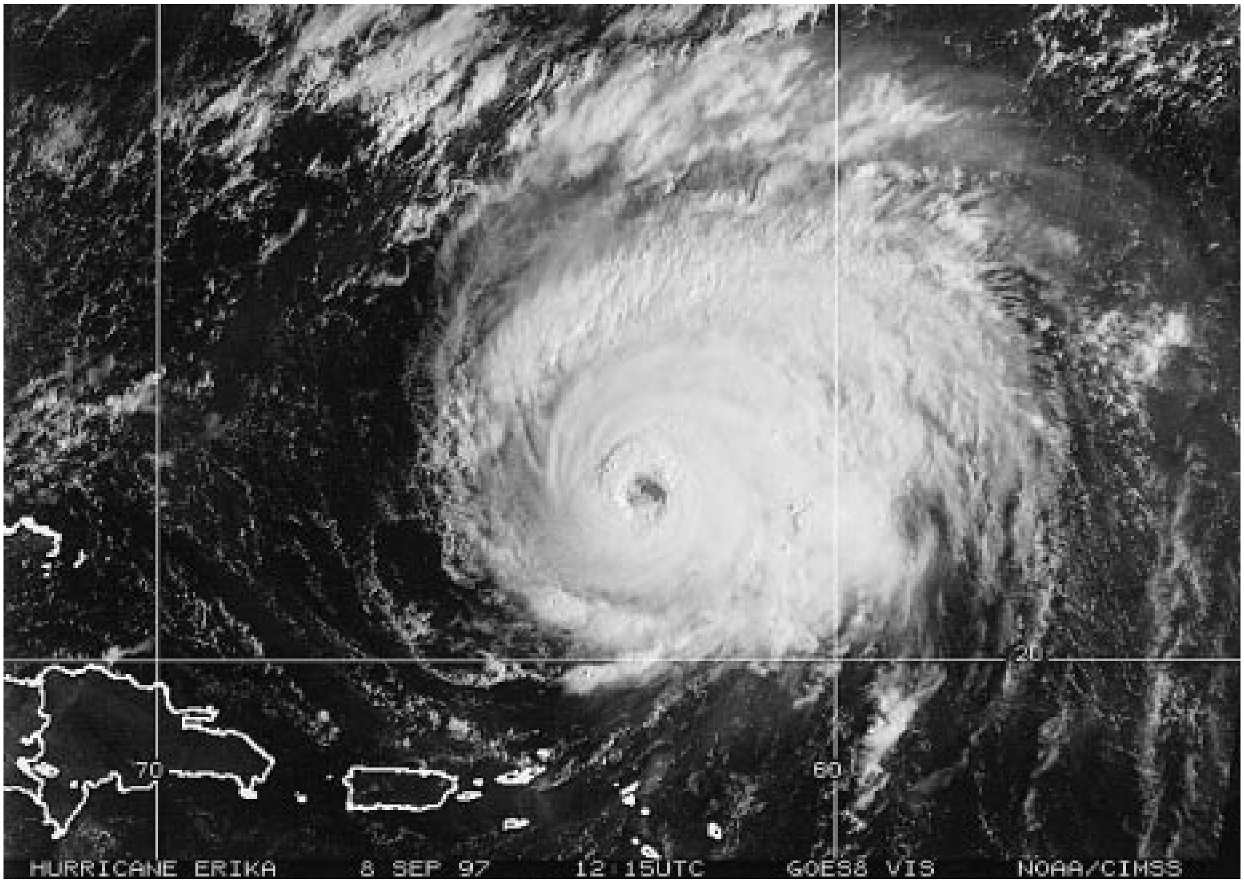

FIG. 7. *GOES-8* visible satellite image of Hurricane Erika at 1215 UTC 8 Sep 1997 when the hurricane was near its peak intensity.

41 kt from St. Thomas in the U.S. Virgin Islands on 7 September, when Erika was centered 125 n mi north-northeast of this location. Undoubtedly, stronger winds occurred over the high terrain of the islands from the Virgin Islands east and southward through Antigua and Montserrat. The largest rainfall total reported from the islands is 82.6 mm from St. Thomas.

The NHC received a large number of ship reports of wind speeds of 34 kt or higher in northern latitudes while Erika passed through the North Atlantic shipping lanes.

The highest sustained surface wind report seen from the Azores Islands was 26 kt with a gust to 39 kt at Lajes Air Base at 1900 UTC on 15 September as Erika's center was passing 180 n mi to the northwest. A report from Flores at 2300 UTC on 15 September gave a gust to 76 kt. Lajes also had a gust to 91 kt atop a 61-m tower. A rainfall total of 59.7 mm was reported from Flores.

3) Casualty and damage statistics

The only effects to Puerto Rico were from the large waves and swells generated by the hurricane. Two surfers died in the northern and eastern waters due to the high wave action. Most of the islands of the northeastern Caribbean suffered minor damage from wave action and minor wind damage likely occurred at high elevations.

The passage of the hurricane caused the lower-tropospheric winds to blow from the southwest and advect a cloud of falling ash over Antigua from the active volcano on Montserrat.

4) Warnings

Hurricane warnings were issued for a number of the islands of the northeastern Caribbean Sea. Although hurricane conditions did not occur in the warning area, the storm passed sufficiently close to the islands to justify the warnings. NHC advisories indicated that tropical storm conditions could occur in the Azores Islands.

g. Tropical Storm Fabian, 4–8 October

Around 22 September, a tropical wave passed Dakar, Senegal, accompanied by a well-marked wind shift and considerable cloudiness between 8° and 12°N. The wave moved westward for several days, with no significant change in the associated convective activity, and reached the Lesser Antilles on 29 September. Surface

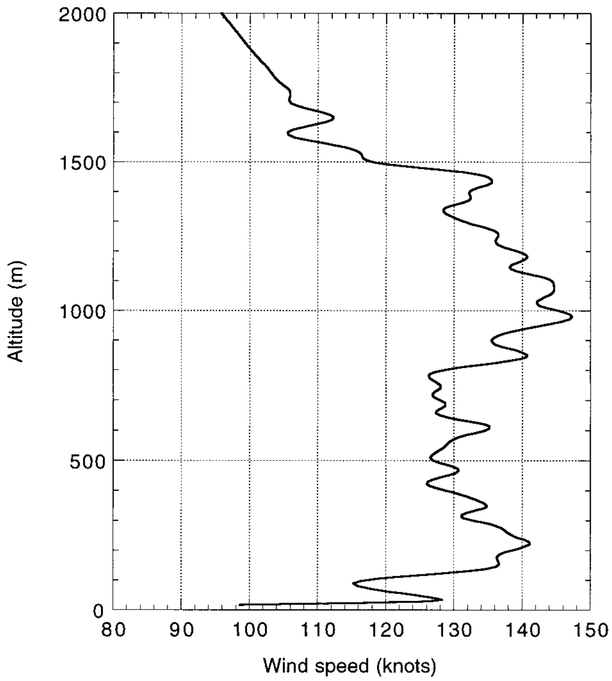

FIG. 8. Vertical profile of wind speed in Hurricane Erika eyewall near 2130 UTC 8 Sep 1997. Data obtained from GPS dropsonde deployed from NOAA P-3 aircraft. Figure provided by NOAA/Hurricane Research Division.

data indicated that a broad area of low pressure with a weak low-level circulation developed over the northern Windward Islands in association with the tropical wave. However, very strong westerly upper-level winds prevented the system from developing further. Nevertheless, reports of very heavy rains and gusty winds were received from some islands.

The circulation center moved toward the north-northwest and passed near Puerto Rico and the Virgin Islands. The system became better organized when it turned to the northeast and east, toward the same heading as that of the upper-level winds. A poststorm analysis of satellite images (not shown) indicates that a tropical depression formed at 1800 UTC 4 October. The depression consisted of a tight swirl of low clouds to the west of a cluster of deep convection. The thunderstorm activity fluctuated considerably during the tropical cyclone's lifetime with the low-level center intermittently under the convection. It is estimated that the depression reached tropical storm status at 1800 UTC 5 October and reached its minimum pressure of 1004 mb at 1200 UTC 7 October during one convective burst.

Operationally, the depression was not upgraded to tropical storm status until 1200 UTC 8 October, when the ship with call sign ZCBB7 reported a wind speed of 40 kt. The poststorm analysis shows that the system was becoming extratropical at that time and the reported winds were associated with a developing frontal zone.

The NHC received no reports of casualties or damage associated with Fabian, although locally heavy rains over the Lesser Antilles could have caused some minor damage.

h. Tropical Storm Grace, 16–17 October

Tropical Storm Grace formed from one of several cyclonic circulation centers that spun up along a frontal trough extending east-northeastward from the western Caribbean Sea to the central North Atlantic Ocean. Surface observations show that the center (an extratropical low) that became Grace formed just north of Hispaniola and that it reached gale strength near 0000 UTC on 15 October. One day later, a large area of deep convection developed over or just northeast of the low-level circulation center, suggesting that the system transformed into a tropical cyclone near 0000 UTC on 16 October. The system did not shed all of its extratropical characteristics, however. Most notably, the circulation remained elongated along the frontal trough and a band of deep convection appeared to link Grace to another low pressure center with gale force winds located about 500 n mi to the east-northeast.

Grace developed in an environment of southwesterly vertical wind shear, generally to the south of a large extratropical cyclone centered south of Newfoundland. The associated steering currents accelerated Grace to about 25 kt on an east-northeast to northeast heading. The limited available ship reports and intensity esti-

TABLE 4. Homogeneous comparison of official and CLIPER track forecast errors (n mi) for tropical storms and hurricanes in the Atlantic basin for 1997, and 1987–96 10-yr average. Forecast error is the great-circle distance between a forecast position and a poststorm analysis best track position for the same time. Range of track forecast error also shown.

	Forecast period (h)					
	0	12	24	36	48	72
1997 average official error	12	48	92	131	155	229
1997 average CLIPER error	12	63	135	197	244	412
(No. of cases)	(94)	(93)	(80)	(67)	(54)	(38)
1987–96 average official error	13	48	89	128	169	251
1997 official departure from 1987–96 average	−14%	+01%	+04%	+02%	−08%	−09%
1987–96 average CLIPER error	13	55	111	172	234	345
1997 average CLIPER departure from 1987–96 average	−14%	+14%	+21%	+15%	+04%	+20%
1997 official error range	0–43	5–184	19–328	12–372	25–436	44–484

TABLE 5. Homogeneous comparison of official and SHIFOR 1-min wind speed forecast errors (rounded to the nearest 0.1 kt) for tropical storms and hurricanes in the Atlantic basin for 1997, and 1990–96 7-yr average. Range of wind speed forecast error also shown. Error = forecast − observed.

	Forecast period (h)					
	0	12	24	36	48	72
1997 average official error	−2.4	−0.9	−0.8	−2.6	−3.8	−3.3
1997 average absolute official error	3.4	5.7	8.7	12.0	15.3	20.7
1997 average SHIFOR error	−2.4	−1.7	−1.6	−1.3	−3.2	−10.4
1997 average absolute SHIFOR error	3.4	7.0	9.7	12.6	15.9	19.9
(No. of cases)	(93)	(92)	(79)	(67)	(54)	(38)
1990–96 average official error	−1.7	−1.3	−1.5	−2.3	−3.6	−3.9
1990–96 average absolute official error	3.5	6.7	10.2	13.0	15.8	19.5
1997 average absolute official departure from 1990–96 average absolute official	−03%	−15%	−15%	−08%	−03%	+06%
1990–96 average SHIFOR error	−1.7	−1.1	−1.7	−2.5	−3.4	−5.6
1990–96 average absolute SHIFOR error	3.5	8.2	11.7	14.0	16.3	18.7
1997 average absolute SHIFOR departure from 1990–96 average error	−03%	−15%	−17%	−10%	−02%	+06%
1997 official error range	−20 to +5	−20 to +20	−25 to +20	−40 to +30	−45 to +30	−45 to +40

mates based on satellite pictures show that Grace was at its strongest, with 40-kt winds, at the time that it became a tropical cyclone. Thereafter, the storm appeared to weaken slowly and, on the morning of 17 October deep convection dissipated. This revealed a weak and diffuse low-level circulation that, over about a day, became indistinguishable from the frontal trough in which it was embedded.

3. Verification

For all cyclones operationally designated tropical or subtropical in the North Atlantic Ocean, Caribbean Sea, and Gulf of Mexico, the NHC issues an ''official'' forecast of the cyclone's center position and maximum 1-min wind speed at 10 m above the surface. These forecasts are issued at 6-hourly intervals, for the periods of 12, 24, 36, 48, and 72 h. After the hurricane season ends, the forecasts are evaluated by comparing the forecast positions and intensities to the poststorm-derived final best track of each cyclone.

Tables 4 and 5 show error statistics for 1997 official (NHC) forecasts of track and intensity, respectively. When reviewing the tables, one should bear in mind that there were few forecasts during 1997 due to the below average number of systems and the storms' generally short durations. Indeed, 37 of the 38 forecasts verified at 72 h occurred during Erika.

Table 4 shows that the average track errors in 1997 are comparable to the 10-yr average at periods through 36 h, and smaller at longer periods. In comparison, most errors of the forecast model based on climatology and persistence (CLIPER) (Neumann 1972) for the same periods were larger than normal. The higher than average CLIPER errors are consistent with most of the 1997 tropical storms and hurricanes occurring at high latitude, where CLIPER performs most poorly.

Table 5 indicates that NHC intensity forecast errors were, overall, a little smaller than the 10-yr averages and were comparable to the climatologically based intensity forecast model SHIFOR (Jarvinen and Neumann 1979). The NHC forecasts had a negative average bias at all periods suggesting that storms usually strengthened more quickly and/or weakened at a slower rate than the NHC forecast.

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