ANNUAL SUMMARY

Atlantic Hurricane Season of 1984

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ABSTRACT

A summary of the 1984 Atlantic hurricane season is given. Twelve tropical cyclones and one subtropical cyclone were tracked in the North Atlantic–Caribbean–Gulf of Mexico region. Diana was a landfalling hurricane on the North Carolina coast and Lili was a rare December hurricane.

1. Introduction

There were twelve named tropical cyclones during 1984 in the North Atlantic–Caribbean–Gulf of Mexico region. Five reached hurricane force and the remaining seven were tropical storms. In addition, there was one subtropical storm. These numbers compare with a long-term average of ten named tropical cyclones, of which six reach hurricane force. Statistics for this year are given in Table 1.

Figure 1 shows this season's storm tracks. Most of the tracks are in the Atlantic Ocean, except for one brief tropical storm in the southwest Gulf of Mexico and one hurricane originating in the eastern Caribbean Sea. Tropical storms Arthur, Bertha, Fran and Gustav can be traced back to disturbances that originated in the deep easterly flow near the west coast of Africa. Hurricane Klaus also originated in the deep tropics. However, the remaining named tropical cyclones formed at higher latitudes and their origins are identified with nontropical frontal cloud systems.

In addition to the storms shown in Fig. 1, there was an extratropical storm over Thanksgiving Day that caused severe beach erosion and coastal flooding along most of the Florida east coast.

A primary observing system for tracking Atlantic hurricanes was the GOES-East geostationary satellite. This system failed on 30 July and GOES-West was shifted eastward from its normal position to partly compensate for the lost satellite coverage. GOES-West was in its new position at 98°W longitude by the end of August and remained there until November. The first named storm did not occur until the end of August, when GOES-West was already stabilized in its new position. It is planned to shift GOES-West to the east again during July 1985.

While the number of named tropical cyclones is a measure of a season's activity, another valid measure is the duration of these cyclones. Figure 2 shows a time history curve of the number of hurricanes per year since 1971 and also a curve of the number of hours of hurricane duration per year. The two variables have similarly shaped curves and the linear correlation coefficient between them is 0.90 for the 14-year period. In 1984, five hurricanes resulted in a total of 414 hurricane hours. Compare this with the year 1977, a year of short-lived hurricanes, when five hurricanes produced only 174 hurricane hours. Since 1971, hurricanes lasted an average of about 80 hours. Thus, the 1984 season is near normal with respect to the duration of hurricanes as well as with respect to the number of hurricanes.

2. Individual storms

a. Subtropical storm, 18–21 August

Bermuda surface observations indicated that a surface low pressure center had formed just north of that island on 18 August, within a frontal trough that had moved eastward off the United States coast three days earlier. This low was identified as a subtropical depression. It moved northeastward, reaching subtropical storm strength on 19 August.

A ship located near the storm center at 0000 GMT 20 August reported a wind speed of 21 m s^{-1} and a surface pressure of 1004 mb. The storm's maximum sustained surface wind and minimum sea level pressure during its lifetime are estimated at 26 m s^{-1} and 1000 mb, respectively.

On 21 August, the storm merged with frontal cloudiness at a position about 900 km east of Newfoundland. Satellite tracking of this storm was somewhat degraded, as its location was on the eastern fringe of GOES-West coverage.

TABLE 1. 1984 Hurricane season statistics.

Number	Name	Type*	Dates**	Maximum sustained wind† ($m\ s^{-1}$)	Lowest pressure (mb)	U.S. Damage ($millions)	Deaths
1	—	ST	8/18–8/21	26	1000		
2	Arthur	T	8/28–9/05	23	1004		
3	Bertha	T	8/30–9/04	18	1007		
4	Cesar	T	8/31–9/02	26	989		
5	Diana	H	9/08–9/16	59	949	65	3
6	Edouard	T	9/14–9/15	28	998		
7	Fran	T	9/15–9/20	28	994		
8	Gustav	T	9/16–9/19	23	1006		
9	Hortense	H	9/23–10/02	33	993		
10	Isidore	T	9/25–10/01	26	999	1	1
11	Josephine	H	10/07–10/21	46	965		
12	Klaus	H	11/06–11/13	41	971		
13	Lili	H	12/12–12/24	36	980		

* T: tropical storm, wind speed 17–32 $m\ s^{-1}$.
H: hurricane, wind speed 33 $m\ s^{-1}$ or higher.
ST: subtropical storm, wind speed 17–32 $m\ s^{-1}$.
** Date begins at 0000 GMT.
† Estimated maximum one-minute average surface wind speed.

b. Tropical Storm Arthur, 28 August–5 September, and Tropical Storm Bertha, 30 August–4 September

Both of these storms originated from African tropical waves in late August. Arthur developed a circulation on 28 August about 1000 km east of Trinidad and Bertha did the same on 30 August, another 1000 km east northeast of Arthur's place of origin. Both moved toward the northwest, briefly reaching storm strength, and then gradually dissipated at sea.

c. Tropical Storm Cesar, 31 August–2 September

Cesar was detected on 30 August, when satellite pictures showed a low-level cloud circulation located about 1000 km east of Jacksonville, Florida. It moved northeastward and slowly became better organized. At 1200 GMT 31 August, a ship reported a wind speed of 18 $m\ s^{-1}$ from a position 100 km west of the circulation center and Tropical Storm Cesar was named. At this time, Cesar was centered midway between Bermuda and Nova Scotia.

For the next two days, the storm continued moving northeastward. Maximum winds gradually increased to 26 $m\ s^{-1}$ as Cesar merged with an extratropical low pressure system to the east of Newfoundland.

d. Hurricane Diana, 8–16 September

1) GENERAL DESCRIPTION

Diana was first observed as a developing low on the end of a frontal trough just north of the Bahama Islands. A ship on 8 September reported a surface wind speed of 18 $m\ s^{-1}$ and the storm was named. Figure 3 is a visible satellite image of the developing storm. The associated frontal system is seen to the northeast of the storm center in this figure.

On the next day, Diana approached within 100 km of the Florida coast and turned northward. By 10 September, Diana had intensified to hurricane force and was moving north-northeastward on a course parallel to the Georgia and South Carolina coasts. The National Weather Service (NWS) issued hurricane warnings along the United States east coast from Georgia through North Carolina at 1300 GMT 10 September. A satellite view of the hurricane four hours after warnings were issued is shown in Fig. 4.

Over the next two days, Diana intensified and moved close to Cape Fear, North Carolina. The eye of the hurricane is clearly visible nearing the coast in Fig. 5. However, Diana did not move directly across the coast. For a period of 30 hours, the center of the hurricane turned to the right, in a tight anticyclonic loop. Also, the hurricane began to lose strength. A detailed track during this looping period is shown in Fig. 6 based on NWS radar observations from Wilmington, North Carolina.

Diana's center crossed the coast near Cape Fear due south of Wilmington at approximately 0700 GMT 13 September and moved inland. It then turned northeastward, moved back offshore and headed to sea.

2) DATA

From its formation on 8 September to landfall on 13 September, Diana was under continuous surveillance by reconnaissance aircraft. These aircraft penetrated into the storm center 50 times during a 111-

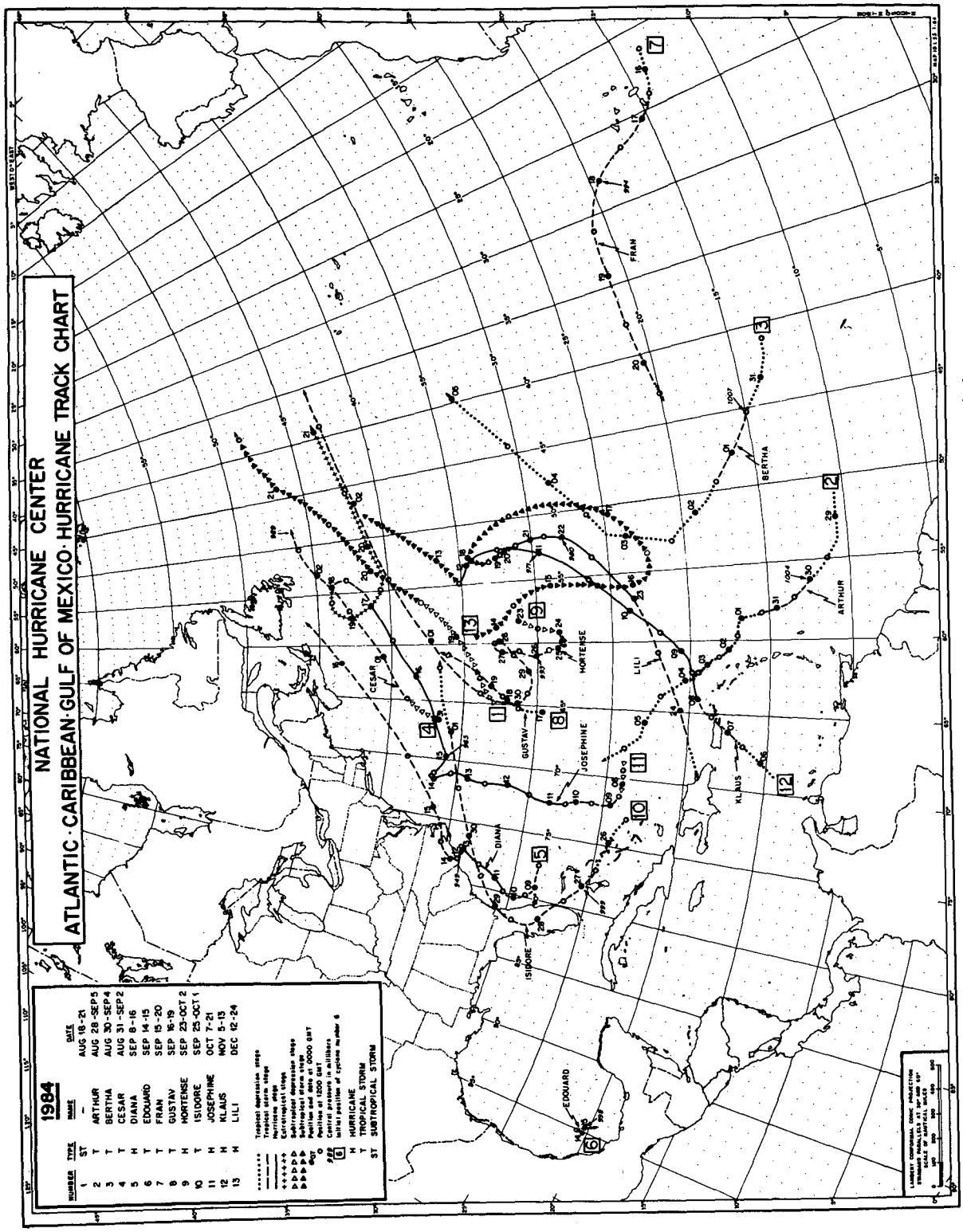

FIG. 1. Tracks of the 1984 tropical storms, hurricanes and subtropical storms.

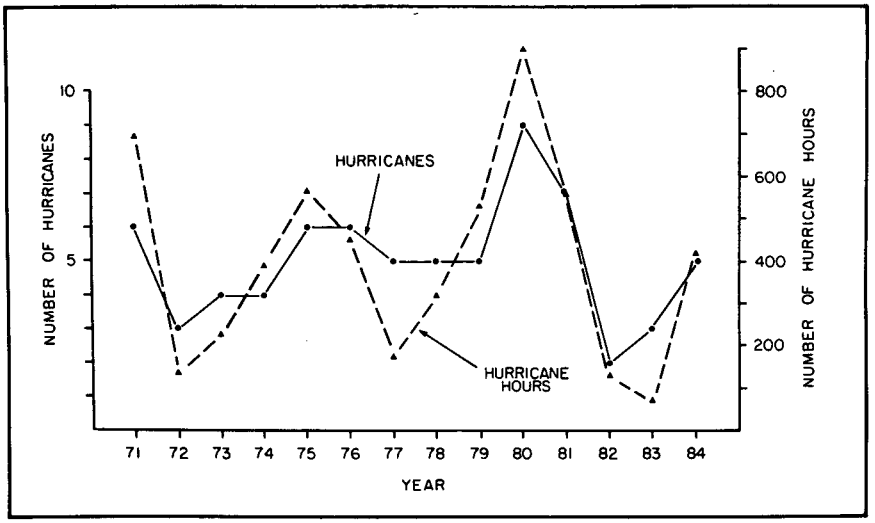

FIG. 2. Graph of number of hurricanes per year (left vertical axis) and number of hurricane hours per year (right vertical axis).

hour period and this averages to one center position fix every 2.2 hours.

Figure 7 is a sample operational plot of 850 mb high density data collected by National Oceanic and Atmospheric Administration (NOAA) aircraft several hours after Diana reached hurricane force. This mission occurred several hours before landfall. A sample plot of 700 mb data collected by a U.S. Air Force (USAF) aircraft is shown in Fig. 8. This data was collected several hours after Diana reached hurricane

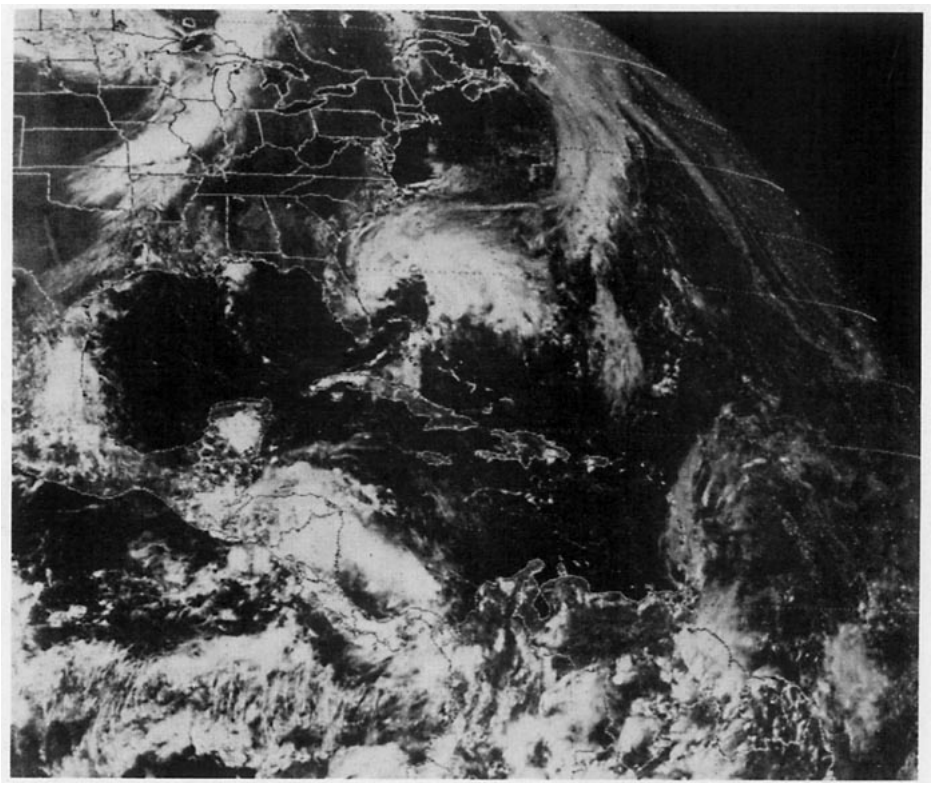

FIG. 3. GOES-West visible satellite picture of Diana as a developing tropical storm at 1930 GMT 8 September 1984.

FIG. 4. GOES-West visible satellite picture of Hurricane Diana at 1700 GMT 10 September 1984.

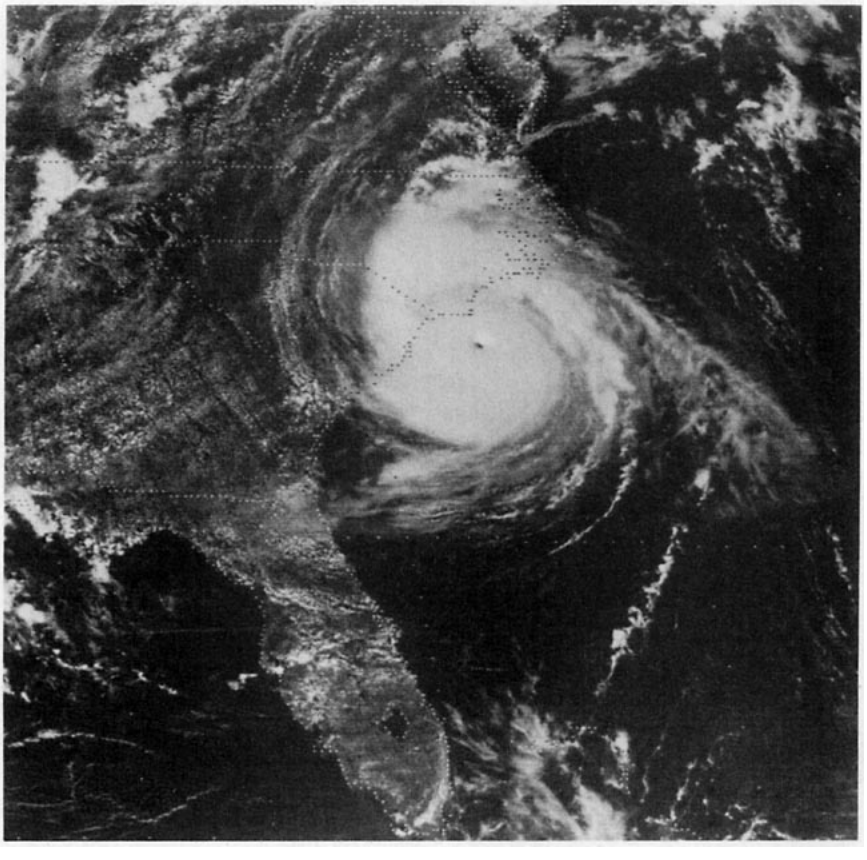

FIG. 5. GOES-West visible satellite picture of Hurricane Diana at 1900 GMT 11 September 1984. The well-defined eye is located near Cape Fear, North Carolina.

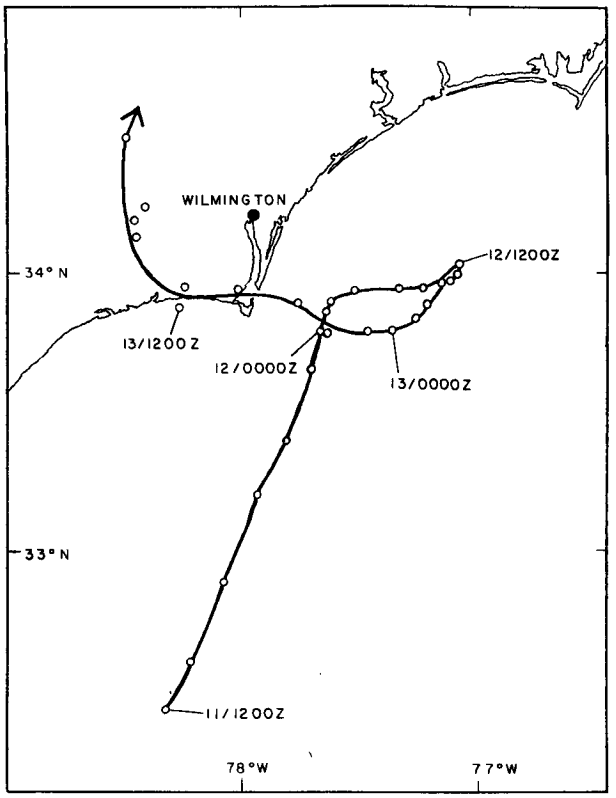

FIG. 6. Track of Hurricane Diana's center during 11–13 September. Open circles on the track are two-hourly position estimates from the Wilmington, North Carolina NWS radar.

status and wind speeds just over minimum hurricane force are plotted east and west of the circulation center.

Reconnaissance central pressure measurements are plotted in Fig. 9. Sea level pressure is either measured by dropwindsonde or estimated from aircraft pressure/altitude data. The central pressure reached its lowest value of 949 mb at 0000 GMT 12 September, when the eye was within 40 km of Cape Fear. During the next 30 hours until landfall, when the center was looping offshore, the central pressure increased by 28 mb. It is estimated that maximum sustained winds were 59 m s^{-1} during the time of the 949 mb minimum pressure. Wind speeds of 70 m s^{-1} were measured by aircraft at the 850 mb level near this time.

The highest sustained (one-minute average) wind observed on land was 52 m s^{-1} at the U.S. Coast Guard (USCG) facility at Oak Island. This observation was taken at 2340 GMT 11 September, when Diana was at maximum intensity and centered a short distance offshore near Cape Fear. The anemometer was at an elevation of 20 m.

Peak surface observations of pressure, wind, tides and rainfall are listed in Table 2. The highest tide height (above normal predicted astronomical tide) or storm surge was 1.7 m at Carolina Beach, located slightly north of the point of landfall. The maximum rainfall total was 348 mm at Wilmington. This amount was accumulated over a three-day period. Rainfall totals decreased sharply, inland from Wilmington.

A single tornado was reported in Nash County in northeast North Carolina. Total storm-related damage is estimated at $65 000 000, of which $26 000 000 was agricultural damage. Three deaths have been attributed to Diana.

e. Tropical Storm Edouard, 14–15 September

A reconnaissance plane investigating an area of disturbed weather observed a small circulation center in the southwestern Gulf of Mexico late on 13 September. The circulation hovered near the Mexican coast and intensified, reaching a maximum sustained surface wind of 28 m s^{-1} at 0000 GMT 15 September. Then the storm quickly weakened. Its remnants moved southward and inland near Vera Cruz, Mexico during 15 September.

f. Tropical Storm Fran, 15–20 September

An African disturbance developed a low-level circulation on 15 September near the Cape Verde Islands in the eastern Atlantic. Tropical storm Fran was named on the next day based on intensity estimates made from satellite pictures. The storm moved northwestward for two days and westward for the next two days. It reached maximum intensity on 17 and 18 September, when surface winds were estimated at 28 m s^{-1}. Fran dissipated at sea on 20 September.

This storm appeared on the far eastern boundary of the GOES-West satellite coverage and the European METEOSAT geostationary satellite provided useful supplementary coverage.

g. Tropical Storm Gustav, 16–19 September

Gustav formed on 16 September about 400 km south of Bermuda. This formation resulted from the interaction between a tropical wave and an upper-level circulation. The system moved north to northeastward, passing near Bermuda on 17 September and it became a tropical storm on 18 September. Gustav then quickly merged with frontal cloudiness at a location 500 km northeast of Bermuda. Maximum sustained winds are estimated at 23 m s^{-1}.

h. Hurricane Hortense, 23 September–2 October

Satellite pictures showed a cloud circulation, east of Bermuda, developing along an extensive frontal cloud band during 20–22 September. A ship reported a sustained wind speed of 28 m s^{-1} on 23 September

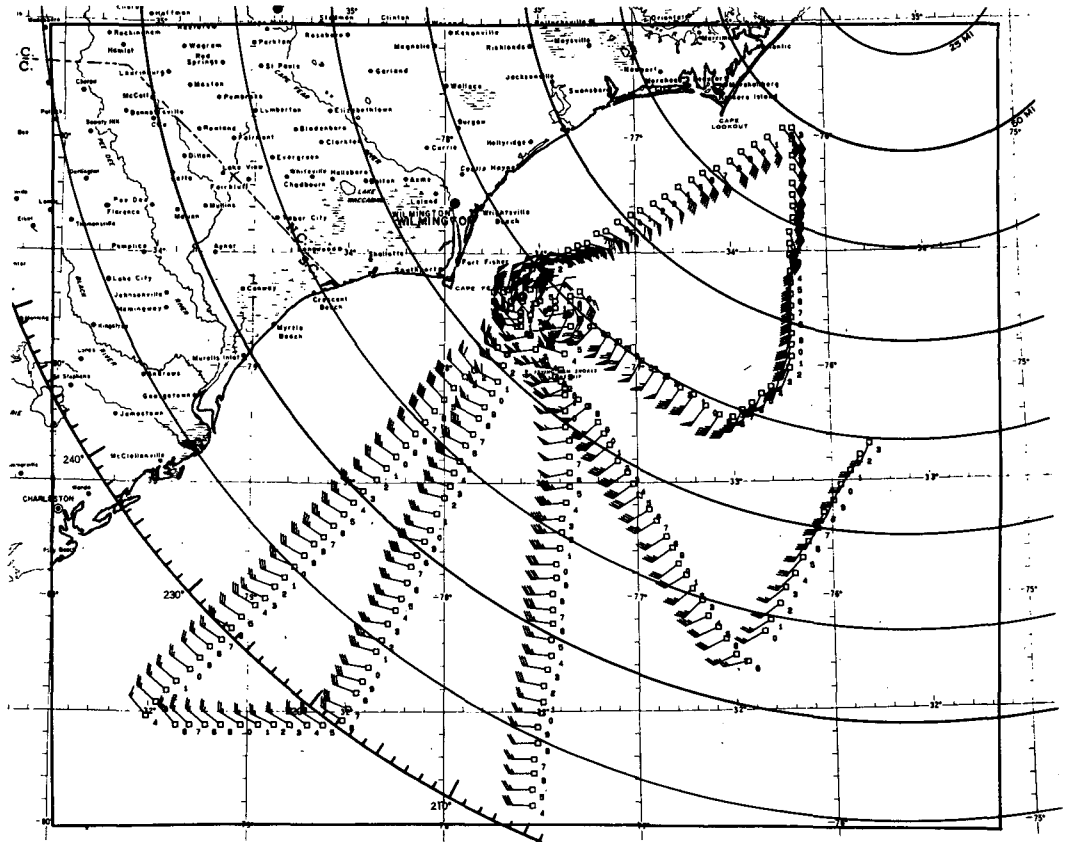

FIG. 7. Composite, operational plot of NOAA reconnaissance high-density data late on 12 September. Observations are at one-minute intervals. Wind bars are in knots.

and Hortense was named a tropical storm on the next day, when a reconnaissance aircraft confirmed the presence of a closed low-level circulation with a central pressure of 998 mb.

Hortense's track was erratic (Fig. 1) and three 180-degree turns were made during a seven-day period. This occurred over an area extending several hundred kilometers east of Bermuda.

On 25 September, a reconnaissance aircraft measured a 36 m s^{-1} wind speed and a sea level pressure of 993 mb. Based on this information, Hortense was designated a minimal hurricane for a 12-hour period beginning at 1800 GMT 25 September.

By 30 September, the weakened storm was making its final turn toward the northeast and the center passed close to Bermuda. Surface winds there backed from easterly at 5 m s^{-1} to westerly at 8 m s^{-1} during a six-hour period as the center passed just east of the island.

Hortense accelerated toward the northeast and merged with an extratropical low pressure system in the north Atlantic. This extratropical low was later responsible for six deaths and damages in France and Spain, according to newspaper reports.

i. Tropical Storm Isidore, 25 September–1 October

Isidore developed near the southeastern Bahamas on 25 September, when a closed low-level circulation formed within a frontal cloud system. This is the same front that spawned Hortense two days earlier and 1500 km further northeast.

The depression moved northwestward through the Bahamas, intensifying to a tropical storm on 26 September. The storm moved onshore across the central Florida east coast on 27 September, recurved and moved back offshore across the north Florida east coast 36 hours later. Isidore then accelerated toward the northeast, paralleling the Carolinas and was absorbed within a frontal system on 1 October, while located 500 km northeast of Bermuda.

Gale warnings were issued by the NWS during 26–30 September along the Atlantic coast from the Florida Keys northward to Virginia and also along the upper west coast of Florida. Some confusion concerning warnings and evacuation occurred when a private meteorological service advised its radio station subscribers that Isidore was expected to intensify to hurricane force.

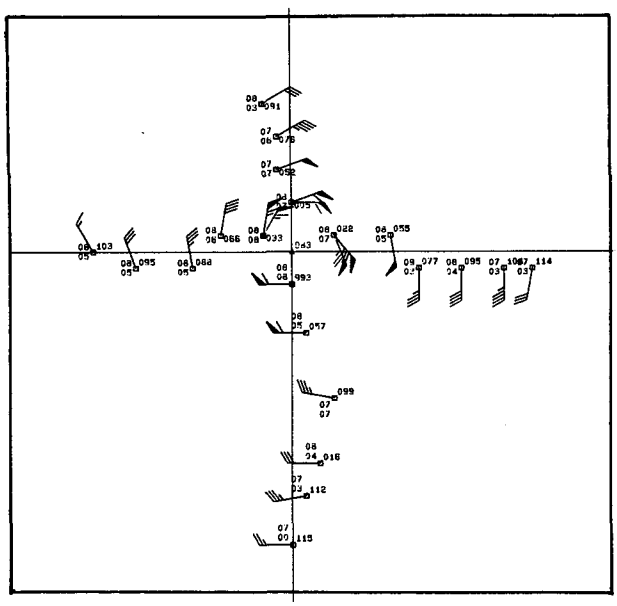

FIG. 8. Composite, operational plot of USAF reconnaissance data from Hurricane Diana during 1945–2112 GMT 10 September 1984. Observations are approximately 25 km apart. Wind barbs are in knots.

The highest sustained wind reported over land was 21 m s^{-1} at Camachee Cove, Florida on 28 September. Maximum flight-level reconnaissance winds were 28 m s^{-1}, both before and during the storm's movement over land. The minimum surface pressure was 999 mb, measured by reconnaissance aircraft on 26 September, while the storm was in the Bahamas.

Rainfall accumulations were in the 125–175 mm range, over north Florida. Storm surge values ranged up to just under one meter above normal, and this caused beach erosion along portions of the Florida east coast. One death in central Florida was attributed to Isidore and the damage estimate is $1 000 000.

Isidore was the last of eight named tropical cyclones to occur during the month of September. This is the most named storms in one month, on record, since 1886.

j. Hurricane Josephine, 7–21 October

A depression formed just east of the Bahama Islands on 7 October, from disturbed weather generated by a frontal trough. Drifting westward, the system strengthened to a tropical storm on 8 October. Josephine turned northward on the next day and reached hurricane force on 10 October.

The hurricane moved slowly northward until 14 October, when it stalled and turned sharply eastward away from the eastern seaboard. Josephine then headed northeastward across the North Atlantic shipping lanes. The track (Fig. 1) shows a cyclonic loop while the storm was weakening during 17–19 October, about 500 km south of Newfoundland. Its remnants were tracked heading east-northeastward for a final 36 hours.

Based on reconnaissance and satellite data, the maximum sustained surface winds are estimated at 46 m s^{-1} during 12 October. The minimum surface pressure of 965 mb occurred more than 48 hours later. Josephine was a hurricane for seven days and, while paralleling the United States east coast, was responsible for high tides and wave action along the barrier islands from North Carolina to Massachusetts.

Two observational field programs were conducted during Hurricane Josephine. Dropwindsondes were released from NOAA aircraft during 10, 11 and 12 October, to provide a comprehensive description of the wind field within 1000 km of Josephine's center in the middle and lower troposphere. Josephine was moving northward at an average speed of 3 m s^{-1} during this time. The Omega dropwindsonde program is described by Burpee *et al.* (1984). Also, three NOAA drifting data buoys were successfully deployed into the path of the storm by USAF aircraft on 10 October.

k. Hurricane Klaus, 5–13 November

Surface winds were westerly along the north coast of Venezuela on 3 November. Three days later, a closed surface circulation formed in the eastern Caribbean and the low was upgraded to a tropical storm at 2200 GMT 6 November when centered just south of Puerto Rico. Gale warnings were issued for Puerto Rico, the Virgin Islands, the Netherlands Antilles of the Leeward Islands, St. Kitts-Nevis and Anguilla.

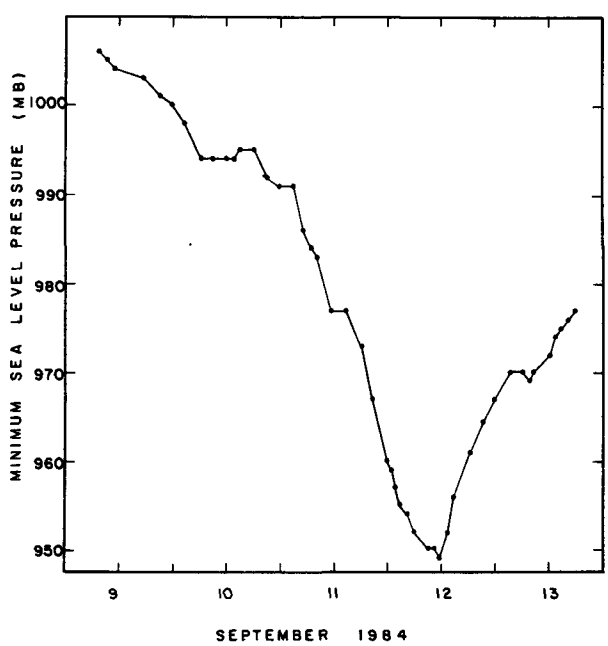

FIG. 9. Hurricane Diana minimum sea level pressure measurements from reconnaissance aircraft.

TABLE 2. Hurricane Diana peak surface observations, September 1984.

Location	Pressure (mb)		Wind ($m\ s^{-1}$)			Tide (m)	Rain (mm)
		Date/time (GMT)	1-min avg.	Gust	Date/time (GMT)	hgt abv normal	Storm total
Florida							
Daytona Beach	1008	10/0000	11	15	09/2145	0.6	68.6
Jacksonville Beach			13	21	10/0130		
Jacksonville NWS	1009	10/0948	9	11	09/1916	0.8	79.5
Melbourne	1010	09/1000		14	09/0000		
St. Augustine Inlet				31	10/0110		
Vero Beach	1011	09/0851		13	08/1656		
Georgia							
Savannah NWS	1010		9	13	09/2145		9.1
Tybee USCG			11	15	10/2200		
South Carolina							
Charleston NWS	1008	11/0800	12		11/1803		
Charleston (downtown)						0.3	
Crescent Beach FAA	1006	13/1550	20		13/1550		
Dillon							50.8
Florence FAA	1010	11/1851	8	13	13/1149		
Myrtle Beach USAF	1008		16		13/1420		
Pee Dee							34.0
North Carolina							
Cape Hatteras NWS	1002	14/1800	14	20	14/1350	0.3	33.0
Carolina Beach			39		13/0345	1.7	
Cherry Point USMC						0.5	
Diamond Shoals			22	29	14/1200		
Duck NWS			12	24	15/0000		
Elizabeth City FAA			15		14/1900		
Elizabeth City USCG							94.5
Figure 8 Island				34			
Ft. Fisher			31	41	13/0205		
Ft. Macon USMC			18	26		1.2	
Frisco Pier						0.4	
Holden Beach	1001		31		11/2250	0.6	
Kure Beach				41			
New Hanover Airport			20	33	13/0653		
New River Inlet						0.6	
Oak Island USCG			52		11/2340		
Ogden			15	34	13/0640		
Oriental						0.6	
Shallotte			22	31	13/0905		
Snows Cut Loran				47			
Southport	969	13/0610	49		13/0851		
Southport nuclear power plant			22	43	13/0915		
Supply	1003		27		11/2327		
Wilmington Loran			41				
Wilmington NWS	1000	12/0050	21	33	13/0640	1.6	348.4
Wrightsville Beach			15	26	13/0100		
Virginia							
Norfolk Int'l Airport			17		14/1957		27.4

Klaus moved northeastward into the Atlantic at the forward speed of 4 $m\ s^{-1}$ and intensified, reaching hurricane force at 0000 GMT 8 November while centered 200 km northeast of Puerto Rico. Forward speed increased to 9 $m\ s^{-1}$ over the next three days as Klaus continued moving into the north Atlantic and intensifying. The hurricane then decelerated and weakened, finally merging with an extratropical system on 13 November.

The central pressure dropped to its lowest value of 971 mb at 0000 GMT 11 November and the maximum surface wind speed estimate was 41 $m\ s^{-1}$.

Strong southwesterly winds affected the Virgin and Leeward Islands for several days, resulting in onshore gales and rough seas along the normally protected south and west sides of these islands. This caused considerable damage to marine interests throughout the northeast Caribbean.

Rainfall totals of up to 150 mm were reported in the islands, and freshwater flooding occurred in Puerto Rico.

l. Hurricane Lili, 12–24 December

Lili is only the third December hurricane on record in the Atlantic basin since 1886. Formation began on 11 December, along a stationary front south of Bermuda. The system moved northeastward and intensified, becoming a subtropical storm by 13 December. For the next ten days, the storm moved around in a large cyclonic loop over an area extending 1500 km eastward from Bermuda.

Convection gradually increased near the storm center. A ship near the center reported a wind speed of 32 m s^{-1} and a pressure reading of 982 mb on 20 December, which indicated that the system was becoming a hurricane.

Lili headed toward the northeast Caribbean, and a hurricane watch was issued for the Virgin Islands and Puerto Rico on 22 December. However, Lili weakened 24 hours later and diminished to a disorganized rain area near Haiti on 24 December.

Acknowledgments. Portions of the storm summaries were prepared by Robert A. Case, Harold P. Gerrish and Robert C. Sheets. Joan David's assistance with the track chart and other graphics is greatly appreciated. A. Barry Damiano programmed the computer graphics in Figs. 7 and 8.

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Burpee, R., D. Marks and R. Merrill, 1984: An assessment of Omega dropwindsonde data in track forecasts of Hurricane Debby (1982). *Bull. Amer. Meteor. Soc.*, **65**, 1050–1058.