THE HURRICANE SEASON OF 1965

ARNOLD L. SUGG*

U.S. Weather Bureau Office, Miami, Fla.

1. GENERAL SUMMARY

Six tropical cyclones, four of hurricane intensity developed over the tropical Atlantic waters during 1965 (fig. 1). This is the smallest number since 1946 except for the 1962 season when there were only five. The average is ten per year during the past three decades. Of the four hurricanes, only one, Betsy, made landfall, first striking the Bahamas and southern Florida and later devastating the central Gulf of Mexico coastal area. Betsy was the most destructive hurricane of record. The damage in Florida was not as great as the amount attributed to Donna (1960) or to Dora (1964), but in Louisiana, damage from Betsy alone exceeds that from any other hurricane by millions. Even if the damage figure were adjusted for the increased property evaluation over the years, the devastation caused by Betsy probably would equal or exceed that attributed to any of the other major natural disasters of all time. See table 1 for a comparison of damage figures for a few selected hurricanes. Table 2 shows damage and casualty figures for the 1965 season. Hurricane days in 1965 totaled 30, which is slightly below average (table 3).

According to Green [1], in his description of the general circulation for August, "Formation of tropical cyclones in the Atlantic was encouraged by . . . height anomalies positive in the north decreasing to negative in the Tropics." Two major changes in the circulation from August to September were noted by Stark [2]. One was the development of a full-latitude trough over North America giving 700-mb. negative height anomalies from eastern Canada through the Northern Plains. The other was 700-mb. height increases over the Gulf of Alaska to 480 ft. above normal, establishing a record height anomaly for September for North America and adjacent areas. This pattern corresponds to Ballenzweig's [3] composite chart for minimum tropical cyclone incidence for North America. Dickson [4] stated that the general circulation in October ". . . underwent a complete reversal . . ." in conjunction with progression of most long wave features in the Pacific and North America. With this change, it was noted that the mean westerlies reached far to the south into the Gulf of Mexico and the southwestern North Atlantic—a feature not associated with above-normal tropical cyclone development. Table 4 shows the 850-mb. temperature anomalies for three stations. Table 5 indicates that the middle and upper troposphere was also cooler than normal, except at Swan Island where thickness values were slightly above normal. The magnitude of the departures from normal of temperature (thicknesses) was not great, but the cool air in the Tropics plus the unfavorable general circulation which developed in September must be considered major factors accounting for the weak tropical activity in 1965.

TABLE 1.—*Damage (in millions of dollars) sustained in United States and Canada from a few selected hurricanes*

Hurricane	Damage (Millions of dollars)
Betsy 1965	$1,419.8
Diana 1955	800.0
Carla 1961	400.0
New England 1938	387.1
Donna 1960	386.5
Hazel 1954	251.6
Audrey 1957	150.0
Florida 1926	111.8
Keys 1935	6.0
Ginny 1963	.4 (loss more than offset by beneficial rains)
Dora 1964	250.0
Cleo 1964	128.5
Hilda 1964	125.0
Isbell 1964	10.0

TABLE 2.—*Damages and casualties, hurricane season 1965*

Date	Storm	United States		Other Areas	
		Deaths	Damages	Deaths	Damages
June 11–18	Unnamed T.	0	Minor	0	0
Aug. 21–26	Anna H.	0	0	0	0
Aug. 27–Sept. 12	Betsy H.	75	$1,419,800,000	1	$14,000,000
Sept. 16–Oct. 1	Carol H.	0	0	0	0
Sept. 24–30	Debbie T.	0	25,000,000	0	0
Oct. 12–19	Elena H.	0	0	0	0
Total	2(T) 4(H)	75	$1,444,800,000	1	$14,000,000

TABLE 3.—*Hurricane days*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1954						1		5	8	16		1	31
1955	4							22	28	2			56
1956							1	9	2		3		15
1957						3			19				22
1958								14	16	5			35
1959						1	2		10	11			24
1960							4	2	13				19
1961							4		*35	9	1		49
1962								1		10			11
1963								11	7	23			41
1964								7	33	6			46
1965								6	*21	3			30
Total	4	0	0	0	0	5	11	77	192	85	4	1	379

*If two hurricanes are in existence on one day, this is counted as two hurricane days.

*Portions of this article are based upon individual storm accounts by Messrs. G. B. Clark, G. E. Dunn, E. C. Hill, and R. H. Kraft of the Miami Weather Bureau and S. C. Pearce of the National Hurricane Research Laboratory. Other contributors were W. C. Connor, New Orleans Weather Bureau, E. W. Hoover, Washington Weather Bureau; and J. A. Colón, San Juan Weather Bureau; and the many state climatologists, especially K. Butson, Gainesville, Fla.; and E. J. Saltsman, New Orleans, La.

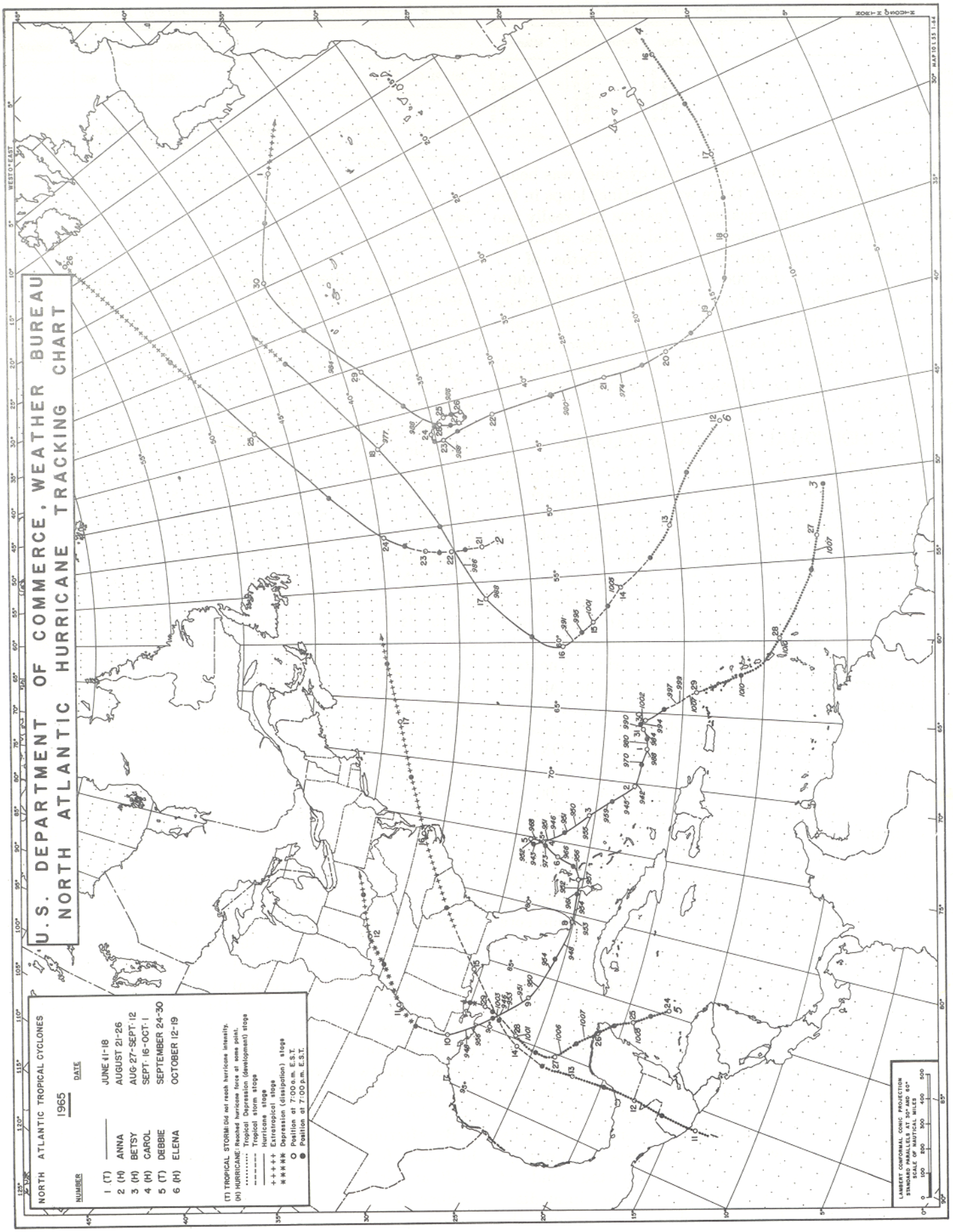

FIGURE 1.—Tracks of hurricanes and tropical storms, North Atlantic, 1965 season.

TABLE 4.—*850-mb. temperature anomalies (° C.) 1965*

	San Juan	Swan Island	Miami
June	−1.0	−0.3	−0.9
July	−0.4	0.0	−0.1
August	−0.9	−0.2	−0.7
September	−0.3	−0.5	−0.6
October	−0.4	−0.1	−0.3

TABLE 5.—*500–200-mb. thickness (decameters) 1965. Normal 651*

	San Juan	Swan Island	Miami
July 21–Oct. 26	648	652	649

TABLE 6.—*Number of loops in tropical cyclone tracks. (Looping cyclones total 39—4 of which had double loops.)*

Period	Total Tropical Cyclones	Clockwise Loops	Counter-Clockwise Loops
1901–1965	518	22	21

Even though the number of tropical cyclones was below normal during this season, there were distinct loops in the tracks of two of the hurricanes—a feature not really too common when one considers the total number of storms and hurricanes. According to Cry [5] "Paths of 37 tropical cyclones, of the 500 tracked during 1901–1963, contained single loops, and four had two loops. Clockwise (20) and counterclockwise (21) loops were almost equally frequent; of the double cases, three were counterclockwise, only one was clockwise." There were no looping tropical cyclones in 1964 and two (Betsy and Carol) in 1965. An up-to-date tabulation is shown in table 6.

2. INDIVIDUAL TROPICAL CYCLONES

UNNAMED TROPICAL STORM, JUNE 11–18.—During the period June 9–10, a cut-off upper Low developed over the northwestern Gulf of Mexico from a shearing trough in the westerlies. The effects of this Low reached well into the Tropics and were probably responsible for the northward movement of a vortex off the intertropical convergence zone. On June 11 a TIROS picture indicated a disturbed area along and south of the Guatemalan coast. During the next 48 hr. the disturbance moved into the Gulf of Mexico, passing just west of Merida, Yucatan. On the afternoon of June 13, a reconnaissance aircraft found evidence of a Low at the 700-mb. level and surface winds estimated at 40 m.p.h. some distance to the east of the Low. The 0600 GMT June 14 report from NOMAD, the automatic weather buoy at 25° N., 90° W., indicated winds near 45 m.p.h. and a sea level pressure of 1006 mb. (29.71 in.). This suggested that some intensification was occurring. A Navy reconnaissance aircraft found no well defined circulation but did report a large, flat low-pressure system with lowest pressure of 1005 mb. (29.68 in.), showery weather, and strongest winds well to the east of the Low as on the previous day. It was not a cold core system.

The approach of an active trough in the westerlies turned the storm toward the northeast and increased its forward speed to 25 m.p.h. The Low moved into the Florida Panhandle between Valparaiso and Panama City on the morning of June 15. An ill-defined Low, the remnants of the storm, moved through the Carolinas and eventually developed into an active wave on a frontal system off the middle Atlantic coast on June 17–18.

Highest sustained winds reported on the Florida Panhandle were 50 to 60 m.p.h., with gusts to 75 m.p.h., at Alligator Point, while Dog Island reported winds of 60 m.p.h. Damage was confined to the immediate coast in the vicinity of Apalachicola and was mainly the result of high tides of 2 to as much as 6 ft. above normal. General rains in excess of 5 in. were reported in the Tallahassee-Apalachicola area. However, there was no flooding of consequence.

HURRICANE ANNA, AUGUST 21–26.—On August 16 the TIROS satellite photographed a weak circulation just northwest of the Cape Verde Islands. Data during the next few days were sparse but this was probably the first indication of Anna, and on August 21 the system was of tropical storm intensity some 800 mi. east of Bermuda.

During the morning of the 23d, a TIROS picture indicated an area 180 mi. in diameter with an eye visible near 36° N., 51° W. By afternoon the aircraft carrier *Randolph* reported a well-defined eye displayed by radar at 37° 45′ N., 51° 53′ W. At this time, Anna, probably of hurricane intensity, was moving on a northerly course. On the 24th several ships reported winds of 60 to 70 m.p.h., and on the 25th the SS *Quisgueya* reported winds of 85 m.p.h. and 15- to 30-ft. seas. Anna was about 600 mi. northwest of the western Azores and moving on a rapidly accelerating northeastward course. The hurricane became extratropical west of Ireland on the 26th.

Anna was most unusual, since the development into a hurricane occurred at a higher latitude in the Atlantic than ever observed before. The reader is referred to [5] and [6] for the climatology of hurricane development.

There was no known damage or loss of life attributed to Anna.

HURRICANE BETSY, AUGUST 27–SEPTEMBER 10.—The TIROS weather satellite photographed a disturbed area on August 23 in the eastern Atlantic near 7.5° N., 29.5° W. Reasonable extrapolation shows that this was probably the same system that was discovered by aircraft reconnaissance as a weak tropical depression on August 27, some 350 mi. east-southeast of Barbados. By midday the central pressure was 1007 mb. (29.74 in.) and by evening the depression was named Betsy. No intensification occurred until two days later after Betsy had passed through the Lesser Antilles. No significant damage was reported from the islands.

By afternoon of the 29th, Betsy had intensified, with hurricane force winds reported from reconnaissance aircraft and it remained a mature hurricane through September 10.

During the formative stages of Betsy from the 28th to

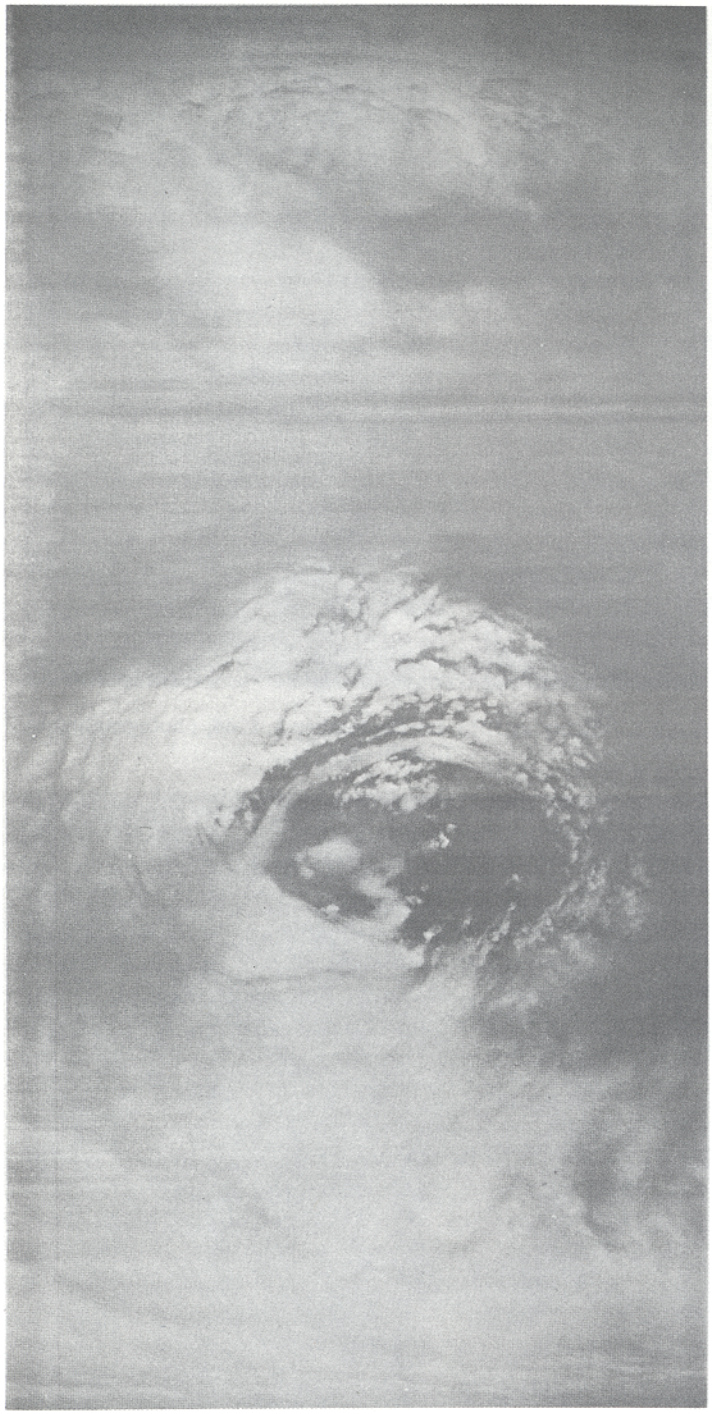

FIGURE 2.—Hurricane Betsy at 1250 EST September 2, 1965, photographed by Air Force Reconnaissance at 11 miles above the earth.

the 29th, there existed an east-west trough of low pressure at 200 mb., to the north of the depression, generally between latitudes 20° N. and 25° N. Immediately above Betsy, ridge conditions prevailed; and, while reports were sparse, the winds were light and indicated no marked outflow. However, by the 29th, the day on which rapid intensification occurred, Betsy had moved to the northwest of the Leeward Islands and was located only a short distance south of the upper trough. By now the 200-mb. winds above Betsy were southwesterly 55 m.ph.; and, from the analysis, one would conclude that moderate ouflow was occurring as a result of speed divergence.

There was a second marked intensification during September 1 and 2 when the central pressure fell approximately 40 mb. to 942 mb. (27.82 in.), the lowest recorded during the hurricane's life history. This deepening cannot be readily explained because of lack of data. Figure 2 is a photograph of Betsy taken at 1250 EST September 2 from an Air Force reconnaissance aircraft 11 mi. above the earth. Figure 3 is a TIROS X photograph of the hurricane taken at 1043 EST, September 3.

The Betsy track is an interesting one since pressure (height) rises to the north completely blocked and changed a well-established northwestward course on two occasions. In both cases there were reductions in forward speed just prior to the near-stationary or looping track so that, in this respect, the two major changes were not entirely unanticipated.

Late on September 5, Betsy began a rather unusual southwestward movement, and on the 6th the hurricane was just off Great Abaco Island. Residents of the Bahamas were warned of the hurricane on the evening of the 5th; southern Florida was placed under a hurricane watch at 0500 EST on the 6th and the warning followed at 1100 EST. Betsy continued through the northern Bahamas with the eye passing just to the north of Nassau. Total losses in the islands were 5 million pounds ($14 million); much of it was crop losses. It is estimated that between 150,000 and 200,000 pounds ($500,000) will be expended by governmental and charitable organizations to repair the damages. Insurance claims are estimated at 1.4 million pounds (nearly $4 million). In spite of the duration and strength of the wind in the islands, there was only one casualty. A man lost his life aboard his ship which was wrecked in Nassau harbor. This low casualty figure is most remarkable and may be due, in part, to the relatively low tides reported. (Tides were negligible in Nassau and were only 4 to 5 ft. above normal on Eleuthera, the only place of measurement in the islands.) However, it is a credit to the people of the Bahamas that they know how to cope with hurricanes and heed the posted warnings. This is something that more people in the United States should be cognizant of and react to when a storm threatens.

After leaving the Bahamas, Betsy moved on a westerly course and passed over the Florida Keys. Damage from winds, high tides, and wave action was confined principally to the area from Ft. Lauderdale southward. Northerly winds, in advance of the center, produced flooding in the Keys by waters of Florida Bay. Southerly winds, following the hurricane, caused inundation by waters of the Atlantic and the Florida Straits. Heaviest damages were noted on the northern side of the islands and flooding on the upper Keys was extensive. Water reached depths of several feet in many places and covered highways and the first floors of many buildings. Farther north,

rising waters flooded sections of Key Biscayne; and in southern Dade County, similar conditions were experienced in areas east of the coastal ridge. Streets in Miami Beach near the ocean and Biscayne Bay were under water; and this was also true of the land south of Homestead Air Force Base east of U.S. Highway 1. On the west side of Biscayne Bay, rising waters reached into businesses and houses near Biscayne Boulevard and Bay Shore Drive. Considerable water damage was noted east of the ridge from Mercy Hospital southward to the Kings Bay area.

Wave action and high tides caused considerable flooding and undermining of beach roads and low-lying property between greater Miami and the Palm Beaches. Damage was less farther north, but was noticeable along the entire Florida Atlantic coast.

Betsy turned toward the northwest on entering the Gulf of Mexico; the hurricane's forward speed increased to 22 m.p.h., well above the average speed for Gulf storms. The eye arrived at Grand Isle, La., shortly after 2100 CST, September 9. The sea level pressure of 28.00 in. reported in the eye at Grand Isle and at Houma a few hours later was the lowest recorded at any land station during the hurricane's life history. The eye was 40 mi. in diameter on the Louisiana coast—just the same as when it passed over the Keys early in the morning of the 8th. See figure 4 for a radar photograph of Betsy taken by the WSR–57 at Miami. Note the Air Force reconnaissance plane in the eye on the eastern side.

Great devastation was caused by high water on the central Gulf coast from the point where the center of the hurricane made landfall to Mobile, Ala. Maximum water elevation records were exceeded on the Mississippi River from Pointe-a-la-Hache to the mouth of the river and between levees from Pointe Michel to Venice; over coastal and inland areas along Breton and Chandeleur Sounds; and along portions of Lake Borgne and Lake Pontchartrain. The river continued to rise at New Orleans until 2350 CST and by then ships, tugs, and barges were torn loose from their moorings. From the greater New Orleans area to Baton Rouge, barges numbering in the hundreds were either sunk or driven aground, including one which contained 600 tons of chlorine gas and sank in 60 ft. of water near the University of Louisiana campus. Evacuation advice prompted 300,000 people in Louisiana to seek safe shelter. In spite of this, 58 people lost their lives (41 in Orleans Parish) because of winds and floods. The loss of life and great damage costs were caused, in part, by circumstances differing from those found in many other localities. First, much of New Orleans is below sea level and drainage at all times in a large portion of the city depends upon an extensive pumping system. The system has a capacity of 28,000 cubic ft. per sec. and has been described as the most powerful in the world. Second, back levees east of the river, which are not as high as those on the river, were topped and broken, permitting vast accumulations of fresh and salt water. This resulted in the overloading and failure of the pumps when about 90

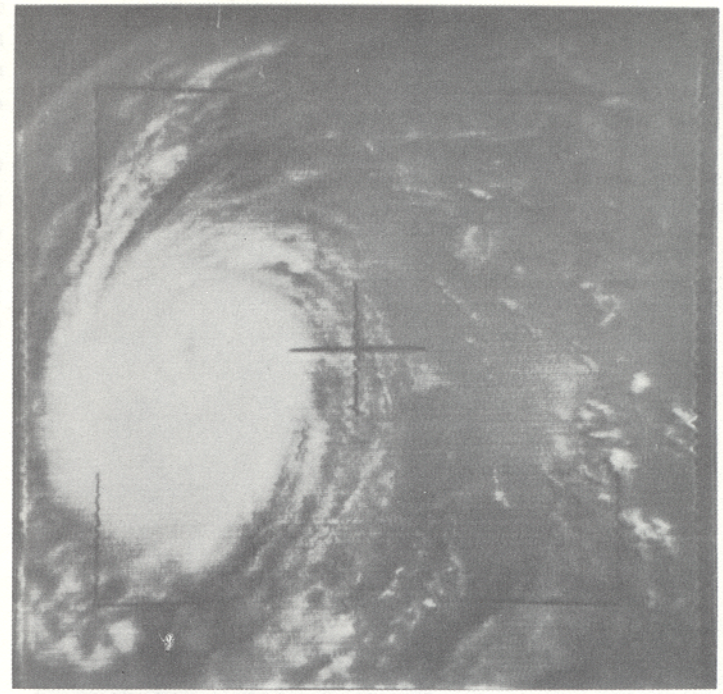

FIGURE 3.—Betsy at 1043 EST September 3, 1965, photographed by TIROS X.

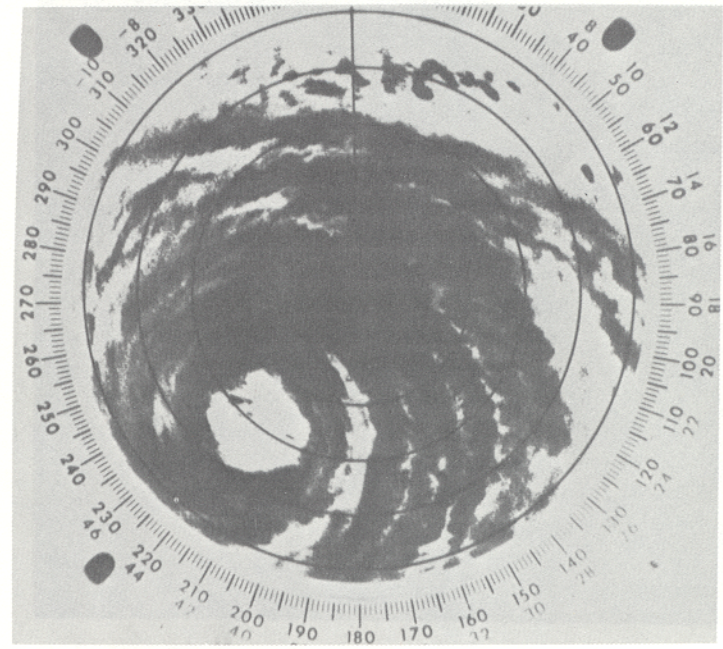

FIGURE 4.—Betsy at 0730 EST September 8, 1965, photographed from WSR–57 radar, Miami. Range marks 20 n.mi.

percent of the city's electric power was knocked out. Some of the flooding occurred several hours after the hurricane and storm surge passage as water drained into the lowest areas. Since natural drainage is not possible, flood waters remained for several days, thus increasing the overall damage and evacuation costs.

In addition to the loss of life in Louisiana, there were four deaths in Florida and nine others lost their lives in the adjacent waters of the Gulf and the Atlantic while

TABLE 7.—*Hurricane Betsy, meteorological data, Aug. 27–Sept. 12, 1965*

Station	Date	Pressure (in.)		Wind (miles per hour)				Highest tide (Ft.)	Date time	Storm rainfall (In.)	Remarks
		Low	Time	Fastest mile**	Time	Gusts	Time				
LESSER ANTILLES	28					35					
BAHAMAS											
West End	7	29.42	1900E	NNE 89	1000E						Grand Bahama.
Green Turtle Cay	6	29.23	1300	ENE 151	0100(7)						Abaco.
Hope Town	6	28.62	1300	NW 178	1300						Abaco.
Alice Town	7	28.94						2.3 ML			Bimini.
Dunmore Town	6	28.40									Harbour Island.
Mangrove	7	29.30	1900	(Complete wind data for the Bahama stations unavailable mainly due to power failure.)							Andros.
Nassau	7	28.53	1000								
FLORIDA											
Jacksonville (WBAS)	8	29.90	0140E					1.6 AN	7–8	0.13	
Daytona Beach (WBAS)	8	29.83	0453	NE 38	2055E(7)	NE 56	2055E(7)	3.0 AN*		0.19	
Orlando (WBAS)	8	29.77	0418	E 27	1255	E 38	1255			0.24	
Lakeland (WBO)	8	29.66	1523	NE 33	1420	NE 50*	1441			0.87	
Melbourne Beach	8	29.72	1900			ENE 60	1900			1.01	
Vero Beach	8	29.69	0800			E 65	0700			0.65	
West Palm Beach (WBAS)	8	29.46	0400	NNE 55	2340(7)	NNE 60	2340(7)	7.0 AN*		0.45	
Juipter Light	8	29.48	0430			NE 75	0220				
Port Everglades	8	29.38	0600			ENE 95	0600	7.0		4.25	
Radio WWIL (Ft. Lauderdale)	8	29.17	0425			NE 120†	0230			4.32	
Miami Beach	8			NNE 92	0252			6.1 ML		4.24	
Miami (WBAS)	8	29.02	0333	NE 69	0410	NE 94	0410			6.02	
Miami (NHC)	8	28.99	0300			NE 104	0246			6.21	
South Miami	8									5.16	
Homestead AFB	8	28.71	0500			ENE 140*	0620			10.89	
North Key Largo	8					E 160*	0500	9.0*			
Plantation Key	8	28.14	0630	ENE 100†	0330	130*, 140*		4.7*		11.80	In eye 0530/0730.
Tavernier	8	28.12	0710	NW 120*	0300	140*	0310	7.7 ML		6.40	In eye 0430/0710.
Islamorada	8										In eye 0545/0745.
Big Pine Key	8	28.68	1120	SW 125*	1145	165*	1145	8.0 AN*		10.52	
Grassy Key	8					160*	0715				
Key West (WBAS)	8	28.97	1040	SW 81	1020	SW 88	1020	5 to 7 MS*		3.97	See text.
Flamingo	8	28.40	0730			NNE 160*	0545	7.3 ML		*5.00	
Everglades City	8	29.19	1030			140*	0840	−1.9		2.63	
Clewiston	8	29.50	0630	50		NE 68	0430			2.51	
Naples	8	29.24	1500			NNE 61	1226	4.8 ML	9	2.70	
Ft. Myers (WBAS)	8	29.43	1445	ENE 46	1051	ENE 56	1051	3.5 AN*	9	0.37	
Ft. Myers Beach	8			NE 53		NE 70					
Punta Rassa	8	29.40				70*					
Tampa (WBAS)	9	29.64	0856	E 31	2055			3.8 AN*		0.42	
Cedar Key								6.3 ML	9		
Tallahassee (WBAS)	9	29.86	0445							0.42	
Apalachicola (WBO)	9	29.79	0530E	SE 33	0920	SE 45	0912	4.5 ML		0	
Pensacola (WBAS)	9	29.78	1840C	SE 43	2307	SE 60	2256C	4.3 ML	10	0.35	
ALABAMA											
Mobile (WBAS)	9	29.70	2355C	SE 32	2355C	SE 44	2355C	4.7 AN		2.19	
Dauphin Island	9					80*					
MISSISSIPPI											
Jackson (WBAS)	10	29.61	0930C	SE 43	1210C	SE 52	1047C			6.22	
Pascagoula	9	29.63	2230	ESE 46	0200 (10)	ESE 60	0200 (10)	7.4 ML	10	0.90	
Bay St. Louis	10					120*		7.0 AN		3.00	
Picayune	10			65		85				3.98	
Gulfport	10					100*					
Purvis	10	29.35	0400	60*	0400	90*	0400			2.02	
Vicksburg	10	29.45	1105	SE 34	1440	SE 55*	1440			2.23	
Tylertown	10			S 50*	0400	S 60*	0400			1.60	
Meadville										6.00	
McComb				NE 28	0256	NE 63	0457			3.93	
LOUISIANA											
Pointe-a-la-Hache								15.2 MS	9		
Grand Isle	9	28.00	2151C	NNE 105*	2000C	NNE 160*	2000C	8.8 MS	9	+3.20	In eye.
Houma	9	28.00								5.71	In eye.
Thibodaux	9	28.02									In eye 0030/0205.
New Orleans (WBO)	9	28.75	2340	125*	2345					1.63	
New Orleans (WBAS)	9	28.65	2347	E 69	2355	E 112	2333			4.09	
New Orleans (AUDIBON)	9							12.4 MS	9	5.13	
Morgan City	9			N 100*	2000	N 128*	0000 (10)			5.70	
Schriever	10	28.26	0015	N 95*	0000	NNE 110*	0000			5.80	
Baton Rouge (WBAS)	10	28.53	0356	ENE 58		NNE 92	0215			3.49	
Covington	9			S 70*	2200	S 100*	0000 (10)			3.00	
Franklinton	10					ESE 100*	0200			3.05	
Lake Charles (WBAS)	10	29.51	0500	NW 26	0456	NW 36	0456			0.28	
Cameron	10	29.58	0330	NNW 23	0200						
Lafayette	10	29.00	0358	NW 49	0358	NW 76	0358			3.97	
Monroe (FAA)	10	29.11	1435	NNE 61	0804					4.37	
Alexandria (WBAS)	10	29.10	0918	N 46	0533	N 62	0533			3.07	
Melville	10	28.65	0630	NE 60*	0230	NW 90*	0000			5.30	
New Roads	9			NE 90*	2330	100*	0300 (10)			5.21	In eye.
Jennings	10	29.08	0330	NE 45	0245	NE 70	0250			0.97	
TEXAS											
Port Arthur (WBAS)	10	29.60	0358C	W 26	1134C			2.4 MS	9/1500	0.02	
ARKANSAS											
Little Rock (WBAS)	11	29.56	0200C	NE 28	2055C(10)	NE 34	2055C(10)			3.25	
Pine Bluff	10			NE 34	1658	NE 46	1658				
Walnut Ridge	10			NE 29	0900	NE 46	0900				

*Estimated.
**Or one minute.
†End of scale.
U Uncorrected.

AN Above normal.
ML Mean low water.
MS Mean sea level.

boating or fishing. Mississippi reported one and Arkansas reported three storm-connected deaths. This totals 75 as indicated in table 2 and is the greatest loss of life in the United States in a hurricane since 1957, when hundreds were killed by the storm tides of Audrey.

Betsy will be remembered as one of the great hurricanes of this century and the most devastating to date in terms of structural damage. A breakdown of the damage figure in table 2 follows: Louisiana $1,200,000,000, Florida $139,300,000, Mississippi $80,000,000, Alabama $500,000, and the Bahamas $14,000,000. The grand total damage attributed to Betsy is $1,433,800,000.

Highest tide in the Florida Keys was estimated at 9 ft. at North Key Largo and measured 7.7 ft. mean low water at Tavernier. Private communication from Key West (WBAS) indicated that tides were estimated 5 to 7 ft. m.s.l. Highest debris line on the highway west of Sugarloaf Key was 9 ft. and 8 ft. on Big Pine Key. The tide was measured at 12.4 ft. m.s.l. in New Orleans and averaged 10 ft. elsewhere on the Louisiana coast from Grand Isle eastward. The river at New Orleans rose 10 ft. during the hurricane. Tides were from 7 to 10 ft. along the Mississippi coast and 3 to 6 ft. m.s.l. eastward to Apalachee Bay. Tides on Lake Okeechobee in Florida were minor. Tides on the Florida Gulf coast were abnormally low on September 7 but rose, late on the 8th, after Betsy moved into the open Gulf of Mexico. There was considerable local flooding and beach erosion, especially south of Clearwater on the 9th and 10th. Damage north of Clearwater and around the Panhandle was mainly confined to beach erosion and to docks, piers, and small boats.

There were two confirmed tornadoes in Florida. One occurred on Big Pine Key (reported by R. L. Higgs, former Meteorologist-in-Charge, San Juan Weather Bureau) moving from the southwest toward the northeast at 1600 EST on the 8th. The other was observed at Marathon and moved from west to east at 0545 EST of the same day. Other tornadoes within or near the circulation were at Theodore (0000 CST, Sept. 10) and in Cullman County (2000 CST, Sept. 11) in Alabama. In Mississippi, there were two, one at Walnut (1830 CST, Sept. 10) and one, at Magee (time unknown). Of the five with known occurrence times, the two in the Keys were south of the hurricane path, while two others, in the northern portions of Alabama and Mississippi, occurred in the right front quadrant, but after Betsy decelerated and degenerated to tropical depression intensity. The fifth at Theodore, Ala., was in the "significant sector" as noted by Smith [7] and Pearson and Sadowski [8]. The relatively low number of tornadoes that was spawned while Betsy was of hurricane force is not surprising. Fast-moving hurricanes and those with westward tracks (as opposed to northward tracks) usually have the least number of tornadoes [9].

Highest rainfall amount was 11.80 in. at Plantation Key in the Florida Keys; nearby Big Pine Key, had 10.52 in. Rainfall over the remainder of extreme southern Florida and in the lower Mississippi and Ohio River valleys ranged from 3 to 7 in. The rains were beneficial and did much to relieve the water shortage in the Everglades. Beneficial rains also occurred in the States from Arkansas northeast and east as far as Maryland and Delaware. In Arkansas, the losses to the cotton and rice crops were more than recovered by the increased soybean yield resulting from the rains. The rains in the central Mississippi River Valley, the Ohio River Valley, and eastward were, of course, associated with the remnants of Betsy after it lost tropical characteristics.

Agricultural losses can be estimated from the following figures. From 25 to 50 percent of the citrus in Florida and nearly 90 percent of the avocadoes were blown from the trees in Dade and Broward Counties. In Alabama, 20 percent of the pecan crop was destroyed, mainly in Mobile and Baldwin Counties. The counties bordering the Mississippi River were hardest hit in Mississippi. Cotton losses were over $17 million, rice and pecan losses near $1 million each, and corn losses were estimated at one-half million dollars. Pecan losses in Louisiana ranged from 25 percent in the northeastern to 100 percent in the southeastern part of the State. Most of the rice crop had been harvested, but damage to fall vegetables was extensive. About 50 percent of the cotton crop was destroyed in the south-central part of Louisiana, but this represented only about 25 percent of the crop since much of it had been havested before Betsy. There will, of course, be some accumulative losses to tree crops over the next year or so because of limb breakage.

Louisiana's oil production virtually ceased with preparations for the onslaught of Betsy. There are nearly 4,800 wells extending as far as 95 mi. into the Gulf representing six major oil companies. Nearly 3,000 men were evacuated from the various operations by helicopters and boats. The industry suffered major losses to supply bases and much of the marine fleet was beached or damaged. Three refineries became inoperative, and there was much water damage to electrical installations.

The utilities suffered greatly in Louisiana. There were 382,000 phones (228,000 in New Orleans) out of service and more than 365,000 electric power customers (168,000 in New Orleans) affected.

More meteorological details on Betsy, are given in table 7.

HURRICANE CAROL, SEPTEMBER 16–OCTOBER 1.—Hurricane Carol probably had its beginning in a weak low pressure area that moved off the African coast on September 15. The disturbance moved rapidly westward as indicated by satellite photographs on the 16th and 17th. On the 18th the ship *Sunpalermo* reported winds of 40 m.p.h., seas of 12 to 15 ft., and about normal surface pressures. These reports indicate that Carol was a storm at that time; and, from the height of the seas, it appears that Carol probably reached storm intensity the previous day. The storm slowed and turned toward the north on the 19th.

A Navy reconnaissance plane located the center by

radar on the 20th. The plane was about 50 mi. south of the center and reported the surface pressure at that point as 1001 mb. (29.56 in.). Undoubtedly Carol was of hurricane intensity at that time. The following day, Air Force reconnaissance penetrated the center and recorded a central pressure of 974 mb. (28.76 in.).

The hurricane continued northward at a rapid rate until late on the 22d. For the next five days through the morning of the 28th, Carol, maintaining hurricane force, drifted but stayed within 100 mi. of 34° N., 42° W.

The hurricane accelerated toward the east-northeast on the 28th and intensified. Highest winds were estimated near 100 m.p.h. on the 29th, and during the night the center passed to the north of the Azores. Carol lost force on the 30th and became extratropical on October 1. The system continued as a low pressure area for several days in the vicinity of the Madeira Islands.

The lowest pressure observed was 974 mb. (28.76 in.), and the highest wind estimated near 100 m.p.h. The highest wind reported at any land station was 64 m.p.h. with gusts to 80 m.p.h. at Corvo, the northwesternmost island in the Azores. There was no known loss of life or damage attributed to this hurricane.

TROPICAL STORM DEBBIE, SEPTEMBER 24–30.—Early on September 24, a weak tropical depression was observed off the coast of Honduras near Guanaja and Swan Island. Air reconnaissance reported a low of 1003 mb. (29.62 in.), but no well-defined circulations near the surface or at 700 mb. There were multiple cloud layers but no significant patterns or any significant temperature gradients. Rainfall had been moderately heavy over the western Caribbean for several days with amounts of over 5.43 in. at Swan Island in a 24-hr. period and 5.22 in. in 30-hr. at Amapala, Honduras.

The depression crossed the extreme northeastern tip of Yucatan on the night of the 25th and emerged into the extreme southern Gulf of Mexico on the morning of the 26th even weaker than before. The sea level pressure was 1007 mb. (29.74 in.) and the shower activity indicated no organization.

The slow northwestward movement increased slightly on the 26th and the course became more directly northward during the 27th. By morning of the 28th, some slight intensification had occurred and the depression just barely reached storm intensity. The sea level pressure was 1001 mb. (29.56 in.), and there were extensive, though poorly organized, radar echoes, mainly in the north and east quadrants. Drier and slightly cooler air was moving into the circulation by this time and no additional intensification occurred.

Debbie never attained a characteristic tropical storm wind profile. By dawn on the 29th, the system was weakening and decelerating just east of the Mississippi River delta; and, by evening, the circulation had disappeared entirely.

Of the several TIROS pictures of Debbie, none showed more than a mass of cloudiness with very little banding,

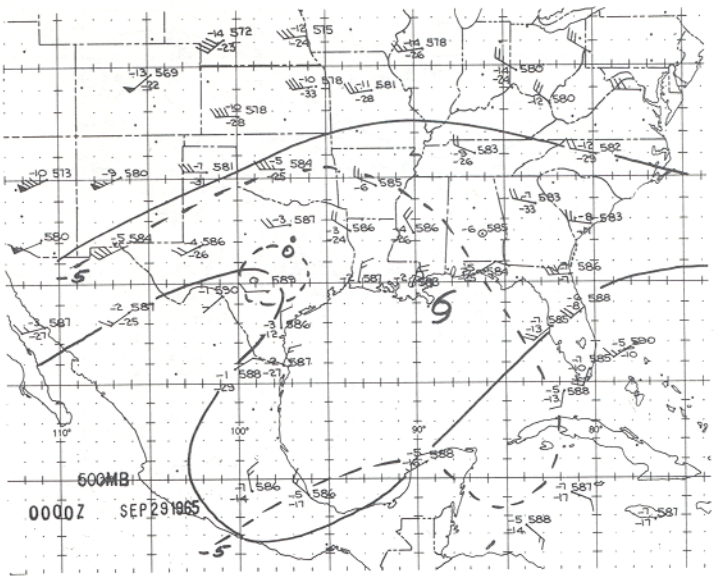

FIGURE 5.—500-mb. chart, 1900 EST, September 2, 1965, when hurricane Debbie was off the coast of Louisiana.

and at no time was the center clearly defined. Reconnaissance by the Air Force, Navy, and Weather Bureau research aircraft was almost continuous during the storm's life history.

No gale force winds were reported at land stations, but vessels did experience gales. Tides were generally 2 to 4 ft. above normal from the mouth of the Mississippi River to Apalachee Bay. A 6-ft. tide was reported on the Industrial Canal in New Orleans. There was some inundation around Lake Borgne southward and on the highways east of New Orleans.

Locally heavy rains occurred in the southeastern States. Mobile, Ala., was hardest hit by rains and flooding. Downtown Mobile had 16.85 in. during the night of the 29th and morning of the 30th. Rainfall amounts of 3 to 5 in. were general over much of Alabama, Georgia, and northern Florida.

Flood damages in the Mobile area were estimated at $25 million; elsewhere damages were light.

It is not certain just why Debbie never developed into a well-organized tropical storm or hurricane. Conditions favorable for intensification were (1) a circulation over warm tropical waters, (2) copious rainfall, and (3) a high-level anticyclone present throughout the period. One might conclude by casual inspection that there never was any well-defined inflow in the lower levels nor was there good outflow aloft. The real reason might very well lie in the unusual upper-air temperature distribution. Marked warming over Texas, especially noted at the 500-mb. level and probably caused by an Eastern Pacific tropical storm (Hazel) which occurred about the same time, was a most obvious synoptic feature. Temperatures were as high as 0° C. at 500 mb. In contrast, Audrey of 1957 did intensify and, while the track was a little farther to the west than Debbie's, temperatures throughout Texas at the 500-mb. level averaged −8° C. during Audrey's life history. See

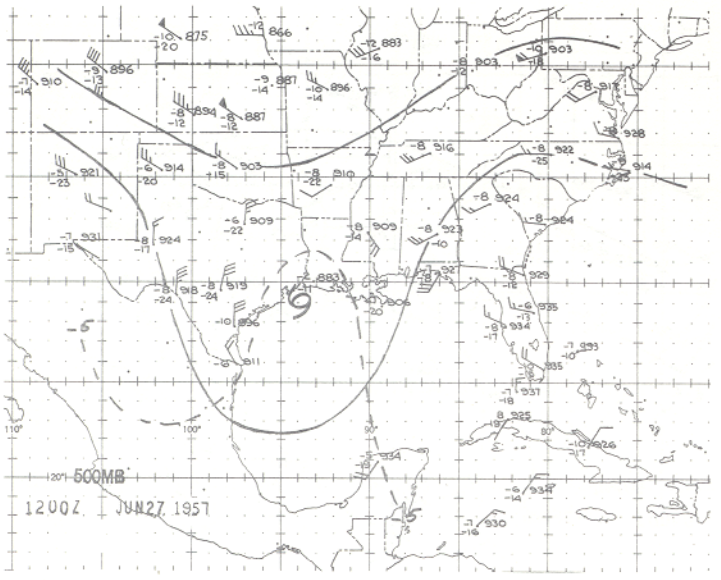

FIGURE 6.—500-mb. chart, 0700 EST, June 27, 1957, when hurricane Audrey was off the coast of Texas.

figures 5 and 6. Also note the anticyclonic westerlies north of Debbie, consistent with the warm air, in contrast to the cylonic circulation in the westerlies north of Audrey.

HURRICANE ELENA, OCTOBER 12–19.—A TIROS observation on October 11 at 1322 GMT indicated a very weak circulation near 12° N., 40° W. This is shown in the upper left portion of figure 7. No additional information was received from this portion of the Atlantic until the evening of the 12th when ship reports suggested a somewhat better-organized circulation at 19° N., 48.5° W. A second TIROS observation on the 13th at 1406 GMT confirmed a better organization. The overall speed of the system was 23 m.p.h., and it does seem logical to accept the continuity and credit TIROS with finding what may be the very weakest kind of a circulation which later developed into a hurricane.

Reconnaissance into the area on the 13th found no well-marked circulation but did report heights at the 850-mb. level low enough to support a sea level pressure of 1005 mb. (29.68 in.). By this time, the speed had decreased to 10 m.p.h. Another TIROS observation located the center at 24° N., 57° W. at 1517 GMT on the 14th. This position was in good agreement with aircraft reconnaissance made during that day. A detailed aircraft report on the morning of the 15th indicated a better organized storm with maximum winds of 45 m.p.h. and a sea level pressure of 1001 mb. (29.56 in.). The air mass within the storm was rather cool as had been reported earlier. The temperature in the center at 700 mb. was 10° C., only 1° higher than elsewhere about the storm. This reported temperature in the center was about 1.5° higher than the mean and about the same amount lower than the mean for a weak hurricane eye. Later the 700-mb. temperature rose to 15° C.

Elena's winds increased to 65 m.p.h. on the 15th and by early on the 16th the central pressure was down to 991 mb. (29.26 in.). This pressure would support hurricane force winds. During the 16th the hurricane recurved into the westerlies and accelerated northeastward during the night and the forenoon of the 17th. The central pressure fell to 977 mb. (28.85 in.) on the morning of the 18th, and by late evening Elena was overtaken by a cold front. There was no known loss of life or damage attributed to this hurricane.

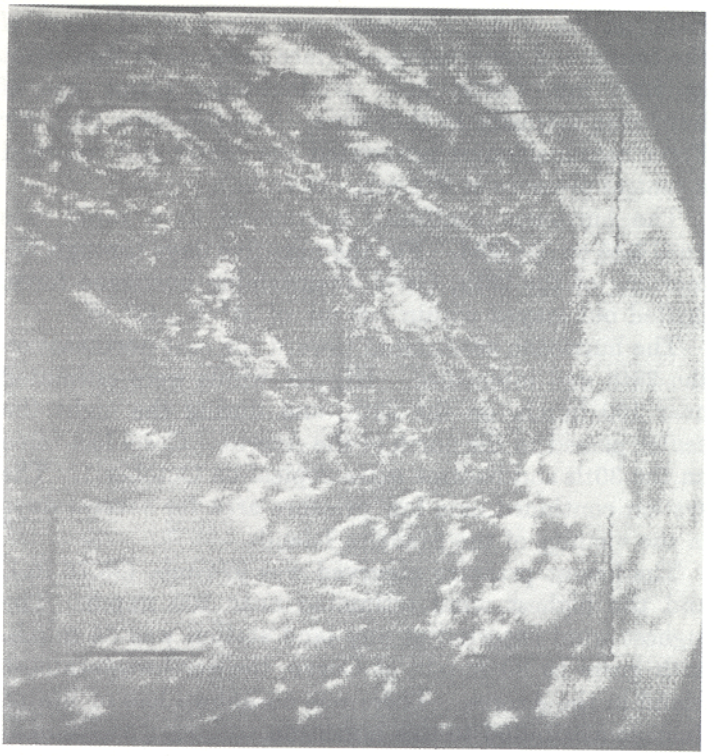

FIGURE 7.—Very weak initial circulation of Elena at 0822 EST, October 11, 1965, from TIROS X.

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