THE HURRICANE SEASON OF 1961

GORDON E. DUNN and STAFF

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

1. GENERAL SUMMARY

While the number of tropical cyclones was exactly the annual average for the last three decades, the hurricane season of 1961 was remarkable for the lack of activity June through August and the very high cyclone frequency of September through November, also for the large number of storms of full hurricane intensity—eight. Indeed, the number could well be nine, or even ten, since Gerda, during a period when it was still regarded as partly tropical, was attended by hurricane-force winds at the Texas Towers off the New England coast. Ships also reported 65-kt. winds in Inga on one or two occasions. Previously in only eight years since 1900 had there been as many as eight hurricanes in the Atlantic area [1]. Only one tropical cyclone developed prior to September. Activity in the tropical Atlantic in August was at a minimum and this was the third consecutive August with subnormal tropical cyclone frequency. Hurricanes occurred over all portions of the Atlantic and there was no concentrated area of activity (fig. 1).

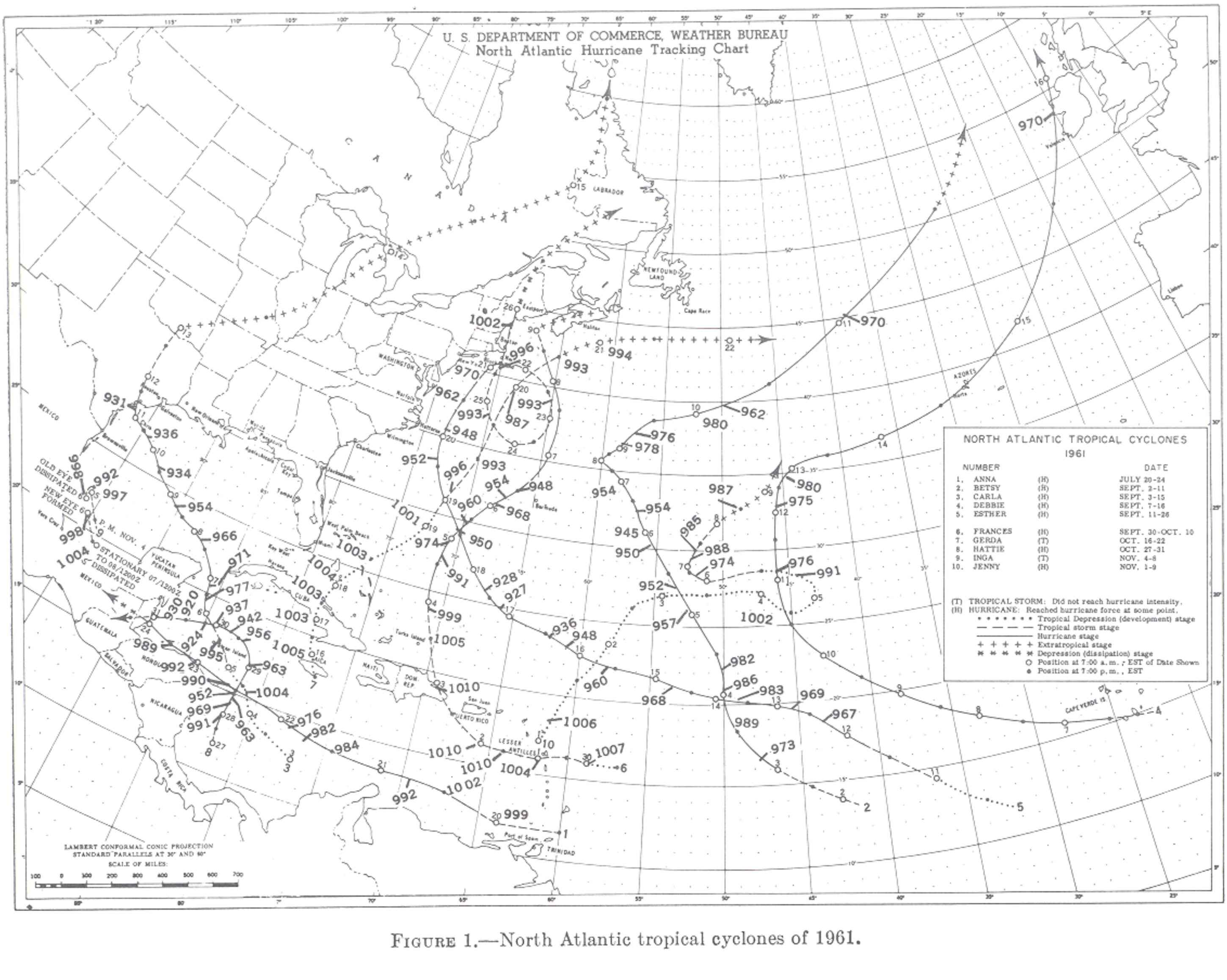

FIGURE 1.—North Atlantic tropical cyclones of 1961.

TABLE 1.—*Fatality and damage statistics, North Atlantic tropical cyclones of 1961*

Storm	Intensity	Date	Damage (Estimated)	Deaths	Principal areas affected
Anna	Hurricane	July 19–24	$300,000	1	Honduras.
Betsy	Hurricane	Sept. 2–11			Remained over ocean.
Carla	Hurricane	Sept. 3–15	$300,000,000 Texas $25,000,000 Louisiana	34 Texas 6 Louisiana 5 Kansas. 1 Missouri.	Texas, Louisiana.
Debbie	Hurricane	Sept. 6–16	"Heavy"	11 Ireland	Ireland, Scotland, Wales.
Esther	Hurricane	Sept. 11–26	$3,000,000 New York $3,000,000 New England		Southern New York. Southern New England.
Frances	Hurricane	Sept. 30–Oct. 10	Minor		S. coast Puerto Rico.
Gerda	Storm	Oct. 16–22	Moderate	5 Jamaica 7 Cuba.	Jamaica, Cuba.
Hattie	Hurricane	Oct. 27–31	$60,000,000 British Honduras $300,000 San Andres	262 British Honduras 1 Honduras 11 Guatemala. 1 San Andres.	British Honduras, Guatemala.
Inga	Storm	Nov. 4–8			Remained over ocean.
Jenny	Hurricane	Nov. 1–9			Remained over ocean.
Total within United States			$331,000,000	46	
Total outside United States			$60,600,000+	299	

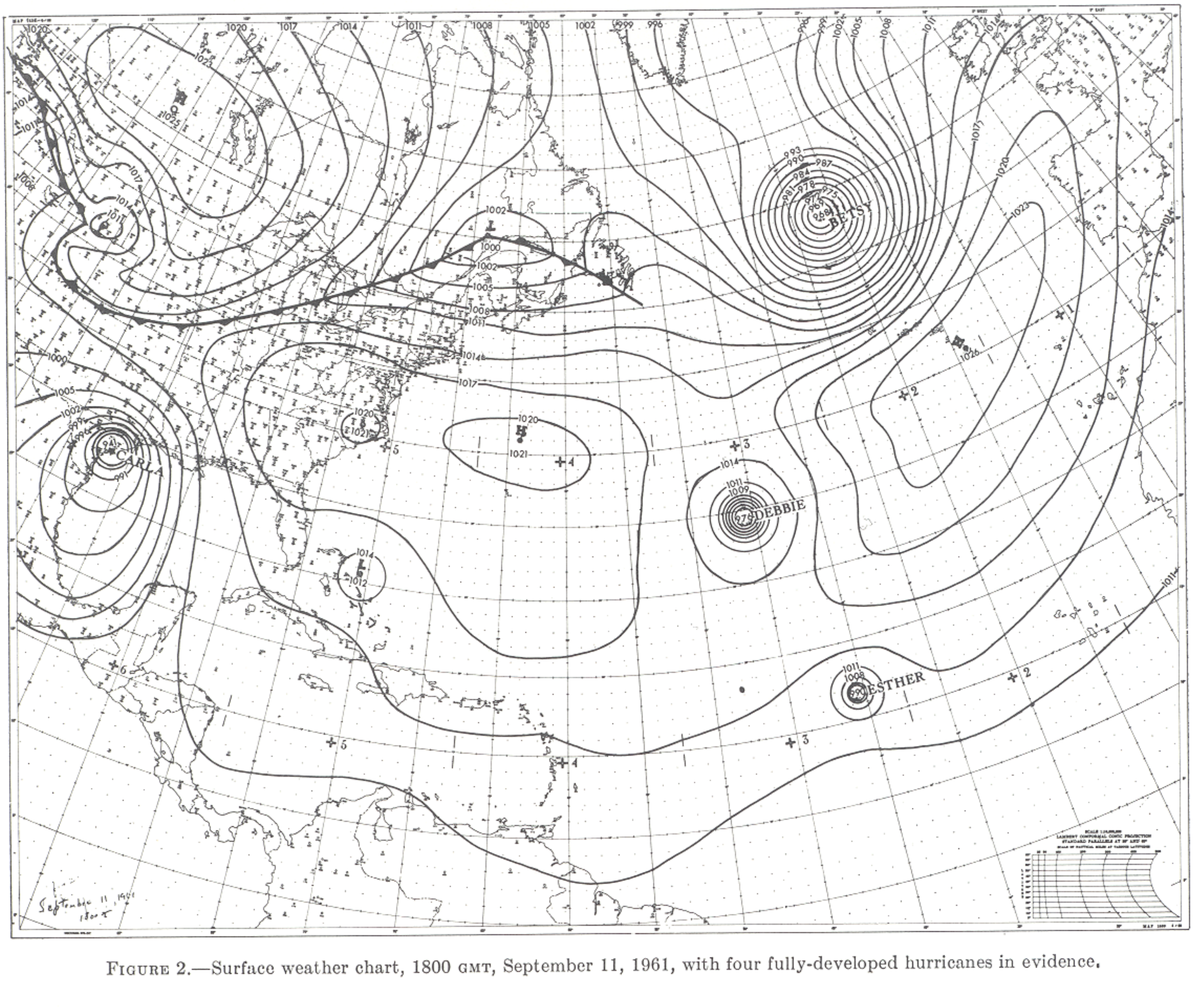

FIGURE 2.—Surface weather chart, 1800 GMT, September 11, 1961, with four fully-developed hurricanes in evidence.

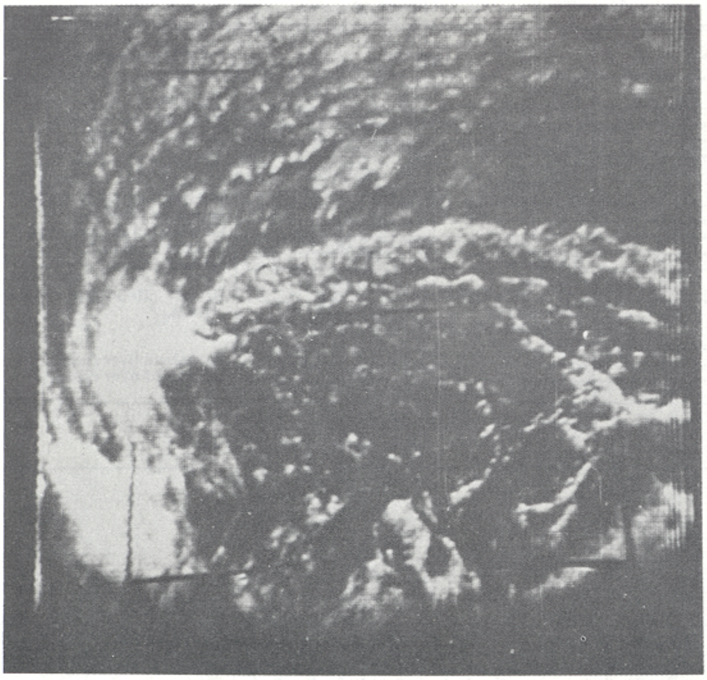

Figure 3.—Satellite photograph made at 0940 EST, July 17, 1961. The cloud mass in middle extreme left (approximately 12° N., 43° W.) is believed to be an early stage of hurricane Anna. In this and the following satellite pictures, the frame is oriented so that higher latitudes are toward the top of the picture.

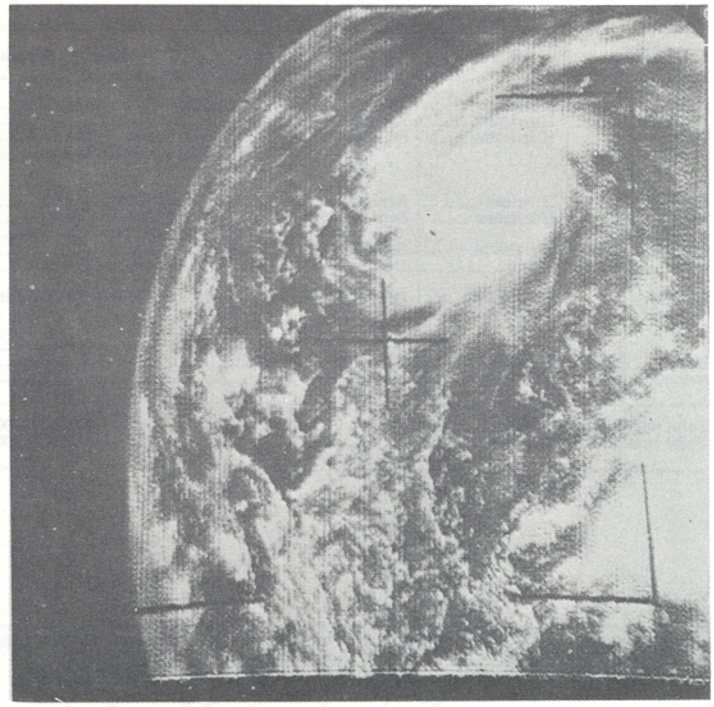

Figure 4.—Hurricane Anna at 1048 EST, July 21, at approximately 14.1° N., 72.4° W. The northern coast of South America and the Gulf of Maricaibo and Isthmus of Panama can be seen south and southwest of the cloud mass.

According to Tisdale [2], there was a pronounced reversal in the general circulation from August to September with the strong ridge over western North America being replaced by a deep trough. Concomitant with this trough development, strong anticyclogenesis took place over eastern North America with a positive height departure of 180 feet at 700 mb. over Maine. The pattern of the height anomaly over the Atlantic at this level resembled the circulation features found by Ballenzweig [3] to be favorable for tropical cyclone development in the eastern Atlantic, and four hurricanes in succession developed in this area during the first half of the month. On September 11 these four were simultaneously of full hurricane intensity in the Atlantic area (fig. 2), the first time this is known to have occurred. Damage and fatality statistics are shown in table 1.

Some of the weather satellite potential in hurricane detection and tracking was demonstrated in 1961. The track of Anna (fig. 1) was begun at 60° W. late on July 19. However, TIROS III at 0940 EST, July 17, at about 12° N., 43° W. showed that at least a depression was present (fig. 3). The line extending eastward from the cloud mass is probably the Intertropical Convergence Zone (ITC). (All these satellite pictures are printed so that higher latitudes are toward the top of the picture.) Hurricane Anna four days later is shown in figure 4. The northern coast of South America and the Gulf of Maricaibo are shown south of the storm and Panama and Costa Rica can be seen at the lower left of the picture somewhat distorted by the angle. The classical spiral band structure of a hurricane is shown in Betsy on September 8 shortly after it began a sharp turn to the northeast (fig. 5). A TIROS picture of unusually large hurricane Carla is shown in figure 6. The center position of the hurricane was indicated by the satellite as near 26° N., 95° W. The actual center position was approximately 27° N. Hurricane Debbie on September 10 is shown in figure 7. This storm was first picked up in the Cape Verde Islands. Since it could not be reached by reconnaissance planes, its movement was forecast on the basis of climatology. The satellite picture on the 10th indicated that there had been a much larger northward component of motion than indicated by climatology. The existence of Esther was not confirmed by reconnaissance until September 12. However, as early as 1412 EST, September 10, TIROS III strongly indicated the existence of a tropical cyclone (fig. 8). Indeed, it seems likely from the photograph it may have been of full hurricane intensity at this time.

It does not appear that it will be difficult to differentiate between the cloud masses associated with upper troposphere vortices and those accompanying tropical cyclones. Thus, the satellite without doubt is already an excellent detection tool. The center can usually be located within ±2°. The more sophisticated weather satellites planned should reduce the average error considerably.

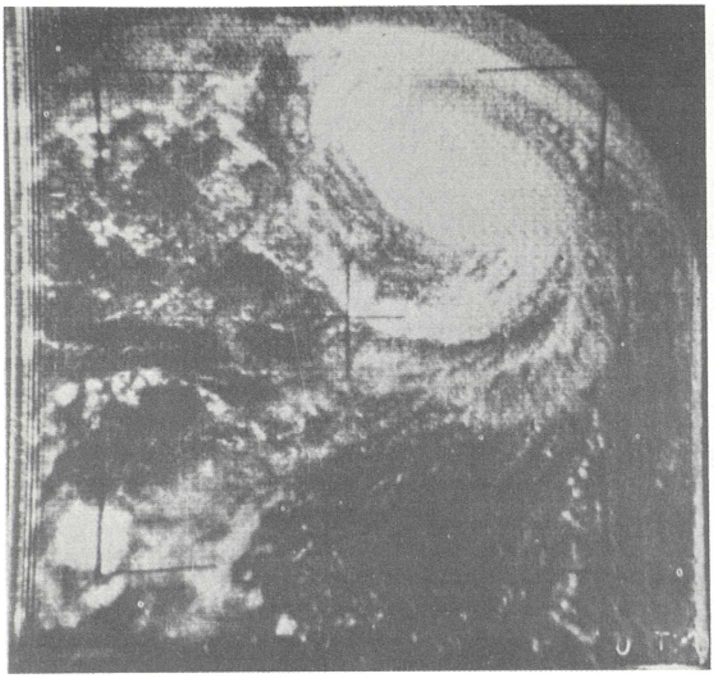

FIGURE 5.—Hurricane Betsy as seen by TIROS III at 1515 EST, September 8, 1961, showing classical spiral structure. The center is at about 36° N., 59° W., or 900 miles east of Virginia.

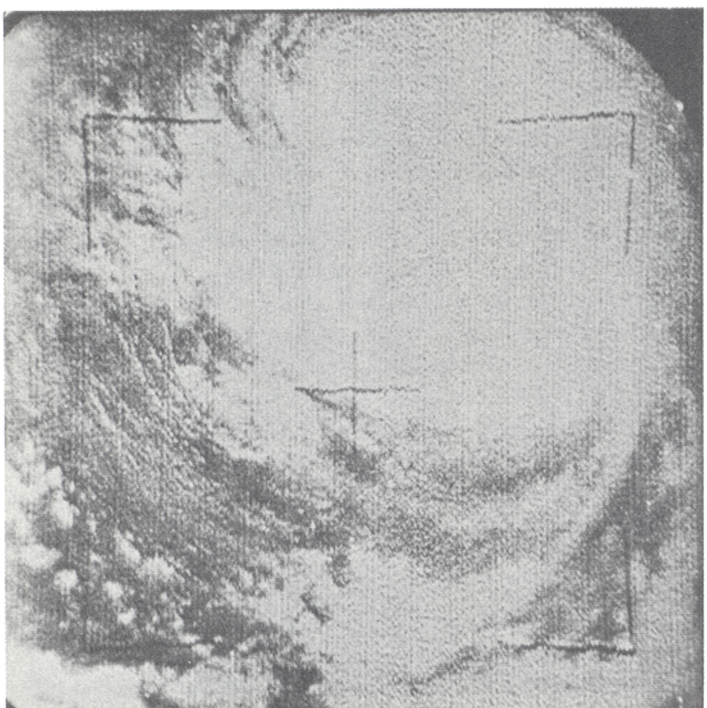

FIGURE 6.—Hurricane Carla, a very large storm, 1730 EST, September 10, 1961 at approximately 26° N., 95° W.

2. INDIVIDUAL TROPICAL CYCLONES

Hurricane Anna, July 19–24.—Anna, the first tropical cyclone of the 1961 Atlantic hurricane season, developed a short distance east of the Windward Islands on the evening of July 19. An area of suspicion was first noted well to the east on July 17 as Navy reconnaissance reported an extensive area of strong radar echoes between 14°–16° N. and 50°–55° W. Shipping in the area also reported numerous showers with winds generally light and variable. TIROS showed the principal concentration of weather near 12° N., 43° W. (fig. 3). During the 18th and 19th the ITC shifted well north of its normal position and cyclogenesis probably occurred at its intersection with the easterly wave first noted by Navy aircraft on the 17th.

Following reports from the island of Grenada, indicating heavy squalls with gusts to 50 m.p.h. and pressure of 1002 mb. around midnight local time on the 19th, reconnaissance aircraft located Anna in the extreme southeastern Caribbean some 75 miles north of the Venezuelan coast on the morning of July 20. By afternoon winds had increased to slightly over hurricane force.

From its inception, Anna maintained a course slightly north of due west on its entire track through the Caribbean Sea with a forward speed between 15 and 23 m.p.h. and with lowest pressure 976 mb. (28.62 inches) on the 22d. On the 23d the center skirted the extreme northeastern coast of Honduras, then passed westward into the mountains of southern British Honduras the next morning.

Since Anna's track was at an unusually low latitude, upper-air data were sparse. Only when the center was near a reporting station would the lower winds be affected, but the available 500-mb. data gave little indication of a hurricane. However, at 200 mb. a well-developed anticyclone was centered to the northeast of Anna and maintained this same relative position as the storm moved through the Caribbean. Operating as an efficient outflow mechanism, this anticyclone played an important part in Anna's development and maintenance. This relationship of the two dependent systems could occur only in a deep easterly circulation such as existed over the Caribbean during this period, and may explain why the size and intensity of Anna remained so static.

Some minor damage occurred at Trinidad and Grenada, but there were no casualties. Considerable damage was reported along the extreme northern Honduras coast with several hundred houses damaged or destroyed, and many plantations suffered heavy damage to fruit trees. One death and a dozen injuries were reported from Trujillo and Bay Islands. More than 5,000 coconut trees were blown down on Utila, a small island off the Honduras coast directly in the path of Anna. No official reports have been received from British Honduras, although unofficial information indicated damage was rather extensive at Punta Gorda in the extreme southeast. The center of Anna moved inland over a sparsely settled area.

Hurricane Betsy, September 2–11.—The formation of hurricane Betsy inaugurated one of the most active tropical cyclone periods in the history of the North Atlantic Ocean. No less than three other hurricanes made their appearance before Betsy dissipated. Betsy formed in the eastern tropical Atlantic apparently from a perturbation moving along the ITC. An observation from the SS *Granheim* at 0300 EST, September 2, located at 13.6° N., 42.2° W., with a barometer reading of "980" which is interpreted as 998.0 mb., was the first indication of Betsy. At 1000 EST the SS *Charlotte Maersk* at 15.6° N., 45.2° W., reported winds of 40 kt. and pressure of 1004 mb., steadily falling. The first advisory was issued by the San Juan Weather Bureau at 2300 EST, September 2, for a tropical storm. A reconnaissance aircraft was dispatched to the storm area September 3 and found surface winds of 90 kt. and a central pressure of 973 mb.

The track and changes of intensity of Betsy can be associated nicely with fluctuations in the westerlies. Ridges near the east coast of the United States and in the eastern Atlantic Ocean with a trough near 50° W. were the main features of the upper-level flow pattern during the period of the storm. This trough not only steered Betsy into higher latitudes, but also later picked up Debbie and even temporarily pulled Esther northward before the trough finally filled.

A closed Low developed and intensified in the trough on September 4, weakening the ridge to the north of the storm, and accordingly Betsy filled, with the central pressure rising to near 990 mb. On September 5, a short wave approached the trough and begun forcing the closed Low northeastward, resulting in height rises north of the storm. In response, Betsy again intensified until September 6, when the central pressure reached its lowest value, 945 mb. Surface winds at this time were estimated to be near 120 kt. Betsy missed connection with the short wave on September 6, slowed almost to a standstill, then was picked up by another minor trough on September 9.

Thirty-five advisories were issued on this hurricane, the last by the Washington Weather Bureau at 1100 EST, September 11. Betsy remained over the ocean and apparently no damage was sustained by vessels along her path.

Hurricane Carla, September 3–15.—Somewhat above normal shower activity was evident in the eastern Caribbean as early as September 1, apparently associated with a weak perturbation in the Intertropical Convergence Zone. The first indication of intensification and a closed circulation was noted on the 0700 EST September 3 surface chart and abnormal pressure and shower activity were mentioned in the tropical weather summary on that date. An anticyclone in the upper troposphere over the Caribbean was located in a position which provided an efficient outflow from the top of the disturbance.

At 0700 EST on September 4 the circulation had increased to depression intensity (winds 32 to 38 m.p.h.) and the light north-northeast wind at San Andres Island the evening before had shifted to westerly 12 m.p.h. and the barometer, while still below normal, had risen slightly. At 1100 EST, the Miami hurricane center prepared the first bulletin on the storm. At 2000 EST the same day, following aircraft reconnaissance, the first formal advisory was issued with a forecast for an increase to storm intensity which was attained by 0500 the following morning.

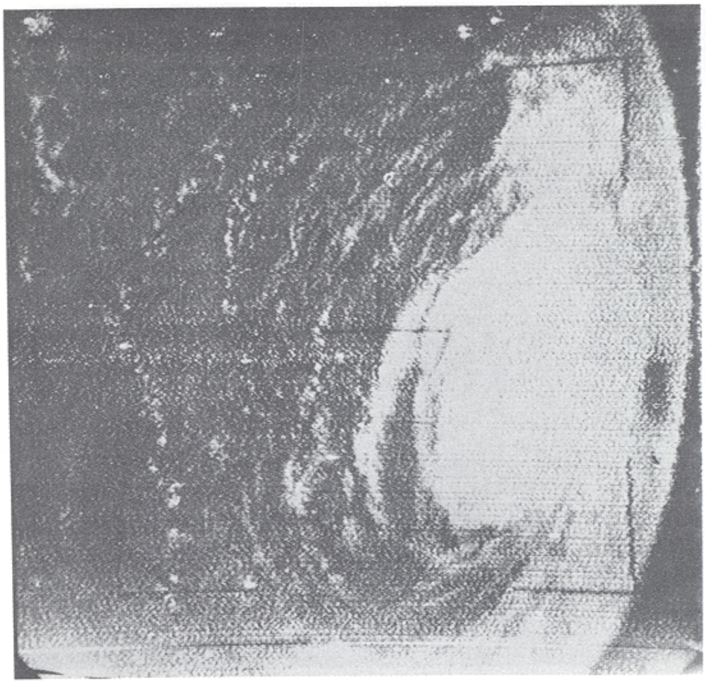

FIGURE 7.—Hurricane Debbie, near 24° N., 42° W., 1407 EST, September 10, 1961.

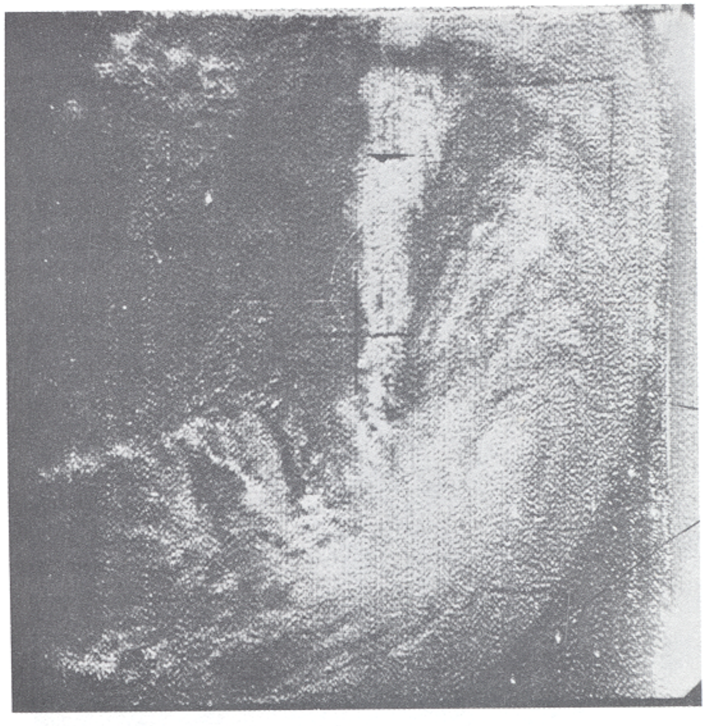

FIGURE 8.—Tropical cyclone Esther, near 11° N., 30° W. at 1412 EST, September 10, 1961—two days before its existence was confirmed by aircraft reconnaissance.

During the next several days Carla continued a slow but remarkably steady intensification (fig. 9) reaching hurricane force on the morning of the 6th and its lowest

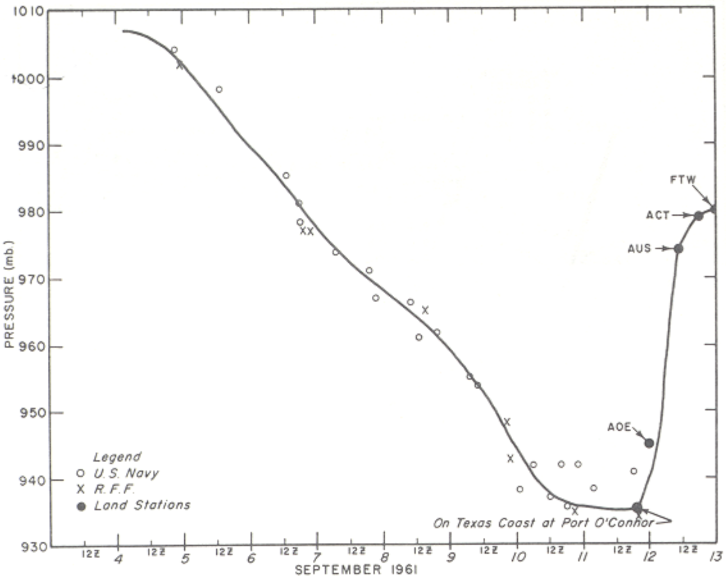

Figure 9.—Central pressure in hurricane Carla, September 4–13, 1961.

central pressure (931 mb.) on the afternoon of the 11th. Upper-air data at the 200-mb. level vividly illustrate the upper troposphere outflow from Carla during its deepening stage (fig. 10).

The center of Carla was under surveillance for some 48 hours by three land-based radars located at Brownsville, Galveston, and Lake Charles. All radars showed a strong cycloidal track during the period preceding landfall [4].

The New Orleans hurricane center described Carla as one of the largest, most intense and destructive hurricanes ever to strike the United States Gulf coast. Carla's center moved inland over the Port O'Connor-Port Lavaca area on the central Texas coast during the afternoon of September 11 (fig. 11). Sustained hurricane force winds were reported from Corpus Christi to Galveston and hurricane gusts were felt along almost the entire length of Texas coast.

High tides began affecting the upper Texas coast on September 8 and waves and tides continued to batter

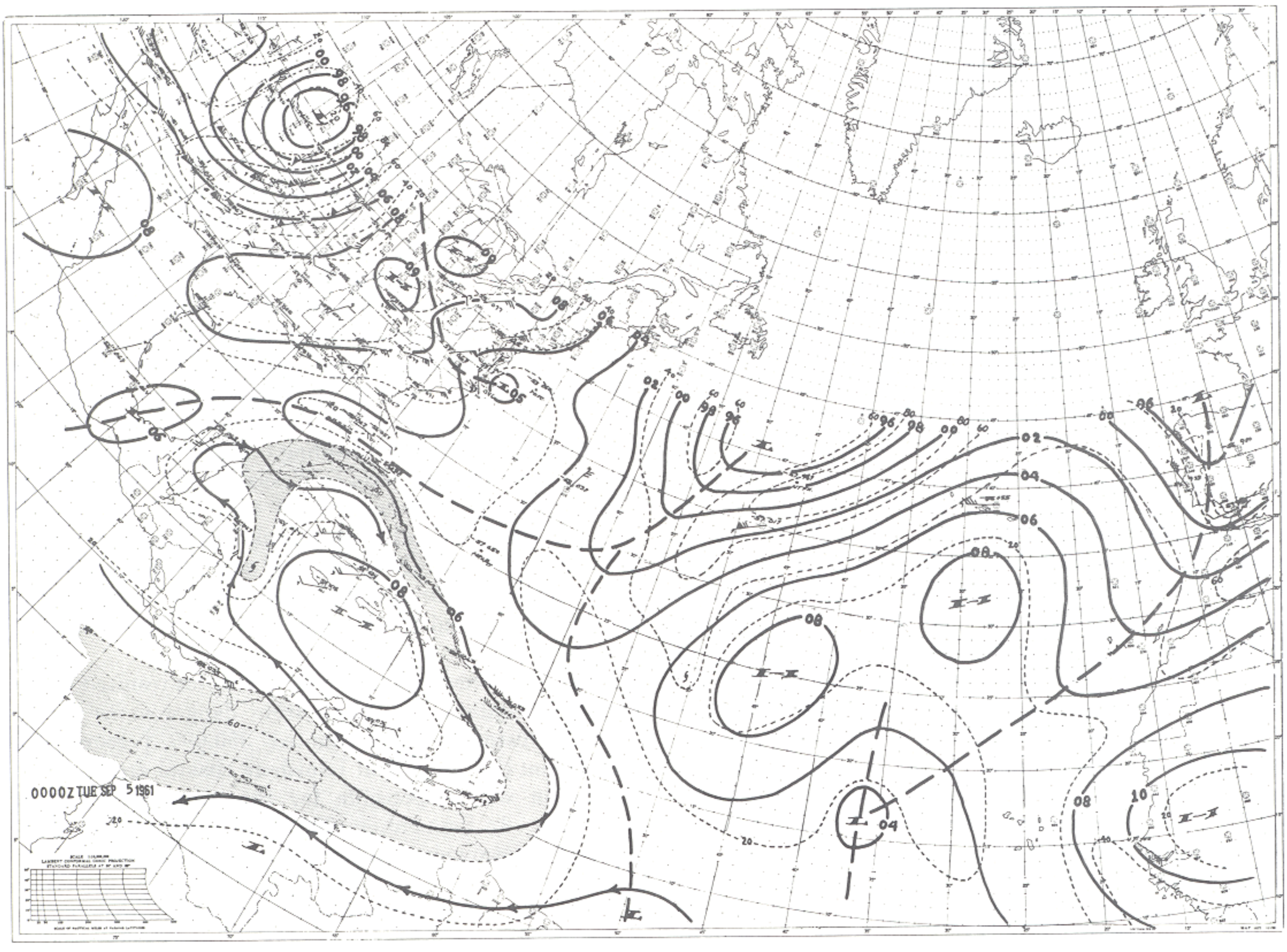

Figure 10.—200-mb. chart for 0000 gmt, September 5, 1961 illustrating the efficient outflow mechanism over intensifying tropical storm Carla (about 16° N., 81.5° W.). Dashed lines are isotachs with values greater than 40 near Carla shaded. (Hurricane Betsy is located near 23° N., 50° W.)

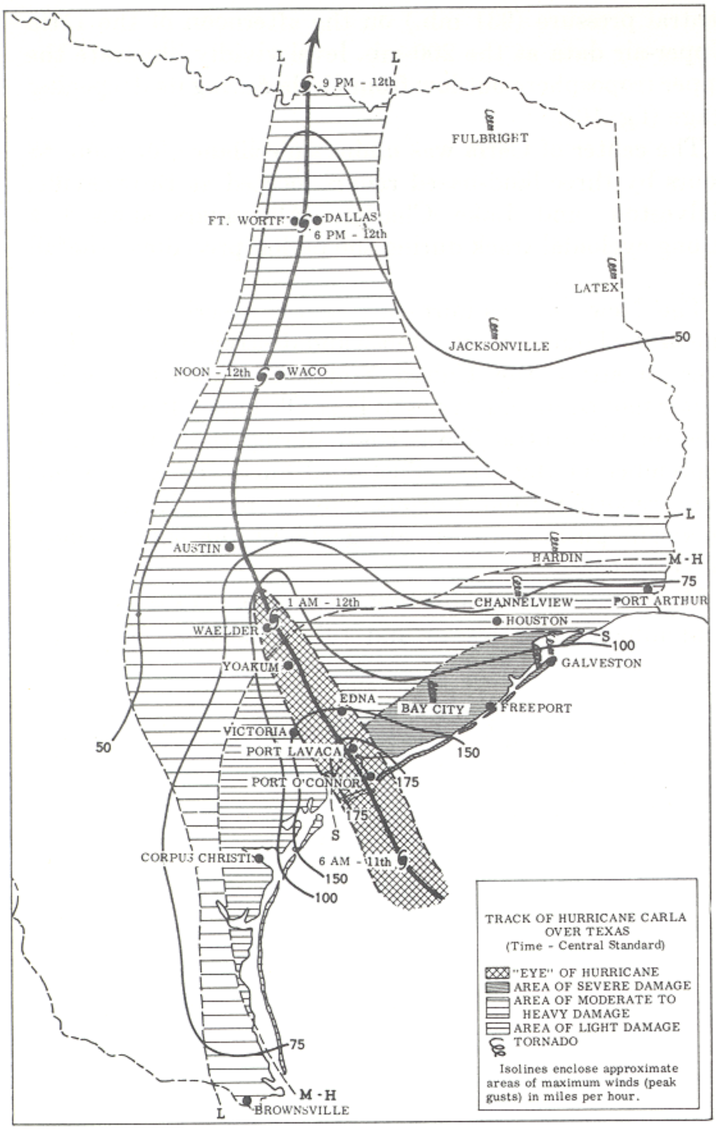

Figure 11.—Track of hurricane Carla on September 11, 1961 over Texas. (From [5].)

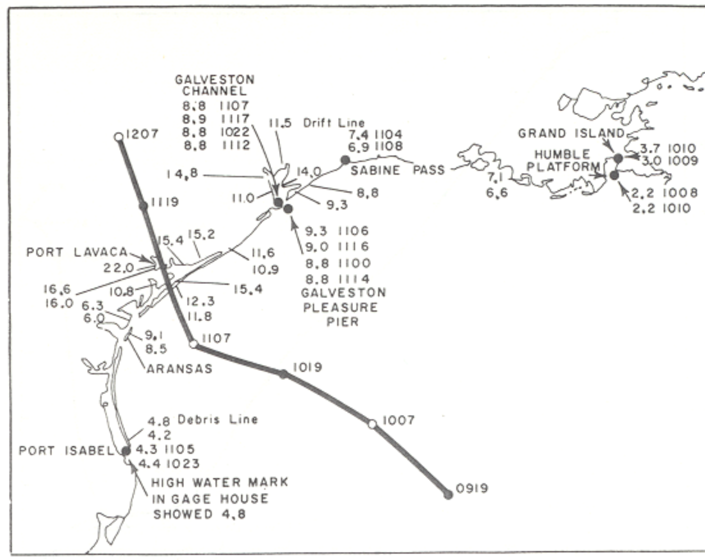

Figure 12.—Storm surge and high water marks (height, in feet. and time) on Texas coast during hurricane Carla. (From [5]), Some of these data are preliminary and may be revised.

the Texas coast with ever increasing fury until the center moved inland three days later. Highest tides were 16.6 feet MSL at Port Lavaca, 14.5 feet MSL at Port O'Connor, 15.2 feet MSL at Matagorda, and 14.8 feet MSL on the upper Houston ship channel. A high water line varying from 15.7 to 22.0 feet MSL was established from the debris near the head of Lavaca Bay. However, this includes an undetermined amount of wave uprush and must be an overestimation of the still-water level in the area of the observation. The unusually slow movement of 6 to 9 m.p.h. resulted in exceptionally prolonged hurricane conditions. A short section of the storm track, the location of the recording tide gages, and a few high water marks and peak surge elevations are shown in figure 12. See [5] for a full explanation of this figure. It is expected that final details concerning the high water marks can be presented in the hurricane summary included in the *Climatological Data, National Summary* Annual 1961 which goes to press about a month later than this article.

Peak gusts of 175 m.p.h. were estimated at Port Lavaca. A gust of 153 m.p.h. was observed on the anemometer of the Bauer Dredging Co. before the instrument failed. The lowest reported pressure at Port Lavaca was 27.62 inches (935 mb.) and it remained at that value from 1545 to 1735 CST. Available information indicates the needle was below the scale during that period.

Total damage in Texas was estimated at $300 million, two-thirds to property and one-third to crops. Fatalities were 34 in Texas, 6 in Louisiana, 5 in Kansas, and 1 in Missouri. Of the 34 dead in Texas 8 were killed in a tornado which swept across Galveston from the Gulf as the hurricane there was subsiding. Eight tornadoes in all were associated with Carla in Texas and 10 in Louisiana. Persons injured in Texas totaled 465; 1,915 homes, 568 farm buildings, and 415 other buildings were destroyed; 7,398 homes, 1,382 farm buildings, and 1,219 other buildings received major damage; and 43,325 homes, 4,238 farm buildings, and 9,268 other buildings received minor damage.

Timely and accurate hurricane advisories resulted in the largest evacuation of persons from danger areas in the Nation's history. An estimated 350,000 persons fled inland from the Texas and Louisiana coastal areas. This evacuation was responsible for the comparatively low death toll. In September 1900 some 6,000 persons died, mostly from drowning, in the well-remembered Galveston hurricane.

Hurricane Debbie, September 6–16.—Hurricane Debbie probably developed between the Cape Verde Islands and Africa. Pressures in that area fell to well below their normal values with evidence of cyclonic circulation during the first few days of September. Late on the 6th and early on the 7th, several reports from the SS *C. Maersk* indicated that a storm, probably already of hurricane intensity, existed near 15° N., 25° W.

The storm moved west-northwestward for the next several days but there were no observations in the area and it was not possible to locate the center accurately. However, on September 10 TIROS photographs indicated that the center was near 25° N., 45° W. (fig. 7). This estimate was less than 200 miles from the actual center. From September 11 through 14 the center was within range of hurricane reconnaissance planes and during this time it moved northward and turned sharply east-northeastward on the 13th passing through the Azores during the night of September 14–15. It then accelerated and turned northward, passing along the western coasts of Ireland and Scotland on the 16th.

The lowest available pressure was 970 mb. reported by a ship a short distance from the center and offshore from Ireland. This agrees well with earlier reconnaissance reports of 975 mb. while the hurricane was in the central Atlantic. Gusts reached 106 m.p.h. at Ballykelly and 104 m.p.h. at Tiree and Snaefill [6].

An Associated Press account of the hurricane from London follows:

"The edge of Hurricane Debbie battered the British Isles Saturday night and left 11 or more dead and at least 50 injured.

"Flooding caused heavy damage in Ireland, Scotland, and Wales. Coastal areas of western Scotland were inundated by pounding surf whipped up by winds of 106 mph.

"Shipping and airplane traffic was disrupted. Coastal radio stations reported the airwaves were jammed with calls for help from small ships and fishing craft.

"Weathermen reported strong winds from northern Norway to the Bay of Biscay."

Hurricane Esther, September 11–26.—On September 11, with Carla moving inland in Texas and Betsy and Debbie still threatening shipping in the Atlantic, evidence of a new disturbance began to appear. At 1330 EST on that date, pictures from the TIROS III satellite showed a vortex near 15° N., 38° W. A reconnaissance flight was therefore dispatched to the area on September 12. It revealed that Esther had formed and was of full hurricane intensity with a central pressure of 967 mb. The first advisory at 1730 EST placed the center at 19° N., 44° W. moving toward the northwest at 15 kt., accompanied by 110-kt. winds. The intensity at this time suggests that Esther undoubtedly reached hurricane strength by September 11. In fact, a "possible" vortex near 11° N., 30° W. in the TIROS III nephanalysis for 1412 EST, September 10 (fig. 8) may have represented near hurricane intensity.

On the 13th and 14th surface pressures to the north of Esther began to rise as Debbie headed toward the Azores and a building anticyclone moved eastward from the vicinity of Bermuda. As a result, Esther was deflected to a west-northwestward course for the next few days. Also, as often happens under the influence of the increased gradient accompanying the passage of a High to the north of a hurricane, a gradual intensification began. By the 17th, the central pressure had dropped to 927 mb. According to the various formulae relating central pressure and maximum wind, this would support 150- to 175-kt. squalls.

Since the storm path was well to the north of the Virgin Islands, Puerto Rico, and the Bahamas, effects in these areas consisted mostly of increased surf and large swells. A gradual curving to the north and subsequently to the north-northeast took the center about 120 miles to the east of Cape Hatteras on the morning of the 20th and to about 35 miles south-southeast of Block Island, R.I., 24 hours later. Gales swept the coastal strip from the Outer Banks of North Carolina to New Jersey and, early on September 12, winds reached hurricane force from eastern Long Island to Block Island. Gusts hit 40 kt. at Ocean City, Md., and 60 kt. at Atlantic City, N.J. Montauk Point, L.I., and Block Island, which were nearer the storm center, reported peak gusts of 94 kt. and 72 kt. respectively, at 0500 EST on the 21st. Cape Cod also experienced hurricane force gusts.

Fortunately for New England, Esther weakened markedly in passing over colder waters north of 35° N., and also took a sharp eastward turn on the afternoon of September 21. This turn was the beginning of a large clockwise loop which carried the center southward almost to the latitude of Cape Hatteras then back to intersect the original path near Nantucket Island four days later. The storm was producing only 35- to 45-kt. squalls on the 22d, but showed some regeneration over the warmer waters at the southernmost part of the loop and when it moved northward again past Cape Cod maximum winds were 50 to 60 kt. The storm accelerated northward through Maine on the 26th, gradually weakened, and turned northeastward toward Labrador as a frontal disturbance.

Prior to the unusual loop, the movement of Esther offered no serious forecast problems. The hurricane began its northward trend under the influence of a short-wave trough associated with an active cold front which passed off the United States east coast on September 15. During the next few days the front remained about stationary and gradually dissipated. The long-wave pattern at this time showed a trough in the western United States and a ridge off the east coast. Weakening of the short-wave trough as it neared the longitude of the hurricane left the upper-level flow generally southerly and permitted the hurricane to continue its northward movement. The next short-wave trough was advancing northeastward from the Plains States as Esther approached southern New England on the 21st, and it seemed likely that the storm would be accelerated to the east-northeast. However, this trough also weakened in the long-wave ridge position, and although the change in course developed, the flattening trough by-passed Esther. The storm then began the southward loop. The movement during this period was not well indicated by conventional forecasting techniques and the factors responsible, even in post-analysis, are not obvious. Esther's northward acceleration after recovery from the loop can be attributed to the effect of a third in the series of short-wave troughs moving through the northeastern United States.

Although not a noteworthy hurricane from the standpoint of damage, Esther will be assured a place in meteorological history. It played a part in demonstrating the potential of satellites for tropical cyclone detection, behaved in very unorthodox fashion in its loop off the east coast, and was the subject of a cloud seeding experiment [4]. The seeding with silver iodide took place on September 16 and 17 and was carefully documented by aircraft of the Navy, Air Force, and Weather Bureau Research Flight Facility. Radar observations showed that large amounts of supercooled water in the seeded area had been converted to ice. It was estimated that the energy released through the change of state which took place in approximately 400 cubic miles of cloud was equivalent to 2×10^8 kilowatt hours of electrical energy or about eight 20-kiloton atomic bombs. Although suggesting a potential source of energy for attempts to alter hurricane behavior, this is, however, actually less than one-tenth of one percent of the energy released by the hurricane in the same 40-minute period. There was no evidence to indicate a material change in movement or intensity.

No deaths have been attributed to Esther. Property damage totaled $5 million to $10 million.

Hurricane Frances, September 30–October 10.—Although there were slight indications of a disturbed area east of the Antilles as early as September 28, it was not until the morning of the 30th that aircraft reconnaissance confirmed the development of tropical storm Frances. On this date the storm was very poorly organized with a sea level pressure no lower than 1005 mb. (29.68 inches).

Tropical storm Frances passed between the islands of Marie Galante and Guadeloupe, French Antilles, between 0000 and 0100 EST on October 1. At 0100 EST, the Netherlands steamship *Viajero* near 16.4° N., 60.8° W., just off the island of La Desirade, French Antilles, reported 60-kt. winds from 120° during a heavy squall. At 0230 EST an amateur radio operator at Guadeloupe reported wind gusting to 50 to 60 m.p.h. from the south.

In the passage from Guadeloupe, French Antilles, to Dominica, West Indies Federation, it appears that the wind field was completely distorted by the 6,000-foot mountains on Dominica and the 5,000-foot range on Guadeloupe. This occasionally happens to tropical storms passing between or over these two islands while in the developmental stage.

Frances never recovered its earlier intensity while in the Caribbean. Indeed, it was here that forecasters were confronted with a most difficult problem. Reconnaissance planes were able to follow an area of weather and relative calm moving westward, while other planes were tracking a very weak circulation moving northwestward toward the extreme eastern portion of Hispaniola. The latter turned out to be most important and the one that eventually intensified. The absence of a good divergence field at high levels was noted during this period and perhaps this was the paramount reason for the slow development and the disorganized state of the storm.

Frances moved just to the west of Bermuda on October 6, then threatened Maine on October 8. It later made an abrupt turn to the right and dissipated over Nova Scotia.

The lowest sea level pressure reported was 948 mb. (27.99 inches) which is in good agreement with the maximum winds estimated at 110 kt. (127 m.p.h.). The maximum intensity occurred when the hurricane was west and northwest of Bermuda and gales were reported throughout the islands at this time. As it turned out, flooding along the south coastal plain of Puerto Rico caused more damage than at any place along the entire path, mainly to roads and bridges. There has been no loss of life reported in connection with Frances.

Tropical Storm Gerda, October 16–22.—Several days before tropical storm Gerda developed, a Navy reconnaissance aircraft investigated an easterly wave in the eastern Caribbean, finding widespread shower activity and some evidence of a weak circulation. However, winds were not strong, generally less than 25 m.p.h. The wave continued slowly westward and began to show evidence of intensification the night of the 15th with pressures dropping in the central Caribbean and heavy rain beginning over Jamaica and eastern Cuba. By the morning of the 16th, pressure at Kingston had dropped to 1005 mb. with winds both at the surface and aloft indicating a circulation with the center a short distance to the north of Jamaica. The poorly organized disturbance moved slowly northward across central Cuba, thence northeastward through the western Bahamas on the 18th with slow deepening but winds still only 25 to 40 m.p.h. in scattered squalls. North of the Bahamas, reconnaissance aircraft found winds up to 60 m.p.h. on the morning of the 19th, although the storm still remained poorly organized with a large center and no evidence of a wall cloud.

Gerda moved north-northeastward to a position just off Nantucket on the 20th reaching its maximum intensity at that time. Texas Towers off the Massachusetts coast reported whole gale winds, occasionally of hurricane force for short periods. From this position Gerda turned to an east-northeastward course gradually accelerating and becoming extratropical on the 21st.

Although Gerda had most of the characteristics of a tropical storm at low levels, conditions in the upper troposphere were not favorable for strong deepening.

Reconnaissance aircraft did not report any indication of wall cloud formation or spiral bands at any time during the course of the storm. Even at the time of the strong winds at the Texas Towers, an Air Force reconnaissance aircraft very near their location reported winds of only 10 kt. at 700 mb. A low-level injection of polar air into Gerda was occurring at this time and the circulation apparently was quite shallow.

Damage from Gerda was not heavy although according to press reports information was received from eastern Cuba of extensive flooding resulting in seven deaths. Five deaths were reported from Jamaica due to drowning. Heavy rains occurred for several days over Jamaica and extreme eastern Cuba. Orographic effects probably caused excessive amounts with flash flooding quite common over the more mountainous sections of these areas. Damage through the New England area was about the same as that from a typical wintertime northeaster. The strong winds reported by the Texas Towers did not occur on the coast where 30 to 50 m.p.h. were the strongest winds reported.

Hurricane Hattie, October 27–31.—Hurricane Hattie was the killer storm of the 1961 hurricane season, although property damage was much greater in Carla. Approximately 275 people perished in Hattie. Not since hurricane Janet, 1955, has a storm inflicted so much damage in the Yucatan Peninsula region.

The first indication of a tropical storm came from a ship, located about 120 miles south-southeast of San Andres Island at 1900 EST, October 26, reporting a 40-kt. southerly wind. By 1000 EST, October 27, the airport at San Andres Island reported that it was closed because of 40- to 50-kt. easterly winds and, based on this report, the first tropical storm advisory for Hattie was issued by the Miami Weather Bureau at 1700 EST.

Hattie passed over, or just to the west of, San Andres in the late afternoon of the 27th. A minimum pressure of 991 mb. was observed at 2100 EST, October 27, and highest steady winds were 70 kt. with 90-kt. gusts. One person was killed on the island and 15 were injured, with property damage estimated at $300,000.

From this point Hattie continued on a generally northerly course for the next 36 hours and intensified with the central pressure reaching 952 mb. near 15° N. By 1900 EST, October 29, a change to a more westerly course became clearly evident. The storm continued on a cyclonic turn passing between Swan and Grand Cayman Islands with maximum winds on these two islands remaining under hurricane force.

Hattie finally settled on a west-southwestward course and intensified markedly during the morning of October 30 when the central pressure probably reached its lowest value, 924 mb., at 0800 EST. A lower pressure of 920 mb. was computed at 1700 EST; however, this was based upon the 700-mb. height and not determined by dropsonde.

Hattie moved inland on the British Honduras coast about sunrise on October 31. The center of the radar

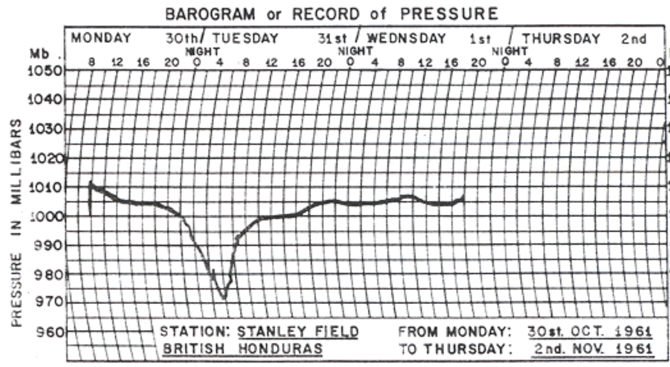

Figure 13.—Barograph trace at Stanley Field, Belize, British Honduras during passage of hurricane Hattie.

eye, which measured approximately 25 miles in diameter, passed 20 miles southeast of Belize. The lowest pressure on the barograph at Stanley Field, Belize, was 972 mb. (fig. 13) indicating a gradient of some 45 to 50 mb. in the 20 miles between that point and the center of the eye. A trained observer estimated winds from 150 to 160 m.p.h. at Belize with unofficial estimates to 200 m.p.h. or more. A copy of the Dines anemometer record is shown in figure 14. The pen remained at the top of the graph for a while. Storm tides of 10 to 11 feet along the Belize waterfront were general and waves deposited mud on the third floor of some buildings. Other locations near Belize reported storm tides up to 14 feet.

Seventy-five percent of Belize, the capital of British Honduras, was either destroyed or severely damaged. Some communities such as Stan Creek were almost completely erased. Damage was so great in Belize that plans are under consideration for its relocation farther inland.

Latest fatality figures show 262 dead in British Honduras. The ready-to-harvest citrus crop scheduled for export and worth $2,000,000 was destroyed and unknown millions were lost in timber, cocoa, and bananas. Damage is estimated near $60 million. Guatemala reported 11 deaths and Honduras 1, most of these apparently occurring in flash flooding.

The Governor of British Honduras stated that hurricane Hattie was much worse than the 1931 hurricane in which 2,000 persons died and the fact that the death toll was not higher at this time was due to the excellent warnings. A large percentage of the people in Belize either evacuated or moved to supposedly safer buildings. In Stan Creek, 3,500 of the 4,500 residents were evacuated.

Hattie continued west-southwestward and southwestward through British Honduras and Guatemala, dissipating in the mountains of Guatemala. Tropical storm Simone was already in existence in the Pacific Ocean as Hattie passed near Belize, and the remnants of Hattie developed into neither Simone nor Inga.

There are a number of interesting points connected with hurricane Hattie which are worthy of mention. This is the fourth hurricane of record to affect San Andres Island,

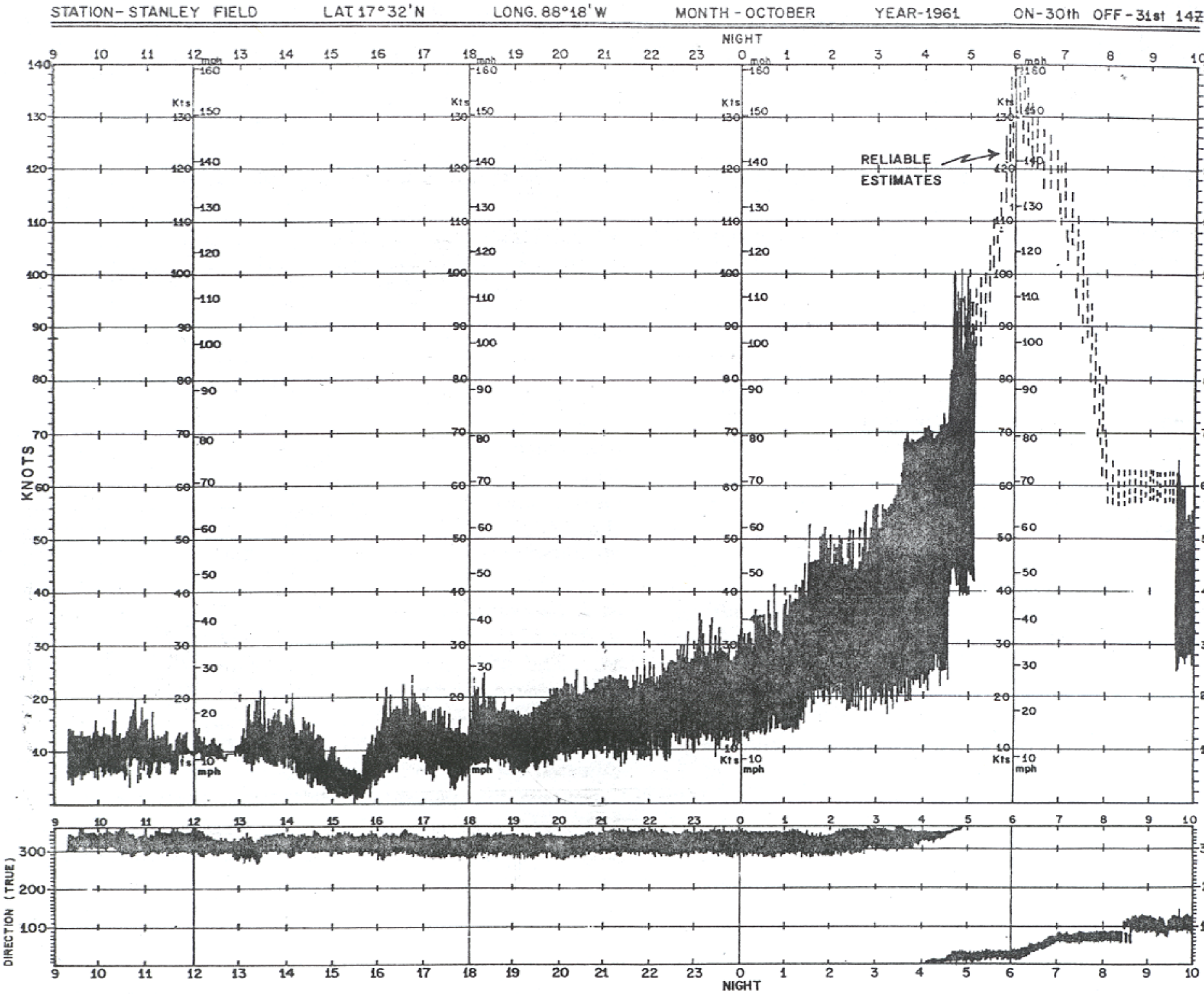

FIGURE 14.—Trace from Dines anemometer, Stanley Field, Belize, British Honduras, during passage of hurricane Hattie.

and it is most unusual to have one form south of the island. Residents could recall only one other hurricane which passed over the island since the turn of the century; this one occurred in October 1908 [7].

This development of hurricane Hattie appears to have been triggered by events near the outflow level. Riehl [8] pointed out the importance of this level suggesting that superposition of high-level divergence over a low-level disturbance could lead to intensification. More recently, Alaka [9] proposed that anomalous winds in the upper troposphere may be the dynamic mechanism for triggering hurricane formation. The common feature of these two and other hypotheses which have been suggested is the occurrence of a high pressure area in the middle or high troposphere near the formation point.

In the case of Hattie, an upper tropospheric anticyclone moved eastward past Swan Island on October 25 to a position just northeast of the formation point. On October 26, a sharp intensifying trough moved into the western Gulf of Mexico from Texas. This combination produced strong southwest to south flow over the western Caribbean thus furnishing an excellent evacuation mechanism for rising warm air currents over the surface perturbation. The 200-mb. chart for 1900 EST is a classic example of the outflow pattern over a hurricane. At this time Grand Cayman Island reported a 95-kt. south wind (fig. 15) at this level.

The final point of interest concerns the marked change in course on the 29th. Climatology [10] indicates that the most probable track for late-season storms in the western Caribbean Sea is northerly with gradual turning to the northeast. Only occasionally a storm recurves rapidly

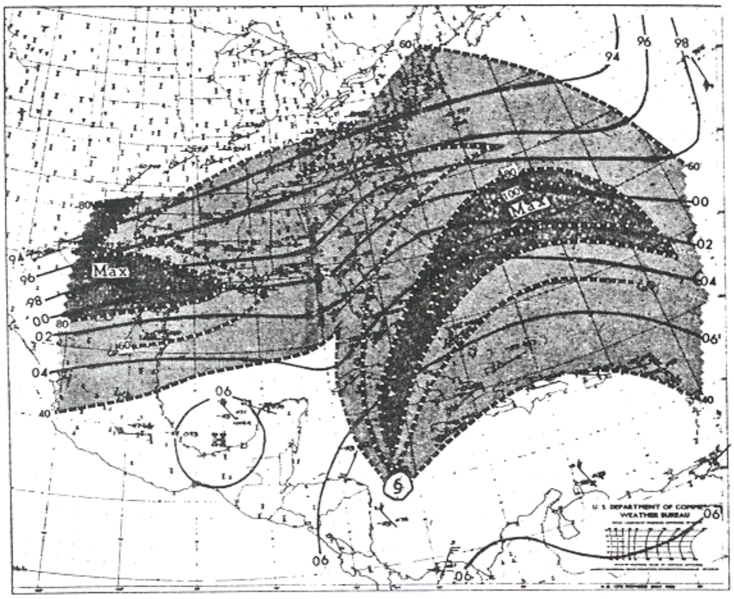

FIGURE 15.—200-mb. chart, 0000 GMT, October 29, 1961, illustrating outflow in upper troposphere from hurricane Hattie. Isotach values greater than 40 are shaded.

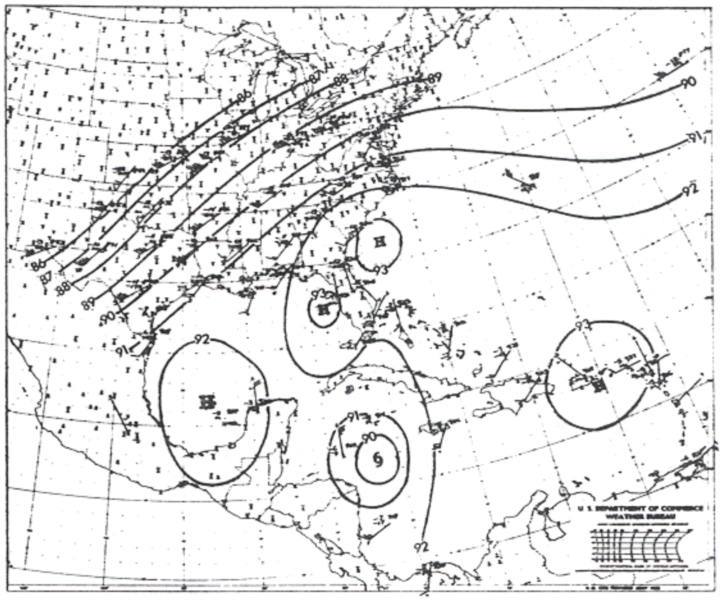

FIGURE 16.—500-mb. chart, 1200 GMT, October 29, 1961, shortly before hurricane Hattie began a sharp recurvature toward the west.

westward on a track similar to that of Hattie. In this case, the change in course can be explained by events which took place in the mid-troposphere. At 500 mb. a building ridge in the Gulf of Alaska caused "digging" in the southwestern United States with a cutoff Low forming and moving to extreme southern California by the morning of the 31st. In response to the trough formation in the Southwest, heights began to rise over the eastern United States with an anticyclone forming over the Gulf of Mexico.

The 500-mb. chart for 0700 EST, October 29 (fig. 16) shows a good trough over the storm with the axis extending from just east of Miami to Nicaragua. All steering techniques based on this chart would indicate a north to north-northeast movement. However, 24 hours later 200- to 300-foot rises from Mississippi westward increasing to 400 to 550 feet in New Mexico and Colorado intensified the mid-tropospheric anticyclone in the Gulf of Mexico and also resulted in a fracture of the trough over Cuba. This combination of events caused recurvature to the westward and rapid intensification of the hurricane. To some extent the broad-scale changes were forecast by both the numerical weather prediction process and by the forecasters, but the small-scale changes in the area of concern were not apparent. Therefore, some unnecessary warnings were issued for the area around western Cuba.

Tropical Storm Inga, November 4–8.—Inga, a very late-season tropical cyclone in the Gulf of Mexico, moved and behaved quite erratically. It was of true tropical nature during only part of its life, and the first of record to form in November in the Gulf.

Early on November 4, the SS *Navigator* reported northwesterly winds estimated at 70 to 80 kt. with pressure dropping rapidly to 1001 mb. at a position about 100 miles northeast of Vera Cruz, Mexico. That afternoon the Navy reconnaissance plane located the center of the storm circulation about 150 miles northeast of Vera Cruz with a central pressure of 998 mb. and the highest winds 50 kt. The storm moved north-northwest to a position about 100 miles east of Tampico by the night of the 5th. A strong pressure rise and cold front pushed southward out of Texas into the northwestern Gulf and southward along the Mexican coast during the night of the 5th. The strong pressure rises to the northwest of the storm caused it to turn southward, and at 0800 EST on the 6th a Navy plane located the center about 100 miles east-northeast of Tuxpan. The plane flew on southward and located a second eye at 0900 EST about 80 miles southeast of the first center. The cold air apparently moved into the first eye and it dissipated rapidly, leaving the southern eye as the main center. This center moved slowly southeastward and became stationary in the Gulf of Campeche about 160 miles east-northeast of Vera Cruz on the afternoon of the 6th. It continued essentially stationary in this area and gradually became extratropical as the cold air moved into it. On the morning of the 8th, the flight into the area encountered no closed circulation but ships a short distance northeast of Vera Cruz continued to report winds of gale force until that night.

The storm was apparently a shallow system, because its movement was determined mainly by the forces at low levels. On the 6th, the strong pressure rises moving southward along the Mexican coast ahead of the cold front apparently caused the new eye or center to develop in the same area where the original circulation was found. This first circulation developed as a strong pressure rise pushed southward along the Mexican coast ahead of a weak cold front on the night of the 3d. This area of development is about 100 miles east of the position where a high mountain range in Mexico protrudes eastward to near the coast in the vicinity of Nautla. The New Orleans hurricane center hypothesized that the funneling effect set up by these mountains may be a factor in the development of the circulations in that particular area.

The lowest pressure reported by dropsonde from reconnaissance was 997 mb. (992 mb. from low-level extrapolation), and the highest wind was 65 kt. in the cold air to the west and south of the center on the afternoon of the 7th, after the storm had been stationary for about 24 hours in the Gulf of Campeche and was becoming extratropical. During the period when the storm was predominantly tropical in nature, the highest winds were about 50 kt.

Hurricane Jenny, November 1–9.—Jenny, the tenth and last cyclone for which advisories were issued in the 1961 hurricane season, was only quasi-tropical, resembling the Kona Low of the Pacific or what has been called the "subtropical" storm in the Atlantic. These develop in connection with cold-core cyclones and are more likely to occur outside the usual hurricane season. Some other examples were hurricane Greta of 1956 [11] and the unusual May hurricane in 1951 [12].

The disturbance which eventually became Jenny was first noted in the vicinity of the Windward Islands on November 1, at which time it was only a broad area of unsettled weather with lowest pressure around 1005 mb. The formation of the disturbance coincided with the development of a cut-off Low in the middle and upper troposphere just to the north of Puerto Rico. The depression moved northeastward during the next two days then turned abruptly eastward in advance of a deepening upper-level trough in the westerlies. On November 5, the 500-mb. charts showed that the trough had sheared, cutting off an intense cold Low some 300 miles northwest of the position of the surface disturbance. This Low moved southwestward during the next 24 hours and the surface Low, apparently steered by the upper system, reversed its course and moved rapidly westward.

As the surface Low began to move under the upper cyclone, it deepened rapidly and the central pressure on November 6 was 974 mb. Maximum winds were barely of hurricane force near the center but gales extended outward as much as 600 miles to the north and 300 miles to the south. This was evidently due to reflection in the surface pressure gradients of the upper Low and not to a true tropical development. However, the latitude of the storm and the concentration of winds of hurricane force about the center made it advisable to treat the storm as tropical for purposes of marine advisories. It has been observed in "subtropical" storms that a warm core may exist within the circulation of the larger cold Low. The possibility that this was true in the case of Jenny cannot be ruled out but it could have been for only a matter of hours and was not observed by the reconnaissance flight on November 6, which reported "no eye, no temperature rise, no spiral bands."

Jenny became essentially stationary on November 7, then began to move to the northeast and weaken, becoming clearly extratropical during the next two days. It was never a threat to land and the only known damage was to the ship *Venore*, an 8,000-ton ore carrier, which required assistance after becoming disabled in the storm on the afternoon of November 6.

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