THE HURRICANE SEASON OF 1958

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1. GENERAL SUMMARY

Ten tropical cyclones, seven of full hurricane intensity, developed in Atlantic waters during the hurricane season of 1958. This number compares with an annual average of 10 storms for the past 20 years, 9 for the past 40 years, and 8 for the last 75 years. Except for a short-lived minor tropical storm in the western Gulf of Mexico in mid-June, conditions over the tropical Atlantic remained stable until the second week in August. Thereafter conditions were very active until the last hurricane of the season, Janice, formed during the first week in October.

In contrast to the concentration of most of the activity in the Gulf of Mexico during 1957, major tropical storm activity shifted to the western Atlantic in 1958 (fig. 1). Only two storms, both lacking hurricane intensity, occurred in the Gulf of Mexico and storm activity affected only the extreme northern Caribbean. While no hurricane center reached the coastline of the United States, one—Helene—caused hurricane winds of major intensity on the North Carolina coast. Ella crossed the Texas coast near Corpus Christi with less than hurricane winds and Alma, Ella, Daisy, and Janice caused fringe squalls at one point or another along the United States coastline. Only two deaths in the United States were directly attributable to tropical cyclones and total damage was estimated at between 11 and 12 million dollars, mostly in the Carolinas in connection with Helene. In the Antilles, tropical cyclones killed 6 or 7 persons in Cuba, 35 or more in Haiti, 3 in Puerto Rico, and 2 in the Bahamas. Total damage outside the United States has been difficult to determine but is estimated at several million dollars, mostly in Hispaniola, Cuba, Jamaica, and Puerto Rico.

Following the formation of tropical storm Alma on June 14, a broad trough developed along the Atlantic coast and persisted throughout the remainder of the month. The accompanying westerlies at comparatively low latitudes are thought to be inimical to tropical storm formation. In July, intense blocking over the Atlantic continued to depress the westerlies [5], and the circulation was highly unfavorable for tropical storms in this area [2] [9].

Tropical storm activity was high during the last two decades of August and the mean circulation for the month as described by Woffinden [16] showed a reasonable similarity to the composite chart developed by Ballenzweig [3] favorable for tropical storm formation in the vicinity of the Lesser Antilles. The somewhat greater than normal amplitude of the trough along the Atlantic coast permitted Becky, Cleo, and Daisy to recurve over the western Atlantic. However, Ella, which formed at a low latitude just east of the Windward Islands at the close of the month, remained in the easterlies when the east coast trough was replaced by a ridge during the first few days of September

2. INDIVIDUAL TROPICAL CYCLONES

Alma, June 14–15.—Tropical storm Alma developed in an easterly wave that was first detected in the central Caribbean on June 9 and 10. Abnormally heavy shower activity was occurring on these dates over the western and central Caribbean Sea and northward across Cuba into the Bahamas. There was some evidence of a closed circulation at 1800 GMT on the 10th near latitude 15° N., longitude 78° W. On succeeding maps, a weak circulation was observed and heavy rains continued over the northwestern Caribbean and eventually spread into Central America.

The weak circulation moved westward into the Yucatan Peninsula-Guatemala area on the 12th and into the Gulf of Campeche on the 13th. The disturbance continued northwestward along and off the Mexican coast and developed into tropical storm Alma about midday on the 14th some 150 miles east of Tampico.

At 2100 GMT on the 14th, the Motor Vessel *Mada*, at latitude 22.8° N., longitude 95.6° W., reported a south-southeast wind of 45 m.p.h., pressure of 997 mb., and mountainous seas. At 0500 GMT on the 15th, this ship, located about 100 miles northwest of Carmen, Mexico, was encountering south-southwest winds of 35 to 40 m.p.h., pressure of 1006 mb., and very rough seas.

A Navy reconnaissance aircraft was dispatched to the storm on the 14th. However, the center had apparently moved inland and broken up before the aircraft reached the area. The plane reported maximum winds of 22 knots and minimum pressure of 1008 mb., and observed no radar echoes.

Highest winds reported were 45 to 50 m.p.h. from the MV *Mada* on the 14th, 50 knots from a Coast Guard aircraft 50 miles south of Port Isabel, Tex., at 0800 CST and 40 to 45 m.p.h. at south Padre Island, Tex., at 1000 CST on the 15th. Heavy rains fell over the hill country to the west of San Antonio, generally averaging 7 to 10 inches with some amounts reported as high as 20 inches a little to the west of Medina, Tex.

Very little damage was caused by wind and tides associated with this storm and major damage to crops and property was associated with floods caused by the attendant rains. One death by drowning occurred in the Galveston area during passage of the storm.

Becky, August 11–15.—Becky, the second tropical storm of the season, was first positively identified on August 11. A series of reports from the ship *Industrious* indicated the storm's existence near latitude 18° N., longitude 45° W., halfway between Puerto Rico and the Cape Verde

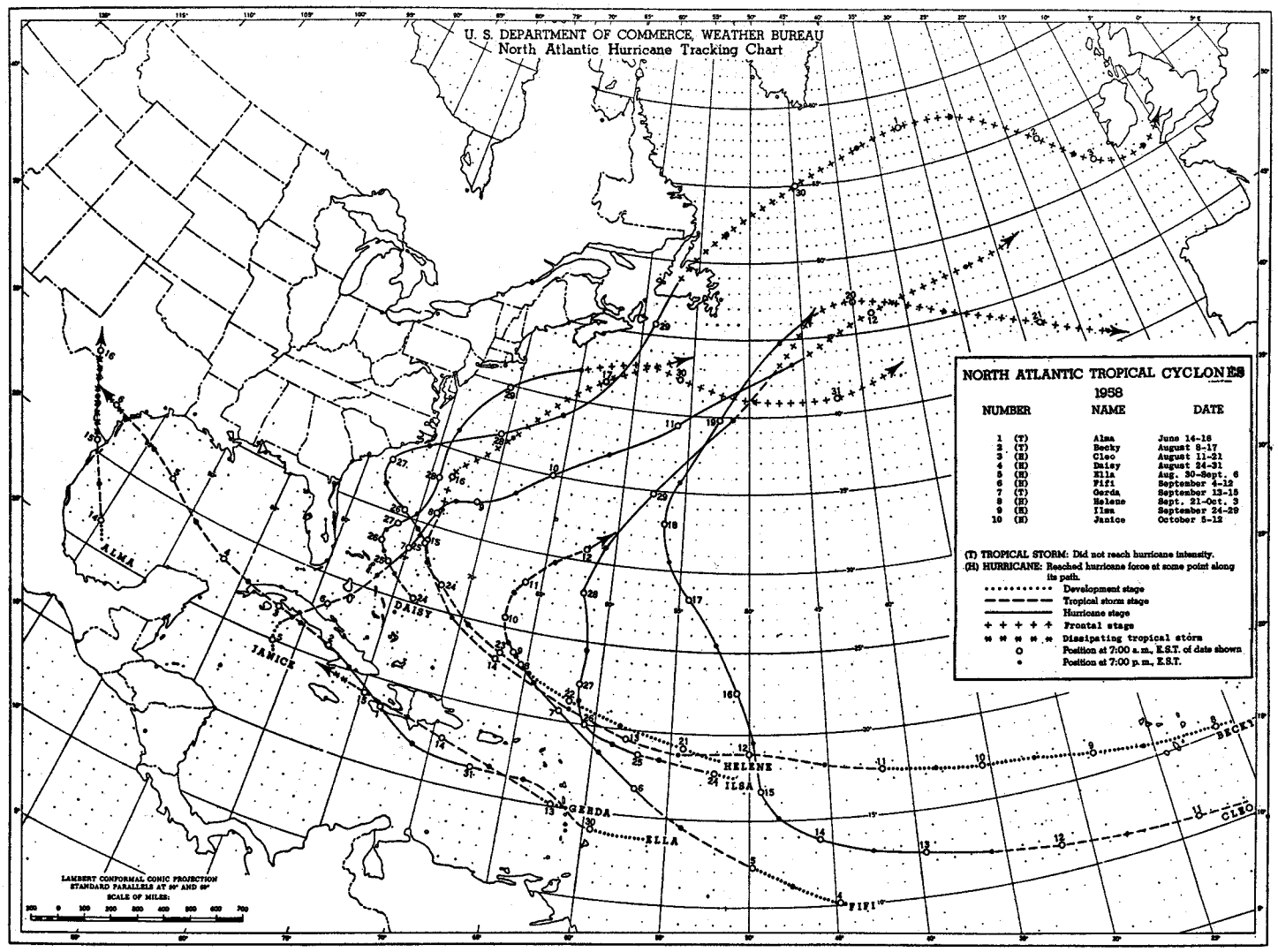

FIGURE 1.—Tracks of tropical cyclones of 1958.

Islands. The Weather Bureau Office at San Juan issued the first advisory at 0400 GMT, August 12. Reports on August 7 and 8 from the Cape Verde Islands had indicated a westward-moving tropical depression. A continued westward movement with some intensification was confirmed on August 9 by reports from the ship *Tatra*.

On August 12, reconnaissance aircraft flying at 700 mb. reported a complete cyclonic circulation, a maximum wind speed at flight level of 60 kt., and minimum sea level pressure by dropsonde of 1006 mb. Thereafter Becky continued on a westward to west-northwestward course passing about 290 miles northeast of Puerto Rico at the nearest point. Then the storm began to recurve broadly to the northwest and north and on the 16th toward the northeast around the western periphery of the subtropical high pressure area.

The minimum pressure of 1006 mb. reported by the first reconnaissance into Becky was as low as any succeeding central pressure report while the storm was under close surveillance by aircraft. The area of gale winds gradually increased in size but remained mostly north and east of the center. Maximum reported winds increased very slowly from about 35 knots up to an estimated 55 or 60 knots during the first two and one-half days. Up to 75-knot winds were reported in squalls about 210 miles east-northeast of the center on August 14. Reconnaissance aircraft made frequent reference to lightning, heavy thunderstorms, and turbulence on the east and north sides of the storm.

From the time of Becky's first confirmed existence until it began a northward course, the subtropical high pressure cell to the north of it remained well established with highest pressures generally above 1023 mb., which is about normal for the month of August. The average speed of the storm during the time it was under close surveillance by aircraft was about 20 knots. The reason for lack of intensification is not known, but an old empirical forecasting rule states that movement of 20 m.p.h. or more is unfavorable for intensification.

Reconnaissance aircraft and ship reports in the region early on August 15 indicated that Becky had degenerated into an area of squalls with little if any cyclonic pattern. However, late on the 16th, after Becky moved into an old frontal zone and became extratropical, rapid intensification took place, with one ship for a short time reporting hurricane-force winds.

Cleo, August 11–21.—The existence of hurricane Cleo was first suspected on August 11 based on reports from the Cape Verde Islands. Weather conditions and 24-hour surface pressure changes indicated that a fairly well developed easterly wave was passing through the area. Judging from surface and low-level wind reports, any possible circulation associated with the wave must have passed well to the south of the Cape Verdes. On August 12 and 13, reports from several ships on the outer periphery of the suspected storm indicated that a large cyclonic circulation was developing; however, none was close enough to even estimate the location or intensity of Cleo.

On August 14, an Air Force reconnaissance aircraft located hurricane Cleo at 1820 GMT near latitude 14.7° N., longitude 47.1° W. By this time, Cleo had developed into a very intense storm with lowest pressure of 962 mb. and winds estimated at 146 m.p.h. On the basis of fringe data, it is believed the storm was moving at about 21 m.p.h. from August 11 to 13; however, on August 14, the time of first aircraft penetration, the storm undoubtedly was decelerating as it began turning northward under the influence of a weak upper trough near longitude 50° W.

On the 16th, the storm turned toward the north-northwest and gradually increased its forward speed. Recurvature south of latitude 20° N. during August is very unusual and in this case was never completed (fig. 1). The trough that influenced Cleo was naturally weak at this latitude and it soon collapsed from the outflow from the hurricane. Again, under the control of a large warm anticyclone over the eastern Atlantic, Cleo resumed a more northwestward course until the 18th.

An active short wave which passed through the Northeastern States on the 16th and 17th began to affect Cleo by the 18th as the storm slowed to about 14 m.p.h. and gradually turned to a northward course. On the 19th Cleo accelerated to around 29 m.p.h. on a northeastward and later a more eastward course until becoming extratropical on the 20th.

Although the highest winds were reported by reconnaissance aircraft on first penetration, the hurricane did not reach maximum intensity (based on pressure and radar pattern) until the 15th when a dropsonde in the eye at 2030 GMT indicated a sea level pressure of 947 mb. (See fig. 2 for minimum pressure as reported by the reconnaissance aircraft.) It is probable that the aircraft did not find the area of maximum winds on this day so it still may be assumed that this was the date of maximum intensity.

Fortunately hurricane Cleo remained at sea throughout its history and no reports were received of any severe damage to shipping or loss of life despite the storm's traversal of the principal transatlantic shipping lanes. An interesting account of a vessel passing through the eye of Cleo can be found in the November *Mariners Weather Log* [15].

Daisy, August 24–31.—Hurricane Daisy formed in a strong easterly wave which passed through the Lesser

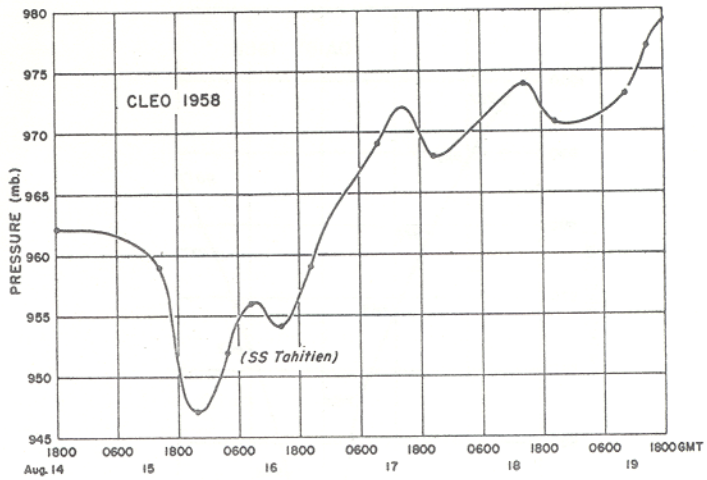

FIGURE 2.—Minimum sea level pressures in hurricane Cleo, reported by reconnaissance aircraft, Aug. 14–19, 1958.

Antilles during August 20–21. There was little indication of intensification, however, until the 23d, when the wave passed through the Windward Passage and a definite increase in its amplitude was evident. A vortex developed on the 24th and reconnaissance aircraft located an eye just north of the central Bahamas with maximum winds of about 55 m.p.h. and a central pressure of 1002 mb. The first advisory was issued at 0100 GMT August 25.

Hurricane Daisy moved very slowly north-northwestward during the 25th and the morning of the 26th. The hurricane recurved initially near latitude 28° N. on the 26th, and its forward speed accelerated. The center passed about 75 miles east of Hatteras on the 28th moving about 20 m.p.h. It then passed about 70 miles southeast of Nantucket, moving east-northeastward about 25 m.p.h. on a second recurve. Neither the North Carolina nor the New England coasts, however, felt much effect of this severe hurricane. The strongest wind at Hatteras was NNW 27 m.p.h., with gusts to 36; Block Island reported 40 m.p.h., with gusts to 45. A Texas Tower, 120 miles east of Cape Cod, experienced a sustained wind of 69 m.p.h. with gusts to 87. There was no loss of life or appreciable property damage in the United States from Daisy.

At the time Daisy formed, the westerlies over the United States were far south of their normal position for the second half of August. At 500 mb. on the 24th, westerly winds extended southward into the Gulf of Mexico. A similar pattern had prevailed during most of the month, a circulation feature which steered Daisy away from the coastal areas of the United States. While the hurricane was forming, however, the subtropical ridge over the western Atlantic at 500 mb. was north of Bermuda. During the first two days of Daisy's history, a weak extension of this ridge separated the hurricane from the westerly flow just to the north. While the storm was small and relatively weak, it was unable to break through this ridge, which partly explains the very slow movement prior to first recurvature. Deepening of the storm took place simultaneously with the passage of a strong short-wave trough through the central portions of

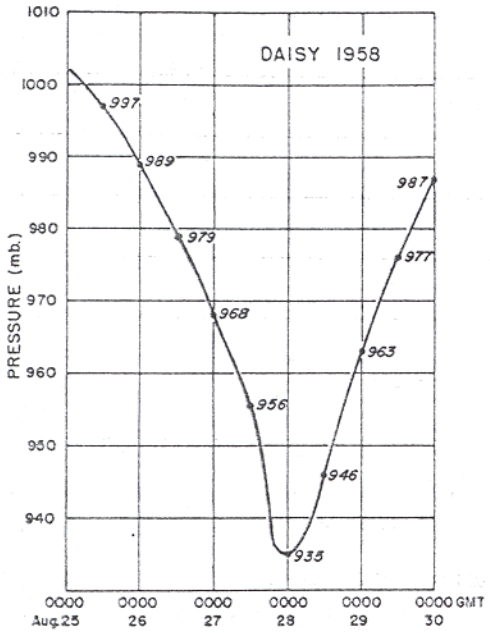

FIGURE 3.—Minimum sea level pressures in hurricane Daisy, Aug. 25–30, 1958.

the United States. The intensification of the storm increased the internal forces which tend to drive a hurricane northward at the same time that the approach of the short wave weakened the already weak ridge north of Daisy. This combination permitted the subsequent rapid northward progress of the storm.

The central pressure dropped steadily from 1002 mb. at the time the first advisory was issued to a minimum of 935 mb. (fig. 3). Thereafter the pressure rose and by the 30th the central pressure was 987 mb. The strongest winds, reported by aircraft, were about 115 m.p.h. It appears likely, however, that the aircraft did not encounter the actual maximum winds within the storm, inasmuch as Fletcher's [6] formula* would indicate a maximum wind in excess of 150 m.p.h. at the time of minimum pressure.

The intensification of the storm is not easy to explain. The initial deepening on the 24th took place while the low-level disturbance was situated under a small 200-mb. anticyclone, a situation postulated by Riehl [10] as favorable for deepening. At the same time there was a large cyclonic vortex (cold) south of Bermuda. On the 25th the small warm anticyclone over the storm disappeared, although the low-level vortex was still under a weak anticyclonic flow. The presence of the cold vortex to the east in all probability inhibited the growth of the high-level anticyclone typically associated with developing hurricanes and the absence of a well developed High at 200 mb. may have retarded Daisy's intensification.

On the 26th, however, the cold 200-mb. Low weakened and moved northward to the west of Bermuda. At the same time the 200-mb. anticyclone in the area of the storm began to increase in size and intensity, and a well-developed trough approached the storm area from the west. Although the size of the 200-mb. High was much smaller, the overall situation closely resembled that described by Miller [7] as being most favorable for maximum intensification. During the 24-hour period beginning at 2100 GMT on the 26th the central pressure in Daisy fell about 40 mb. That intensification was also accompanied by growth of the 200-mb. anticyclone is evidenced by the fact that during a comparable 24-hour period beginning at 0000 GMT on the 27th, the size of the high-level anticyclone more than quadrupled.

Daisy was within range of land-based radar during much of the time it retained its tropical nature. Various radar installations all the way from Miami, Fla., to New England had Daisy's eye under surveillance at one time or another. The Weather Bureau station at Hatteras was particularly effective in tracking the storm during the period when the forecast problem was most acute.

The forecasts on this hurricane at the critical times when it posed a threat to coastal areas were excellent. The turn to a more northerly course while the first recurving was in progress was forecast. The recurving south of the New England coast was also forecast because it was indicated by all except one of the techniques for forecasting movement now in general use. However, hurricane warnings were eventually issued for the area from Provincetown, Mass., to Block Island, R.I., when it appeared that the center would come close to Nantucket Island. This hurricane warning was fully warranted in view of the normal error in forecasting the path of any storm continually changing direction and speed of movement with time.

Ella, August 30–September 6.—First indication of Ella was a fairly active easterly wave in the vicinity of longitude 50° W. on August 29. Reconnaissance aircraft on a routine flight east of the Windward and Leeward Islands reported a wind shift and above average shower activity, but no indication of a cyclonic circulation. The wave moved through the islands during the 30th causing heavy rains and winds of 35 to 40 m.p.h. and lowest pressure around 1010 mb. Reconnaissance aircraft located a center by radar at latitude 16.3° N., longitude 64.7° W., during the evening of the 30th (local time) and the first advisory was issued on tropical storm Ella. Highest winds were estimated at 55 to 60 m.p.h. near the center and the minimum pressure had dropped to about 1009 mb. Advice to small craft and residents of the islands from Puerto Rico eastward and southward had been given previously by bulletins from the San Juan Weather Bureau Office.

The storm intensified rapidly as it moved westward at about 18 m.p.h. in the eastern Caribbean and by 1600 GMT of the 31st winds were estimated by aircraft at 85 m.p.h., increasing to 110 m.p.h. by 0400 GMT of September 1. The course had changed to the west-northwest during the day, as the center skirted along and just south of the Dominican Republic and Haitian coasts, causing torrential rains and considerable damage on the southern slopes of the mountains. It was thought that the hurricane passed over the southwestern peninsula of Haiti, however, since the original intensity was maintained until it encountered

*There is some evidence that Fletcher's formula is more nearly indicative of gusts than of sustained wind (c.f., Myers [8]).

the Sierra Maestra in eastern Cuba, the center of the hurricane may have skirted along the immediate south coast of Haiti. In fact, reports from the Haitian Meteorological Service indicate the hurricane followed a path parallel to the peninsula.

Reconnaissance aircraft on September 1 reported winds of 115 m.p.h. and lowest pressure of 989 mb. while the center was over the Caribbean Sea between Jamaica, Haiti, and eastern Cuba. The center passed inland over the Sierra Maestra in Oriente Province in eastern Cuba a short distance west of Santiago and the storm weakened below hurricane strength. It never regained hurricane force in its long path along the southern coast of Cuba, across the Gulf of Mexico, to the lower Texas coast.

As the storm moved west-northwestward along the southern coast of Cuba, a building high pressure system was moving into the Atlantic States, and consequently gale warnings were hoisted on the lower east coast of Florida and in the Florida Keys, because of the anticipated increase of pressure gradient caused by interaction between the two systems. Highest winds had dropped to 40 to 50 m.p.h. in squalls but the area of squalls and rather heavy rains extended across Cuba into the southern Bahamas and the Florida Straits and Keys. The center crossed extreme western Cuba on the 3rd, moving toward the west-northwest at 12 m.p.h. A west-northwestward course was continued at 12 to 15 m.p.h. across the Gulf of Mexico, with highest winds generally about 50 m.p.h.; however, Grand Isle, La., reported gusts to 75 m.p.h. during a squall on the morning of the 5th, and the SS *Jean Lykes* reported a wind of 55 knots near latitude 24.5°N., longitude 85.5°W. late on the 3d. Highest winds on the Texas and Louisiana coasts were generally around 40 m.p.h. with tides 2 to 4 feet above normal.

As the easterly wave in which Ella was spawned moved into the eastern Caribbean, deep easterlies existed to elevations beyond 500 mb. and at 200 mb. a vigorous anticyclone appeared, with a weak cyclone at this height 600–800 miles to the northwest. Rapid intensification occurred during the night of the 30th and on the 31st. The high-level anticyclone was in a position to give rapid outflow to the hurricane, a necessity for deepening according to Riehl [10], but became steadily less so after the storm entered the Gulf. Riehl [11], in studying a number of the tropical cyclones during the past several years, has found the problem of hurricane formation and intensification much more complex than earlier thought. There are apparently additional constraints not yet known or defined.

Several factors may have contributed to the nondeepening of Ella after it was weakened by passage through the Sierra Maestra of Cuba: (1) The storm lost, to some extent, its high-level anticyclone which seems to be a necessity for deepening and maintaining strength. The vortex was deep vertically even after passage into the Gulf. (2) The storm moved quite a bit faster during the previous and succeeding 48-hour periods than while passing south of Cuba. The bad weather pattern, caused by the combination of growing surface high pressure to the north and the storm circulation, spread rapidly across Florida and the entire Gulf of Mexico, dispersing the energy over a considerable area rather than having it concentrated near the center of the storm, as was the case on the 31st and the 1st. (3) The storm moved along parallel to the south Cuban coast the entire length of the island, with the northern half and strong side over land for approximately 48 hours. Friction due to the rugged terrain of Cuba contributed materially to the prevention of intensification there.

No reports of damage have been received from the islands east and south of the Virgins. In Puerto Rico and the Virgin Islands, maximum winds were around 40 to 50 m.p.h. in gusts. Heavy rains were recorded over the southwestern sections of Puerto Rico and some local flooding occurred, but damage in general was minor.

Heavy rains and floods caused damage estimated at $100,000 in the Dominican Republic, most of which occurred in the southwestern portion. No fatalities were reported there.

Torrential rains along the entire southern portion of Haiti caused considerable flooding. Thirty persons were reported drowned near Aux Cayes, probably due to a flash flood in a small rivulet. There were no casualties or losses of property in Jérémie or in general in any of the towns and villages located in the northern half of the southwestern Haiti peninsula; however, three persons were reported missing. After the passage of the hurricane, thousands of people along the southern coast were without shelter because of damaged or unroofed homes. Although no monetary estimate of the damage has been received, it would appear to be considerable.

In Cuba, six to eight persons were drowned due to floods resulting from torrential rains. Total damage to property on the island was estimated at $100,000.

Damage was minor in extreme southern Florida and the Florida Keys, where strong to gale force winds and rather heavy rains occurred. A vessel, the *Erikboye*, was disabled southeast of Miami due to the storm and towed in by the Coast Guard.

Very little damage was reported in Texas as a result of Ella. Rainfall was spotty but quite heavy in some localities. Galveston Airport measured 13.60 inches in three and a half days, with 8.44 inches occurring on September 7. A shrimp trawler was lost on the Galveston Jetty on the night of September 3. One man was washed overboard from a snapper boat near Galveston on the same night.

Fifi, September 4–12.—Possibly the increase in winds at 700 mb. shown by the regular Gull Papa reconnaissance flight on September 3 was the first bit of evidence of the existence of the easterly wave which later developed into Fifi. On the 4th, the suspicious area was confirmed by the SS *Robin Hood*, located near latitude 12° N., longitude 48° W., which reported squalls and pressure of 1008.8 mb., falling. Later that day the *Robin Hood*'s wind veered from east to south but the development was so weak and slow that no cyclonic circulation could be found by the aircraft. The flight did observe cumulonimbus

tops being blown toward the northeast and this was in agreement with a high-level vortex over the extreme eastern part of the Caribbean Sea.

Early on the 5th, reconnaissance indicated possibly two centers of action, but by afternoon a single center was firmly established. The first advisory, at 2200 GMT September 5, located tropical storm Fifi at latitude 15.1° N., longitude 55.0° W. with highest winds of 50 to 55 m.p.h. A solid wall cloud was observed and the sea level pressure was 1000 mb. This was the lowest central pressure observed during the history of the storm although it was equaled at a later date.

Fifi had been moving rapidly northwestward about 23 m.p.h., but by early afternoon of the 6th the forward speed had decreased to 16 m.p.h. and the storm had increased to hurricane intensity. It was located near latitude 17.0° N., longitude 57.5° W. at 1330 GMT on the 6th, attended by surface winds up to 92 m.p.h. north of the center. This was the maximum intensity of hurricane Fifi. The storm slowed to around 12 m.p.h. and highest winds decreased to 75 m.p.h. on the 7th.

During the 8th, Fifi continued on a northwestward course at 7 m.p.h. and maximum winds dropped to 60 m.p.h. Prior to this time, a jet maximum at high levels had worked around peninsular Florida, and by evening of the 8th it was located from the central Bahamas to Bermuda. It was this wind field which influenced the storm to make a turn to the north during the 9th and 10th. There were times when the jet appeared to be in a favorable position for an increased divergent field over the storm. The analysis delineating the jet maximum at this high level may have been in error due to lack of data.

Fifi turned northeastward and accelerated during the 11th. The storm passed within 150 miles of the Leeward Islands and approximately the same distance southeast of Bermuda. No loss of life or property damage was reported.

Gerda, September 13–15.—The seventh tropical cyclone of the season, Gerda, developed in an easterly wave which was first identified about 400 statute miles east of the Lesser Antilles on September 11. Reconnaissance aircraft found no evidence of cyclonic flow or unusual weather in the wave on September 12 but on the following day, September 13, surface reports from the Windward Islands indicated that the wave had intensified. The same reports indicated some evidence of cyclonic circulation in the Caribbean Sea, a short distance west of Martinique, but apparently it was not well defined because aircraft reconnaissance did not confirm its existence until about noon (EST) of September 14. At that time the cyclonic circulation was centered 75 miles southwest of Ciudad Trujillo, Dominican Republic, with highest winds 60 kt. in the southeastern quadrant and a minimum central pressure of 1004 mb.

The center of Gerda, moving west-northwestward about 18 m.p.h., passed over the southern peninsula of the Dominican Republic and evidently the mountainous terrain of that island disrupted the cyclonic flow around its center. On September 15, reconnaissance planes could not locate evidence of a circulation and reports thereafter indicated that tropical storm Gerda had again degenerated into an easterly wave.

Gale warnings were issued for the southern coasts of Puerto Rico and Dominican Republic in connection with Gerda. Three deaths in Puerto Rico, two of which were drownings, were attributed to the storm.

On September 19 and 20, the Weather Bureau Office in New Orleans issued bulletins in connection with a low pressure center which moved north-northwestward out of the Gulf of Campeche having apparently formed in the same easterly wave in which Gerda had developed earlier. A weak polar trough moving into the western Gulf of Mexico at the time of the easterly wave's arrival there appears to have initiated reintensification and development of a vortex. The small low center moved inland near Brownsville, Tex., on September 20, then continued along the Texas coast to the Louisiana border, losing its identity on September 21. Its minimum pressure, as indicated by a barograph record mailed in by the SS *Kendall Fish* was 1003.5 mb., and the highest wind reported was a gust of 52 m.p.h. at Nederland, Tex.

Helene, September 22–29.—Hurricane Helene, one of the most intense storms of the 1958 season as well as the most destructive, developed from an easterly wave which can be traced back to the Cape Verde Islands on September 16. Slow intensification of the wave began near longitude 50° W. on September 20 with pressure falls and above normal shower activity reported by shipping in the area. On the 21st, aircraft located evidence of a weak circulation near 19° N., 54° W. with maximum winds of 35 to 40 m.p.h. in scattered squalls.

The incipient storm moved on a west-northwestward course at approximately 20 m.p.h. on the 22d with little change in intensity. However, an extensive anticyclone in the upper troposphere was developing off the South Atlantic coast during this period so that the disturbance was moving into a much more favorable environment for the deepening process to begin. On the morning (EST) of the 23d, reconnaissance aircraft located a center near 23° N., 68° W., indicating a slowing of forward speed to 12 m.p.h. and an increase of winds to 50 m.p.h. in squalls. Helene continued on a west-northwestward course at 12 to 15 m.p.h. through the 24th with slow intensification.

On September 23, a large and very warm upper tropospheric anticyclone, which had been located over Texas for several days, began to move rapidly eastward (approximately 45 m.p.h.) reaching the middle Atlantic coast on the 25th. This displacement resulted from a temporary change in the long-wave pattern over the Northern Hemisphere. In the lower troposphere, a mean trough was located off the Atlantic coast during September according to Ballenzweig [4], but this trough was either very weak or entirely absent on the Extended Forecast Section's mean charts during the period September 13–27. Without this large-scale adjustment in the general circulation, Helene would have moved around the western edge of the Azores-Bermuda anticyclone a safe distance off the east coast of the United States in the same manner as

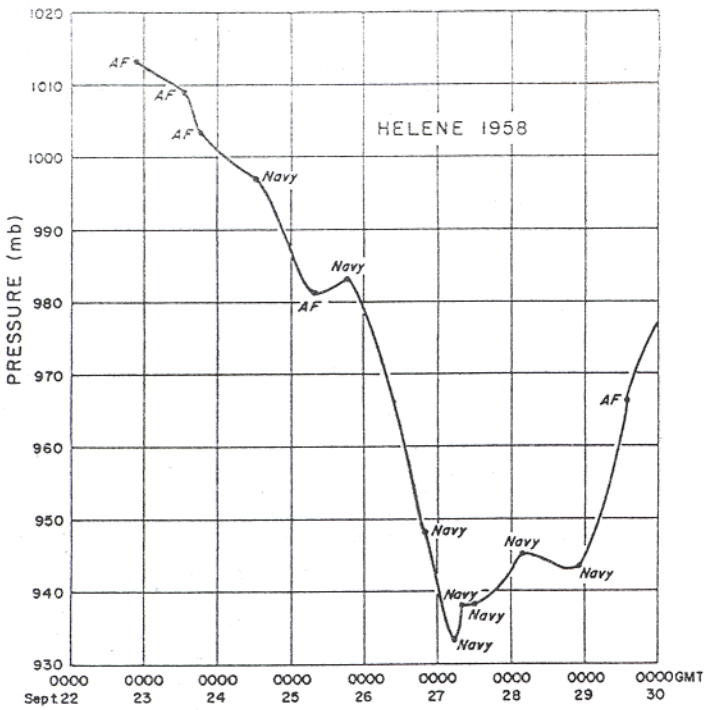

FIGURE 4.—Pressure profile for hurricane Helene, from Air Force and Navy dropsondes, Sept. 22–30, 1958.

Becky, Daisy, and later, Janice. In response to the arrival of the anticyclone in the upper troposphere, hurricane Helene slowed to about 8 m.p.h., veered to the left on a northwestward course with rapid deepening, in the manner described by Riehl [12] and Miller [7] for a hurricane moving under an intense anticyclone. The minimum pressure curve of the hurricane is shown in figure 4.

On the 26th, reconnaissance aircraft found that the hurricane's central pressure had dropped to 948 mb. with winds near the center in excess of 100 m.p.h. compared to 988 mb. and 75 to 90 m.p.h. winds the day before. Helene moved on a northwestward course at 8 to 10 m.p.h. during the 26th as it continued to deepen, finally attaining a minimum pressure of 933 mb. around midnight (local time) at a position some 80 miles east of Charleston, S.C.

On September 26, at 1100 EST, hurricane emergency warnings were issued for the coastal areas from Savannah, Ga., to Cape Fear, N.C. At this time the center of Helene was located about 260 miles east of Brunswick, Ga., moving northwestward toward the coast at 14 m.p.h., and the hurricane center was forecast to reach the coast in the vicinity of Charleston. During the evening it became apparent that Helene was gradually acquiring a more northward component of motion and hurricane warnings were extended northward along the North Carolina coast to Cape Hatteras. The western edge of the hurricane eye came within approximately 10 miles of the coast at Cape Fear and a portion of the intense convective wall cloud passed over land in this area. After recurvature, Helene moved northeastward at an accelerated rate and crossed Newfoundland on the 29th. The storm continued across the Atlantic as a large and vicious extratropical Low that dominated the weather over a large area for several more days.

As indicated by Ballenzweig [4] the broadscale circulation continued to change rapidly and heights fell strongly on the 26th at 70° and 80° W. at all levels as a trough approached the east coast inducing the recurvature. At midnight on the 25–26 (EST) winds at 200 mb. had already shifted from east to southeast and in retrospect it is believed clues were available which might have permitted a more accurate 500-mb. prognostic and consequently a stronger inference of recurvature.

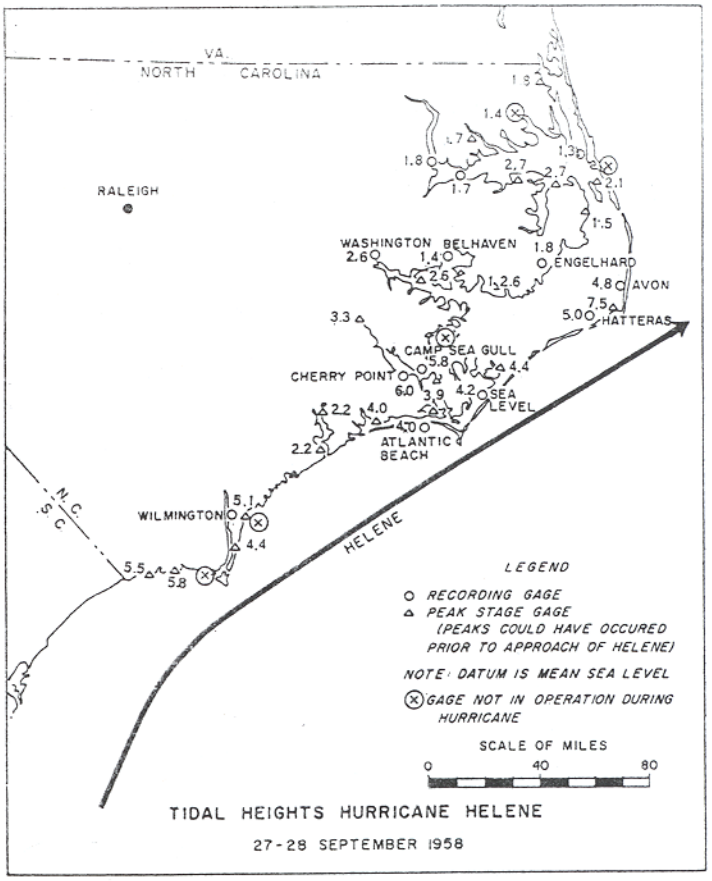

FIGURE 5.—Storm tide produced by hurricane Helene. (Data furnished by U.S. Army Engineer District, Wilmington, N.C.)

Hurricane-force winds, accompanied by high tides and torrential rains, pounded the coastal areas from Cape Fear to Cape Lookout. The Weather Bureau at Wilmington, N.C. recorded a maximum wind (one mile) of 88 m.p.h. and a peak gust of 135 m.p.h. Both of these speeds greatly exceeded all previous records there. Total rainfall at Wilmington during the hurricane was 8.29 inches. At Cape Fear, winds were estimated at 125 m.p.h. with gusts to 150 to 160 m.p.h. According to Sumner [14], the wind speeds and wind damage associated with Helene indicate a more intense hurricane than Hazel of 1954, but the fact that the center of Helene passed about 20 miles off the coast prevented the extremely high tides and wave damage associated with the 1954 hurricane.

A careful swell count made at Wrightsville Beach on the morning of September 27 by a staff member of the Weather Bureau Office at Wilmington, showed only 2½ to 3 per minute. This figure is probably the lowest count ever recorded for the area and indicates a storm of exceptional intensity. Figure 5, prepared from data furnished by the U.S. Army Engineer District, Wilmington, shows the elevation and extent of the storm tide produced by

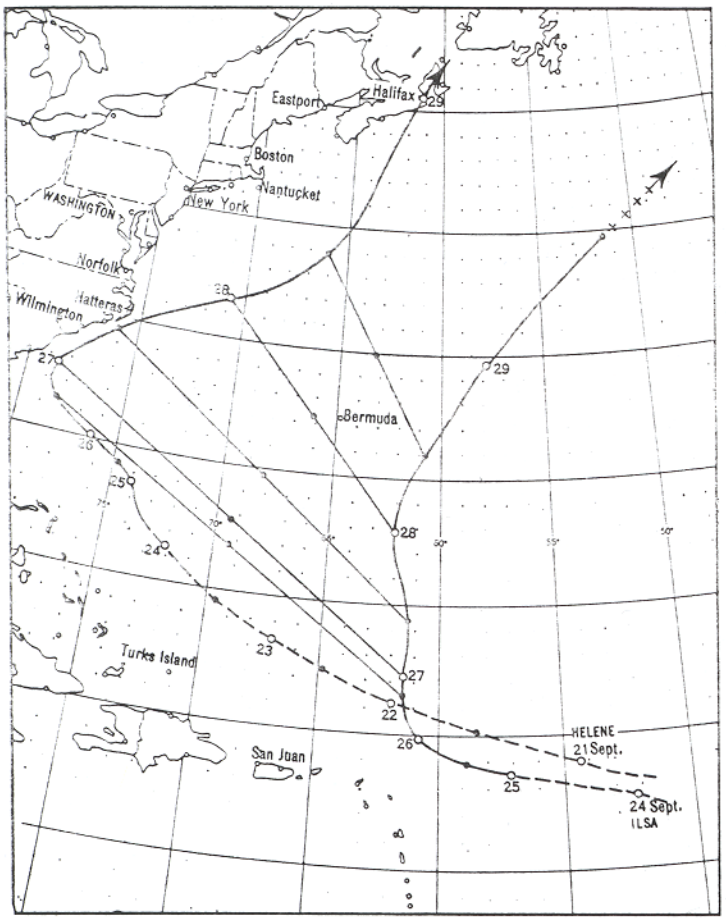

FIGURE 6.—Tracks of hurricanes Helene and Ilsa, September 1958, with midpoints indicated.

Helene. It is worthwhile to remember, when examining this figure, that the highest storm surges nearly always occur to the right of the storm track. If the storm center had moved inland south of Cape Fear on a northwestward or northward trajectory, the accompanying tides might have exceeded the 16 feet of Hazel. The Carolina coast missed a potential disaster of the first magnitude by a very close margin.

Although property damage was estimated at $11,000,000 in North Carolina and $200,000 on the upper South Carolina coast, no lives were lost directly as a result of the hurricane and only one indirectly. The lack of fatalities was due to extensive and detailed warnings, excellent detection and tracking by land-based and airborne radar, and effective community action with respect to evacuation and other protective measures. Evacuation of beaches was complete in most cases.

Reconnaissance and other types of observational data from hurricane Helene provided a wealth of material for research and some interesting experimental work was accomplished. Two balloon-borne radio tracking beacons were dropped into the eye of Helene by aircraft of the National Hurricane Research Project and remained in the eye for a significant period. A Navy plane also dropped a metallicized inflated plastic ball on the ocean surface in the eye for radar tracking. It was observed on radar for 12 hours or more.

Ilsa, September 24–29.—Ship reports on September 23 indicated that special aircraft reconnaissance into the area east of the Antilles was necessary. Tropical storm Ilsa was located at 1606 GMT on the 24th at latitude 17.7° N., longitude 54.0° W., about 800 statute miles east of San Juan, P.R., and 1,300 miles east-southeast of the position of tropical storm Helene. At this time, highest winds were 40 m.p.h. and central pressure 997.6 mb. By the 25th, Ilsa and Helene, both of hurricane intensity, were located some 1,100 miles apart.

A method to determine the interaction between vortices, first noted by Fujiwara and later investigated by Haurwitz, is described by Riehl [13]. The results of this check are given in table 1. The tracks of Ilsa and Helene and a plot of the midpoint between the two hurricanes are shown in figure 6. That there was some relative counterclockwise rotation is shown in figure 7, where a plot has been made of the relative motion during the last 36 hours of table 1.

Ilsa deepened rapidly on the 26th, reaching 932 mb. (dropsonde), a fall of 48 mb. in about 24 hr. The eye was well defined, and spiral bands were described as a typical textbook picture. Winds were estimated to exceed 125 m.p.h. The storm began to fill on the 27th and regular advisories were discontinued on the 30th. No loss of life or property damage was reported.

Janice, October 5–11.—A fairly active easterly wave passed through the Lesser Antilles on September 30 and into the Virgin Islands on October 1. By midday of the 2d, the wave had reached central Hispaniola, and 24 hours later extended from extreme eastern Cuba southward near Jamaica. By the 4th the wave had moved to the central Cuba-Grand Cayman Island area.

This wave had been attended by heavy shower and thunderstorm activity from the central Caribbean northward across Puerto Rico, Hispaniola, Cuba, and into the Bahamas as it progressed westward. A broad flat quasi-circulation was evident southwest of Jamaica on the 3d, however, reconnaissance aircraft on this date found no

TABLE 1.—*Data for checking interaction between vortices, Helene and Ilsa.*

Date (Sept.)	Time (GMT)	Ilsa		Helene		Midpoint		Ilsa—Midpoint [2]		Helene—Midpoint [2]	
		Course [1]	Speed [1] (kt.)	Course [1]	Speed [1] (kt.)	Course [1]	Speed [1] (kt.)	Course	Speed (kt.)	Course	Speed (kt.)
27	0000	335°	8.0	305°	10.0	320°	9.6	090°	3.0	235°	3.0
27	1200	360	5.0	350	7.5	355	5.6	140	0.8	340	2.5
28	0000	360	10.4	045	12.4	030	10.4	285	5.5	095	3.5
28	1200	360	17.5	070	23.0	035	15.0	300	9.5	110	13.5
29	0000	015	16.5	070	21.8	040	17.1	290	7.5	120	11.0

[1] Mean during 12 hours prior to time indicated.
[2] Subtraction of the displacement of the midpoint from the tracks. (During period of study hurricanes were near same intensity so midpoint was considered center of gravity.)

closed circulation. Squalls in the northern semicircle were attended by maximum winds of 40 m.p.h. and the lowest sea level pressure observed was 1010 mb. By the 4th this circulation was located a short distance southwest of Grand Cayman Island. The aircraft found a large but very weak circulation with minimum pressure of 1008 mb. and maximum winds of 25 m.p.h.

The weak circulation drifted slowly north-northwestward during the night, gradually becoming better organized, and by afternoon of the 5th had developed into a tropical storm with the center just south of the central Cuban coast. Winds had increased to 40 to 45 m.p.h. in squalls within 60 miles north and east of the center. The storm turned northeastward and crossed Cuba during the night and by midday of the 6th was centered between New Providence and Andros Island in the central Bahamas. The storm, gradually increased in force and size and accelerating in forward speed during this period, reached hurricane intensity during the evening of the 6th. Minimum sea level pressure at this time by dropsonde was around 996 mb.

A cold front extending from the Ohio Valley northeastward across New England on the morning of the 6th was being followed by a cold, growing, 1026-mb. high pressure area centered in northeastern Minnesota at that time. Twenty-four hours later the cold front had moved to southern Georgia and the high pressure center to the New York-Pennsylvania area. The hurricane decelerated in forward speed from 15–20 m.p.h. to 7 m.p.h. by afternoon of the 7th.

The hurricane drifted slowly north-northeastward to northeastward then began accelerating northeastward to east-northeastward on the 9th, and continued until the 11th when it began losing tropical characteristics and later merged with a deep low pressure system that moved from the Canadian Maritime Provinces into the North Atlantic.

Gale warnings for northeasterly winds were hoisted at 2300 EST on October 6 from Cape Hatteras, N.C., southward to Vero Beach, Fla., and lowered on the 8th and 9th as the hurricane began its definite track away from the United States mainland. Minimum sea level pressure by dropsonde was 968 mb. on the 10th. Highest winds were estimated at 90 m.p.h. over a small area near the center of the hurricane on the 7th and again on the 10th, with slightly lower wind speeds on intervening days. Minimum pressure in the Bahamas was 988 mb. at Harbour Island, Eleuthera. Highest wind was 63 m.p.h. at San Salvador, although Nassau reported 61 m.p.h.

One man lost his life in Nassau harbor while attempting to move a skiff. Eighteen Haitians were reported lost when their craft capsized in the Central Bahamas, but this later proved false. Total monetary damage in the Bahamas was probably between $200,000 and $300,000. One yacht was seriously damaged and a dredger lost. In Jamaica, rains in excess of 20 inches caused floods which destroyed homes and caused severe crop damage. Most of the loss was from damage to wharves, coastal roads, and crops.

In mid-October a reversal of the hemispheric trough-ridge systems [1] resulted in a split jet and polar air flooded the Florida area. Tropical cyclone development abruptly terminated.

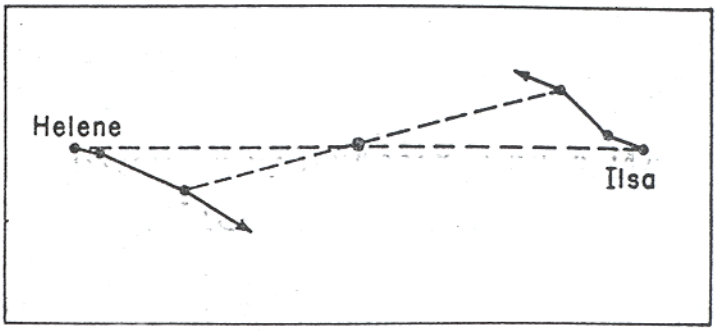

FIGURE 7.—Diagram of relative motion of Helene and Ilsa during last 36 hours shown in table 1.

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