THE HURRICANE SEASON OF 1967

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1. GENERAL SUMMARY

The 1967 hurricane season in the North Atlantic was singular for a number of reasons. The first named tropical cyclone, Arlene, developed late in the season on August 28 and reached hurricane intensity on September 2. There have been only seven seasons, 1897, 1905, 1914, 1920, 1923, 1925, and 1941, that began later in the summer. None of these produced more than seven tropical storms or hurricanes. The total of eight in 1967 establishes a record for such a late-starting season.

The late season is explained mainly by the general broadscale circulation features at middle and low latitudes. According to Wagner [1], higher than normal heights at 700 mb. became established across the central Atlantic Ocean during June. The pattern of height anomalies agreed very well to Ballenzweig's [2] composite chart for maximum tropical cyclone incidence for North America. While there were no named cyclones during June, the month was active since there were four well-defined tropical depressions [8]. The strongest of these was the one which entered the Carolinas on the 17th.

Dickson's [3] analyses for July indicate a reversal of June's long wave distribution and his 700-mb. anomaly chart is not too unlike Ballenzweig's composite for minimum cyclone activity. Consistent with these data, there were no depressions in July. Indeed, satellite pictures were practically void of disturbances or cloud features which are usually antecedent to cyclone development.

This unfavorable pattern for tropical cyclone development persisted through August. The feature is revealed in the similarity of the departures from normal charts (700 mb.) for July and August. In discussing the circulation for August, Posey [4] states that the long wave pattern changed very little during the 2 months and that the positive anomaly over the western Atlantic continued in the same lacation. Dunn and Miller [5] have shown that "persistent departures from normal in either position or strength (Azores-Bermuda High) have a profound influence on hurricane freqúency. . . . " The 700-mb. positive anomaly in the western Atlantic was consistent with a pronounced westward shift of the surface Azores-Bermuda High; both are considered unfavorable for genesis.

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The persistence of circulation features from month to month is a very interesting field and is watched very closely by operational forecasters. Namias and O'Conner [2] have suggested that too much persistence on a daily basis results in a fewer than normal shearing troughs. This, of course, inhibits lower tropospheric circulations, or positive vorticity maxima, at low latitudes, which are often the synoptic forerunners of development. In summary, it is thought that the statistically unfavorable positions and the persistence of monthly and daily circulation features accounted for the lack of tropical cyclone development in July and August.

Beulah, Chloe, and Doria quickly made up for lost climatological time. All three, with hurricane force intensity, were on the same weather map for portions of 5 days. On September 16, a noteworthy first in satellite photography occurred when all three were photographed on the same orbital pass by ESSA 2 [9]. Figure 1 is a composite of ESSA 2 photographs taken on September 17, showing the three simultaneous storms. At that time Beulah and Chloe were intense hurricanes while Doria, on the North Carolina coast, was barely of storm intensity. Beulah and Doria were the only two that affected the United States. Beulah was a great hurricane and should be added to the list compiled by Kraft [6]. This totals 12 great hurricanes since 1955.

Hurricane days numbered 44, which is about 10 more than the yearly average established during the past 14 yr. (table 1). The tracks of the eight named tropical cyclones

TABLE 1.—*Hurricane days, 1954–1967*

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
1966						7	8	9	11	10	5		50
1967									*33	11			44
Total	4					12	19	86	236	106	9	1	473

*If two hurricanes are in existence on 1 day, this is counted as 2 hurricane days.

[2] Private communication between J. Namias and G. E. Dunn.

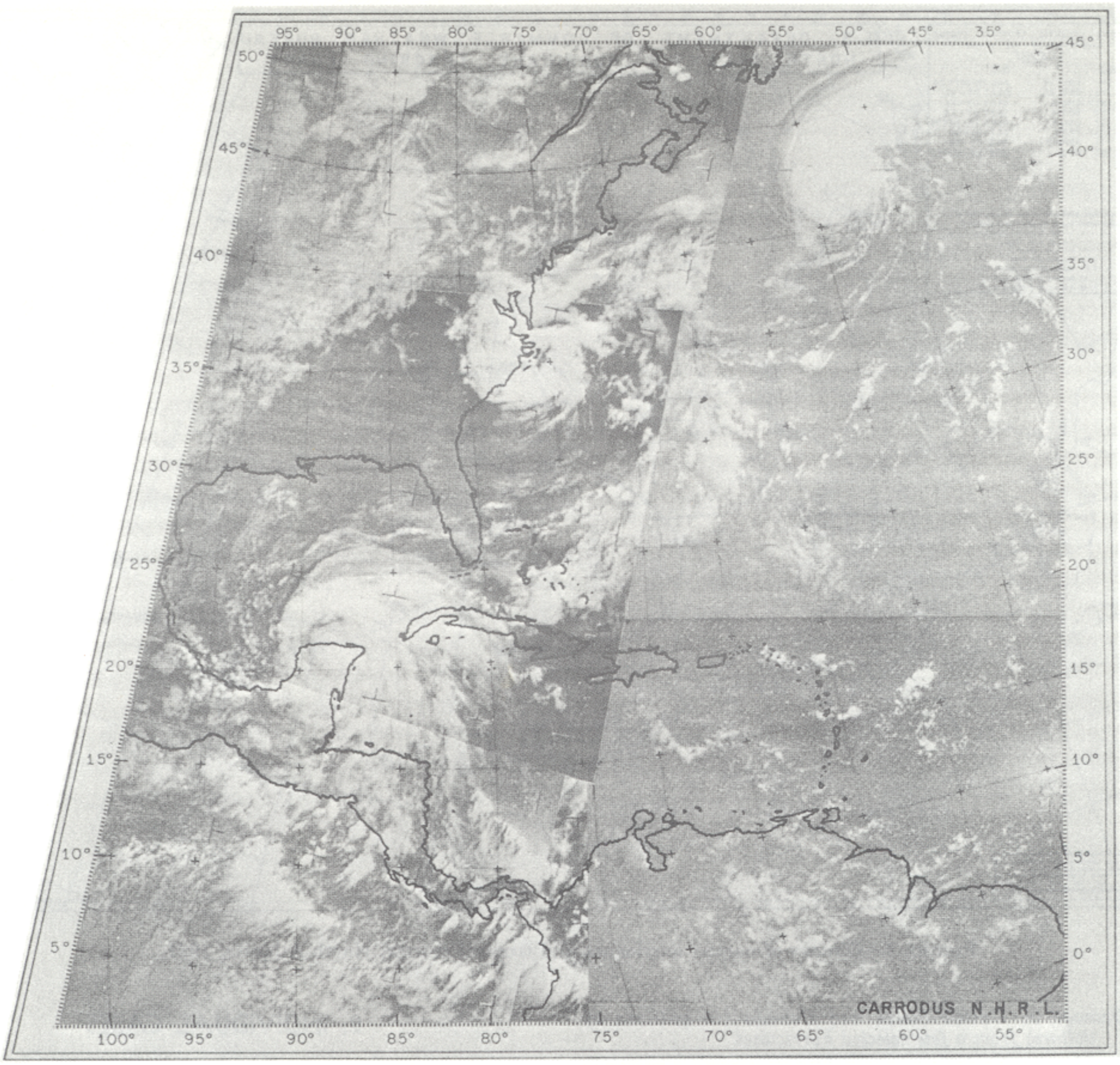

FIGURE 1.—Composite of ESSA 2 photographs, September 17, 1967, showing Beulah (over the northern Yucatan Peninsula), Doria (over the North Carolina coast), and Chloe (southeast of Newfoundland).

TABLE 2.—*Estimated damages and casualties, hurricane season 1967*

Date	Storm	United States		Other areas	
		Deaths	Damages	Deaths	Damages
June 14–18	Tropical depression	0	*$15,000	0	0
Aug. 28–Sept. 4	Hurricane Arlene	0	0	0	0
Sept. 5–22	Hurricane Beulah	Texas 15	200,000,000	Martinique 15	$4,500,000
				St. Vincent 2	minor
				Dominica 0	minor
				St. Lucia 0	3,000,000
				Puerto Rico 1	**150,000
				Dominican Republic 2	***unknown
				Haiti unknown	***unknown
				Cozumel Island 0	***unknown
				Yucatan 5	***unknown
				Northern Mexico 19	***unknown
Sept. 5–21	Hurricane Chloe	0	0	3	0
Sept. 7–19	Hurricane Doria	3	minor	0	0
Sept. 26–Oct. 1	Tropical storm Edith	0	0	0	minor
Oct. 1–4	Hurricane Fern	0	0	Tampico 3	minor
Oct. 5–8	Tropical storm Ginger	0	0	0	0
Oct. 19–Nov. 1	Hurricane Heidi	0	0	0	0
Totals	2 tropical storms 6 hurricanes 1 tropical depression	18	$200,000,000	50	$7,650,000

*Not included in total since beneficial rains and sand deposition offset entire amount.
**Some beneficial rains.
***Considerable damage to crops and houses but no dollar estimate available.

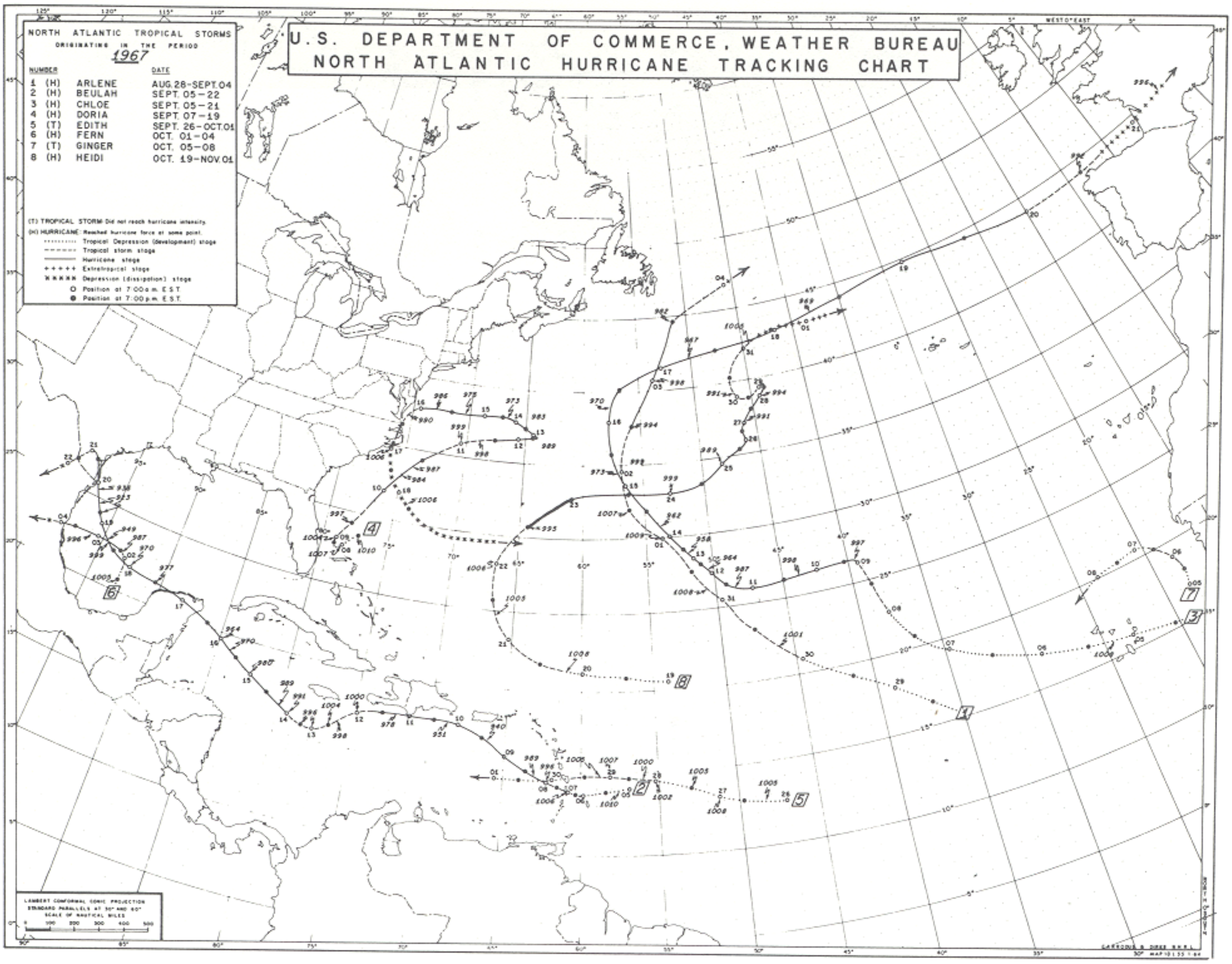

FIGURE 2.—Tracks of named hurricanes and tropical storms, North Atlantic, 1967.

TABLE 3.—*Damage in United States and Canada (in millions of dollars) from a few selected hurricanes*

Hurricane	Damage $10^6	Hurricane	Damage $10^6
Betsy 1965	1,419.8	Cleo 1964	128.5
Diane 1955	800.0	Hilda 1964	125.0
Carla 1961	400.0	Florida 1926	111.8
New England 1938	387.1	Isbell 1964	10.0
Donna 1960	386.5	Alma 1966	10.0
Hazel 1954	251.6	Keys 1935	6.0
Dora 1964	250.0	Inez 1966	5.0
Beulah 1967	200.0	Ginny 1963	*0.4
Audrey 1957	150.0		

*Loss more than offset by beneficial rains.

are shown in figure 2. Estimated damage figures are tabulated in table 2. A tropical depression has been added to the list since it was the most important one of the season. Damages from Beulah were not nearly so large as first estimated. Actually the $200-million figure is not far from the average dollar damage of all hurricanes making landfall in the United States. Beulah ranks eight in this respect and table 3 is an updating of the tabulation prepared by Sugg [7].

Considering that the first-named cyclone began August 28 and that there was a great hurricane which ranks with the greatest in intensity, numbeı of associated tornadoes, and rainfall amounts, one might say that this was the "late and great hurricane season of 1967."

2. INDIVIDUAL CASES

TROPICAL DEPRESSION, JUNE 14–19

Satellite pictures and ship data were sufficient to observe and track the weak tropical depression which formed northeast of the Bahamas on June 14. By the 17th, it was possible to track the center on the WSR-57 radar at Charleston, S.C., and later that day, a Navy reconnaissance plane located the center of circulation. The depression entered the North Carolina coast southwest of Wilmington during the evening of the 17th, drifted northward during the 18th, and was overtaken by a cold front later the same day. It was not clearly defined on the Wilmington radar. From the remnants, there developed a frontal wave which moved east-northeastward into the Atlantic.

While there was fairly good inflow in the low levels and wind speed did approach tropical storm force at times, other conditions were not favorable for intensification. Outflow at high levels was virtually nonexistent and the air mass was really too cold to be transformed in such a relatively short time. The release of latent heat from the heavy rainfall was probably much too local to have been important. The lowest sea level pressure recorded at any land station was 1010 mb. (29.81 in.). This occurred at Charleston, S.C. A similar pressure was reported by the aircraft.

Damage was confined to the area between Myrtle Beach, S.C., and Shallotte, N.C., and was estimated to be $15,000. This was the result of some flooding and the destruction of crops caused by tides ranging up to 2.5 ft. above normal and by heavy rains. Rainfall amounts ranged up to 7.61 in. at Myrtle Beach and 7.65 in. at Ocean Drive Beach, S.C. Rains were beneficial farther north in the Mid-Atlantic States.

HURRICANE ARLENE, AUGUST 28–SEPTEMBER 4

During the latter part of August, satellite photographs revealed that the Intertropical Convergence Zone (ITC) had become more active after remaining quiescent and somewhat farther south than normal until that time. During the period from August 24 to September 3, a series of four rather well-defined cloud masses were observed to move westward off the African coast along the ITC. The first of these later formed Arlene, the second was to become Beulah, the third failed to develop further, and the fourth subsequently produced Chloe. Thus the season's first three hurricanes were spawned in rapid succession in the previously unproductive ITC.

As the first disturbance moved westward off the African coast on August 24, the upper air sounding at Dakar, Senegal, showed a windshift from northeast to southeast late on the 24th in the lower levels of the troposphere. During the following 24 to 36 hr., 3- to 4-mb. 24-hr. pressure falls were observed in the Cape Verde Islands.

Around 1800 GMT on the 25th a Pan American Airways flight reported "cyclonic circulation apparent with falling pressures between lat. 10°N. to 14°N. and long. 20°W. to 25°W." At the same time the British ship *Ripon* reported a west-southwest wind of 29 m.p.h. and heavy intermittent rain to the southwest of this area.

ESSA 5 Digitized Mosaics on the 25th, 26th, and 27th showed the disturbance continuing generally westward about 10 to 15 m.p.h. Little additional information was received in the vicinity of the disturbance during these days. On August 28 around 1800 GMT the ESSA 3 and ESSA 5 satellites showed a well-organized area of clouds and weather near lat. 16°N., long. 36°W. This was chosen as the starting point for the official track of Arlene (fig. 2). On this day the disturbance was first classified a strong tropical depression under the Satellite Classification System of the National Environmental Satellite Center. Once the strong tropical depression had formed, it moved northwestward about 17 m.p.h. Late on the 29th, the Norwegian ship *Thorsriver* reported an east wind of 46 m.p.h. near lat. 21°N. and long. 20°W. Another ship, the American *Mormacdraco* reported a 45-m.p.h. wind early on the 30th, and the first advisory on tropical storm Arlene was issued at 0800 EST on the 30th.

Navy reconnaissance aircraft reached Arlene on the afternoon of the 30th and found maximum winds of 70 m.p.h. near the center of the storm. Little change in intensity, as determined by Navy and Air Force reconnaissance, or course occurred through the late afternoon of September 1 with Arlene continuing northwestward about 17 m.p.h. with only minor variations. During this period minimum sea level pressure varied between 1001 mb. (29.56 in.) and 1009 mb. (29.80 in.). Although the central pressure was relatively high, it would appear that the observed maximum winds were produced by the strong high pressure ridge in which Arlene was embedded. This high pressure ridge also built strongly southward to the rear of the storm and apparently maintained the latter on a northwestward course into a relatively strong surface-to-500-mb. ridge. Lack of intensification can be attributed to the fact that Arlene was crossing the mid-Atlantic upper tropospheric trough.

During the evening of September 1, Arlene began to recurve sharply and accelerate to the north as the storm came under the influence of a 500-mb. trough in the westerlies moving eastward from the northeastern United States. Arlene continued northeastward through September 3 and during this period attained hurricane force. Being a minimal hurricane, Arlene probably achieved hurricane intensity at times when only tropical storm status is indicated on the track, and vice versa (fig. 2).

The minimum sea level pressure of 982 mb. (29.00 in.) and maximum surface wind of southwesterly 86 m.p.h. were recorded by Navy reconnaissance aircraft at 1700 EST on the 3d. The ESSA 5 Mosaic for approximately the same time clearly showed a break in the frontal cloudiness just west of Arlene with inflow into the southwestern quadrant of the storm.

Arlene was absorbed into a warm frontal system during the next 12 hr., filled rapidly, and decelerated appreciably. Although strong westerlies at 500 mb. were over the storm, it became a weak frontal wave which had moved only 350 mi. in the next 48 hr. Such slow movement, even as a frontal wave, may be attributable to a blocking pattern at higher latitudes with the long wave ridge position approximately in the area of deceleration. The shallowness of the storm may also have been a factor, but neither reason would appear suitable to explain a movement of less than 10 m.p.h. over that period of time.

One interesting feature of Arlene observed by APT ESSA 2 during the period August 31 through September 3 was that the convective cloud bands associated with the storm rotated almost completely around the center. Maximum winds observed by Navy and Air Force reconnaissance correlated fairly well with this feature.

No deaths or injuries were reported from shipping interests, and no warnings, other than marine, were required since Arlene remained well at sea.

HURRICANE BEULAH, SEPTEMBER 5–22

Although the 1967 hurricane season started late, Beulah ensured that it would be long remembered, especially in the minds of residents of the Rio Grande Valley where devastation of an extent previously unknown to that area was inflicted by this great storm. The disturbance from which Beulah developed emerged from the African coast on August 28, and moved westward as a "humping up" of the ITC, i.e., in the form of an "inverted vee." This configuration of cloudiness has come to be recognized from satellite photographs as a rather characteristic feature of the Atlantic ITC. With minor fluctuations this westward progression continued until September 4, when a Navy reconnaissance aircraft found a weak wind circulation. Early on September 5, ship reports verified that a weak depression had formed, with lowest pressure about 1010 mb. (29.83 in.), located near lat. 14.0°N., long. 57.0°W., at 0700 EST. Here the official track of Beulah began (fig. 2).

On September 6 the depression passed just north of Barbados and satellite photographs indicated that the circulation was becoming better organized. On September 7, a Navy reconnaissance aircraft obtained a cloud eye and a pressure center of 1006 mb. (29.70 in.) near 13.8°N., 60.5°W., at 0900 EST with maximum winds of 40 m.p.h. On that day the circulation moved into the eastern Caribbean near the southern tip of Martinique. The same afternoon an investigating aircraft measured 58 m.p.h. and 1005 mb. (29.68 in.) with the center 20 mi. off the west coast of Martinique.

The San Juan Weather Bureau issued a bulletin at 1100 EST, September 7, warning residents of the Windward Islands to expect thundershowers and squalls and advising small craft to stay in port. The first advisory on tropical storm Beulah was issued the same day at 1900 EST, placing the center 35 mi. west of Martinique.

Beulah recorded the first chapter of her long tale of death and destruction during this period. The northern Windward Islands sustained considerable water damage, either from prolonged heavy rains or tidal and wave action along the coast. Fifteen persons died on Martinique and two on St. Vincent. Heavy rains, associated with an upper trough, began as early as September 4 on Martinique and St. Lucia, setting the stage for the flooding which accompanied the torrential downpours from the storm itself. An 18-hr. rainfall of 11.85 in. was recorded on Martinique on September 8. Flooding on the two islands tremendously damaged houses, bridges, roads, and crops. The St. Lucia banana crop was 30 percent destroyed. Total damage on the island was estimated by the government at \$3 million and that on Martinique was placed at \$4.5 million.

Beulah rapidly strengthened and attained hurricane insensity by midday on September 8. Thus Beulah became only the third September storm of this century to gain hurricane force in the eastern Caribbean. Deepening continued as Beulah moved on a northwestward track and came under surveillance of land-based radar at San Juan. Air Force reconnaissance measured a central pressure of 940 mb. (27.75 in.) on September 9 when the hurricane was about 100 mi. south of Puerto Rico. This was the lowest pressure found during her trek through the Caribbean. Beulah now threatened Hispaniola and on the morning of September 9 a hurricane watch was advised for the Dominican Republic and Haiti, with emphasis on the south coastal areas. Gale warnings were raised for the south coast of Puerto Rico.

On September 10 radar reports indicated a more westward track as the hurricane crossed to the west of a weak trough and came under the influence of an upper anticyclone located to the northwest, over the Bahamas. Beulah thus aimed her fury at the Barahona Peninsula of the Dominican Republic, the same area ravaged by hurricane Inez just 1 yr. ago. However this time 200,000 residents evacuated the coast and only two deaths were reported, compared to a death toll of approximately 100 from Inez. No dollar estimate is available, but considerable damage to roads, bridges, and the banana and coffee crops was reported.

In Puerto Rico there was scattered damage along the south coast mainly to small craft and as the result of flooding. This was partially offset by beneficial rains, ending a period of severe drought. After skirting the Barahona Peninsula on September 11, Beulah continued westward, moving parallel to, and about 50 mi. south of the Tiburon Peninsula of Haiti, sparing that beleaguered area from the full force of her winds and inflicting relatively minor water damage.

During the period from the 10th to the 13th a remarkable weakening occurred. In this interval, the central pressure rose approximately 55 mb. (1.63 in.) and maximum winds decreased from 150 m.p.h. to only 40 m.p.h. The hurricane was downgraded to a tropical storm early on the 12th. Thus Beulah, after having initially intensified in an area usually considered unfavorable, proceeded to weaken in region generally regarded as conducive to intensification. Beulah's brush with Hispaniola probably contributed, at least initially, to her decay but it is felt that the major factor was the environmental changes in the upper troposphere. A strongly confluent jet stream to the rear of a 200-mb. trough penetrated from the mid-Atlantic southwestward over the storm, greatly impeding its outflow. This northeasterly current also served to deflect the storm from its westward course, thus eliminating any serious threat to Jamaica.

As the confluent zone aloft moved eastward and was replaced by a ridge, Beulah once again became a hurricane and turned toward the northwest. It soon became apparent that Beulah would become a large and dangerous storm and that landfall on the Yucatan Peninsula or the Gulf of Mexico coast was inevitable.

As the northwestward course became more firmly established, the threat to Cozumel Island and northeastern Yucatan increased. Residents of these areas, in the midst of Mexico's Independence Day celebration, were warned to make preparations against hurricane force winds. The advisories and bulletins issued by the Miami Weather Bureau on Saturday, September 16, stressed the need for continued vigilance in these areas as Beulah hesitated momentarily on her northwestward course. Landfall on Cozumel occurred during the evening of September 16 with maximum winds about 100 m.p.h. Forty percent of the houses on the Island, virtually all of light construction, were totally destroyed, and several hotels were severely damaged. Tourism, the major source of income on the Island, suffered heavily in Beulah's aftermath.

Beulah next took aim across sparsely populated northeastern Yucatan toward the coastal city of Progresso, where 15,000 people had been evacuated in 1966 as Inez skirted the coast. Five persons were killed in the town of Tizimim, near the north-central coast, when a clocktower was toppled by the winds. Farther west, damage was relatively minor.

Beulah entered the southwestern Gulf of Mexico on the afternoon of September 17 (fig. 1), weakened only slightly from her traverse of the Yucatan coastal lowlands. The pressure rose only 10 mb. (967 to 977 mb.) or 0.3 in. between reconnaissance measurements preceding and following the land crossing. Forecasters were thus faced with the gloomy predicament of an already substantial hurricane bounded within the limited confines of the Gulf of Mexico, and being further energized by its warm waters. A hurricane watch was issued for the Texas coast at 1100 EST, September 17.

Expectations of further intensification soon materialized as Beulah attained a lower central pressure with each succeeding measurement. The hurricane deepened to such an extent that, on the afternoon of September 19 and once again that evening, reconnaissance aircraft of the Air Force and ESSA recorded a central pressure of 923 mb. (27.25 in.), second only to the 920 mb. (27.17 in.) found in hurricane Hattie of 1961, in the history of hurricane reconnaissance.

Early on September 18 Beulah, continuing on a northwestward course, came under surveillance of the Weather Bureau radar at Brownsville. Radar reports indicated that Beulah's motion was somewhat erratic, reminiscent of the cycloidal path that hurricane Carla followed through the western Gulf of Mexico in 1961. At 0500 EST, September 19, hurricane warnings were issued for the Texas coast from Brownsville to Port Aransas and precautionary measures along the northeastern coast of Mexico were urged.

Beulah made landfall between Brownsville and the mouth of the Rio Grande about daybreak on September 20. Before the hurricane eye struck land the central pressure rose gradually and was probably a little less than 950 mb. (28.05 in.) at the time of landfall. At 0800 EST, the pressure at Brownsville fell to 951 mb. (28.07 in.), which was the lowest land station reading. The SS *Shirley Lykes*, at anchor in Port Brownsville, reported winds of 136 m.p.h. The Brownsville Weather Bureau Office recorded a peak gust of 109 m.p.h. but the anemometer shaft tilted 30°, so the actual wind was probably higher.

The center remained over land as it moved north-northwestward parallel to the lower Texas coast during the day. The storm gradually weakened but hurricane force winds occurred as far north as the Corpus Christi-Alice area during the evening of September 20. The storm stalled near Alice during the night and then arced slowly southwestward. On September 22 the circulation finally broke up in the mountainous terrain near Monterrey, Mexico.

The storm surge left dramatic evidence of its magnitude along Padre Island. A post-storm Weather Bureau-ESSA inspection team [3] surveying the Island found a total of 31 cuts completely through the Island in the portion extending south from a point 30 mi. south of Corpus Christi. At lat. 26.4°N., the storm surge was found to have reached a height of at least 18 ft. The height of the storm surge diminished southward toward Port Isbell, but a reliable high-water mark of 12 ft. m.s.l. was ascertained in a damaged house in the community of South Port Isbell (26°N.). Some maximum tide gage readings along the mainland included 7.4 ft. at Rockport, 7.0 ft. at Corpus Christi, and 5.5 ft. at Port Aransas.

Torrential rains fell in southern Texas and northeastern Mexico and produced major floods. Every river and stream in southern Texas south of San Antonio flooded. Storm rainfall amounts ranged from 10 to 20 in. over much of southern Texas, and totals exceeded 30 in. in some areas. Previous flood records were erased as the rain waters collected in the lower Texas rivers. The San Antonio crested at a record 53.4 ft. near Goliad, 18 ft. above flood stage. The Nueces reached 46 ft., exceeding the previous all-time high by 2 ft. The Lauaca crested at 26.3 ft. at Edna; flood stage is 21 ft. The Navidad at Ganado surpassed the flood level of 29 ft. by a full 10 ft.

Beulah's record-setting potential was not confined to flooding. It also spawned an unsurpassed number of tornadoes—47 in all [4]—far exceeding the previous high of 26 triggered by Carla in 1961. The tornadic activity was confined to Texas, but encompassed a vast area extending from the coast to the Big Bend. However most of the tornadoes were small, occurred in rural areas, and inflicted only minor damage. A few exceptions, however, had tragic consequences. Four persons were killed and six injured when a tornado struck near Palacios on the 20th and another claimed a fifth fatality at Louise on the same day. Damage ranging into six figures occurred at Burnet, New Braunfels, Sweet Home, and Fulton Beach.

The death toll from Beulah reached 15 in Texas, five as the result of tornadoes and 10 from flooding. South of the border, 19 people died in Mexico and 100,000 were left homeless by the flooding. A summary of meteorological data associated with Beulah in Texas is given in table 4.

HURRICANE CHLOE, SEPTEMBER 5–21

As the fourth in the series of disturbances moved off the African Coast on September 4, Dakar reported winds shifting from northeast to southeast in the layer extending from the surface to 700 mb. The next day, the Low passed through the Cape Verde Islands (fig. 2) with a minimum pressure of 1008 mb. (29.76 in.) and 25- to 30-m.p.h. winds. On the 7th, the depression turned northwestward under the influence of a rather vigorous middle-latitude trough. However, the trough filled and moved eastward without picking up Chloe. Slowly intensifying during the northward motion, Chloe attained tropical storm strength on the 8th. The next day, an Air Force reconnaissance plane reported 86-m.p.h. winds and a central pressure of 997 mb. (29.44 in.). Failing to make contact with the trough, hurricane Chloe turned sharply westward.

Low pressure off the eastern United States coast associated with Doria provided a southerly steering current which began influencing Chloe by September 11. The hurricane deepened again as it took on a northward component of motion. The minimum central pressure reported in Chloe was 958 mb. (28.29 in.) on September 13.

[3] R. H. Simpson, H. E. Foltz, and L. L. Means.

[4] This figure represents the best minimum estimate. Investigations now underway may update this figure in the future.

TABLE 4.—*Hurricane Beulah, meteorological data, September 5–22, 1967*

Station	County	Date	Pressure		Wind						Tide		Rainfall		Remarks
Texas			Lowest (in.)	Time (CST)	Fastest mile (m.p.h.)	Dir.	Time (CST)	Peak gust	Dir.	Time (CST)	Highest (ft. m.s.l.)	Time (CST)	Storm total (in.)	Largest 24-hr. total (in.)	
Alice	Jim Wells	21	29.15	0100	*58	ENE	20/1900	*97	ENE	20/1915			14.84	6.65	
Aransas Pass	San Patricia	20	29.44	1700–1900	*68	SE	1920	*84	SE	1920			16.71	7.38	
Beaumont	Jefferson	20	29.85	1900	30	E	1505				3.0	1500	0.04		
Bishop	Nueces	20	28.94		83	SE	0800	94	SE				14.08	6.30	Wind data from NAAS, Kingsville
Brownsville	Cameron	20	28.07	0700				109	NE	0119			15.57	*12.09	Anemometer support tilted 30°
Corpus Christi	Nueces	20	29.24	1710	72	ESE	1934	86	ESE	1935	7.0	2200	14.43	6.52	
Edinburg	Hidalgo	20			*85	NW	1500	*104	NW	0800–1000			15.34	7.52	
Galveston	Galveston	20	29.80	0600	31	SE	19/2155	37	SE	1458	3.4	2230	0.01	0.01	
Houston	Harris	20	29.78	1756	28	ESE	1355	41	ESE	1355			2.80	2.46	
Karnes City	Karnes	20–21						*50	NE				19.72	7.95	
Kingsville	Kleberg	20	29.00	1758	*90	E	0900–1000	*108	E	1000–1100			11.41	4.16	
Laredo	Webb	21	29.41	0900–1100	29	N	1400–2400	53	ENE	1400			7.25	3.68	
Palacios	Matagorda	20						69	E	0559			11.55		
Pharr	Hidalgo	20	27.98	1530	*70	NW	0930–1530	*102	NW	1000–1500			21.50		
Pierce	Wharton	20	29.82	0700				*35	NE	0700			7.09	3.86	
Port O'Connor	Calhoun	20						*75	E	2100			8.85	4.85	
Premont	Jim Wells	20	28.82	1900	*85	S	1900	*100	S	21/0100			*18.00		
Raymondville	Willacy	20	28.12	1250	*115	NE&E	1100–1400	*120	NE&E	1220			16.15	8.90	
Refugio	Refugio	20	29.54										13.42	7.92	
Robstown	Nueces	20											14.22	6.38	
Rockport	Aransas	20	29.52	1430–1830	*58	E	2230–2330	*81	ESE	2230	7.4	2230	*18.38		
San Antonio	Bexar	20	28.91	1917	27	NE	1938	35		1607			5.55	2.45	
Sebastian	Willacy	20			*95	S	0500	*100		0630			*19.00	*15.00	
Victoria	Victoria	20	29.64	1645	35	E		47	E				12.97		24.05 in. downtown; 28.28 in. 10 mi. north

*Estimated values.

Approaching Doria on the 15th, Chloe turned northward. Westerlies steered the storm eastward, away from Doria, on September 17 (fig. 1). Satellite pictures suggest that Chloe remained rather intense and probably retained tropical character while crossing the North Atlantic. The last good data regarding intensity were received on September 18 from an Air Force plane that found a central pressure of 969 mb. (28.61 in.). No additional information concerning the thermodynamic nature of the storm was collected until its remnant reached Europe. When the baroclinic effects became dominant is not known. The extratropical stage may have occurred 12 to 24 hr. earlier than indicated in figure 2.

The only casualties attributed to Chloe resulted from the sinking of the *Fiete Schulze* in the Bay of Biscay on September 21. Three crewmen drowned and 11 were reported missing.

TABLE 5.—*Hurricane Doria meteorological data September 16–17, 1967*

Station	Lowest pressure (in.)	Wind			Total rainfall (in.)
		Fastest mile (m.p.h.)	Time (EST)	Peak gust (m.p.h.)	
New Jersey					
Atlantic City (WBAS)	29.84	26	16/0056	39	0.53
Maryland					
Ocean City				58	
Ocean City (Motel)		55		59	1.03
Salisbury		25		48	
Virginia					
Wallops Island (NASA 37°51′N., 75°29′W.)	29.63	51	16/1131	60	0.66
Norfolk (WBAS)	29.60		16/1619	55	0.53
North Carolina					
Cape Hatteras		26	16/2018		1.04
Wilmington (WBAS)	29.83	26	17/1313		1.40
Delaware					
Indian River Inlet		50		83	

HURRICANE DORIA, SEPTEMBER 7–19

Doria was one of the most erratic storms ever observed. It moved in every possible direction at one time or another during its life (fig. 2) and, if one goes back to its beginning as a wave cyclone, it crossed over its previous track twice. Doria's intensity also was quite variable as cold or dry air entered its circulation intermittently.

Circulation was first observed around a cold frontal low pressure system off the northeast Florida coast on September 4. This Low drifted aimlessly for 3 days in a small area (radius 100 mi.) centered 250 mi. east of Jacksonville. On September 7, the lowest pressure was 1010 mb. (29.82 in.) and on the 8th 1007 mb. (29.74 in.). The center at that time was about 50 mi. north of Grand Bahama Island. Doria reached tropical storm intensity the following day about 100 mi. east of Cape Kennedy and began moving more rapidly northeastward. A gradual warming of over 3°C. had occurred since the first circulation was observed. The upper air soundings from Cape Kennedy, Fla., show a warming of about 3°C. between 10,000 and 20,000 ft. during this period.

Doria reached hurricane intensity and passed about 100 mi. southeast of the North Carolina capes on the 10th. The following day cold air entering Doria's circulation weakened it to less than hurricane force as the center moved almost due east. Doria warmed again on the 12th as its movement slowed markedly and its winds reached hurricane force once more. High pressure at the surface and aloft over the New England area turned Doria westward and it continued as a hurricane to within a few miles of the Virginia capes on September 16. Then Doria again encountered cold and drier air and moved over colder water. These influences and that of a large portion of its circulation being over land weakened Doria rapidly as it turned southward. Hurricane warnings remained in effect because of high tides and rough seas, even though Doria no longer had hurricane force winds. It is indeed fortunate for the mid-Atlantic coastal areas that this weakening and turning southward occurred.

The weakened center reached land near the Virginia-North Carolina border and continued southward across the North Carolina capes and back to sea on September 17 (fig. 1). Doria continued southward and then eastward as a weak depression but was still recognizable 4 days later south of Bermuda (fig. 2).

Doria attained her lowest central pressure, 973 mb. (28. 73 in.), well at sea, about midway between Nantucket and Bermuda, on September 14. The highest measured wind, 114 m.p.h., was recorded by the ship, *Esso New Orleans*, at midnight on the 15th. The highest wind reported by a land station near the center was 50 m.p.h. with gusts to 83 m.p.h. at Indian River Inlet, Del. The highest tide, 6.5 ft. above normal, also occurred there. A summary of meteorological data from stations near Doria's path is given in table 5.

Only minor damage occurred along the coast from New Jersey to North Carolina. Doria claimed three lives when a small boat sank in high seas off Ocean City, N.J.

TROPICAL STORM EDITH, SEPTEMBER 26–OCTOBER 1

Tropical storm Edith originated on the intertropical convergence zone. The disturbance was initially noted very near the African Coast on the satellite pictures of September 20. Successive pictures showed that this disturbance moved westward 5° to 6° of long. per day. But it was not until September 26 that sufficient circulation features, established by ships and by satellite and aircraft reconnaissance, justified the upgrading of the disturbance to a tropical depression (fig. 2). Possibly Edith vacillated between depression and storm intensity during the next 2 days, but the track was not drawn for storm intensity until the 28th. This decision was based mainly upon the lowest pressure, 1000 mb. (29.53 in.), and highest winds, 55 m.p.h., measured during Edith's life history.

The reason for the weakening and dissipation of the storm is not known. But two contributing factors may have been 1) the westward movement of Edith under a cold upper trough and 2) the release of latent heat at a location too far from the surface minimum pressure. The latter feature is suggested by satellite pictures which show a large overcast area situated well to the east of the center of circulation.

Edith moved through the Northern Windward Islands during the morning of the 30th; the center had become enlarged and elongated. There were no sustained strong winds reported in the Island Chain, although gustiness was noted, especially around Martinique and Guadeloupe. Some local flooding might have occurred, but damage should be considered minor. No deaths were reported.

HURRICANE FERN, OCTOBER 1–4

During the latter part of September, a cold front swept through the southwestern Gulf of Mexico and Bay of Campeche. On September 29 Carmen, Mexico, reported northwesterly gusts over 60 m.p.h. as the front passed. By the 30th, pressures were falling in the Bay of Campeche and satellite pictures on the morning of October 1 indicated a large circulatory cloud mass centered near 20°N., 93°W.

The satellite pictures on the morning of October 2 showed that the system had become better organized. Navy reconnaissance aircraft that afternoon located Fern's center about 300 mi. east of Tampico, Mexico. On the same day the British ship *Plainsman* encountered storm force winds, 1004-mb. (29.65 in.) pressure, and a pressure drop of 10 mb. (0.30 in.) in 16 hr.

The northward movement of the depression (fig. 2) was not a result of steering currents, but of intensification processes. After rapidly attaining hurricane intensity, with peak winds about 85 m.p.h., and central pressure of 987 mb. (29.15 in.), the storm moved slowly westward to west-northwestward about 7 m.p.h. and turned west-southwestward as it neared the coast. The center moved inland about 30 mi. north of Tampico early on the 4th. This storm dissipated rapidly over land. Fern was of maximum intensity at the time it was first located but weakened slowly and remained a very small storm as it moved through the southwestern Gulf of Mexico. When the center crossed the coast the highest winds were probably slightly less than hurricane force.

The weakening of Fern in an area where storms seldom lose intensity was probably the result of two contributing factors: 1) cooler sea water undoubtedly left in the wake of severe hurricane Beulah, which moved through the area 2 weeks earlier, and 2) a strong outbreak of cold air, mentioned above, also following Beulah. Thus the available air flowing into the circulation was of modified tropical origin.

No forecast problems arose with Fern as a moderately strong ridge of high pressure at the surface and aloft over the northern Gulf of Mexico held firmly during the next 2 days and thus steered the storm westward.

Although the rainfall accompanying Fern as it moved inland was not excessive, it was sufficient to cause additional flooding on the Panuce River, which was swollen from the effects of Beulah. Three persons drowned in the rising waters, but only minor damage was attributed to Fern.

TROPICAL STORM GINGER, OCTOBER 5–8

Ginger formed in the wake of a tropical depression that moved off the African Coast on October 3. Although data are limited, it appears that the storm developed within an area of convection 200 to 300 mi. northeast of the depression center. Satellite pictures on October 5 and 6 showed a well marked vortical cloud character suggesting tropical storm intensity (fig. 2). This was confirmed early on the 6th when three different ships reported 40- to 45-m.p.h. winds. Based on this information, Ginger was named.

The storm turned to a more westward track and rapidly weakened on the 7th. One ship near the center at 1200 GMT reported a pressure of only 1012 mb. (29.88 in.) and 10-m.p.h. winds. Satellite pictures on this same day verified the weakening trend. The reason for weakening is unknown. The remains of Ginger could still be detected on satellite pictures on the 8th. However, 24 hr. later all evidence of circulation had dissappeared.

In summary, Ginger was a minimal tropical storm for no more than 24 hr.

HURRICANE HEIDI, OCTOBER 19–NOVEMBER 1, 1967

Heidi appeared, in embryonic form, as a cloud mass revealed by satellite photographs in the tropical central Atlantic in mid-October. From this area of convective activity a depression formed about 500 mi. northeast of the Lesser Antilles on October 19, and it is at this point that the official track of Heidi began (fig. 2).

The SS *Sunrana* passed through the depression on October 20 and found winds of 58 m.p.h. in squalls and lowest pressure of 1008 mb. (29.76 in.). Although the winds were of tropical storm intensity, the system did not appear to have a warm core, and its designation as a named storm was withheld pending receipt of additional data.

A Navy investigative flight was dispatched on October 21, and maximum winds of only 35 m.p.h. and minimum pressure of 1005 mb. (29.68 in.) were measured. A weak wind circulation was found but no eye was visible on radar. The system was located on the edge of a strong baroclinic zone to the northeast, with very little surface pressure gradient on the west side. The SS *Homeric*, passing a short distance east of the center early on October 22, found winds of 70 m.p.h. in squalls, but on the west side no wind of over 25 m.p.h. was reported. The thermal character of the system remained in doubt until an Air Force reconnaissance flight later in the day found that the center had warmed 2°C. through the middle levels. A short time later a Navy aircraft reported that rapid deepening had occurred, with the central pressure falling to 995 mb. (29.38 in.). Heidi was upgraded to hurricane status in the midnight advisory issued by the Miami Weather Bureau. At this time Heidi was recurving into a trough in the westerlies, and the hurricane proceeded on an east-northeastward course about 20 m.p.h. for the next 2 days, while maintaining minimal hurricane intensity.

On October 25 the westerlies weakened and retreated northward as a strong upper ridge built from Nova Scotia to Bermuda. The hurricane was thus embedded in an environment of light and variable winds at upper levels, while at the surface, high pressure, extending from the east around through the north and northwest, impeded appreciable northward movement. The hurricane's path thus became essentially blocked, and for the next 5 days, from October 25 to 30, Heidi wandered mainly northward about 5 m.p.h. Minimum pressure of 981 mb. (29.00 in.) was attained on October 26, while maximum surface winds of 115 m.p.h. were found on the previous day.

This slow northward movement permitted progressively cooler air and water to weaken Heidi to tropical storm intensity on October 29. By the 30th the storm had lost its tropical characteristics and turned eastward as a low pressure area. Finally, on November 1, ship and satellite data indicated that the remnants of Heidi had become absorbed into the broad-scale features of the North Atlantic.

Heidi posed no serious threat to any land areas and was of interest mainly to shipping. No reports of casualties of damage attributable to the hurricane were received.

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ATLANTIC TROPICAL DISTURBANCES, 1967

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1. INTRODUCTION

The meteorological satellite has provided many new horizons for the tropical meteorologist, especially in his efforts to relate the observed cloudiness and rainfall dynamically to circulation analyses. In the Tropics, where vast areas have few if any observing facilities, the development and application of tropical circulation models have had to lean hard upon the imagination and intuitive talents of the analyst.

Since the establishment of a WMO Regional Center for Tropical Meteorology (RCTM) at the National Hurricane Center, Miami, Fla., a renewed effort has been underway to classify, track, and understand Atlantic tropical disturbances using as fully as possible the observations from satellites. The main concern with tropical disturbances, perhaps nine out of 10 of which remain benign rain-producing systems, is to increase the skill with which "seedling circulations" can be identified and their potential for developing into hurricanes determined. This task will employ several new approaches to tropical analysis, and experimentation to this end will be discussed elsewhere. However, the disturbances of 1967 discussed in this paper are those which have been identified from operational circulation analyses at the surface, and at 850 and 700 mb. after superimposing the cloud and precipitation areas viewed by the satellite.

This is the first of a series of annual articles prepared by the National Hurricane Center summarizing the weaker disturbances of the season in the same manner as the annual summary of hurricanes [23], also prepared at the National Hurricane Center.

2. TROPICAL ANALYSIS MODELS

The evolution of perturbation or tropical disturbance models has been inhibited or biased, first because of the poor distribution of observations and second because the conclusions and the models derived from experience in the few limited areas where data are more abundant are not always applicable in other regions where large-scale circulation regimes may be quite different. The most commonly used models in tropical analysis are the Intertropical Convergence (ITC), *waves in the easterlies*, *surges in the trades*, *shear lines*, and *cold Lows* or subtropical cyclones. Even today tropical meteorologists disagree on the definition, if not the validity, of some of these models. Any discussion of tropical disturbances, therefore, needs to begin by reviewing and redefining the analysis models to be used in describing disturbances.

The concept of an intertropical convergence began with the recognition that in some areas the doldrums were generally quite narrow and, from aircraft observations, seemed to comprise one or more continuous lines of convection (e.g. Fletcher [10]). As more observations became available, important regional differences in the character of the ITC became evident, and some investigators (e.g. Palmer [20]) went so far as to suggest that the ITC is in reality only a statistical entity, day-to-day weather distributions in the equatorial trough consisting only of that weather associated with a succession of eddy circulations. The meteorological satellite has shown incontrovertibly that the ITC frequently involves a single, narrow, sometimes continuous band of convection in its east-west extent over several thousand miles.[1] At other times and in other locations it breaks up into a succession of eddies which migrate westward locally providing a succession of alternately fair and foul weather [15, 16, 17]. Circulationwise, the ITC may be identified as a "fluence line" (generally confluent) in the equatorial trough, having good continuity both in space and in time, and comprising one of the most conservative features of circulation in the Tropics.

The wave in the easterlies, originally described by Dunn [5] as an isallobaric wave and later as an easterly wave, is probably the most overworked "model" used in tropical analyses. In addition to its use in identifying the barotropic wave in the trade wind easterlies (whose dynamics have been described by Riehl [22, 24]), it is also frequently used to identify the weak trough in the trade winds which reflects the presence of the cold Low, or equatorial extension of a mid-latitude trough, in the upper troposphere. The barotropic easterly wave, while commonplace in the Atlantic, is sufficiently rare in the Pacific that some Pacific analysts have convinced themselves that all so-called easterly waves are reflections of cold Lows.[2] Although the satellite leaves no doubt about the frequent existence of perturbations or disturbances in the trade winds, the dynamics of these wave disturbances needs further study. In many instances, for example in figure 3, the convection associated with these waves tends to be concentrated near and downstream from the apparent wave axis rather than upstream as in the classical model. The recent analytic studies of Rosenthal [25],

[1] For example, see the National Environmental Satellite Center's time lapse movie: "Tropical Atlantic Cloud Patterns, ESSA Digital Product—May 14 to September 30, 1967," produced by W. A. Bohan for the Applications Group, NESC, 1967.

[2] J. C. Sadler, "The Easterly Wave—the Biggest Hoax in Tropical Meteorology," Seminar at the National Center for Atmospheric Research, Boulder, Colo., August 1966.

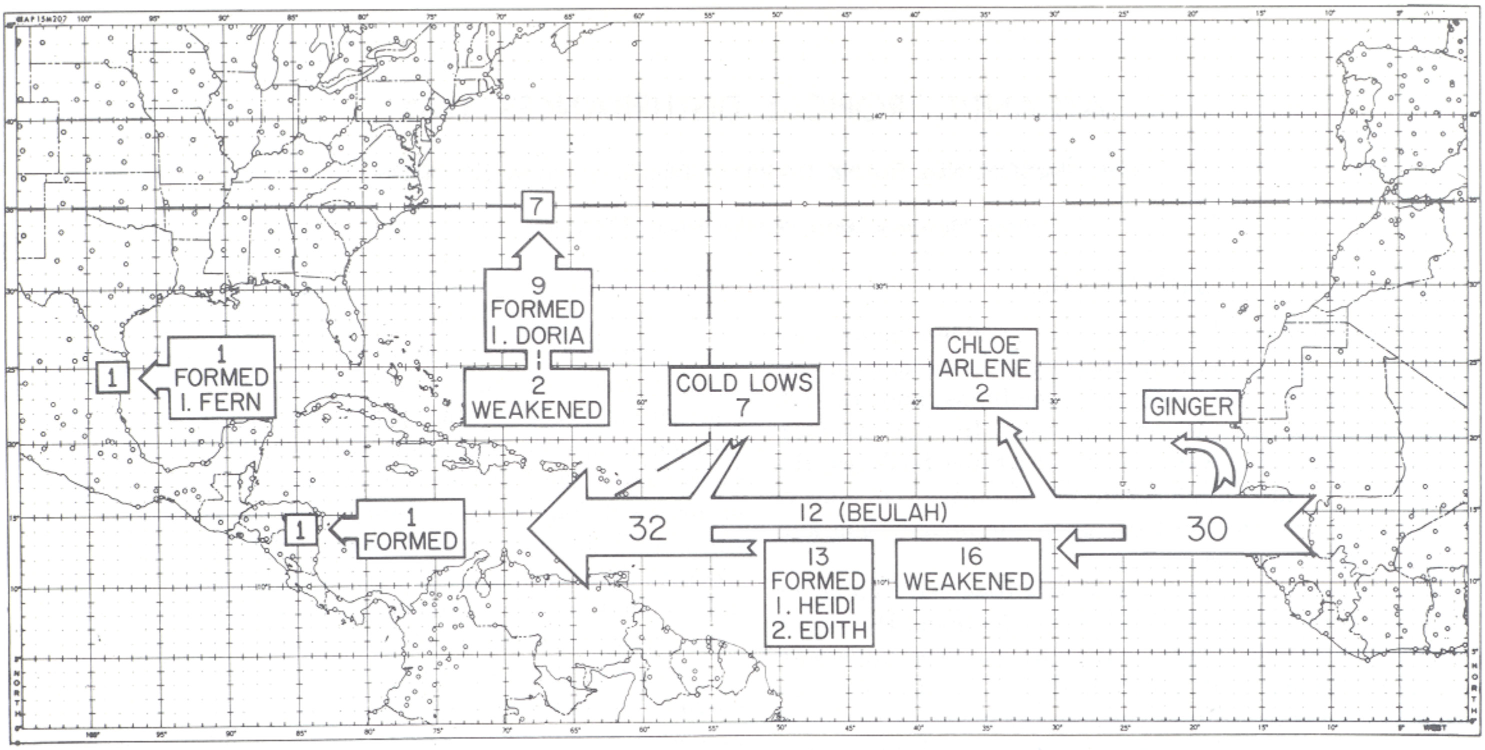

FIGURE 1.—The seasonal summary of tropical waves for the period June through October 1967, in the Gulf of Mexico, Caribbean Sea, southwestern Atlantic Ocean and the central and eastern tropical Atlantic. Within the boxes are shown the number of waves which formed, weakened, and moved through or out of the region.

and Krishnamurti and Baumhefner [18], investigate the dynamics of, respectively, equatorial waves and a wave associated with an upper tropospheric cold Low (both also referred to as "easterly waves"), and illustrate useful modern approaches, but concern a somewhat different aspect of circulation than the wave disturbances discussed here.

The so-called *surge in the trades*, or wind speed maximum, sometimes generates discrete migratory patterns of disturbed weather which when viewed from the satellite resembles the cloudiness of a wave disturbance. However, this type of disturbance rarely exhibits a detectable pressure minimum, unless it moves into a region of preexisting low-level convergence. In at least one instance during 1967 such a windspeed maximum moved across the Caribbean, Central America, and into the Eastern Pacific where in the presence of a preexisting deformation associated with the ITC pressure rapidly fell and tropical storm Francene formed.

The meteorological satellite continually shows the convective evidence of *shear lines*, the remnants of wornout frontal systems, which migrate deep into the Tropics and on some occasions appear to cross the Equator extending lines of convection 8° to 10° into the opposite hemisphere. Still other discrete areas of disturbed weather, nonfrontal and migratory, are observed by satellite occurring in the absence of detectable disturbances in the wind field. According to J. Simpson et al. [28], even when research aircraft reports supplement a good network of surface and upper air observations, it is sometimes impossible for the analyst to identify a dynamical mechanism to support the convection observed. It has been suggested that in some instances the S_2 wave may provide the initial stimulus for such disturbances.

In the light of the foregoing discussions, the Regional Center at Miami has adopted the following definitions of circulation entities which are used in the analyses at this Center, and will be used in the discussion which follows:

1) *Intertropical Confluence (ITC):* A nearly continuous "fluence line" (usually confluent) representing the principal asymptote of the Equatorial Trough. In the Northern Hemisphere it is generally continuous from Africa across the Atlantic and portions of the Americas to the Western Pacific. It comprises the circulation axis about which patterns of low-level mass divergence produce variable, often continuous, bands of convection. The convection frequently is concentrated at or near the fluence line, but may be arranged in bands or in extensive areas of convection to either side of the ITC, depending on the circulation dynamics, e.g. near West Africa and Southeast Asia. Secondary ITC's may be identified in the Southern Hemisphere, but are generally more transitory.

2) *Tropical Wave:* A trough, or cyclonic curvature maximum, in the trade wind easterlies. The wave may reach maximum amplitude in the low or middle troposphere, or may be the reflection from the upper troposphere of a cold Low or equatorward extension of a mid-latitude trough.

3) *Tropical Disturbance:* A discrete system of apparently organized convection, generally 100 to 300 mi. in diameter, originating in the Tropics or subtropics, having a non-

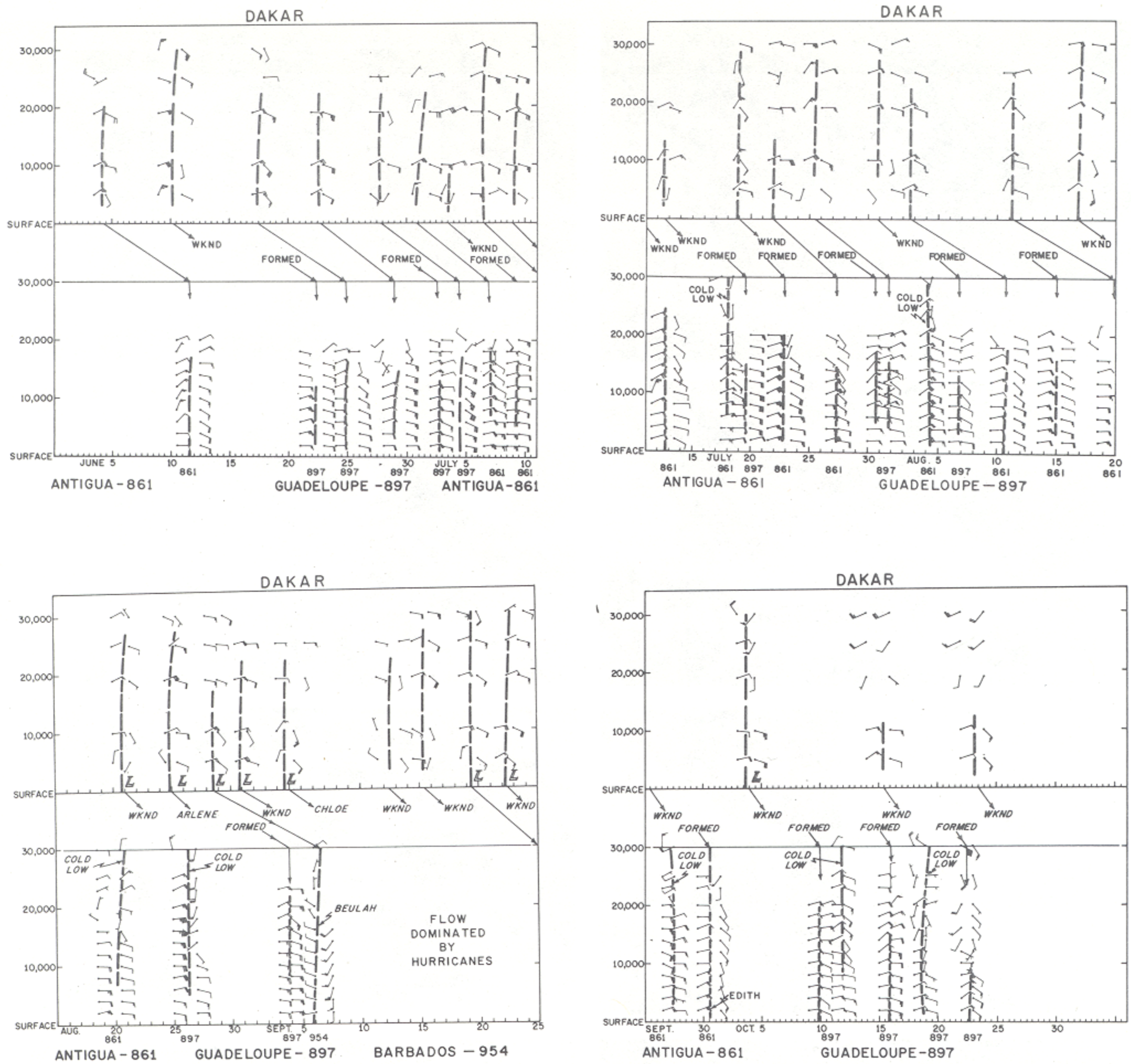

FIGURE 2.—Selected portions of the time-sections for Dakar and various stations in the Antilles Island chain showing the vertical wind structure of waves which passed each location. The layer affected by the wave is shown by the heavy dashed line. Lines between the two time-sections indicate the history or continuity of these waves.

frontal, migratory character, and having maintained its identity for 24 hr. or more. It may or may not be associated with a detectable disturbance in the wind field.

4) *Tropical Depression:* A tropical disturbance with definite closed circulation but with maximum wind speeds less than 34 kt.

5) *Shear Line:* A line of maximum horizontal shear, frequently associated with the remnant deformation of old frontal zones that have reached a barotropic environment. These are usually identified with lines of convection which at times are the only means of maintaining circulation continuity in time and space.

3. TROPICAL DISTURBANCES OF 1967

The following summary pertains to the tropical waves in the Atlantic observed during the period June through October 1967, the only portion of the year in which the RCTM, Miami, attempted to classify and track disturbances. From table 1 and figure 1, it will be seen that

TABLE 1.—*Monthly summary of the number of tropical waves over the central and eastern Atlantic Ocean for the period June through October 1967*

Month	Number which passed Dakar		Number which weakened in Atlantic	Number which formed in Atlantic	Number which passed Antilles
June	6	0	1	2	4
July	8	2	4	4	10 (1)
Aug.	7	7	3	3	8 (3)
Sept.	6	4	5	1	5 (1)
Oct.	3	1	3	3	5 (2)
Total	30	14	16	13	32 (7)

_ Indicates the number of waves which were of depression strength.
( ) Indicates the number of waves which were downward reflections of the upper tropospheric cold Lows (only includes those which reached below 700 mb).

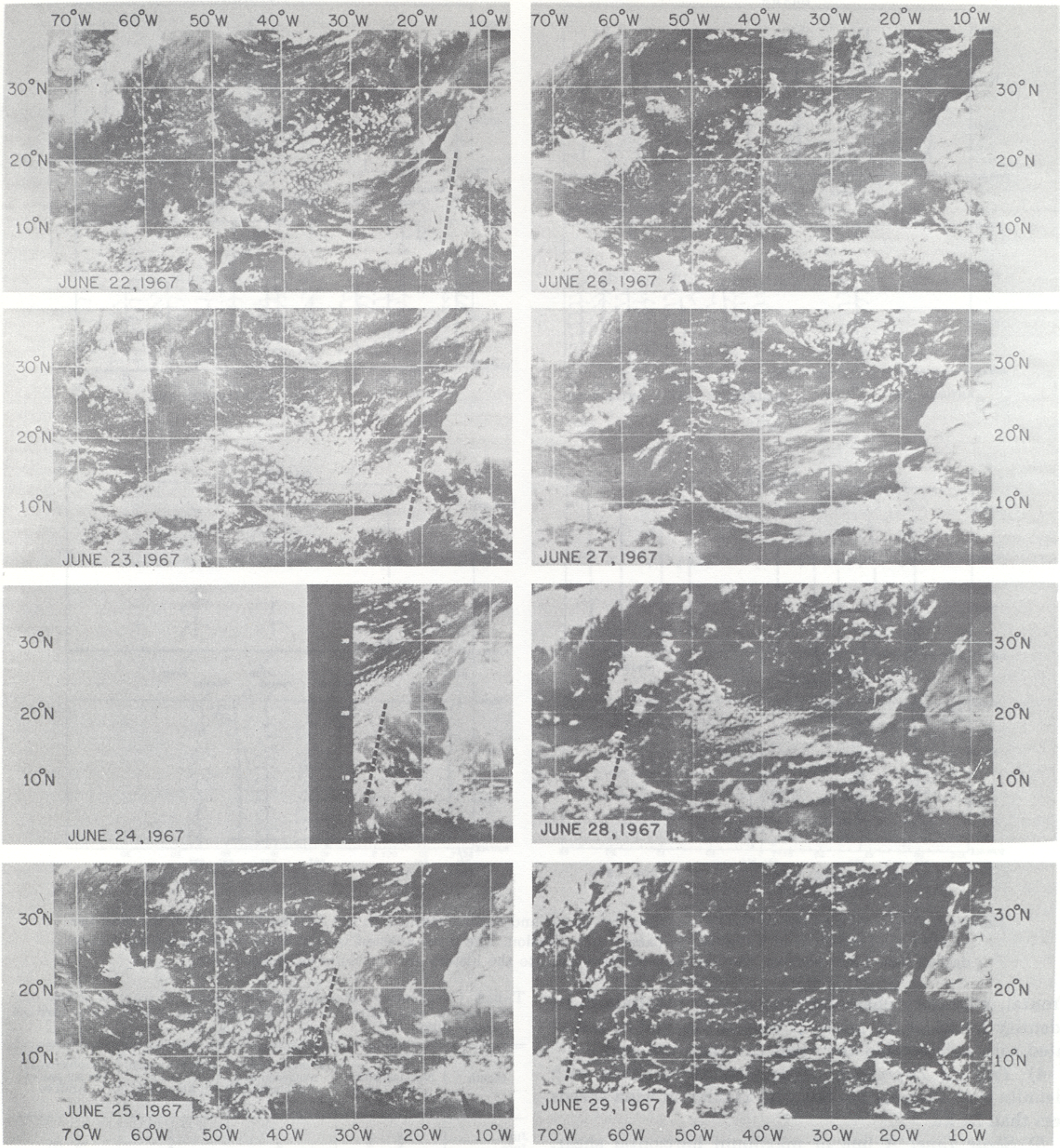

FIGURE 3.—A series of eight digitized mosaics for a period in June when a tropical wave crossed the Atlantic. The wave axis is indicated by a dashed line.

a total of 61 disturbances, or waves, occurred and were tracked. Of these, 30 were first observed near the African Continent and were tracked into the Atlantic. Twenty additional waves were first detected in the mid-Atlantic area, and of these seven had their origin from cold Lows which had spun off from the mid-latitude westerlies. Only those cold Lows which influenced the circulation below the 500-mb. level were considered.

Figure 1 shows that 16 of the African waves weakened and died over the Atlantic while four others developed and became hurricanes Arlene, Beulah, and Chloe, and tropical storm Ginger. Hurricanes Heidi and Edith

TABLE 2.—*Comparison of tropical wave frequencies over western Africa with other investigations*

Month	Author and Period of Study					
	NHC 1967	Piersig [21] 1891–1911	Eldridge [8] 1955	Erickson [9] 1961	Arnold [4] 1961	Aspliden et al. [1, 2, 3] 1963
June	6		2			
July	8		0		10–12	
Aug.	7	Max	3	8–10		5
Sept.	6	Max	4	8–10		6
Oct.	3		5			1

TABLE 3.—*Comparison of tropical wave frequencies over the Antilles Islands with other investigations*

Month	Author and Period of Study				
	NHC 1967	*Durham et al. [7] 1944	Frank [11] 1958	Dunn [5] 1935	Riehl [23] Mid 40's
June	4	2			
July	10	7	6	7–10	~8
Aug.	8	6	10	7–10	~8
Sept.	5	3		7–10	~8
Oct.	5	4			

*Did not consider weakest waves.

developed from waves first detected in the open Atlantic, while hurricanes Doria and Fern developed from disturbances which first were observed in the Gulf of Mexico. A total of 32 waves passed westward across the Lesser Antilles, of which 12 had their origin over Africa.

Table 2 compares the tropical wave frequencies over Western Africa in 1967 with results found by other investigators. One must be careful in drawing conclusions from this comparison since different techniques were used in defining a disturbance. In the present study great emphasis was placed on satellite and upper air data while earlier studies were restricted to surface reports. This is particularly true with the work of Eldridge [8]. He tracked disturbance lines (lines of thunderstorms) utilizing surface synoptic reports and classified these features according to their length. The values listed in table 2 apply to his maximum class which are lines greater than 350 mi. It appears likely that systems of this size are associated with synoptic scale perturbations in the flow pattern. Schove [27] and Johnson [14] both state that line squalls generally accompany troughs in the upper easterlies. Some of the shorter disturbance lines considered by Eldridge may have been associated with tropical waves. This would account for the lower frequencies listed under his name. Aspliden et al. [1, 2, 3] also relied mainly on surface reports to obtain vortex tracks. The number listed under their names include only those tracks which crossed the West African Coast. Table 3 shows a similar comparison for the Antilles Islands. The character of these waves as they passed over Western Africa and the Eastern Caribbean is reflected in the vertical time cross section of figure 2. This diagram shows vertical wind distribution for each tropical wave which reached Dakar and/or the Antilles. It should be noted that the greatest amplitude of these waves occurred between 5,000 and 15,000 ft., similar to the classical wave in the easterlies discussed by Riehl [22].

Of the waves tracked during 1967, a total of 29 developed into depressions, eight reached gale force, and six hurricane intensity. Once again the question must be asked as to

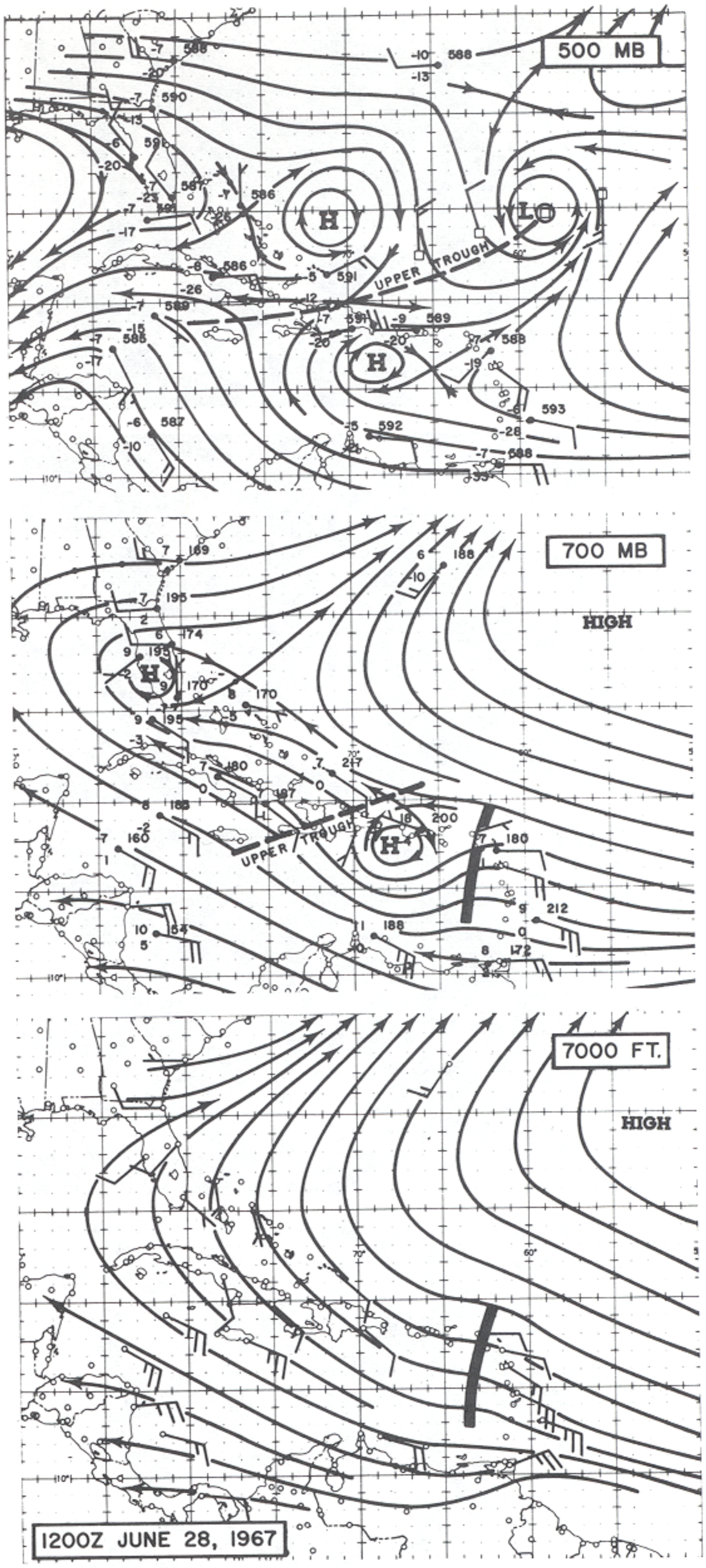

FIGURE 4.—Three streamline charts (7,000-ft., 700-mb., and 500-mb. levels) for June 28, 1967, 1200 GMT, showing the horizontal structure of the tropical wave shown in figure 3 as it crossed the Antilles Islands.

why so few tropical disturbances manage to make hurricanes. Recent work by Gray [12] provides some insight to this problem but further investigations are needed.

Tropical waves, or disturbances without closed circulations, emerged over the Atlantic in a configuration which

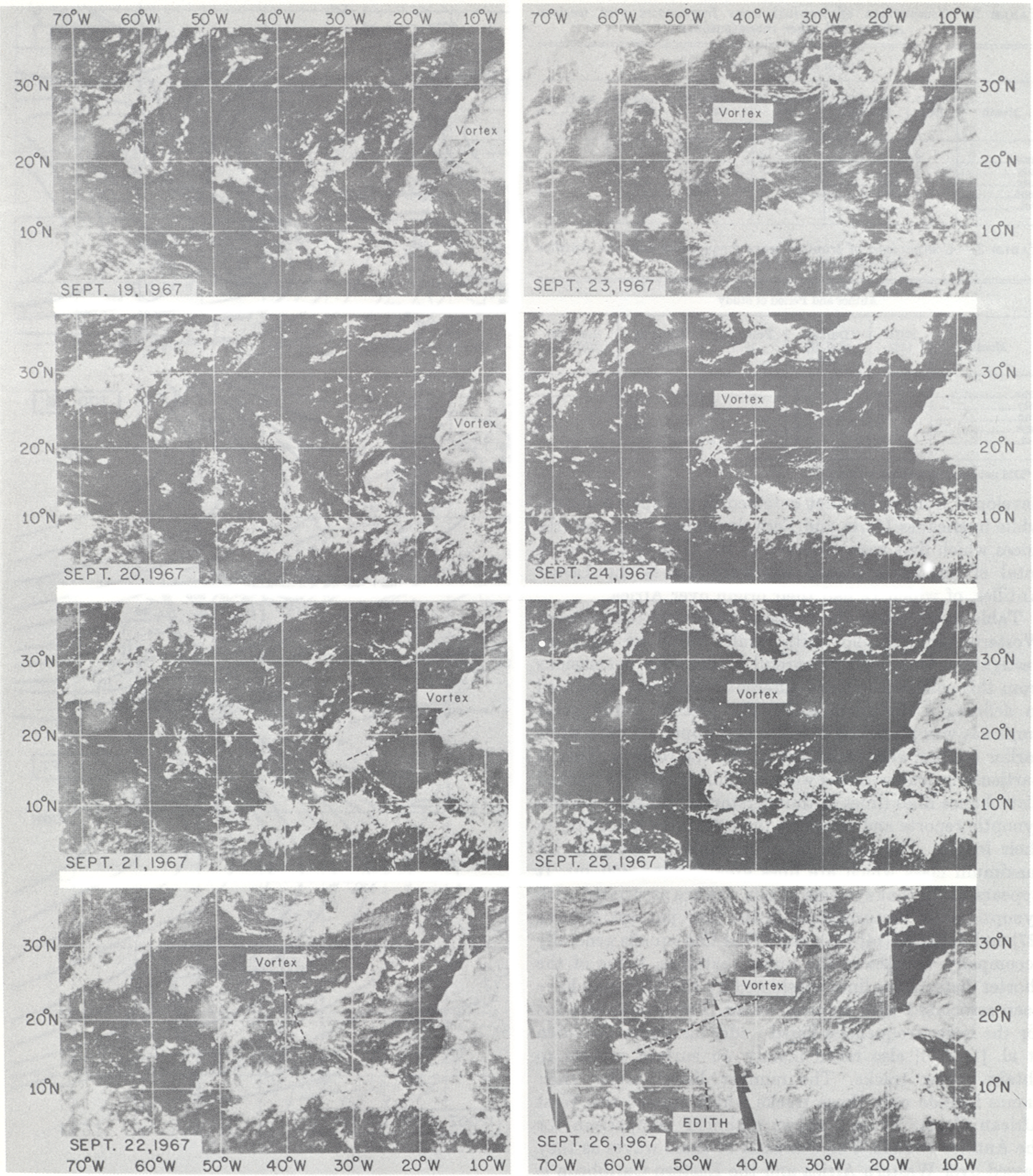

FIGURE 5.—A series of eight digitized mosaics for a period in September when a tropical depression crossed the Atlantic. The vortex center has been indicated.

might be described as an "inverted V." These extend poleward from the vicinity of the ITC, and may or may not be associated with this fluence line. They have distinct cloud bands, apparently parallel to the winds. They are large amplitude waves similar to those described by Malkus and Riehl [19], in their study of Pacific disturbances.

Figure 3 presents a succession of satellite mosaics of a tropical wave as it emerged from the African coast on June 22 and moved westward across the Atlantic into the Central Caribbean 1 week later. It is interesting to note that cloudiness of the wave on June 22 merged with that of the ITC. However, by the 26th the cloud bands associated with the wave appear as separate entities while the

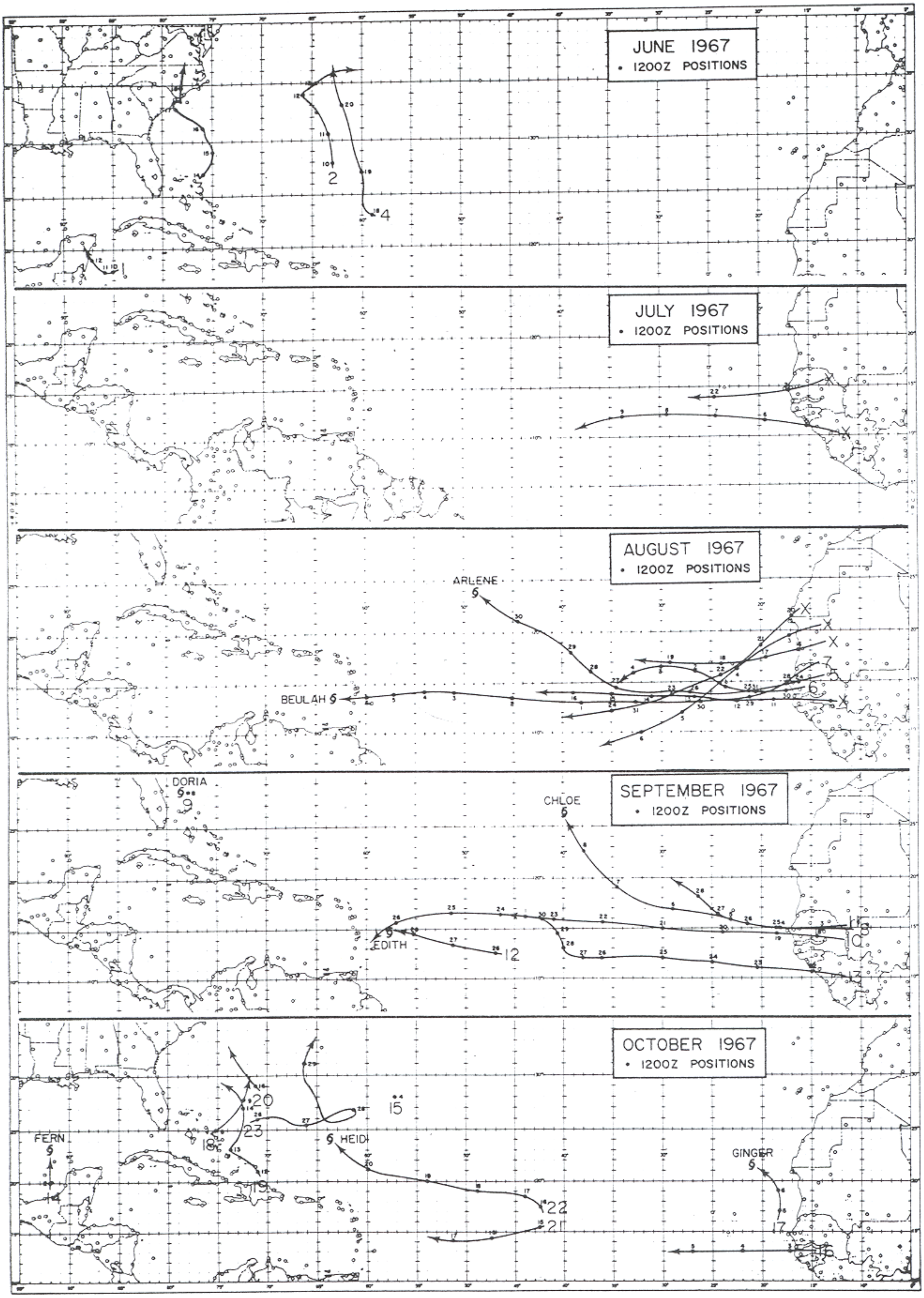

FIGURE 6.—Monthly tropical depression tracks for 1967. Those depressions which developed into named storms have been indicated.

cloudiness at the ITC, still deformed at the meridian of the wave, is reestablished in a continuous east-west band This particular wave did not deepen or form a vortex. However, when a vortex did form from such waves, in most instances the initial evidence of west winds was observed north of the ITC. This is in agreement with the dynamic climatology studies of Gray [12] and the disturbance study of Hubert and Erickson [13].

The horizontal structure of the wave shown in figure 3 is presented in figure 4 for the day when the system crossed the Lesser Antilles. The wave appeared to weaken considerably while crossing the Atlantic and by this time could only be detected in a rather limited layer extending from 4, 000 to 16,000 ft. The maximum amplitude was near 700 mb. where the wind shifted from 070/15 kt. to 120/15 kt. at Guadeloupe as the wave passed.

Figure 5 shows an example of a vortex which has formed in a tropical wave near the ITC at 14°N. and 19°W., September 19. The history of this vortex as it proceeded westward across the Atlantic is shown in successive mosaics for September 20 to 26. In its transit across the Atlantic this disturbance progressively lost intensity and

TABLE 4.—*Summary of the central and eastern Atlantic tropical waves for the period June through October 1967. Included in the table are the dates on which the waves passed Dakar and the Antilles along with information concerning their source and history. This information is displayed graphically in figure 2*

Date disturbance passed Dakar	Disturbance weakened over ocean	Disturbance formed over ocean	Date disturbance passed Antilles	Disturbance was named
June 4	No	No	June 11	
June 10	Yes	No		
	No	Yes	June 22	
June 17	No	No	June 24	
June 22	No	No	June 28	
June 28	No	No	July 4	
	No	Yes	July 2	
June 30	No	No	July 7	
	No	Yes	July 9	
July 3	Yes	No		
July 6*	No	No	July 12	
July 9	Yes	No		
July 12	Yes	No		
	No	No	"July 18"	
July 19	Yes	No		
	No	Yes	July 19	
		Yes	July 23	
July 21*	No	No	July 27	
July 25	No	No	Aug. 1	
	No	Yes	July 30	
July 30	Yes	No		
Aug. 2*	No	No	Aug. 10	
	No	No	"Aug. 4"	
	No	Yes	Aug. 6	
	No	Yes	Aug. 15	
Aug. 11*	No	No	Aug. 19	
Aug. 16*	Yes	No		
Aug. 20*	Yes	No		
	No	No	"Aug. 20"	
Aug. 24*	No	No		Arlene
	No	No	"Aug. 26"	
	No	Yes	Sept. 3	
Aug. 28*	No	No	Sept. 6	Beaulah
Aug. 30*	Yes	No		
Sept. 4*	No	No		Chloe
Sept. 12	Yes	No		
Sept. 15	Yes	No		
Sept. 19*	No	No	Sept. 26	
Sept. 22*	Yes	No		
Sept. 25*	Yes	No		
	No	No	"Sept. 27"	
	No	Yes	Sept. 30	Edith
Oct. 3*	Yes	No		
	No	Yes	Oct. 9	
	No	No	"Oct. 11"	
Oct. 15	Yes	No		
	No	Yes	Oct. 15	
	No	No	"Oct. 18"	
	No	Yes	Oct. 22	Heidi
Oct. 23	Yes	No		
Total 30 *14	16	13	7	

*Indicates the disturbance was of depression strength as it moved by Dakar.
"" Indicates that the "tropical wave" was a downward reflection of an upper tropospheric cold Low. Only those Lows were considered which extended their influence below the 700-mb. level.

passed innocuously into the Caribbean without significant impact upon the Leeward Islands but still exhibiting a closed circulation in the lower troposphere. However, a few degrees to the southeast a new disturbance formed on the 26th and became the initial circulation of tropical storm Edith.

The National Hurricane Center numbered and tracked incipient or weaker tropical cyclones as an operational procedure for the first time in 1967. The criterion for numbering was that the disturbance should be a nonfrontal cyclone of synoptic scale, developing over tropical or subtropical waters and having a definite organized circulation. Cyclones of storm and hurricane intensity received a name in addition to the number. In all, 23 depressions were numbered, of which eight attained storm intensity and received names. Six other disturbances were subsequently determined to have attained depression intensity in post analysis, and their tracks are included.

The depressions cluster into three groups. The largest group originated east of mid-Atlantic. The second group originated not far east of the North American land mass. Most of these had their origins in an old frontal zone. The western group, comprising only two cyclones, formed in the Western Caribbean and Gulf of Mexico respectively.

Figure 6 shows the tracks of disturbances which reached depression intensity during the period June through December 1967, some of which were antecedent to the hurricanes described in another paper in this issue (Sugg and Pelissier [29]). No depressions were observed in November and December. Seedling disturbances which preceded the development of depressions could be traced across portions of Africa in 14 instances. While some evidences have been reported of the existence of such seedlings over the Arabian Sea (Sadler [26]), the RCTM was unable to track disturbances of this kind east of the high plateau in Ethiopia.

4. SUMMARY

Sixty-one tropical waves were detected and followed over the Gulf of Mexico, Caribbean Sea, and Tropical Atlantic Ocean during the hurricane season of 1967 (table 4). Of these more than half had their origins over Africa in a yet-to-be-identified source region. Typically these appeared to the meteorological satellite as "inverted V" cloud bands north of the ITC. Approximately 40 percent of the seedling disturbances which reached the Lesser Antilles could be tracked back to Africa, another 40 percent formed in the mid-Atlantic, and 20 percent were traceable to cold Lows in the high troposphere.

Twenty-nine of the 61 waves reached depression intensity. Fourteen of these were observed emerging from the African Continent. The normal geographical shift of tropical depression activity (Dunn and Miller [6]) was observed with a mid-season maximum in the Eastern Atlantic and early and late season activity in the southwestern Atlantic, including the Gulf of Mexico and Western Caribbean Sea. Almost all (11 out of 13) of the disturbances which moved off Africa in August and September became depressions.

The present meteorological satellite provides an excellent source for identifying disturbances and has provided for the first time an opportunity to track these systems accurately. Satellite information may suggest hypotheses from which more intelligent investigations can be made of the dynamics of the instabilities which cause "seedlings" to grow to hurricane intensity. The Advanced Technology (synchronous) satellites have demonstrated the feasibility and importance of stationary satellite observations in the Tropics and offer perhaps the most powerful tool available for studying tropical cyclogenesis. The full exploitation of the satellite as an observing tool may require the simultaneous use of research aircraft to relate the dynamical properties of the circulation to the growth of cloud systems observed by the satellite. Meanwhile, the development of a climatology of tropical disturbances may help the design of experiments which would use aircraft and satellites, and should help develop more objective approaches to analysis in the Tropics.

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