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THE ATLANTIC HURRICANE SEASON OF 1968

ARNOLD L. SUGG and PAUL J. HEBERT[1]

National Hurricane Center, Weather Bureau, ESSA, Miami, Fla.

ABSTRACT

The 1968 hurricane season in the North Atlantic area, considered in its entirety, and synoptic and statistical aspects of individual storms are discussed.

1. GENERAL SUMMARY

The two hurricanes and one tropical storm in June equaled a record established in 1886.[2] While there were two other years, 1959 and 1936, with a total of three June tropical cyclones, each is not unique as there were two storms and one hurricane in those years. Two hurricanes occurring in June are noteworthy when one considers there have only been 20 since 1886. This is approximately one every 4 yr, rather than two for any one June. In spite of this beginning, the season ended with a total of only 13 hurricane days, except for 1962, the lowest number for two decades and well below the yearly average. See table 1 showing the most recent 15 yr.

Synoptic meteorologists are particularly interested in why there are deviations in the normal monthly or seasonal incidence of tropical cyclones. We can, in most situations, recognize planetary circulation patterns that are favorable or unfavorable for development. In retrospect, and aside from the climatology, what transpired in June 1968 is more difficult to explain than the activity that occurred in other abnormal months of past years. Specifically, Stark (1968) has shown negative anomalies for May ranging from 50 to 80 m at 700 mb from the Great Lakes eastward to Europe. This anomaly was associated with blocking conditions at higher latitudes that resulted in farther-south-than-normal westerlies across the Atlantic. Based upon the work of Ballenzweig (1957), the preferred pattern for tropical cyclogenesis along the Gulf Coast would depict above-normal 700-mb heights in the Great Lakes with a strong positive axis eastward to southwestern Europe. Green's (1968) analyses of the June data do not show this. Indeed, the June chart was more similar to what Ballenzweig has described as unfavorable for tropical cyclone development, although the May–June change was a favorable trend. Correlations during past years have been acceptable; this one is disappointing but certainly not discouraging. Since we know so little about pressure change mechanisms in the Tropics and the causes of cyclogenesis, perhaps June 1968 will prove very revealing to research meteorologists. The relatively large amount of data and events of this month should be remembered and studied, not written off without further examination. While this report does not encompass new basic research on the subject, we will return to this unusual month with some pertinent observations after some general remarks about the remainder of the season.

Table 1.—*Hurricane days, 1954–1968*

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
1968	-----	-----	-----	-----	-----	3	-----	5	-----	5	-----	-----	13
Total	4	-----	-----	-----	-----	15	19	91	236	111	9	1	486

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

Changes in circulation features from June to July were minor as indicated by Wagner (1968). Since there were no storms, the agreement with Ballenzweig's types is very good.

The westerlies dipped deep into the low latitudes of the Atlantic in August—frequently below 30°N lat. This caused geopotential heights in the lower troposphere

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[1] Other contributors include R. H. Simpson, G. B. Clark, N. L. Frank, J. R. Hope, R. H. Kraft, and J. M. Pelissier of NHC, and W. C. Conner of the New Orleans Hurricane Weather Office.

[2] Actually, Tannehill (1956) describes the cyclone of June 13–14, 1886, as a hurricane. This would total three hurricanes for the month. Existing data do not prove that it was; however, it may have been a minimal one. The authors choose to accept the judgments of Dunn and Miller (1960), Cry (1965), and Dunwoody (1886). These references indicate that this early June cyclone was only of storm intensity. One tropical cyclone in 1959 formed on May 28.

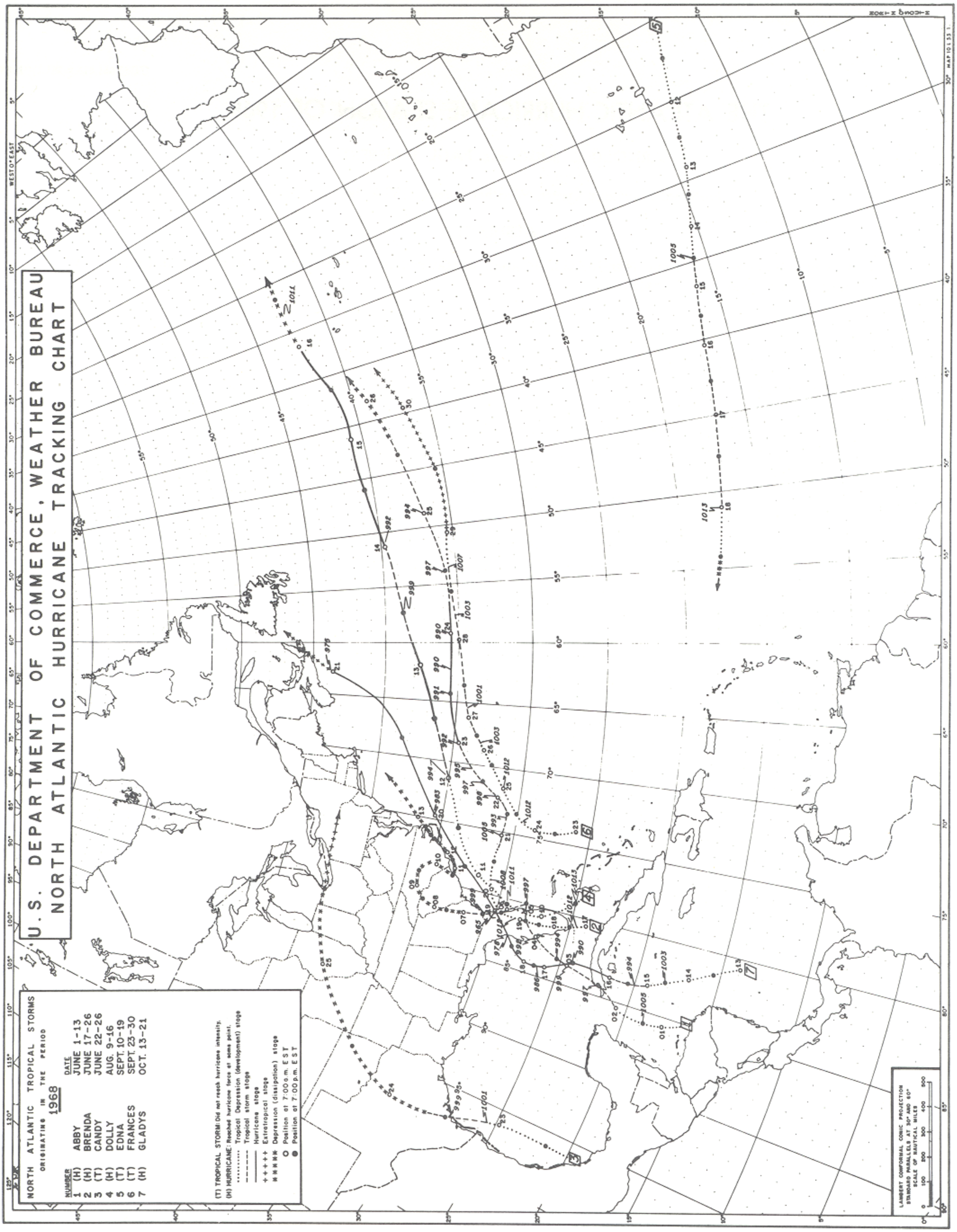

FIGURE 1.—Tracks of hurricanes and tropical storms, North Atlantic, 1968.

to be well below normal over most of the ocean—a pattern that experience has shown to be unfavorable for development. (For example, see Andrews (1968) for an inspection of the anomaly fields.) August produced only one named cyclone. This is less than the monthly average for hurricanes, not to mention the combination of storms and hurricanes. The relatively quiet month was not surprising.

The pattern remained unfavorable into September. Posey (1968) states there were below-normal heights at 700 mb from the western Atlantic to the Black Sea. Again, this is not what the forecaster looks for as a favorable pattern for the development of the long-trajectory, Atlantic-Cape Verde-type cyclones so typical of August and September. In figure 1, note that Edna never attained hurricane force and failed to hold together long enough to make the usual recurvature or landfall.

Two conclusions might be drawn from this general summary. The first is most obvious and can be stated as a good forecasting rule: *tropical cyclone development is not favored by blocking Highs at northern latitudes that produce westerlies and below-normal heights in the midtroposphere at midlatitudes and in the subtropics.*[3] For the second conclusion, we return to the month of June.

The authors can only reaffirm what several others have said before, that the environment and its changes near the disturbance or depression are just as important for development, if not more so, than the large-scale features discussed in previous paragraphs. Riehl (1963) has emphasized that there are two schools of thought and goes on to comment on whether most of the research should be done on the "internal factors" or the "external forcing mechanisms." In this reference, he apparently thinks the latter very important, for he alludes to the influences produced by the passing (to the north) of midlatitude troughs in the westerlies. He postulates external cooling from this arrangement but is quick to point out "There would be only a few days in each hurricane season when formation from external forces was a possibility." The following paragraphs will attempt to flag some of the more obvious internal features of the June storms and touch on some of the applied research in progress by hurricane specialists recently assigned to the National Hurricane Center.

First of all, let us examine the depression, located at lat. 18.8°N, long. 85.8°W, at 1900 EST, June 1; central pressure was 1055 mb. Figure 2 is an ESSA–5 picture of the circulation on the same day. Intensification processes produced storm force winds (Abby) within 12 hr and a central pressure of 997 mb after 24 hr. Riehl and Malkus (1961) have remarked on the importance of "hot towers" that cover only a small fraction of the developing cyclone. Later, Malkus and Williams (1963) concluded that the "interaction between large cumuli and severe storms (hurricanes) is essential to the dynamics of both." We believe the satellite picture shows the presence of isolated and tall cumuli near the area of minimum pressure which support the research mentioned above. Besides the visual evidence, figure 3 is presented to show the very weak shear in the vertical at Swan Island, the station nearest the depression. This would certainly seem to support the conclusion of Gray (1967)—". . . most disturbances from which storms form are generated from an environment in which a horizontal trade-wind current is present with minimum vertical shear." Similarly, it supports the conclusions of Simpson and Riehl (1958), who had demonstrated that where "ventilation" exists it acts as a constraint upon the hurricane heat engine (development).

Another interesting observation, and surely a clue to the formation of Abby, is presented in figure 4. Here we see the unanalyzed data from the so-called "TOE chart" (top of the Ekman layer)[4] regularly prepared by the Regional Center for Tropical Meteorology (RCTM) at NHC. By inspection, one can easily see the obvious inflow which is so important. A computation of the radial component with these data within a radius of 4° lat. produced a speed of 0.8 kt. This value yields greater convergence than the threshold radial inflow of 1.5 kt around the Gulf of Mexico (much larger radius) which is considered favorable for development by Riehl, Baer, and Veigas (1962). A second computation was not made; however, contrast figure 4 with figure 5. The latter is the TOE chart for a September depression that persisted for several days; the winds show no net inflow; the depression never developed. For the track of this depression and others the reader is referred to the accompanying article by Simpson et al. (1969).

Damage and casualty figures for the 1968 hurricane season are given in table 2. Table 3, presenting hurricane statistics in the United States in less than a century of hurricanes, helps to emphasize the small amount of damage and relatively low loss of life in 1968.

2. INDIVIDUAL CASES

HURRICANE ABBY, JUNE 1–13

When the 1968 hurricane season officially began on June 1, processes underway during May had already indicated it would start actively. A midtropospheric trough had persisted over the extreme northwestern Caribbean Sea during the latter part of May. A short-wave trough moving eastward through the semipermanent Caribbean trough pushed a weak cold front southward into the Florida Straits near the end of the month. The low-level convergence field gradually increased, and satellite pictures showed the merging of the cloud systems associated with the frontal zone and upper trough. The extensive and prolonged rains produced by these systems, together with another minor midtropospheric trough that moved into

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[3] This circulation pattern does not preclude the development in the westerlies of the cold hybrid system or subtropical cyclone that frequently produces storm force winds and occasionally warms to resemble the tropical cyclone of lower latitudes.

[4] This chart utilizes surface ship winds, and 3,000-ft wind observations from ships, land upper air stations, and aircraft to depict flow patterns in the Tropics above the friction layer. (Important cloud systems as depicted by satellite products are superimposed upon a streamline analysis to pinpoint synoptic systems.)

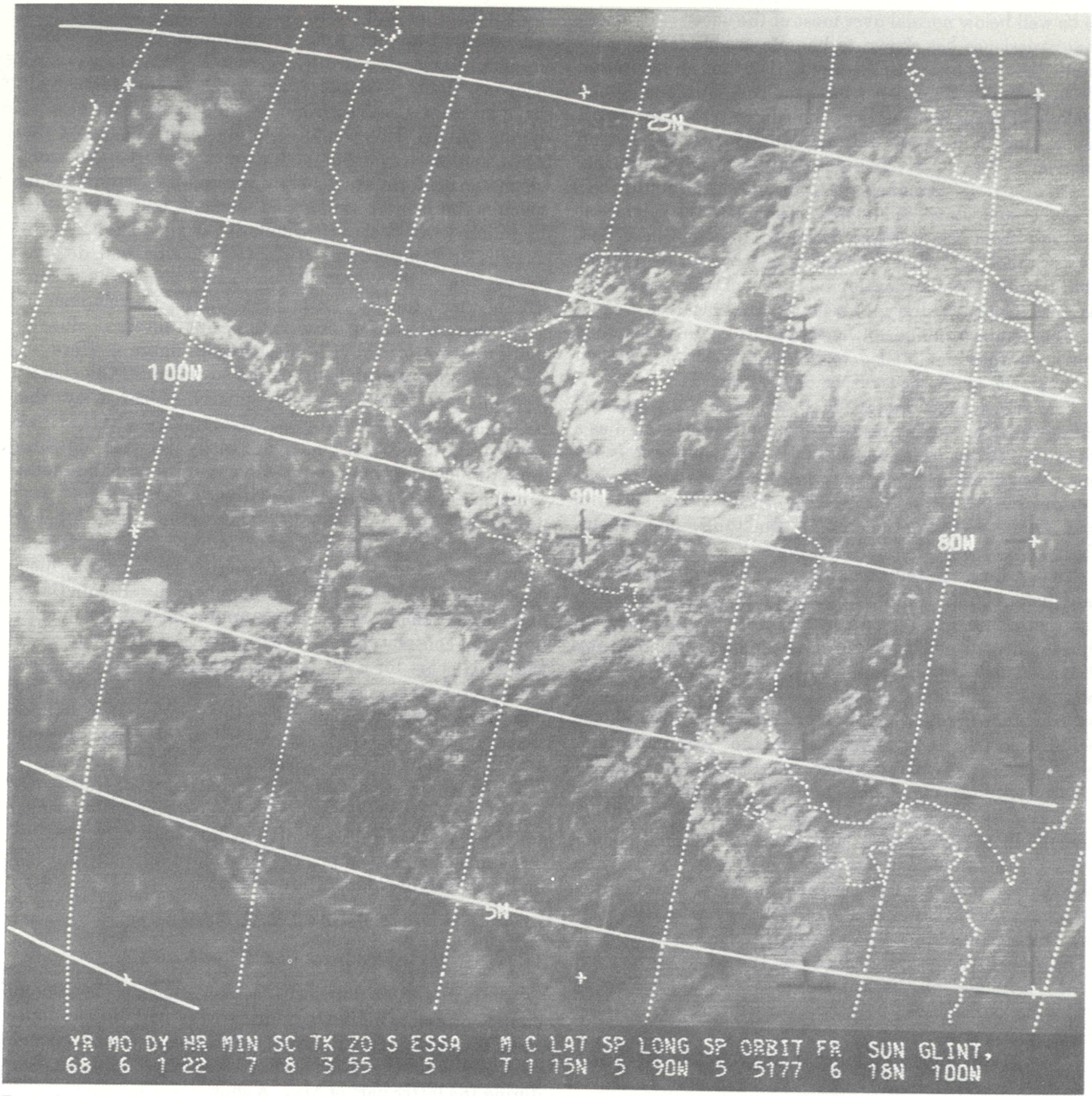

FIGURE 2.—An ESSA–5 satellite picture taken June 1, 1968, 1707 EST, showing the circulation associated with the depression depicted on the TOE chart in figure 4.

the mean trough on the 1st, caused general pressure falls throughout the extreme western Caribbean Sea. The trough probably also helped start Abby on her northward trek. As the pressure fell, deep southwesterly flow began through Central America and over the adjoining Pacific Ocean (a *temporale*) advecting very warm and moist tropical air into the area of maximum pressure falls. A warm-core tropical cyclone gradually organized on June 1 and reached tropical storm intensity on June 2. A general warming of the upper troposphere took place over the Gulf of Mexico and western Caribbean Sea during this time, and a strong west-southwesterly jet-

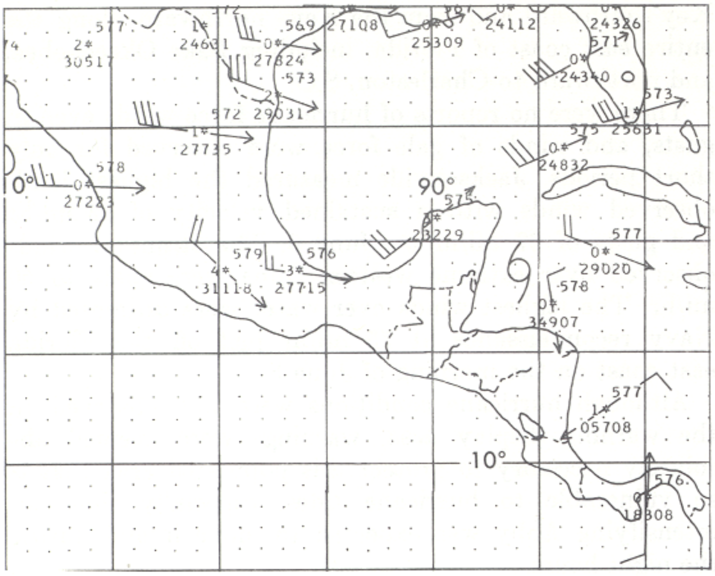

FIGURE 3.—Troposphere mean temperature (shear) chart, 600- to 200-mb layer minus 1000- to 600-mb layer on June 1, 1968, 1900 EST. Note that besides the two charts used to prepare this shear chart, the Regional Center for Tropical Meteorology at the National Hurricane Center, Miami, Fla. (RCTM), also produces a deep-layer mean chart from 1000 mb to 100 mb.

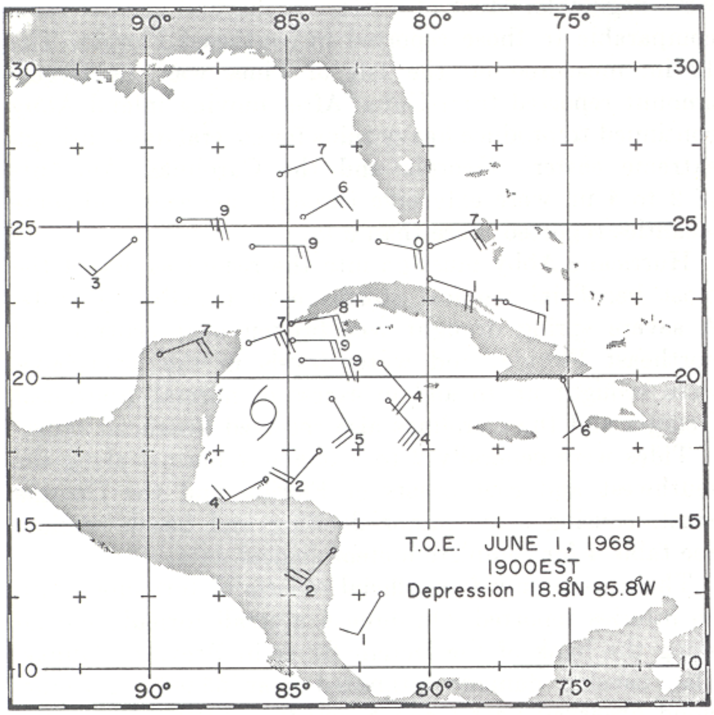

FIGURE 4.—TOE chart (top of the Ekman layer ships and 3,000-ft winds chart), June 1, 1968, 1900 EST, depression 18.8°N, 85.8°W.

stream persisted from southern Mexico to southern Florida; conditions were quite similar to the predevelopment stage of hurricane Alma in 1966.

Tropical storm Abby crossed extreme western Cuba on the evening of June 2, moving on a north-northeast

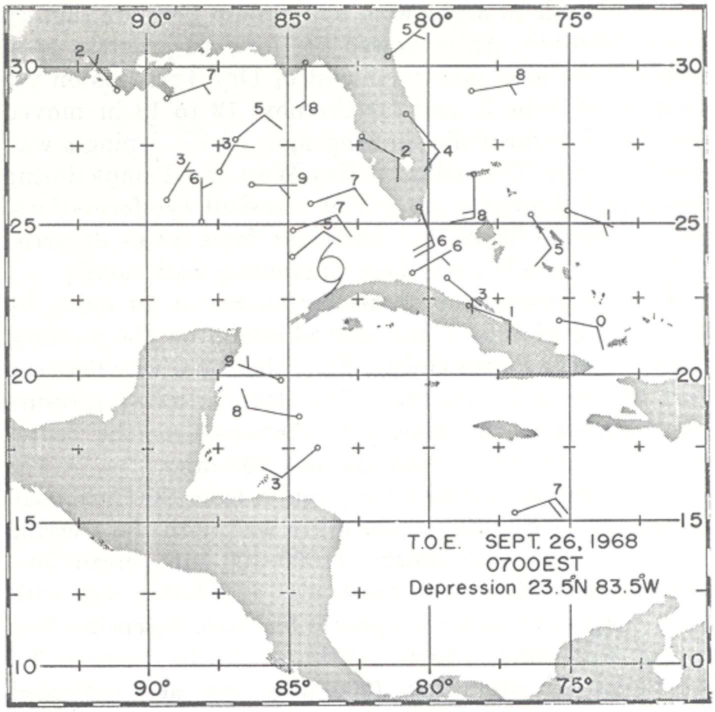

FIGURE 5.—TOE chart (top of the Ekman layer ships and 3,000-ft winds chart), Sept. 26, 1968, 0700 EST, depression 23.5°N, 83.5°W.

TABLE 2.—*Estimated damages and casualties, hurricane season 1968*

Date		United States		Other Areas	
		Deaths	Damages	Deaths	Damages
June 1-13	Abby (H)	Florida 6	$450,000	0	(*)
June 17-26	Brenda (H)				
June 22-26	Candy (TS)		2,730,000		
Aug. 9-16	Dolly (H)				
Sept. 10-19	Edna (TS)				
Sept. 23-30	Frances (TS)				
Oct. 13-21	Gladys (H)	Florida 3	6,700,000	Cuba 1 Nova Scotia 1	(*)
Totals	3 tropical storms 4 hurricanes.	9	9,880,000	2	

*There were conflicting reports on damages in Cuba. The authors have concluded there was little if any connected with Abby, but some unknown amount should be attributed to Gladys in connection with crop losses.

TABLE 3.—*Memorable hurricanes of the United States*

	Year	Damages ($ million)		Year	Deaths
Betsy	1965	1419.8	Galveston	1900	6000
Diane	1955	800.0	Louisiana	1893	2000
Carol	1954	450.0	South Carolina	1893	1000–2000
Carla	1961	400.0	Okeechobee	1928	1838
New England	1938	387.1	Keys and Texas	1919	600–900
Donna	1960	386.5	Georgia and South Carolina	1881	700
Hazel	1954	251.6	New England	1938	600
Dora	1964	250.0	Audrey	1957	550
Beulah	1967	200.0	Keys	1935	405
Audrey	1957	150.0	Atlantic coast	1944	390
Cleo	1964	128.5	Mississippi and Louisiana	1909	350
Miami	1926	111.8	Galveston	1915	275
			Mississippi and Louisiana	1915	275

course around 10 mi/hr with a minimum pressure slightly below 1000 mb. Abby slowed her forward progress upon reaching the area just northwest of Dry Tortugas on the morning of June 3, and for the next 12 to 18 hr moved less than 5 mi/hr while showing signs of developing a wall cloud and eye. The radars at Key West and Tampa during this period showed a number of transient eye formations, and it is quite likely that hurricane force winds occurred in heavier squalls near these organizing wall clouds.

Abby resumed a northeasterly course at 10 mi/hr by the evening of June 3 and moved inland on the morning of June 4 near Punta Gorda, Fla. (about halfway between Fort Myers and Sarasota). The storm's lowest pressure was reported at this time with stations near the center indicating barometric readings near 992 mb.

Abby's general northeasterly course from the Caribbean to landfall in Florida agreed quite well with the steering implied in the tropospheric (1000–100 mb) mean flow with minor variations in track also correlating well with weak shortwave midtropospheric features. Intensification during this time, which continued to be favored by the high-level circulation (200 mb), was also indicated by the tropospheric mean shear chart mentioned earlier. The trough that had persisted over the eastern United States during this time moved off the coast late on the 3d; it was followed on the 4th by ridging to the north, which resulted first in a more nearly eastward course across the peninsula and then blocked further northeastward movement after the morning of the 5th.

During the following 24 hr, the storm remained in the general area of Cape Kennedy awaiting eastward movement of the blocking high-pressure system. The 994-mb central pressure measured by Navy reconnaissance aircraft on the morning of the 5th was essentially the same as that measured by the ESSA reconnaissance aircraft (993 mb) just prior to landfall on the west coast about 24 hr earlier. On June 6, Abby began moving north-northwestward just off the upper east coast of Florida and moved inland north of Jacksonville at nightfall. Both the maintenance of storm intensity and its movement related well to the shear and deep-layer mean charts.

The gradually weakening circulation of Abby moved through extreme eastern Georgia and northwest South Carolina during the next several days, reaching central North Carolina on June 9. Thereafter, a very weak and diffuse circulation center could be followed on a hairpin-shaped track through eastern North Carolina until it was finally absorbed in a cold frontal trough off the Virginia capes on June 13. Once the remnants of Abby reemerged over water from the mainland, neither lower nor upper tropospheric conditions gave any indication of significant reintensification.

Hurricane warnings were issued at 1200 EDT on June 3 from Marco Island to Tarpon Springs on the Florida west coast. Gale warnings were issued during the course of the storm elsewhere on the west coast from Cedar Key southward and from the Keys northward along the entire east coast of Florida, including Lake Okeechobee, and northward to Charleston, S.C.

There were no reports of hurricane force winds even in gusts, and winds of gale force were observed for only short periods. Jacksonville measured the highest land-observed winds with a sustained velocity of 52 mi/hr and gusts of 67 mi/hr on June 6. The strongest winds observed over extreme western Cuba were gusts to 50 mi/hr. The highest winds over water were estimated by Navy reconnaissance at 75 mi/hr just off the Florida east coast on the morning of June 5.

Although hurricane conditions were not observed in the warning display area, warnings were deemed absolutely necessary to protect this populated area that is so vulnerable to hurricane tides, especially since an intensifying Abby was expected to move inland during the night hours.

Rainfall was moderate to heavy north and east of the storm. Average amounts of 4 to 8 in. were recorded over eastern and southern Florida with portions of east-central Florida measuring amounts in excess of 10 in. The heaviest rainfall reported was 13.86 in. at Titusville. Northwestern portions of the peninsula reported totals less than 2 in., and in the Florida Panhandle amounts were negligible. Most of western Cuba had general rains comparable to those reported in southeast Florida. The 12 in. measured on the Isle of Pines was the largest amount reported from Cuba. After moving inland Abby continued to produce heavy rains for several days through extreme eastern Georgia and the Carolinas. Amounts of 2 to 4 in. were extensive through this area and some localities reported more than 6 in.

Hurricane Abby must go into the record as one of the most beneficial tropical storms ever to affect Florida. A severe spring drought was broken over central and northeast Florida, and water levels in the Everglades were brought up to and in excess of normal. Southeast Georgia and the Carolinas also received beneficial rains.[5]

Tides were generally 2 to 3 ft above normal along the southwest and east coasts of Florida and the Georgia coast, causing some minor flooding and beach erosion. See table 4 for complete meteorological data.

There were only four official reports of tornadoes with no injuries reported. On June 4 a small tornado moved along the bank of the Indian River in Brevard County, Fla., causing damage estimated near $5,000. A funnel cloud observed near Cape Kennedy a little later in the morning briefly touched the surface with little or no damage. A very small tornado touched down in the northwest section of Haines City in central Florida causing about $3,000 property damage. A small tornado struck a sparsely settled area just north of Monroe, N.C., on June 7 and apparently continued northwestward touching down again on the southeastern edge of Char-

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[5] See the crop moisture index maps in the *Weekly Weather and Crop Bulletin*, June 10 and 17, by Environmental Data Service, ESSA (1968).

TABLE 4.—*Hurricane Abby, meteorological data, June 1–13, 1968*

Station	Date	Pressure (in.)		Wind (mi/hr)				Highest tide (ft)	Date/time	Storm rainfall (in.)	Remarks
		Low	Time (EST)	Fastest mile	Date/time	Gusts	Date/time				
Cuba											
Havana	2					50					
Isle of Pines										12. 00	
Florida											
Avon Park										6. 62	
Big Pine Key	3	29. 53	2100	55* SSE	04/0400	60* SSE	03/2320			5. 47	
Bradenton										5. 84	
Cape Kennedy	5	29. 41	0300	28	1230	46 NE				8. 55	
Clearwater	4	29. 56		30* NNW						1. 93	
Cocoa	5	29. 46	0000	60* E	1000	65* E	1000			14. 20	
Daytona Beach WBO	6	29. 48	0400	37 N	05/1656	62 NE	05/2205	2. 6 AN	05/1758	6. 17	
Dry Tortugas	3	29. 46	2230								
Everglades City	4	29. 52	0330	30* SSE	0255	50* SSE	04/0255	5. 6	04/0800	4. 82	
Flamingo	4	29. 56	0310			56 SSW	0108			3. 10	
Fort Lauderdale										4. 99	
Fort Myers WBO	4	29. 38	1353	23 W	1353	35 SW	1815			6. 20	
Fort Pierce	5	29. 39	0530			35 SSW	04/1200			7. 12	
Hillsboro Light	4	29. 57	1500	41	03/1900						
Homestead AFB	4	29. 55	0158	29 S		45 S				3. 18	
Jacksonville WBO	6	29. 49	1816	52 N	0854	66 NNE	0908	2. 2 AN	07/0600	6. 61	
Jupiter Light	4	29. 50	2225	45 SE	2000	48 SE	2004				
Key West WBO	3	29. 51	2230	43 SE	0917	47 SE	2156	0. 7 AN	03/1424	6. 65	
Lake Alfred										7. 05	
Lakeland WBO	4	29. 41	1430	30 NE	0316	37 NNW	05/1056			5. 53	
Lake Placid	3	29. 44	1400	35* WNW	04/1800	45* WNW	1800			6. 25	Eye passage
Lake Wales										7. 78	
Merritt Island	5	29. 45	0300			64 NE	1442			9. 50	
60-Ft Tower	5			69**		87	05/1500				
Miami NHC	4	29. 58	0350	46 SW	1200	52 SW	1200			4. 82	
Miami WBAS	4	29. 56	0400	32 SW	1732	38 SSW				4. 67	
Naples	4	29. 46	1900	40* WSW	05/0200	45* ENE	05/0200	2. 0 AN		4. 54	
North Key Largo	4	29. 74	1330	46	0530						
Orlando WBO	4	29. 47	1456	29 ENE	1456	46 NNE	05/0810			10. 87	
Patrick AFB	5	29. 37		28 N	0357	38 N	0357			9. 03	
Plantation Key	3	29. 68	0600	52	04/0255						
Punta Gorda	4	29. 35	0430			80* NNW	2130			6. 50	
St. Petersburg	4	29. 52	0700	35* SW	03/2000	45* SW	03/2000			2. 25	
Sanford				30* ENE		45* ENE				6. 50	
S. Melbourne Beach	5	29. 38	1700			46* ESE	04/2316			6. 12	
Tampa WBO	4	29. 50	0655	25 N	05/1413	39 NE	1030			2. 51	Tide BN
Titusville	5	29. 49	0615	40 NNE	1221	55 NNE	1221			13. 86	In eye 0600–0642
W. Palm Beach WBO	4	29. 54	1730	29 WSW	05/1457	41 WSW	05/1759			5. 34	
Georgia											
Savannah WBO	7	29. 63	0400	30	06/2346	41 E	07/0043	2–3 AN	06/1700	3. 90	
South Carolina											
Charleston WBO	7	29. 77	0445	46 SE	0211			2. 2 AN	06/2200	1. 05	
North Carolina											
Charlotte	8	29. 78	0400	20 NW	09/1947	46 NW	09/1938			5. 11	

*Estimated; AN, above normal; BN, below normal. **5-min measurement.

lotte, N.C. Damage in Monroe was minor, although many trees were blown down or their tops twisted off. Damage in Charlotte was considerably greater and probably exceeded $30,000.

There were six deaths reported, all in Florida, but none of them can be directly attributed to the storm. They include three drownings, two electrocutions, and one traffic fatality. Damage from hurricane Abby was estimated to be $250,000 in Florida and was probably less than $100,000 each in Georgia and the Carolinas. No casualty figures or damage statistics have been received from Cuba.

HURRICANE BRENDA, JUNE 17–26

Conditions antecedent to the formation of Brenda were similar in several respects to those preceding Abby's development. A closed 500-mb Low formed over south Florida on the 14th as a trough in the westerlies sheared to the north. Brenda began as a tropical depression over the Florida Straits on June 17, forming under the persistent mean June trough in which the closed Low was embedded. Environmental midtropospheric temperatures had gradually warmed during this period, and upper level flow shifted from west-northwesterly to south-southwesterly on the morning of the 17th. When the midlevel anticyclone following the front moved off the southeast coast of the United States, the weak depression formed in the Straits. This depression then drifted up the Florida peninsula for 2½ days with little change in intensity. While the depression was over Florida, the heaviest showers and a few squalls with wind gusts occasionally 40 mi/hr or better were well east of the depression. The shear chart indicated increasingly favorably conditions for intensification during the time the depression was over land, in good agreement with the maintenance of intensity.

The depression left northeastern Florida early on the 20th and turned toward the east over the open Atlantic as it was picked up by a weak trough in the westerlies. Intensification began when its circulation moved under the western portion of the main rain area. At this time Brenda was also under the northern edge of a weak shear field[6] much the same as that near Abby and later Candy when they intensified.

Brenda reached storm intensity on June 21 as the favorable weak shear field continued. Movement of the depression up the peninsula and eastward from northeastern Florida was in good agreement with the deep layer mean flow. The Bermuda ridge built southwestward late on the 21st and 22d as a weak trough passed to the north, causing Brenda to take a northeastward turn. Brenda encountered the midlatitude westerlies on the 23d near latitude 35.0°N, reaching minimal hurricane force for a little over a day in the Atlantic, during which time it passed about 200 mi north of Bermuda. After a day and a half the storm was cut off from the very moist tropical air by a ridge of high pressure to the south extending across most of the Atlantic. Brenda lost intensity on the 26th when it was engulfed by a strong extratropical system.

Highest wind was estimated to be 80 mi/hr by Air Force reconnaissance on the 23d, and the lowest pressure measured was 990 mb early on the 24th.

No deaths or damage of consequence have been attributed to Brenda, and the only warnings were marine advices for ships.

TROPICAL STORM CANDY, JUNE 22-26

Candy climaxed one of the most active early seasons on record, as previously discussed in the general summary. A 500-mb cutoff Low over east Texas on the 17th gradually filled. (At this time Brenda was reaching depression status in the Florida Straits. A similar occurrence was observed during the formation of Abby when a cutoff Low in Texas formed on June 2 as Abby reached tropical storm intensity in the western Caribbean.) A weak trough persisted in the area until the 21st when another cutoff Low developed with the trough continuing well southward into Mexico. This trough brought very warm air northward from the Pacific at midtropospheric levels; general high-level warming was also observed late on the 22d over the western Gulf of Mexico and adjacent land areas.

As had been observed in the developmental stages of Abby and Brenda, a high-level anticylcone existed to the southeast of the forming depression with a strong southwesterly jet about 10° of latitude to the north. A weak shear field existed over the southwestern Gulf of Mexico and satellite pictures showed above-normal cloudiness and shower activity for several days prior to the formation of a depression off the Mexican coast on June 22.

A Navy reconnaissance aircraft was dispatched on June 23 and found tropical storm Candy. The plane indicated a central pressure of 1001 mb and 52 mi/hr winds. Before the arrival of the plane, three separate and distinct circulation centers appeared on the Brownsville radar: one 40 mi north-northwest, another 125 mi south-southeast, and a third 70 mi east-southeast. The latter intensified and became Candy while the other two dissipated.

The storm moved towards the north-northwest about 20 mi/hr on the 23d and crossed the Texas coast near Port Aransas during the late afternoon. Movement and continued intensification were well correlated with the RCTM mean charts. A 500-mb ridge building over the eastern Gulf of Mexico as Brenda moved northeastward probably contributed to the north-northwesterly movement into Texas. The acceleration of the storm was associated with a deepening trough over the Rockies.

Over land, Candy weakened slowly and passed over Fort Worth early on the 24th. The remnants accelerated towards the northeast on the 25th ahead of an approaching cold front, encountered cold air on the 26th, and lost tropical characteristics.

The lowest pressure reported was 997 mb at Aransas Pass, on the mainland, about 25 mi north-northeast of Corpus Christi. (The 999 mb shown in fig. 1 was at Austwell.) Winds were in excess of 60 mi/hr for nearly an hour at Austwell, just north of Port Aransas, where the peak gust recorded in the storm was 71 mi/hr. Gale force winds occurred in squalls along the coast from Corpus Christi to Galveston.

Locally heavy rains caused minor flooding from east Texas to Illinois. The highest rainfall recorded was 11 in. at Point Comfort, about 20 mi north-northeast of Austwell. Amounts of 3 to 6 in., and locally 8 in. near the center, were common in southeast Texas. Amounts of 2 to 4 in. accompanied the remains of Candy through eastern Oklahoma, Arkansas, Missouri, and Illinois.

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[6] Results of one hurricane season suggest that a favorable shear field is one in which the velocity of the shear vectors near or over the tropical cyclone is 10 kt or less. Anticyclonic shear is more favorable than cyclonic. Figure 3 is an example of such a field.

In contrast to Abby and later Gladys, the surprisingly heavy rainfall from such a fast-moving storm was responsible for considerable damage to crops along with minor damage to roads and bridges in east Texas. The trough that had persisted over Texas prior to the development of Candy produced 8 to 10 consecutive days of rain culminating with the torrential storm rainfall. The heavy rains caused some flooding on most middle and upper coastal rivers. Significant flood damage was confined to the west and east forks of the San Jacinto River in Harris and Montgomery Counties.

Tides ranged up to 4 ft in San Antonio Bay and Corpus Christi Bay and were 2 to 3 ft elsewhere on the central and upper Texas coasts. Damage was confined mainly to the formation of cuts along Padre Island and coastal oil industry equipment. See table 5 for a summary of meteorological data.

Nineteen tornadoes or funnel clouds were spawned on June 23 and 24. Ten (five funnel clouds) occurred in Texas, five in Arkansas, three in Louisiana, and one in Missouri. The five tornadoes reported in eastern Ohio on the afternoon of the 25th were associated with the extratropical remnant. Only one of the tornadoes caused major destruction. A school in Morning Star, Ark., was nearly demolished causing appreciable monetary loss.

Figure 6, which shows the distribution of tornadoes relative to the storm center and direction of motion, is in good agreement with results published by Hill, Malkin, and Schultz (1966), and others.

Total property losses are conservatively estimated to be about one million dollars with crop damage in east Texas approaching two million dollars. There were no known deaths.

Gale warnings were issued at 1200 CDT on June 23 from Corpus Christi to Galveston, Tex., and they were adequate.

HURRICANE DOLLY, AUGUST 9–16

A tropical wave that emerged from the African coast on July 31 provided the initial impulse from which Dolly eventually developed. This wave traversed the tropical Atlantic in rather typical fashion, reaching the Florida Straits on August 9. An upper cold Low, which had formed north of Hispaniola on the 6th, moved west-northwestward through the 10th, about 5° lat. ahead of the wave, with an anticyclone southeast or over the wave. A strong anticyclone over the Middle Atlantic States caused subsidence and gradual warming over the Southeastern States during this time, with warming over south Florida by the 9th. The upper Low moved into the warming environment with the tropospheric wind shear gradually becoming weak anticyclonic from the weak cyclonic shear of the previous 2 days. A depression formed just off the southeast Florida coast late on the 9th.

TABLE 5.—*Tropical storm Candy, meteorological data, June 22–26, 1968*

Station	County	Date	Pressure (in.)		Wind (mi/hr)				Highest tide (ft)	Date/time	Storm rainfall (in.)
			Low	Time (CST)	Fastest mile	Time	Gusts	Time			
Texas											
Aransas Pass	San Patricio	23	29.45	1645	41 ENE	0645	41 ENE	0645	1.5 AN	...	1.70
Austwell	Aransas	23	29.49	1630	60 SE	1700–1800	71 SE	1700–1800	...	...	8.57
Caldwell	Burleson	...	...	...	...	...	...	...	...	...	7.26
Corpus Christi WBO	Nueces	23	29.61	1640	23 NE	0458	...	...	4.0 MLW	...	2.11
Dime Box	Lee	...	...	...	...	...	...	...	...	...	7.20
Freeport	Brazoria	23	29.70	2000	...	...	44 SSE	1440–1610	...	...	4.41
Galveston WBO	Galveston	24	...	...	37 SW	...	55 S	0442	2.7 MSL	24/0550	2.55
Ganado	Jackson	...	...	...	...	...	...	...	...	...	7.80
Goliad	Goliad	23	29.69	1600	...	...	60* NW	1600–1900	...	...	2.16
Gonzales	Gonzales	23	29.70	...	...	...	50 SE	0230	...	...	...
Houston WBO	Harris	24	29.78	0155	29 SSE	0230	48 SSE	0100	...	...	2.72
Long Mott	Calhoun	23	...	...	60	...	65*	1800	...	...	10.25
McFaddin	Victoria	23	...	...	60* SE–NW	...	65*	...	...	...	...
Moscow	Polk	...	...	...	...	...	...	...	...	...	8.04
Palacios	Matagorda	23	29.67	1859	...	...	58 E	1606	4.5 AN	...	4.34
Point Comfort	Calhoun	23	29.65	1900	...	...	58 SE	1900	...	...	10.98
Port Lavaca	Calhoun	23	29.62	1630	45 SSE	1600	53 SSE	1630	3.0 MSL	23/1800	9.78
Port O'Connor	Calhoun	23	...	...	...	...	65	...	...	...	...
Rockport	Aransas	23	29.54	1630	29 ENE	1030	40 ENE	1030	2.4 AN	23/2030	1.68
Speaks	Lavaca	...	...	...	...	...	...	...	...	...	6.40
Victoria WBO	Victoria	23	29.52	1759	...	...	56 ESE	1747	...	...	3.10
Yoakum	Lavaca	23	...	...	...	...	40* NE	...	...	...	...

*Estimated; AN, above normal; MSL, mean sea level; MLW, mean low water.

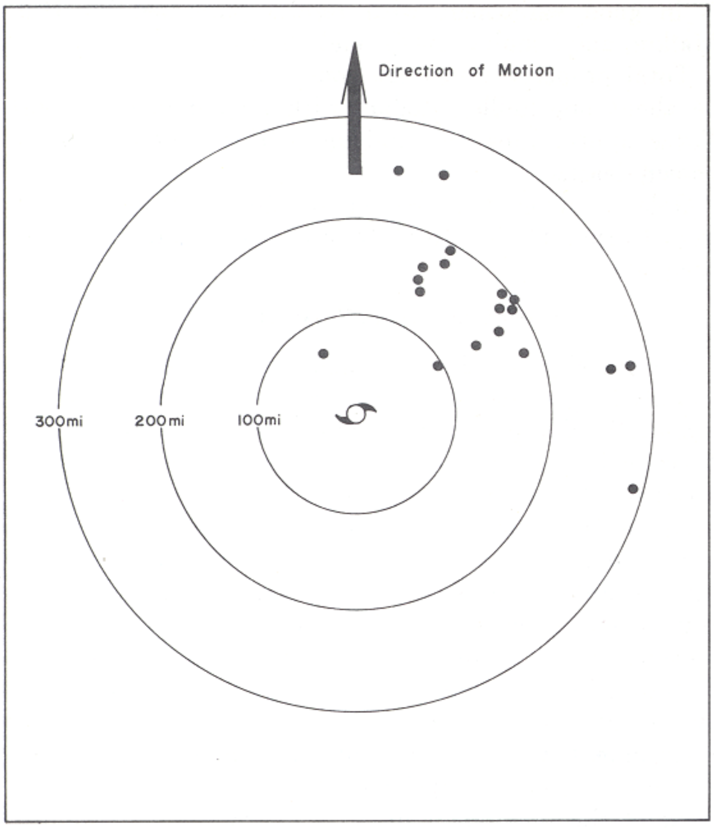

FIGURE 6.—Tornadoes in tropical storm Candy located relative to the direction of motion of the center.

Small-craft warnings were issued along the Florida coast from Cape Kennedy to Key West on the afternoon of the 9th, and a bulletin was issued by the National Hurricane Center cautioning against heavy showers and squalls.

The depression moved inland just north of Fort Lauderdale during the night and back out to sea during the afternoon of August 10, ahead of a trough in the westerlies approaching the eastern United States. Squalls with gusts to 30 mi/hr accompanied the depression as it hugged the coast.

Although the shear field remained favorable for the next 2 days, the depression showed no significant intensification. This can be attributed primarily to the approach of the upper trough and accompanying accelerations in the lower tropospheric winds, which effectively destroyed most of the inflow.

The depression moved northeastward, moving parallel to and about 125 mi off the Georgia and Carolina coasts. Weather Bureau radars at Daytona Beach, Charleston, and Hatteras had the depression under surveillance during this time.

At this stage, the future of the depression depended on whether or not it could avoid absorption by a cold front approaching from the northwest. It was still moving through a zone of anticyclonic low tropospheric wind shear and over warm waters, making the prospect for intensification favorable if the circulation remained detached from the frontal zone.

Satellite photographs and Navy reconnaissance reports on August 12 revealed that this was the case, and tropical storm Dolly was christened during the morning of that day. Low-level inflow had been generated again late on the 11th as environmental pressures rose behind the passing upper trough.

The storm was embedded in a well-established zonal flow pattern, moving east-northeastward about 20 mi/hr. This course and speed were to continue with only minor fluctuations throughout the life history of the storm, carrying it some 2,600 mi along a remarkably uniform track.

Such uniformity did not apply to the storm's intensity, however. Rapid deepening occurred on August 12 with the central pressure falling to 994 mb by 0900 EDT, although highest winds were only about 50 mi/hr as the circulation remained somewhat poorly organized due to the frontal effects. Dolly attained hurricane force late the same day but was able to maintain it for only about 24 hr, having been cut off somewhat from the tropical air mass by the Atlantic ridge. After being downgraded to a tropical storm for about 36 hr, Dolly once again became a hurricane. By this time Dolly was nearly at lat. 40°N, which is probably the most northerly point at which a tropical storm ever became a hurricane. At such northerly latitude, baroclinic deepening would seem to be a logical explanation. A careful examination of the surface data beginning at 00 GMT on the 14th, shows dewpoint temperatures in the southwesterly flow into the storm as high as 77°F (25°C) from near the storm southwestward almost to Bermuda. Another contributing feature could be a break in the Atlantic ridge allowing moist air also to come up around the Azores high-pressure cell. An interesting change also occurred at 200 mb at Ship Easy (35°N, 48°W) where the wind changed from northwest at 45 kt at 00 GMT on the 14th to southwest at 10 kt at 12 GMT on the 14th, with a weak anticyclone southeast of the storm. Shear charts were not available on the 14th, but synoptic patterns certainly suggest conditions similar to those observed during intensification at lower latitudes. These conditions seemed to continue until the 16th.

Dolly finally became extratropical some 300 mi north of the Azores on August 16. The hurricane posed no threat to any land areas and caused no injuries or damage. She attained her greatest force on August 14, when an Air Force aircraft measured winds of 81 mi/hr at the 700-mb flight level and a central pressure of 992 mb. Only marine advices were issued other than the small-craft warnings in Florida.

TROPICAL STORM EDNA, SEPTEMBER 10–19

The disturbance which was to become tropical storm Edna made its appearance over the Atlantic when it moved off the African coast late on September 10 and was almost immediately classified a tropical depression. A weak high-level trough off the African west coast on the 10th together with a warm anticyclone to the east-northeast of the disturbance resulted in a favorable weak shear field in the vicinity of Dakar, Senegal, as the incipient depression moved off the coast.

ESSA–7 satellite pictures on September 11 indicated it was a well-developed depression. No appreciable change in organization was noted through the 13th, although some decrease in cloud brightness was observed on the 12th and 13th. Satellite views on successive days suggested some intensification.

The existence of a tropical storm was confirmed by the ship *Sal Mela* (CPHN), when it reported, at 0300 GMT on September 15, experiencing winds of 69 mi/hr from the east-northeast while located about 1,900 mi east of Puerto Rico. Subsequently, the ship *Mormac Elm* (KPSG) reported winds of about 45 to 50 mi/hr at 1800 GMT on September 15 and 0000 GMT, September 16. The reports from these two ships were most helpful in establishing the existence and location of the storm.

Four Air Force and Navy investigative flights were flown into Edna on the following 4 days. Only on the first flight was there clear evidence of a closed circulation. Subsequent satellite pictures also suggested a gradual decrease in intensity. On September 18, Edna was downgraded to a tropical depression, and on the 19th it was downgraded further to an easterly wave. Satellite pictures and ship reports indicated the possibility of a weak vorticity center turning northwestward on the 19th while the wave continued on its westerly course about 400 mi east of the Leeward Islands.

When Edna first reached tropical storm intensity, it was under a high-level anticyclone and seemed to enjoy an environment favorable for intensification. In its westward movement, however, it encountered an upper level cold trough that had remained nearly stationary as the storm approached, and the storm gradually weakened.

The maximum wind known to have been associated with Edna was 69 mi/hr reported by the aforementioned ship, the *Sal Mela*. The lowest pressure achieved by Edna was estimated to have been 1005 mb and is based on ship and reconnaissance reports.

Only marine advices were issued, and there were no known injuries or damage at sea.

TROPICAL STORM FRANCES, SEPTEMBER 23–30

Events in the upper troposphere controlled the destiny of tropical storm Frances. A circulation developed at the surface east of the Bahamas on September 23. Convection was enhanced by the presence of a midtropospheric trough and the depression gradually intensified.

A moderate 500-mb trough moving off the mainland late on the 25th turned Frances northeastward. Best indications are that the shear field became increasingly favorable in a manner quite similar to that observed in Dolly, that is, a change from weak cyclonic to weak anticyclonic. As in Dolly, mean layer speeds tended to be better than direction of motion.

On September 26, a Navy reconnaissance aircraft found a warm core, a minimum pressure of 1003 mb, and 52 mi/hr winds. Thickness charts indicated a warm pool over the disturbance 24 hr before tropical storm formation. Baroclinic effects from the approaching upper trough probably aided intensification.

The motion of Frances was dictated by a second upper Low, which formed near Ship Easy (35°N, 48°W) on the same day that Frances developed. The steering current provided by this Low carried Frances almost due east.

The close proximity of the second Low, which also reflected downward into the surface pressure pattern, undoubtedly prohibited further intensification of Frances and contributed significantly to her short life. The hostile environment provided by the cold Low proved to be an insurmountable obstacle. A ship late on the 28th found Frances had weakened and was no longer a storm.

With the demise of Frances, 1968 became the 12th season since 1886 when not one tropical cyclone attained hurricane intensity during September. With the occurrence of Gladys in October, the 1968 season total of seven storms (three of hurricane intensity with one October hurricane) agreed quite well with the average for the other 11 inactive Septembers, which had five storms, two of hurricane intensity with one in October.

An Air Force reconnaissance aircraft recorded the lowest central pressure of 1001 mb and 59-mi/hr winds on September 28, the maximum observed. There were no fatalities nor damages reported, and only marine advices issued.

HURRICANE GLADYS, OCTOBER 13–21

The 1968 hurricane season had been relatively quiet until Gladys formed in the Caribbean on October 15, even though an unusually large number of disturbances had been tracked across the tropical Atlantic. The formation process was a complex one, involving the interaction of three separate disturbances.

A tropical wave passed through the Lesser Antilles on October 6 and traversed the Caribbean with no appreciable intensification during the next 4 days. On October 11, a depression formed on the wave near Swan Island. On the following day satellite photographs revealed that a disturbance had developed south of Jamaica. On October 13, still a third disturbed area formed on the ITC near San Andres. Thus, the western Caribbean was the scene of a broad zone of low pressure and extensive shower activity. It was this third system which, after drifting slowly north-northwestward for 48 hr, developed into Gladys. The shear chart had shown a favorable trend during the preceding 72 hr prior to the 13th, changing from a weak cyclonic pattern to weak anticyclonic.

A Navy investigative flight found winds of 52 mi/hr and a surface pressure of 999 mb on the morning of October 15. Upon receipt of these data, tropical storm Gladys was named.

The storm was forecast on a slow northward course and, with further intensification expected, the threat to Florida's Keys and lower west coast increased. Gale warnings were hoisted on the keys, and a hurricane watch was issued for the keys northward to Clearwater at midnight.

Gladys became a hurricane shortly before crossing the south coast of western Cuba and continued to strengthen while crossing this narrow but mountainous part of the island. Winds gusted to 80 mi/hr at Gerona on the south coast, and Havana experienced sustained gale force winds for several hours. Reports from radio Havana told of serious flashfloods with heavy damage to crops and industrial installations. The rich tobacco crop was virtually wiped out. One death in Cuba was attributed to Gladys.

At this time, the tropospheric mean flow was characterized by a deep trough over the Great Plains with a weak anticyclone between the east coast and Bermuda. Thus, Gladys was embedded in a light southerly environmental flow. It became evident that the hurricane would make landfall somewhere along the west-central coast, with the location dependent upon the eastward progression of the Plains trough.

Hurricane warnings were in effect in the lower keys and along the southwest Florida coast, and northward to Cedar Key.

Gladys emerged into the Florida Straits and continued slowly northward, passing just to the west of Dry Tortugas. Highest winds measured on the island were 64 mi/hr with gusts to 86 mi/hr; the pressure fell to 997 mb. The only wind of hurricane force recorded elsewhere in the keys was an 87-mi/hr gust at Plantation Key. Only minor damage was reported.

Gladys took a temporary jog to the north-northwest as it passed abeam of the lower west coast, while radars at Tampa, Key West, and Miami indicated that the eye was undergoing some internal reorganization. This tended to minimize the effects to extreme south Florida—thus, no significant damage. This turn to the north-northwest may have been associated with the development of a midlevel Low over Alabama on the 15th which drifted southwestward to southern Mississippi on the 16th. This Low opened up on the 17th as the Plains trough reached east Texas. Warming in the middle and upper troposphere was also taking place over northwestern Florida at this time.

The hurricane took its expected turn toward the east on October 18, but not before hurricane warnings were extended northward to Cedar Key with a watch to St. Marks at noon. This precaution was necessary because each hour the turn did not occur increased the threat farther to the north.

Shear fields were favorable for intensification throughout the lifetime of the storm, and especially while Gladys was in the Gulf of Mexico. Gladys maintained only minimum hurricane intensity during its trek through the southeast Gulf of Mexico, however, mainly because a large portion of the circulation was over land. Tropospheric mean layer steering of Gladys was not as good as it had been in most earlier storms.

The center passed inland between Bayport and Crystal River, very near Homosassa, about midnight on Saturday, October 19. Gladys began to accelerate in advance of the upper trough, crossing the peninsula at about 15 mi/hr, passing just north of Ocala, and back out to sea near St. Augustine around daybreak.

Sustained hurricane force winds were confined to the west coastal area from Clearwater to Bayport and maximum gusts were in the 100 mi/hr range. Highest tides were estimated at 6½ ft, causing considerable beach erosion and flooding of coastal areas. Extensive wind damage also resulted, with mobile homes the main casualties. Three motorists died while trying to escape the storm, two from heart attacks and the other in a submerged automobile. As Gladys crossed the State, about 85 percent of the citrus crop was affected to varying degrees. Almost all of the $6.7 million damage that occurred in Florida, however, was structural. Winds on the east coast were well below hurricane force, and damage was minor. Rainfall amounts were generally less than 6 in., and flooding from rain was not a serious problem. A 2-day total of 7.79 in. at Homestead Air Force Base is the greatest amount reported. Over 12 in. fell at Cape Kennedy between October 14 and 18, but not all of this can be attributed directly to Gladys. See table 6 for a summary of meteorological data.

Gladys moved from the upper east coast of Florida to the northeast about 25 mi/hr in advance of the upper trough, skirting the coasts of Georgia and the Carolinas. Hurricane warnings, which had been issued north of Charleston to Hatteras, were gradually narrowed to the Hatteras area as the storm continued to parallel the coast, and the highest winds became confined to the east portion of the storm. Radar reports indicated that the track was somewhat erratic, reminiscent of the cycloidal paths of some past hurricanes.

The center passed very near Cape Hatteras early on October 20 while continuing to accelerate northeastward. Damage along the Carolina coast was minor. Gusts of hurricane force were confined to the Cape Hatteras area. Tides ranged from 2 to 4 ft above normal as the hurricane passed abeam. The damage was more than offset by beneficial rains, which broke the worst drought since 1932 in North Carolina.[7]

Gladys turned north-northeastward in advance of an intensifying trough in the Great Lakes and gradually became extratropical as it merged with a cold front off the coast of Nova Scotia on October 21. The remnants passed over Cape Breton Island as a deep low pressure area, which produced rainfalls of 2 to 4 in. The benefits resulting from these rains overcompensated for the minor damage that occurred; however, one death in Nova Scotia was attributed to the storm.

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[7] See the crop moisture index maps in the *Weekly Weather and Crop Bulletin*, October 28 and November 4, by the Environmental Data Service, ESSA (1968).

TABLE 6.—*Hurricane Gladys, meteorological data, Oct. 13–21, 1968*

Station	Date	Pressure (in.)		Wind (mi/hr)				Highest tide (ft)	Date/time	Storm rainfall (in.)
		Low	Date/time (EST)	Fastest mile	Date/time	Gusts	Date/time			
Cuba										
Havana	16			58						
Isle of Pines										8. 49+
Gerona	16					80				
Florida										
Bayport	18			84 SE**						
Blind Pass				70		96 SSE				
Brooksville	19	29. 39				68				6. 28
Cedar Key	19	29. 45	0130	35 NNE	18/2350	48		1.0 AN	18/1300	1. 10
Coquina Key	18	29. 53		55 S		80 S		4.0 AN		4. 32
Clearwater Beach	18	29. 62	2200	90* SSW	2100	100* SSW	2100	4.0 AN	18/2300	2. 70
Crescent City	19			40* SE	0430	65* SE	0430			5. 31
Daytona Beach WBO	19	29. 56	0615	35 SSW	0625	63 SSW	0625	1.0 AN		6. 57
Dry Tortugas	16	29. 44		64 E		86 E				
Egmont Key	18	29. 54	1720			59				
Flamingo	17	29. 76				59		1.0 AN		2. 56
Fort Myers WBO	17	29. 68	17/1400	30 SE	16/1430	37 SE	16/1430	2.5 AN		6. 09
Forty Mile Bend	17	29. 88				44				3. 19
Homestead AFB										7. 79
Homosassa	18	29. 59				100* NE		1.0 AN		
Inglis	19			94	0130					
Jacksonville WBO	19	29. 56	0637	39 SE	0305			1.3 AN		4. 26
Jacksonville Beach	19	29. 49	0700	56 ESE	0640	74 ESE	0640	2.5 AN		5. 42
Key West WBO	16	29. 62	17/0230	49 SE	16/2112	55 SE	16/2114	0.6 AN		2. 95
Lakeland WBO	18	29. 66	2235	33 SE	2153	48 SE				2. 84
Miami Beach	17					63		2.7 MLW		2. 39
Miami NHC	17	29. 74				58				4. 32
Miami WBAS	17	29. 74				53				3. 79
New Port Richey	18–19			67		85				
North Key Largo	16–17	29. 74				47				
Ocala	19			65 W	0200	85 W	0300			5. 25
Orlando WBO	19	29. 66		38		40				3. 40
Plantation Key	16–17	29. 71				87				4. 14
Ponte Vedra Beach	19	29. 60	19/0700					2.5 AN		2. 60
Port Everglades	17	29. 79				63				2. 15
St. Augustine	19	29. 32	0630	60* SE	0600	70* SE	0600			3. 55
St. Petersburg	18			60 SW	18/2100	75 SW	2100	5.0 AN	18/2359	2. 60
S. Melbourne Beach	17	29. 77				47				5. 05
Tampa WBO	18	29. 52	1955	37 SSE	1855	55 SSE	1855			3. 12
Tarpon Springs	18					90*		4.5 AN		5. 41
Tavernier						57		0.5 AN		2. 31
Treasure Island	18	29. 68	1900	52 SE	2000	87 SE	2200	3.0 MSL	18/2300	3. 05
W. Palm Beach	17	29. 73	1558	35 SE	0258	45 SE	0258			3. 73
South Carolina										
Charleston	19	29. 62	1541	23 N	1838	32 N	1834	0.8 AN		6. 41
North Carolina										
Atlantic Beach	20	29. 32	0145			69 NW	0225			6. 65
Cape Hatteras CG	20					85				
Cape Hatteras WBO	20	29. 17		51		79		4.0 AN		3. 03
Cape Lookout	20					90				
Carolina Beach	20	29. 53	2215			53	2215			
Nags Head	20			63**						
Okracoke CG	20					85				
Topsail Beach	20	29. 52	0100			63 N	19/2330			
Wilmington	20	29. 58	20/0137	35 N	19/2327	39 N	19/2255	5.0 AN		2. 52
Virginia										
Norfolk	20	29. 71				46		0.8 AN		2. 91

*Estimated.

**Before anemometer cups blew away; AN, above normal; MLW, mean low water; MSL, mean sea level.

The central pressure in Gladys reached 977 mb shortly before the storm crossed the Florida west coast around midnight of the 19th; this value is about the same as that recorded by Air Force aircraft as the storm was becoming extratropical.

There were reports of two small tornadoes in Florida at Boca Raton and Palatka.

Residents of the coastal areas of the Carolinas were indeed fortunate that the hurricane maintained a distance of some 50 mi from shore while paralleling the coastline,

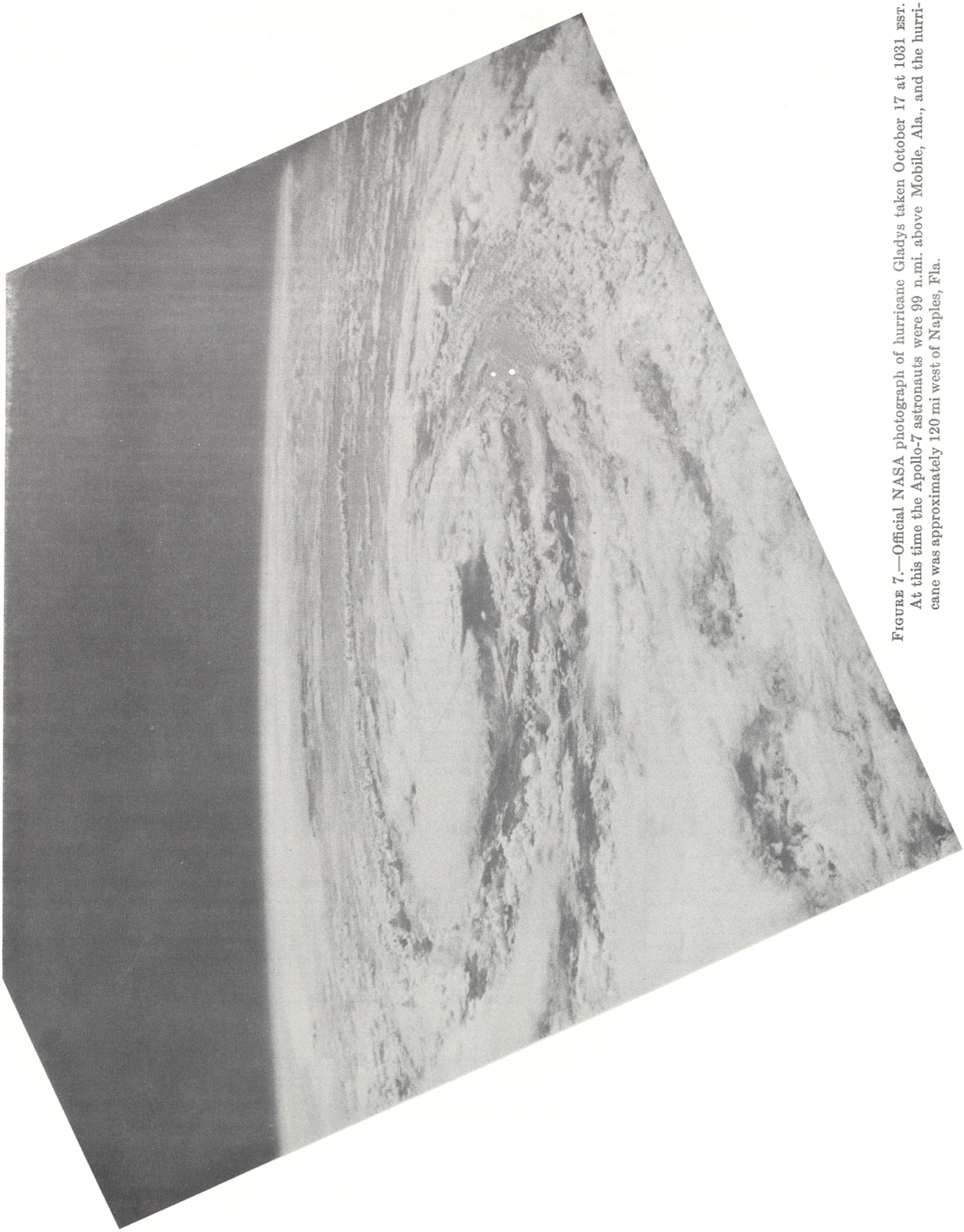

FIGURE 7.—Official NASA photograph of hurricane Gladys taken October 17 at 1031 EST. At this time the Apollo-7 astronauts were 99 n.mi. above Mobile, Ala., and the hurricane was approximately 120 mi west of Naples, Fla.

since highest winds near the center were 80 to 100 mi/hr at this time, and any turning of the storm toward the coast would have greatly increased the amount and extent of the damage.

Figure 7, NASA photograph, is a striking view of Gladys when the hurricane was near the Florida west coast. The photograph was taken by the Apollo-7 astronauts on October 17.

There was a total of five deaths attributed to Gladys, three in Florida, and one each in Cuba and Nova Scotia. Property damage of $6.7 million occurred almost exclusively in Florida.

SIGNIFICANT DEPRESSIONS

There were three tropical depressions of note during the 1968 season, other than those that became named storms. A tropical depression that formed off the Carolina coast on the evening of September 9 and moved rapidly north-northeastward, crossing Long Island, N.Y., early on the 11th, may have briefly been of storm intensity as it crossed. Wagner (1968) has written a short paper dealing with the interaction of tropical and extratropical systems.

The tropical depression that formed in the northeast Gulf of Mexico on August 28 moved slowly across the Florida peninsula by the 31st. It produced over 15 in. of rain in the Jacksonville area, which caused extensive local flooding. A tornado 10 mi north of Daytona Beach early on the 30th destroyed a motel and several houses.

A late season tropical depression formed on November 24 north of Mayaguana in the southeastern Bahamas and passed near Bermuda about midafternoon of the 25th. It may also have briefly attained tropical storm intensity before being absorbed in a large rapidly deepening extratropical storm to the northwest.

ACKNOWLEDGMENTS

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REFERENCES

Andrews, J. F., "The Weather and Circulation of August 1968—Sharp Contrasts in Temperature and an Unusually Strong Summer Index Cycle," *Monthly Weather Review*, Vol. 96, No. 11, Nov. **1968**, pp. 826–832.

Ballenzweig, E. M., "Seasonal Variation in the Frequency of North Atlantic Tropical Cyclones Related to the General Circulation," *National Hurricane Research Project Report* No. 9, U.S. Weather Bureau, Washington, D.C., July **1957**, 33 pp.

Cry, G. W., "Tropical Cyclones of the North Atlantic Ocean—Tracks and Frequencies of Hurricanes and Tropical Storms, 1871–1963," *Technical Paper* No. 55, U.S. Weather Bureau, Washington, D.C., **1965**, 148 pp.

Dunn, G. E., and Miller, B. I., *Atlantic Hurricanes*, Louisiana State University Press, Baton Rouge, **1960**, 326 pp.

Dunwoody, H. H. C. (Editor), "Areas of Low Pressure," *Monthly Weather Review*, Vol. XIV, No. 6, June **1886**, pp. 148–151, (see p. 149).

Environmental Data Service, ESSA, *Weekly Weather and Crop Bulletin*, Vol. 55, Nos. 24–25 and 44–45, June 10 and 17, Oct. 28, and Nov. 4, **1968**, pp. 1–8.

Gray, W. M., "Global View of the Origin of Tropical Disturbances and Storms," *Atmospheric Science Paper* No. 114, Colorado State University, Fort Collins, Oct. **1967**, 105 pp., (see p. 89).

Green, R. A., "The Weather and Circulation of June 1968—Unusual Tropical Activity," *Monthly Weather Review*, Vol. 96, No. 9, Sept. **1968**, pp. 662–667.

Hill, E. L., Malkin, W., and Schultz, W. A., Jr., "Tornadoes Associated With Cyclones of Tropical Origin—Practical Features," *Journal of Applied Meteorology*, Vol. 5, No. 6, Dec. **1966**, pp. 745–763.

Malkus, J. S., and Williams, R. T., "On the Interaction Between Severe Storms and Large Cumulus Clouds," *Meteorological Monographs*, Vol. 5, No. 27, Sept. **1963**, pp. 59–64.

Posey, J. W., "The Weather and Circulation of September 1968—Cool Over Much of the Nation With Progression of the Long Waves," *Monthly Weather Review*, Vol. 96, No. 12, Dec. **1968**, pp. 893–898.

Riehl, H., "On the Origin and Possible Modification of Hurricanes," *Science*, Vol. 141, No. 3585, Sept. **1963**, pp. 1001–1010.

Riehl, H., Baer, F., and Veigas, K., "Hurricane Formation in the Gulf of Mexico," *Third Technical Report*, prepared for the American Petroleum Institute (Panel on Hurricanes), New York, Oct. **1962**, 27 pp. (see p. 7).

Riehl, J., and Malkus, J., "Some Aspects of Hurricane Daisy, 1958," *Tellus*, Vol. 13, No. 2, Sept. **1961**, pp. 181–213, (see p. 206).

Simpson, R. H., Frank, N., Shideler, D., and Johnson, H. M., "Atlantic Tropical Disturbances of 1968," *Monthly Weather Review*, Vol. 97, No. 3, Mar. **1969**, pp. 240–255.

Simpson, R. H., and Riehl, H., "Mid-Tropospheric Ventilation as a Constraint on Hurricane Development and Maintenance," paper presented at the First Technical Conference on Hurricanes, Miami Beach, Fla., Nov. 19–22, **1958**.

Stark, L. P., "The Weather and Circulation of May 1968—Cool Weather With Widespread Blocking," *Monthly Weather Review*, Vol. 96, No. 8, Aug. **1968**, pp. 577–583.

Tannehill, I. R., *Hurricanes, Their Nature and History, Particularly Those of the West Indies and the Southern Coasts of the United States*, 9th Revised Edition, Princeton University Press, N.J., **1956**, 308 pp., (see p. 159).

Wagner, A. J., "The Weather and Circulation of July 1968—Rather Changeable but Predominantly Cool," *Monthly Weather Review*, Vol. 96, No. 10, Oct. **1968**, pp. 746–752.

Wagner, A. J., "Picture of the Month—Illustrating the Merger of Tropical and Extratropical Systems," *Monthly Weather Review*, Vol. 96, No. 12, Dec. **1968**, pp. 889–892.

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ATLANTIC TROPICAL DISTURBANCES OF 1968

R. H. SIMPSON, NEIL FRANK, DAVID SHIDELER, and H. M. JOHNSON

National Hurricane Center, Weather Bureau, ESSA, Miami, Fla.

1. INTRODUCTION

This is the second of an annual series of reports on Atlantic tropical disturbances prepared by the National Hurricane Center (NHC), Miami, Fla. Simpson et al. (1968) defined the tropical models used by the National Hurricane Center. These models and definitions continue to apply and will not be restated here. The primary goal and emphasis in the NHC analyses are the detection and tracking of the antecedent conditions, or seedling disturbances, from which hurricanes and severe storms grow. In the absence of conventional data from the tropical oceans the meteorological satellite has been the primary tool of detection and for tracking the significant migratory rain disturbances and distinguishing them from minor or transitory convective systems. It has become the means of "separating the wheat from the chaff" and significantly has shown that often the most innocuous-appearing cloud systems in a satellite mosaic may be the most important ones from the viewpoint of severe storm development. Nevertheless, the progress in understanding of the structure and dynamics of these seedlings will continue to be slow until the satellite observations can be supplemented by some direct probing of the circulation which bears the disturbed weather. This year the first research aircraft flight[1] was made across the tropical Atlantic to investigate disturbances that were under satellite surveillance. It is hoped that this program can be extended and expanded in the next few years, to enhance the value of satellite observations.

In the absence of detailed synoptic circulation data, one must look to some form of dynamic climatology to gain a clearer understanding of the circulation instabilities which set the stage for the intensification of the disturbances. The NHC is striving to develop such a climatology of disturbances and will report the important results in this annual series of articles.

2. CENSUS OF 1968 TROPICAL SYSTEMS

The year 1968 was an illustrious one for tropical disturbances for two reasons. First, there appears to have been an abnormally large number of waves and other disturbances. While an accurate climatology of tropical disturbances has not been possible in the past, some forecasters who have given professional attention to this problem for several decades indicate there seem to have been more waves in the easterlies this season than in any previous year since the 1940's.[2] Secondly, in spite of the abundance of disturbances, 1968 was a minimal year for hurricane activity in the Atlantic. A discussion of the 1968 hurricane season by Sugg and Hebert (1969) appears in another article in this issue.

Table 1 shows that there were 110 tropical systems in 1968, from which evolved 22 depressions and seven tropical storms. Four of the storms became hurricanes. Fifty-seven of the 110 systems were tropical waves and ITC disturbances whose origin was in Africa. Twenty-five disturbances first appeared as a part of the intertropical confluence (ITC). This census does not include many sprawling, elongated, weak and transitory convective areas associated with the ITC or those of subsynoptic scale, but is confined to those of discrete and persistent dimensions, usually 100–300 n.mi. in diameter, with apparently intense convection.

Figures 1–3 and table 1 summarize the tropical systems of 1968. Table 1 shows the number of systems which formed within various geographical areas. This information is displayed graphically in figure 1. Figure 2 shows the tracks of depressions and certain disturbances. Disturbances that remained a part of the intertropical confluence are not included since experience has shown that these do not develop until or unless they break away and become imbedded in the trade winds. Nevertheless, they are reflected in the census summary of figure 1. A tropical disturbance has been defined (Simpson et al., 1968) as a migratory tropical convective system, which nominally brings rain to a synoptic-scale area 100–300 mi in diameter and which has been tracked for at least 24 hr. It is the classification of tropical weather systems that includes in ascending order of intensity the tropical depression, tropical storm, and hurricane. While these criteria are

TABLE 1.—*The number of tropical systems which formed in various geographical areas in 1968 (upper troposphere cold Lows not included)*

System type	AREAS OF FORMATION					Total independent systems
	Africa	Tropical Atlantic	Subtropical Atlantic	Caribbean	Gulf	
1 Waves	39	18	0	0	0	57
2 ITC disturbance	17	1	....	7	....	25
3 Disturbance (other)	0	....	6	5	0	11
4 Depressions	1	(4)	9 (1)	4	3	17 (5)
5 Named Storms	0	(1)	(3)	(2)	(1)	0 (7)
Total	....	....	....	....	....	110

Numbers in parentheses indicate those systems which were counted in a weaker stage.

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[1] ESSA's Research Flight Facility conducted this flight on behalf of the National Hurricane Center under the direction of the Environmental Research Laboratory.

[2] Private communication from Dunn (1969).

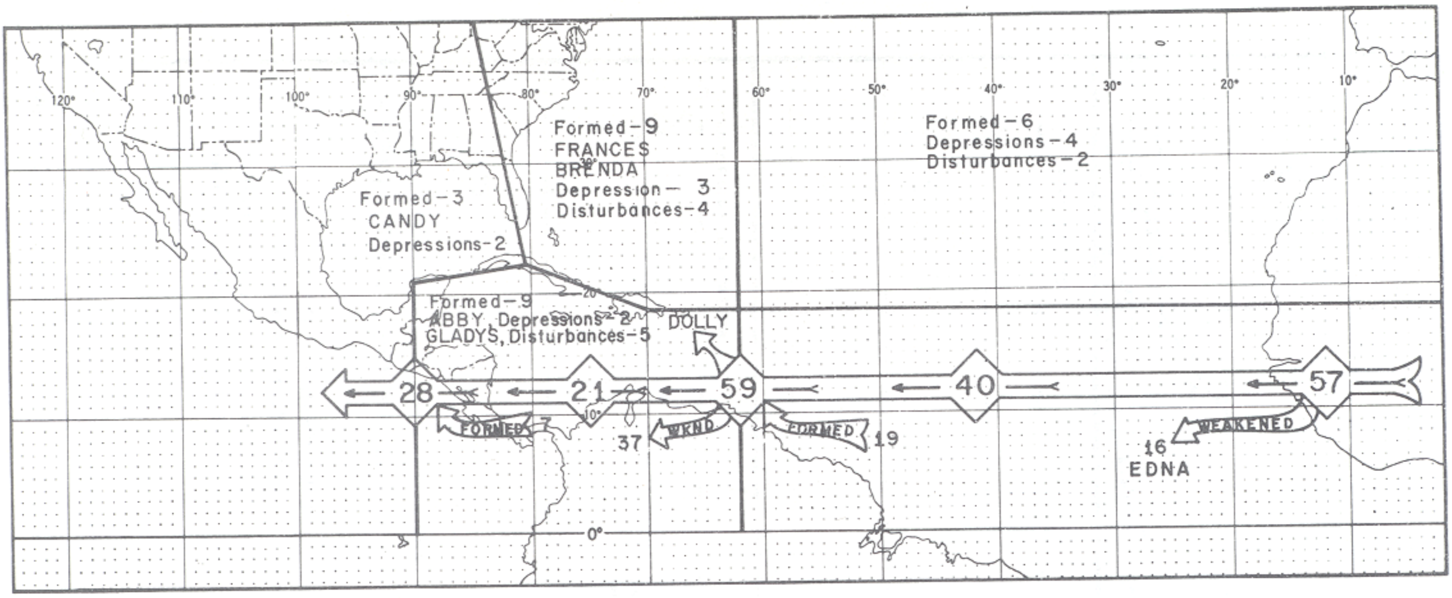


Figure 1.—Summary of the synoptic-scale tropical systems observed from western Africa to the eastern Pacific during the hurricane season June–November 1968. The number of systems passing five areas, the West Coast of Africa, the mid-Atlantic Ocean, the Lesser Antilles the Caribbean, and the Far Eastern Pacific Ocean, are indicated by the large numerals. The line along 18.5°N separates low-latitude Tropics from high-latitude Tropics and subtropics (see text).

used operationally at the National Hurricane Center, this census, in an attempt to eliminate the more transitory systems, counted only those disturbances which could be identified on at least three successive satellite mosaics (a 48-hr period).

Figure 3 presents graphically the record of the tropical systems which emerged from Africa or evolved over the tropical Atlantic. It includes a time cross-section for Dakar including the 700-mb geopotential for Dakar, and a similar time cross-section for Barbados. The wind shifts associated with the passage of waves are shown at the standard levels. The vertical length of the trough lines corresponds to the depth of the layer influenced by the waves.

The agreement between the 700-mb geopotential minima and the wind shift line of these waves is good except at Dakar in June and October. During June and October the upper troposphere flow here was westerly and dominated by a persistent trough. Carlson (1969*a*) found similar substantial responses in the surface pressure to the passage of tropical waves.

At Dakar the first wave of the season occurred on June 12 and the last on October 20. Easterly wave activity over western Africa reaches a maximum in the months from July through September. This is precisely the period of time when the upper tropospheric easterly jet was well established. When in October the high-level flow reversed, wave activity ceased.

Figure 4 shows the history of three disturbances which formed over subtropical portions of the western Atlantic in early July 1968. Disturbance A, with a large, bright, almost circular cloud system near 30°N and 65°W on July 4, was one of the more deceptive disturbances viewed in 1968. It apparently formed in situ, and the initial mosaic indicated considerable organization of convective cells suggesting the possibility that a storm might be developing. However, the data show that the surface pressure under this cloud was 1023 mb, and there was no evidence of cyclonic flow in the lower tropospheric wind field, nor was there evidence of a cold Low in the upper troposphere.

Two other disturbances are shown in figure 4. Disturbance B developed southeast of Disturbance A on the 5th, and Disturbance C formed within a weak stationary trough which had persisted off the southeast U.S. coast for several days.

A typical movement of an ITC disturbance in the Atlantic is shown in figure 5. This system appeared near the West Africa coast on August 19. The small, bright cloud mass can be followed easily across the Atlantic in this figure.

Of the 57 tropical systems which emanated from Africa (fig. 1), 40 maintained their identity as far west as the Lesser Antilles. Of the 40, 29 were tropical waves of the "inverted V" type, and 11 were disturbances on the ITC. Nineteen others, first detected over the tropical Atlantic, also migrated as far west as Barbados so that a total of 59 systems moved into the Caribbean from the open Atlantic. It is remarkable (and we believe characteristic) that less than half the wave disturbances which moved into the Caribbean survived the transit of this sea. There is a rationale which may be cited in support of this observation. First, the midlatitude westerlies intrude into the Caribbean and displace or reduce the depth of the easterlies more frequently than in the tropical Atlantic east of the Caribbean. Secondly, the upper tropospheric trough which extends in a narrow zone southwestward from temperate latitudes into the central Caribbean, appears to serve as a damper on convective systems approaching from the east. Experience has repeatedly shown this to be true in the case of tropical cyclones. This may be due to pronounced advection of

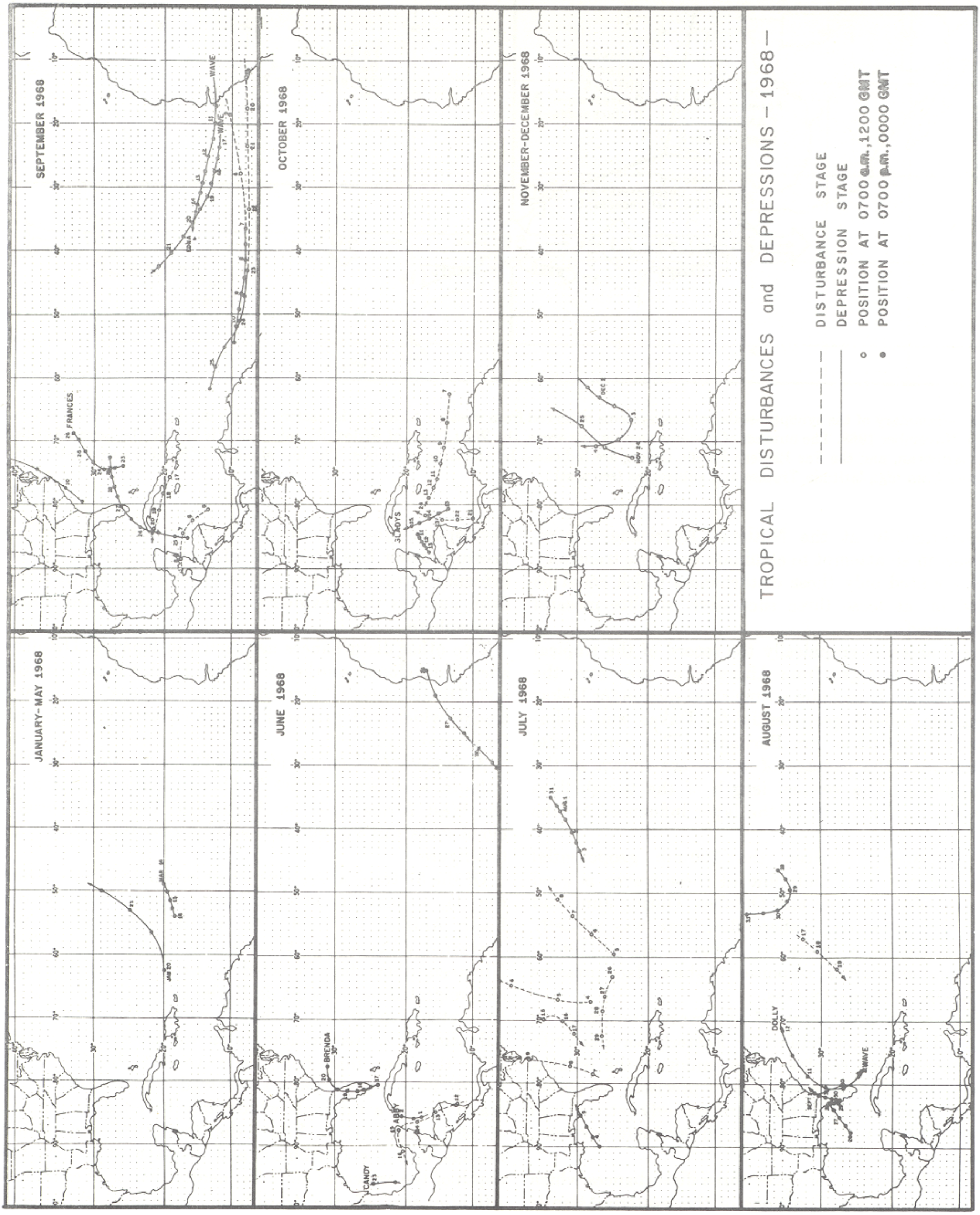


FIGURE 2.—Tracks of all tropical depressions and of the tropical disturbances that originated away from the ITC during 1968 over the North Atlantic Ocean.

shear vorticity in the high troposphere which inhibits the divergent outflow of these systems. "Seedling" disturbances even in the absence of an orgainzed outflow are apparently subdued similarly by a high troposphere trough or shear line.

The 21 wave disturbances which survived the trek across the Caribbean were joined by seven others which formed in the Caribbean (mainly in the western portion) with the result that a total of 28 Atlantic disturbances extended their influence across Central America into the eastern Pacific where a number of them triggered the formation of eastern Pacific hurricanes.

The average westward speed of the 40 systems which originated in Africa was 15.5 kt; the range was 8.5 to 25.0 kt. The average speed of the waves was somewhat faster than that of the ITC disturbances (16 kt and 14 kt, respectively).

Nine depressions formed over subtropical portions of the north Atlantic. Two of these intensified and became named storms (Brenda and Frances). Two others nearly became tropical storms (see Sugg and Hebert, 1969). One formed off the South Carolina coast on September 9, moved northward skirting eastern North Carolina, and crossed Long Island during the predawn hours of the 11th. It had a central pressure slightly below 1000 mb and winds to gale force. The other near miss was initiated over the southeastern Bahama Islands on November 24. This depression raced rapidly northeastward, but was completely engulfed by a tremendous baroclinic development as it approached Bermuda on the 25th.

3. COMPARING 1967 AND 1968

Two procedural changes in 1968 make it difficult to compare the census for 1968 with that of 1967.

The 1967 survey was confined to wave disturbances for which there was supporting evidence in the circulation. ITC disturbances were not counted unless they broke away and became trade wind eddies. In 1968 all disturbances that met the criteria given by the definition stated earlier were tracked. Also in 1967 the Antilles time cross-section was based on data from Antigua and Guadeloupe, both stations north of 16°N. However, in 1968 Barbados (13°N) was used so that possibly more low-latitude disturbances were recorded.

Excluding cold Lows, a total of 54 tropical systems were identified in 1967. In 1968, 110 systems were recorded. This total includes 11 subtropical disturbances and five ITC disturbances which would not have been considered in 1967. However, after deleting these, a total of 94 systems were identified in 1968 compared to 54 in 1967. Table 2 compares the number of depressions and the wave disturbances emerging from Africa in 1968 with those of 1967, by months. The numbers in parentheses indicate ITC disturbances which passed south of Dakar and would not have been included in 1967. Every month in 1968 had more disturbances moving out of Africa than in 1967.

In sharp contrast, table 2 shows a significant decrease in the number of depressions in 1968. This is particularly true if the off-season depressions are not considered in 1968. A significant difference concerns the strength of the African systems during August, normally the time of maximum activity for east Atlantic and African disturbances. In 1967, seven systems emerged from Africa. All were of depression strength, while not one of the 1968 African systems was as strong.

4. THE LARGE CIRCULATION ENVIRONMENT

Normal circulation data for the tropical and equatorial Atlantic are difficult to apply, first because the paucity and irregularity of observations in this area yield a nonhomogeneous record and large probable errors in the normals. Secondly, gradients of pressure, temperature, and wind within the trades are generally small, so that small deviation errors may lead to large errors when one interprets the impact of deviations (from normal) on the circulation. However, as we have seen in 1968 there were significantly more disturbances than in 1967, and it is interesting and useful to compare the mean circulations for these 2 yr. For purposes of this discussion we shall consider the month of August in which the greatest difference in numbers of disturbances occurred. On a planetary scale, figure 6 shows the differences in geopotential (1968–1967) at 700 mb. While in tropical latitudes the geopotential was a bit higher in 1968 than in 1967, in temperate latitudes there was a decidedly lower geopotential in 1968 than in 1967. This reflects the fact that storm tracks over the central Atlantic moved at a lower latitude in 1968 than in 1967 and implies the possible intrusion of baroclinic conditions into lower latitudes in 1968.

Figure 7 allows comparison of the surface circulations for August 1967 and 1968 and figure 8 that at 200 mb. In August 1967 the lower troposphere circulation was more vigorous and the easterlies extended through a greater depth than in 1968. In the upper troposphere the semipermanent trough extending southwestward from north of the Azores to Puerto Rico was more persistent in 1967 than in 1968, but was significantly farther south in 1968 than in 1967. While a comparison of these circulation features does not provide explicit answers to the differences observed in disturbance activity, it is apparent that the occurrence of tropical disturbances or, as we prefer to call them, "hurricane seedlings," does not correlate positively with the depth of the easterlies or the strength and persistence of the trade winds.

On the other hand, a relatively low base of westerlies during 1968, and the presence of large vertical shear may have exercised a substantial constraint to the development of disturbances. In general the large vertical shear of the horizontal wind, according to Gray (1968), is unfavorable for the development of hurricanes because of the inability of organized rain storms to compact the latent heat released into a relatively small deep column (100–300 mi

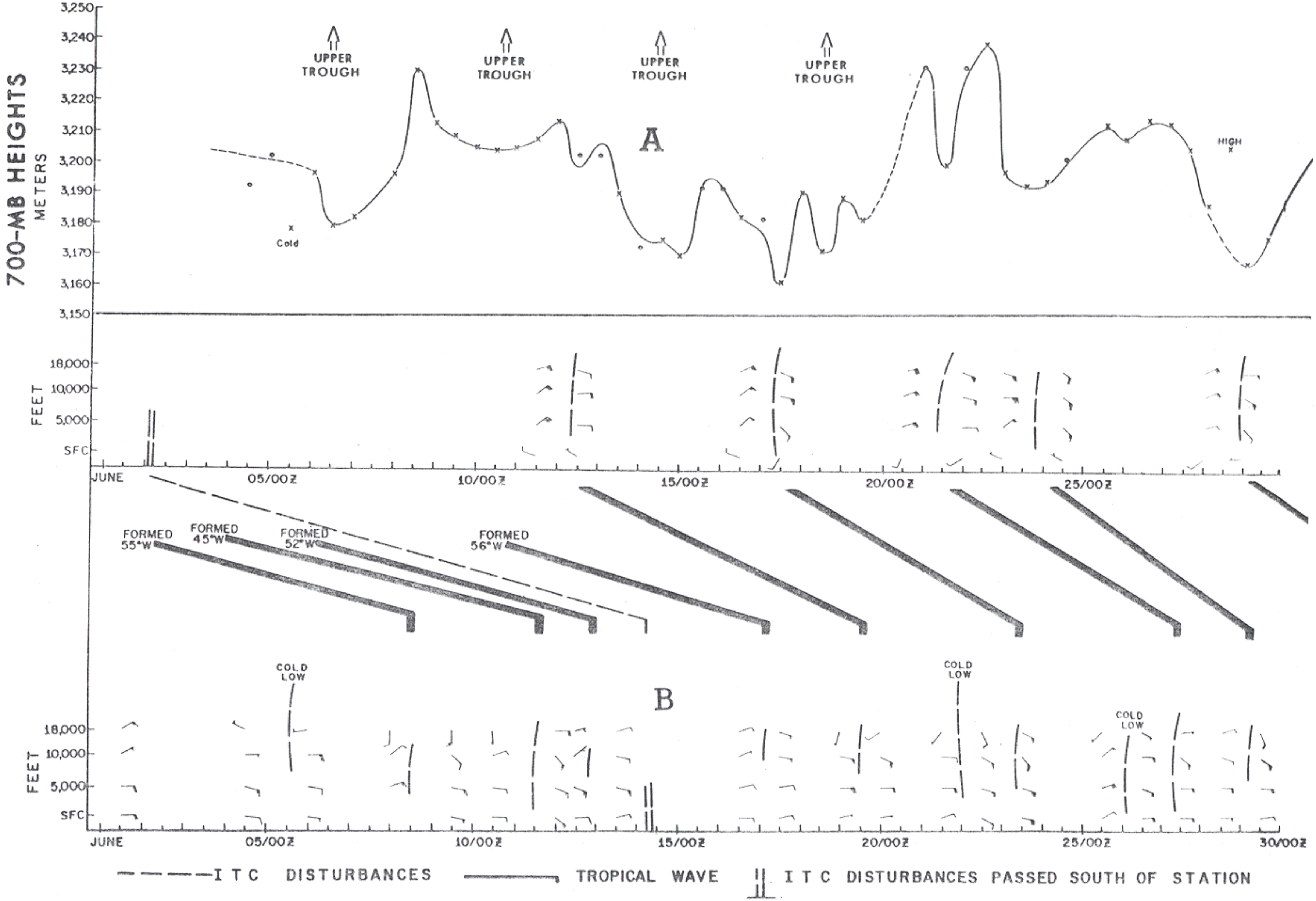
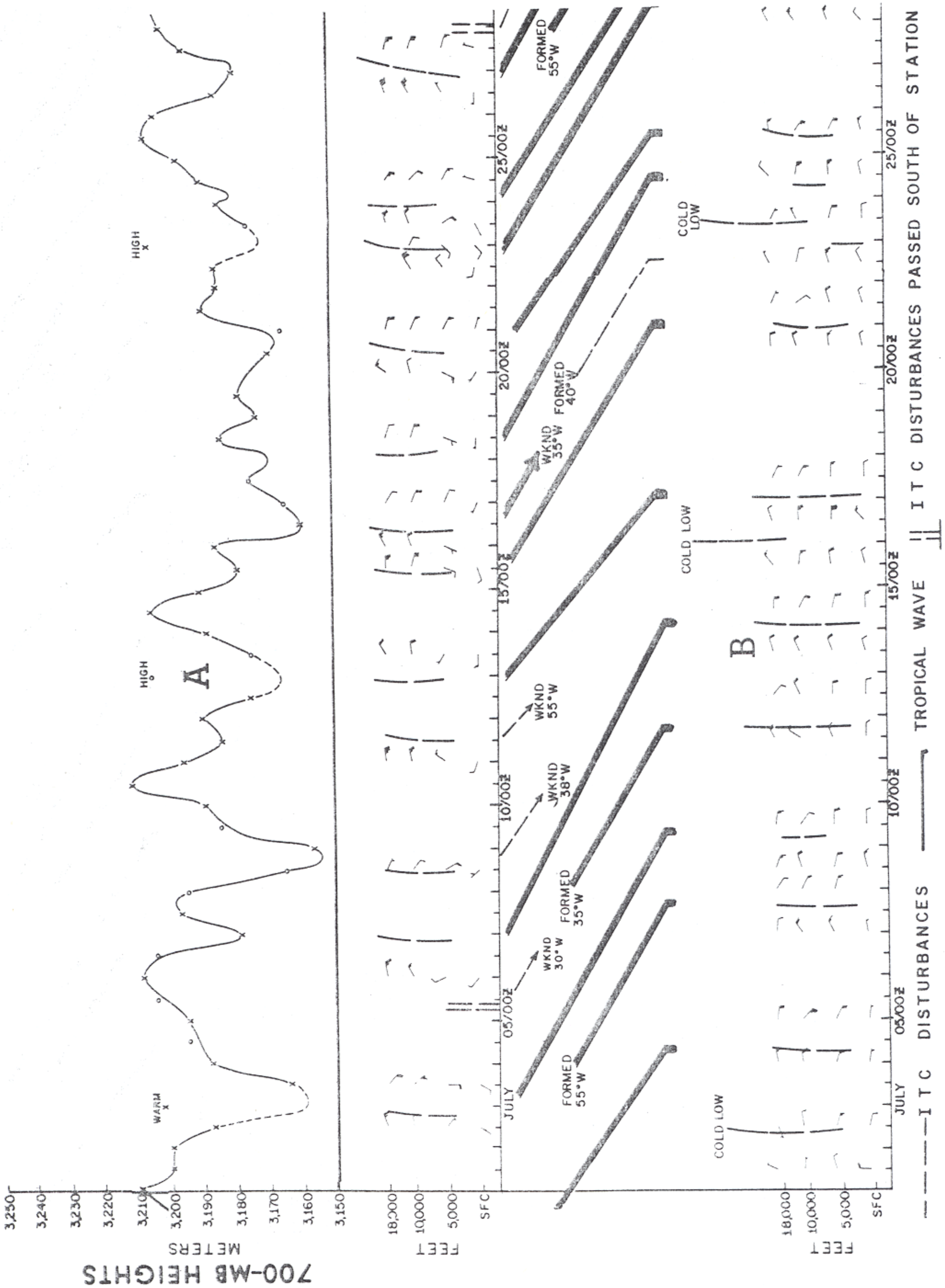


Figure 3.—Time cross-sections for Dakar (A) and Barbados (B) for the period June 1 to Oct. 30, 1968. Wave axes are indicated by dashed lines. Solid bars connect times when a given wave passed first Dakar and then Barbados; thin dashed lines do the same for ITC disturbances. The continuous time-series curve presents the Dakar 700-mb geopotential height variation. Upper trough positions are indicated by arrowheads (see text). Some of the 700-mb height values were considered to be in error. These have been indicated by *high*, *low*, *cold*, and *warm*.



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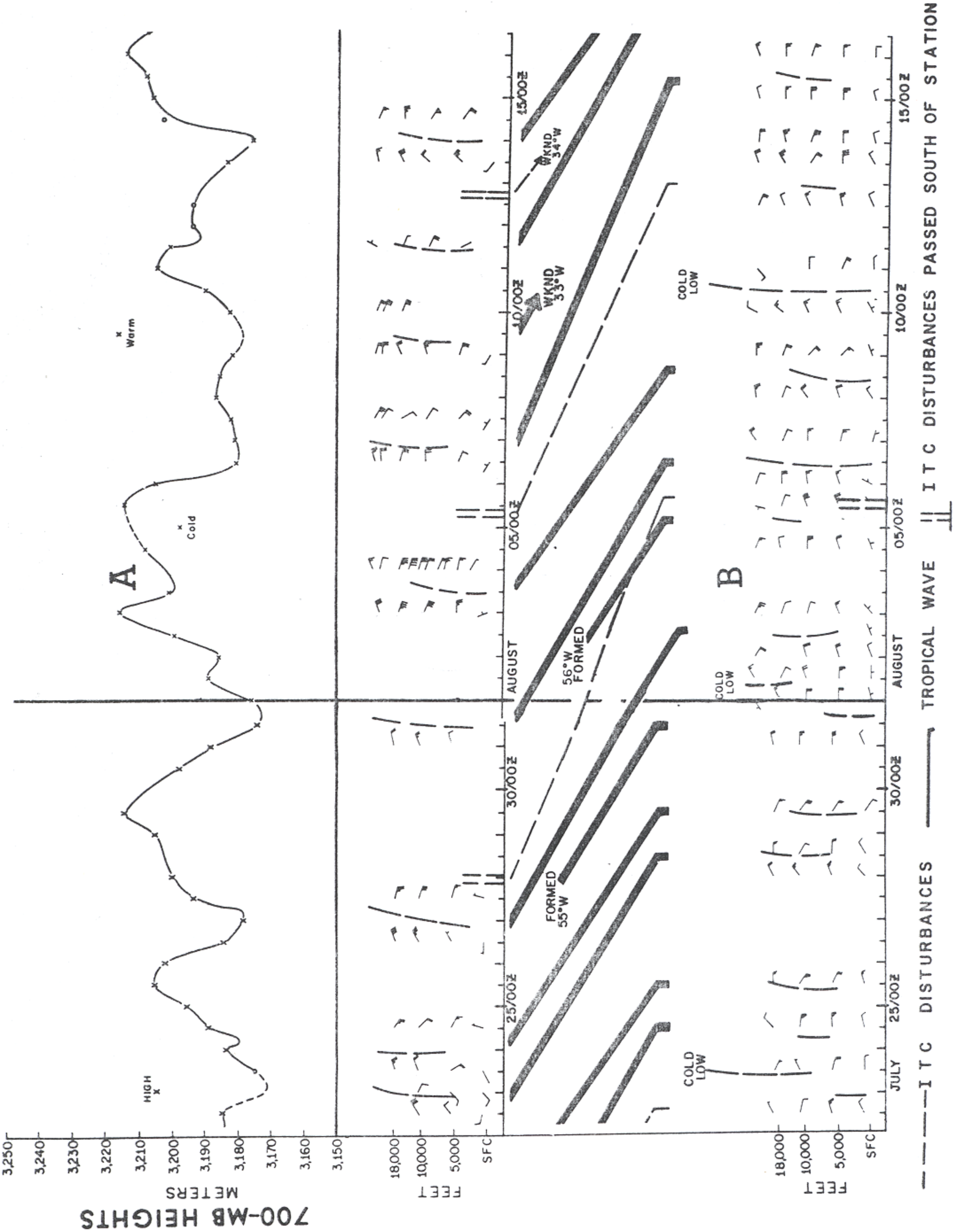

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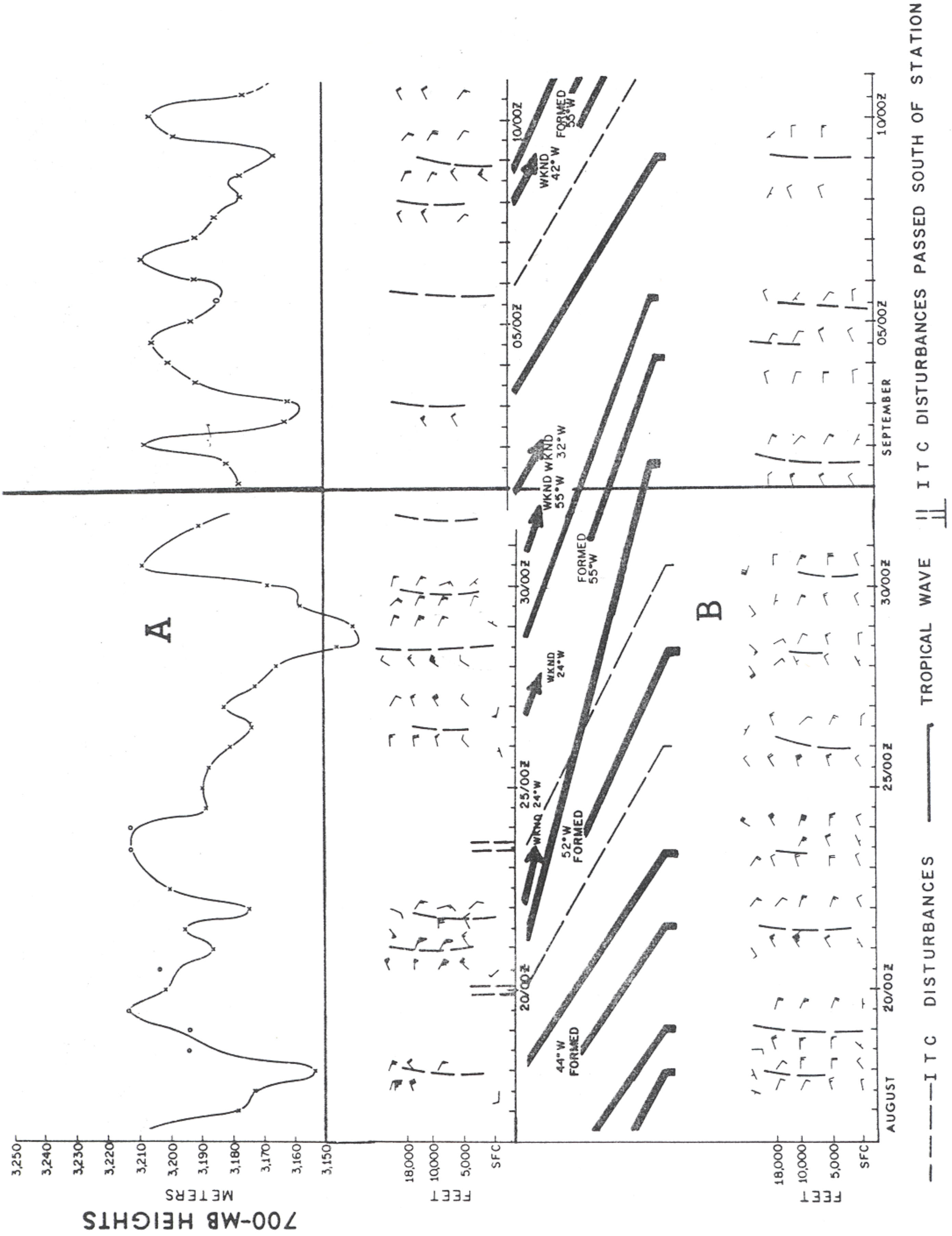

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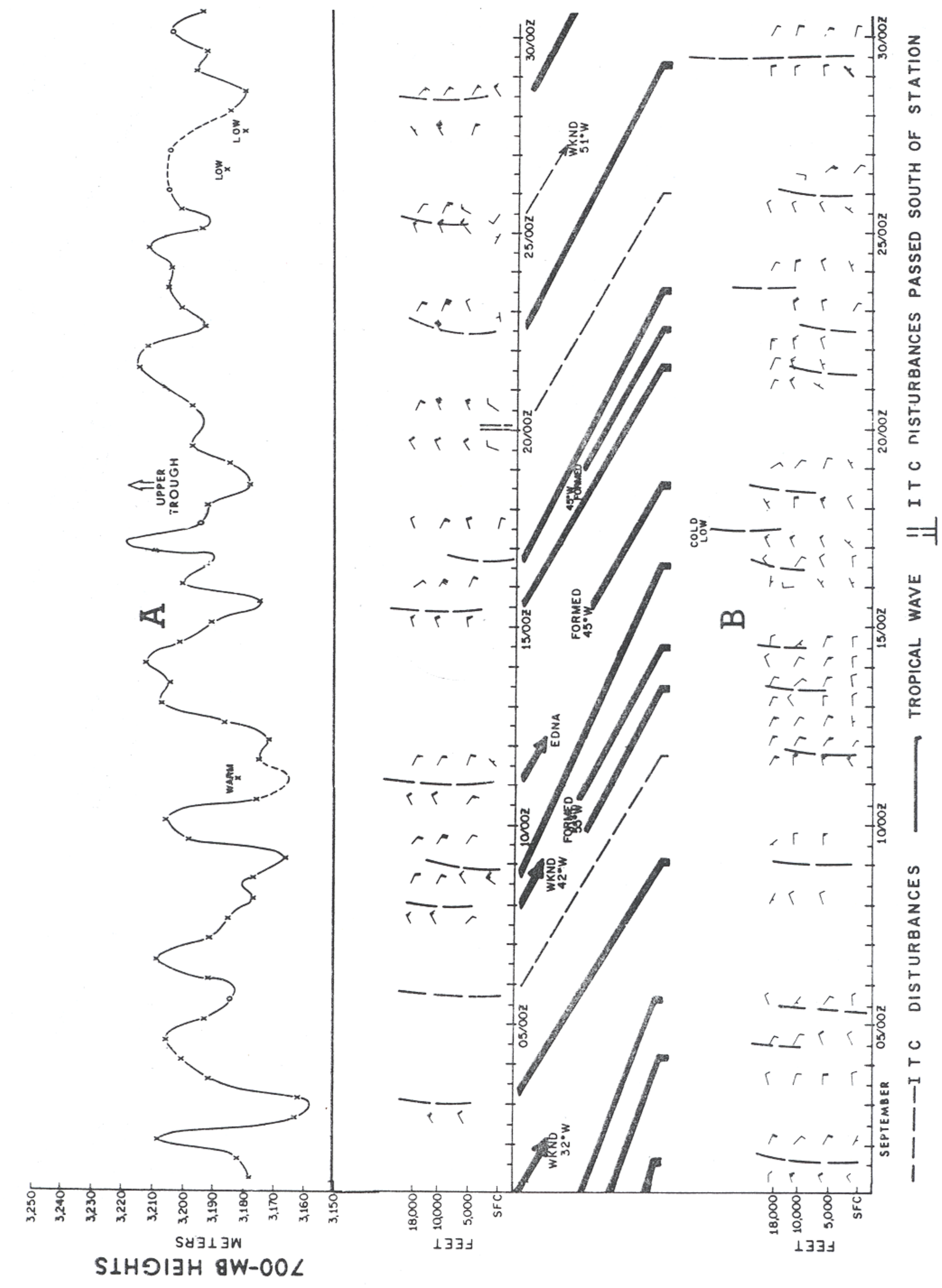

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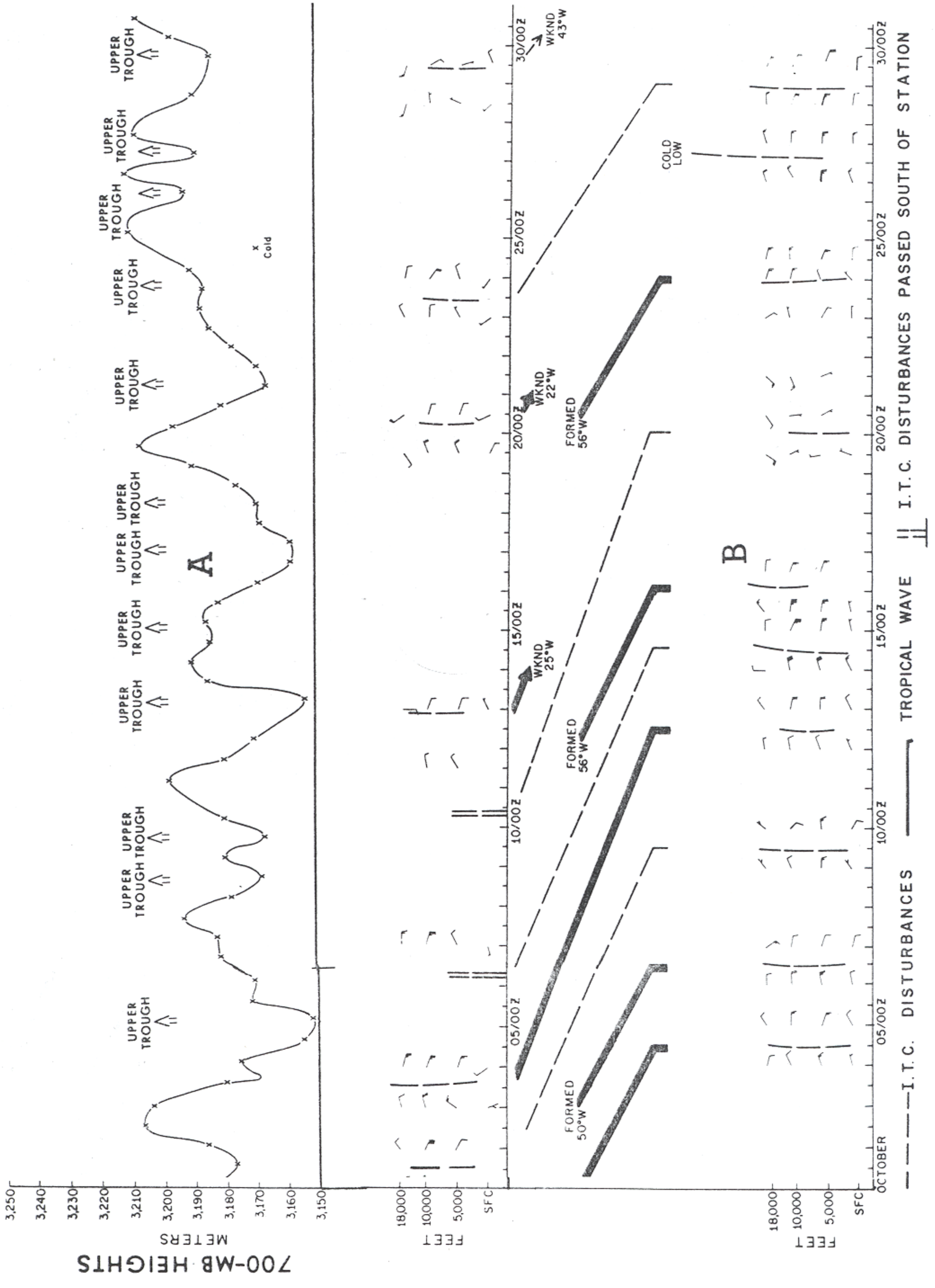

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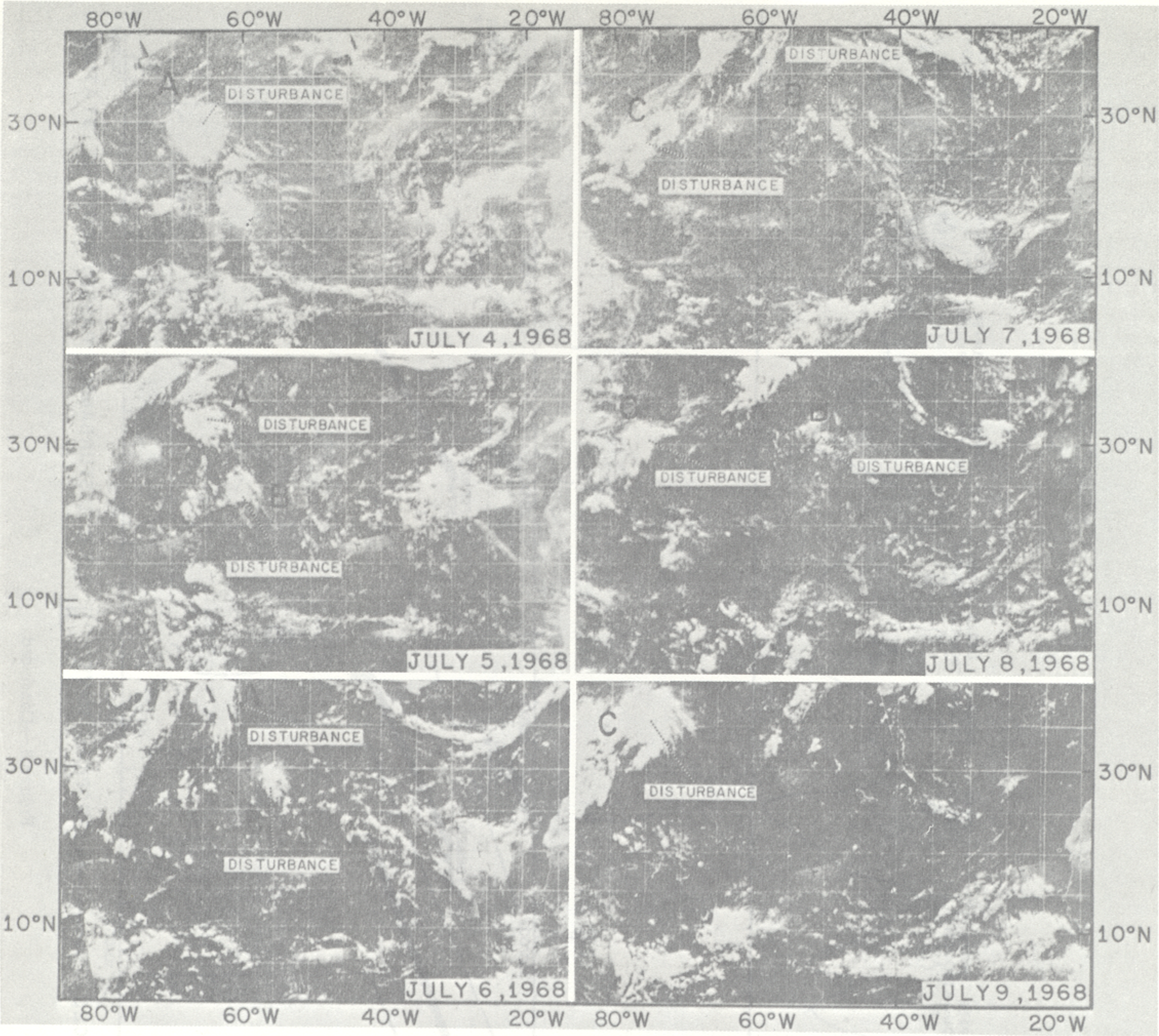

Figure 4.—A series of six digitized mosaics for early July showing three tropical disturbances that formed over subtropical areas of the North Atlantic. Disturbance A, near 30°N, 65°W, on July 4, is depicted three times; Disturbance B, near 25°N, 60°W, on July 5, is shown four times; and Disturbance C, near 30°N, 75°W, on July 8, is shown three times.

wide) of the troposphere where the resulting pressure falls would significantly increase pressure gradients. It is appropriate to comment that the daily tropospheric mean shear chart[3] used in hurricane predictions at the National Hurricane Center during the 1968 hurricane season was most effective in delineating days in which cyclogenesis was favorable. Cyclogenesis during the 1968 season occurred in locations where the troposphere mean wind shear was less than 10 kt.

It is generally recognized that disturbances in the Tropics develop into hurricanes only when certain conditions exist (even though these conditions may not be sufficient for formation). The most important of these are 1) the presence of deep easterlies, 2) the presence of a forcing mechanism for mass transport into the depression in the friction layer, 3) minimum vertical shear of the horizontal wind, and 4) at the storm periphery, the presence of a high tropospheric current which systematically conducts the heat away from the storm center to a colder environment. (See e.g., Dunn, 1960; Riehl, 1954; Simpson, 1967.) In August 1968 it appears that the main conditions not met were 2) and 3). Westerly shear pervaded the areas of potential development most of the month.

5. THE ATLANTIC AS A SOURCE OF EAST PACIFIC HURRICANES

Many of the disturbances from Africa and the eastern Atlantic moved into the Caribbean Sea without development; but when they extended their influence across

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[3] The tropospheric mean shear is obtained by subtracting the pressure weighted mean wind for the layer 1000–600 mb from that of the layer 600–200 mb.

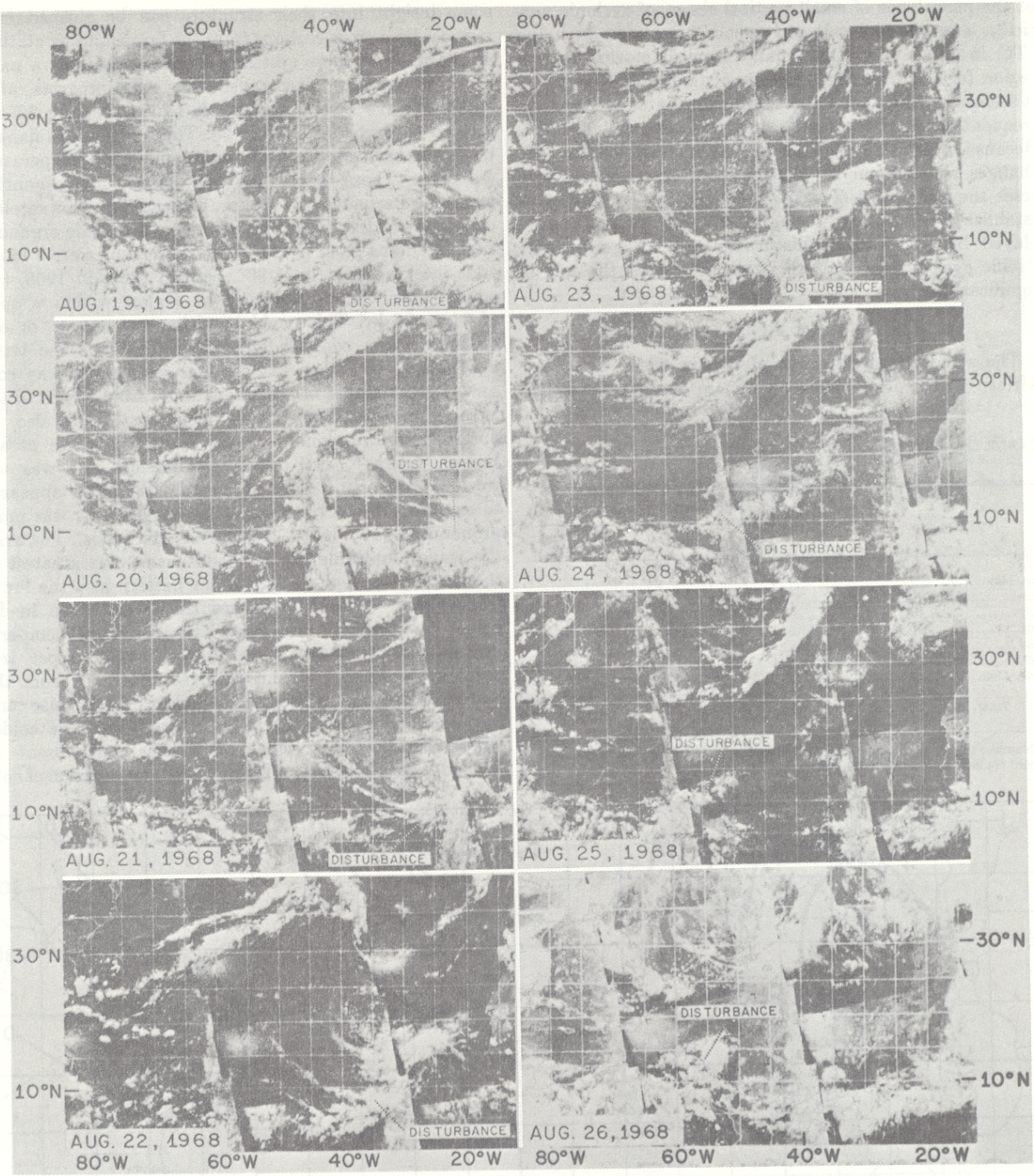

Figure 5.—A series of eight digitized mosaics for the period Aug. 19–26, 1968, showing the westward progress of a typical relatively strong ITC disturbance. A well-marked African tropical wave is shown near 20°N, 30°W, on August 19 and can be followed easily for 4 more days.

Central America into the Pacific, they found a more hospitable environment for development, mainly one of lower vertical wind shear. At least four of the 19 tropical storms which formed in the eastern Pacific were triggered from disturbances which had their origins in Africa or the Atlantic.

The Pacific west of Nicaragua and Costa Rica is a fertile genetical region for tropical storms mainly because of the persistence of small vertical shear, of cyclonic vorticity, and of low-level convergence associated with the ITC in this area. While many tropical storms in this region form within this envelope of favorable conditions, it seems clear that the impulse which initiates cyclogenesis frequently comes from migratory Atlantic disturbances. Because of the paucity of upper air information and the changes which occur in cloud patterns as wave systems cross the mountains of Central America, it is difficult to establish with certainty in all instances the exact role played by the Atlantic disturbances in triggering east Pacific cyclogenesis; but the evidence is that the role is significant.

6. STRUCTURE OF AFRICAN WAVES

The structure and sources of energy which drive the African waves or inverted V's remain obscure. However, some insight into their structure can be gleaned from vertical time cross-sections from the few sounding stations in the path of these systems. Figure 9 contains a panel of three satellite pictures showing the progress of a complex wave system which left Dakar on July 22 and arrived at Barbados on July 28. These panels are flanked by time cross-sections of the wind and temperature anomaly. These anomalies are based upon monthly means at Barbados and Dakar, respectively. The satellite mosaics reveal a rather extensive synoptic-scale organization extending from 5°-25°N lat., spreading over a longitude interval of at least 30°. Several times in 1968, two wind shifts were experienced at Dakar within a span of 24 to 36 hr. This could be either two waves, or one system with a complex structure. We favor the latter alternative. In either case a dual wind shift was conserved in a number of systems tracked from Africa to the Lesser Antilles. The double structure could also be observed in the cloud pattern. When the wave passed Dakar, figure 9, the principal windshift line was the western axis about which a closed circulation appeared to exist in the lower 5,000 ft. The eastern axis was more pronounced at higher levels. At Barbados, however, the wave amplitude of the western axis was greatest in the middle troposphere and of the eastern axis the lower troposphere. In both instances the largest falls in D-values occurred with the eastern axis. The largest temperature anomaly was the positive area in the upper troposphere which at Dakar occurred upstream from the eastern axis, but at Barbados had grown in size and dominated the area between the two axes. The colder temperatures in low levels at Dakar and absent at Barbados were probably a result of the combination of cold

TABLE 2.—*Monthly comparisons of tropical systems between 1967 and 1968*

	Depressions		Dakar waves	
	1967	1968	1967	1968
Jan.-May		2		
June	4	4	6	7 (1)
July	2	2	8	15 (1)
Aug.	7	3	7	16 (4)
Sept.	6	7	6	11 (1)
Oct.	10	2	3	8 (3)
Nov.-Dec.	0	2		
Total	29	22	30	57 (10)

Numbers in parentheses indicate ITC disturbances which passed south of Dakar and would not have been considered in 1967.

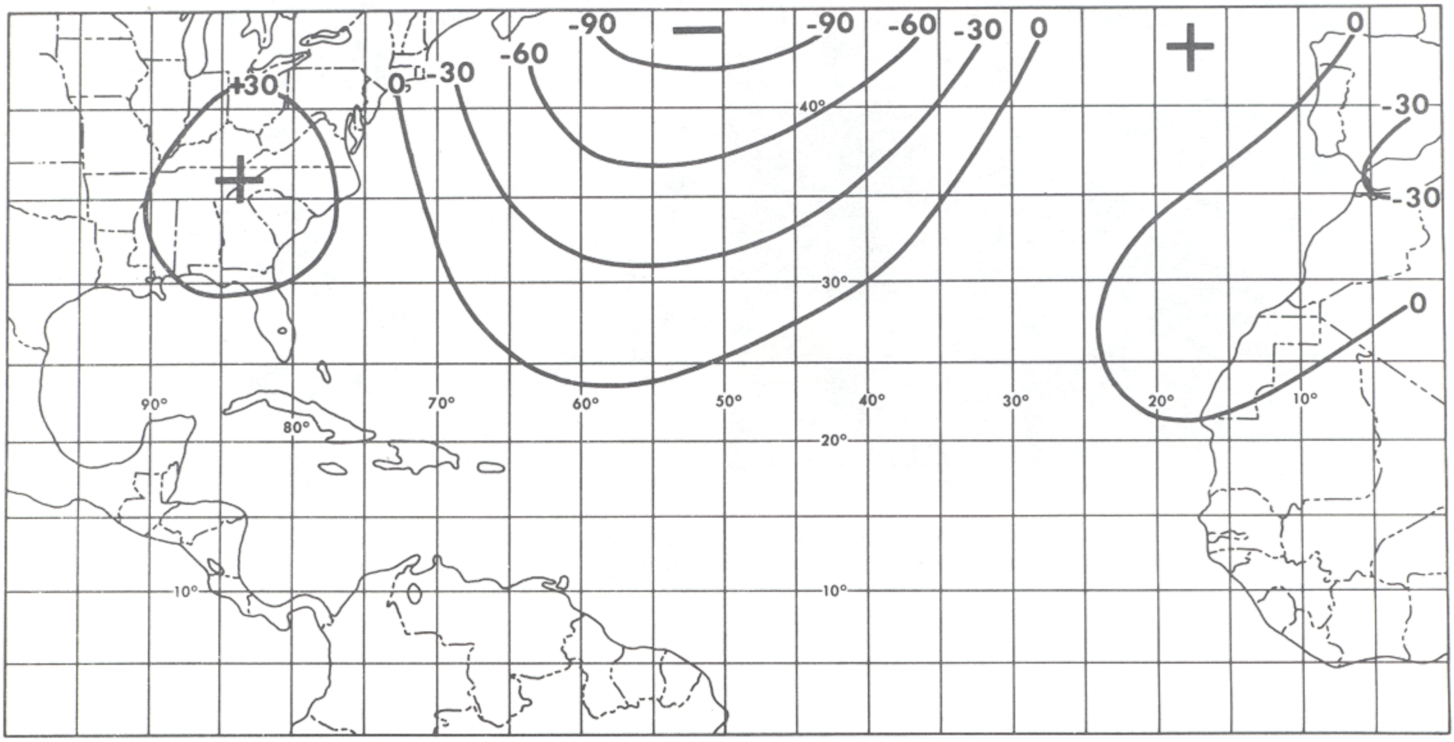

FIGURE 6.—The difference in the August 700-mb geopotential heights (meters) from 1967 to 1968.

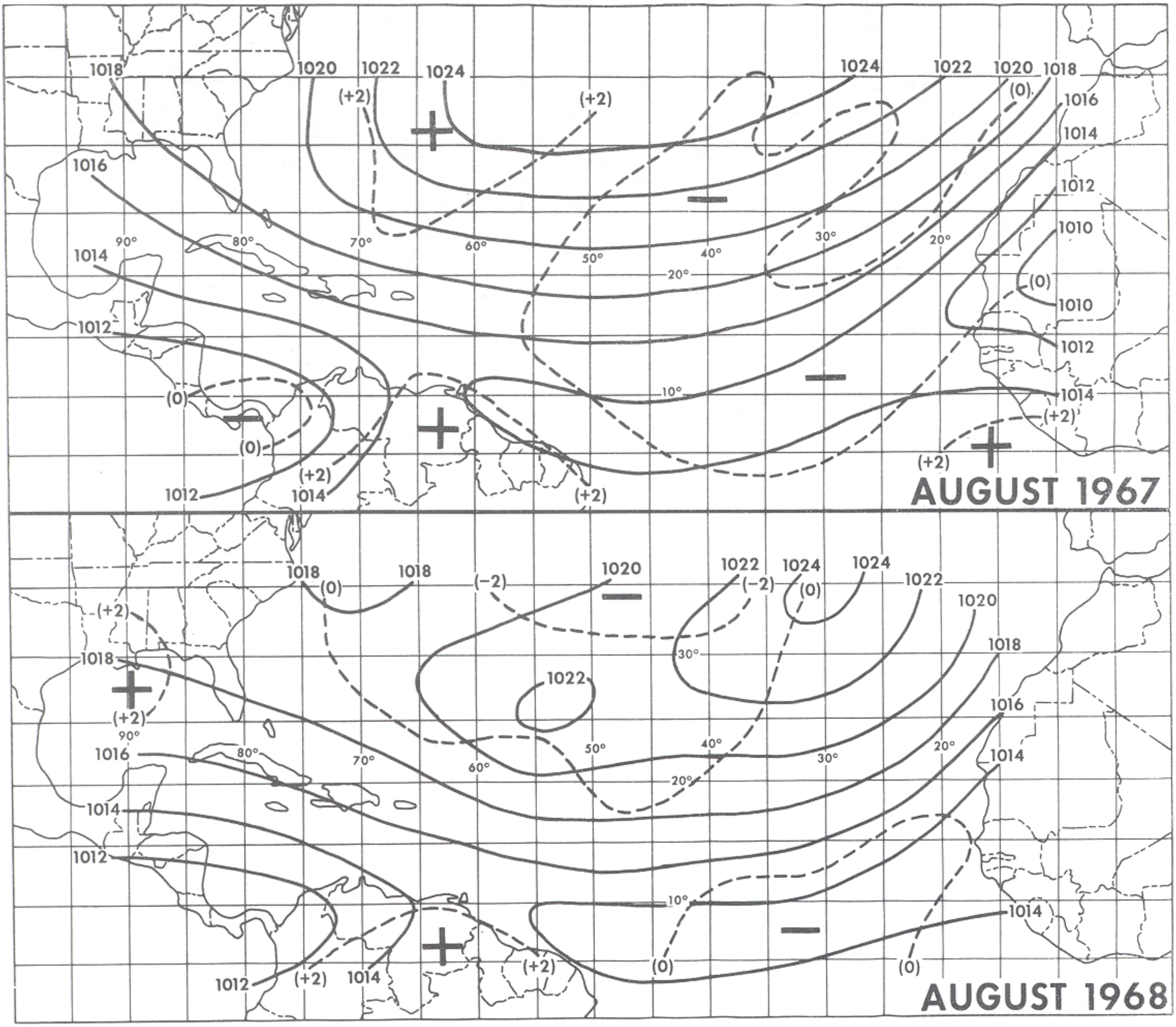

FIGURE 7.—The mean August sea-level pressures for 1967 and 1968 and departures from normal.

water and low-level convergence at Dakar. While the positive anomalies in the upper troposphere may reflect the accumulation of latent heat from organized convective cells, there is essentially no measurable horizontal temperature gradient in the active (large amplitude) levels of the wave disturbance.

7. CONCLUDING REMARKS

One hundred ten tropical systems were detected and followed over the tropical North Atlantic, Caribbean Sea, and the Gulf of Mexico during 1968. Like 1967, more than half originated over Africa. A more detailed analysis of circulations associated with the systems as they crossed Africa was made daily by Carlson (1969*a*, *b*). Approximately two-thirds of the African systems maintained their identity as far west as the Antilles, and nearly half of these continued westward across the Caribbean and into the Pacific where some appeared to have triggered tropical storms.

There were significantly more seedling disturbances in 1968 than in 1967. Yet, in sharp contrast, a much lower percentage of the systems developed into named storms. The primary difference seems to have been attributable to two factors. First, there was a persistence of large vertical shear of the horizontal wind in genetical regions. Secondly, the systems which formed initially over Africa were weaker when they reached the Atlantic in 1968 than in 1967. In 1967 nearly all the systems which moved off Africa were initially, or soon became, depressions.

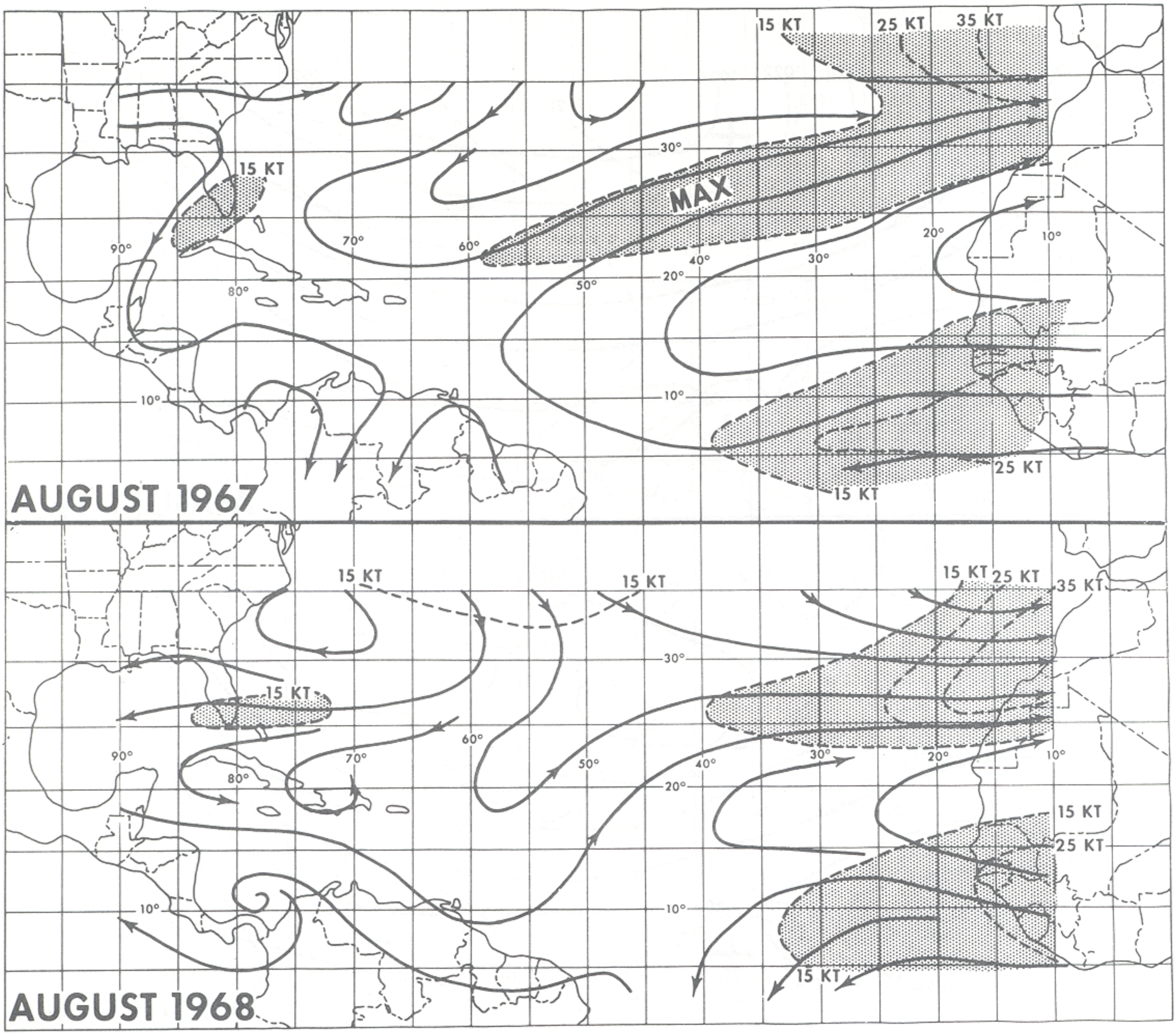

FIGURE 8.—The mean August 200-mb streamline-isotach charts for 1967 and 1968. Shaded areas represent regions of wind speeds greater than 15 kt.

This was undoubtedly related to large-scale circulation differences. In 1968, the flow pattern over the subtropical central North Atlantic was influenced greatly by several dramatic baroclinic developments in August and September. The negative anomalies dictated by the lower latitude tracks of temperate latitude storms produce unfavorable conditions for tropical storm development.

Finally, it appears that the occurrence of tropical waves does not correlate positively with geopotential anomalies over the midlatitudes of the central Atlantic Ocean. This differs from the findings of Landers (1963) who reported that the initiation of easterly waves seems to be associated with surges of below-normal pressure in temperate latitudes, which result in stronger pressure gradients in the Tropics.

On one occasion in 1968 the ESSA's Research Flight Facility made a long reconnaissance mission from Barbados to Dakar and return in support of the National Hurricane Center. This flight had the primary objective to investigate two disturbances. Unfortunately, one of the systems weakened rapidly and the length of the flight prohibited diverting to make a detailed investigation of the other one. The energetic nature and the structure of these disturbances will probably remain uncertain until a more complete investigation can be made with aircraft in conjunction with satellite observations.

It is apparent that the maximum amplitude of these wave disturbances occurs in the layer between 5,000 and 15,000 ft. The horizontal temperature gradients across the waves are very small, and no conclusion can yet be drawn as to whether these systems are warm or cold core.

ACKNOWLEDGMENTS

Appreciation is expressed to Dr. J. Kuettner, Director of Special

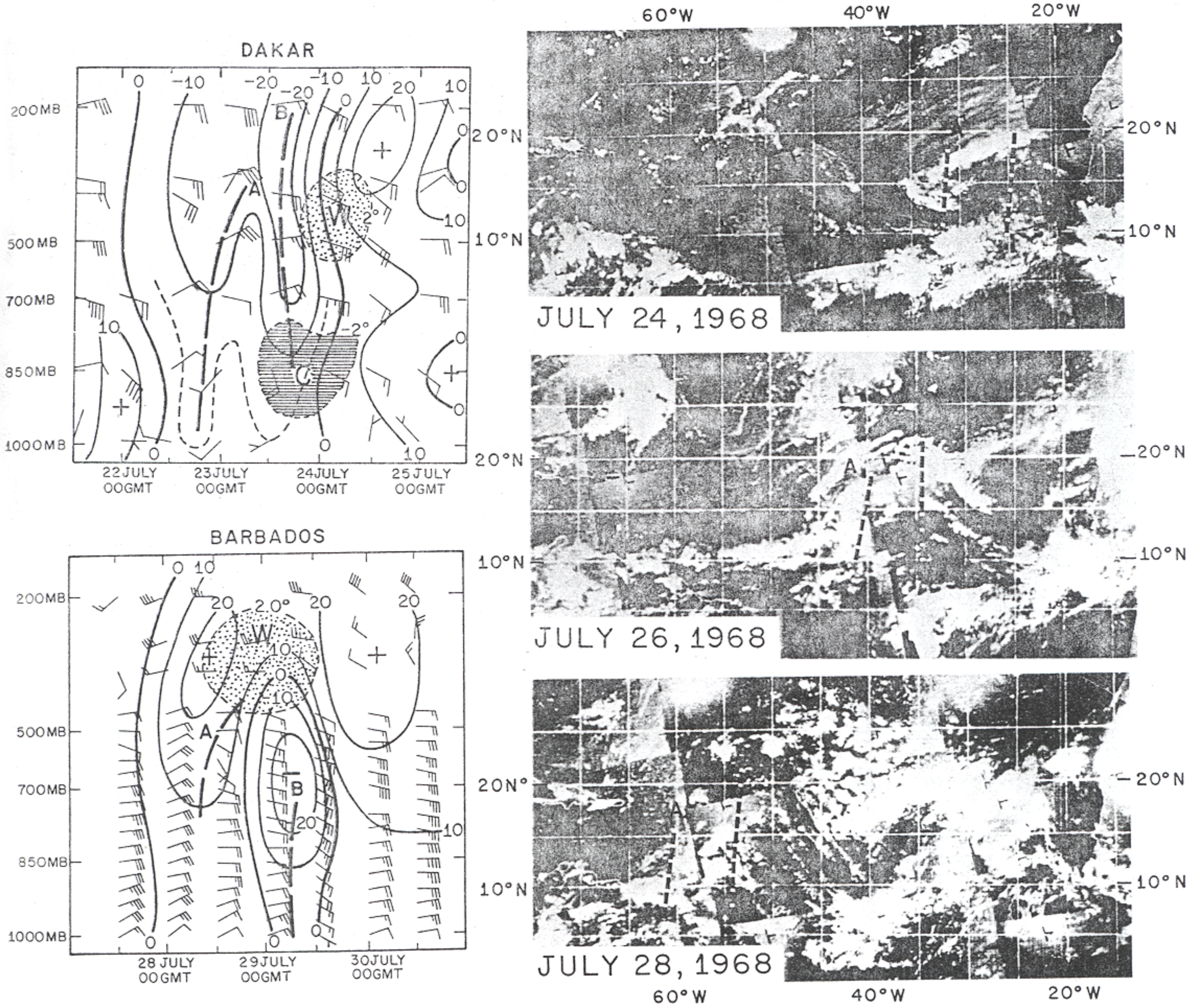

FIGURE 9.—Satellite pictures and time cross-sections for Dakar and Barbados showing the structure of a tropical wave which crossed the Atlantic in late July 1968. The solid lines are height departures (meters) from mean monthly values. Shaded or stippled areas represent temperature anomalies greater than 2° K.

Projects, ESSA's Environmental Research Laboratory and Mr. H. Mason, Chief of ESSA's Research Flight Facility (RFF) for making available the facilities of RFF to investigate two tropical systems in October. Thanks also to Mr. R. Carrodus and Mr. C. True of the National Hurricane Research Laboratory for preparing the illustrations.

REFERENCES

Carlson, T., "Some Remarks on African Disturbances and Their Progress Over the Tropical Atlantic," National Hurricane Research Laboratory, Weather Bureau, ESSA, Miami, Fla., **1969***a*, (manuscript in preparation).

Carlson, T., "Synoptic Histories of Three African Disturbances That Developed Into Atlantic Hurricanes," *Monthly Weather Review*, Vol. 97, No. 3, Mar. **1969***b*, pp. 256–277.

Dunn, G. E., National Hurricane Center, Weather Bureau, ESSA, Miami, Fla., **1969,** (private communication).

Dunn, G. E., and Miller, B. I., *Atlantic Hurricanes*, Louisiana State University Press, Baton Rouge, **1960,** 377 pp.

Gray, W. M., "Global View of the Origin of Tropical Disturbances and Storms," *Monthly Weather Review*, Vol. 96, No. 10, Oct. **1968,** pp. 669–700.

Landers, H., "On the Formation and Development of Tropical Cyclones," *Journal of Applied Meteorology*, Vol. 2, No. 2, Apr. **1963,** pp. 206–218.

Riehl, H., *Tropical Meteorology*, McGraw-Hill Book Co., Inc., New York, **1954,** 392 pp.

Simpson, R. H., "Progress and Problem Areas in Forecasting Tropical Cyclones, a Resume," paper presented at the Fifth Technical Conference on Hurricanes and Tropical Meteorology, Caracas, Venezuela, November 20–28, **1967**.

Simpson, R. H., Frank, N., Shideler, D., and Johnson, H. M., "Atlantic Tropical Disturbances, 1967," *Monthly Weather Review*, Vol. 96, No. 4, Apr. **1968,** pp. 251–259.

Sugg, A. L., and Hebert, P. J., "The Atlantic Hurricane Season of 1968," *Monthly Weather Review*, Vol. 97, No. 3, Mar. **1969.** pp. 225–239.

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