ATLANTIC TROPICAL DISTURBANCES, 1967

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

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

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 [28], 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.

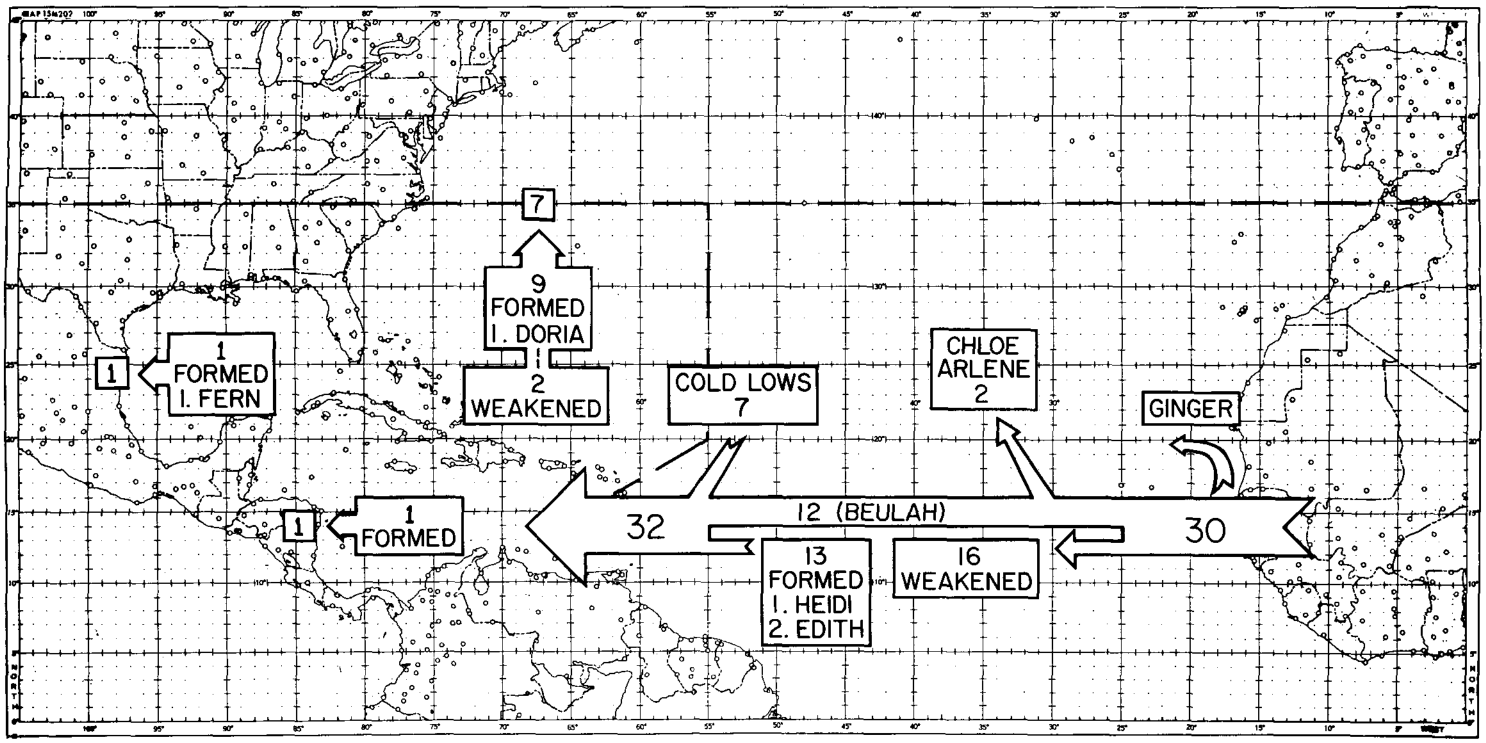

FIGURE 1.—The seasonal summary of tropical waves for the period June through October 1967, in the Gulf of Mexico, Caribbean Sea, southwestern Atlantic Ocean and the central and eastern tropical Atlantic. Within the boxes are shown the number of waves which formed, weakened, and moved through or out of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

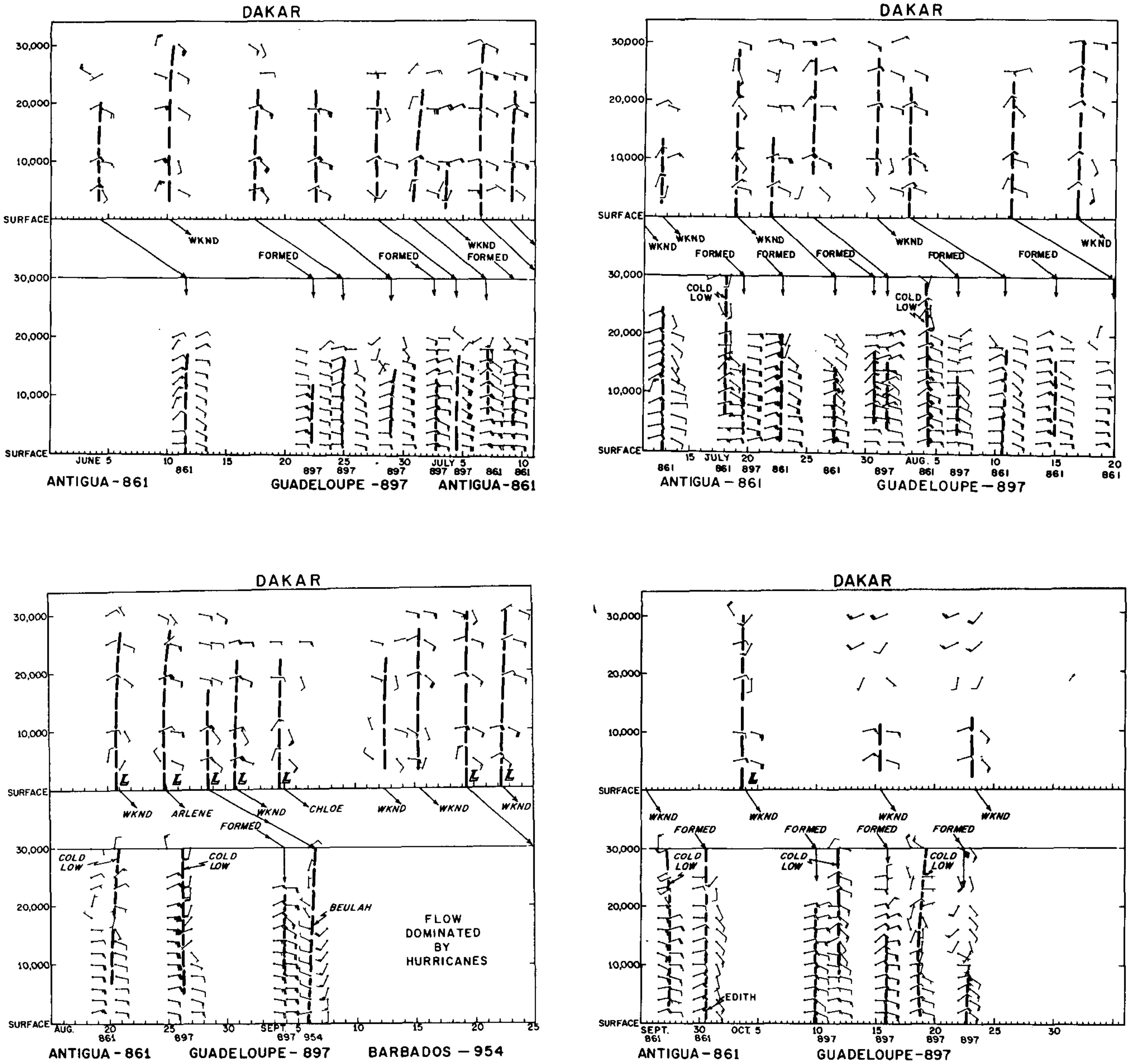

FIGURE 2.—Selected portions of the time-sections for Dakar and various stations in the Antilles Island chain showing the vertical wind structure of waves which passed each location. The layer affected by the wave is shown by the heavy dashed line. Lines between the two time-sections indicate the history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

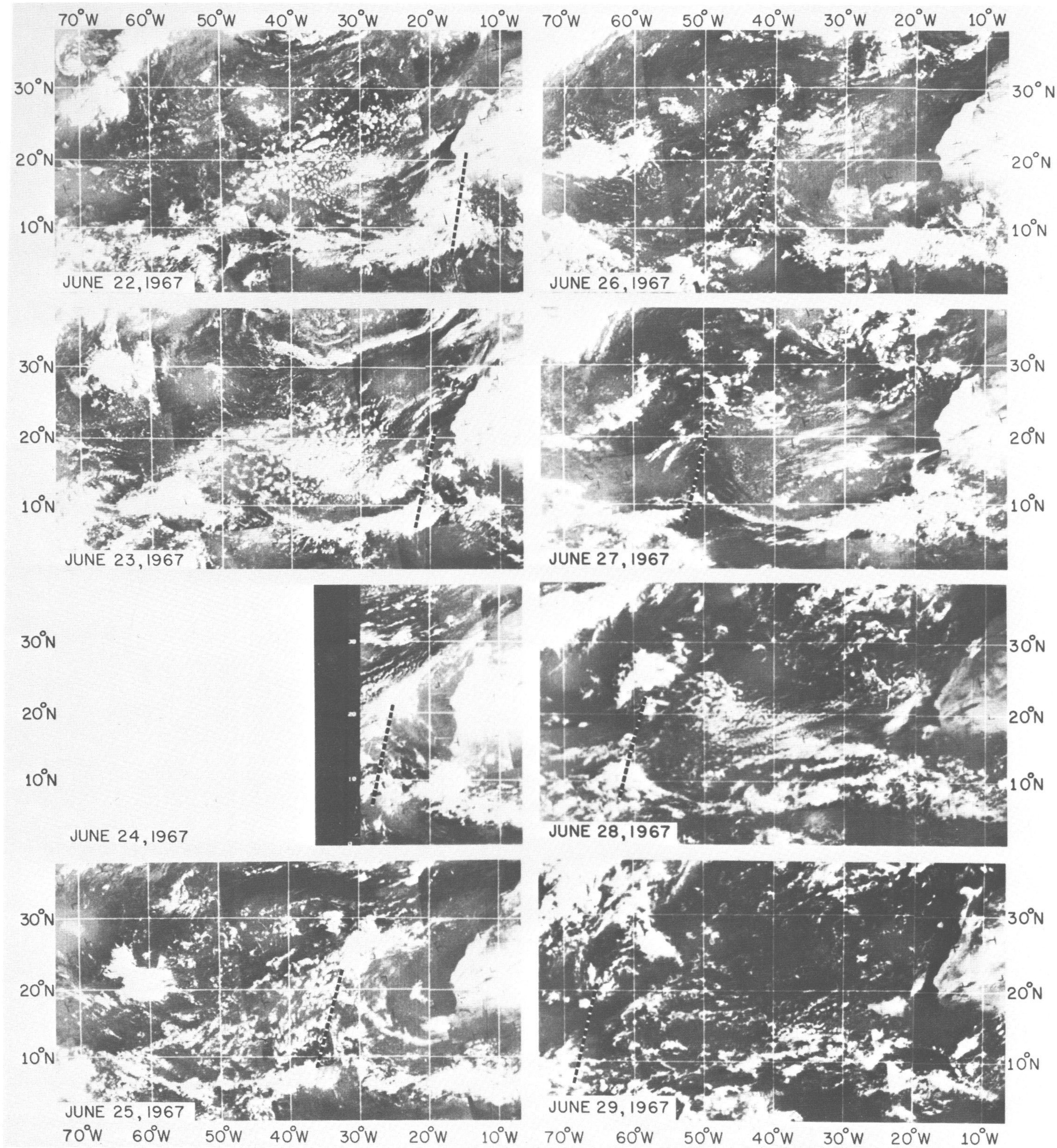

FIGURE 3.—A series of eight digitized mosaics for a period in June when a tropical wave crossed the Atlantic. The wave axis is indicated by a dashed line.

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	NHC 1967	Piersig [21] 1891–1911	Eldridge [8] 1955	Erickson [9] 1961	Arnold [4] 1961	Aspliden et al. [1, 2, 3] 1963
	Author and Period of Study					
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	NHC 1967	*Durham et al. [7] 1944	Frank [11] 1958	Dunn [5] 1935	Riehl [23] Mid 40's
	Author and Period of Study				
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. Asplidén 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 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.

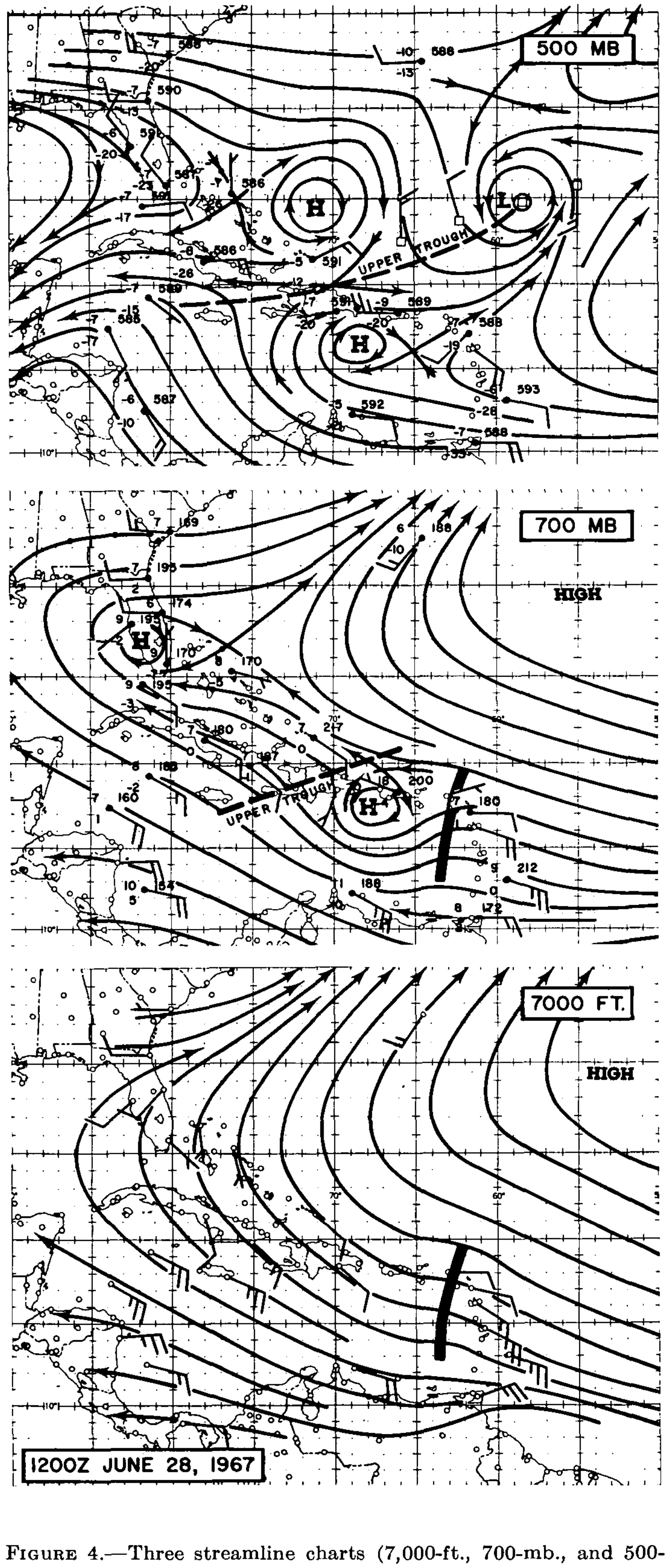

FIGURE 4.—Three streamline charts (7,000-ft., 700-mb., and 500-mb. levels) for June 28, 1967, 1200 GMT, showing the horizontal structure of the tropical wave shown in figure 3 as it crossed the Antilles Islands.

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

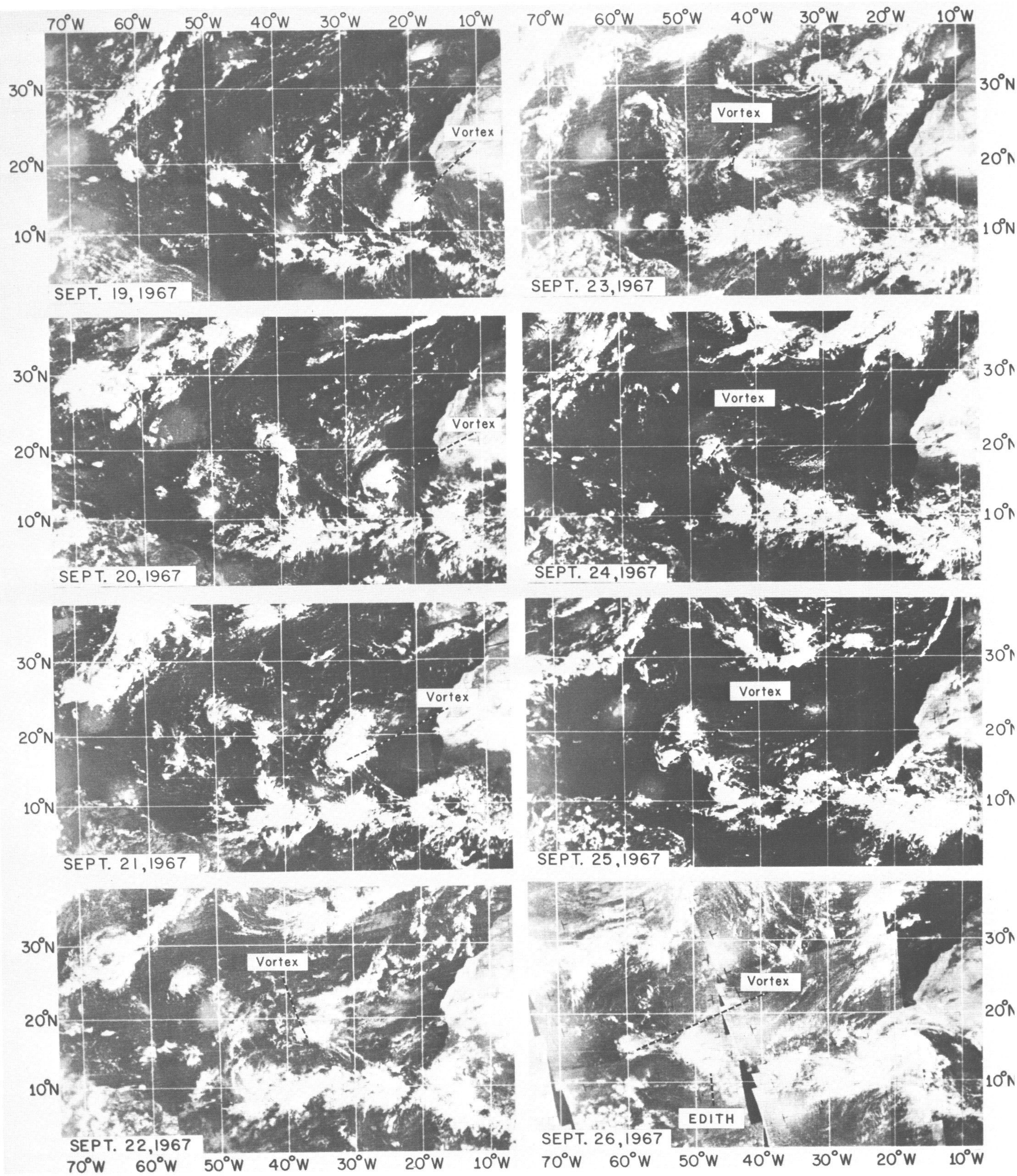

FIGURE 5.—A series of eight digitized mosaics for a period in September when a tropical depression crossed the Atlantic. The vortex center has been indicated.

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

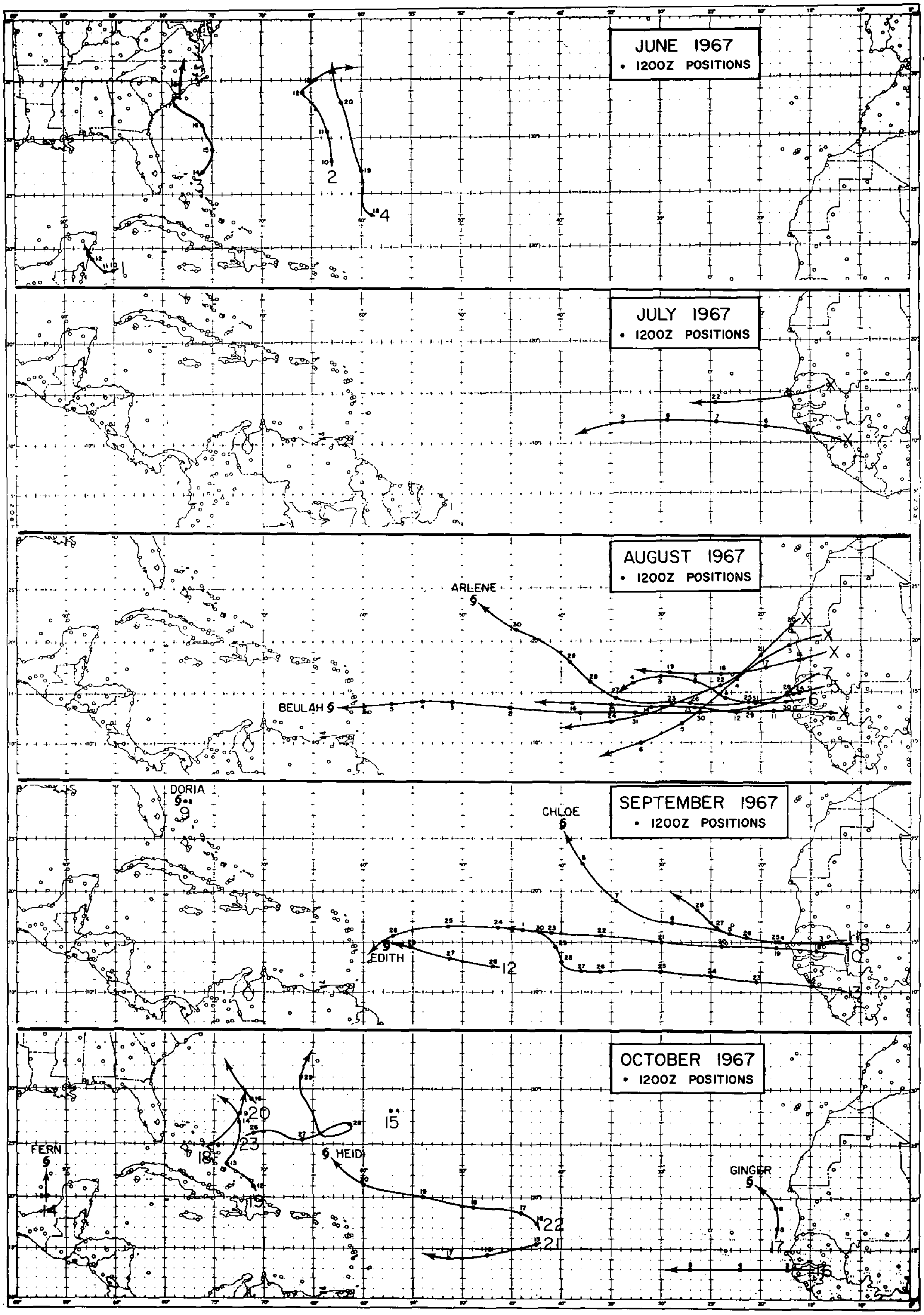

FIGURE 6.—Monthly tropical depression tracks for 1967. Those depressions which developed into named storms have been indicated.

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 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.

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.

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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PICTURE OF THE MONTH

View of Snow-Covered Northeastern United States and a Developing East Coast Storm

RALPH K. ANDERSON

Applications Group, National Environmental Satellite Center, ESSA, Washington, D.C.

Figure 1, received on January 1, 1968, from the ESSA 6 APT satellite, shows an excellent clear-sky view of the northeastern United States as it appears when covered with fresh snow. The storm responsible for the most recent snowfall is centered near the southern coast of Nova Scotia at the time of the picture. This storm deepened rapidly from a weak disturbance just east of Cape Hatteras during the previous 24 hr.

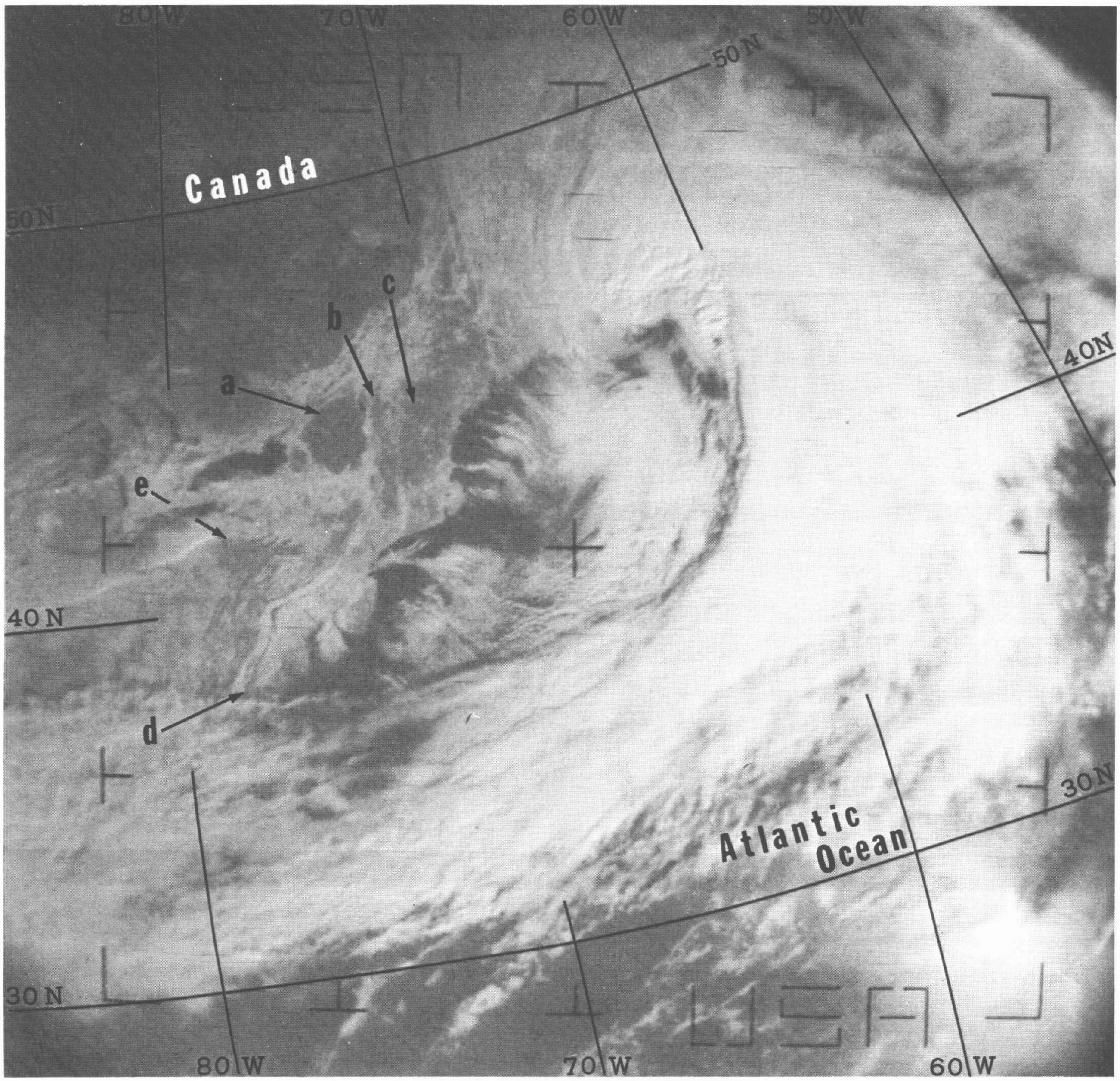

FIGURE 1.—ESSA 6 photograph. Pass 650, 1429 GMT, Jan. 1, 1968.

In satellite picture interpretation, recognition of the patterns produced by snow-covered terrain helps in distinguishing between snow and cloud. Of particular interest in this photo is the pattern produced by snow cover on the Appalachian Highlands. Variations in surface reflectivity make it possible to identify the boundaries of portions of several of the physiographic provinces [1] of this region. The Adirondacks (a), primarily forested with spruce and fir, appear as a darker area. Here, the coniferous forest tends to obscure the snow-covered ground. The lighter appearing land immediately east and south of these mountains reflects different land use and different vegetative cover. More open fields and different vegetation make the area look whiter when covered with snow. To the east, the Green Mountains (b), as well as the White Mountains (c), appear lighter than the Adirondacks. Conover [2] attributes this difference to the presence of open fields interspersed throughout the Vermont and New Hampshire forests; whereas, the Adirondacks are covered by a continuous forest.

The Blue Ridge appears in the picture as a thin dark area extending from point (d) in southern Virginia northeastward into southern Pennsylvania. Again, the dark area can be attributed to the forests of Shenandoah National Park and state parks to the north. Immediately to the west is a broad, lighter band that marks the Great Valley of Virginia and Pennsylvania. It runs along the eastern edge of the Valley and Ridge Province of Appalachia and contains several different river valleys. The light appearance of this band suggests that the area is primarily open farmland.

A distinctive darker area (e), with a fingered appearance to its northern edge, appears in north-central Pennsylvania. This dark area corresponds to a predominantly forested region in the Plateau Province of the Appalachian Highlands. Immediately to the south and east in Pennsylvania and Virginia, forests alternate with croplands in the Valley and Ridge Province to produce a lighter mottled appearance to the area. Taggert et al. [3] studied a Nimbus 1 view of Pennsylvania taken in late summer.[1] They concluded that patterns produced by the earth's surface, as seen from the satellite at that season, corresponded more to the different reflectance of the geological formations of the area than to forest distribution. However, when the ground is snow covered, the satellite observed patterns should primarily represent differences in vegetative cover and land use.

Other surface features that can be seen in the picture are Lake Champlain, Lake Ontario, the northern part of Lake Erie, the Connecticut River Valley, Long Island, and Delaware and Chesapeake Bays. The southern edge of the detectable snow cover passes northeastward through southern Maryland to the Atlantic shore.

Of meteorological interest is the frontal band which curves southwestward from the storm center to 33°N., 80°W. The edge of a cirrus cloud shield enters the western portion of the picture at 37°N. and extends eastward out over the ocean. The shadow cast by this formation can be seen along its poleward edge, both on the snow-covered land and on the lower clouds off shore. The highlighted southeastern edge of the clouds obscuring Lake Erie appears as a bright line extending northeastward from the left-hand edge of the picture. The clouds forming in the cold offshore flow from New Jersey northward are low-level cumuli produced by surface heating of the air. It is interesting to speculate as to why the clouds appear to form at the coastline immediately east of both New York City and Boston.

[1] For a similar late summer Nimbus view, see "Picture of the Month," *Monthly Weather Review*, vol. 92, No. 11, Nov. 1964, p. 494.

REFERENCES

1. C. B. Hunt, *Physiography of the United States*, W. H. Freeman and Co., San Francisco, 1967, 480 pp. (see pp. 167–204).
2. J. H. Conover, "Note on the Flora and Snow Cover Distributions Affecting the Appearance of Northeastern United States as Photographed by TIROS Satellites," *Monthly Weather Review*, vol. 93, No. 10, Oct. 1965, pp. 644–646.
3. C. I. Taggert, J. R. Kenny, and A. J. Lewis, *APT Project NAIREC at Frobisher Bay, N.W.T., September 1964*, ERB-706, National Research Council of Canada, Ottowa, 1965, 192 pp. (see pp. 187–189).