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DISTURBANCES IN THE TROPICAL AND EQUATORIAL ATLANTIC

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DISTURBANCES IN THE TROPICAL AND EQUATORIAL ATLANTIC

By R. H. Simpson
National Hurricane Center, Miami

INTRODUCTION

The life of the weather forecaster and analyst is always less complicated, if not happier, when there is a minimum of data upon which to make decisions. Invariably the analysis model is easier to apply when observation points are far apart. And when a forecast based upon such analyses fails, a critique of the case frequently ends up showing that if only a few more observations had been available, the failure could have been avoided. In this sense, the meteorological satellite has made life more complicated and less comfortable for the tropical meteorologist. He has not only had to re-examine the validity of his "tried and true" models, but has been confronted with a hierarchy of new problems he didn't even realize existed.

The National Hurricane Center and the WMO Regional Center for Tropical Meteorology, co-located at Miami, are trying to make effective use of the meteorological satellite in the detection, tracking, and classification of disturbances in the tropical and equatorial Atlantic with the primary goal of understanding their structure and the conditions for intensification. As part of this process the Center is evolving a dynamic climatology of these disturbances. To accomplish this without prejudicing the results it has been necessary to redefine analysis models and disturbance types, mainly to generalize the description of circulations which support disturbances. The purpose here is to define or describe analysis models used at the National Hurricane Center and present some examples of disturbances which are being studied. Finally, a census of the Atlantic disturbances which were identified and tracked by the Regional Center in 1968 will be presented and compared with the census for 1967.

BACKGROUND ON TROPICAL MODELS

More than two decades ago students of tropical meteorology were being taught to apply the model concepts of Gordon Dunn (1935), Herbert Riehl (1951), and others concerning isallobaric waves, or waves in the easterlies, the intertropical convergence zone, and the shear line in the tropics. Kinematically, most of these models have withstood the tests of time and, with minor variations as to format, are to be found in tropical analyses at most forecast centers the world over. There are a few notable exceptions. Some meteorologists are not convinced that the classical easterly wave exists, especially in the Pacific, nor that the ITC, as a continuous east-west zone of convection in the equatorial trough, is a valid concept for synoptic analysis. The meteorological satellite has been of great service in clarifying these questions. Nevertheless, much uncertainty continues concerning the sources and the energetics of these disturbances as well as the environmental circulation properties which cause intensification. Long before satellite information was available it was clear that wave disturbances have no single unique source, nor single unique circulation setting for intensification. The meteorological satellite reveals further complications. It must now be acknowledged that some migratory disturbances producing general rains of synoptic scale occur in the absence of vorticity or divergence patterns which can be identified from synoptic scale observations, even in data-rich regions further supported by information from research aircraft. In view of the new questions raised, it has appeared to us that our attempts to develop more effective analyses to identify the seedlings from which severe storms grow should begin by redefining and generalizing the analysis models. The following model definitions are in use currently at the National Hurricane Center:

INTERTROPICAL CONFLUENCE (ITC). A nearly continuous "fluence line" representing the principal asymptote of flow in the equatorial trough.

TROPICAL DISTURBANCE (T_d). A discrete rain system generally 100 - 300 miles in diameter of non-frontal, migratory character.

TROPICAL WAVE (TW). A T_d which is reflected in the circulation as a trough or cyclonic curvature maximum in the trade wind easterlies.

TROPICAL DEPRESSION (T_c). A T_d associated with closed circulation in the lower troposphere, maximum winds less than 34 knots.

SHEAR LINE. A line of maximum horizontal shear frequently associated with the remnant deformation of old frontal zones which have reached a barotropic environment.

The ITC is defined as a circulation entity rather than a zone of weather. Experience shows that the so-called inter-tropical convergence zone involves cloudiness which may be associated mainly with wind-speed convergence, with confluent flow, with cyclonic eddies, or a combination of these. Therefore, it seems more appropriate for purposes of analysis to define a circulation entity which may produce the characteristic cloudiness of the equatorial trough than simply to identify the cloudiness by a pair of railroad tracks of varying width which does not explicitly relate to circulation.

There is no question about the existence of wave disturbances in the trade wind easterlies. The uncertainty concerns the structure and the source of these disturbances. For this reason we employ the term tropical wave as a general classification of all migratory wave disturbances regardless of structure or source.

Since many migratory disturbances are apparently associated with vorticity or divergence patterns which cannot be detected from a field of synoptic scale observations (e.g. J. Simpson et al 1967), we define the tropical disturbance, T_d, as a migration system of organized convection several hundred miles in diameter which maintains itself for a minimum of 24-hours. As such it is the basic generic form which, in successive stages of intensification may be designated the tropical wave (TW), the tropical cyclone (T_c) in which a closed circulation is identified, and the more severe forms--the tropical storm and hurricane.

THE INTERTROPICAL CONFLUENCE

Perhaps the only way one can truly appreciate both the validity and the role played by the ITC in generating and supporting seedling disturbances is to view a movie of daily, weekly, biweekly, and monthly changes of cloudiness in the trade wind and equatorial trough regions. Such a movie developed for ESSA by the Walter Bohan Company from AVCS mosaics has been made and is available at many meteorological centers. The technique used was to integrate the daily digital data stored on tape from the AVCS satellite for successive periods of 30 days, 15 days, and 5 days during 1967.

Sequences of 30 and 15-day average cloudiness, May to November 1967, show particularly the predominance, continuity, and seasonal migration of ITC cloudiness. From this sequence one acquires the impression that almost all the important action in the tropics and the equatorial trough originates with, or occurs on, this clearly identified band of convection. However, in the sequence of 5-day and single-day averages, one comes to realize this initial impression was a deception. In the latter, the ITC cloudiness is much less continuous both in time and in space. One sees here disturbances entirely separate from the ITC emanating from Africa and leap frogging across the Atlantic. There seems to be a pulsating character of cloudiness from a maximum one 5 day period to a minimum the next. During early September, one sees Beulah, then Chloe emerging from the African region directly into the trade winds, Beulah moving westward across the Caribbean Sea, Chloe moving northwestward toward the mid-Atlantic coastline. Finally, Doria joins the grouping near Norfolk at mid-month. The experience at the National Hurricane Center in analyzing the daily AVCS satellite mosaics is that the most important disturbances, from the viewpoint of potential for intensification, that is hurricane seedlings, are often quite innocuous appearing cloud systems as compared to the flamboyant cloudiness associated with the ITC circulations. The seedlings appear to be embedded entirely within the trade winds.

<u>Figure 1</u> is a typical analysis of what is known as the "TOE chart"--"Top of the Ekman Layer". This is presented here mainly to indicate the circulation concept of the ITC or intertropical confluence line. Often the ITC extends across the Atlantic and Eastern Pacific as an almost continuous line.

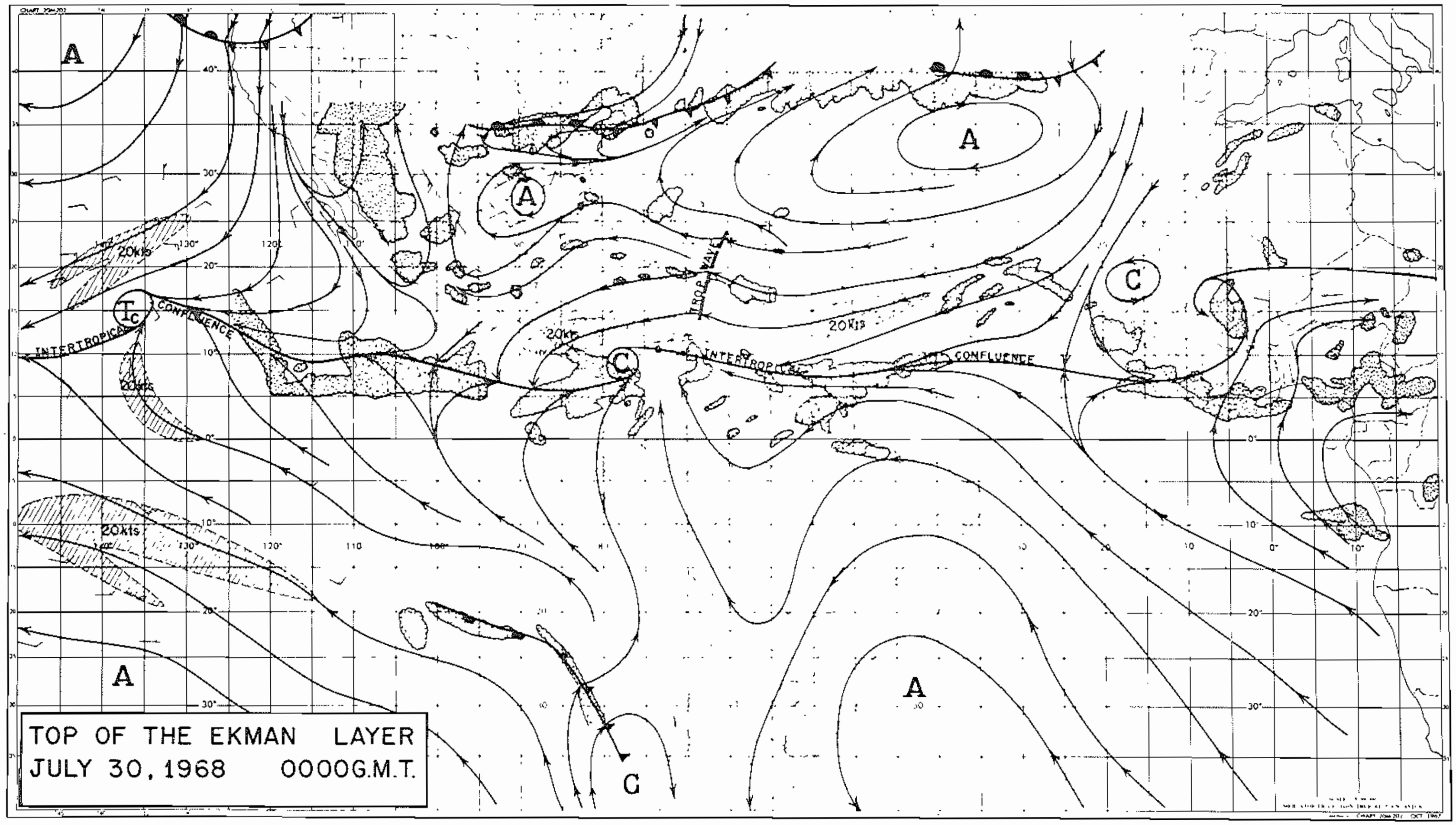

Figure 1. Streamline analysis of the "Top of the Ekman layer" (TOE) charts. This analysis is based upon winds 3000 feet above the surface. Ship winds at deck level are superimposed to assist in the directional analysis. Stippled areas represent the cloudiness viewed by satellite.

However, it is not necessarily a continuous zone of cloudiness. Moreover, there are periods when this asymptote becomes disfigured into a succession of cusps or cyclonic vortices. It is of no small interest in this regard to note that rarely is the ITC found in its undisturbed or continuous form both in the Atlantic and in the eastern Pacific simultaneously. When the eastern Pacific breaks up into a series of cusps or eddies, the Atlantic tends to become more undisturbed, and vice versa. This chart identifies a tropical wave and a depression (T_c).

HURRICANE SEEDLINGS AND THEIR SOURCES

The Hurricane Center is mainly concerned with disturbances which can be tabbed as hurricane seedlings. It is not always easy to "separate the wheat from the chaff" in this regard. However, as experience accumulates it appears that the largest number of hurricane seedlings emanate from the African continent separate from the ITC. Those which originate on the ITC remain benign until they break away and embed themselves in the trade winds. Still others have their origin in cold lows which migrate into the trade wind regimes. Finally, and most curiously, some disturbances originate in the sub-tropics, the initial falls of pressure seemingly associated with accelerations of a baroclinic environment which becomes quickly modified. Additional pressure falls then depend upon the release of latent heat.

Figure 2 is a satellite mosaic of convective systems over the African continent.* The surface and 700 mb circulations have been superimposed. A continuous parade of such systems move out into the Atlantic mainly

*Analyses supplied by Dr. Toby Carlson

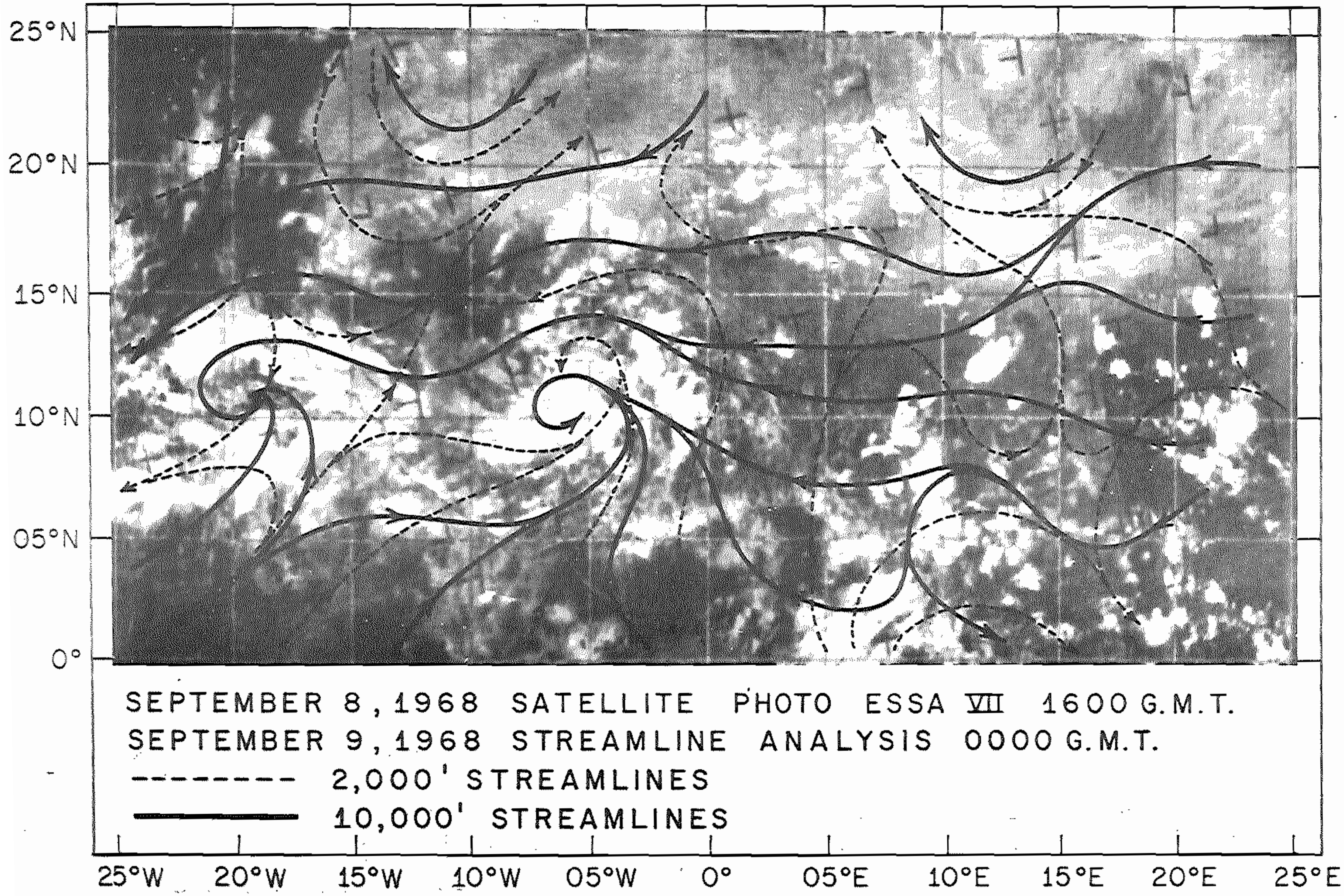

Figure 2. A succession of tropical disturbances in the easterly flow over Africa.

during July, August, and early September. The numbers and the intensity of such disturbances appear to increase with the intensity and westward extension of the easterly jet in the upper troposphere over equatorial Africa. As these depressions emerge into the Atlantic many seem to have closed circulations at some level in the lower troposphere. Nevertheless, as they move westward across the Atlantic they generally degenerate, the evidence of circulation disappears, and they tend to acquire the character of a barotropic wave disturbance similar to the classical easterly wave.

Despite the tendency for deterioration of circulation in the eastern Atlantic, the reasons for which may be associated with cold water in this area, the cloud forms of these disturbances can usually be tracked by satellite with good continuity across the Atlantic and the Caribbean. Many reach the Lesser Antilles with remarkable preservation of the structure observed at Dakar--except of course for the initial closed circulation near the surface.

Figure 3 shows a complex wave form which left Dakar in West Africa on July 22nd and reached the Lesser Antilles six days later. The satellite mosaics for three periods show the sprawling but conserved character of this system as it migrated westward. The time cross-sections for Dakar and Barbados show how the complex or double-wave structure was conserved. It is interesting that within the limits of observational accuracy it is not possible to distinguish a temperature gradient across these waves either at Dakar or Barbados. The warmth in the upper troposphere at both places is undoubtedly associated with the storage of latent heat from

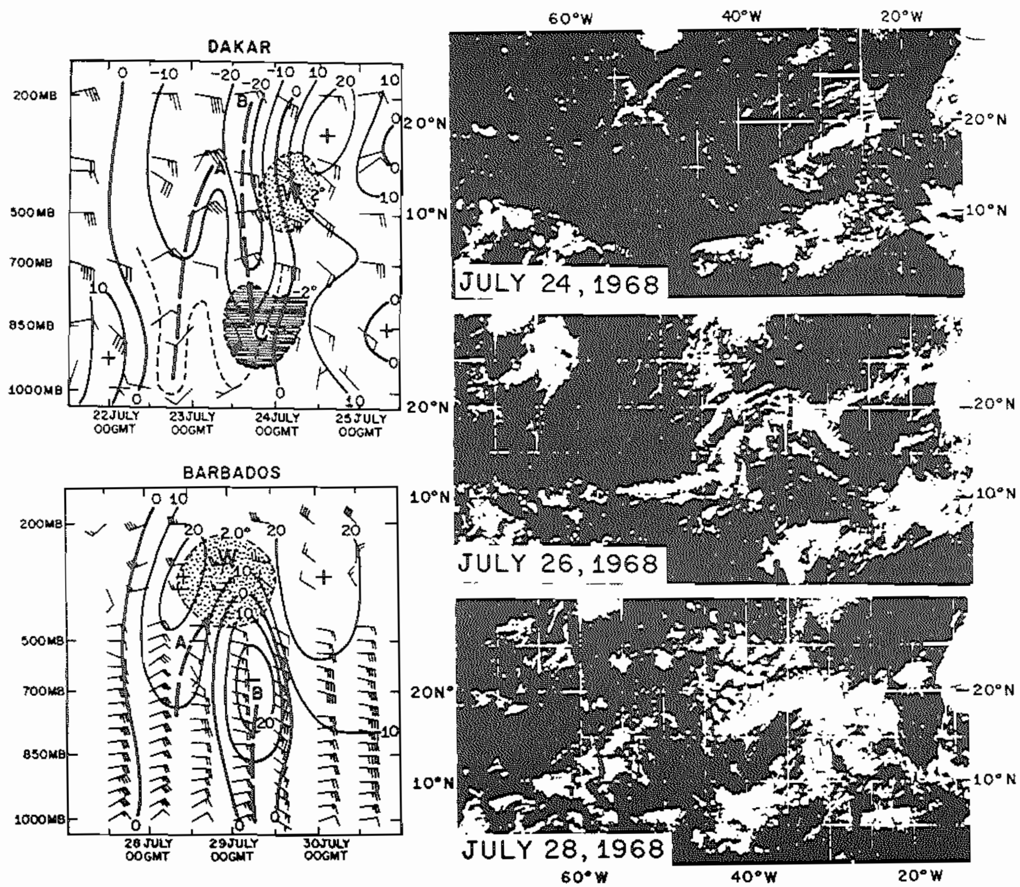

Figure 3. A complex tropical wave in the Atlantic trade winds. The two broken lines on each mosaic represent wave axes of the complex system. The vertical time cross-section at Dakar and later at Barbados shows the double axis form of the system as it left Africa and as it approached the Lesser Antilles.

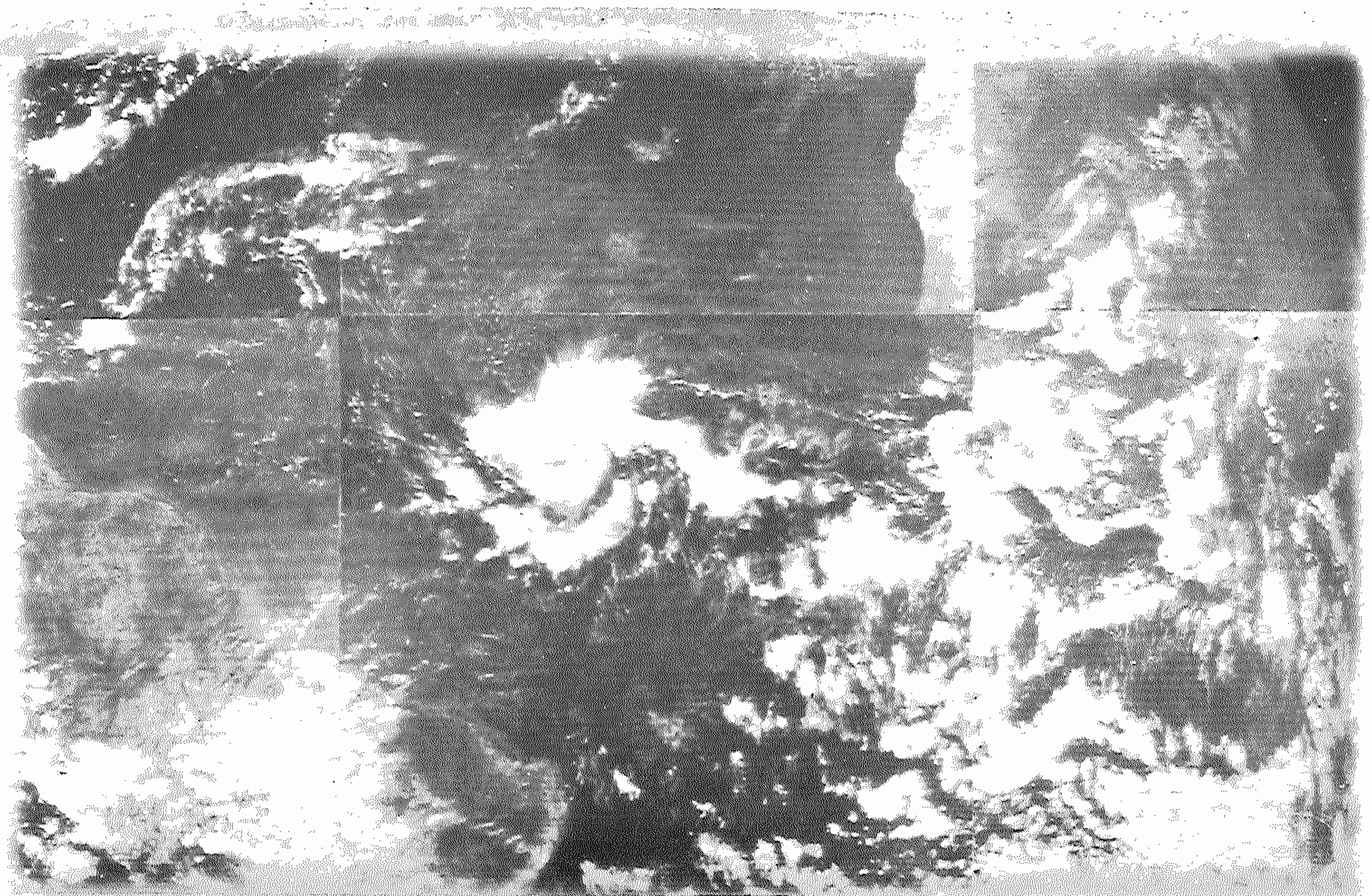

Figure 4. A typical disturbance on the ITCC between the coast of Africa and northeast South America appears in the center of this mosaic with strongly curved massive cloud bands. Note the absence of cloudiness further west along the intertropical confluence.

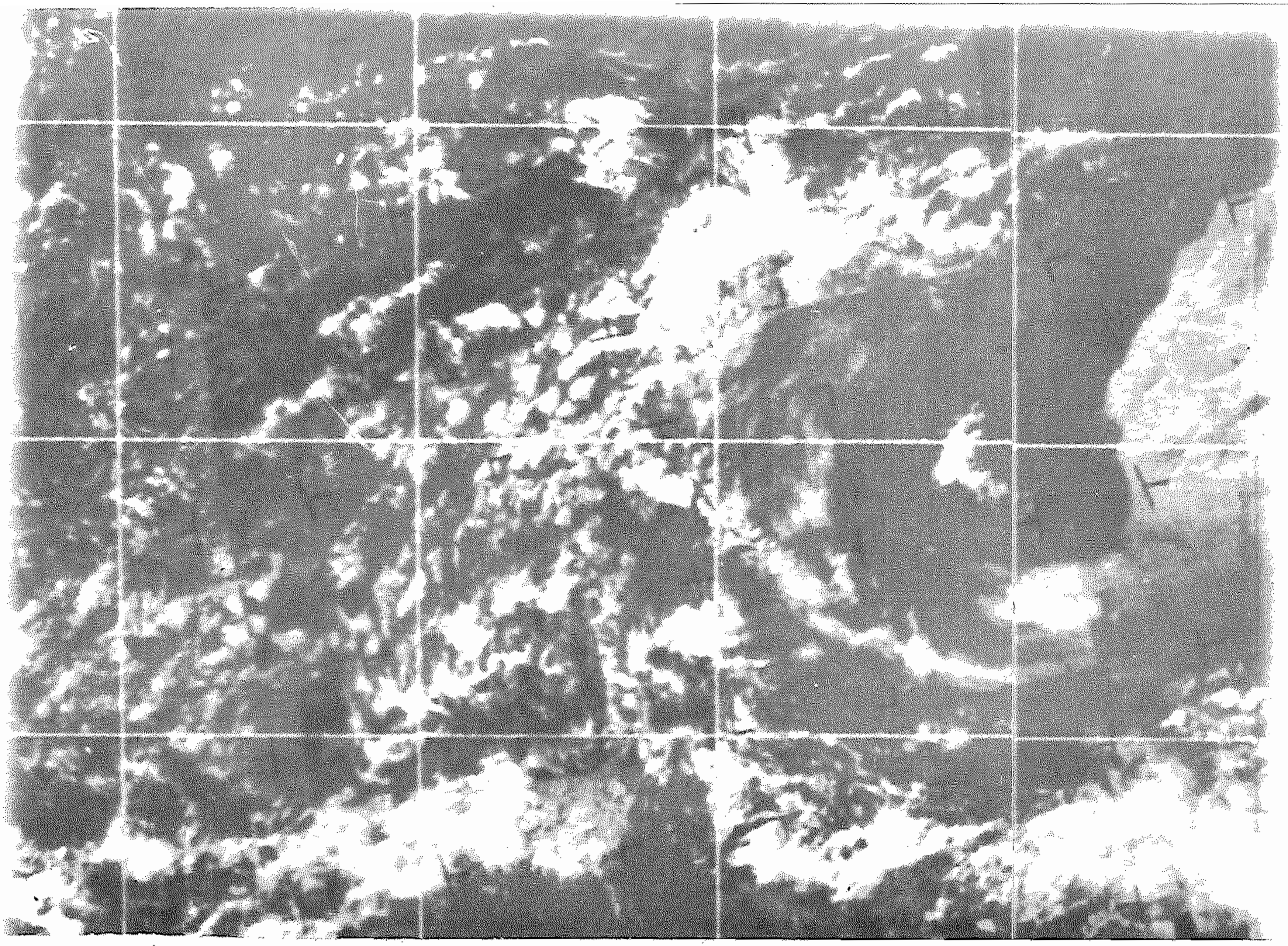

Figure 5. An "inverted V" wave disturbance in the Central Atlantic imbedded in the trade winds north of an active ITC. The latitude and longitude squares are for intervals of 5 degrees. The amplitude of the wave disturbance as regards circulation in the lower troposphere is not self evident from the orientation of cloud lines in this system.

the convection in these waves.

Figure 4 shows a typical disturbance on the ITC which remained benign as it progressed westward from a point near Africa to the South American continent.

Figure 5 shows a typical wave disturbance of the "inverted V" type embedded in the trades (see Frank 1969). While some meteorologists would insist that this is a typical barotropic wave, it is uncertain whether the winds are parallel to the cloud streets or transverse.

Figure 6 shows a pair of disturbances each of which had migrated from the African coast independent of the ITC. The first moved north of the Antilles, became a depression near the Florida Peninsula, intensified and finally became Hurricane Dolly as it recurved northeastward. The second continued westward across the Caribbean. It is shown here as a weak tropical wave. This disturbance migrated across Central America into the eastern Pacific where it became tropical storm Madeline four days later. It is interesting that the second of these disturbances followed a course across the Atlantic which was characteristic of the majority of disturbances in 1968 few of which managed to develop into tropical cyclones, but many of which migrated across Central America to add to the bumper crop of tropical storms in the eastern Pacific where a total of 19 named storms occurred. It is our conclusion that the reason so few disturbances were able to develop in the Atlantic in 1968 while so many developed in the eastern Pacific is that the Atlantic was pervaded by persistent vertical wind shear while the area of the eastern Pacific near Central America had very little wind shear. Gray

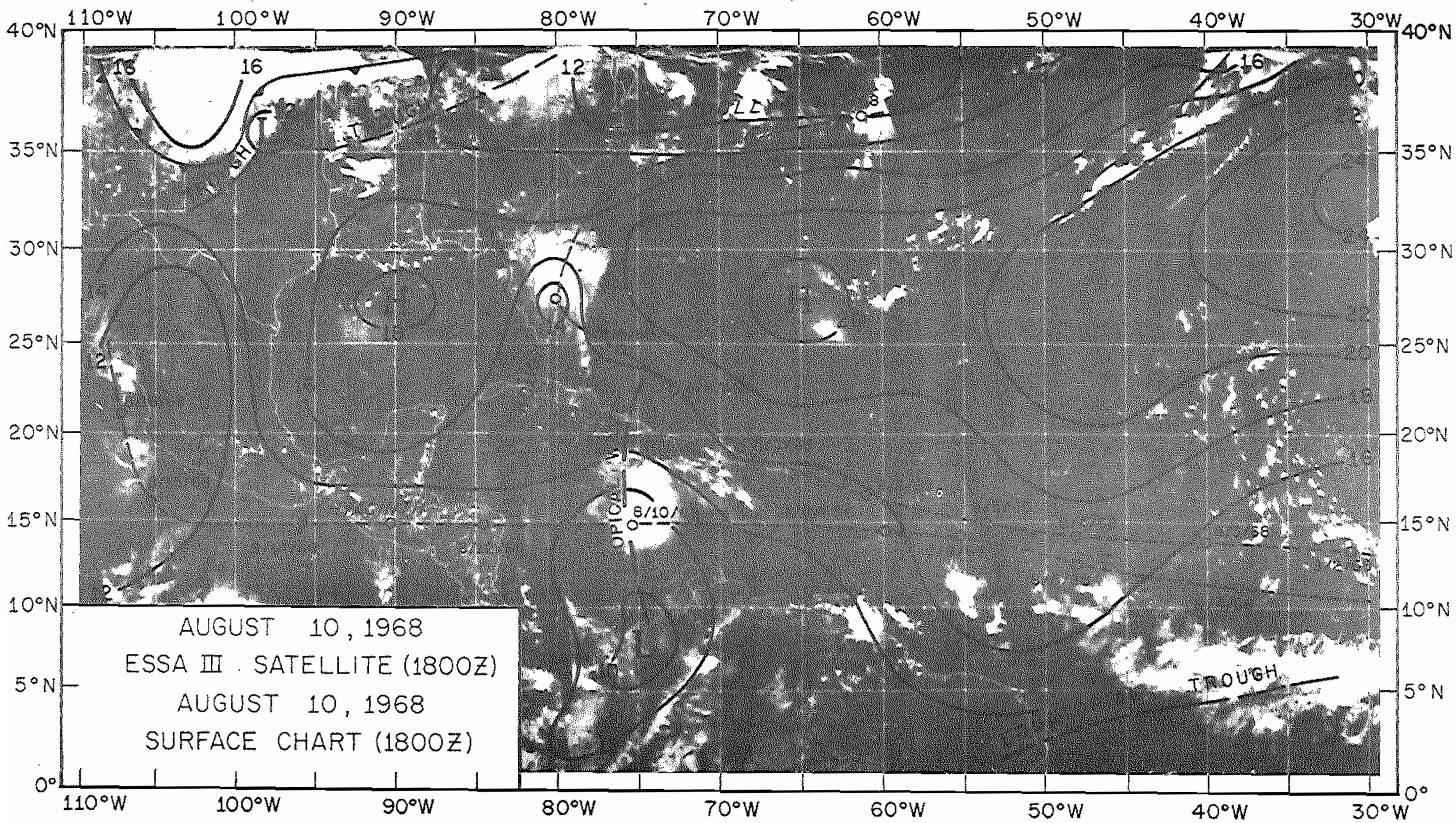

Figure 6. Two tropical disturbances, one at the 75th meridian in the Caribbean, the other near the Florida east coast, each had migrated across the Atlantic from the African coast in the trade winds separate from the ITC.

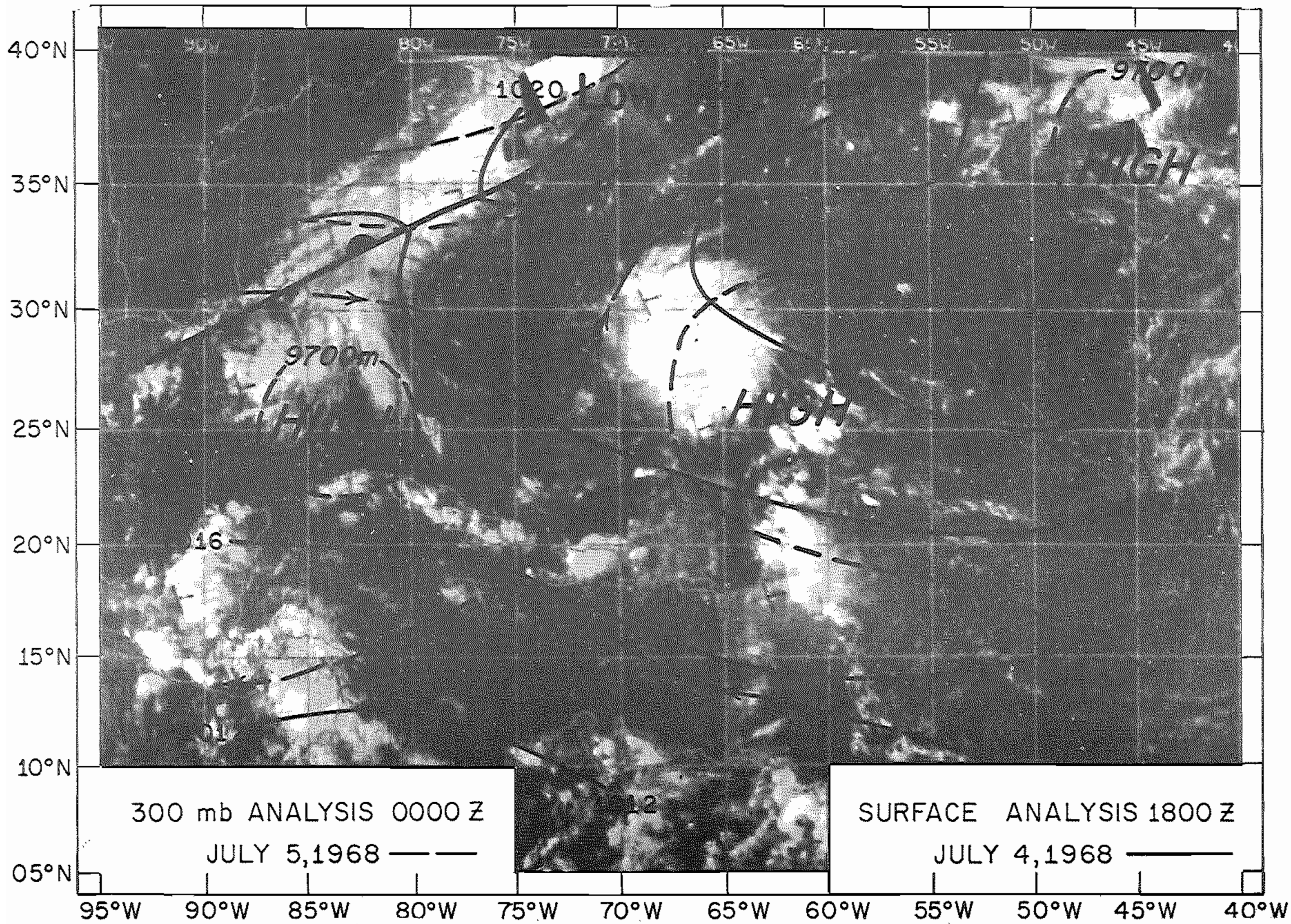

Figure 7. A large sub-tropical disturbance near the 65th meridian which is not closely associated with the synoptic scale circulations of either the lower or upper troposphere.

and others have pointed out that development of disturbances into hurricanes requires the presence of a minimum vertical wind shear. The experience in 1968 supports this conclusion.

Figure 7 is an example of a subtropical disturbance which never developed but which puzzled the analysts and forecasters both at the National Environmental Satellite Center and the National Hurricane Center this summer. This interesting cloud pattern has all the earmarks of a rapidly developing tropical cyclone. Yet as you can see, the surface pressure beneath this disturbance was 1023 mb and there was no evidence of a cold low or of cyclonic activity in the upper troposphere to support this area of convection. As a migratory disturbance this system moved northeastward and gradually dissipated.

TROPOSPHERIC MEAN CIRCULATIONS

The weak gradients of atmospheric properties in the tropics make it difficult to identify the conservative properties and reject the local and transitory influences when one analyzes the circulation. In seeking a means of filtering the transitory embroidery of circulations and retaining those which bear conservatively on movement and intensification, The National Hurricane Center has experimented during the past year with a series of deep layer mean circulation charts with encouraging results.

Figure 8 shows four charts which have come to be highly valued and are presently analyzed daily at this Center. I should like to acknowledge at this point that the use of these charts was inspired by the work of Sanders and Burpee (1967) who spent 9 months at the Center

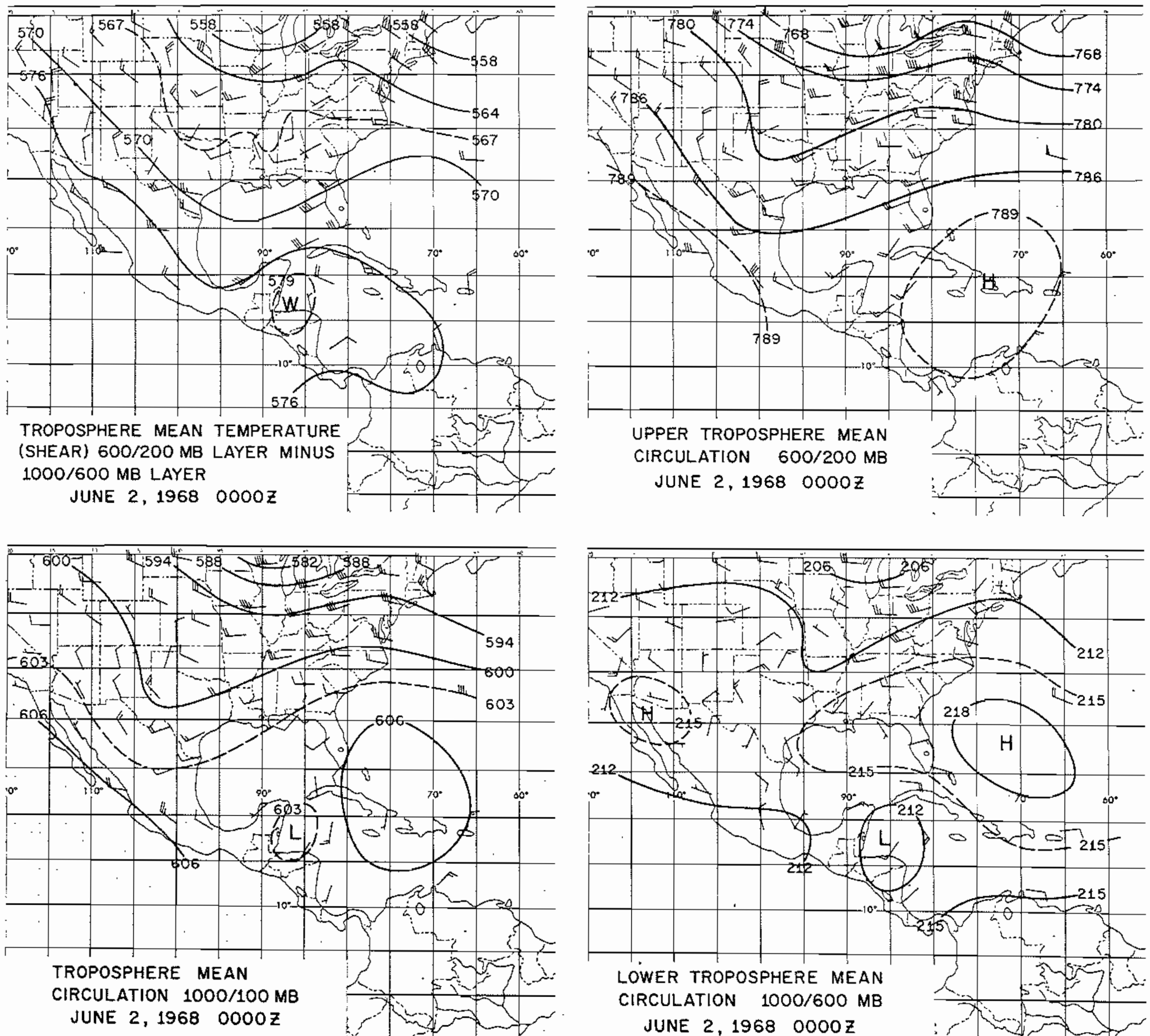

Figure 8. Examples of troposphere mean circulation and temperature analysis for the tropical Atlantic and Caribbean.

working on a hurricane prediction method which applies a barotropic model to a tropospheric mean wind analysis. In the lower right panel is a mean circulation analysis for the layer 1000 to 600 mb; in the upper right 600 to 200 mb; in the upper left the subtraction of these charts shows the vertical shear of the mean wind for the troposphere, and finally in the lower left the total tropospheric mean chart 1000 to 200 mb. The last of these has been shown to be a conservative indicator of the instantaneous motion of tropical storms, and the shear chart in the lower right has proved to be a valuable tool in identifying the areas which are available for deepening or intensification due to low shear. The other two charts retain the conservative features of wave disturbances while rejecting the more transitory details which sometimes confuse the analyst. We expect the emphasis in future years to be upon further application of these mean charts from which we hope to develop basic prediction programs.

SUMMARY OF 1968 ATLANTIC TROPICAL DISTURBANCES

Now let us turn to the 1968 (Simpson et al, 1969) census of Atlantic tropical disturbances and see how this year's production compared with that of 1967 (Simpson et al, 1968).

Figure 9 shows schematically the source regions and migrations of all classes of disturbances, identifying those which intensified into storms or hurricanes. A total of 110 separate disturbances were logged and tracked by the Regional Center in 1968. Of these, 56 (about half of them) emanated from Africa, 17 of which were initially part of an ITC

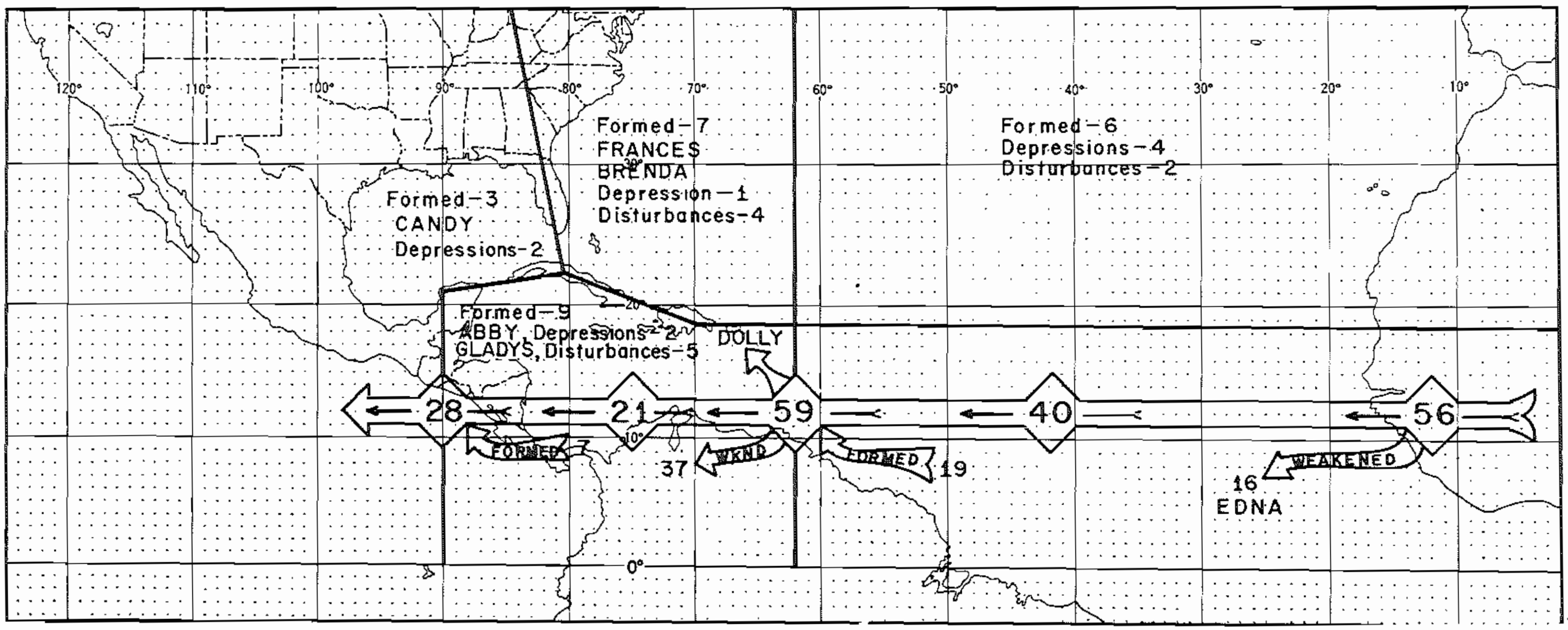

Figure 9. Sources of tropical disturbances in the Atlantic and the migration of these disturbances during 1968.

Monthly comparisons of Atlantic tropical systems in 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	--	--	
	29	22	30	57	(10)

( ): ITC disturbances which passed south of Dakar and would not have been considered in 1967.

Figure 10. A comparison of the tropical disturbance censuses for 1968 and 1967

system. The 40 which survived the Atlantic crossing were joined by 19 others which formed in the Atlantic. A total of 28 crossed the Caribbean, emerged into the eastern Pacific, and contributed to the abundant cyclogenesis west of Nicaragua. Only 7 Atlantic tropical storms formed in 1968. Of these, 4 formed from African waves. In the eastern Pacific, however, 19 storms occurred, at least 4 directly from African waves, and a larger number from the conjunction of African waves with pre-existing disturbances in the East Pacific.

Figure 10 compares the 1968 and 1967 censuses, insofar as identification procedures common to both years would permit. Here it is clear that intensification occurred more readily in 1967 than in 1968, although the number of African wave disturbances in 1968 was almost twice that of 1967. The interesting question of course is what inhibited itensification in 1968.

Figure 11 compares the 700 mb circulation of August for these two years. The isopleths here represent the mean geopotential of August 1968 minus that of 1967. While there was little difference in geopotential at low latitudes, in 1968 there was decidedly lower geopotential than in temperate latitudes in 1967. This reflects in part the fact that storm tracks over the central Atlantic moved at a lower latitude in 1968 than in 1967 and baroclinic conditions intruded more deeply into the tropics with appreciable vertical shear of the horizontal wind.

Figure 12 compares the surface circulation for August 1968 with that of 1967. While the 1016 mb isobar is identically located both

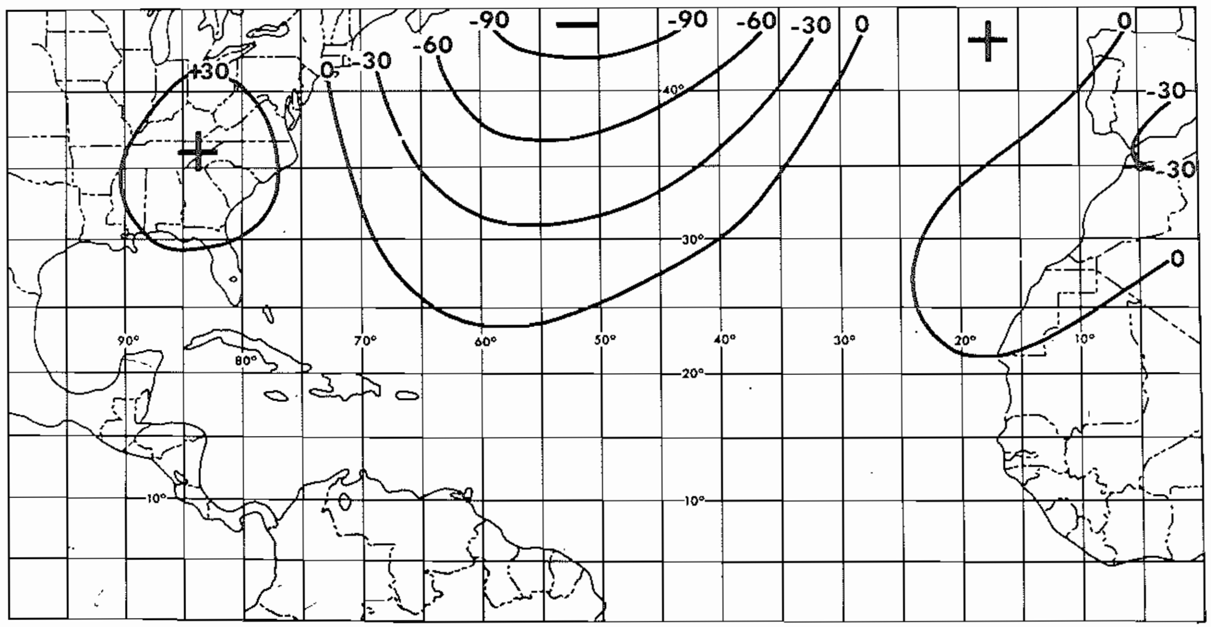

Figure 11. The difference in mean geopotential for August 1968 and that of 1967. Units are in decameters.

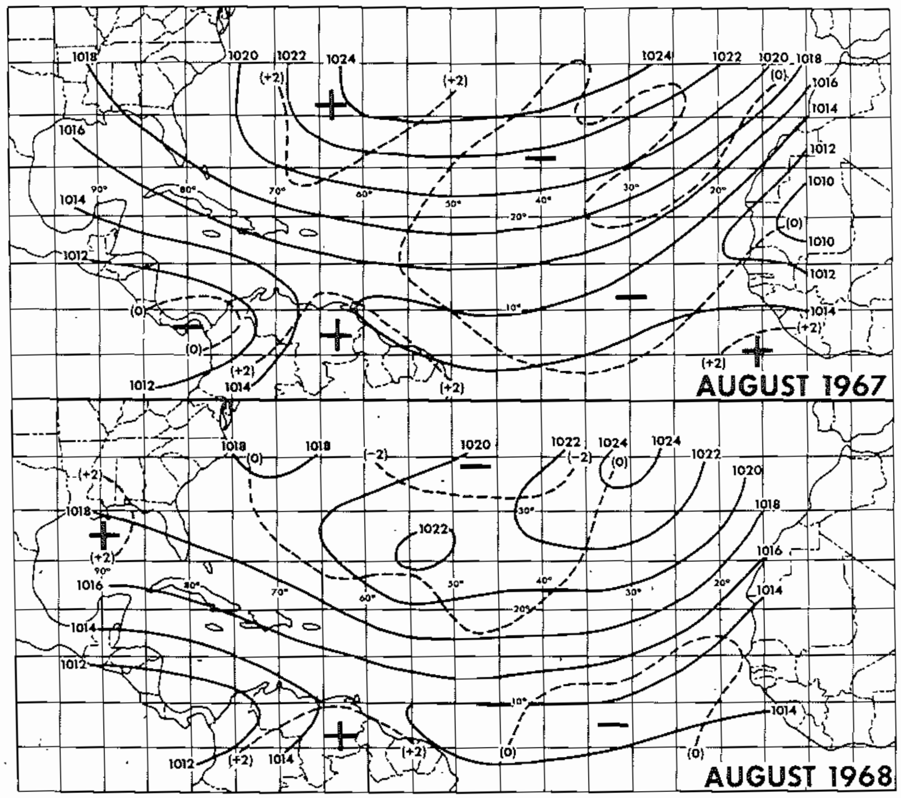

Figure 12. A comparison of the surface circulation of August 1968 with that of 1967.

years, the trade winds were more vigorous and the easterlies deeper in 1967 than in 1968. This suggests that the occurrence of "hurricane seedlings" may not correlate positively with the depth and strength of easterlies although this condition may relate directly to the potential for intensification.

Figure 13 shows the August mean circulation at 200 mb. The semi-permanent trough or shear line in the Atlantic, extending from north of the Azores to Puerto Rico was more persistent in 1967 than in 1968 but was significantly further south in 1968 than in 1967. This feature again works to increase the vertical shear and thus to inhibit intensification.

In 1968 tropical cyclogenesis occurred only in those circulation environments where the vertical shear of mean winds for the lower and upper troposphere was less than 10 knots. This supports the findings of Gray (1968) and others relating vertical wind shear and tropical cyclogenesis.

CONCLUDING REMARKS

There is a hierarchy of disturbance types and sources in the tropical Atlantic. Apparently only those which become or remain embedded in the trade wind circulation can be considered hurricane seedlings. The total number of disturbances in a season does not specifically relate to the strength or depth of the easterlies, nor to the number which can be expected to intensify into severe storms. At least one of the necessary conditions for intensification, though not for continued existence of the disturbance, is the presence of minimum vertical wind shear.

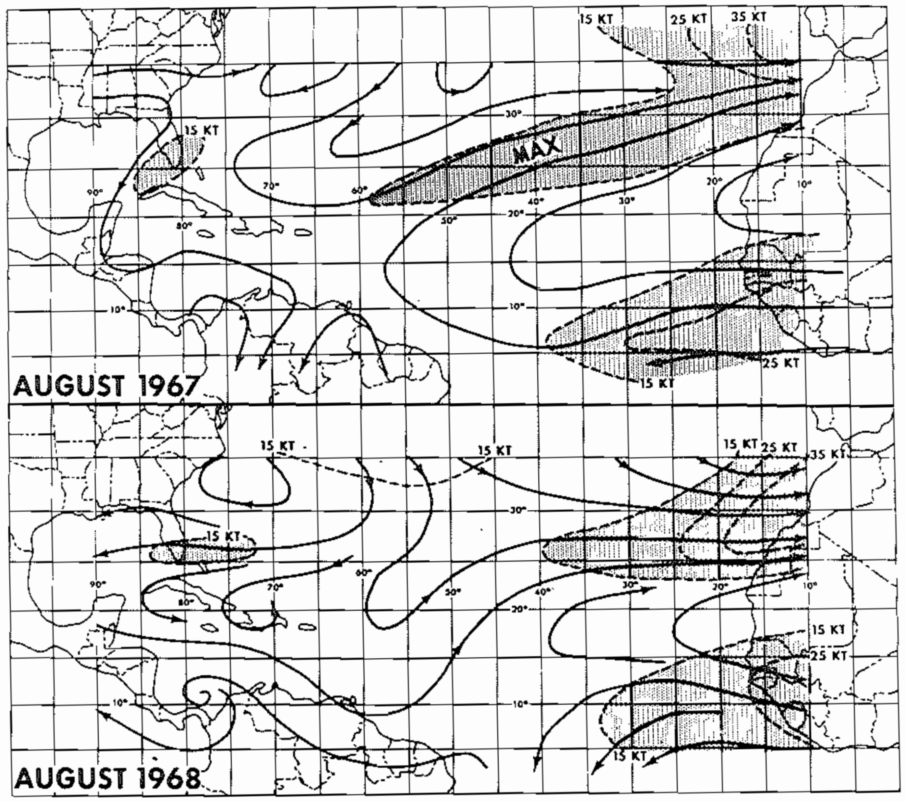

Figure 13. A comparison of the 200 mb circulation for August 1968 with that of 1967.

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