Atlantic Tropical Systems of 1993

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ABSTRACT

A total of 70 tropical waves (also known as African or easterly waves) were counted in the Atlantic basin during the 1993 hurricane season. These waves led to the formation of 9 of the 10 total number of tropical cyclones in the Atlantic hurricane basin. It appears that tropical waves led to the formation of practically all of the eastern Pacific tropical cyclones in 1993.

1. Introduction

The importance of westward-propagating disturbances, referred to as tropical waves (also called African or easterly waves), has been recognized for more than half a century (Dunn 1940). These disturbances, which are usually traced back to western Africa, can lead to the formation of tropical cyclones over the Atlantic and eastern Pacific basins. Typically, the strongest Atlantic hurricanes of the year originate from tropical waves (e.g., Landsea 1993).

Initially, the waves were detected as series of centers of falling and rising sea level pressure moving from east to west across the Atlantic. When upper-air observations became available, it was noted that those pressure centers were accompanied by a cyclonic wind shift (typically from northeast to southeast) that is largest near the 700-mb level. Currently, satellite images are an extremely valuable supplement to surface and upper-air data for the tracking of tropical waves.

The primary purpose of this annual article is to tabulate and summarize certain weaker synoptic-scale systems of 1993, namely, tropical waves and tropical depressions. Tropical waves were identified and tabulated using satellite imagery and surface and upper-air observations across the Tropics from Africa to Central America. Since some tropical waves have very poor cloud definition, it is difficult to track such waves across the data-sparse tropical Atlantic areas, and there is a certain amount of noise in their identification and positioning. In general, when deep convection was minimal or absent and the cloud pattern was not well defined, the position of such waves was estimated by continuity. Figure 1 is a vertical–time section of the wind for Trinidad for 1–15 September 1993. Similar time sections, prepared for several stations along the Atlantic tropical belt, are used in conjunction with daily satellite imagery to locate the waves. The presence of a lower-tropospheric cyclonic wind shift and/or the propagation of an organized and distinct cloud mass are the primary parameters used in locating the wave axis.

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2. Census of the 1993 Atlantic systems

Tropical cyclone activity in the Atlantic continued below normal in 1993. The season featured a total of eight named tropical cyclones, four of which became hurricanes. Additionally, there were two tropical depressions that did not intensify into tropical storms. Excluding one tropical depression that formed from a disturbance of nontropical origin, all of the 1993 systems developed from tropical waves.

For a third consecutive year, residents of the Caribbean were not affected by a hurricane. As noted by Pasch and Rappaport (1995), no hurricane was observed south of 21°N in 1993. This lack of hurricanes over the lower latitudes of the Atlantic basin for three consecutive seasons is a rather unusual event. Nevertheless, the rainfall associated with Tropical Storms Bret and Cindy and the developing stages of Gert killed 222 people in the Caribbean and Central America. In addition, floods caused by the first tropical depression of the season killed seven people in Cuba.

a. Tropical depressions

In terms of tropical depression frequency, 1993 continued to be below average with a total of only 10 tropical depressions as compared to the average of 19 for the period of 1967–92. August and September were the two most active months of the year, with four trop-

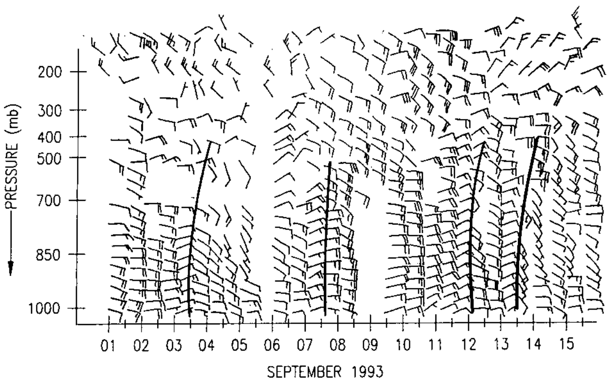

FIG. 1. Vertical time section of the wind at Trinidad from 1 to 15 September 1993. Winds plotted every 12 h according to convention with each full barb and half barb denoting 5.1 and 2.6 m s^{-1}, respectively, and the solid flag denoting 25.7 m s^{-1}. Thick lines indicate the positions of the tropical wave axes.

ical depressions each. One depression was observed in May and another one in June. No depressions formed in July, October, or November. Figure 2 shows the Atlantic tropical depression tracks for 1993. Those depressions that did not reach tropical storm status are described herein. Depressions that did reach tropical storm intensity are described in Pasch and Rappaport (1995).

1) Tropical Depression One

The development of Tropical Depression One appears to be related to the interaction of a tropical wave with a broad lower-tropospheric cyclonic circulation over Central America. The wave exited the coast of Africa on 13 May and reached the western Caribbean on 25 May. At that time a midlevel trough over the Gulf of Mexico drew the intertropical convergence zone (ITCZ) northward over Central America, resulting in the formation of a broad low-level circulation near Cozumel, Mexico. Weather conditions gradually deteriorated over the northwest Caribbean, and surface pressures were falling. The weather system moved east-northeastward to near the Isle of Youth, Cuba, where it became the first tropical depression of the 1993 season on 31 May. Figure 3 shows Tropical Depression One approaching Cuba.

Surface observations from Cuba indicated that the poorly defined center of the tropical depression moved over the central region of that island and then into the Straits of Florida just east of Varadero, Cuba, early on 1 June. A short-wave trough approaching from the west forced the depression to accelerate northeastward over the Bahamas to near Nassau and over the Atlantic.

Observations from a reconnaissance plane indicated a minimum pressure of 999 mb between 1 and 2 June and a few spots of strong winds well removed from the center. The wind field continued to expand outward from the center and the depression gradually acquired extratropical characteristics on 2 June.

Due to the prevailing westerly vertical wind shear, most of the thunderstorms were located east of the center of the depression. Those strong bands of convection produced heavy rains, primarily over portions of central and eastern Cuba, Jamaica, and Hispaniola. In Cuba, rainfall totals ranged from 150 to 600 mm. Heavy rains were also reported over portions of South Florida.

In a broadcast monitored in Miami, Florida (*Miami Herald*), Cuba's radio stations reported that the intense rains associated with the depression left seven people dead, including a two-year-old girl who fell from her mother's arms into floodwaters. The report also mentioned five people missing, about 230 homes destroyed, and another 3700 damaged by the downpour. More than 40 sugar mills were incapacitated.

2) Tropical Depression Ten

Tropical Depression Ten was a short-lived tropical cyclone that formed late on 29 September. On 26 September, a mid- to upper-tropospheric trough located several hundred kilometers east through southeast of Bermuda appeared to induce the formation of a surface trough. The surface trough moved slowly west-northwestward, then northwestward, for a couple of days. The system formed into a weak surface low on 28 September and turned to a more northerly heading. On the following day, the surface circulation associated with the low became distinct, and a tropical depression formed about 300 km south-southeast of Bermuda. The depression accelerated northward just to the east of Bermuda and then merged with a cold front very early on 31 September. The weather at Bermuda was not significantly affected by the depression. Figure 4 is a satellite image of Tropical Depression Ten.

b. Tropical waves

Figure 5 shows that during 1993, 70 tropical waves crossed the northwest coast of Africa and moved westward over the tropical Atlantic, the Caribbean, and Central America, and appeared to continue into the eastern Pacific. The average period of the waves was 3.05 days, which is very similar to the period that was observed during the past three years. The first tracked wave exited Africa on 2 May and the last one crossed Dakar during late November.

For the third consecutive year, tropical waves appeared to be poorly defined in the wind and cloud fields relative to other years wherein large-amplitude waves were observed to move off the coast of Africa (e.g., Simpson et al. 1968). However, a comparison of vertical time sections from several rawinsonde stations has

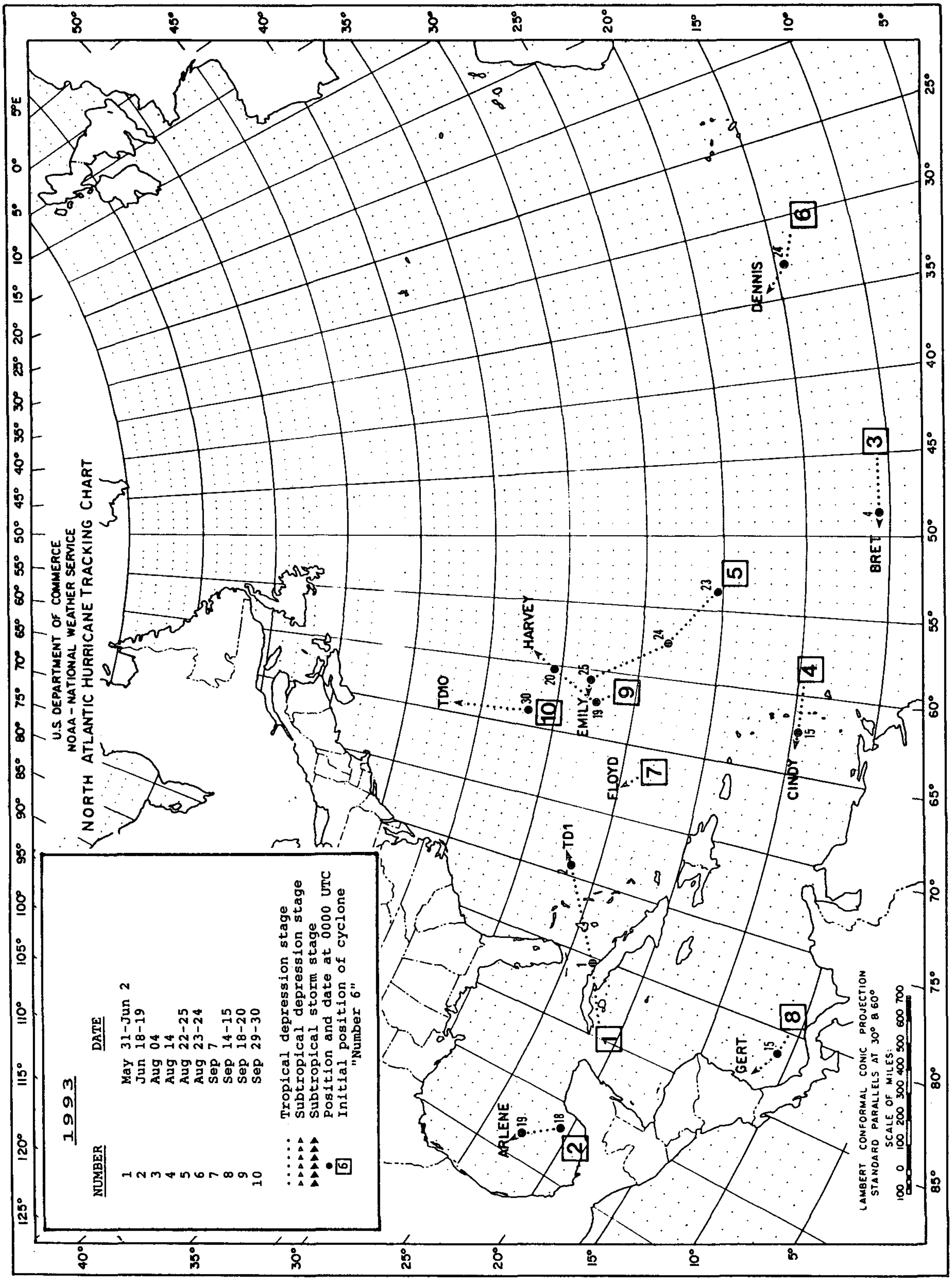

FIG. 2. Tropical depression tracks for 1993.

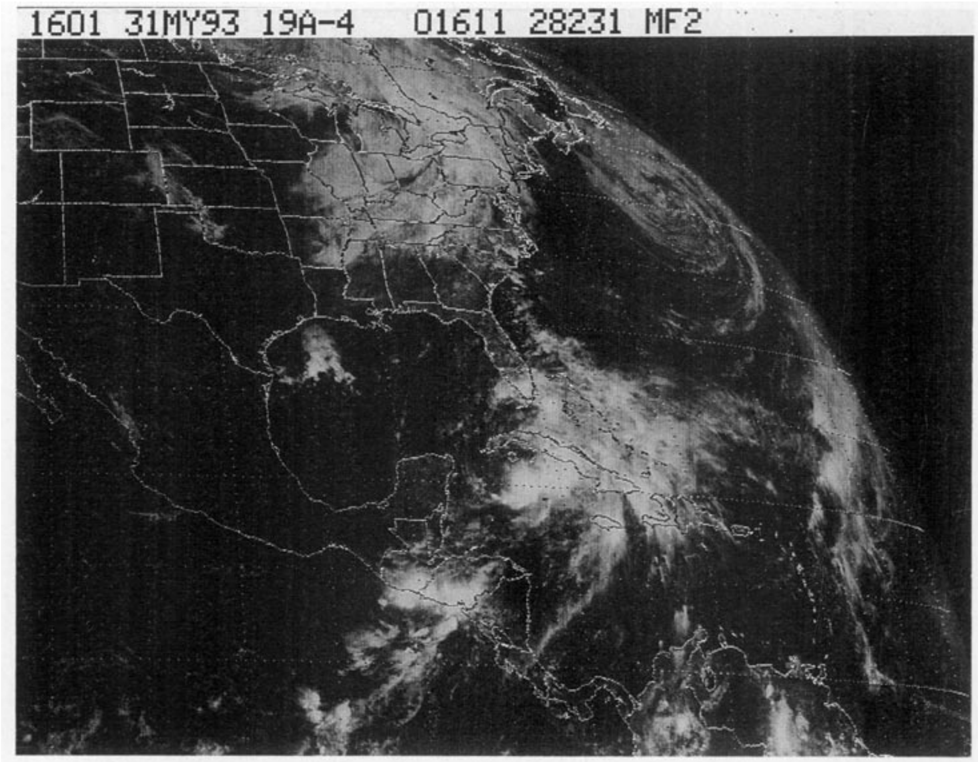

FIG. 5. GOES-7 visible satellite picture of Tropical Depression One at 1601 UTC 31 May 1993. The poorly defined center is to the west of the cloud mass that is spreading over Cuba and adjacent waters.

consistently shown that the wind shifts associated with the waves were more marked in 1993 than in 1992. In addition, during 1993 the westward propagation of the convective cloud clusters associated with many of the tropical waves was easily discernible on satellite images. For example, by inspecting Fig. 1, one detects a marked wind shift associated with the wave that passed over Trinidad on 12 September, while the convection associated with this wave can be traced back for several days in the longitude versus time satellite images displayed in Fig. 6. This weather system became Gert in the southwestern Caribbean a couple of days later.

Some other characteristics of the 1993 waves can be inferred from Fig. 7a, which depicts the average low-level (approximately 900 mb) wind anomalies for August. During that month, an anomalous monsoon-type flow extended northward across the tropical Atlantic to about 18°N where a large anomalous cyclonic flow prevailed. This region of anomalous cyclonic flow centered along 20°N from 60°W to Africa in Fig. 7a is probably related to the primary path of the vorticity maximum associated with the waves during August. Since that anomalous region was located over relatively cool sea surface temperatures, the development of deep convection associated with the waves moving through that area was very limited. For example, the tropical wave that triggered Emily exited northwest Africa and continued westward along 17°N as a well-defined low-to midlevel circulation (as indicated by visible satellite imagery) but devoid of deep convection. The system did not intensify until it reached the western Atlantic where the ocean was warmer and deep convection developed.

Another group of tropical waves moved westward through lower latitudes than usual (between 5° and 10°N), spreading their associated maximum convection over South America. In active years, the maximum cyclonic curvature in the wind field and the strong thunderstorm activity associated with the waves usually extends from around 10°N northward into the Atlantic and through the Caribbean. The waves caused some convection over portions of the Caribbean during 1993 as indicated in Fig. 6. Near-normal rainfall or positive rainfall anomalies over the eastern Caribbean during August and September of 1993 (Climate Analysis Center 1993a,b) were probably related to the passage of convectively active tropical waves.

Figure 7b suggests the low-level flow pattern underwent a reversal during September, when anticyclonic flow anomalies became established over the tropical Atlantic east of 50°W. At the same time, a region of anomalous cyclonic flow was observed over the eastern Caribbean area. This could be interpreted to signify that the waves were generally weaker in September over

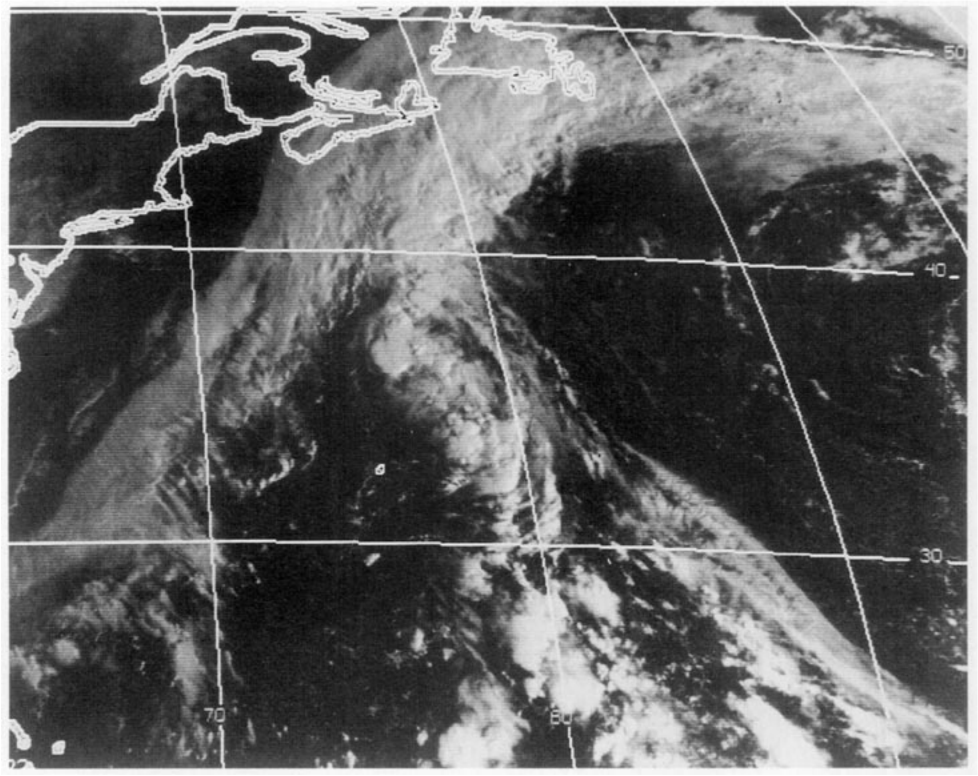

FIG. 4. Meteosat visible satellite picture taken in the morning of 30 September 1993 of Tropical Depression Ten.

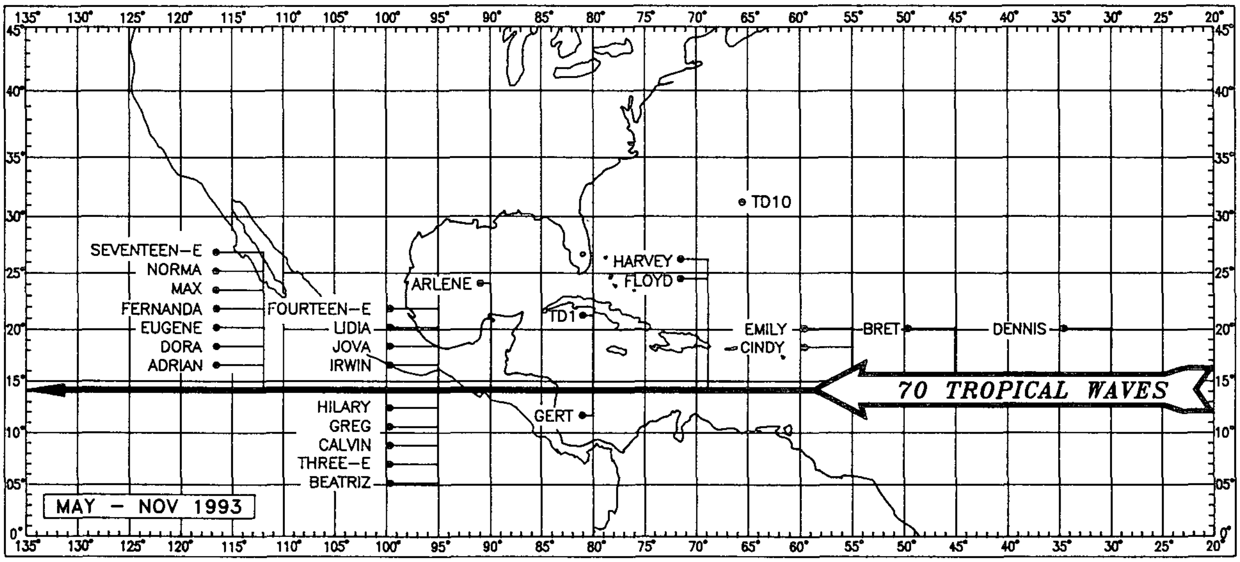

FIG. 5. Total number of waves that maintained their identities while traveling the Atlantic, Caribbean, the Gulf of Mexico, and the eastern Pacific. The figure highlights the longitude bands in which tropical cyclones developed. Over the Atlantic basin, the separate dot (for TD10) denotes the approximate location of the tropical cyclone formation from a nontropical disturbance.

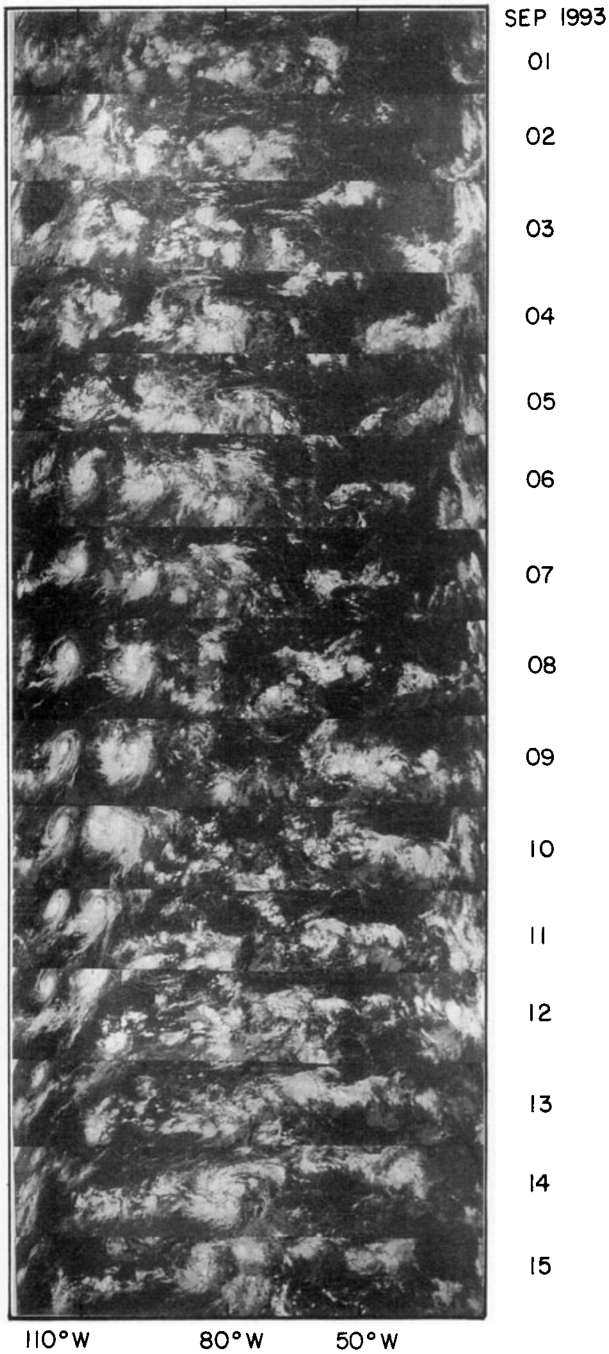

FIG. 6. Time sequence of Meteosat infrared images taken once a day at 1500 UTC from 1 to 15 September 1993. The daily images cover the area from roughly the equator to 20°N. Note the sequence of distinct cloud masses spreading westward from the Atlantic through the Caribbean and into the eastern Pacific associated with tropical waves.

the eastern Atlantic and became better defined as they approached the eastern Caribbean. The positive rainfall anomalies over the eastern Caribbean during September support this argument. Historically, September is the month during which the most active tropical waves emerging from the west coast of Africa have a significant potential to develop into intense tropical cyclones.

The last tropical storm of the 1993 season formed around mid-September. On 23 September, the upper-tropospheric flow over the eastern tropical Atlantic around 15°N reversed from an easterly to a westerly component. This change produced an increase in the vertical wind shear, thus diminishing the potential for tropical waves to develop. Climatologically, this event would be expected to occur a few weeks later. A similar early reversal of the upper-level flow was observed in 1992 (Pasch and Avila 1994).

In contrast with 1991 and 1992, when most of the tropical cyclones developed from nontropical sources (Pasch and Avila 1994), 9 of the 10 tropical cyclones in 1993 developed from tropical waves over the Atlantic and the Caribbean. Those tropical cyclones are represented in Fig. 5 by lines attached to the main "stream" of waves. As in the two previous years, none of the tropical cyclones attained hurricane strength south of 21°N. The strong vertical wind shear appeared to be the main inhibiting factor during 1991 and 1992, as indicated by Gray (1992) and Mayfield et al. (1994). In 1993, the interaction of several waves with land may have been a major factor in inhibiting devel-

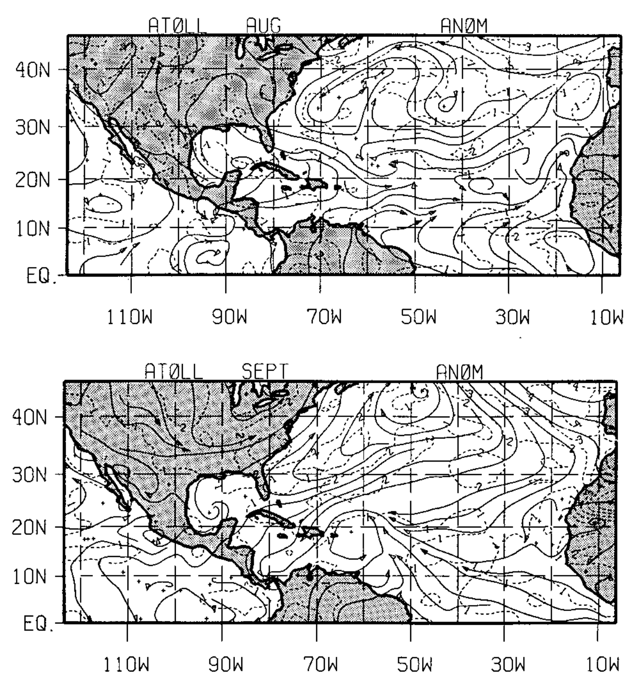

FIG. 7. (a) Average low-level (approximately 900 mb) wind anomalies for August 1993. Anomalies are the mean for 1993 minus 1975–93 average. Units are meters per second. The acronym ATOLL refers to analysis of the tropical oceanic lower layer. (b) Same as (a) but for September 1993.

opment. Low-latitude systems that seemed to have the most potential for significant development moved over the landmasses of South and Central America or Hispaniola (i.e., Bret, Gert, and Cindy). Notwithstanding, vertical wind shear may have had some adverse effect on the strengthening of Bret when it was approaching the Lesser Antilles, and on Cindy when it was over the eastern Caribbean Sea.

The development of eastern Pacific tropical cyclones from tropical waves has been suggested previously by Frank and Clark (1980). During the summer months it is typical for weak vertical shear to prevail over the warm Pacific waters to the south of Mexico, and tropical cyclogenesis in this region is frequently favored. In 1993, it is likely that tropical waves again played a significant role in the formation of the majority of the eastern Pacific tropical storms (Avila and Mayfield 1995). These waves usually take more than a week to traverse the Atlantic and Central America after emerging from West Africa. In Fig. 6 one can observe the westward propagation of the convection associated with some of the tropical waves crossing Central America from the Caribbean into the eastern Pacific. Some of those systems clearly developed into tropical cyclones over the latter basin. The cloud system that crossed Central America around 4 September, and later became Hurricane Lidia, is a good example.

Figure 5 shows two longitude bands centered along 100° and 112°W, where the majority of the eastern Pacific tropical cyclones likely formed from tropical waves. In some cases, particularly for those eastern Pacific tropical cyclones that formed closer to Central America, it is possible that the orographic effects of the adjacent mountainous landmass can aid in their formation, as theorized by Zehnder (1991).

3. Comparison with other years

Figure 8a and Table 1 show the number of tropical waves from 1967 through 1993. In 1993, the number of waves was somewhat higher than the average. However, year to year variations in the total number of waves are probably not significant. Since the process of identifying tropical waves has not been uniformly applied over the years, one must be careful in interpreting the total number of such events.

Table 1 indicates that peaks in the number of tropical waves do not coincide with peaks in the number of tropical storms. This reaffirms Frank's (1975) statement that the number of waves is not related to the total number of tropical storms. The large-scale atmospheric and oceanic environment exercises the largest control on the yearly variation in the number of tropical storms forming from tropical waves.

Table 1 and Figs. 8b,c show the seasonal totals of tropical depressions and storms since 1967. A trend

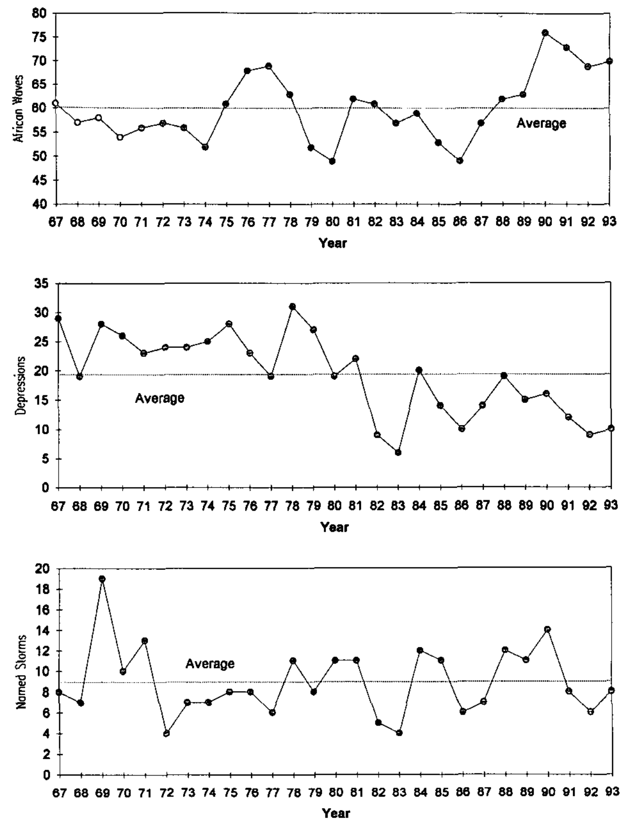

FIG. 8. (a) Total number of tropical waves from 1967 to 1993. Horizontal dashed line represents the average for the 1967–92 period. (b) Same as (a) but for tropical depressions. (c) Same as (a) but for named storms.

toward fewer tropical depressions per year began around 1980, as indicated by Avila and Pasch (1992). In 1993 that trend continued, with a total of only 10 depressions, a number that is well below the more recent 1980–92 average of 15. It is likely that during the 1967–80 period, some nontropical cyclones may have been classified as tropical depressions. Examples of such cases have been documented by Pasch and Avila (1994).

Figure 9a displays the ratio of the number of tropical depressions of African origin to the total number of tropical depressions per year (ratio 1). Low values of ratio 1 indicate that a high number of depressions originated from upper-tropospheric cold lows or along frontal zones, that is, from nontropical "seedling" disturbances (Frank 1975). In light of the above discussion on depression totals, the values of ratio 1 prior to 1980 may be somewhat questionable. However, for completeness, the entire record is presented here. In 1993, ratio 1 was 0.9, a number that is substantially higher than that observed in 1991 or 1992, when many depressions originated from nontropical sources. Furthermore, this value was higher only in 1989.

TABLE 1. Atlantic tropical systems statistics for 1967–93.

Year	Waves	Total TD[a]	Total TS[b]	Total H[c]	African TD	African TS	African H	Ratio African TD / Total TD	Ratio African TS / Total TS	Ratio African H / Total H
1967	61	29	8	6	14	5	5	0.48	0.63	0.83
1968	57	19	7	4	8	4	2	0.42	0.57	0.50
1969	58	28	18	12	16	10	8	0.57	0.56	0.66
1970	54	26	10	5	16	7	3	0.82	0.70	0.60
1971	56	23	13	6	12	6	2	0.52	0.56	0.33
1972	57	24	4	3	6	1	1	0.25	0.25	0.33
1973	56	24	7	4	10	4	2	0.42	0.57	0.50
1974	52	25	7	4	12	5	4	0.48	0.71	1.00
1975	61	28	8	6	14	5	5	0.50	0.63	0.83
1976	68	23	8	6	10	5	5	0.43	0.63	0.83
1977	69	19	6	5	7	3	2	0.37	0.50	0.40
1978	63	31	11	5	18	6	4	0.58	0.55	0.80
1979	52	27	8	5	20	8	5	0.74	1.00	1.00
1980	49	19	11	9	14	8	6	0.78	0.73	0.66
1981	62	22	11	7	17	6	6	0.77	0.55	0.85
1982	61	9	5	2	6	3	2	0.67	0.60	1.00
1983	57	6	4	3	3	1	1	0.50	0.25	0.33
1984	59	20	12	5	8	5	1	0.40	0.42	0.20
1985	53	14	11	7	9	8	5	0.64	0.73	0.71
1986	49	10	6	4	6	3	2	0.60	0.50	0.50
1987	57	14	7	3	11	5	2	0.79	0.71	0.66
1988	62	19	12	5	16	9	4	0.84	0.75	0.80
1989	63	15	11	7	14	11	7	0.93	1.00	1.00
1990	76	16	14	8	12	10	5	0.75	0.71	0.62
1991	73	12	8	4	7	3	0	0.58	0.38	0.00
1992	69	9	6	4	4	2	1	0.44	0.33	0.25
Average	59	20	9	5	11	6	4	0.58	0.59	0.62
1993	70	10	8	4	9	8	4	0.90	1.00	1.00

[a] TD: tropical depression.
[b] TS: tropical storm.
[c] H: hurricane.

The ratio between the number of tropical storms of African origin to the total number of tropical storms (ratio 2) has been found to be a useful parameter to describe the overall character of the hurricane season (Avila and Clark 1989). Figure 9b and Table 1 display the values of ratio 2 since 1967. The 26-yr average contribution from tropical waves to the total number of storms was 0.59. In 1993, ratio 2 was 1.00, a marked increase from the low values of 1991 and 1992. Such a high value occurred only in 1979 and 1989.

Typically, tropical waves are the main source of hurricanes for the Atlantic basin. There have been exceptions, namely, the 1971, 1972, 1977, 1983, 1984, 1991, and 1992 seasons, when tropical waves induced only a few hurricanes. The 1993 season was different from those years in the sense that all of the named storms developed from tropical waves, as occurred in 1989 and 1979. However, the 1993 season was similar to 1991 and 1992 by virtue of the fact that the tropical cyclones did not reach hurricane strength at low latitudes. Table 1 shows that on average, 62% of the hurricanes in the Atlantic basin develop from tropical waves. All of the 1993 hurricanes can be traced back to tropical waves.

It is of interest to note that 1991, 1992, and 1993 can be designated as years of generally moderate "El Niño" conditions, based on equatorial Pacific sea surface temperatures and atmospheric indices (Climate Analysis Center 1993b). Many of those years when tropical waves induced only a few storms and hurricanes coincided with moderate to strong El Niño events, as indicated by Gray (1984). Although tropical waves were present during those years, Gray speculated that a hostile environment, induced by El Niño episodes, prevented many of the waves from developing over the deep Tropics in the Atlantic basin.

Avila and Clark (1989) arbitrarily used ratio 2 to quantify the relative contribution to tropical storm development by tropical waves. Years in which ratio 2 is greater than or equal to 0.7 are termed "African"

TABLE 2. Comparison of African, non-African, and average years with season averaged hurricane destruction potential (HDP) and major hurricanes (MH). African years: ratio of the number of tropical storms of African origin to the total number of storms is higher than or equal to 0.70. Non-African years: ratio of the number of tropical storms of African origin to the total number of storms is lower than or equal to 0.50. Average years: ratio of number of tropical storms of African origin to the total number of tropical storms is less than 0.70 and higher than 0.50. HDP: sum of the square of each hurricane's maximum wind for each 6-h period of its existence (Gray et al. 1992) scaled by 10^{-4}. MH: total number of major hurricanes [category 3 or higher on the Saffir–Simpson scale (Simpson 1974)] during those years.

											HDP	MH
African years	1970	1974	1979	1980	1985	1987	1988	1989	1990	1993	62	19
Non-African years	1971	1972	1977	1983	1984	1986	1991	1992			30	7
Average years	1967	1968	1969	1973	1975	1976	1978	1981	1982		55	17

years. "Non-African" years are those for which ratio 2 is less than or equal to 0.5. Intermediate values correspond to "average" years. Clearly, 1993 was an African year, and its tropical character was totally different from the so-called non-African years such as 1972, 1983, and 1992, when most of the storms and hurricanes did not developed from tropical waves.

While ratio 2 provides information about tropical cyclone origin, the hurricane destruction potential (HDP) measures a hurricane's potential for wind and storm surge destruction. The HDP is defined as the sum of the square of each hurricane's maximum wind speed for each 6-h period of its existence (Gray et al. 1992). Table 2 summarizes the African, non-African, and average years, including the HDP and the total number of major hurricanes [category 3 or higher on the Saffir–Simpson hurricane scale (Simpson 1974)]. The average HDP of African years for the 1967–93 period was substantially larger than (more than double) the average HDP of the non-African years. The HDP for 1993 is 23, which is a very low number for an African year. As noted earlier, several 1993 tropical cyclones (Bret, Cindy, and Gert) appeared to have the potential for significant strengthening and thus could have acquired a relatively high HDP. However, the development of these cyclones was restricted by the proximity of the landmasses of the Greater Antilles, South America, Central America, and Mexico.

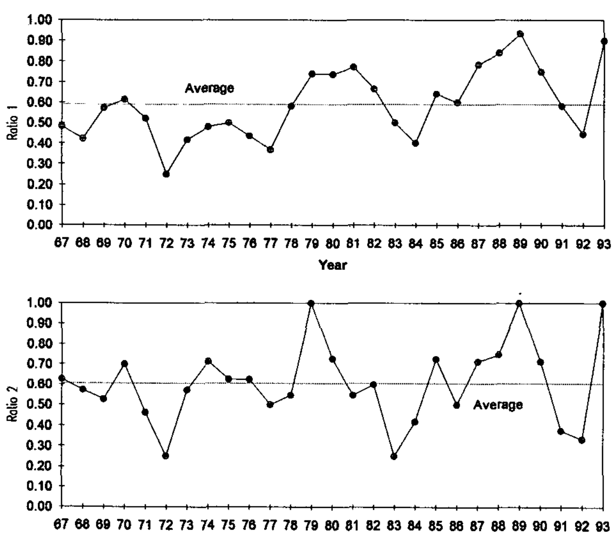

FIG. 9. (a) Ratio of the number of tropical depressions of African origin to the total number of depressions (ratio 1), annually from 1967 to 1993. Horizontal dashed line represents the average for the 1967–92 period. (b) Same as (a) but for named storms of African origin to the total number of named storms (ratio 2).

It has been seen that tropical waves play a dominant role as the precursors to major hurricanes and that the majority of eastern Pacific tropical cyclones can likely be traced back to these waves. In addition, the difference between the two well-established seasons in the Caribbean region (namely, dry and wet seasons) are determined by the passage of such waves. The significance of tropical waves is further highlighted by the fact that these systems are largely responsible for the enhancement of rainfall in the Caribbean area. Therefore, it is important to continue to monitor and to study these systems.

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