ANNUAL SUMMARY

Atlantic Tropical Systems of 1996 and 1997: Years of Contrasts

LIXION A. AVILA, RICHARD J. PASCH, AND JIANN-GWO JIING

NOAA/NWS/Tropical Prediction Center/National Hurricane Center, Miami, Florida

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ABSTRACT

A total of 62 and 63 tropical waves were counted in the Atlantic from May to November during 1996 and 1997, respectively. These waves led to the formation of 12 of the 13 total number of tropical cyclones in 1996 and only 3 of 7 tropical cyclones in 1997. All of the tropical depressions became tropical storms in 1996 and only one failed to become a named storm in 1997. On average, 62% of the Atlantic tropical depressions develop from tropical waves. These waves contributed to the formation of 92% of the eastern Pacific tropical cyclones in 1996 and 83% in 1997. Tropical waves and their environment during the 1996 and 1997 seasons are discussed.

1. Introduction

Tropical waves not only play a dominant role as precursors to tropical cyclone formation over the Atlantic and eastern Pacific Oceans but are also responsible for the modulation of rainfall in the Caribbean Basin (Riehl 1954). The importance of tropical waves has been emphasized in previous updates of this yearly article. References to publications about tropical wave structure and properties are included in Pasch et al. (1998).

This article is concerned with operational tracking of tropical waves in Atlantic and eastern Pacific basins. The primarily purpose is to tabulate and summarize certain weaker synoptic-scale systems of 1996 and 1997, namely tropical waves and tropical depressions. The compilation is then used to update the statistics of such systems, which began in 1967.

2. Data and analysis

The Tropical Prediction Center/National Hurricane Center (TPC/NHC) performs surface synoptic analyses four times daily. The following data/tools are used by the analysts: animation of real-time satellite imagery from Meteosat, *Geostationary Operational Environmental Satellite-8* and *-10* (*GOES-8* and *-10*) that, together, cover the earth from the Indian Ocean westward to the central Pacific. Also the analysts use Hovmöller (longitude vs time) diagrams of imagery from all three satellites and surface reports including 24-h pressure changes from ground stations, ships, and buoys. Radiosonde data are used to construct time series of vertical wind profiles (vertical time sections) from the sounding stations.

In general, the analysis of tropical waves begins with the examination of satellite animation of cloudiness over northern Africa. Areas of concentration of cloudiness with cyclonic rotation (including vortices) were marked and tracked in time as they move westward. Satellite Hovmöller diagrams were examined to identify the time continuity of those areas of cloudiness that exist for several days (a timescale greater than that of mesoscale clusters or squalls). These procedures assure the analysts that they are tracking synoptic-scale systems. Time sections of vertical wind profiles at western African radiosonde stations were checked to identify the cyclonic wind shift as the troughs or vortices moved over those stations.

Once the tropical waves move into the Atlantic Ocean, they can be identified by (a) areas of increased convection, (b) cyclonic curvature in low- to mid-level clouds, (c) increased concentration of stratocumuli on the north side if the waves moved over cooler waters, and (d) ship and buoy reports. Recently, high-density winds derived from satellite imagery (Velden 1997) were also used to analyze and track the tropical waves.

Satellite Hovmöller diagrams were examined for the continuity of the waves as they propagate westward. The analysts can estimate the mean westward motion and period of the waves from the Hovmöller diagrams. If there is no clear cloud pattern over a region where the waves are expected to propagate through, estimated positions were derived based on the derived mean propagation speed.

Corresponding author address: Dr. Lixion A. Avila, Tropical Prediction Center/National Hurricane Center, 11691 SW 17th Street, Miami, FL 33165-2149.
E-mail: lixion@nhc.noaa.gov

When the waves propagated into the Caribbean Sea, time sections from the area were used to identify the passage of the waves and make adjustments to their locations if necessary. Twenty-four-hour surface pressure changes from those stations were also used for the analysis. Additional discussion of the wave-tracking methodology is included in Pasch et al. (1998).

Figure 1 displays vertical time sections of the wind for Dakar and Trinidad from 15 to 30 August 1996 and 1997. Figure 2 shows sequences of twice-a-day satellite images for 15–31 August of 1996 and 1997. This sample represents the period in 1996 when tropical waves were the strongest and most convectively active.

3. Summaries of Atlantic systems

a. The 1996 Atlantic systems

Tropical cyclone activity in the Atlantic during 1996 was above the long-term average of 10 tropical storms and six hurricanes. There were 13 named storms, 9 of which became hurricanes (Pasch and Avila 1999). Two tropical storms and two hurricanes made landfall in the continental United States, and all but Gustav and Isidore affected land. Nine of the systems reached hurricane strength in the deep Tropics between 10° and 20°N. Moreover, six of them, reached category 3 or higher intensity on the Saffir–Simpson hurricane scale (Simpson 1974). All 13 tropical depressions intensified into tropical storms and 12 of the tropical cyclones developed from tropical waves. Those tropical cyclones are represented in Fig. 3a by lines attached to the main ‘‘stream’’ of waves.

Tropical depressions

A tropical depression is officially defined as a tropical cyclone (a nonfrontal, synoptic-scale cyclone originating over tropical or subtropical waters with organized deep convection and definite cyclonic surface wind circulation) in which the maximum 1-min sustained surface wind is 17 m s^{-1} or less. In terms of tropical depression frequency, 1996 was below average with a total of only 13. The average for the period of 1967–96 is 19. There were tropical depressions in each month from June to November. August was the most active month with four tropical depressions and all of them reached hurricane status. Because all the depressions became tropical storms in 1996, their history is provided in Pasch and Avila (1999).

b. The 1997 Atlantic systems

In contrast with 1996, the number of tropical cyclones during the 1997 season was significantly below average. There were six named tropical cyclones of which three became hurricanes and three of the season's tropical cyclones developed from tropical waves, as indicated in Fig. 3b. Hurricane Danny was the only tropical cyclone that made landfall in the United States. In addition, there was a subtropical storm. A detailed summary of the 1997 hurricane season is included in Rappaport (1999).

1) Tropical depressions

The number of tropical depressions in 1997 was significantly below average with a total of eight. This number is less than half of the long-term average of 19. July was the most active month with a total of four tropical depressions. There was one tropical depression in June, another one in September, and two in October. Remarkably, no tropical depressions developed during August. Tropical depression five, the only cyclone triggered by a tropical wave in July, failed to become a tropical storm and it is the only system described in this paper. Figure 4 shows the Atlantic tropical depression tracks for 1997.

2) Tropical depression five

Tropical depression five formed from a tropical wave that emerged from the west coast of Africa on 11 July. The wave moved westward across the tropical Atlantic and finally began to show consistent evidence of a cloud system center. Deep convection associated with the wave became concentrated on satellite images, and it was estimated that the disturbance became tropical depression five around 0600 UTC 17 July while centered about 880 km east of Barbados.

The tropical depression moved toward the west-northwest at 6 m s^{-1}. The first aircraft reconnaissance flight investigated the depression from a flight level near 455 m around 2100 UTC on 17 July and found a cyclonic circulation with 19 m s^{-1} peak winds both north and south of the center. Although satellite intensity estimates never exceeded 15 m s^{-1}, the fact that 19 m s^{-1} winds were measured by the aircraft at flight level to the south of the center suggests that tropical depression five might have been a minimal tropical storm earlier. However because of the reduction of wind speeds from flight level to the surface, and the uncertainties inherent in intensity estimates, this system has been kept as a tropical depression in the postanalysis.

The cloud pattern of the depression soon lost its organization in satellite imagery, and an aircraft reconnaissance flight on the afternoon of 18 July had difficulty in finding a center, suggesting that the system had degenerated into a tropical wave. However, the disturbance continued to show some signs of organization in satellite imagery, and another reconnaissance flight found a very weak circulation center at 1200 UTC on 19 July in the northeastern Caribbean Sea. Convection associated with the wave moved over portions of the Lesser Antilles, Puerto Rico, the Bahamas, and the Florida Straits.

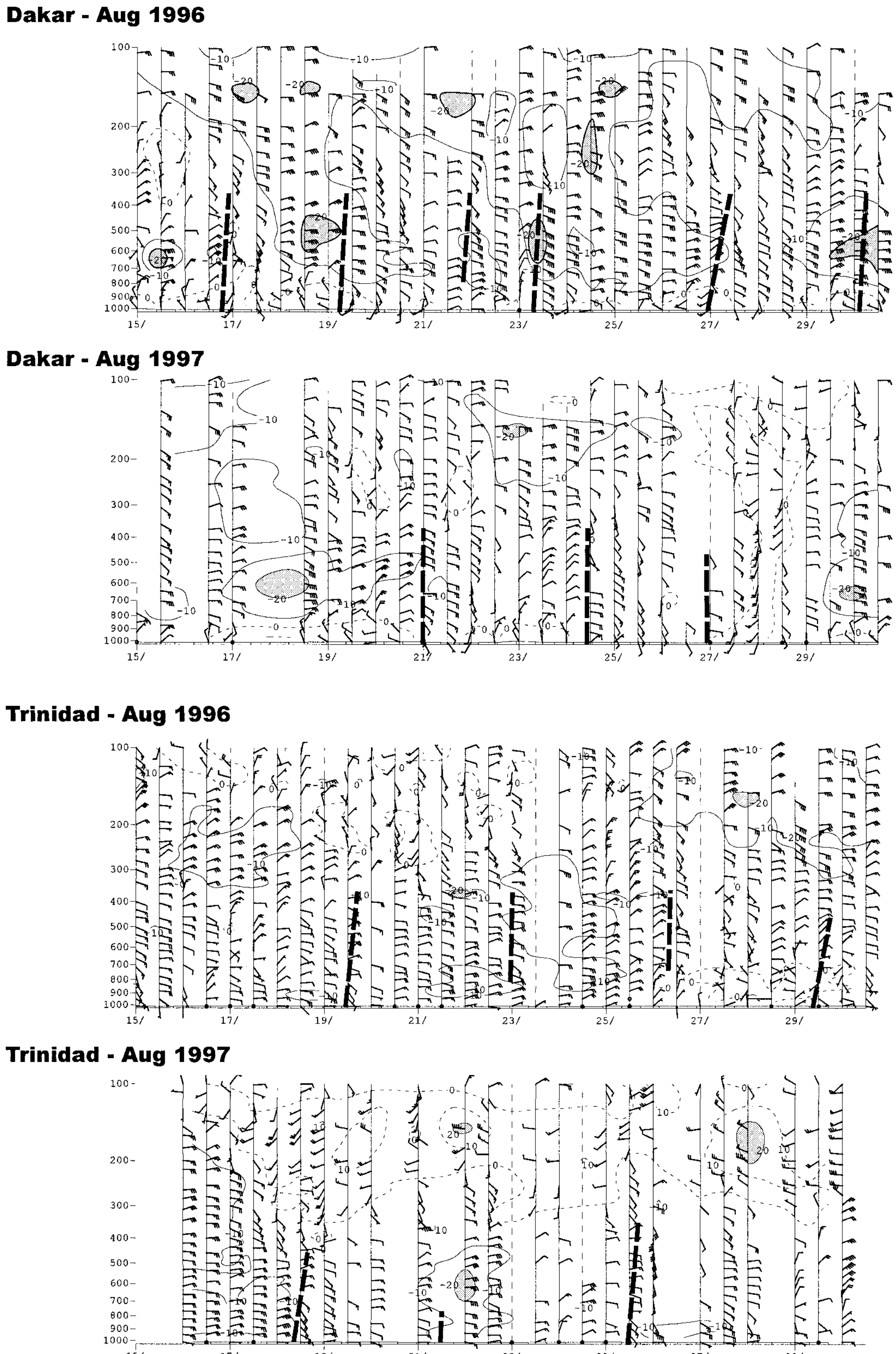

FIG. 1. Vertical time section of the wind at Dakar and Trinidad from 15 to 30 Aug 1996 and 1997. Winds plotted every 12 h according to convention with each full barb and half barb denoting 5.1 and 2.6 m s^{-1}, respectively, and the solid flag denoting 25.7 m s^{-1}. Thick lines indicate the positions of the tropical wave axes.

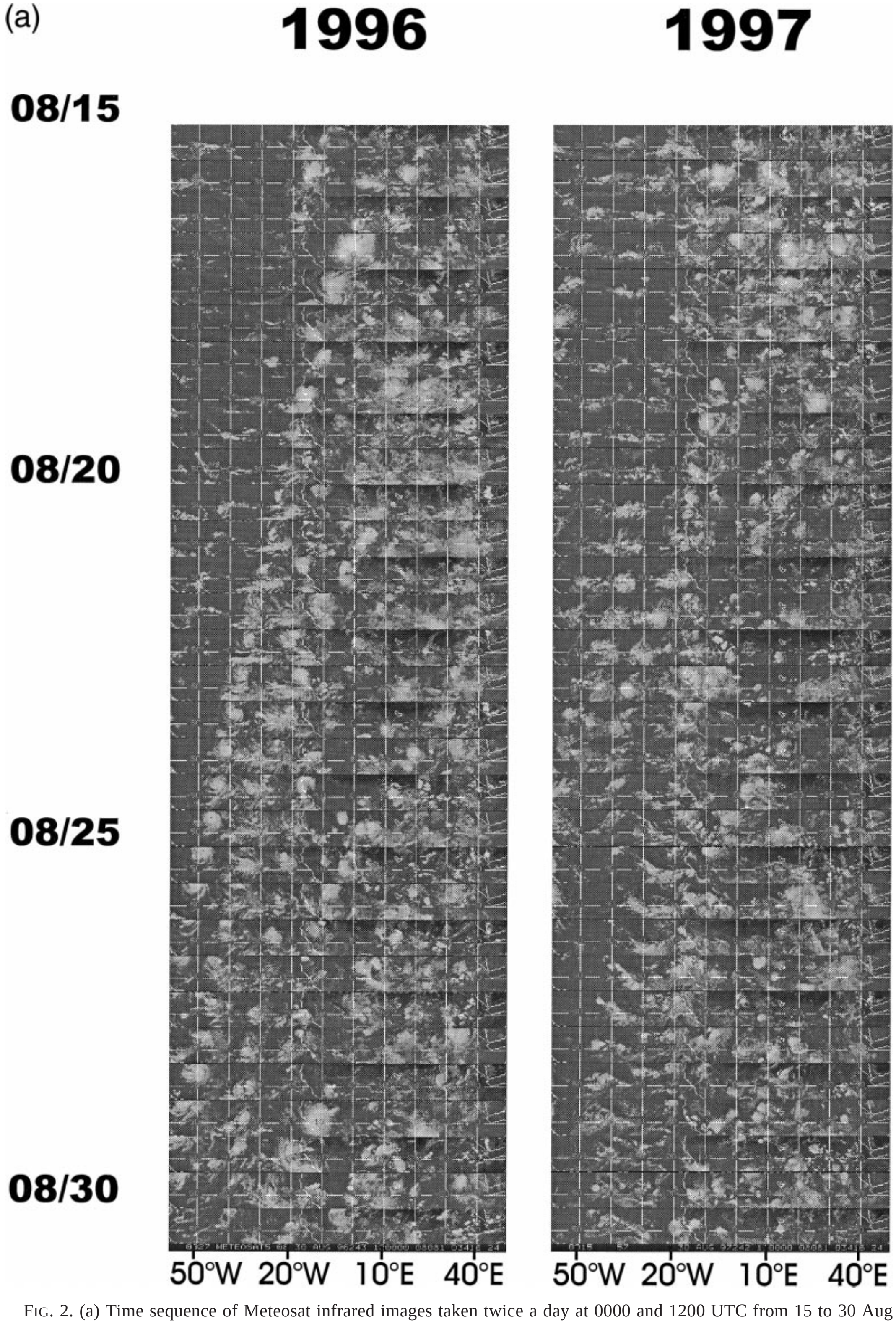

FIG. 2. (a) Time sequence of Meteosat infrared images taken twice a day at 0000 and 1200 UTC from 15 to 30 Aug 1996 and 1997. (b) Time sequence of *GOES-8* infrared images taken twice a day at 1145 and 2345 UTC from 15 to 29 Aug 1996. Dashed lines mark in (b) are the approximately position of selected tropical waves. The latitude belt is roughly 5°–20°N.

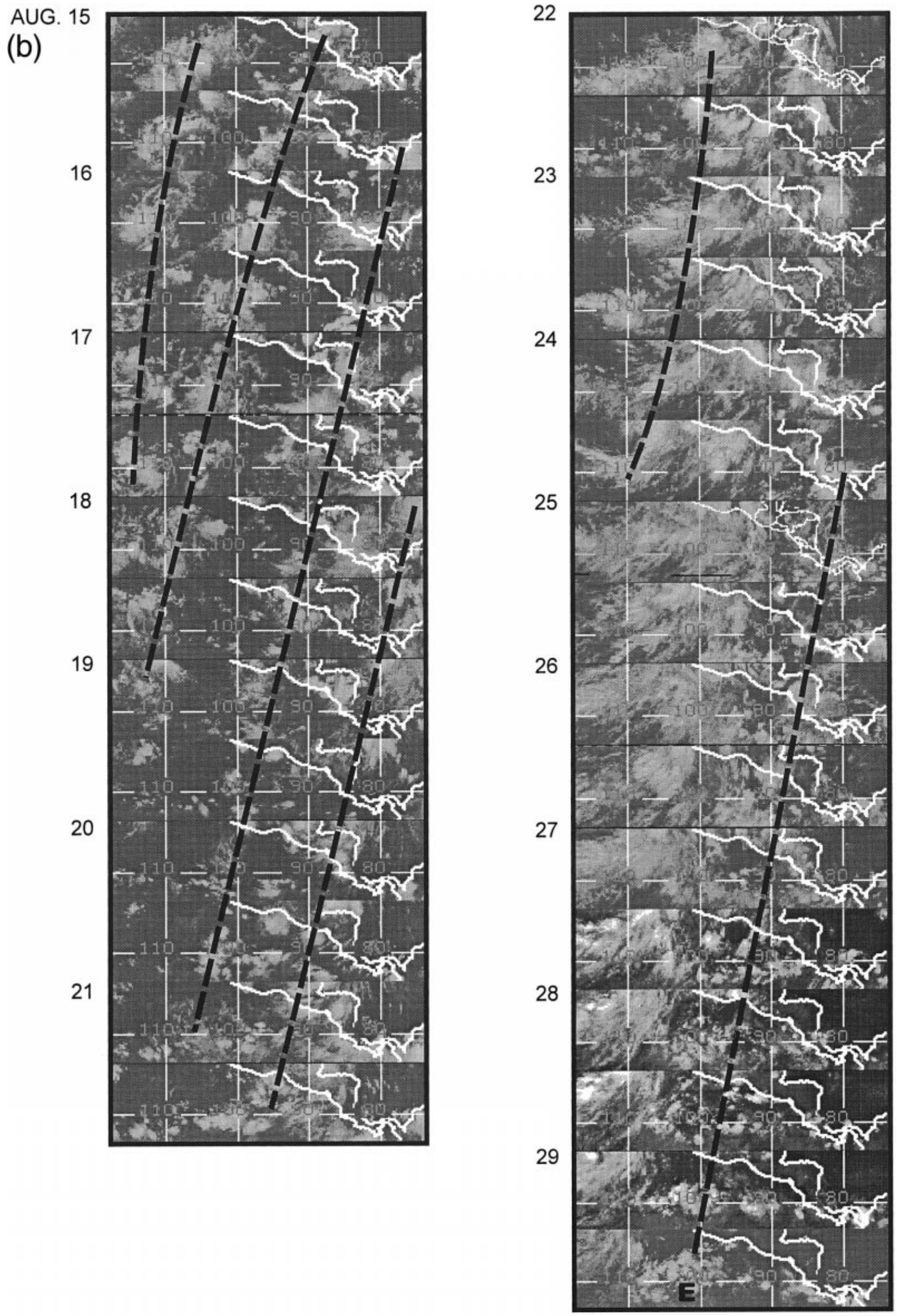

FIG. 2. (*Continued*)

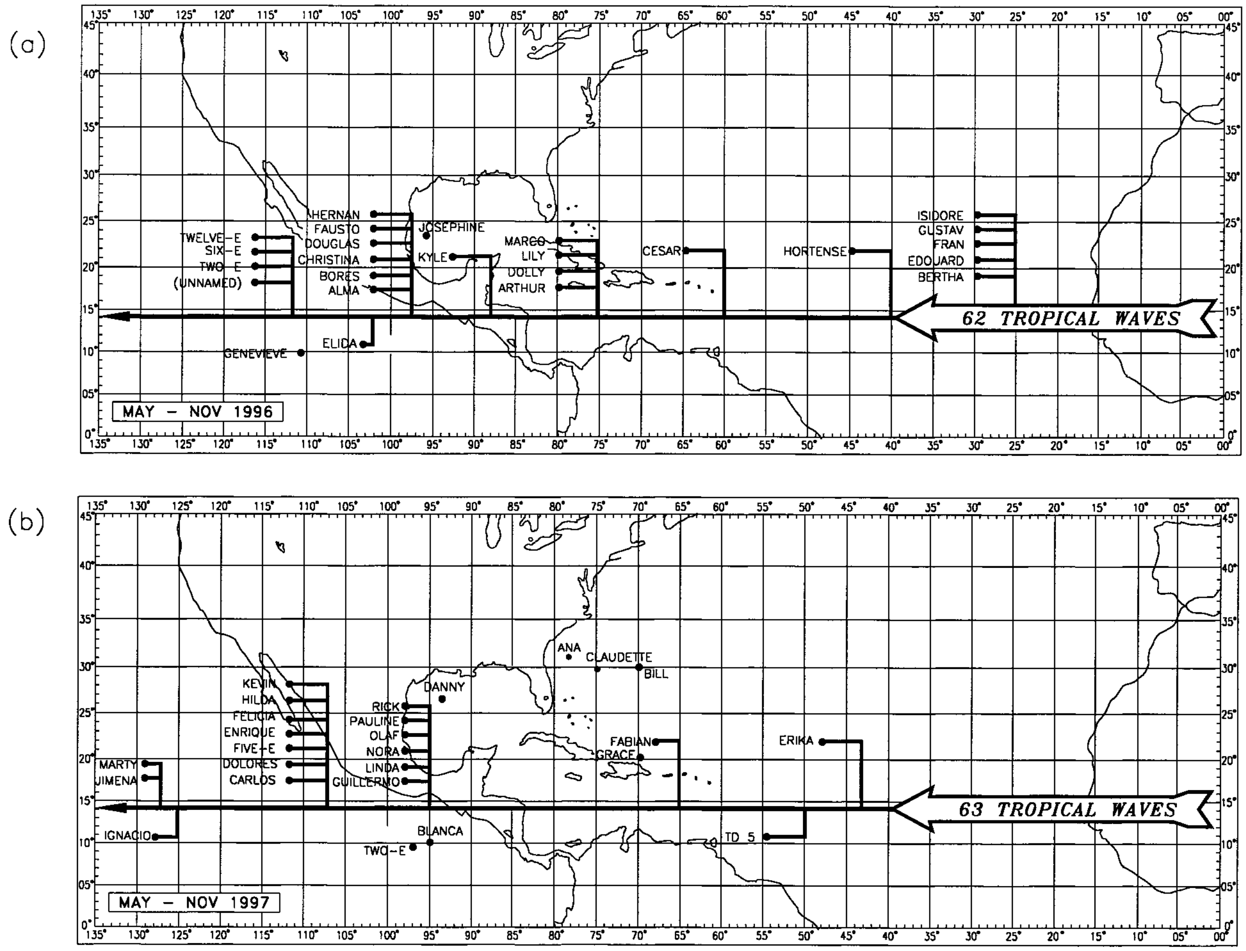

FIG. 3. Total number of waves that maintained their identities while traveling the Atlantic, Caribbean, the Gulf of Mexico, and the eastern Pacific during (a) 1996 and (b) 1997. The figure highlights the longitude bands in which tropical cyclones developed. Separate dots denote the approximate locations of tropical cyclone formation from disturbances other than tropical waves.

4. Tropical waves during 1996 and 1997 and their contrasting environment

Figures 3a and 3b show that from May to November of 1996 and 1997, 62 and 63 tropical waves crossed Dakar and moved westward over the tropical Atlantic, the Caribbean Sea, and Central America. Most of them appeared to move into the eastern North Pacific. Approximately, there was a wave crossing Dakar every 3 days. The average number of waves observed between May and November is 61. Figures 3a and 3b also highlight the tropical cyclones that formed from the waves.

Figure 1 shows the wind field structure of the waves as they crossed Dakar during 1996 and 1997, respectively. The time section for 1996 reveals that the tropical waves were well marked in the wind field and were accompanied by sharp cyclonic low- to middle-level wind shifts. In particular, note the strong wave that crossed Dakar on 19 August 1996, preceded by a strong 20 m s^{-1} middle-level easterly jet and a distinct low-level cyclonic wind shift. The time section for Trinidad, also in Fig. 1, shows that the wind shift associated with the waves at that location was a little less marked. This resulted from the fact that during that period, and at that longitude, most of the waves already spawned a tropical cyclone (located at a higher latitude) and only a portion of the wave continued westward through the Caribbean Sea. Vertical time sections from several other rawinsonde stations over the Caribbean Sea also showed wind shifts associated with the passage of the waves. Figure 2a shows that, in general, the waves were clearly discernible on satellite images during that period. Note the distinct convective clusters associated with the waves propagating westward over the tropical Atlantic. In particular, the wave alluded to above is depicted by a large and organized area of convective clouds.

One notices in Fig. 1 that during 1997 the waves appeared to be less defined in the wind field than during 1996 as they crossed Dakar. In addition, the midlevel easterly jet associated with the waves was also weaker in 1997 than in 1996 for the same period as noted in Fig.1.

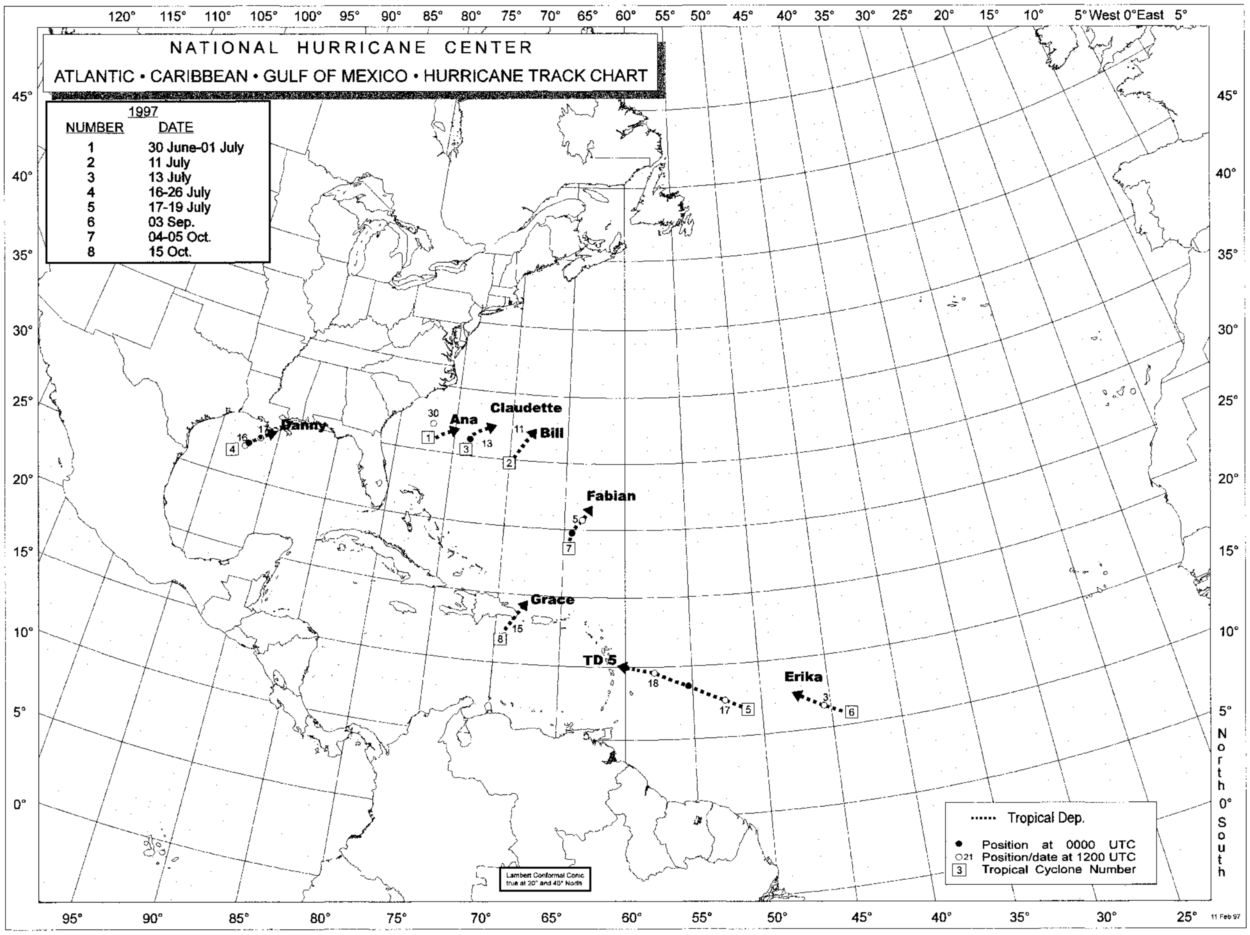

FIG. 4. Tropical depression tracks for 1997.

The sequence of satellite images displayed in Fig. 2b also reveals that the waves were poorly defined in terms of convective cloudiness in 1997. With the exception of the wave that moved off Dakar on 20 August, the convective clusters associated with other waves were practically unidentifiable and weakened significantly as they moved westward. This lack of convective activity became even more evident later in the period from 8 to 15 September (not shown) when the tropical Atlantic between Africa and the Lesser Antilles was practically devoid of organized westward-moving convective clusters.

In an attempt to determine the causes for the large variation in the tropical wave activity between 1996 and 1997, mean vertical profiles of the zonal wind were examined. These profiles shown in Fig. 5 were constructed from upper-air observations from Dakar, Sal, Barbados, and Trinidad. The Augusts of 1996 and 1997 were selected because of the large contrast in tropical cyclone activity spawned by waves observed during those two years. The vertical distributions of the mean zonal wind at Dakar and Sal for both years were, in general, quite similar. Although easterlies prevailed through the entire troposphere in both years, the midlevel jet was significantly weaker in 1997 at Sal and Dakar as suggested by the wind profile from these sites. There is no other upper-air site to the north or to the south of Sal to determine if this resulted from a northward or southward shift of the jet or indeed was a weakening of it.

The midlevel easterly jet is considered of great importance in relation to the structure of the tropical waves. Burpee (1972) has shown that the meridional variations of the horizontal wind at the midlevels is related to wave amplification. The presence of a relatively weaker jet at Dakar in August of 1997 coincided with the fact that August was extremely quiet when compared with August 1996 or any other year with average tropical cyclone activity.

The wind profiles for August 1996 and for August 1997 were significantly different at upper-air sites in the Lesser Antilles. Over this region in 1997, there was a large variation of the mean zonal wind with height at Barbados and Trinidad. In general, strong westerly winds prevailed above the 300-mb layer resulting in average vertical zonal wind shear of 15–20 m s^{-1}. This

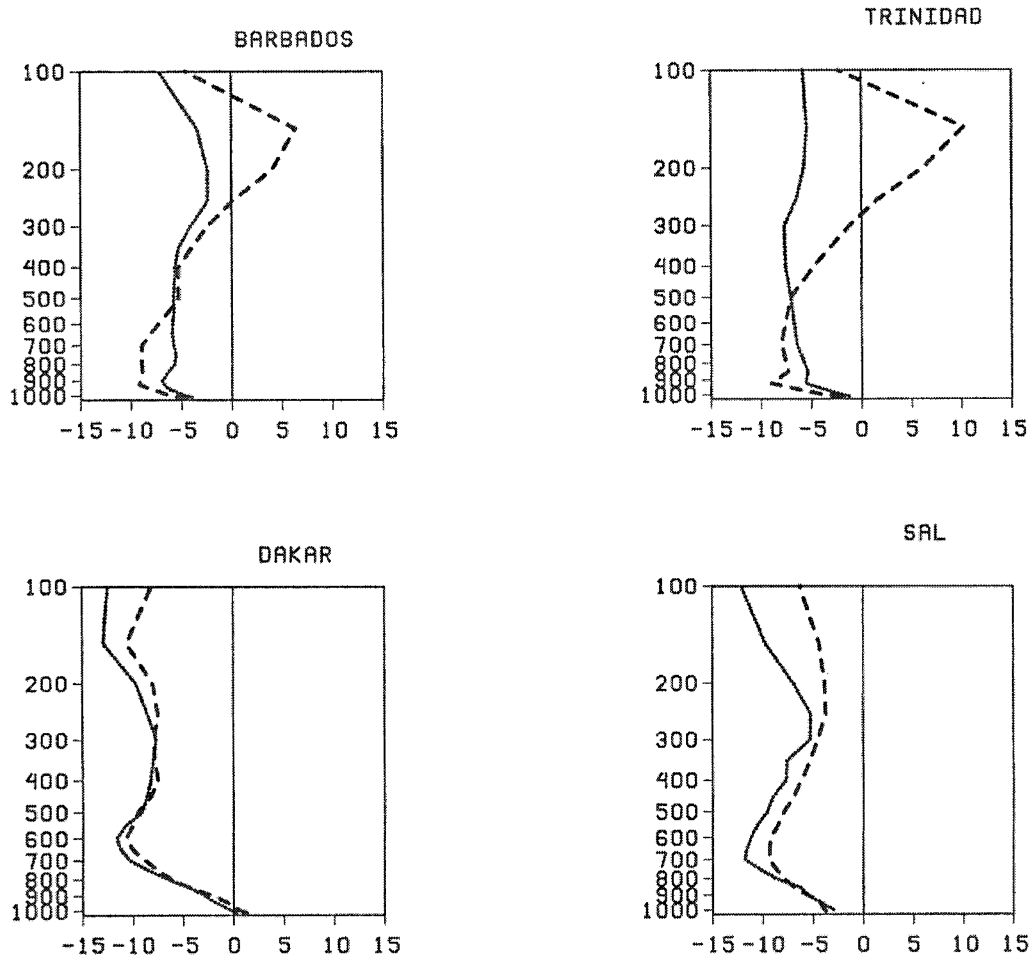

FIG. 5. Vertical profiles of the mean zonal wind for Dakar, Sal, Barbados, and Trinidad for Aug 1996 and 1997. Solid and dashed lines are 1996 and 1997, respectively. The *x* axis is the mean zonal wind in m s^{-1} and the *y* axis is pressure in mb.

value is generally too high to allow tropical cyclogenesis (Gray 1968). This is in contrast with 1996 when mean easterly winds dominated most of the troposphere at these sites resulting in a favorable low-shear environment for tropical cyclogenesis.

Moist static stability is a parameter commonly used to estimate the potential for the development of convection. A moist static stability parameter was determined by calculating the difference between 200-mb mean temperature of the environment from August mean soundings and the temperature of a parcel lifted dry adiabatically from 1000 mb to saturation and then moist adiabatically to 200 mb. This assumes that the relative humidity at 1000 mb is 80%. Figure 6 shows the values of stability for 1996 and 1997. The numbers for Dakar and Sal in 1996 were 2.6 and −0.2 and for 1997 were 0.3 and −2.7, respectively. These numbers suggest that the environment was more statically stable in 1997 than in 1996, especially over the genesis area near the Cape Verde Islands. This less stable environment observed during 1996 may have been associated with a planetary-scale upper-level divergence that prevailed over the tropical Atlantic area as indicated by Jiing (1999). Jiing also found similar results by calculating the August mean convective available potential energy for the same area. In 1997, the environment allowed the waves to produce only limited convection as indicated by the sequence of satellite images in Fig. 2. This was corroborated by the lack of rainfall over the tropical eastern Atlantic during August 1997 as indicated in the *Climate Diagnostic Bulletin* for that month (Climate Prediction Center 1997).

One can then speculate that despite the prevailing favorable dynamical conditions over the eastern Atlantic (low vertical wind shear as indicated by the wind profiles) the waves failed to develop in 1997. The stability parameter suggests that the apparently thermodynamic conditions to produce convection were not present. Over the Lesser Antilles, with the exception of the area near Guadeloupe, the environment in 1997 was not significantly different in terms of stability if compared with 1996 as indicated in Fig. 6. However, dynamical con-

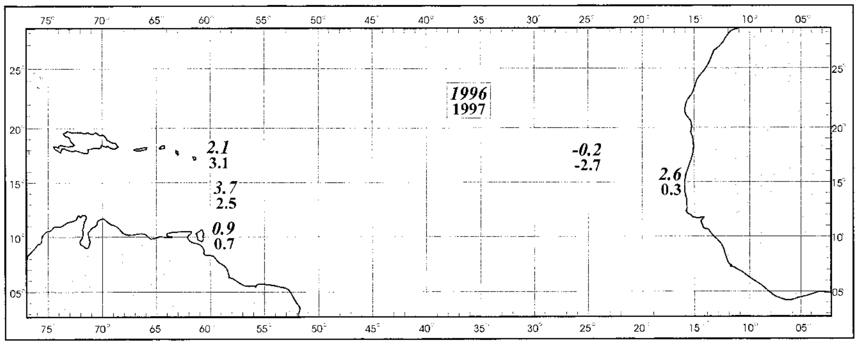

FIG. 6. Average moist static stability determined from several upper-air sites for Aug of 1996 and 1997. Larger positive numbers correspond to more unstable environment.

ditions were highly unfavorable for waves to grow since strong vertical wind shear prevailed over the entire area.

In contrast, during 1996 there was a combination of low wind shear and an unstable environment over the eastern Atlantic and the Lesser Antilles when many waves developed into tropical cyclones. In fact, the four consecutive waves that crossed Dakar during the last 10 days of August became hurricanes.

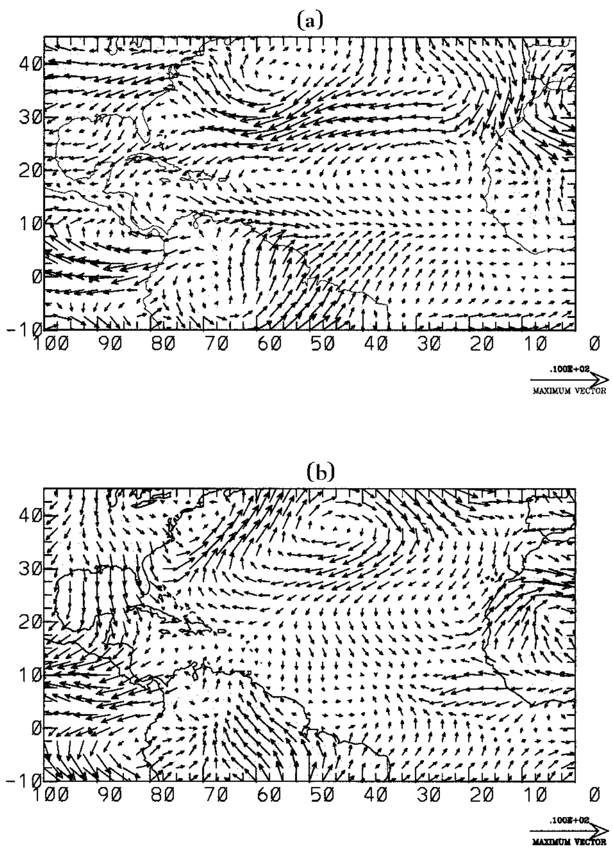

FIG. 7. The 850-mb wind anomalies (m s^{-1}) for Aug (a) 1996 and (b) 1997. Anomalies are taken from the 1975–95 average of the initial National Centers of Environmental Prediction Aviation Model analysis. Scale vectors in lower right of each panel correspond to 10 m s^{-1}.

Figures 7a and 7b show the 850-mb-level wind anomalies (from the 1975–95 mean) during August of 1996 and 1997. In 1996, over the breeding region of the tropical Atlantic, there was an anomalous monsoon-type flow that extended northward from South America to 10°N across the tropical Atlantic. This flow occurred in conjunction with a large anomalous cyclonic gyre that covered the tropical North Atlantic. This pattern probably resulted from having weaker than normal trade winds over the tropical belt. In addition, there was a large anomalous anticyclonic gyre centered along 35°N, extending from the Azores to the northeast U.S. coast. This suggests that the subtropical ridge was well established and positioned farther north than normal. The combination of a stronger than normal ridge displaced toward higher latitudes and anomalous cyclonic flow over the tropical belt has been used operationally to indicate favorable conditions for tropical cyclone development. This pattern also favors a meridional distribution of the horizontal wind that in theory favors wave amplification as indicated by Burpee (1972). In addition, the region of anomalous cyclonic flow along the main path of the waves was located over warm waters where the atmosphere was less stable, producing deep convection.

An opposite scenario prevailed in 1997. Figure 7b depicts that during August, an anomalous low-level anticyclonic flow dominated the deep Tropics east of 35°W. This suggests that the waves exiting Africa were moving into an unfavorable environment.

5. Eastern North Pacific tropical cyclone developments from waves

The development of eastern North Pacific tropical cyclones from tropical waves is common and has been extensively documented in annual summaries published by the NHC. Tropical waves played a significant role in the formation of many of the eastern North Pacific tropical cyclones (Mayfield and Rappaport 1998; Lawrence 1999). These waves usually take more than a week to traverse the Atlantic and Central America after emerging from west Africa. In 1996 and 1997, 92% and 83% of the tropical cyclones, respectively, developed from tropical waves. In Fig. 2b one can observe the westward propagation of areas of organized convection associated with some of the tropical waves crossing Central America from the Caribbean Sea into the eastern North Pacific. These waves led to the development of tropical cyclones in the latter basin. In Fig. 2b, note the westward progression of an area of cloudiness from the Caribbean Sea across South and Central America and then moving into eastern Pacific during the period from 24 to 29 August 1996. This system eventually developed into Tropical Storm Elida just south of Manzanillo, Mexico, as indicated by E in Fig. 2b.

These waves are not always clearly depicted once they move into the eastern North Pacific. In some cases, the waves interact with a cyclonic monsoon-type flow, which is a climatological feature in this region during the hurricane season.

There are other cases in which the development occurred from a disturbance that was first detected within the ITCZ over the eastern North Pacific and tropical cyclogenesis cannot be traced back to an African wave. For example, Hurricane Genevieve in 1996 formed in situ from a disturbance in the ITCZ. Another example of tropical cyclone development not associated with a wave is Tropical Storm Blanca in June 1997.

6. Comparison with other years

Figure 8a and Table 1 show the number of tropical waves from 1967 through 1997. In 1996 and 1997, the number of waves, 62 and 63, respectively, was near the average of 61. However, year-to-year variation in the total number of waves is probably not significant because the process of identifying tropical waves has not been uniformly applied over the years.

Table 1 and Figs. 8b and 8c show the seasonal totals of tropical depressions and storms since 1967. In 1996, there were 13 depressions and only 8 in 1997. These depressions, with the exception of the one in July 1997, reached tropical storm status and their histories were well documented with surface observations, reconnaissance aircraft data, and satellite imagery.

The number of tropical depressions for both 1996 and 1997 is much lower than the long-term average of 19 and the more recent 1980–96 average of 14. The trend of having fewer depressions began in 1980. During the 1967–80 period, which includes years before the implementation of the Dvorak technique (Dvorak 1984), some nontropical cyclones may have been classified as tropical depressions. Examples of such cases have been already documented by Pasch and Avila (1994).

The ratio between the number of tropical storms of African origin to the total number of tropical storms (R) is used to describe the overall character, of the hurricane season (Avila and Clark 1989). Low values of R indicate that a high number of tropical storms originated from

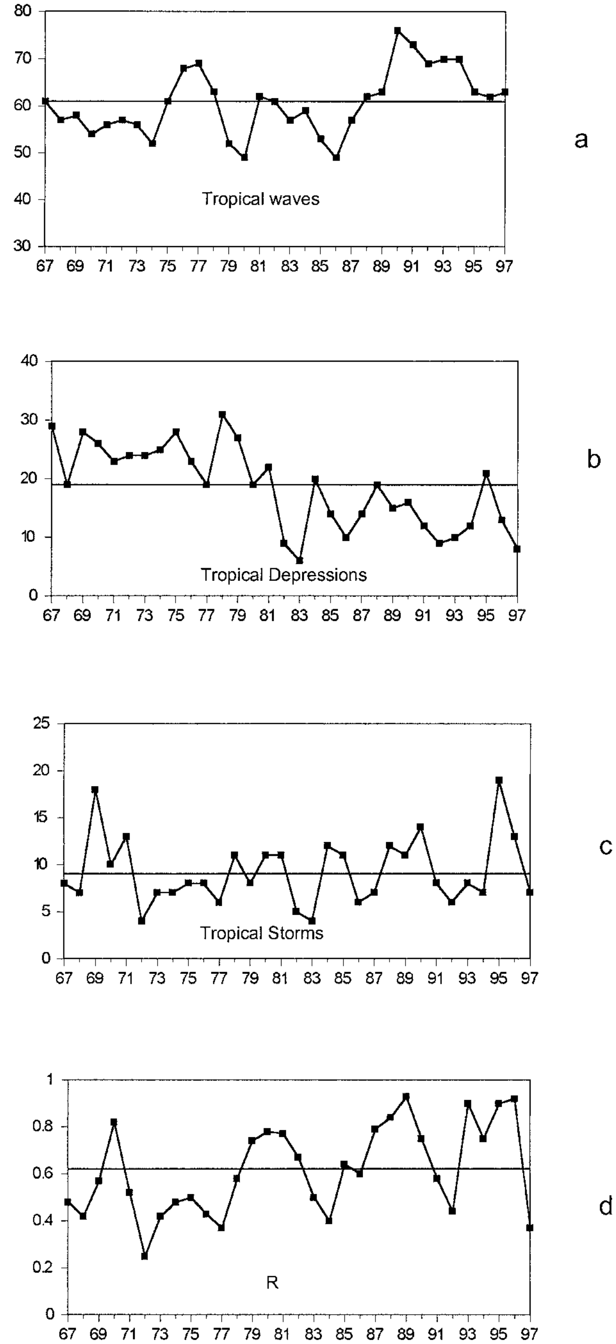

FIG. 8. (a) Total number of tropical waves from 1967 to 1997. (b) Total number of tropical depressions from 1967 to 1997. (c) Total number of named storms from 1967 to 1997. (d) Ratio (R) of the number of named storms of African origin to the total number of named storms from 1967 to 1997. Horizontal line represents the average for the 1967–96 period.

upper-tropospheric cold lows or along frontal zones, that is, from nontropical ''seedling'' disturbances. Figure 8d and Table 1 display the values of R since 1967. The 1967–96 average contribution from tropical waves to the total number of storms is 0.62. In 1996, R was 0.92,

TABLE 1. Atlantic tropical system statistics for 1967–97.

		Total			African			Ratio		
								African TD	African TS	African H
Year	Waves	TD	TS	H	TD	TS	H	total TD	total TS	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
1993	70	10	8	4	9	8	4	0.90	1.00	1.00
1994	70	12	7	3	9	5	2	0.75	0.71	0.66
1995	63	21	19	11	19	17	11	0.90	0.89	1.00
1996	62	13	13	9	12	12	9	0.92	0.92	1.00
Average	61	19	9	5	11	6	3	0.62	0.63	0.66
1997	63	8	7	3	3	2	1	0.37	0.28	0.33

TD: tropical depression.
TS: tropical storm.
H: hurricane.

a value well above normal. On the other hand, *R* was only 0.28 in 1997. This number has been lower only in 1972 and 1983, which were, as 1997, strong ''El Niño'' years. There are exceptions, like 1987 when *R* was relatively high. During that year, the El Niño event was fading fast. The relationships among El Niño; the environment, and tropical cyclone activity associated with tropical waves have been vastly discussed in previous season summaries and by Gray (1984).

Table 1 shows that on average 65% of the hurricanes in the Atlantic basin develop from tropical waves. In 1996, all nine hurricanes developed from waves but in 1997 only one was triggered by a tropical wave. This reaffirms the notion that during strong El Niño years, the large-scale environment becomes unfavorable for hurricanes to develop from tropical waves.

Avila and Clark (1989) have been arbitrarily using *R* to quantify the relative contribution to tropical storm development by tropical waves. Years when *R* is greater than or equal to 0.7 are termed ''African'' years. ''Non-African'' years are those for which *R* is less than or equal to 0.5. Intermediate values correspond to ''average'' years. The value of *R* in 1996 was 0.92 and there were six intense hurricanes. The latter is a characteristic only observed in African years, in other words, in years that hurricanes form from tropical waves. In 1997, *R* was 0.28, indicating that the year was characterized by tropical cyclone formations primarily from frontal zones and cold lows and not from tropical waves. It appears that these type of years coincide with El Niño conditions.

While *R* 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 squares of a hurricane's maximum wind speed for each 6-h period of its existence (Gray et al. 1992). Table 2 summarizes the HDP, African, non-African, and average years, including average number of major hurricanes (category 3 or higher on the Saffir–Simpson hurricane scale). The average HDP of African years for the 1967–96 period was substantially larger (more than double)

TABLE 2. Comparison of African, non-African, and average years with season-averaged 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 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 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: average number of major hurricanes [category 3 or higher on the Saffir–Simpson scale (Simpson 1974)] during those years.

														HDP	MH
African years	70	74	79	80	85	87	88	89	90	93	94	95	96	100	2.3
Non-African years	71	72	77	83	84	86	91	92	97					28	0.8
Average years	67	68	69	73	75	76	78	81	82					55	1.8

than the average HDP of the non-African years. The HDP for the African year 1996 was 135, which is a remarkably high number. The HDP for the non-African year of 1997 was only 26, a number much lower than the mean 1950–90 HDP of 71 (Gray 1997).

This study reaffirms the importance of tropical waves as the precursors to Atlantic major hurricanes and to the formation of eastern Pacific tropical cyclones. Also, tropical waves 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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REFERENCES

Avila, L. A., and G. B. Clark, 1989: Atlantic tropical systems of 1988. *Mon. Wea. Rev.,* **117,** 2260–2265.

Burpee, R. W., 1972: The origin and structure of easterly waves in the lower troposphere of North Africa. *J. Atmos. Sci.,* **29,** 77–90.

Climate Prediction Center, 1997: *Climate Diagnostics Bulletin.* Vol. 97, No. 8, 82 pp.

Dvorak, V. F., 1984: Tropical cyclone intensity analysis using satellite data. NOAA Tech. Rep. NESDIS 11, National Oceanic and Atmospheric Administration, Washington, DC, 47 pp. [Available from National Technical Information Service, U.S. Dept. of Commerce, Sills Bldg., 5285 Port Royal Road, Springfield, VA 22161.]

Gray, W. M., 1968: Global view of the origin of tropical disturbances and storms. *Mon. Wea. Rea.,* **96,** 669–700.

——, 1984: Atlantic seasonal hurricane frequency. Part I: El Niño and 30 mb quasi-biennial oscillation influences. *Mon. Wea. Rev.,* **112,** 1649–1668.

——, 1997: Summary of 1997 Atlantic tropical cyclone activity and verification of author's seasonal prediction. Department of Atmospheric Science, Colorado State University, 27 pp. [Available from Department of Atmospheric Science, Colorado State University, Fort Collins, CO 80523.]

——, C. W. Landsea, P. W. Mielke Jr., and K. J. Berry, 1992: Predicting Atlantic seasonal hurricane activity 6–11 months in advance. *Wea. Forecasting,* **7,** 440–455.

Jiing, J. G., 1999: Comparison of large-scale environment over the tropical Atlantic during August 1994–1997. Preprints, 23d *Conf. on Hurricanes and Tropical Meteorology,* Dallas, TX, Amer. Meteor. Soc., 258.

Lawrence, M., 1999: Eastern North Pacific hurricane season of 1997. *Mon. Wea. Rev.,* **127,** 2440–2454.

Mayfield, B. M., and E. N. Rappaport, 1998: Eastern North Pacific hurricane season of 1996. *Mon. Wea. Rev.,* **126,** 3068–3076.

Pasch, R. J., and L. A. Avila, 1994: Atlantic tropical systems of 1992. *Mon. Wea. Rev.,* **122,** 540–548.

——, and ——, 1999: Atlantic hurricane season of 1996. *Mon. Wea. Rev.,* **127,** 581–610.

——, ——, and J. Jiing, 1998: Atlantic tropical systems of 1994 and 1995: A comparison of a quiet season to a near-record-breaking one. *Mon. Wea. Rev.,* **126,** 1106–1123.

Rappaport, E. N., 1999: Atlantic hurricane season of 1997. *Mon. Wea. Rev.,* **127,** 2012–2026.

Riehl, H., 1954: *Tropical Meteorology.* McGraw-Hill, 392 pp.

Simpson, R. H., 1974: The hurricane disaster potential scale. *Weatherwise,* **27,** 169 and 186.

Velden, C. S., 1997: Update on high density satellite-derived multispectral winds produced by UW-CIMSS over the Tropics. Preprints, *22d Conf. on Hurricanes and Tropical Meteorology,* Fort Collins, CO, Amer. Meteor. Soc., 35–36.