Atlantic Tropical Systems of 1991

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ABSTRACT

The 1991 hurricane season in the Atlantic basin featured 73 tropical waves (also known as African waves), most of which were relatively weak. These waves generated fewer than normal Atlantic tropical cyclones: seven tropical depressions, of which only three intensified into tropical storms. Remarkably, none of these systems became hurricanes. The remainder of the Atlantic tropical cyclones formed from other sources. African waves triggered nearly all of the eastern Pacific tropical cyclones in 1991.

1. Introduction

Residents of the Caribbean and Gulf of Mexico areas experienced a quiet hurricane season in 1991. Not only were there fewer named storms than normal, but most of the tropical storms and hurricanes remained over the open subtropical Atlantic. Furthermore, there was an absence of a classical strong hurricane that is typically initiated by an African wave over the tropical Atlantic east of the Lesser Antilles. Others were not so lucky. Some residents within the northeast United States suffered greatly from Hurricane Bob, which developed from a disturbance of nontropical origin.

Tropical storms and hurricanes in the Atlantic basin during 1991 are described by Pasch and Avila (1992). This article summarizes the weaker synoptic-scale systems in 1991. The data used for the tabulation consisted of satellite imagery as well as surface and upper-air observations across the tropics from Africa to Central America. Tropical waves, also known as African waves, were recognized by analyzing the wind, pressure, and cloud patterns.

Some African waves have very poor cloud definition. They are difficult to track across the data-sparse tropical Atlantic areas, and there was a certain amount of noise in the identification and positioning of tropical waves. Therefore, during the periods when deep convection was minimal or absent and the cloud pattern was not well organized, the positions of the waves were estimated by continuity. An example of the wave tracking method is shown in Figs. 1a,b. These figures show a vertical time section of the wind and a time sequence of the cloud pattern for the eastern tropical Atlantic area, respectively. The presence of a lower tropospheric cyclonic wind shift, the propagation of an organized and distinct cloud mass, or both are the primary parameters used in locating the wave axis. Additional details on the counting method are described by Avila and Clark (1989).

Analysis of routine satellite imagery at the National Hurricane Center (NHC) suggests that tropical waves, or at least weak perturbations in the lower-tropospheric wind field, may be present throughout the year over the Atlantic basin. During the winter and spring, these weak impulses appeared to spread westward but through much lower latitudes than the tropical waves of the active summer and fall months. In general, these winter–spring systems consist of synoptic-scale patches of low clouds (typically with some evidence of cyclonic curvature) void of deep convection. In this article the tabulation covers the period from May to November when, on the average, waves are more convectively active.

2. Census of the 1991 Atlantic systems

Tropical cyclone activity in the Atlantic was below normal in 1991. The season featured eight tropical storms, four of which became hurricanes. Only three named storms, Danny, Erika, and Fabian, developed from African waves. African waves also produced four tropical depressions that did not intensify into named storms. The remainder of the 1991 depressions formed from disturbances of nontropical origin outside of the deep tropics.

a. Tropical depressions

A total of 12 tropical depressions developed throughout the season. The maximum activity occurred in October with 4 systems, of which only 2 were related to African waves. There were no tropical

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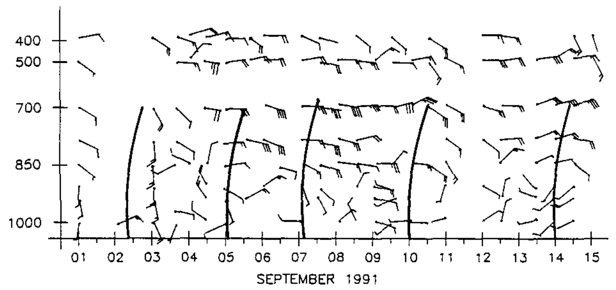


FIG. 1a. Vertical time section of the wind at Dakar, Senegal, from 1 to 15 September 1991. Winds plotted every 12 h according to convention with each full barb and half-barb denoting 5.1 and 2.6 m s^{-1}, respectively. Thick lines indicate the position of the tropical wave axes.

depressions in May, June, or November. The Atlantic tropical-depression tracks for 1991 are shown in Fig. 2. The following descriptions apply only to those tropical depressions that did not reach tropical-storm status.

Short-lived Tropical Depression Two formed near Tampico, Mexico, on 5 July. It originated from an African wave that traveled across the Atlantic and the Caribbean for more than 15 days with no significant development. The depression drifted westward and dissipated over Mexico on 7 July. Although there were no reports from Mexico, satellite images indicated that very heavy rain associated with the depression probably occurred over portions of northeast Mexico. A tropical-storm watch was issued from Baffin Bay, Texas, to Tampico, Mexico. Figure 3 shows Tropical Depression Two nearing the Mexican coast.

Tropical Depression Four formed on 24 August over the eastern tropical Atlantic from one of the few vigorous African waves of the season. This wave exited Africa with a large area of convective cloudiness and produced marked lower- to midtropospheric cyclonic wind shift at Dakar. The depression was fairly well organized on satellite images when it moved over the Cape Verde Islands (Fig. 4). It quickly dissipated, however, on 26 August over cooler waters a few hundred kilometers west of those islands.

On 26 August another wave exited Africa, and formed Tropical Depression Five on 28 August. The depression moved westward for several days through low latitudes and then was sheared by strong upper-tropospheric winds on 31 August before reaching the Lesser Antilles. The remnants of the depression produced some showers over those islands.

Yet another African wave spawned Tropical Depression Ten midway between Africa and the Lesser

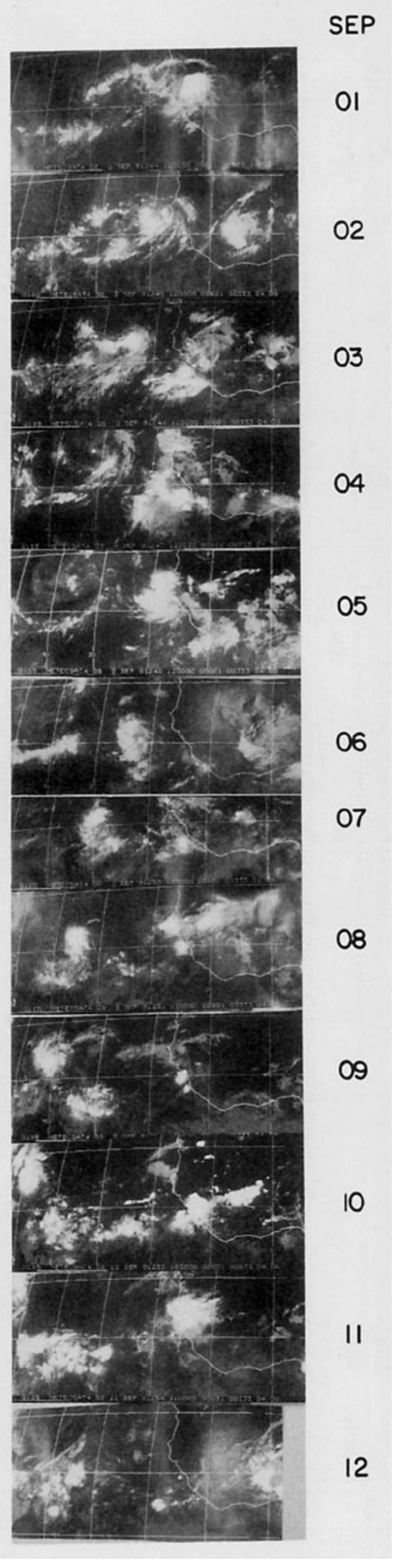


FIG. 1b. Time sequence of Meteosat infrared satellite images taken once a day at 1200 UTC from 1 to 12 September 1991. Note the sequence of distinct cloud masses exiting the coast of Africa associated with the tropical waves.

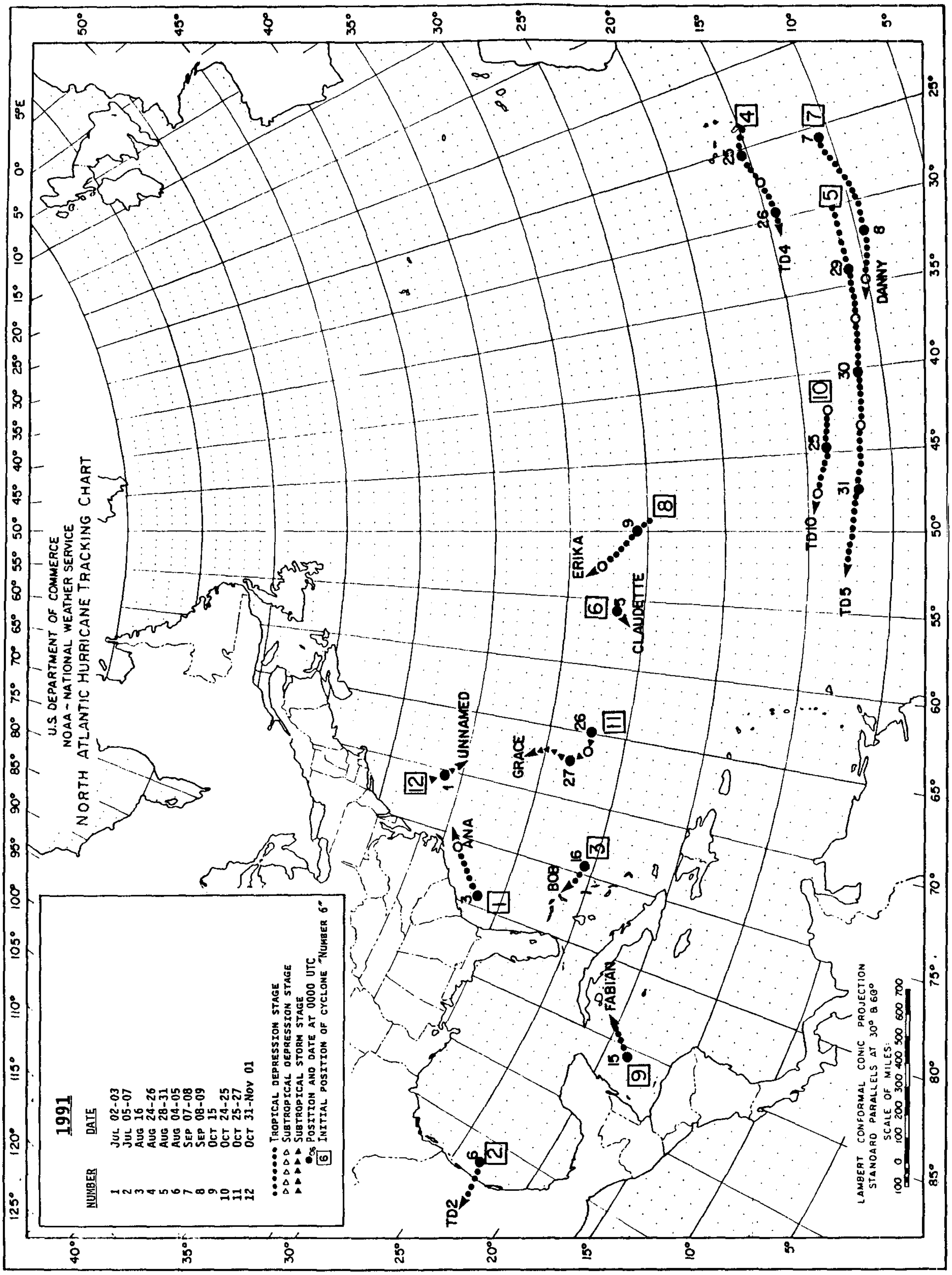


FIG. 2. Tropical-depression tracks of 1991.

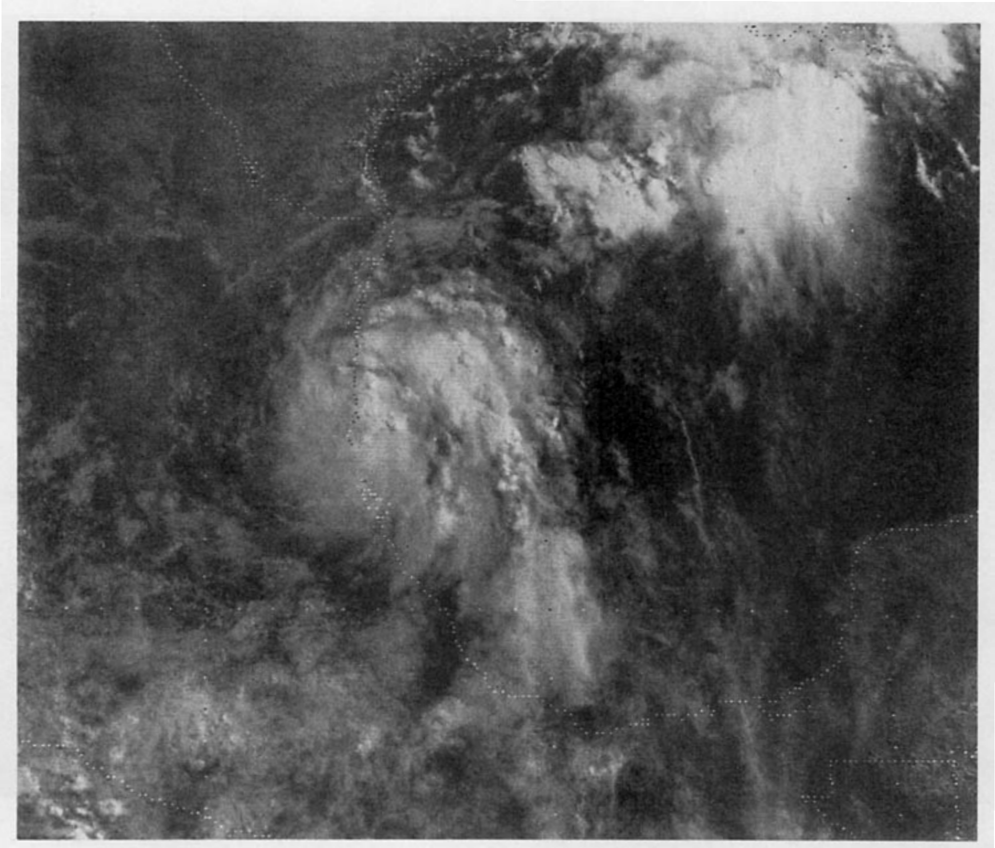


FIG. 3. GOES visible satellite image of Tropical Depression Two at 1431 UTC 6 July 1991.

Antilles on 24 October. The depression remained in an environment of strong shear and never threatened to become a tropical storm. It dissipated late on the 25th.

b. *African waves*

Figure 5 shows that, during 1991, 73 tropical waves exited the northwest coast of Africa and moved westward over the tropical Atlantic, the Caribbean, Central America, and into the eastern Pacific. The average period of the waves was 2.9 days, which is similar to the period that was observed during the 1990 season. The first tracked wave exited Africa in late April and may have been responsible for the formation of Tropical Storm Andres in the eastern Pacific in mid-May. The last tracked wave crossed Dakar during late November.

The 1991 season was characterized by poorly defined (in the wind field) and convectively inactive African waves. Only a few of the 73 observed waves were clearly distinct in satellite images or synoptic data. In general, the waves were very difficult to track over the Atlantic and the Caribbean. Figure 6 shows the average low-level (roughly 900 mb) wind anomalies for August, September, and October. Note the presence of an anomalous anticyclone centered over the west coast of Africa near 12°N with a ridge extending westward to 45°W. This feature was located over the area where westward-moving low-level cyclones associated with African waves periodically enhance the monsoon circulation. This could be interpreted as a period when the African monsoon and waves were weaker than normal. During the first 10 days of September, the hurricane season typically reaches its peak with strong waves passing offshore from the west coast of Africa; these waves often lead to the season's most intense hurricanes. Figures 1a,b cover this time period during 1991. Note the series of waves that crossed Dakar, most of them defined by weak cyclonic wind shifts. It can be seen that these waves were attended by some convective activity as they moved off the coast. The amount of deep cloudiness inferred from these images, however, was rather unimpressive when compared to the same period of the previous 3 years (not shown). Figure 1b does show one of the most vigorous waves of the season—defined by a distinct and organized cloud system over Africa near 10°N,5°W on 2 September. That wave crossed Dakar on the 5th and eventually triggered Tropical Storm Danny. Figure 1a shows the wind shift associated with the passage of that wave over Dakar at 0000 UTC 5 September.

Many of the 1991 waves moved through lower lat-

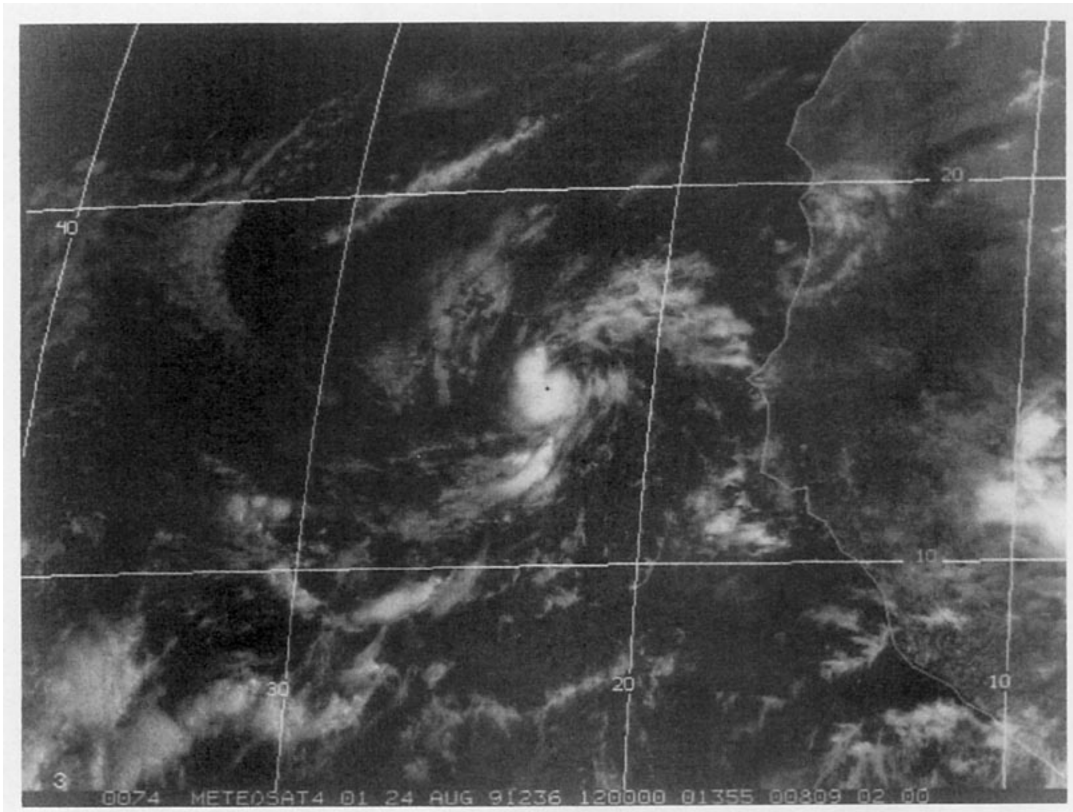


FIG. 4. Meteosat infrared satellite image of Tropical Depression Four at 1331 UTC 19 September. Note that the dot near the middle of the cloud system is a computer cursor.

itudes than usual with their maximum convection over South America. This is in contrast with the more active years when the maximum cyclonic curvature in the wind field and thunderstorm activity associated with the waves extended northward through the Caribbean into the Atlantic.

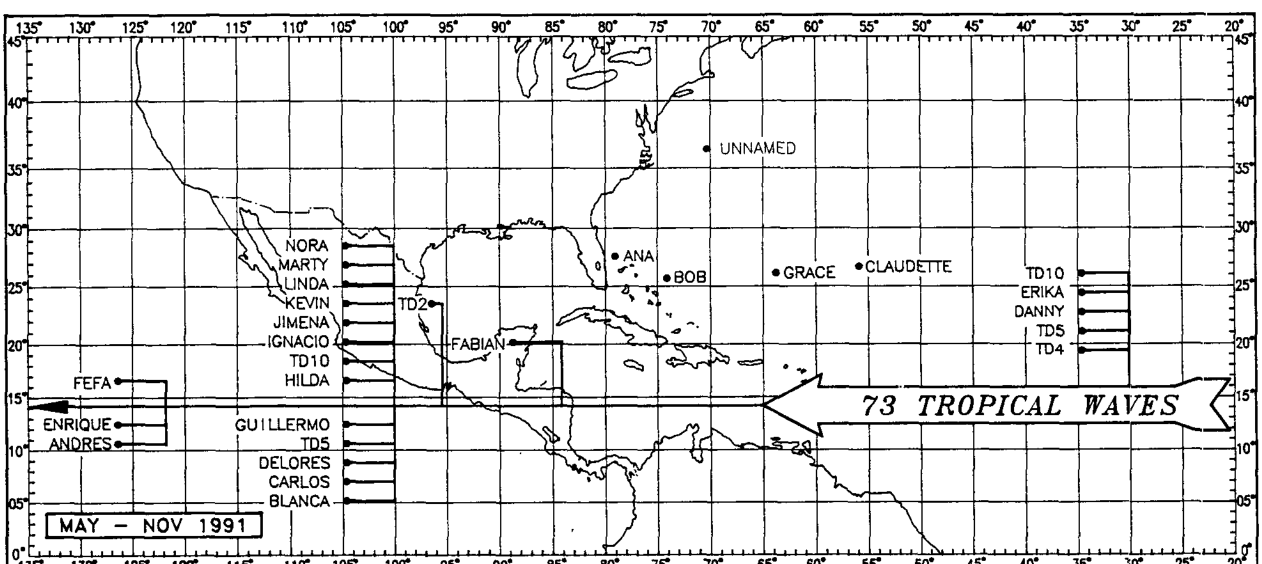


FIG. 5. Total number of waves that maintained their identities while traveling the Atlantic, Caribbean, the Gulf of Mexico, and the eastern Pacific. The figure highlights the longitude bands in which tropical cyclones developed.

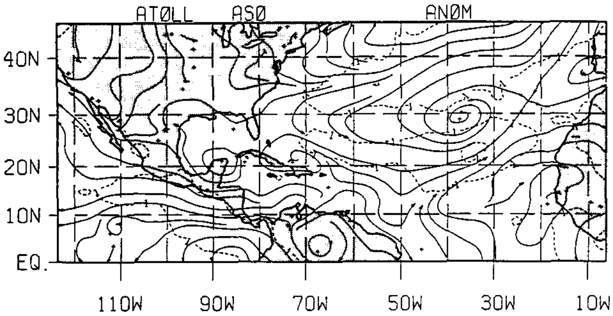


FIG. 6. Average low-level (approximately 900 mb) wind anomalies (m s^{-1}) for August, September, and October 1991. Anomalies are mean for 1991 minus 1975–91 average. The acronym ATOLL refers to analysis of tropical oceanic lower layer.

It is not clear why relatively few tropical cyclones were spawned by African waves over the Atlantic tropical belt during 1991. Pasch and Avila (1992) suggested that one of the factors was the stronger-than-normal vertical shear, which prevailed over the main hurricane "brewing" areas of the Caribbean and adjacent tropical Atlantic. This shear appeared to severely dampen the development potential of African waves as they approached the Lesser Antilles. A few tropical depressions formed within the deep tropics but soon moved into regions of above-normal magnitude of vertical shear. Gray (1991) claimed that one of the factors related to the scarcity of low-latitude tropical cyclones during 1991 was the below-average rainfall in the western Sahel. In contrast, most of the 1991 tropical storms developed at higher latitudes, within an area of weaker than normal vertical shear over the subtropical Atlantic. The tropical cyclones of nontropical origin, Ana, Bob, Claudette, Grace, and the unnamed hurricane, are represented in Fig. 5 by dots detached from the mainstream of waves.

A large number of the waves did become convectively active in the eastern Pacific, where weaker-than-normal vertical shear prevailed south of 15°N, likely leading to the formation of the majority of the 1991 tropical cyclones in that basin. Figure 5 shows a longitude band centered along 100°W where most of the eastern Pacific tropical cyclones formed from these African waves. The development of the eastern Pacific tropical cyclones from African waves has been suggested previously by Frank and Clark (1980). As has occasionally been observed in the past, one wave appears to have caused the development of more than one tropical cyclone. This year, the southern portion of the wave that triggered Danny in the Atlantic apparently spawned Hurricane Jimena in the Pacific.

TABLE 1. Atlantic tropical system statistics for 1967–91.

		Total			African			Ratio		
Year	Waves	TD	TS	H	TD	TS	H	African TD / Total TD	African TS / Total TS	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
Average	59	21	9	5	12	6	4	0.57	0.62	0.66
1991	73	12	8	4	7	3	0	0.58	0.38	0.00

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

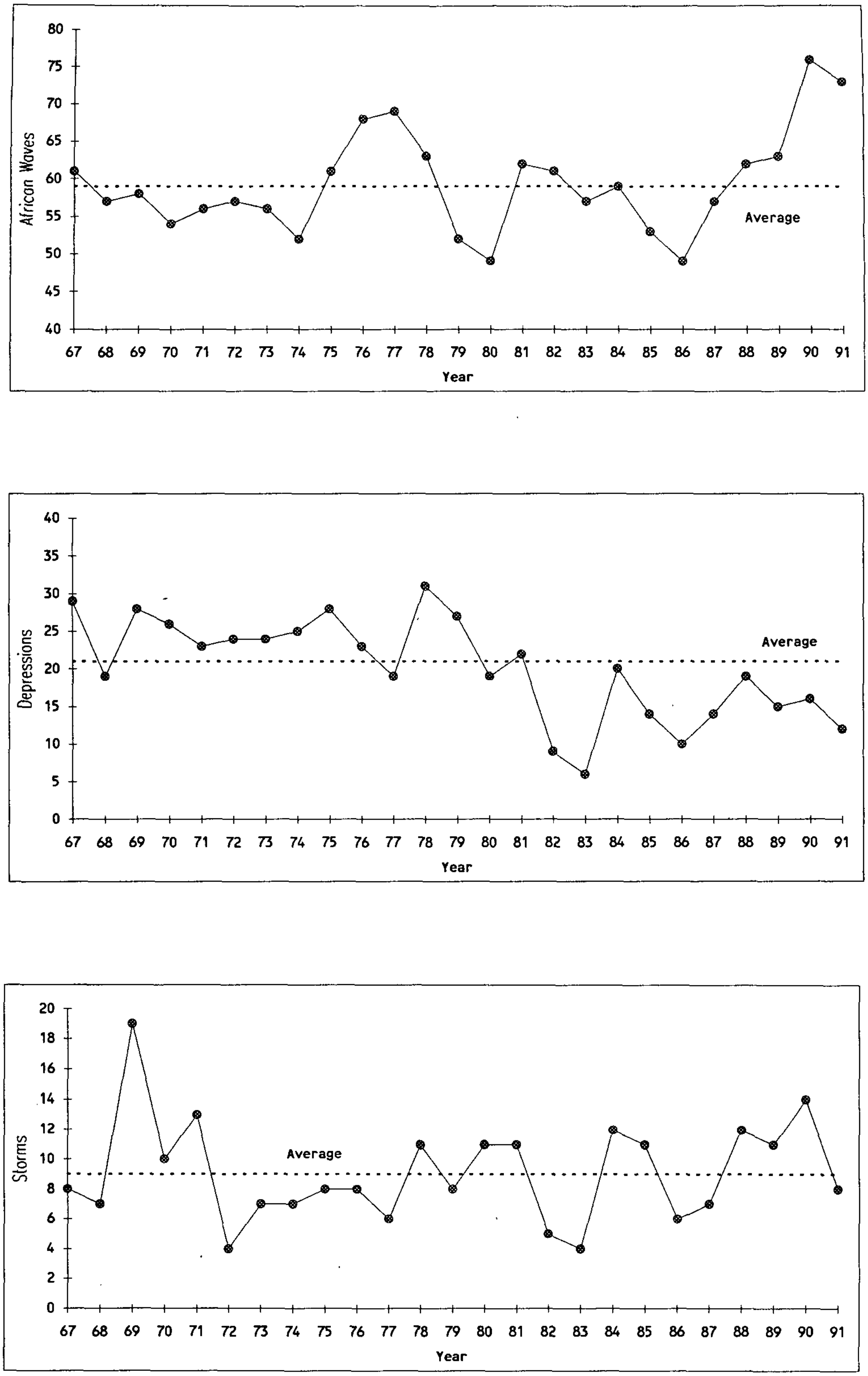
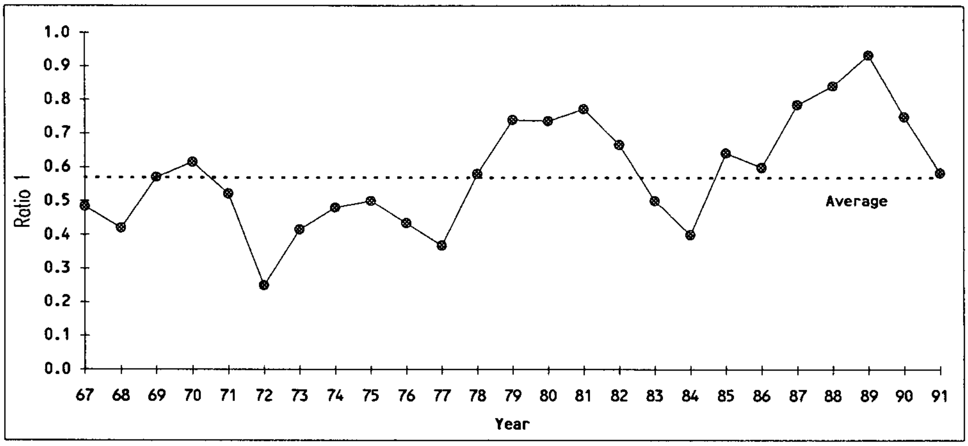


FIG. 7. (a) Total number of African waves from 1967 to 1991. Horizontal dashed line represents the average for the 1967–90 period. (b) Total number of tropical depressions from 1967 to 1991. Horizontal dashed line represents the average for the 1967–90 period. (c) Total number of named storms from 1967 to 1991. Horizontal dashed line represents the average for the 1967–90 period.



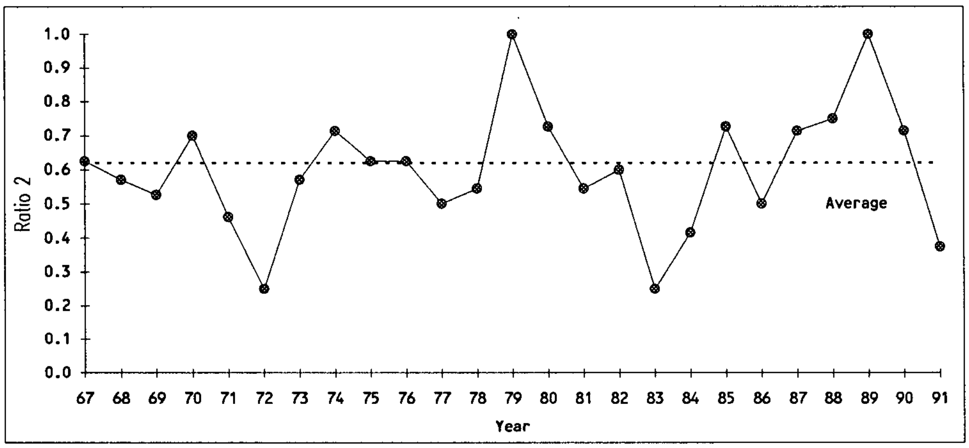


FIG. 8. (a) Ratio of the number of tropical depressions of African origin to the total number of depressions (ratio 1) from 1967 to 1991. Horizontal dashed line represents the average for the 1967–90 period. (b) Ratio of the number of named storms of African origin to the total number of named storms (ratio 2) from 1967 to 1991. Horizontal dashed line represents the average for the 1967–90 period.

3. Comparison with other years

Figure 7a and Table 1 show the number of tropical waves from 1967 through 1991. In 1991 the number of waves was quite similar to 1990 and somewhat higher than the average. Year-to-year variations in the total number of waves, however, may not be not significant. Since the process of identifying tropical waves has not been uniformly applied over the years, one must be careful how to use the total number of such events.

Table 1 indicates that there was a peak in the number of tropical waves as well as in the number of tropical storms in 1990. There was a similarly large number of tropical waves again in 1991 but, as opposed to 1990, there was a below-average number of tropical storms. This supports previous findings that the number of waves is not related to the total number of tropical storms (e.g., Frank 1975). It appears that the large-scale environment exercises the largest control on the yearly variation in the number of tropical storms forming from African waves.

Table 1 and Figs. 7b,c show the seasonal totals of tropical depressions and storms since 1967. There were 12 tropical depressions in 1991. This year continued the trend, begun around 1980, of having fewer tropical depressions. The average number of tropical depressions for 1980–90 is 15. It is speculated that during the 1967–80 period, systems classified as tropical depressions may have been midlatitude frontal lows. If that is the case, the apparent reduction in the number of tropical depressions over the past decade is an artifact of the depression classification scheme, which is a somewhat subjective process. The fact that the number of tropical storms per year shows no such long-term trend would seem to partially support that conjecture.

Figure 8a 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 orig-

TABLE 2. Comparison of African, non-African, and average years with season-averaged hurricane destruction potential (HDP). 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 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 1990) 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	62	18
Non-African years	1971	1972	1977	1983	1984	1986	1991			28	6
Average years	1967	1968	1969	1973	1975	1976	1978	1981	1982	55	17

inated from cold lows or along frontal zones (Frank 1975). In 1991 ratio 1 was 0.58, the lowest since 1984 but very close to the 1967–90 average. 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 8b and Table 1 display the values of ratio 2 since 1967. The 24-yr average contribution from African waves to the total number of storms was 0.62. In 1991 ratio 2 was 0.38, and this value has been lower only in 1972 and 1983.

Typically, African waves are the main source of storms for the Atlantic basin. Some exceptions have occurred (e.g., 1972, 1977, 1983, and 1986) when African waves induced only a few storms. The year 1991 is included in that group and, in fact, *this is the first time since the tabulation of weaker tropical systems began in 1967 that none of the hurricanes originated from African waves in the Atlantic basin.* This is interesting because, by inspecting Table 1, one can see that on the average 66% of the hurricanes in the Atlantic develop from African waves. Many of those years when African waves induced only a few storms coincided with moderate to strong El Niño events (Gray 1990). Although African waves were present during those years, Gray has speculated that a hostile environment, induced by El Niño episodes, prevented many of the waves from developing in the Atlantic basin. Although an El Niño was clearly in progress in 1992, it is uncertain if it was present throughout the 1991 hurricane season.

Avila and Clark (1989) arbitrarily used ratio 2 to quantify the relative contribution to tropical-storm development by African waves. Years in which ratio 2 is greater than or equal to 0.7 are termed "African years." "Non-African years" are those for which ratio 2 is less than or equal to 0.5. Intermediate values are "average years." Clearly, 1991 was not an African year, and its tropical character was totally different from 1988 and 1989, when many of the storms and hurricanes 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 1990). 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 scale, Simpson 1974). The average HDP of African years for the 1967–91 period was substantially larger than the average HDP of the non-African years. In fact, the HDP for 1991 was only 23, which is less than a third of the long-term average (Gray 1991). Furthermore, the total number of major hurricanes during African years is much larger (about three times) than the number of major hurricanes during the non-African years. Thus, not only are a large number of hurricanes observed to develop from African waves, but usually the most intense hurricanes are spawned by those waves. Consequently, it is important to continue to monitor such waves.

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