The 1995 and 1996 North Atlantic Hurricane Seasons: A Return of the Tropical-Only Hurricane

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(Manuscript received 30 September 1996, in final form 2 July 1997)

ABSTRACT

Hurricane activity over the North Atlantic basin during 1995 and 1996 is compared to the combined hurricane activity over the previous four years (1991–94). The earlier period produced a total of 15 hurricanes compared to a total of 20 hurricanes over the latter period. Despite this similarity in numbers, the hurricanes of 1995 and 1996 were generally of the tropical-only variety, which marks a substantial departure from activity during the early 1990s. The return of tropical-only hurricanes to the Atlantic basin is likely the result of several global and local factors, including cool SST conditions in the equatorial central and eastern Pacific and warm SSTs in the tropical Atlantic. The hurricane activity of 1995 and 1996 is more reminiscent of activity of some seasons during the early and mid-1950s.

1. Two record hurricane seasons

Both the 1995 and 1996 Atlantic hurricane seasons had many more hurricanes than average, and several long-standing records were broken during these two seasons. Overall, the combined 1995–96 seasons produced a record 20 hurricanes. A hurricane is defined as a tropical cyclone whose maximum sustained (1-min average) winds exceed 33 m s^{-1} (64 kt). A brief review of the two very active seasons is given here.

On average the Atlantic basin records five to six hurricanes per season. In fact, the long-term average is approximately five over the period 1886–1990 and nearly six over the shorter, but more reliable, period 1950–90. Hurricane formation during the 1995 season was well above these long-term averages with a total of 11 hurricanes. The season's record-setting nature is illustrated through a list of notable occurrences. Hurricane Allison was the first June hurricane since Bonnie of 1986; the frequency of June hurricanes is approximately one in five years (Neumann et al. 1993). Moreover, five tropical storms were named by the end of July. At the height of the 1995 season, an outbreak of tropical cyclogenesis occurred to the east of the Lesser Antilles with five tropical storms originating within a span of seven days. Three of these five (Humberto, Iris, and Luis) were hurricanes simultaneously over the waters of the Atlantic. Only the 1961 Atlantic season experienced as many hurricanes active at one time. This outbreak made August an extremely active month; in fact, it was the most active month since September 1949.

The 1995 Atlantic hurricane season also featured many intense (or major) hurricanes. A hurricane is classified as intense when maximum sustained winds are at least 50 m s^{-1} (100 kt). A total of five major hurricanes during 1995 was well above the long-term average of two and was the most active outbreak of major hurricanes since 1964. All of these hurricanes had their origins from African easterly waves that developed over tropical latitudes south of 20°N. This is consistent with the recent finding of Landsea (1993) that greater than 80% of all intense Atlantic hurricanes originate from African waves. Despite the above-average intense hurricane activity, only the late-season Hurricane Opal made landfall in the United States. Hurricane Opal was the strongest hurricane to visit the Gulf of Mexico since Hurricane Allen of 1980 and was one of the strongest hurricanes on record during the month of October (strongest since Hurricane Hattie of 1961). Furthermore, Opal gets the distinction of being the strongest October Gulf of Mexico hurricane, the strongest hurricane to make landfall in northwestern Florida this century, and one of the costliest hurricanes to date (Hebert et al. 1996).

Increases in low-latitude hurricanes in 1995 contributed to the first hurricane to affect the Caribbean basin since Hugo of 1989. As one of the five intense hurricanes, Luis lashed the island communities of Antigua and Barbuda in early September. The absence of Caribbean hurricanes since 1989 is part of a longer trend of little activity in this part of the Atlantic basin dating

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back to 1982. In fact, over the 13-yr period from 1982 to 1994, 10 years were without any Caribbean hurricanes. Assuming each year is independent, the probability of this occurrence is less than 1%.[1] The recent downturn in the number of hurricanes affecting the Caribbean basin has been discussed in Landsea et al. (1996). Additional information regarding the details of individual tropical cyclones of 1995 can be found in Lawrence and Mayfield (1998, manuscript submitted to *Mon. Wea. Rev.*), and further speculations as to the possible causes of the abundant tropical cyclone activity during 1995 can be found in Saunders and Harris (1997) and Landsea et al. (1998, hereafter LA98).

The 1996 hurricane season appeared as an extension of the 1995 season with another round of above-normal activity. A total of 13 tropical storms of which 9 became hurricanes and 6 became intense hurricanes was recorded during 1996. Only four other years this century had six or more intense hurricanes in a single season (1916, 1926, 1950, and 1961). The 1996 season also continued the trend from the previous season as most of the storms originated from African easterly waves. Six of the nine hurricanes visited the Caribbean Sea, the most since 1916. Hurricane Bertha's formation on 5 July signified the earliest tropical cyclone formation in the far eastern Atlantic. It later reached intense hurricane status four days later as it passed north of Puerto Rico and became the earliest intense hurricane in the Atlantic since Hurricane Alma of 1966. Of the six intense hurricanes, only Fran made a direct landfall in the United States (North Carolina) as a major hurricane. Hurricane Fran was the second hurricane of 1996 to strike North Carolina near the city of Wilmington; it followed Hurricane Bertha, which hit in July. Multiple-hit years for North Carolina are actually relatively common. Using hurricane strike data back to 1851 (Fernández-Partagás and Diaz 1996), we find that the annual probability of a North Carolina hurricane landfall is approximately 20% and the probability of two or more hurricane landfalls in any given year is less than 5%. Yet if North Carolina gets hit by a hurricane, there is a 24% chance that it will be hit again that same year. This clustering of landfalls makes physical sense since a season often displays preferred paths of tropical cyclone movement based on the positions of the semipermanent synoptic weather features.

As with the 1995 season, a significant outbreak of tropical cyclogenesis occurred near the peak of the 1996 hurricane season. During a week-long span in late August, three tropical cyclones developed with two of the three reaching hurricane strength. This was part of a month-long stretch of nearly continuous tropical cyclone activity. Hurricane Hortense hit the southwest corner of Puerto Rico during September, causing considerable damage and several fatalities. Late season activity in the western Caribbean Sea was again rather prolific with Hurricanes Lili and Marco developing at this time.

This paper offers descriptions, speculations, and a possible explanation of the reversal in hurricane activity between the inactive early 1990s to the hyperactive 1995 and 1996 seasons. The underlying question is how effectively can the distinction between tropical-only and baroclinically initiated hurricanes be used to summarize the differences between these two consecutive short epochs.

2. Comparisons to the early 1990s

In sharp contrast to the very active 1995 and 1996 seasons, the four years immediately prior were characterized by well-below-average hurricane activity. In fact, the average annual number of hurricanes over the earlier 4-yr period was 3.8 compared to 10 over the more recent 2-yr period. Moreover, the hurricanes of the early 1990s were generally of shorter duration, were less intense, and had a tendency to form farther north and west. Figure 1 shows the points at which hurricane intensity was achieved for the 15 hurricanes of the 1991–94 period and the points of origin for the 20 hurricanes of the 1995–96 period. Striking differences are noted in both the latitude and longitude of formation. During the earlier period, 13 of the 15 hurricanes formed north of 25°N, while only 2 of the 20 during the latter period formed north of this cutoff. Reading (1989) investigated interdecadal trends in Caribbean hurricane activity and noted hurricane formation during the 1980s had shifted to the subtropics and midlatitude waters instead of the typical deep tropical formations. Clearly this tendency continued into the early 1990s.

Along with the higher latitude of development, tropical cyclones during the early 1990s were generally less intense than the long-term average. For instance, only four major hurricanes were observed from 1991 to 1994 compared to an approximate average of 2.3 major hurricanes per season (1950–95) and in stark contrast to the 11 of 1995–96. It is interesting to note that only Hurricane Gert of 1993 and Hurricane Andrew of 1992 either formed over or passed into the Gulf of Mexico during the early 1990s, whereas there was a total of five hurricanes during the period of 1995–96. Lehmiller et al. (1997) show that major hurricane activity in the Gulf of Mexico has experienced a decline since the early and mid-1970s. In spite of this decline, overall Gulf of Mexico activity has remained nearly constant.

Hurricane longevity was also shorter during the early 1990s compared to the more recent period. Total hurricane days over the latter period was 107 compared to 41 for the earlier period. In particular, LA97 mention that Hurricane Luis ranked as the third longest-lived intense hurricane since 1950. Only Hurricane Donna of

[1] Given an annual probability of 40% of no Caribbean hurricane (1950–95 base period) and assuming that successive years are independent, the probability of 10 no-hurricane years out of 13 is given by the binomial expansion as $p = (13!/10!3!)(0.4)^{10}(0.6)^3$.

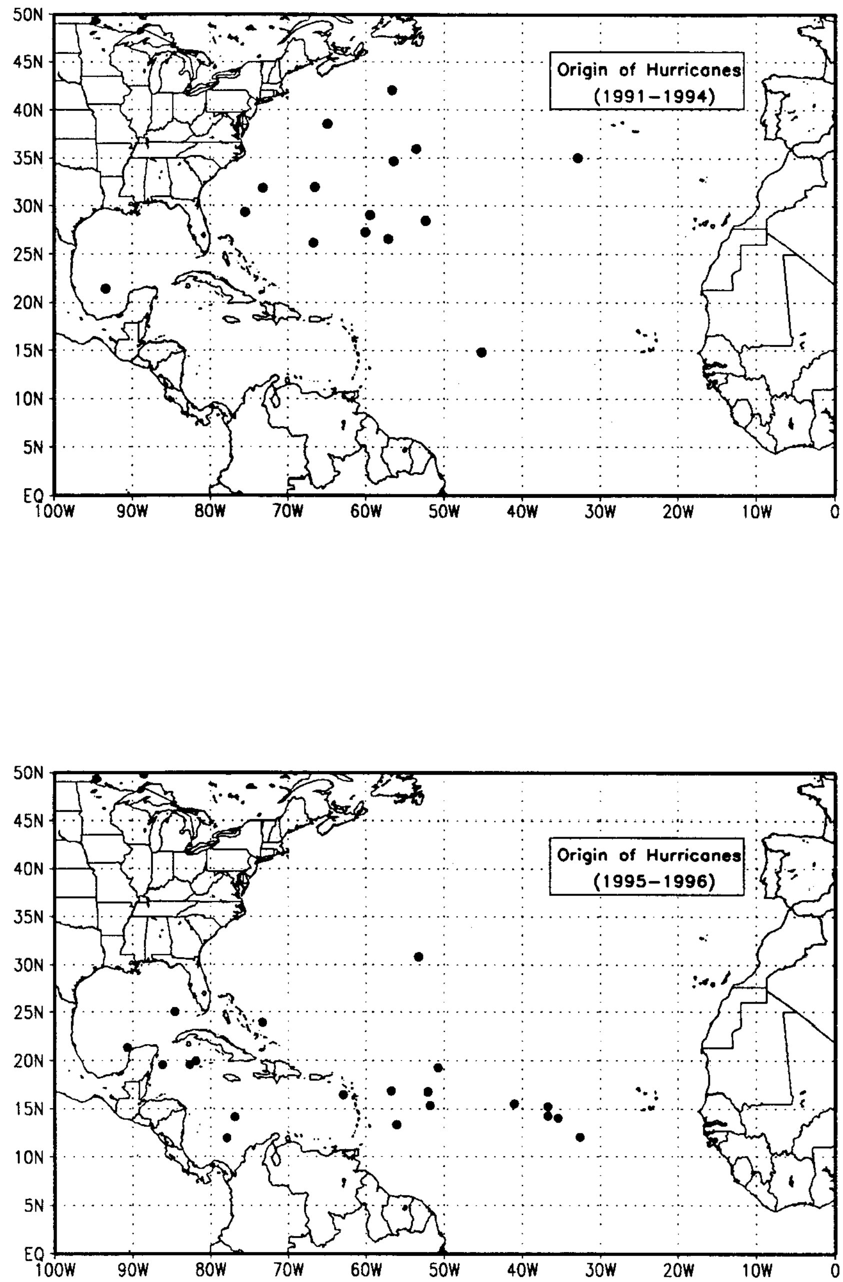


FIG. 1. Points at which all tropical storms became hurricanes for the period 1991–94 (top) and for 1995–96 (bottom). Over the 4-yr period beginning with 1991, 13 hurricanes formed north of 25°N, mostly over the western Atlantic. During 1995–96, 18 formed south of 25°N and 10 of these became hurricanes east of the Lesser Antilles and south of 20°N.

1960 and Hurricane Esther of 1961 surpassed Luis in the number of days as an intense hurricane. Hurricane Edouard of 1996 was also an exceptionally robust major hurricane.

3. Tropical-only and baroclinically initiated hurricanes

Disparities in North Atlantic hurricane types have recently led to a new classification system that identifies origin and development mechanisms related to tropical cyclone formation and intensification. Previously, Spiegler (1972) expressed concern over the accepted nomenclature of cyclones, noting that it is too simplistic to consider just two cyclone types, tropical and extratropical; there must be room to include the many intermediate stages that lie between the two. He recognized the importance of devising a system that is more reflective of the complexity of cyclone development.

Namias (1973) remarked that a common flaw in attempting to solve the theoretical questions directed at hurricane formation is to dismiss the complexity of the genesis and development issue, while ascribing a single unique cause to a cyclone's origin, development, and decay. What seems more plausible is that hurricane genesis is a result of a number of processes working on different scales of motion with the potential for self-organization resulting from a balance between nonlinear interaction of the different processes and dissipative forces.

The idea of dividing North Atlantic tropical cyclone activity into separate subsets, each characterized by its own intrinsic origins and developmental processes, is a powerful assumption that has begun to change the way we view tropical cyclones and seasonal forecasting techniques. The shortcoming in considering hurricane activity aggregately is that oversimplification will result, whereas creating too many classification categories may limit attempts to understand common tropical cyclone processes. Hess and Elsner (1994) and Hess et al. (1995) were the first to partition the annual Atlantic hurricane count based on differences in origin and development mechanisms. The scheme they proposed is the following: a *tropical-only* hurricane is defined to be a hurricane that originates from a tropical wave or disturbance (see Frank 1975) and develops to hurricane intensity devoid of any enhancing midlatitude baroclinic influences. This is not to say that tropical-only hurricanes are exempt from interactions with baroclinic weather systems. Adverse environmental conditions produced by midlatitude upper-air currents often hinder the development of a tropical cyclone. A developing tropical cyclone that reaches hurricane strength despite encounters with adverse effects from baroclinic weather systems is still considered a tropical-only hurricane. Only when baroclinic influences are such that they aid development is the hurricane not considered a tropical-only hurricane. Hurricane Luis of 1995 is a recent example of a tropical-only hurricane.

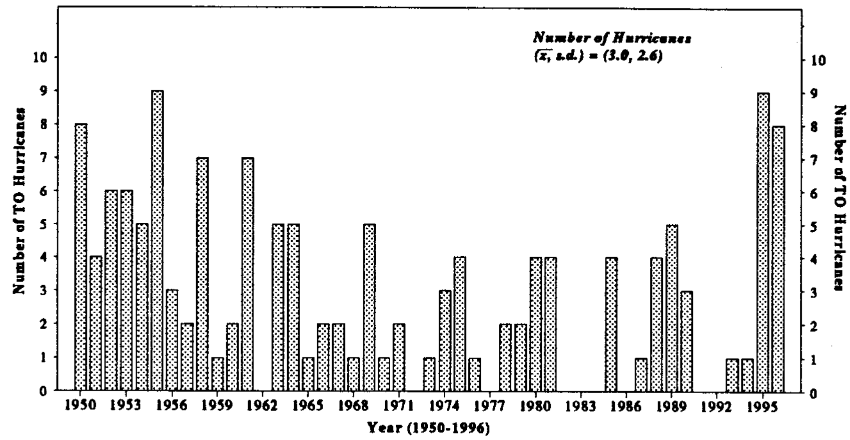
As mentioned, the designation of some Atlantic hurricanes as tropical only was first proposed by Hess and Elsner (1994). They performed the separation through a judicious review of published literature that describes past hurricanes dating back to 1950. Through Monte Carlo simulations based on comparable but arbitrary separations, they determined that the subjective classification was statistically significant. They also demonstrated that the separation was physically meaningful by showing that the seasonal number of tropical-only hurricanes is a significantly better predictand (in a strict statistical sense) than are total numbers with respect to the predictors of seasonal Atlantic hurricane activity identified by Gray et al. (1993). This was done by stating a null hypothesis that an arbitrary subset of all hurricanes would lead to similar improvements in forecast skill when predicted using the Gray et al. predictors and then rejecting this hypothesis at an a priori significance level by examining 10^4 forecasts of random subsets. Since forecast skill using the random subsets was small, one is led to conclude that the improvement in skill using the tropical-only subset is not likely due to chance. Moreover, Elsner et al. (1996) recently used the designations of Hess and Elsner (1994) to build an objective classification scheme for separating hurricane types. Their classification was found to be both parsimonious and accurate, further supporting the implicit contention of a close association between hurricane type and underlying physical mechanisms.

Despite the strong empirical support of tropical-only hurricanes as a separate category of seasonal Atlantic hurricane activity, the idea has met some resistance. The main objection stems from the difficulty in labeling all hurricanes with 100% accuracy. More succinctly, what is the essence of a tropical-only hurricane? Are there necessary and sufficient conditions that can be used to perfectly identify all tropical-only hurricanes? The answer is clearly no. Yet the selection of an objective latitudinal cutoff will also be in error as the physics of hurricane origin and growth are omitted. On the other hand, the subjective method specifies and preserves the underlying, essential physics; the dilemma is clear. Our option is to err on the side of subjectivity.

To emphasize this further, though there is no clean way to distinguish all tropical-only hurricanes, this does not imply that it is best to consider all hurricanes as having a common origin and/or development mechanisms. Past work has shown (Hess and Elsner 1994; Hess et al. 1995; Elsner et al. 1996) that it is *useful* to consider the Atlantic hurricane activity as the sum of several different components because such distinctions allow one to see otherwise hidden structures in the data. There is little doubt that significant new insights are to be gained from this perspective.

More recently, Kimberlain (1996) defined *baroclinically initiated* hurricanes as hurricanes originating from cold-core waves (e.g., diffuse frontal troughs, upper-tropospheric low pressure areas with surface reflections, etc.). These hurricanes typically form over subtropical or midlatitude waters and have shorter overall lifespans and weaker intensities. Hurricane Josephine (1984) is an example of a baroclinically initiated hurricane. We stress that tropical-only and baroclinically initiated hurricanes are defined with respect to origin and development processes and that, once a tropical storm reaches hurricane strength, it is often impossible to discern the different categories (tropical only and baroclinically initiated) as each type may enter environments that do not reflect their origin and development to hurricane strength.

There exists large interseasonal variability in tropical-only hurricanes. Figure 2 shows the wide variation since 1950. The years of 1962, 1968, 1972, 1977, 1982, 1984, 1986, 1991, and 1992 feature no tropical-only hurricanes. Tropical-only hurricane activity appears to have been more active during the 1950s but has since ex-



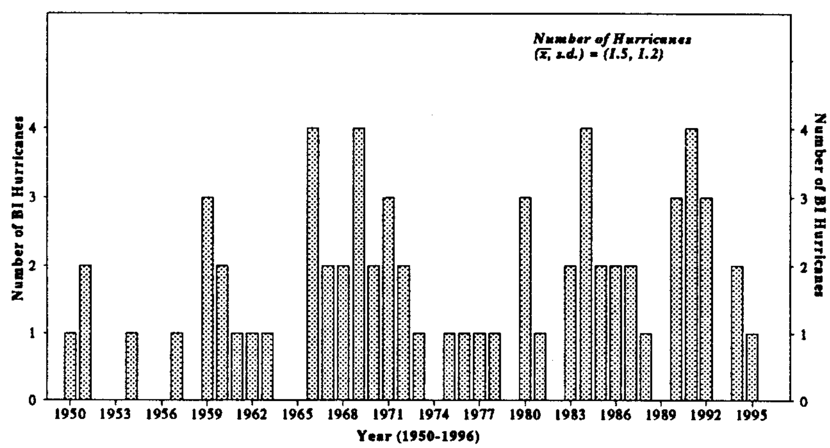


FIG. 2. Annual number of tropical-only (top) and baroclinically initiated (bottom) hurricanes from 1950 to 1996. Note the large number of tropical-only hurricanes for 1995 and 1996.

perienced a decline. Elsner et al. (1996) indicate that there has been a reduction in tropical-only hurricanes since the mid-1960s. As they point out, these findings should be tempered, however, as it can also be inferred that, with the routine use of the weather satellite imagery, a decline in tropical-only hurricane activity could be an artifact of our increasing knowledge of higher-latitude weather systems and their effects on developing hurricanes. Interestingly, the 1995 and 1996 seasons saw a return of the tropical-only hurricane.

This is clear by comparing tropical-only activity with the previous four years. For example, only two tropical-only hurricanes were recorded over this 4-yr period. Of these two, Chris of 1994 was badly sheared and developed only into a minimal hurricane. Hurricane Gert of 1993, the other tropical-only hurricane, was a hurricane for less than a day as it moved inland over Mexico before appreciable development. The 1991 and 1992 seasons were void of any tropical-only hurricanes. In fact, all of the hurricane formations during the 1991 season resulted from baroclinic disturbances. Avila and Pasch (1992) note that 1991 had the lowest ratio of tropical-originating tropical storms to total storms since 1984. Also of note, Hurricanes Bob and Claudette of 1991, both baroclinically initiated, became intense hurricanes. The average number of tropical-only hurricanes per season is 3.0. From this average, it is estimated that a total of nearly 12 tropical-only hurricanes would result over any 4-yr time span.

Also shown in Fig. 2 is the interseasonal variability of baroclinically initiated hurricanes. There are several years since 1950 with no baroclinically initiated hur-

TABLE 1. Climatology of Atlantic hurricane activity over the period 1950–96 for the seven warmest (top) and seven coolest (bottom) Septembers based on SSTs in a region to the east of the Lesser Antilles. Here H_T and H_B are the number of tropical-only and baroclinically initiated hurricanes during the season, respectively. Also, IH is the number of intense hurricanes. Median latitude is computed from the 6-hourly best-track positions for all tropical cyclones of hurricane strength for a given year.

Rank	Year	SST (°C)	H_T	H_B	IH	Median lat (°N)
46	1952	29.32	4	0	3	25.9
45	1955	29.26	8	0	6	24.6
44	1969	29.12	6	4	3	28.5
43	1958	29.11	7	0	5	28.8
42	1966	29.09	2	4	3	24.9
41	1988	29.09	4	1	3	18.5
40	1995	29.02	9	1	5	24.3
Totals/avg		29.14	40	10	28	25.07
7	1984	28.36	0	4	1	31.1
6	1974	28.33	3	0	1	21.2
5	1992	28.32	0	3	1	35.6
4	1972	28.31	0	2	0	38.8
3	1976	28.25	1	1	2	33.4
2	1991	28.22	0	4	2	31.6
1	1982	28.15	0	0	1	36.4
Totals/avg		28.23	4	14	8	32.59

ricanes (most recently 1979, 1989, 1993, and 1996). The interseasonal variability of this hurricane type is less extreme. The highest number recorded in a season is four (1966, 1969, 1984, and 1991). An average of 1.47 baroclinically initiated hurricanes is expected per season (Kimberlain 1996). The 1991–94 period experienced a slight increase in baroclinically initiated hurricanes (nine developed and the average is six). The 1995 season saw only one baroclinically initiated hurricane (Tanya) and 1996 had none.

4. Speculations

As mentioned above, much of the hurricane activity during the 1995–96 seasons originated to the east of the Lesser Antilles within the area known as the main development region (MDR) (Shapiro and Goldenberg 1998; Saunders and Harris 1997); it is also part of the region where tropical-only hurricanes originate (Elsner et al. 1996). Based on this observation, we examine the SSTs over this region (5° latitude × 5° longitude box centered at 12.5°N and 47.5°W) and find that the waters were considerably warmer during September of 1995 and 1996 than during the previous four Septembers. The average temperature for both 1995 and 1996 was approximately 29°C, which compares with the 4-yr (1991–94) September average temperature of 28.4°C. None of the four Septembers exceeded 29°C. Even though the difference between these two periods is less than 1°C, we find this relationship between SSTs and tropical-only hurricane activity to be quite robust over the 46-yr period from 1950 to 1995. Both observations and theory support the idea that hurricane formation is sensitive to very small changes in SST in the range of 27°–29°C (Carlson 1971; Emanuel 1991; Evans 1993). This is partly explained by the fact that the presence of the trade wind temperature inversion at low levels keeps the development of deep cumuli in check until rather abruptly enough heat and moisture have accumulated in the boundary layer to erode the inversion. Therefore, it seems plausible that even a 1°C difference in SST can mean the difference between an active and an inactive year. Table 1 summarizes the seven warmest years and the seven coolest years for the region defined above.

We note that 1995 is ranked the seventh warmest on record and that 1996 [derived from National Centers for Environmental Prediction (NCEP) monthly, optimally interpolated Reynold's SSTs] falls just below the 1995 value. Both 1991 and 1992 ranked in the top five for the coolest on record. Saunders and Harris (1997) mention that 1995 featured the warmest SSTs in the MDR since records began in 1865. There are 40 tropical-only hurricanes during the seven warmest years compared to only four during the seven coolest years. Conversely, we find that the cool years generally support more baroclinically initiated hurricanes compared to the warm years. These findings reflect the fact that the average median latitude of the hurricanes during warm years is 25.1°N compared to 32.6°N during the cool years (the hurricanes of 1996 had a median latitude of 23.3°N). We speculate that these warm SSTs may not only be responsible for lower sea level pressures resulting in enhanced convection and a strengthened convergence zone but also a shift in trade wind strength or direction (Carton et al. 1996) over the central North Atlantic.

Additionally, we mention that Goldenberg and Shapiro (1996) have remarked on the peculiar shift in hurricane formation from the deep Tropics to the subtropics and midlatitudes. They note that years of high-latitude activity commensurate to the 1991–94 period are commonly associated with below-normal rainfall over portions of west Africa and/or above-average SSTs over the equatorial central and eastern Pacific (El Niño conditions). These two elements are linked to hostile environmental conditions for tropical cyclogenesis and hurricane formation over the tropical belts (south of 20°N) of the North Atlantic. Moreover, they indicate that changes in vertical wind shear over the subtropical and midlatitude western Atlantic are unrelated to, or in a weakly opposite phase, when compared to vertical shear south of 20°N. As such, hurricane developments north of the tropical belts in these years are more likely from either baroclinically initiated disturbances or perhaps tropical weather disturbances that are able to survive the unfavorable environmental conditions over the deep Tropics.

5. Summary

Conditions during the early 1990s of fewer and weaker Atlantic hurricanes with origins north of the climatologically favored breeding grounds were abruptly broken with the activity of the 1995–96 hurricane seasons. A total of 32 named tropical cyclones developed. Of these, 20 reached hurricane status and 11 of those reached intense hurricane status. The 1995 season featured the greatest number of hurricanes since 1969, and the 1996 season saw the greatest number of major hurricanes since 1961.

The reversal in Atlantic hurricane activity between the early 1990s and 1995–96 is accentuated by considering tropical-only and baroclinically initiated hurricanes separately. There were nine tropical-only and one baroclinically initiated hurricanes during 1995 and eight tropical-only and no baroclinically initiated hurricanes in 1996 compared with two tropical-only and nine baroclinically initiated hurricanes during the previous four years. The average median latitude of hurricanes over 1995 and 1996 is approximately 24°N compared to 33.4°N for the hurricanes over 1991–94.

One likely factor that contributed to a dearth of tropical-only hurricane activity during the early 1990s was the prolonged warm ENSO phenomenon over the central and eastern Pacific. Gray (1984) shows that these Pacific El Niño conditions foster anomalously strong upper-tropospheric westerly winds, which lessen the likelihood of hurricane development and maintenance over the tropical Atlantic, including the Caribbean basin. In addition, they also tend to produce an anomalous Walker circulation as a consequence of upward vertical motion in the eastern equatorial Pacific and increased mid- and upper-tropospheric subsidence over the Atlantic basin; this development has a two-pronged effect. Increased subsidence is equated with higher surface pressure. The result is increased surface trade winds across the tropical Atlantic that, in turn, lead to enhanced upwelling and cooler SSTs close to the MDR. Second, subsidence produces a dry midtroposphere and hence does not support convection. Finally, it is also noted that the Tropical Upper Tropospheric Trough is often more energetic in these years (Knaff 1997). All of these factors inhibit hurricane formation and development.

Weak to moderate cool conditions developed over the central and eastern equatorial Pacific by June 1995. The NCEP Climate Prediction Center diagnostic reports substantiated the formation of large pockets of cooler-than-normal waters over these areas by October 1995. The result was a noticeable absence of deep convection over the tropical belts of the Pacific during the 1995 and 1996 Atlantic hurricane seasons.

Additionally, it is likely that the SSTs to the east of the Lesser Antilles played a role in the return of tropical-only hurricanes during 1995 and 1996. September SSTs were above the long-term average during 1995 for the first time since 1990 and continued at this level into the 1996 season. Historically, when SSTs in this region are high, the number of tropical-only hurricanes is substantially greater compared to years of below-normal SSTs. The reverse is true to a lesser degree with the baroclinically initiated hurricanes. Physically, warmer SSTs allow tropical storms to maintain organization and possibly intensify through a strengthening of the low-level convergence zone even under somewhat adverse upper-level atmospheric conditions. Finally, this paper does not intend to offer a prognostication as to future hurricane activity. It is simply a synopsis of the variability of the hurricane count during the past several years. It is not known whether high numbers of tropical-only hurricanes will result during subsequent seasons.

Acknowledgments. Some support for this work came from NOAA through the Cooperative Institute on Tropical Meteorology and from the Risk Prediction Initiative of the Bermuda Biological Station for Research. Additional support was provided by the National Science Foundation Grant ATM-9618913. Data obtained for tropical cyclone analyses are from the ''best'' track dataset provided by the Tropical Prediction Center. We thank Dr. H. Diaz for kindly providing us the Atlantic SST data and both A. Birol Kara and Dr. John A. Knaff for their help in the preparation of the manuscript.

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