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Deciphering the Long-Term Trend of Atlantic Basin Intense Hurricanes: More Active Versus Less Active During the Present Epoch

Robert M. Wilson
Marshall Space Flight Center, Marshall Space Flight Center, Alabama

December 1998

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TECHNICAL PUBLICATION

DECIPHERING THE LONG-TERM TREND OF ATLANTIC BASIN INTENSE HURRICANES: MORE ACTIVE VERSUS LESS ACTIVE DURING THE PRESENT EPOCH

1. INTRODUCTION

Humans have always demonstrated an affinity to be near the water and the population of the United States is no exception. In particular, Williams[1] has shown that the population of counties located along the Atlantic and Gulf coasts has steadily increased with the passage of time and that, associated with this burgeoning population growth, an escalating cost of hurricane damage, reaching into the tens of billions of dollars, has occurred (see also, Gray and Landsea[2]). In terms of severity, hurricanes are ranked according to their central pressure, maximum sustained wind speed, and accompanying storm surge using the "Saffir-Simpson hurricane damage potential scale" (see Simpson[3]) which ranges from 1–5, where, collectively, those of category 3–5 are the classes of "intense hurricanes." These particular hurricanes have central pressure ≤964 mbar, maximum sustained wind speed ≥50 $msec^{-1}$, and storm surge ≥2.5 m.

Previous investigations[4–12] have described the long-term variation of the frequency of hurricanes, in particular, in relation to El Niño, wet-dry years of West African rainfall, a perceived active-inactive pattern of hurricane activity, and an inferred long-term steady decline of hurricane activity spanning the past five decades (see also, Wilson[13] and Landsea et al.[14]). In this paper, the long-term trend of the annual frequency of intense hurricanes is reexamined, specifically, on the basis of its 4- and 10-yr moving averages (moving averages are often used to reduce the effect of random movements on time series data[15]), comparing them against those for the annual mean temperature at the Armagh Observatory (Northern Ireland), first, to determine the possible effect of climatic change on the frequency of intense hurricanes and, second, to determine the probable direction of its long-term trend during the current epoch. Recall that the annual mean temperatures at Armagh are based on the use of maximum and minimum thermometers and extend back to 1844 (see Butler[16] and Butler and Johnston[17]). Recently, Wilson[18] showed that the Armagh temperatures can be used as a proxy for climatic change, since they are found to compare quite favorably with northern hemispheric and global standards (i.e., those of Parker et al.[19] based on global fields of area-weighted averages of Meteorological Office Historical Sea Surface Temperature). Moreover, Wilson showed that the current long-term trend of temperature now appears to be *upward*, being statistically related to the Sun's Hale cycle (also called the "double sunspot cycle"). Because the intensity of hurricanes may be related to changes in climate,[20–24] the current warming seems to portend a return to the more active state of intense hurricane activity, perhaps, like the one that was prevalent prior to the mid 1960's.

2. RESULTS AND DISCUSSION

Figure 1 displays the variation of decadal averages of temperature anomalies (top) from Parker et al.,[19] mean temperatures at Armagh (middle) from Wilson,[18] and the frequency of intense hurricanes in the Atlantic basin from Wilson.[13] Noticeable is that all three parameters strongly resemble each other; i.e., they have higher values in the 1940's, followed by a downward trend, a flattening, and the hint of an upward trend (with hurricane activity, perhaps, slightly lagging those of the temperature anomalies and means). Because of the strong resemblance to temperature, one infers that *shifts* in the activity state for intense hurricanes (from more active to less active and vice versa) may, in fact, be related to changes in climate. Hence, a strong statistical association between temperature and the frequency of intense hurricanes is anticipated, especially, one based on moving averages. (Strictly speaking, the comparative data sets are limited by the length of the reliable record of intense hurricanes of the Atlantic basin as determined by routine aircraft reconnaissance (see Neumann et al.[25]) a timespan of only about 54 yr. Therefore, one cannot yet rule out the possibility that the inferred association between the annual frequency of intense hurricanes and temperature may be the result of a mere statistical fluke.)

Figure 2 compares annual mean temperatures at Armagh (top) and the frequency of intense hurricanes (bottom), both plotted as the thin lines. Superposed on the yearly values are the 4- and 10-yr moving averages, plotted, respectively, as the thicker and thickest lines. Identified across the top are the occurrences of El Niño (taken from Trenberth[26] and supplemented by Quinn et al.[27, 28] for the years preceding 1950) and the onsets of the Sun's Hale cycles 18–19, 20–21, and 22–23, where each pair of numbers refers to individual sunspot cycles that comprise them. Recall from Wilson[18] that the Hale cycle represents the fundamental cycle of solar magnetic activity and that each has a preferred pairing (specifically, "even-odd," in that order).

From figure 2, one finds that the annual frequency of intense hurricanes has ranged from 0 to 7, with the annual counts ≥4 only for the years of 1948, 1950, 1955, 1958, 1961, 1964, 1995, and 1996. The timeframe before 1965 has previously been identified as being more active than after 1965 (e.g., Gray[5] and Wilson[13]); the same, however, cannot, as yet, be said for the present epoch (i.e., has a new active era already begun?).[13, 14]

Interestingly, for 41 of the 54 yr displayed (76 percent) the annual frequency of intense hurricanes has measured 2±1, with only 5 of 54 yr (9 percent) having no occurrences per year and 8 of 54 yr (15 percent) having an annual frequency ≥4. Of the five zero occurrence years, only the year of 1962 failed to be an El Niño year. Previously, on the basis of the seasonal number of hurricane days for the years of 1900–1982, Gray[4] found that in most El Niño years hurricane activity was diminished in comparison to non-El Niño years. More recently, Wilson,[29] using the detailed listing of El Niño for the interval of 1950–1997 by Trenberth,[24] contrasted El Niño- and non-El Niño-related hurricane seasons and found the annual frequency of intense hurricanes to be ~2.8 for non-El Niño-related seasons and to be only 1.3 for El Niño-related seasons, where the observed difference is noted to be statistically important at the 0.2 percent significance level. Predicting the annual frequency for 1998, however, posed a difficult problem at the beginning of 1998 because of the continuing (though waning) effects of the strong El Niño of 1997–1998.

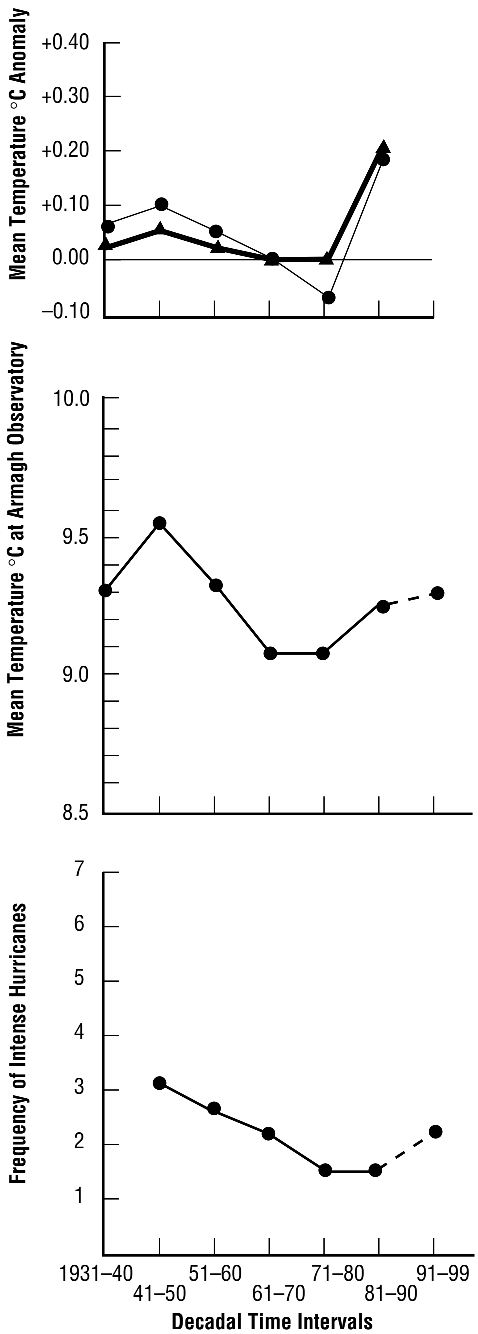

Figure 1. Decadal averages of mean temperature anomalies (top), mean temperature at the Armagh Observatory (middle), and frequency of intense hurricanes (bottom). For the anomalies, the filled circles refer to the northern hemisphere, while the filled triangles refer to the globe.

Had the event been found to extend *beyond* June 1998, the season would have had to be classified as "El Niño-related," indicating that probably ≤2 (thus far, always ≤3) intense hurricanes would form in the Atlantic basin. Now, however, because the event appears to be officially over (Trenberth, private communication), having ended *prior* to the start of the current hurricane season, the 1998 season must be recognized as "non-El Niño-related;" consequently, the frequency of intense hurricanes probably will be ≥2. Complicating this issue, however, is the observation that the yearly rate for the year *following* one in which a frequency of 1 event per year has been recorded has always been ≤3 (true for 13 of 13 yr); for 10 of 13 yr the next year's rate was ≤2. Because in 1997 only one intense hurricane was recorded, it follows that, statistically speaking, ≤3 events probably should be expected during the current 1998 season. Thus, it seems quite plausible that an *average* hurricane season for 1998 may be the "best guess" (i.e., 2±1 intense hurricanes). Through September 1998 two intense hurricanes have formed thus far in the Atlantic basin—"Bonnie" and "Georges," a category 3 and 4 hurricane, respectively (generally speaking, intense hurricanes occur most frequently after August 1st during the interval of August–October[30–37]). On the other hand, because of the strong likelihood that the 1999 season will also be "non-El Niño-related" (perhaps, even a "La Niña-related" season)[29] one probably should anticipate an *increase* in the number of intense hurricanes for next year's season (i.e., possibly ≥4).

On the basis of a Poisson distribution for intense hurricanes (one having a mean of 2.22 events per year—from the actual data of 120 events per 54 yr), one easily computes the probability of having *no* events per year as 10.9 percent (or, about 1 chance in 9.2), of having ≥4 events per year as 18.5 percent (or, about 1 chance in 5.4), and of having 2±1 events per year as 70.7 percent (or, about 1 chance in 1.4). Thus, by always predicting an "average" number of events for any given year (i.e., 2±1 events per year), one expects to be correct ~71 percent of the time. (The rate of 2 events per year is also the *mode* and *median* values for the observed distribution of intense hurricanes.)

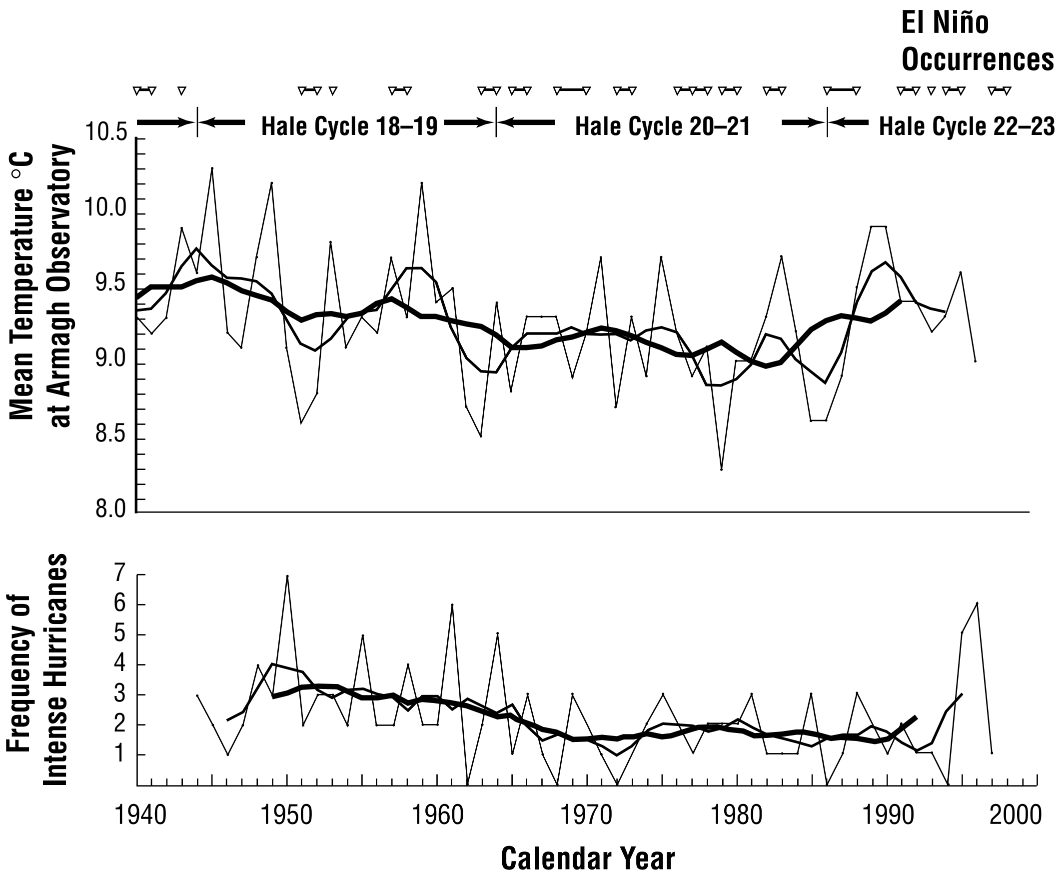

Figure 2. Annual mean temperature at Armagh Observatory (top) and the annual frequency of intense hurricanes (bottom). The thin lines are the yearly values, while the thicker and thickest lines are the 4- and 10-yr moving averages, respectively. El Niño occurrences and individual Hale cycles are identified across the top.

From figure 2 it is found that the 4- and 10-yr moving averages of the annual frequency of intense hurricanes appear to be in fairly steady decline from about 1950 through about 1970, then to be relatively flat until about 1990, when an upswing seems discernible. Similarly, the 4- and 10-yr moving averages of the annual mean temperature at Armagh appear to be in decline from the mid 1940's to the mid 1960's, then flat from the mid 1960's to the mid 1980's, when an upswing also seems discernible. This coordinated behavior (with temperature leading) suggests the presence of a strong statistical association between them.

Figure 3 displays scatter plots of the frequency of intense hurricanes versus temperature using the 4-yr (right) and 10-yr (left) moving averages, both with temperature leading by 6 yr (a lead time that is associated with the *strongest* correlations). In each panel the regression line is plotted and the results of the linear regression analysis are given, as is the probability *P* of obtaining the observed 2×2 contingency table, or one more suggestive of a departure from independence, where the table is determined by the medians, shown as the thin vertical and horizontal lines (i.e., using Fisher's exact test). For the 4- and 10-yr moving averages, both correlations are inferred to be statistically important at <<0.1 percent significance level, suggesting that the leading trend of temperature, indeed, can be used to predict the consequential trend of the frequency of intense hurricanes.

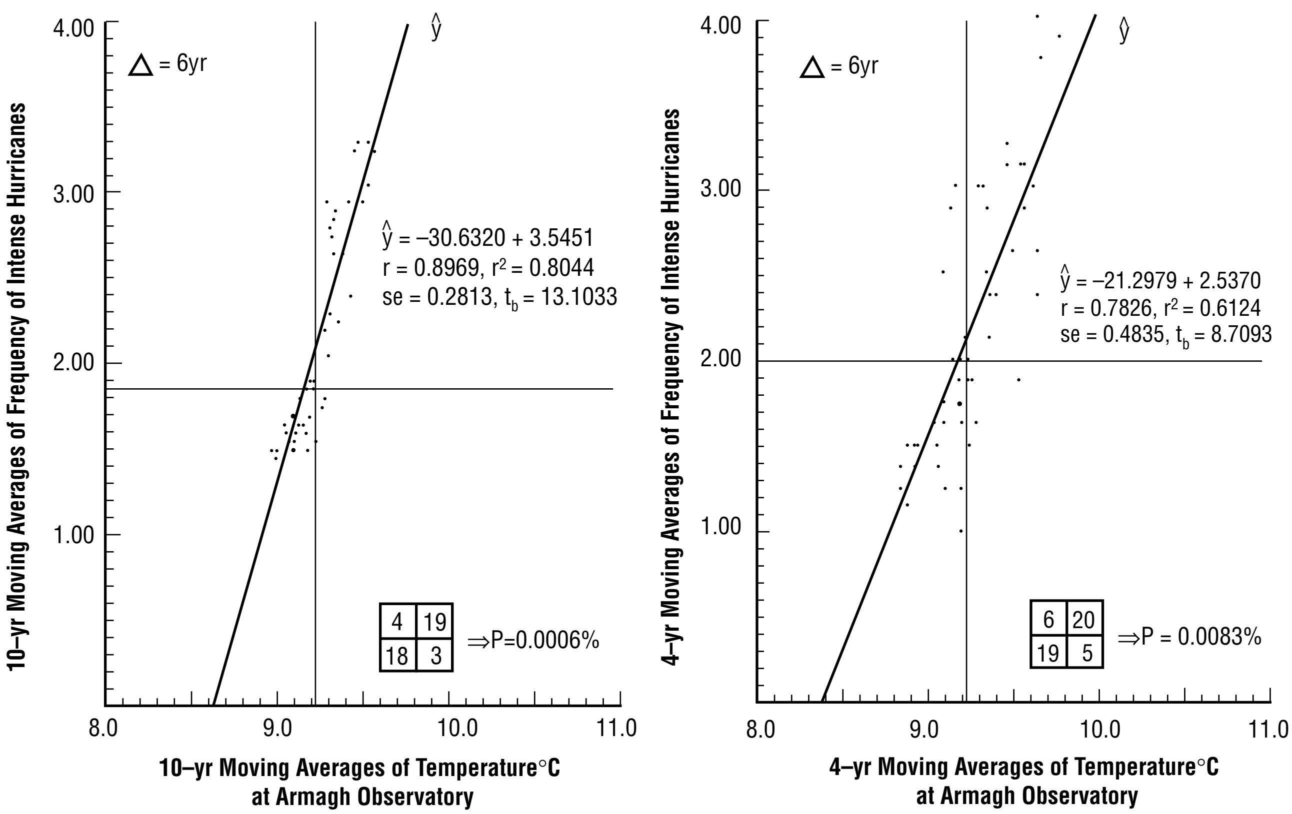

Figure 3. Scatter plots of the frequency of intense hurricanes versus mean temperature at the Armagh Observatory, using 4-yr moving averages (right) and 10-yr moving averages (left) and employing a lag of 6 yr (temperature leading).

As an example, for the 10-yr moving averages, the leading trend of temperature (see Fig. 2) is found to exceed its median of 9.235 °C for the years of 1986–1991, implying that the predicted values of the frequency of intense hurricanes for the years 1992–1997 will be in the upper-right quadrant of figure 3 (i.e., above its median of 1.85 and being indicative of the more active state). Indeed, the observed 10-yr moving average of frequency for 1992 is found to exceed the median. For 1987–1991, the leading 10-yr moving averages of temperature, respectively, equal 9.31, 9.29, 9.27, 9.32, and 9.39 °C, all above its median; hence, one estimates that for the years of 1993–1997, the 10-yr moving average of frequency, respectively, will be about 2.37, 2.30, 2.23, 2.41, and 2.66 intense hurricanes per year (all above its median value). Such values are certainly consistent with the notion that a shift to the more active state probably has already occurred, and that the yearly frequencies of intense hurricanes during the present epoch (1998 and later) will usually be above the median, as well (though modulated, of course, by the appearances of El Niño).

As to why a 6-yr lead time should be incorporated in the correlations (with temperature leading), the answer is not intuitively obvious. Perhaps, it is related to the average length of time between El Niño events, being about 3–4 yr in length,[28, 29] and/or to the timing and strength of the quasi-biennial oscillation (a 2–3 yr oscillation) over the Tropics, both of which have previously been shown to have an influence on Atlantic tropical cyclone activity.[4, 6, 37, 38] Perhaps, instead, it bespeaks of a subtle relationship between climate and the Sun,[29, 39] where transitions between states are not driven instantaneously, but require a few years or so for the change from one state to the other to be manifested. Then again, perhaps, it is simply an artifact of the analysis, using moving averages based on the rather short interval (54 yr) for which reliable records exist for determining the annual frequency of intense hurricanes.[11, 25] While a physical basis for the 6-yr lead time remains nebulous, the strength of the inferred correlations between temperature and the annual frequency of intense hurricanes provides encouragement that one can use them (in combination with the well-established El Niño-Atlantic hurricane activity relationship[4, 29]) in formulating a prediction for intense hurricane activity during the current epoch (at least, until it fails to have predictive ability).

One of the most important factors affecting a successful prediction of the number of intense hurricanes during any particular season seems to be whether or not the season is deemed to be “El Niño-related” or not.[4, 29, 37, 38] Thus, when anomalous periods of El Niño activity suddenly occur,[28, 40–46] as during the recent interval of 1990–1995, they can play havoc with trying to accurately predict the level of intense hurricane activity during a specific year, and, in particular, with trying to observe the transition from one state to the other. Hence, the recent “expected” transition from the less active state of intense hurricane activity (in vogue after the mid 1960’s) to the more active state (that was not really apparent until after the 1995–1996 seasons, having levels reminiscent of the active interval prior to the mid 1960’s) essentially went unnoticed. Obviously, more indepth work modeling the occurrences of these anomalous periods of El Niño activity must be accomplished. (Previously, Quinn et al.[28] have noted several extended periods of time when the amount and/or strength of El Niño activity and its resulting effects appeared to represent significant long-term climatic changes. These anomalous periods include 1607–1624, 1701–1728, 1812–1832, 1864–1891, 1925–1932, and now 1990–1995.)

3. CONCLUSIONS

In conclusion, on the basis of the most reliable data (1944–1997) of intense hurricanes, this study has found strong statistical evidence (at <<0.1 percent significance level) linking the annual frequency of intense hurricanes with climatic change, in particular, as gauged using annual mean temperature at the Armagh Observatory (Northern Ireland). Hence, by monitoring the trend in temperature (which has been shown to be strongly related to the Sun's Hale cycle[18]), one has at his disposal a tool for assisting in the accurate prediction of the seasonal frequency of intense hurricanes and for observing the transitional phasing from one state to the other (i.e., from more to less active and vice versa). Furthermore, the upswing in temperature that began in the mid 1980's (associated with the start of the current Hale cycle) strongly suggests that the present epoch of intense hurricane activity, modulated, of course, by the appearances of El Niño, will likely be reminiscent of the more active era that was prevalent before the mid 1960's. This active state, as modulated by El Niño, should continue until near the end of the first decade of the new millennium, when a return to the less active era should once again be apparent (due to the onset of a new Hale cycle in about 2006). Because a Poisson distribution (having a mean of about 2.22 events per season) yields a good match to the observed distribution of annual frequencies of intense hurricanes, one finds that the "best guess" prediction for any year is about 2±1 intense hurricanes per season, being preferentially lower (more often ≤2) during El Niño-related seasons and preferentially higher (more often ≥2) during non-El Niño-related seasons, and matching the observed level of activity about 71 percent (or more) of the time. Because the 1998 season is now recognized as being "non-El Niño-related" and the 1999 season, likewise, is expected to be "non-El Niño-related" (perhaps, even, "La Niña-related"), one expects ≥2 intense hurricanes during the seasons, probably 2–3 for 1998 and possibly ≥4 for the 1999 season.

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13. ABSTRACT *(Maximum 200 words)*

During the interval of 1944–1997, 120 intense hurricanes (i.e., those of category 3 or higher on the Saffir-Simpson hurricane damage potential scale) were observed in the Atlantic basin, having an annual frequency of 0–7 events per year, being more active prior to the mid 1960's than thereafter (hence a possible two-state division: more active versus less active), and being preferentially lower during El Niño years as compared to non-El Niño years. Because decadal averages of the frequency of intense hurricanes closely resemble those of average temperature anomalies for northern hemispheric and global standards and of the average temperature at the Armagh Observatory (Northern Ireland), a proxy for climatic change, it is inferred that the long-term trends of the annual frequency of intense hurricanes and temperature may be statistically related. Indeed, on the basis of 4- and 10-yr moving averages, one finds that there exists strong linear associations between the annual frequency of intense hurricanes in the Atlantic basin and temperature (especially, when temperature slightly leads). Because the long-term leading trends of temperature are now decidedly upward, beginning about the mid 1980's, it is inferred that the long-term consequential trends of the annual frequency of intense hurricanes should now also be upward, having begun near 1990, suggesting that a return to the more active state probably has already occurred. However, because of the anomalous El Niño activity of the early to mid 1990's, the switch from the less active to the more active state essentially went unnoticed (a marked increase in the number of intense hurricanes was not observed until the 1995 and 1996 hurricane seasons, following the end of the anomalous El Niño activity). Presuming that a return to the more active state has, indeed, occurred, one expects the number of seasonal intense hurricanes during the present epoch (continuing through about 2012) to usually be higher than average (i.e., ≥2), except during El Niño-related seasons when the number usually will be less than average.

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