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Decadal Variation of the Number of El Niño Onsets and El Niño-Related Months and Estimating the Likelihood of El Niño Onset in a Warming World

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LIST OF ACRONYMS AND SYMBOLS

<AT>	mean decadal Armagh Observatory surface-air temperature
Dur	event duration
<Dur>	mean decadal duration
EN	El Niño
ENSO	El Niño–Southern Oscillation
ERSST.v3b	extended reconstructed sea-surface temperature, version 3b
M	moderate
MSFC	Marshall Space Flight Center
max ONI	maximum value of the ONI
N	north latitude
NENM	number of EN-related months
NENO	number of EN onsets
No.	number
NOAA	National Oceanic and Atmospheric Administration
ONI	Oceanic Niño Index
<ONI>	mean value of the ONI over the entire event
RP	recurrence period
S	strong; south latitude
t	elapsed time in months from EN onset
T	total
W	weak; west longitude

NOMENCLATURE

cl	confidence level
i	event number
r	coefficient of correlation
r^2	coefficient of determination
sd	standard deviation
se	standard error of estimate
x	independent variable
y	regression equation

TECHNICAL PUBLICATION

DECADAL VARIATION OF THE NUMBER OF EL NIÑO ONSETS AND EL NIÑO-RELATED MONTHS AND ESTIMATING THE LIKELIHOOD OF EL NIÑO ONSET IN A WARMING WORLD

1. INTRODUCTION

About a decade ago, a number of papers were published describing the apparent 'anomalous' behavior during the 1990s of the El Niño-Southern Oscillation (ENSO) quasi-periodic cycle, suggesting, perhaps, a link with global climatic change.[1–6] Research[7] conducted at Marshall Space Flight Center (MSFC), however, indicated that the frequency and severity of El Niño events during the 1990s compared quite favorably with preceding decades, suggesting instead that the 1990s should not be regarded as anomalous, but rather as a normal fluctuation in the pattern. While true, it was noted at that time that the number of El Niño-related months per decade was sharply higher in the 1990s as compared to the preceding four decades, hinting of a marginally statistically significant upward trend (confidence level (*cl*) >90%).

Nearly a decade has now passed since the earlier study was performed, so it seems appropriate to revisit the issue once again in light of nearly another decade's worth of observations. Is the number of El Niño onsets and/or the number of El Niño-related months per decade increasing with time, possibly being related to global warming, or do the numbers better reflect normal fluctuation? Also, given the last occurrence of an El Niño onset, can the likelihood for the occurrence of the next El Niño onset be estimated? This latter aspect is of particular importance as it relates directly to extended forecasts of North Atlantic basin tropical cyclone activity for the 2009 hurricane season.[8–11]

2. RESULTS AND DISCUSSION

Table 1 lists the El Niño events occurring during the interval 1950–2008, some 17 events, determined from the Oceanic Niño Index (ONI). This ONI is a 3-month running mean of the extended sea-surface temperature (ERSST.v3b) anomalies based on the 1971–2000 base period in the Niño 3.4 region, an area in the Pacific Ocean located between 5° N and 5° S latitude and between 120 and 170° W longitude. El Niño refers to the warm phase and La Niña refers to the cold phase of the ENSO pattern. While various methodologies[12–13] have been used in the past to discern the occurrence of these warm and cold events, today the ONI has become the de facto means for identifying them. In particular, an El Niño is said to be occurring when the ONI has at least a 5-month continuous value of 0.5 °C or warmer, and a La Niña is said to be occurring when the ONI has at least a 5-month continuous value of –0.5 °C or cooler. When the peak ONI value is between 0.5 and 0.9 °C, the El Niño event is termed weak (W); when the peak ONI value is between 1.0 and 1.4 °C, the event is termed moderate (M); and when the peak ONI value is 1.5 °C or warmer, the event is termed strong (S). Similarly, when the peak ONI value is between –0.5 and –0.9 °C, the La Niña event is termed weak; when the peak ONI value is between –1.0 and –1.4 °C, the event is termed moderate; and when the peak ONI value is –1.5 °C or cooler, the event is termed strong. When the ONI fails to meet the threshold for establishing the occurrence of either an El Niño or La Niña event, the conditions are described as being ENSO-neutral. The ONI values can be found online and are updated monthly.[14]

In the earlier study, the listing of El Niño events was taken from the combined listings of Quinn et al.[12] and Trenberth.[13] The decadal distribution of events (58 El Niño events over 20 decades) appeared normally distributed about a mean of three events per decade, with a range of one to four events per decade. In table 1, the listing is based strictly on the ERRST.v3b, which is the newly revised sea-surface temperature dataset introduced in December 2008 replacing the earlier version ERSST.v3, which will no longer be updated. Table 1 gives the onset and peak dates for each of the 17 El Niño events (month-year), the maximum ONI value (max ONI) (in degrees Celsius), the average ONI value (<ONI>) (in degrees Celsius) during the event, the strength (W, M, or S), and the recurrence period (RP) (in months) from event onset to next event onset. At the bottom of table 1 are the mean, standard deviation (*sd*), median, and range for all events. Thus, on average, the 17 El Niño events had a duration (Dur) of about 10 months, max ONI of about 1.4 °C, <ONI> of about 0.97 °C, and RP of about 41 months.

Inspection of onset dates reveals that all El Niño events had onsets between April and November, with most occurring in May (6 of 17 events). Weak events had onsets in June (one event), August (one event), and September (three events); moderate events had onsets in May (one event), July (one event), August (one event), and November (one event); and strong events had onsets in April (one event), May (five events), June (one event), and August (one event). Ten of 12 moderate/strong events had onsets in May–August, a timeframe associated with the yearly hurricane season (June–November).

Table 1. Listing of El Niño events and parametric values, based on ONI (ERSST.v3b).

Event No.	Onset Date	Peak Date	Dur	max ONI	<ONI>	Strength	RP
1	08-1951	10-1951	5	0.8	0.70	W	68
2	04-1957	01-1958	15	1.7	0.99	S	75
3	07-1963	11-1963	7	1.0	0.86	M	23
4	06-1965	11-1965	11	1.6	1.12	S	41
5	11-1968	01-1969	8	1.0	0.79	M	10
6	09-1969	11-1969	5	0.8	0.66	W	32
7	05-1972	12-1972	11	2.1	1.32	S	52
8	09-1976	11-1976	6	0.8	0.63	W	12
9	09-1977	11-1977	5	0.7	0.64	W	56
10	05-1982	12-1982	14	2.3	1.39	S	51
11	08-1986	08-1987	19	1.6	1.11	S	57
12	05-1991	01-1992	15	1.8	1.13	S	36
13	05-1994	12-1994	11	1.3	0.83	M	36
14	05-1997	11-1997	13	2.5	1.74	S	60
15	05-2002	11-2002	11	1.5	1.03	S	25
16	06-2004	09-2004	9	0.9	0.72	W	26
17	08-2006	11-2006	6	1.1	0.83	M	–
All:							
mean			10.1	1.4	0.97		41.3
sd			4.2	0.6	0.31		19.5
median			11	1.3	0.86		38.5
range			5–19	0.7–2.5	0.63–1.74		10–75

Likewise, inspection of peak dates, i.e., the month when max ONI first occurred, reveals that all events had peaks between August and January, with most occurring in November (8 of 17 events). Weak events had peaks in September (one event), October (one event), and November (three events); moderate events had peaks in November (two events), December (one event), and January (one event); and strong events had peaks in August (one event), November (three events), December (two events), and January (two events). Of 12 moderate/strong events, 11 had peaks in November–January.

Table 2 gives the decadal counts and mean values for the number of El Niño onsets (NENO), the number of El Niño-related months (NENM), the mean duration (<Dur>) (in months) and the mean surface-air temperature (<AT>) (in degrees Celsius) as recorded by the Armagh Observatory (Northern Ireland) for each decade from 1950 (e.g., 1950–59, 1960–69, etc.). The 17 events over the past 6 decades suggest an average of about 3 events per decade, ranging between 2 and 4 events per decade, as was found in the earlier study. Every decade has had at least one strong event (range: one–two). For the current decade, only one strong event has occurred, at least, through 2008: an 11-month event having onset in May 2002 (event 15, in table 1). The strongest event overall, in terms of max ONI and <ONI>, is the 13-month event having onset in May 1997 (event 14: max ONI = 2.5

Table 2. Decadal values for El Niño events and <AT>.

	NENO				NENM				<Dur>		
Decade	W	M	S	T	W	M	S	T	All	M/S	<AT>
1950–59	1		1	2	5		15	20	10.0	15.0	9.43
1960–69	1	2	1	4	5	15	11	31	7.8	8.7	9.17
1970–79	2		1	3	11		11	22	7.3	11.0	9.15
1980–89			2	2			33	33	16.5	16.5	9.28
1990–99		1	2	3		11	28	39	13.0	13.0	9.74
2000–09*	1	1	1	3	9	6	11	26	8.7	8.5	10.11
Total	5	4	8	17	30	32	109	171			

Note: * means only thru 2008.
Temperature in degrees Celsius.

and <ONI> = 1.74). The longest duration event is the 19-month strong event having onset in August 1986 (event 11), while the shortest strong events each have had duration of 11 months (events 4, 7, and 15).

Figure 1 plots the decadal variation of (a) NENO, (b) NENM, and (c) <Dur> for moderate/strong El Niño events since 1950 and of (d) <AT>. Concerning NENO (fig. 1(a)), for all decades since 1950 there has always been at least one event. The median is two events per decade and the range is one to three events per decade. Including the five weak events only slightly alters the NENO, yielding a median of three events per decade and range of two to four per decade. There appears to be no evidence for an increase in the decadal frequency of El Niño events with time. The current decade (2000–2009) has experienced two moderate/strong events (2002 and 2006) and one weak event (2004). The last El Niño onset was August 2006, peaking in November 2006, moderate in strength, and ending in January 2007. As of this writing (May 2009), some 33 months had elapsed since the last El Niño onset and some 28 months had elapsed since its end. The mean recurrence period, as shown in table 1, is about 41 months using all events, with a median of 38.5 months and a range of 10–75 months. The three moderate events with known RP were each followed by El Niño events after about 23 months on average (range: 10–36 months), two being followed by strong events and one by a weak event. Because the elapsed time between El Niño onsets is well within the range of known RP (in particular, the range of RP for moderate events), it seems quite possible that another El Niño could suddenly appear sometime during the interval June–December 2009. Mitigating this, however, is the National Oceanic and Atmospheric Administration's (NOAA's) extended forecast, which calls for ENSO-neutral to La Niña-like conditions to prevail during 2009.[15] Table 1 shows that 10 of 17 El Niño events had onsets during the interval June–November, these events consisting of 5 weak events, 3 moderate events, and 2 strong events, with the greatest likelihood of onset being August–September.

Concerning NENM (fig. 1(b)), it has a median of 24 months. With the addition of the latest decade, it is now quite apparent that the former finding of a marginally statistically significant upward trend was premature. The number of El Niño-related months for 2000–2009 measures only

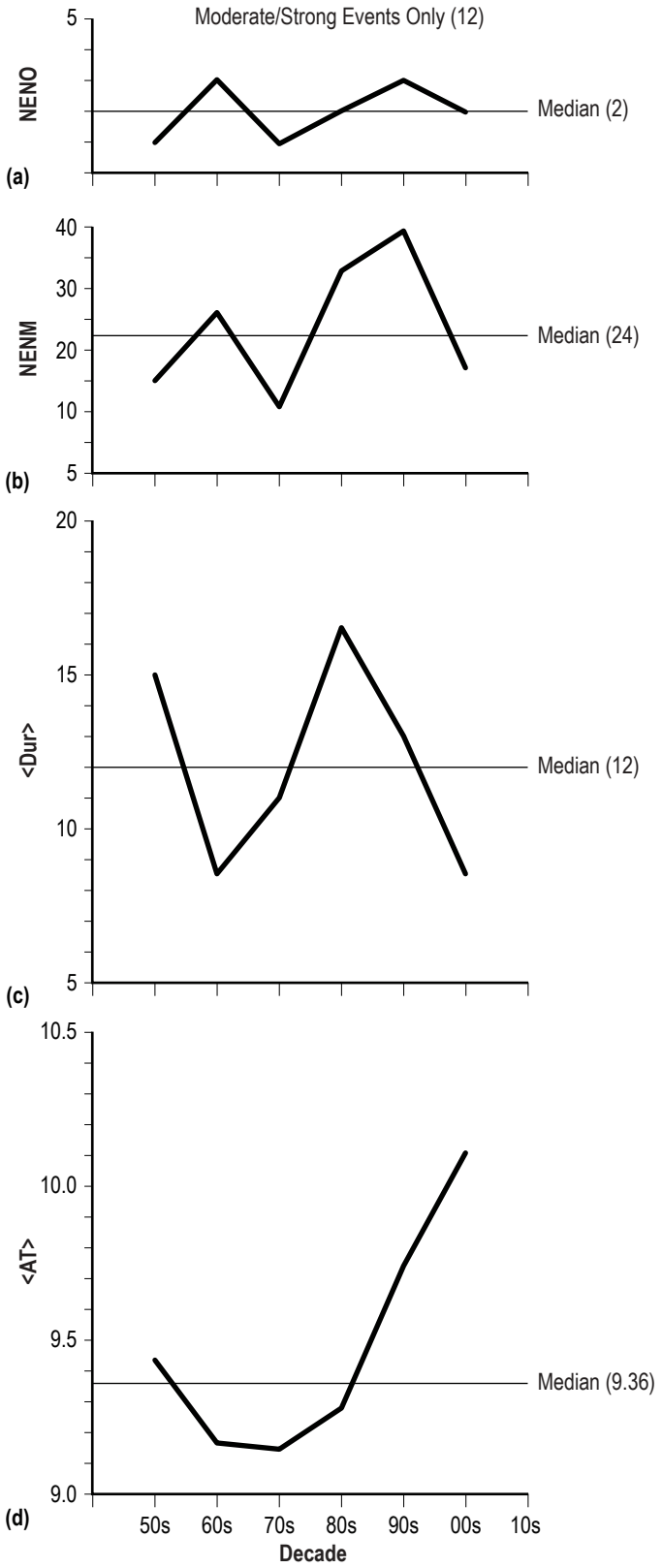

Figure 1. Decadal variation of (a) NENO, (b) NENM, (c) <Dur>, and (d) <AT>.

17 months (through May 2009), using moderate/strong events, and only 26 months when including the 9-month weak event of 2004 (event 16). Certainly, the decades of the 1980s and 1990s both had more El Niño-related months (33 and 39, respectively) than the current decade. If another El Niño should happen to develop during the latter half of 2009, the greatest number of El Niño-related months for the current decade would still be lower than was seen in the 1980s and 1990s.

Concerning <Dur> (fig. 1(c)), its median is 12 months. The decade of the 1980s seems to have had the longest average duration (16.5 months), while the decade of the 1960s appears to have had the shortest average duration (8.7 months). The average duration of El Niño events during the current decade measures about 8.5 months using only the moderate/strong events, or about 8.7 months when including the lone weak event of 2004. As for NENO and NENM, no evidence appears for an increase with time of the average duration for El Niño events.

Concerning <AT>, its median mean decadal temperature is 9.36 ˚C. The <AT> is observed to have cooled during the 1960s and 1970s to about 9.17 and 9.15 ˚C, respectively, before warming to its highest mean decadal temperature ever (10.11 ˚C) during the current decade (the record extends back to 1844). Previous research has shown that the Armagh Observatory temperature dataset can be used as a proxy for studying trends in global temperatures.[16–20]

Comparisons of NENO, NENM, and <Dur> against <AT> (not shown) provide no evidence for statistically significant associations to exist between them. Thus, it cannot be claimed, as yet, that global warming is influencing the frequency, strength, or duration of El Niño events with the passage of time (i.e., over the past six decades).

Figure 2 plots the variation by event number (i) of (a) Dur and (b) RP of the 17 El Niño events in the interval 1950–2008 (from table 1), and shows (c) the scatter plot of RP(i) versus Dur(i), where i simply identifies the event number, based strictly on moderate/strong events. Concerning the event durations (fig. 2(a)), the median is 11 months, with strong events usually having the longest durations (11–19 months) and weak events usually having the shortest durations (5–9 months). Moderate events have durations between weak and strong events (6–11 months).

Concerning the event recurrence periods (fig. 2(b)), the median is 38.5 months, with strong events usually having RPs longer than the median (6 of 8 strong events) and weak and moderate events usually having RPs less than the median (7 of 8 events). The fact that the last El Niño was a moderate event, suggests that the next onset of El Niño likely will follow within 38.5 months from the onset of the August 2006 event. Thirty-eight months from the last onset corresponds to October 2009. So, it seems that another El Niño might possibly appear during the latter half of 2009, perhaps in late summer or early fall of 2009.

Supporting this conjecture is the scatter plot for moderate/strong events (fig. 2(c)). The numbers beside the symbols simply refer to the event numbers and the arrow shows the known duration of event 17, the last observed El Niño, having a duration of only 6 months (the shortest of all moderate events). The inferred regression (y) is displayed as the diagonal line. It has a coefficient of correlation (r) equal to 0.712, a coefficient of determination (r^2) equal to 0.506 (meaning that about half the variance can be explained by the inferred regression), a standard error of estimate (se) equal to about

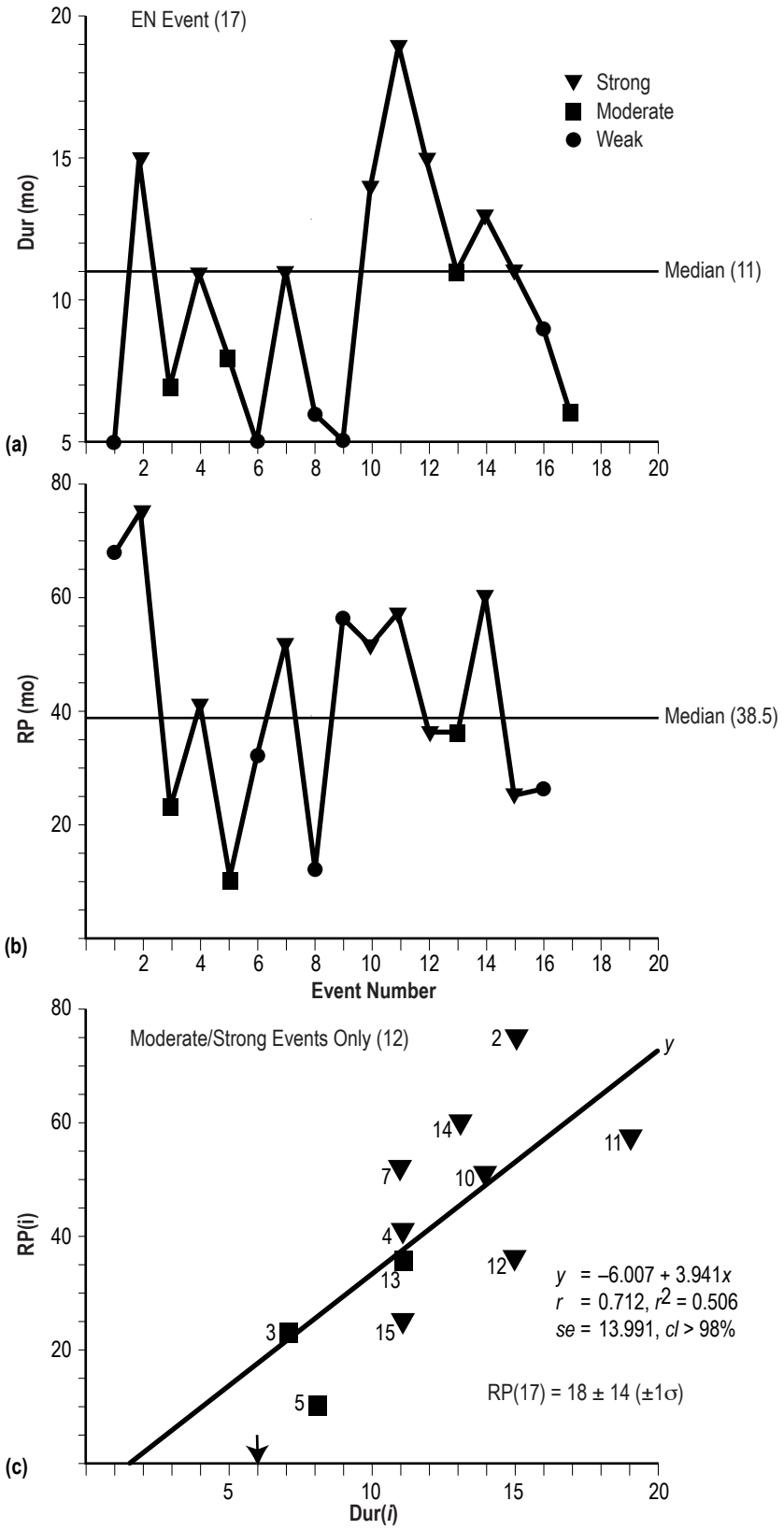

Figure 2. Variation of (a) Dur and (b) RP by event number and (c) scatter plot of RP(i) versus Dur(i) for moderate/strong events.

14 months and *cl* > 98%. Based upon the inferred linear regression, the RP for event 17 (RP(17)) is estimated to be about 18 ± 14 months (i.e., ±1 *se* accuracy). The regression can be slightly improved if weak events 6, 8, and 16 are also included, but it becomes statistically unimportant if all weak events (i.e., events 1 and 9 appear to be statistical outliers) are included. Thus, event 17 is expected to be followed by another El Niño within about 32 months from its onset in August 2006, inferring only about a 16% chance of following by more than 32 months, unless, of course, event 17 is a statistical outlier as are events 1 and 9. Thirty-two months corresponds to about April 2009. Using the slightly improved regression ($y = -1.158 + 3.563x$, having $r = 0.739$, $r^2 = 0.545$, *se* = 13.234, and *cl* >99.5%) yields an expected RP(17) = 20.2 ± 13.2 months, inferring only about a 16% chance of being longer than 33 months, or onset after about May 2009.

The ONI values are presently known only through March 2009. For December 2008 through March 2009 the values have been indicative of La Niña-like conditions (–0.6, –0.8, –0.7, and –0.5 ˚C, respectively). However, December 2008 will not be classified as an onset for La Niña unless the month of April 2009 also has an ONI value of –0.5 ˚C or cooler. Because the trend now appears to be towards warmer values, another La Niña event with onset in December 2008 seems unlikely. Previously, there has been only one La Niña onset in December during the interval 1950–2008. It was a weak event with onset in December 1967 and a duration of 5 months.

Figure 3 is a superposed epoch analysis of ONI values for (a) the 12 moderate/strong El Niño events and (b) all events, using event onset as the common epoch. ONI values tend to be, on average, about 0.0–0.3 ˚C just prior to onset of El Niño events, whether using all events or only the moderate/strong events. Moderate/strong events, on average, peak about 6 months after onset and fall below threshold value (0.5 ˚C) after about 11 months. Including the weak events, on average, El Niño events peak about 5 months after onset and fall below threshold after about 10 months. Based on the ±1 *sd* spread, moderate/strong events, on average, peak anytime between 4 and 7 months following onset and fall below threshold anytime between 7 and after 12 months. Similarly, based on the ±1 *sd* spread, El Niño events (including the weak events) peak, on average, anytime between 2 and 7 months following onset and fall below threshold anytime between 4 and after 12 months.

Presuming the sudden appearance of an El Niño in 2009, if the event is of moderate/strong strength, its onset is anticipated about May–August 2009 with peak in November 2009–January 2010. If, on the other hand, the event is only of weak strength, its onset is anticipated in June–September 2009 with peak in September–November 2009. Either way, the onset of El Niño would have a diminishing effect on the frequency of tropical cyclones in the North Atlantic basin during the 2009 hurricane season.[10] This may mean that the initial early extended forecasts for the 2009 hurricane season might be too high. In fact, while the initial December 2008 forecasts for the 2009 hurricane season called for average-to-above average frequency (in terms of numbers of tropical cyclones, hurricanes, and major or intense hurricanes), the April updates of hurricane activity have been revised slightly downward closer to long-term average values. Such is the precarious nature of prediction.[8–11] (On May 21, 2009, NOAA issued their 2009 Atlantic hurricane season outlook.[21] The outlook calls for a 50% chance for a near-normal season, with a 25% chance of being either an above-normal or below-normal season. NOAA estimates a 70% probability of having 9–14 named storms, 4–7 hurricanes, and 1–3 major hurricanes during the 2009 season.)

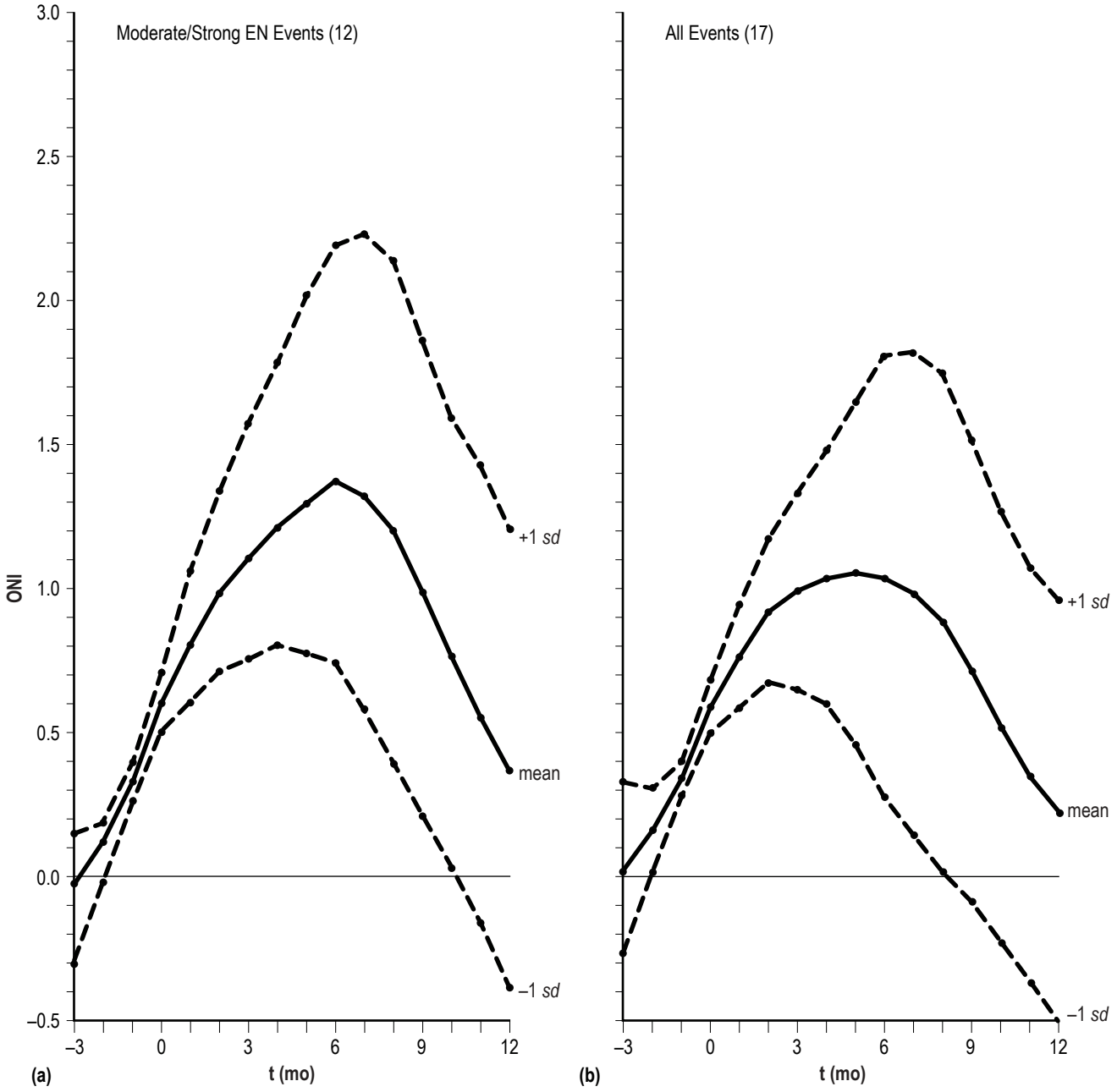

Figure 3. Superposed epoch analysis of (a) moderate/strong El Niño events and (b) all El Niño events.

3. SUMMARY

This study has revisited one performed nearly a decade ago,[7] updating it to include the values for the current decade (at least, 2000–2008). It is apparent that the number of El Niño onsets and the number of El Niño-related months display decadal frequency variations more attuned to being natural variations than being driven by global warming. The same appears true for the average decadal duration of El Niño events. About two moderate/strong El Niño onsets occur each decade, having a range of one to three events per decade; including weak events, the range increases to two to four events per decade. Every decade since 1950 has experienced, at least, one strong event. Two moderate/strong events have occurred in the current decade (through 2008). On average, there have been about 24 El Niño-related months per decade, having a range of 11–39 El Niño-related months per decade based on the moderate/strong events only. The fewest El Niño-related months occurred in the 1970s and the most occurred in the 1990s. During the current decade, thus far, some 17 El Niño-related months have occurred (26 months, including the lone 9-month weak event of 2004). In contrast to the natural variation pattern for El Niño, surface-air decadal temperatures have steadily increased since the 1970s, being at their highest levels in the current decade.

Individually, there have been 17 El Niño onsets since 1950, including 8 strong events, 4 moderate events, and 5 weak events. Strong events usually have the longest duration, while weak events usually have the shortest duration. The longest event (19 months) had onset in August 1986. During the current decade, the longest event persisted for 11 months (in 2002).

Moderate/strong El Niño events tend to recur about every 3 years (median). Since the last El Niño event of moderate/strong strength had onset in August 2006, another might be expected before August 2009. Certainly, for moderate/strong events, a statistically significant linear relationship is found to exist associating recurrence period against duration. Because the last El Niño of moderate/strong strength had a duration of only 6 months (the shortest moderate event during the interval 1950–2008), provided that it is not a statistical outlier, the next El Niño onset is expected to occur soon, probably sometime during the latter half of 2009. If true, then the 2009 North Atlantic basin hurricane season will be influenced by the occurrence of El Niño, thereby, causing a slight decrease in the expected frequencies of tropical cyclones, hurricanes, and major hurricanes from one of average-to-above average frequencies to one of near average-to-below average frequencies.

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14. ABSTRACT

Examination of the decadal variation of the number of El Niño onsets and El Niño-related months for the interval 1950–2008 clearly shows that the variation is better explained as one expressing normal fluctuation and not one related to global warming. Comparison of the recurrence periods for El Niño onsets against event durations for moderate/strong El Niño events results in a statistically important relationship that allows for the possible prediction of the onset for the next anticipated El Niño event. Because the last known El Niño was a moderate event of short duration (6 months), having onset in August 2006, unless it is a statistical outlier, one expects the next onset of El Niño probably in the latter half of 2009, with peak following in November 2009–January 2010. If true, then initial early extended forecasts of frequencies of tropical cyclones for the 2009 North Atlantic basin hurricane season probably should be revised slightly downward from near average-to-above average numbers to near average-to-below average numbers of tropical cyclones in 2009, especially as compared to averages since 1995, the beginning of the current high-activity interval for tropical cyclone activity.

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