



# On the Bimodality of ENSO Cycle Extremes

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## LIST OF ACRONYMS

|      |                              |
|------|------------------------------|
| cl   | confidence level             |
| ENSO | El Niño-Southern Oscillation |
| sd   | standard deviation           |
| SST  | sea surface temperature      |

## TECHNICAL PUBLICATION

### ON THE BIMODALITY OF ENSO CYCLE EXTREMES

#### 1. INTRODUCTION

The term El Niño-Southern Oscillation (ENSO), refers to the coupled quasi-periodic fluctuation of sea surface temperature (SST) and atmospheric pressure that dominates the Earth's tropical Pacific Ocean region.<sup>1-5</sup> The extremes of the ENSO cycle have come to be called "El Niño," referring to the warm episodes, and "La Niña," referring to the cold episodes.<sup>6-9</sup> Changes in weather and climate worldwide have been linked to the extremes of the ENSO cycle via the "teleconnection" process.<sup>10-38</sup>

Although an annual chronology<sup>15,39-41</sup> of El Niño has been developed historically back to 1525, a more detailed listing, giving the specific year-month for the onsets and demises of the events, has been lacking until only recently. In particular, on the basis of the quantitative definition that an El Niño (La Niña) is said to occur when the 5-mo running mean of SST anomaly in the El Niño 3.4 region, bounded by 5° N.–5° S. and 120°–170° W., exceeds 0.4 °C (–0.4 °C) for ≥6 mo, Trenberth<sup>9</sup> was able to precisely identify the onsets, demises, and duration for some 16 El Niño and 10 La Niña during the interval of 1950–1997, with the exception of the end of the 1997–1998 El Niño which did not occur until after his paper's publication. In this study, these 26 events are reexamined to determine some of the statistical properties of the extremes and to ascertain whether any predictive aspects might exist. Indeed, statistically meaningful associations are found in the distributions of duration (i.e., the elapsed time from onset to demise) and recurrence period (the elapsed time between successive onsets), especially, for El Niño that appear useful in the prediction of onsets and duration of immediately succeeding ENSO cycle extremes.

## 2. RESULTS AND DISCUSSION

Table 1 lists the 16 El Niño and 10 La Niña previously identified by Trenberth<sup>9</sup> during the interval of 1950–1997, updating his listing to include the end of the 1997–1998 El Niño, called the strongest on record.<sup>42,43</sup> Tabulated are the begin and end dates as well as the duration and recurrence period in months, this latter parameter not given in Trenberth’s original table. Below each grouping is the median, range, mean, and standard deviation (sd) for the distributions of duration and recurrence period.

Close examination of table 1 reveals the following. Concerning the distributions of the observed frequencies of duration and recurrence period for the extremes, both can be regarded as having a positive (or rightward) skew and broad peak (or platykurtic) about their respective means, as compared to the normal distribution. Also, runs testing<sup>44</sup> shows that both distributions (as well as the sequence of extremes) can be regarded as varying randomly. Hence, evidence is not apparent for important secular trends in the frequencies of duration or recurrence period for the extremes, or in the clustering of the types of extremes.<sup>45</sup> During each of the past five decades, extending back to the 1950’s, two to four onsets of El Niño and one to three onsets of La Niña were always seen. Consequently, describing the decade of the 1990’s as being “anomalous,” especially with regard to the frequency of El Niño onsets, seems unwarranted.<sup>46–49</sup> The perceived frequency increase instead appears to be the result of a natural climatic fluctuation. While true, it may be important to note that the actual number of El Niño months per decade (the sum of the duration of each event during each decade) has been higher in the 1990’s, as compared to previous decades (also noted by Trenberth,<sup>9</sup> cf. Wilson<sup>50,51</sup>).

Additionally, inspection of table 1 reveals that an El Niño nearly always has had its onset (begin) and demise (end) in boreal spring or summer (cf. Rasmusson and Carpenter,<sup>52</sup> Deser and Wallace<sup>53</sup>). For example, 13 of 16 are found to have had a begin date during the 6-mo interval of March–August and none, as yet, has been found to have a begin date during the colder months of November–January. Likewise, 13 of 16 are found to have had an end date during the 6-mo interval of February–July. For La Niña, 9 of 10 are found to have had a begin date during the 5-mo interval of May–September and 9 of 10 are found to have had an end date during the 6-mo interval of January–June. Clearly, because the onsets and demises of these extremes almost exclusively occur in the boreal spring and summer, a linkage exists between the timing of the extremes and the annual (seasonal) cycle (cf. Wang,<sup>28</sup> Mitchell and Wallace,<sup>29</sup> Rasmusson and Carpenter,<sup>52</sup> Tziperman et al.<sup>54</sup>).

Figure 1 depicts plots of the history of duration (from table 1) in months for El Niño (panel (c)) and La Niña (panel (a)), where the median duration for each is clearly identified as 11 and 12.5 mo, respectively. While it was aforementioned that the distributions of duration for the extremes could be described in terms of the normal distribution, having a broad peak and a positive (or rightward) skew, another more interesting interpretation seems apparent. Namely, because there is an obvious lack of central clustering bounding the medians (or means), especially for El Niño, yet evidence for stronger clustering both below (shorter) and above (longer) the medians, the distributions possibly are bimodal, perhaps even bifurcated. From figure 1, 8 of 16 El Niño have had a duration of  $\leq 10$  mo, while 7 of 16 have had a duration of  $\geq 14$  mo and only 1 has had a duration near the mean. Also, 4 of 10 La Niña have had a duration of  $\leq 10$  mo, while 3 of 10 have had a duration of  $\geq 19$  mo and only 3 have had a duration near the mean. Presuming that the

distributions of duration for El Niño and La Niña are inherently bimodal (or bifurcated), the  $t$  statistic for independent samples can be evaluated,<sup>55</sup> the results of which are also given in figure 1. For El Niño, the  $t$  statistic measures  $\approx 8.0$ , while it measures  $\approx 4.3$  for La Niña, both evaluations indicating that the differences in the means for the two samples of shorter and longer than median groupings (for each distribution) are statistically important at a  $>99$  percent confidence level (cl). (If the distributions truly are normally distributed, then greater numbers of ENSO cycle extremes are expected to have duration clustering near their respective means rather than widely apart, implying that the differences in the means for the two classes probably would not be statistically important, something that was not found here.)

Table 1. Listing of El Niño and La Niña (1950–1998).

| Event No.      | Begin Date (mo-yr) | End Date (mo-yr) | Duration (mo) | Recurrence Period (mo) |
|----------------|--------------------|------------------|---------------|------------------------|
| <b>El Niño</b> |                    |                  |               |                        |
| 1              | 08-51              | 02-52            | 7             | 19                     |
| 2              | 03-53              | 11-53            | 9             | 49                     |
| 3              | 04-57              | 06-58            | 15            | 74                     |
| 4              | 06-63              | 02-64            | 9             | 23                     |
| 5              | 05-65              | 06-66            | 14            | 40                     |
| 6              | 09-68              | 03-70            | 19            | 43                     |
| 7              | 04-72              | 03-73            | 12            | 52                     |
| 8              | 08-76              | 03-77            | 8             | 11                     |
| 9              | 07-77              | 01-78            | 7             | 27                     |
| 10             | 10-79              | 04-80            | 7             | 30                     |
| 11             | 04-82              | 04-83            | 16            | 52                     |
| 12             | 08-86              | 02-88            | 19            | 55                     |
| 13             | 03-91              | 07-92            | 17            | 23                     |
| 14             | 02-93              | 09-93            | 8             | 16                     |
| 15             | 06-94              | 03-95            | 10            | 34                     |
| 16             | 04-97              | 05-98            | 14            | –                      |
|                |                    | median           | 11            | 34                     |
|                |                    | range            | 7–19          | 11–74                  |
|                |                    | mean             | 11.9          | 36.5                   |
|                |                    | sd               | 4.4           | 17.6                   |
| <b>La Niña</b> |                    |                  |               |                        |
| 1              | 03-50              | 02-51            | 12            | 51                     |
| 2              | 06-54              | 03-56            | 22            | 23                     |
| 3              | 05-56              | 11-56            | 7             | 96                     |
| 4              | 05-64              | 01-65            | 9             | 74                     |
| 5              | 07-70              | 01-72            | 19            | 35                     |
| 6              | 06-73              | 06-74            | 13            | 15                     |
| 7              | 09-74              | 04-76            | 20            | 120                    |
| 8              | 09-84              | 06-85            | 10            | 44                     |
| 9              | 05-88              | 06-89            | 14            | 88                     |
| 10             | 09-95              | 03-96            | 7             | a                      |
|                |                    | median           | 12.5          | 51                     |
|                |                    | range            | 7–22          | 15–120                 |
|                |                    | mean             | 13.3          | 60.7                   |
|                |                    | sd               | 5.4           | 35.8                   |

<sup>a</sup> If a new La Niña began September 1998, then the recurrence period is 36 mo.

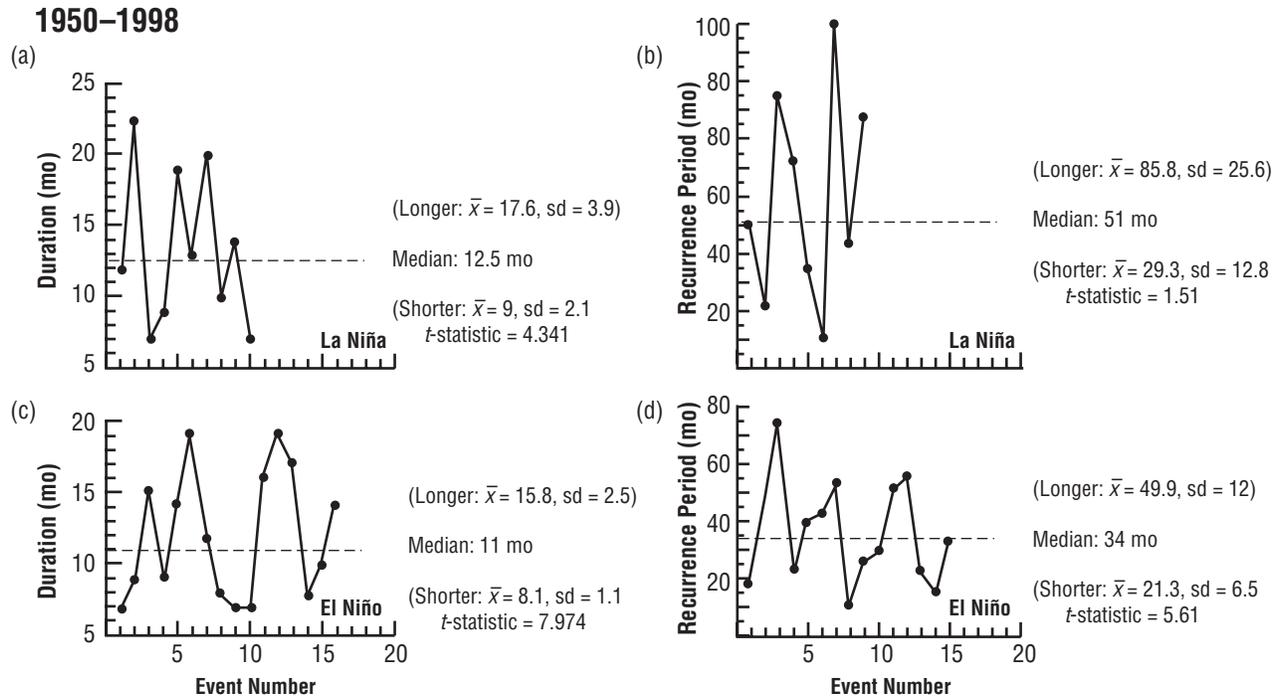


Figure 1. History of the duration ((a) and (c)) and recurrence period ((b) and (d)) for El Niño ((c) and (d)) and La Niña ((a) and (b)) for the interval of 1950–1998.

Accepting that the distribution of duration for El Niño is characteristically bimodal, the two preferred modes for its distribution occur near 8 and 16 mo. Speculating that the distribution of duration for El Niño actually represents a real bifurcation into shorter and longer classes, the class of shorter duration El Niño has a mean of  $\approx 8$  mo, an  $sd$  of  $\approx 1.1$  mo, and a range of 7–10 mo, while the class of longer duration El Niño has a mean of  $\approx 16$  mo, an  $sd$  of 2.5 mo, and a range of 12–19 mo. Since none of the shorter duration El Niño previously has been classified as “strong” or “very strong” on the basis of Quinn et al.’s categorizations,<sup>40</sup> the duration of stronger El Niño preferentially is longer than the median of 11 mo. (Strictly speaking, only about half of the El Niño of longer duration since 1950 has been classified as strong or very strong on the basis of Quinn et al.’s categorizations.<sup>40</sup>)

Likewise, accepting that the distribution of duration for La Niña is characteristically bimodal, the two preferred modes for its distribution occur near 9 and 18 mo. Again, speculating that the distribution of duration for La Niña actually represents a true bifurcation into shorter and longer classes, the class of shorter duration La Niña has a mean of  $\approx 9$  mo, an  $sd$  of 2.1 mo, and a range of 7–12 mo, while the class of longer duration La Niña has a mean of  $\approx 18$  mo, an  $sd$  of 3.9 mo, and a range of 13–22 mo. From Trenberth’s study<sup>9</sup> (his figure 1 on p. 2773), it is important to note that the strongest (coldest) La Niña occurred between May 1988 and June 1989 and was of longer than average duration (14 mo). Because this event immediately preceded the so-called “anomalous” interval of El Niño activity that occurred during the early 1990’s, and it immediately followed one of the longest duration El Niño on record (duration=19 mo), and one of the longest duration La Niña (duration=19 mo; table 1, event 5) immediately followed the other longest duration El Niño (duration=19 mo; table 1, event 6), it can be surmised that longer duration extrema of the ENSO cycle (which tend to be stronger events), whether they are classified as El Niño or La Niña, often occur closely together in time. Hence, the abrupt appearance of one may be a harbinger that the other soon will follow (cf. Tziperman et al.,<sup>54</sup> Chen et al.,<sup>56</sup> Clarke and Li<sup>57</sup>).

Figure 1 also contains plots of the history of the recurrence period in months for El Niño (panel (d)) and La Niña (panel (b)). As before, the median values are plainly identified, being 34 and 51 mo, respectively, for El Niño and La Niña, and each distribution arbitrarily has been divided by their respective medians into shorter and longer recurrence period groupings. As before, the  $t$  statistic for each pair is evaluated and while there is no statistically meaningful difference for La Niña ( $t=1.51$ ), the one for El Niño is found to be statistically important ( $t=5.61$ ). Hence, one speculates that the distribution of recurrence period for El Niño, like duration, may be inherently bimodal, either having two preferred modes near 21 and 50 mo or resulting from the superposition of two distinct classes (populations) of recurrence period, one shorter (mean=21.3 mo, sd=6.5 mo, and range=11–30 mo) and the other longer (mean = 49.9 mo, sd=12 mo, and range=34–74 mo) than the median.

Figure 2 (bottom panel) displays the scatterplot of recurrence period versus duration (for the same event, number  $n$ ) for the 15 fully described El Niño tabulated in table 1. Expressed as a  $2 \times 2$  contingency table (determined by the medians—the thin vertical and horizontal lines in the scatterplot) and on the basis of Fisher’s exact test,<sup>44</sup> the probability  $P$  of obtaining the observed result, or one more suggestive of a departure from independence (chance), is computed to be 0.9 percent, thereby inferring that the association between recurrence period and duration for El Niño is statistically very important. Also, displayed are the results of a linear regression analysis between recurrence period and duration which indicates a positive correlation (shown as the diagonal line, having  $r=0.589$ ), one that can explain  $\approx 35$  percent of the variance and one that is statistically important at  $cl > 98$  percent.

Since the last onset of El Niño occurred in April 1997 (see table 1, event 16) and the event was of long duration (14 mo), it can be inferred from the contingency table that the next onset of El Niño really should not be expected until February 2000 or later; i.e.,  $\approx$ April 1997+ $\geq 34$  mo). Likewise, on the basis of the regression equation (using duration of 14 mo), the onset for the next El Niño should follow the onset of the last El Niño by  $\approx 42$  mo; i.e., it should occur about October 2000 $\pm 7$  mo, where the spread of  $\pm 7$  mo captures 8 of 15 events. Taken together, this strongly suggests that the recurrence period for event 16 (the 1997–1998 El Niño) will lie within the upper-right quadrant of the scatter plot and that the next onset of El Niño (event 17) will not occur until sometime during the year 2000 or later.

Figure 2 (top panel) displays the scatterplot of duration (event  $n+1$ ; i.e., the following event) versus recurrence period (event  $n$ ; i.e., the current event). Statistically speaking, while the contingency table suggests only a marginally significant relationship between the two parameters ( $P=10$  percent), one associating longer (shorter) duration with longer (shorter) recurrence period, a linear regression analysis using all data points yields a regression (denoted by the solid line) that does not appear to be statistically important ( $cl < 90$  percent). It is noteworthy, however, that by ignoring the two data points located in the lower-right quadrant (corresponding to events 3 and 7) and performing another linear regression analysis on the reduced sample, a much stronger fit is inferred between the parameters (denoted by the dashed line). This latter fit is found to explain  $\approx 59$  percent of the variance in the reduced sample and is inferred to be statistically important at  $cl > 99.5$  percent. Hence, as soon as the start (onset) of the next El Niño is precisely determined, it follows that one knows exactly the length of the recurrence period for the previous event (16), which then allows for an early estimate of the duration for the newly developing El Niño.

Concerning event 7, it is peculiar in that either the event’s recurrence period is too long with respect to the following event’s duration (event 8), or the following event’s duration is too short for the preceding event’s recurrence period. Trenberth<sup>9</sup> previously noted that events 8 and 9 arguably could be a single event

rather than two separate events (since the onset of event 9 follows the end of event 8 by a mere 4 mo). Presuming events 8 and 9 to actually be just one event instead of two, one finds that this greatly improves the inferred association between duration ( $n+1$ ) and recurrence period ( $n$ ).

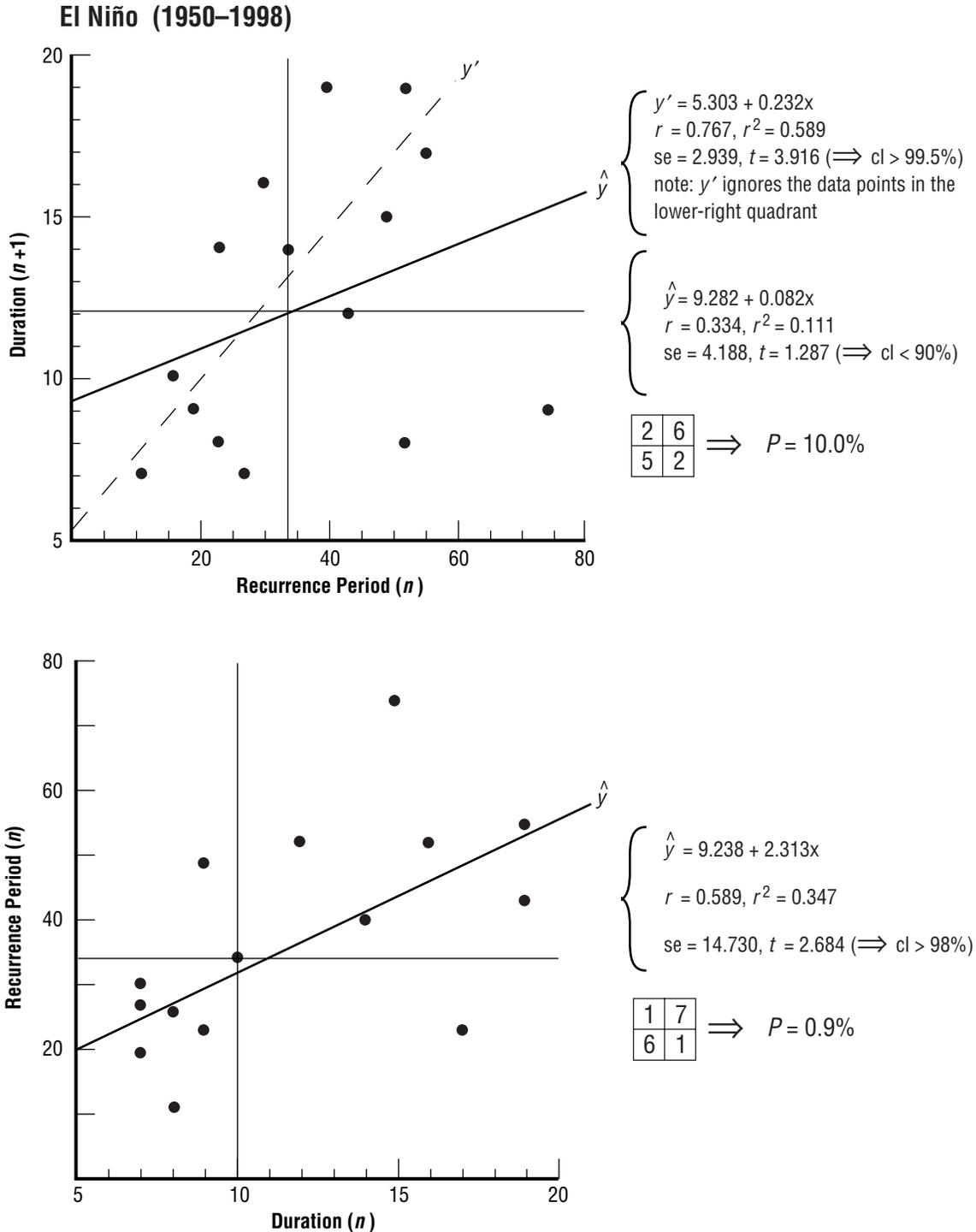


Figure 2. Scatterplots of recurrence period versus duration (bottom) for same event  $n$  and duration for event  $n+1$  versus recurrence period for event  $n$  (top).

Concerning event 3, note that, like event 7, it too is peculiar in that either its recurrence period is far too long (being 74 mo, or  $\approx 2$  sd units longer than the mean for the longer recurrence period group), or the duration of the following event (event 4), being 9 mo, is too short. The interval between the end of event 3 and the onset of event 4 is perceived to be one long, continuous interlude when neither an El Niño nor a La Niña occurred (cf. Deser and Wallace,<sup>53</sup> Wilson<sup>50</sup>). It may be noteworthy that during this interlude there were no significant injections of volcanic aerosols into the stratosphere (no cataclysmic volcanic eruptions are known to have occurred, according to Simkin and Siebert<sup>58</sup>), at least, not until March 1963 when Agung (8.3° S., 115.5° E.) abruptly erupted. This eruption is found to precede by  $\approx 3$  mo the appearance of the short duration El Niño (event 4). Perhaps, somehow the eruption of Agung may be associated with the disruption of the interlude and, hence, the peculiarity associated with events 3 and 4 (cf. Handler,<sup>59</sup> Robock and Mao,<sup>60</sup> Wilson<sup>61</sup>).

Repeating the analyses (fig. 2) for La Niña yields results (not shown) that are inconclusive, probably due to the small sample size. For example, the resultant 2×2 contingency tables are found to have  $P=35.7$  percent, and the inferred regressions (each ignoring one suspect data point) are found to be only of marginal statistical significance, hinting of inverse correlations between the parameters that link longer (shorter) recurrence period with shorter (longer) duration for the same event  $n$  and longer (shorter) duration for event  $n+1$  with shorter (longer) recurrence period for event  $n$ . Even so, the recurrence period and duration for La Niña can still be estimated using the results of table 1 and figure 1.

As applied to the present epoch, the last onset of La Niña (before the onset of the 1998–1999 event) was September 1995, and its duration was 7 mo. Following the demise of the 1997–1998 El Niño in May 1998, indications were high that a La Niña would appear soon and that it probably would be exceptionally strong (Webster and Palmer,<sup>43</sup> Monastersky<sup>62</sup>). In particular, onset for this new La Niña was expected sometime during the summer or fall of 1998 (Trenberth<sup>63</sup>). Presuming the official onset for the current La Niña to have been September 1998, it can be deduced that the recurrence period for event 10 measures 36 mo, a value well below the median of 51 mo. Presuming any earlier onset date (sometime during June–August 1998) only reduces the length of the recurrence period, inferring an even greater departure from the median. On the basis of satellite imagery, the present ongoing La Niña has been described as being “frozen in” in November 1998, “weakening” in January 1999, “beginning to fade” in April 1999, “barely having a pulse” in June 1999, and “continuing to prevail” in November 1999. (See reference 64 and other links found there regarding the 1997–1998 El Niño and the 1998–1999 La Niña.) The duration of the current La Niña, presuming bimodality, can easily be estimated to be either  $\approx 9 \pm 4$  mo (if it is of the shorter variety) or  $18 \pm 8$  mo (if it is of the longer variety), where the stated ranges are the 90 percent prediction intervals. Presuming June 1998 to be the actual onset for the current La Niña, (Trenberth<sup>63</sup>) it can now be obviously concluded that it must be of the longer variety, for had it been of the shorter variety the current La Niña would already have been over by June 1999. Although the La Niña was very weak in June 1999, it persisted and, in fact, has restrengthened, thereby concluding that it is of the longer variety. Hence, the current La Niña cannot be expected to end until sometime in the year 2000. Following its demise, a recurrence of La Niña really should not be expected until 2002 or later.



year 2000 hurricane season would be “non-El Niño-related” and that a higher than average number of intense hurricanes in the Atlantic basin might be expected (a la 1995, 1996, 1998, and 1999). Because conditions typically are revealed in the latter portion of a year preceding the year of onset for an extreme in the ENSO cycle, observable changes in the Pacific Ocean should soon begin to manifest themselves, especially if El Niño is imminent for the year 2000. Close monitoring of SST, sea level asymmetry, etc. will provide the taletell signs for accurately forecasting an impending onset of El Niño.

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