

The Definition of El Niño



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ABSTRACT

A review is given of the meaning of the term “El Niño” and how it has changed in time, so there is no universal single definition. This needs to be recognized for scientific uses, and precision can only be achieved if the particular definition is identified in each use to reduce the possibility of misunderstanding. For quantitative purposes, possible definitions are explored that match the El Niños identified historically after 1950, and it is suggested that an El Niño can be said to occur if 5-month running means of sea surface temperature (SST) anomalies in the Niño 3.4 region (5°N–5°S, 120°–170°W) exceed 0.4°C for 6 months or more. With this definition, El Niños occur 31% of the time and La Niñas (with an equivalent definition) occur 23% of the time. The histogram of Niño 3.4 SST anomalies reveals a bimodal character. An advantage of such a definition is that it allows the beginning, end, duration, and magnitude of each event to be quantified. Most El Niños begin in the northern spring or perhaps summer and peak from November to January in sea surface temperatures.

1. Introduction

The term “El Niño” has evolved in its meaning over the years, leading to confusion in its use. Because the phenomenon involving El Niño has become very visible in recent years as a dominant source of interannual climate variability around the world, there is a need to provide a more definitive meaning. However, this works only if it is accepted by everyone, and past attempts have not achieved such a consensus. This article arose from a query to the World Climate Research Programme’s CLIVAR (Climate Variability and Predictability) program expressing the view that the definition of El Niño needed to be clarified. A draft response was published in the CLIVAR newsletter *Exchanges* for commentary, and this article provides the final outcome after taking the comments

received into account. A brief review is given of the various uses of the term and attempts to define it. It is even more difficult to come up with a satisfactory quantitative definition. However, one such definition is explored here, and the resulting times and durations of El Niño and La Niña events are given. While unsatisfactory, the main recommendation is that any use of the term should state which definition is being used, as the definition is still evolving. However, this should help reduce possible misunderstandings.

2. El Niño definitions

The term “El Niño” originally applied to an annual weak warm ocean current that ran southward along the coast of Peru and Ecuador about Christmastime (hence Niño, Spanish for “the boy Christ-child”) and only subsequently became associated with the unusually large warmings that occur every few years and change the local and regional ecology. The coastal warming, however, is often associated with a much more extensive anomalous ocean warming to the international date line, and it is this Pacific basinwide phenomenon that forms the link with the anomalous

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global climate patterns. The atmospheric component tied to El Niño is termed the “Southern Oscillation.” Scientists often call the phenomenon where the atmosphere and ocean collaborate together ENSO, short for El Niño–Southern Oscillation. El Niño then corresponds to the warm phase of ENSO. The opposite “La Niña” (“the girl” in Spanish) phase consists of a basinwide cooling of the tropical Pacific and thus the cold phase of ENSO. However, for the public, the term for the whole phenomenon is “El Niño.”

Accordingly, it has been very difficult to define El Niño or an El Niño event. The term has changed meaning: some scientists confine the term to the coastal phenomenon, while others use it to refer to the basinwide phenomenon, and the public does not draw any distinction. There is considerable confusion, and past attempts to define El Niño have not led to general acceptance. Clearly, the term El Niño covers a diverse range of phenomena. Earlier, Glantz and Thompson (1981, 3–5) pointed out the numerous meanings of El Niño and a general review of the terminology confusion was given by Aceituno (1992).

Glantz (1996) has formally put forward a definition of El Niño as it should appear in a dictionary:

El Niño \ 'el nē' nyō *noun* [Spanish] \ 1: The Christ Child 2: the name given by Peruvian sailors to a seasonal, warm southward-moving current along the Peruvian coast <la corriente del Niño> 3: name given to the occasional return of unusually warm water in the normally cold water [upwelling] region along the Peruvian coast, disrupting local fish and bird populations 4: name given to a Pacific basin-wide increase in both sea surface temperatures in the central and/or eastern equatorial Pacific Ocean and in sea level atmospheric pressure in the western Pacific (Southern Oscillation) 5: used interchangeably with ENSO (El Niño–Southern Oscillation) which describes the basin-wide changes in air–sea interaction in the equatorial Pacific region 6: ENSO warm event *synonym* warm event *antonym* La Niña \ [Spanish] \ the young girl; cold event; ENSO cold event; non-El Niño year; anti-El Niño or anti-ENSO (pejorative); El Viejo \ 'el vyā hō \ *noun* [Spanish] \ the old man.

This definition reflects the multitude of uses for the term but is not quantitative. There have been several attempts made to make quantitative definitions, although always by choosing just one of the myriad of possibilities and therefore falling short for general acceptance.

Quinn et al. (1978) provided a listing of El Niño events and a measure of event intensity on a scale of 1 to 4 (strong, moderate, weak, and very weak) beginning in 1726. The measures used to define the El Niño and its intensity were primarily based on phenomena along the coast of South America and were often qualitative.

In the early 1980s, a Scientific Committee for Ocean Research working group, SCOR WG 55, was set up to define El Niño (SCOR 1983) and came up with the following:

El Niño is the appearance of anomalously warm water along the coast of Ecuador and Peru as far south as Lima (12°S). This means a normalized sea surface temperature (SST) anomaly exceeding one standard deviation for at least four (4) consecutive months. This normalized SST anomaly should occur at least at three (3) of five (5) Peruvian coastal stations.

This definition clearly refers to the event right along the South American coast and it did not achieve acceptance from the scientific community.

For some time, the focus of much activity related to ENSO has been the Niño 3 region, defined as 5°N–5°S, 90°–150°W. This has been, for instance, the primary predicted ENSO-related quantity by models verified by observed data. The following is the working definition used by the Japan Meteorological Agency (JMA). It is an objective procedure and the obtained El Niño periods are quite consistent with the consensus of the ENSO research community.

1. Analyze monthly mean SSTs in 2° × 2° grids.
2. Calculate monthly SST anomalies averaged for the area 4°N–4°S and 90°–150°W. This is essentially the region known as “Niño 3” (although the latter extends to ±5° latitude).
3. Find periods during which 5-month running means of the monthly SST anomalies in the above-mentioned area are +0.5°C or more for at least six consecutive months.

The 5-month running mean of SST anomalies is made in order to smooth out the possible intraseasonal variations in the tropical ocean. The periods that qualify define the El Niño periods and provide a quantitative measure of the intensity. The results of this technique, applied to the Niño 3 data from NOAA, are shown in Fig. 1.

Kiladis and van Loon (1988) used a standard Southern Oscillation index (SOI) combined with an

SST anomaly index for the eastern tropical Pacific (within 4° of the equator from 160°W to the South American coast) to define an “event” and required that the SST anomaly had to be positive for at least three seasons and be at least 0.5°C above the mean, while the SOI had to remain negative and below -1.0 for the same duration. They provide a listing of “Warm” and “Cold” events from 1877 to 1982.

Various versions of the SOI exist although, in recent years, most deal only with atmospheric pressures and usually only those at Darwin and Tahiti. In using the SOI based on just two stations, it must be recognized that there are many small-scale and high-frequency phenomena in the atmosphere, such as the Madden–Julian Oscillation, that can influence the pressures at stations involved in forming the SOI but that do not reflect the Southern Oscillation itself. Accordingly, the SOI should only be used when monthly means are appropriately smoothed (Trenberth 1984; Trenberth and Hoar 1996a). For many years, Tahiti data were available only after 1935. Ropelewski and Jones (1987) outline an extension of the SOI prior to then using newly discovered Tahiti data, and they also discuss different ways of standardizing the data for use in the SOI. However, there are questions about the integrity of the Tahiti data prior to 1935 (Trenberth and Hoar 1996a) as the Tahiti–Darwin correlation is much lower in spite of strong evidence that the SO was present from other stations and the noise level and variance in the early Tahiti data are higher than in the more recent period. Although Ropelewski and Jones (1987) state that they believe that months with data contained a full complement of daily values, several monthly means are missing and the monthly means that are present for the earlier period are more consistent with the view that they originate from an incomplete dataset in which values contributing to monthly means are missing. There are also questions about whether the diurnal cycle in surface pressure, which contains a strong semidiurnal tide component, has been adequately dealt with in forming the means. Ropelewski and Jones (1987) use a 5-month running mean to define their indices (as is done in NOAA’s *Climate Diagnostics Bulletin*).

In recent years, it has been apparent that the key region for coupled atmospheric–ocean interactions in ENSO is somewhat farther west (Wang 1995; Trenberth 1996a; Trenberth and Hoar 1996a). As shown by the latter paper, the negative correlations of the smoothed SOI and SSTs exceed -0.8 only through a broad region from about 120° to 180°W , 5°N to 10°S .

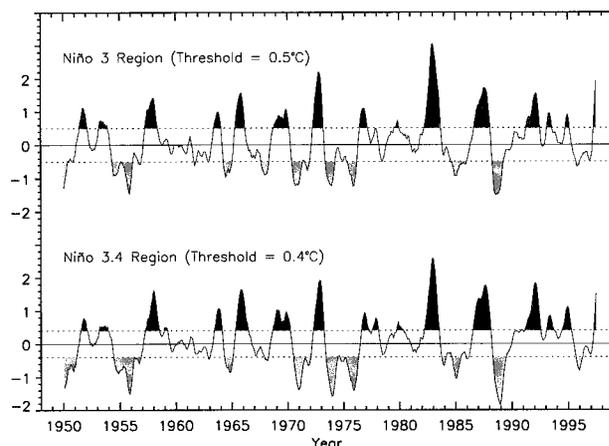


FIG. 1. Time series plots of the Niño 3 (upper) and Niño 3.4 SST indices as 5-month running means using data from NOAA and relative to a base period climatology from 1950 to 1979. Values exceeding thresholds of $\pm 0.5^\circ\text{C}$ for Niño 3 and $\pm 0.4^\circ\text{C}$ for Niño 3.4 are stippled to indicate ENSO events.

Thus, Trenberth and Hoar (1996b) proposed this as the Niño 3.5 region as it straddles part of the Niño 3 and Niño 4 regions although extending farther into the Southern Hemisphere as the key region for ENSO. For this region, ENSO events might more appropriately be defined by a threshold of 0.3°C . This slight shift in focus in the area of SST of importance has also been found in the Climate Prediction Center of NOAA’s National Centers for Environmental Prediction, where, since April 1996, they have introduced a new SST index called Niño 3.4 for the region 5°N – 5°S , 120° – 170°W in their monthly *Climate Diagnostics Bulletin*. Similar criteria to the JMA definition could be applied to such a region, although a threshold lower than 0.5°C might be appropriate. Because the Niño 3.4 values are now widely disseminated, we use those and the Niño 3 values to examine the record after 1950.

3. The recent ENSO record

Figure 1 shows the 5-month running mean SST time series for the Niño 3 and 3.4 regions relative to a base period climatology of 1950–79 given in Table 1. The base period can make a difference. This standard 30-year base period is chosen as it is representative of the record this century, whereas the period after 1979 has been biased warm and dominated by El Niño events (Trenberth and Hoar 1996a). Mean temperatures are higher in the Niño 3.4 region than in Niño 3, and its proximity to the Pacific warm pool and main

TABLE 1. Means and standard deviations (s) for SST in the Niño 3 and 3.4 regions for the base period 1950–79 in °C. In the last line, “All” refers to the overall means and standard deviation of monthly anomalies.

Month	Mean Niño 3	s (Niño 3)	Mean Niño 3.4	s (Niño 3.4)
1	25.4	0.93	26.4	1.05
2	26.2	0.68	26.6	0.79
3	26.9	0.44	27.1	0.59
4	27.2	0.53	27.6	0.53
5	26.7	0.63	27.5	0.52
6	26.2	0.67	27.4	0.53
7	25.4	0.75	27.0	0.60
8	24.8	0.85	26.7	0.72
9	24.6	0.87	26.4	0.80
10	24.7	0.89	26.5	0.88
11	24.7	1.03	26.4	1.04
12	24.9	1.08	26.4	1.06
All	25.64	0.79	26.83	0.77

centers of convection is the reason for the physical importance of Niño 3.4.

The monthly standard deviations in Table 1 are of considerable interest. Largest standard deviations of comparable values for both indices occur in the northern winter of slightly over 1°C, while lowest values occur in the northern spring. In Niño 3 the minimum in March of 0.44°C is less than half the November, December, and January values and the standard deviations are mostly slightly larger in the Niño 3.4 region from January to March. From May to October, the reverse is the case; the standard deviations in the Niño 3 region are slightly larger than those in Niño 3.4. This annual cycle of variance in the SSTs is perhaps a primary reason for a focus on the northern winter for ENSO that has been evident in much of the literature, as that is clearly the time of year when the largest SST changes occur in the central Pacific. However, the annual cycle in standard deviations of outgoing

longwave radiation (OLR) in the Tropics, which indicates the direct convective response in the atmosphere, is displaced one to two months later (see Trenberth et al. 1997). For OLR there is a distinct minimum in interannual variance in September, corresponding to the time of year when the equatorial east–west SST gradients are strongest and so conditions remain cooler in the east for typical El Niño events. Thus, SST anomalies have less effect on the location of atmospheric convection. In March and April, however, when SST gradients along the equator in the Pacific are weakest, small SST anomalies in Niño 3.4 can greatly influence the location of the warmest water and thus the preferred locations of convection. Accordingly, the background climatology sets the stage for the atmospheric response to tropical Pacific SST anomalies.

Overall, the standard deviations of Niño 3 and Niño 3.4 monthly anomalies for 1950–79 are 0.79° and 0.77°C, respectively, and for 5-month running means both of these drop to 0.71°C. If the entire period from 1950 to March 1997 is considered, then the standard deviations increase by 0.05° to 0.07°C. The reasons for this increase can be seen from Fig. 2.

In selecting a single threshold and duration to define ENSO events, it was considered desirable to keep the criteria as simple as possible and for the results to match conventional wisdom as to what have historically been considered as events. In addition, both cold and warm phases of ENSO are considered. Moreover, we use the same threshold for each although this is not necessarily required. We adopt the JMA duration, which requires a minimum of 6 months for the 5-month running mean to exceed the threshold. We have examined in detail three thresholds for the Niño 3 and 3.4 indices as indicators of ENSO events. These are 0.3°, 0.4°, and 0.5°C, which were chosen as rounded numbers rather than fractional standard deviation values. As seen in Table 1, the latter vary with the annual cycle. For the top threshold, several single historic events are broken up into multiple events because the index drops below the threshold for a month or two. For the bottom threshold, the duration of events seems excessive. Overall, the best match with historical judgements was achieved for the Niño 3.4 index for a threshold of 0.4°C. (While the 3.4 really refers to 40% of the way between the Niño 3 and Niño 4 regions, this could give new meaning to the 0.4 adjunct.)

El Niño events identified using Niño 3 and 0.5°C threshold include the following years: 1951–52, 1953, 1957–58, 1963–64, 1965–66, 1968–70, 1972–73,

1976–77, 1979, 1982–83, 1986–88, 1991–92; see Fig. 1. Using this index and threshold, there are exactly 6 months from July to December 1979 that exceed the threshold and thus this qualifies 1979 as an El Niño event, whereas from the JMA analyses it is not so qualified and it is not normally so identified. It is one event that could be eliminated if a more recent base period were chosen. Also, in both 1993 and at the end of 1994, 5 consecutive months exceed the threshold but not 6. However, examining -0.5°C as a threshold for La Niña events does not work very well. The 1950 La Niña enters only at the 0.3°C level. The 1954–56 cold event is broken into two pieces. The 1964 event qualifies, but so too does 1967–68, which is not usually identified. The events during 1970–71, 1973, and 1975 qualify as La Niñas, as do 1984–85, 1988–89, and 1995–96.

Most of these exceptions are remedied if the 0.4°C threshold and Niño 3.4 is chosen (Fig. 1). The exact periods of events so defined are given in Table 2. Here we see the El Niños as 1951–52, 1953, 1957–58, 1963–64, 1965–66, 1968–70, 1972–73, 1976–78, 1979–80, 1982–83, 1986–88, 1991–92, 1993, and 1994–95. The La Niñas are 1950–51, 1954–56, 1964–65, 1970–72, 1973–74, 1974–76, 1984–85, 1988–89, and 1995–96. The 1979–80 event still qualifies as an El Niño with a duration of 7 months, although it would drop out at a threshold of 0.5°C where the duration is 4 months. But whereas 1953 qualifies here for 9 months, it would not qualify at the higher threshold, where the longest duration exceeding 0.5°C is 3 months. April 1956 breaks the 1954–56 La Niña into two parts and the fairly strong La Niñas in 1973–74 and 1974–76 are not separated by a return to above normal SSTs. Similarly, the 1976–77 El Niño event extends to January 1978 with a brief break from April to June 1977.

The perspective of whether the 1990–95 period was one long event with three more active phases or three events varies considerably depending upon the index used. At the 0.3°C threshold, a prolonged El Niño begins in March 1990 until April 1995 with brief breaks from August to December 1992 and December 1993 to April 1994 when the index remained positive. At the 0.4°C threshold this event began in March 1991 and the breaks are a bit longer. From the perspective of the Niño 4 region farther west the SST anomalies were more uniformly positive although with smaller amplitude, and the SOI remained of one sign (Trenberth and Hoar 1996a). At the time of writing, a new strong El Niño event is developing,

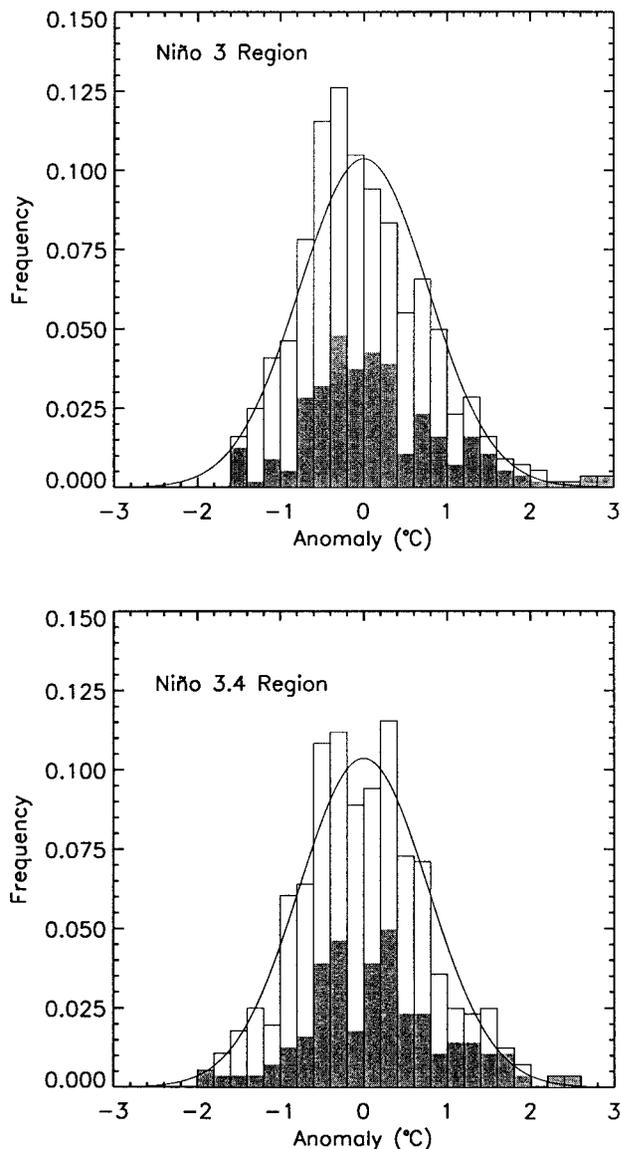


FIG. 2. Histograms of the distribution of SST anomalies for Niño 3 and 3.4 from 1950 to March 1997 relative to the mean for the entire period. The contribution from the post-1979 period is shown by the stippled areas. Also given is the corresponding normal distribution with the same variance.

with April 1997 conditions surpassing the Niño 3.4 threshold of $+0.4^{\circ}\text{C}$.

With these quantitative assignments of events, it is readily seen that there are 177 out of 567 months (January 1950–March 1997) assigned as El Niño (31%) and 133 months assigned as La Niña months (23%). Thus, 55% of the time there is either an El Niño or La Niña underway and only 45% of the time is one not present. Considering that there is a broad 3–6-year period spectral peak in ENSO indices, it is reasonable

TABLE 2. Listings of El Niño and La Niña events after 1950 as defined by SSTs in the Niño 3.4 region and exceeding $\pm 0.4^\circ\text{C}$ threshold. The starting and ending month of each is given along with the duration in months. Coupled events where SSTs remained of one sign are indicated by a brace (}).

El Niño events			La Niña events		
Begin	End	Duration	Begin	End	Duration
Aug 1951	Feb 1952	7	Mar 1950	Feb 1951	12
Mar 1953	Nov 1953	9	Jun 1954	Mar 1956	22
Apr 1957	Jan 1958	15	May 1956	Nov 1956	7
Jun 1963	Feb 1964	9	May 1964	Jan 1965	9
May 1965	Jun 1966	14	Jul 1970	Jan 1972	19
Sep 1968	Mar 1970	19	Jun 1973	Jun 1974	13
Apr 1972	Mar 1973	12	Sep 1974	Apr 1976	20
Aug 1976	Mar 1977	8	Sep 1984	Jun 1985	10
Jul 1977	Jan 1978	7	May 1988	Jun 1989	14
Oct 1979	Apr 1980	7	Sep 1995	Mar 1996	7
Apr 1982	Jul 1983	16			
Aug 1986	Feb 1988	19			
Mar 1991	Jul 1992	17			
Feb 1993	Sep 1993	8			
Jun 1994	Mar 1995	10			

to consider generically that the average time between events is 4 years or so and, because each event typically lasts a year, therefore about 50% of the time would be assigned to either an El Niño or La Niña. The distribution of Niño SST anomalies can also be examined via histograms (Fig. 2). The distribution of monthly anomalies for January 1950–March 1997 is shown along with those from the post-1979 period and the corresponding normal distribution. Here the zero corresponds to the mean for the entire period, and a comparison of the shaded post-1979 months shows the recent warm bias. Also readily apparent here is the much greater spread in the more recent period with both tails of the distribution being filled out.

The short record means that there is uncertainty in the histogram, as can also be seen by comparing the 1950–79 period with the post-1979 period. There is evidence for a flat distribution for Niño 3.4 anomalies between about -0.6° and $+0.4^\circ\text{C}$ and perhaps even a bimodal character. This is not so evident for Niño 3, where instead the overall distribution is strongly skewed so that there is a deficiency of negative

anomalies less than -1.6°C , a surfeit of negative anomalies of -0.2° to -0.6°C and a surfeit of positive anomalies above 1.2°C relative to the normal distribution. The long tail on the right provides evidence supporting the attention given to excessive warm conditions: the El Niño events. This is also why the list of La Niña events is much shorter than that for El Niños in Table 2. Clearly the varying amplitude of events throughout the record, combined with the fact that the peak values are not sustained for very long (compared with a sine curve), means that in spite of the quasi periodicity in ENSO, the distribution is not that far from normal. For Niño 3.4 it may be bimodal. And for SSTs farther east it is skewed, presumably because of the shallowness of the thermocline. Note that the normal distribution with the same standard deviation as for the observed data would have 60% of the values exceeding $\pm 0.4^\circ\text{C}$. This is more than the 55% assigned as ENSO events in part because of those SST values that exceed the threshold but that do not endure for longer than 6 months and are therefore not included.

One further point worthy of note in Table 2 is that the starting dates of events are not uniformly distributed throughout the year. Most events begin between March and September. The exceptions are the 1979 case, which is very weak, and the 1993 El Niño, which was a continuation of the previous warm phase. A preferred ending time for events is February–March. Perhaps it is not surprising that the transition times occur in the northern summer half year while the peak amplitudes of the interannual variability (Table 1) are in the northern winter. However, these observations show that there is a distinct seasonality to the onset and occurrence of ENSO events, which seems to be difficult for models to get right.

4. Recommendation

It is hoped that the above provides a quantification of ENSO events in several ways, including when they have occurred, their duration, and, from Fig. 1, a measure of their amplitude, all of which may be useful for some purposes. A listing of the duration of the El Niño and La Niña events after 1950 is provided. Nevertheless, these measures are not unique and alternative criteria can be used. In particular, different criteria might be used if the interest is the coast of South America, where the term El Niño originated. It is useful to know that ENSO events occur about 55% of the time with the definition used above, so that most of the time the Tropics is regarded as being in one phase or the other and average conditions are less common.

It is clear from the standpoint of quantifying El Niño and related phenomena that the definition is still evolving and, in any case, needs to recognize the richness of the phenomenon. If a definition is needed, then the one proposed by Glantz should be promulgated although this is not quantitative. Precision can only be achieved if the particular definition is identified in each use, and this is to be recommended in all cases to reduce the possibility of misunderstanding. For more quantitative purposes, the JMA definition is suitable in most cases, although it is suggested that it should be modified to apply to Niño 3.4 and

with a threshold of 0.4°C . However, we have concluded that it does not appear to be appropriate for any particular definition to be officially recognized by CLIVAR.

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References

- Aceituno, P., 1992: El Niño, the Southern Oscillation, and ENSO: Confusing names for a complex ocean–atmosphere interaction. *Bull. Amer. Meteor. Soc.*, **73**, 483–485.
- Glantz, M. H., 1996: *Currents of Change: El Niño's Impact on Climate and Society*. Cambridge University Press, 194 pp.
- , and J. D. Thompson, 1981: *Resource Management and Environmental Uncertainty: Lessons from Coastal Upwelling Fisheries*. John Wiley & Sons, 491 pp.
- Kiladis, G. N., and H. van Loon, 1988: The Southern Oscillation. Part VII: Meteorological anomalies over the Indian and Pacific sectors associated with the extremes of the oscillation. *Mon. Wea. Rev.*, **116**, 120–136.
- Quinn, W. H., D. O. Zopf, K. S. Short, and R. T. W. Yang Kuo, 1978: Historical trends and statistics of the Southern Oscillation, El Niño, and Indonesian droughts. *Fish. Bull.*, **76**, 663–678.
- Ropelewski, C. F., and P. D. Jones, 1987: An extension of the Tahiti–Darwin Southern Oscillation Index. *Mon. Wea. Rev.*, **115**, 2161–2165.
- SCOR, 1983: Prediction of El Niño. *Proc. No. 19*, Paris, France, Scientific Committee for Ocean Research Working Group 55, 47–51.
- Trenberth, K. E., 1984: Signal versus noise in the Southern Oscillation. *Mon. Wea. Rev.*, **112**, 326–332.
- , and T. J. Hoar, 1996a: The 1990–1995 El Niño–Southern Oscillation Event: Longest on record. *Geophys. Res. Lett.*, **23**, 57–60.
- , and —, 1996b: The 1990–1995 El Niño–Southern Oscillation event: Longest on record. *Proc. Eighth Symposium on Global Ocean–Atmosphere–Land System (GOALS)*, Atlanta, GA, Amer. Meteor. Soc., 84–87.
- , G. W. Branstator, D. Karoly, A. Kumar, N.-C. Lau, and C. Ropelewski, 1997: Progress during TOGA in understanding and modeling global teleconnections associated with tropical sea surface temperatures. *J. Geophys. Res.*, in press.
- Wang, B., 1995: Interdecadal changes in El Niño onset in the last four decades. *J. Climate*, **8**, 267–285.

