Ancient Mesoamerica, **13** (2002), 159–170

DOI: 10.1017.S0956536102131129

LOS MAYAS Y EL NIÑO

Paleoclimatic correlations, environmental dynamics, and cultural implications for the ancient Maya

Lewis C. Messenger, Jr.
Department of Anthropology, Hamline University, 1536 Hewitt Avenue, Saint Paul, MN 55104, USA

Abstract

During the spring of 1998, an El Niño event produced harsh drought conditions in much of Mexico, including the Maya area. Similar events surely occurred in the distant past. This paper reports on investigation of chronological correlations between El Niño event sequences as suggested by glacial ice-core data from Quelccaya in the Peruvian Andes, historical-severity-ranked El Niño event sequences, and historical drought documentation for the Maya area. Positive correlations between Andean ice-core data sets and historical sequences were expected to provide evidence for earlier discrete El Niño event sequences as far back as A.D. 470 that could be used as proxy data to reconstruct annual El Niño events affecting southern Mesoamerica, including the Maya Classic through Postclassic periods. Correlations of these data sets proved inconclusive, suggesting the need for alternative approaches toward reconstructing discrete El Niño sequences for the Maya area.

The summer of 1998 witnessed what many refer to as a "record El Niño year," with extremely high temperatures and drought experienced in portions of the southern United States, while in the northern Midwest there was considerable wetness. To the south, in Mexico, there were weeks when the major newspapers reported hundreds of forest fires burning within the Valley of Mexico alone. *National Geographic* profiled the phenomena on its cover. During spring 1998, researchers described southeastern Campeche as a "Green Desert"—a virtual tinderbox. The nearby, and normally moist, parts of lowland Tabasco also were often in flames. Smoke from Mexican fires was credited with creating haze as far away as Florida.

Because of the heavy damage that this El Niño event was inflicting on Mesoamerica, I reasoned that similar events must have occurred in the past—hence, this paper's focus on El Niño and the ancient Maya.

PRECURSORS TO THE RESEARCH

Definitions of an El Niño event draw one to South America's equatorial Pacific coast. It is in that area that the first references to El Niño appear (Glantz 1996). That this phenomenon appeared around Christmastime has contributed to the capitalization of its name—El Niño, or the Christ Child. It is characterized by the appearance of warmer-than-normal surface water just off the coasts of Peru and Ecuador. Of immediate consequence to the coastal peoples there are the disruptions to the fishing industry and to the birds who donate their nitrogen-rich guano. As well, one must consider those people in Peruvian settlements who are unlucky enough to live in normally arid valleys transformed by flooding and mud slides resulting from the extremely rare heavy downpours accompanying such events.

We now know that El Niño events do not occur in isolation. They are situated within larger atmospheric and oceanic dynamics. The world now becomes attentive when signals of an emerging El Niño are discerned. The accompanying vocabulary now includes the terms "El Niño-Southern Oscillation" (Allan et al. 1996), generally referred to by its acronym ENSO, and people speak of a "sister" event, "La Niña." We also have the so-called North Atlantic Oscillation (NAO), and, as recently as 1999, researchers had begun reporting similar patterns, or a "cousin of El Niño," in the Indian Ocean (Monastersky 1999).

The severe drought and accompanying fires and agricultural hardships that Mexico experienced in 1999 suggested such participation within a greater global atmospheric and oceanic system. Pre-Conquest anecdotal ethnohistorical sources, as well as drought chronologies for various regions of the country going back to the Spanish Conquest (Florescano and Swan 1995), indicate that El Niño phenomena have been recognized as significant for a long time in Mexico.

Sources with dated events suggest that ancient climatic perturbations could be analyzed for periodicity correlation with other parts of the world, perhaps allowing researchers to link sequentially the Maya area with the Andean Highlands (Figure 1).

Several studies have suggested that a detailed sequence of El Niño events are recorded in the annual ice laminations found in tropical ice cores in the Andes taken from the Quelccaya and Huascaran glaciers (Thompson et al. 1984, 1992). These studies

Figure 1. Map illustrating approximate location of places mentioned in text (indicated by plus signs).

implied that the study of Andean ice-core laminations, can reveal evidence that:

1. El Niño events can be discerned and their sequence reconstructed;
2. El Niño event records are potentially specific to individual years within the time period represented by a particular core; and
3. Interannual climate variability also can be used to rank the severity of individual El Niño events.

Furthermore, the period represented by the ice-core "archive" extended back to at least 1,500 to 2,000 years ago (Thompson 1996; Thompson et al. 1994). Peruvianist archaeologists had already been investigating potential ancient cultural implications of the Andean ice-core paleoclimatic data (Shimada et al. 1991).

METHODOLOGICAL ASSUMPTION

The points listed earlier led me to develop a research methodology that would utilize Peruvian ice-core data as proxies for suggesting a sequence of severity-ranked El Niño events that would have affected the Maya areas of southern Mesoamerica. The location of sites mentioned in the Maya region and where the Andean ice cores were taken can be seen in Figure 1.

DEVELOPMENT OF RESEARCH DESIGN

Ice-core research by L. G. Thompson, E. Mosley-Thompson, and B. M. Arnao (1984) reports on 1975–1983 observations of variables relating to the amount of mass accumulation on Quelccaya and tropical El Niño Tropical Oscillation (ENSO) events. They note that reduced annual accumulation on Quelccaya temporally correlates with two prominent indicators of major ENSO events:

1. Southern Oscillation Index (SOI, or the mean values of the atmospheric-pressure anomaly at sea level at Tahiti, minus that of Darwin); and
2. Annual sea-surface-temperature (SST) anomalies as recorded at Puerto Chicama, Peru.

A strong negative SOI correlates with abnormally low sea-surface temperatures. This strongly correlates with abnormally low annual water accumulations in Quelccaya ice. Thus, one should be able to determine the El Niño sequence for the 1,500-year record archived in Quelccaya glacial laminae.

Statistical data from Quelccaya Core 1 representative of A.D. 470–1984 was downloaded and imported into a Quattro Pro spreadsheet (data for the Summit Core and Core 1) from the National Oceanographic and Atmospheric Administration/National Geophysical Data Center Paleoclimatology Program, Boulder, Colorado (Thompson 1992). This was done to enable comparisons of the Quelccaya data with other forms of time-series data. The ultimate goal was to use the lengthy Quelccaya series to reconstruct an El Niño sequence that—because the severe 1998 El Niño affected both Peru and Mexico—could be used to reconstruct equivalent precipitation anomalies for Mesoamerica, and ultimately for the Maya area.

The Quelccaya ice cores (hereafter referred to as the Quelccaya Summit Core and Core 1) provide annual sequential data extending from A.D. 470 to 1984. The data to be analyzed for this paper was taken from L. G. Thompson (1992) and organized variable categories in eight columns.

For each thermal year there were seven columns:

- Three columns indicated particulate concentrations ranging from diameters of .63 to.83 μm, of $<$.63 μm, and of $>$1.59 μm. High incidences of extremely small dust particles suggest prevailing aridity upwind from the Quelccaya site during the indicated years. Increasing particle concentrations suggest increased aridity.
- One column indicated electrical conductivity in microsiemens per centimeter, whereby higher conductivity was seen to correlate with increased aridity.
- One column showed oxygen isotopic ratios (O-18/O-16) used to suggest past prevailing temperatures whereby negative O-18 values were seen to suggest cooler conditions.
- One column showed net annual accumulation (in meters of water equivalent) reflecting annual precipitation to suggest variations in local annual precipitation whereby decreased amounts imply reduced precipitation or relative aridity.
- One column showed net annual accumulation as standard deviations from the complete series mean to illustrate trend and deviations from a calculated "normal."

L. Thompson and E. Mosley-Thompson (1989) have used these data sets to suggest long-term climatic reconstructions for the Peruvian Andes that appear to correlate chronologically with significant Holocene climatic events such as the Little Ice Age (LIA) (Thompson and Mosley-Thompson 1989:17), as well as ENSO events (Thompson et al. 1984). Geomorphological data (Sandweiss et al. 1996) and data from pollen analysis (Hansen and Rodbell 1995) have suggested a rough paleoclimatic correspondence—hence, an increasingly high confidence level in the Quelccaya implications.

https://doi.org/10.1017/S0956536102131129 Published online by Cambridge University Press

Peruvianist archaeologists have incorporated and used data obtained from the Quelccaya cores to assist in reconstructing climatic regimes for coastal areas of Peru, in particular for areas of ancient Moche culture. Correlations have been noted between cultural discontinuities in archaeological sequences and episodic climatic perturbations detectable in data from the Quelccaya ice core (see, e.g., Thompson 1996; Thompson and Mosley-Thompson 1987; Thompson et al. 1994). Correlations between cultural and paleoclimatic discontinuities—prolonged periods of drought interspersed with intense episodic flooding—have led to further suggestions of culture–environment systemic relationships (see, e.g., Paulsen 1976; Shimada et al. 1991; and, most recently, Fagan 1999:119–138 [cf. Erickson 1999]).

Given such methodological security in the Quelccaya data as paleometeorological proxies with potential cultural implications, it seemed possible to pinpoint possible chronological "flashpoints" for ancient southern Mesoamerica, perhaps to the point of suggesting that the agricultural sector of, say, La Milpa (Dunning et al. 1999) or perhaps Pacal's "realml," may have been stressed in a particular year of his reign.

IMPLEMENTATION OF CORRELATIONAL METHODOLOGY

Discerning correlations in the form of pronounced graphic, visual "signatures" required being able to match the Quelccaya core data sets with other historically known El Niño event sequences. The 463-year series of historical anecdotal references to ranked El Niño events found by W. H. Quinn, V. T. Neal, and S. E. Antuñez de Mayolo (1987) was input into the same spreadsheet. Additional spreadsheet columns were created to show the timing of historical drought events, focusing on the southern part of Mexico, using data from Florescano and Swan (1995).

Although the time frame represented by these data sets represented a maximum of about 1,500 years, the data in Quinn et al. (1987) and Florescano and Swan (1995) covered only the Spanish arrival to the present. Confidence in empirical data increases with the proliferation of standardized instrument-based measurement. Therefore, it seemed prudent to look first at the recent 100 years to see whether the Andean Quelccaya ice-core—the anecdotal, ranked historical El Niño—and Mexican drought data sets showed significant correlations and what kinds of recognizable signatures there were.

RESULTS OF CORRELATIONAL ANALYSIS

The time frame was limited to the twentieth century, with the various Quelccaya data sets placed sequentially in a spreadsheet and matched with historical El Niño (Quinn et al. 1987) and southern Mexico (Florescano and Swan 1995) drought events. Graphs matching Quelccaya data variables, with event labeling placed adjacent to the relevant years' bars, were created. Try to discern regularities of placement of "very strong" El Niño events in the following graphs:

1. A line graph matching Quelccaya Core 1 water-accumulation deviations with historical, ranked El Niño events (Figure 2).
2. A horizontal bar graph matching Quelccaya Core 1 water-accumulation deviations with historical, ranked El Niño events (Figure 3).
3. A horizontal bar graph for Quelccaya Core 1: accumulation deviations with Mexican drought events for 1900–2000 (Figure 4).
4. A line graph matching Quelccaya Core 1 water-oxygen-isotope ratios with historical El Niño events (Figure 5).

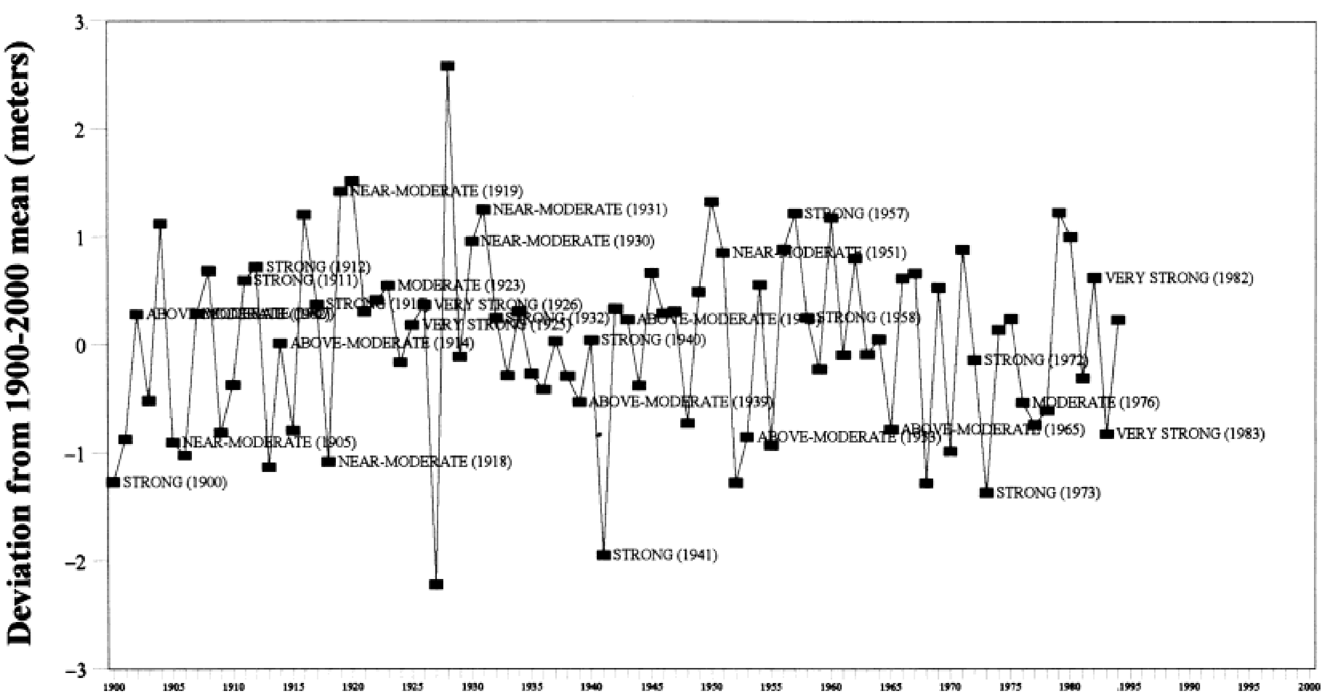

Figure 2. Line graph matching Quelccaya Core 1 water-accumulation deviations with historically ranked El Niño events.

https://doi.org/10.1017/S0956536102131129 Published online by Cambridge University Press

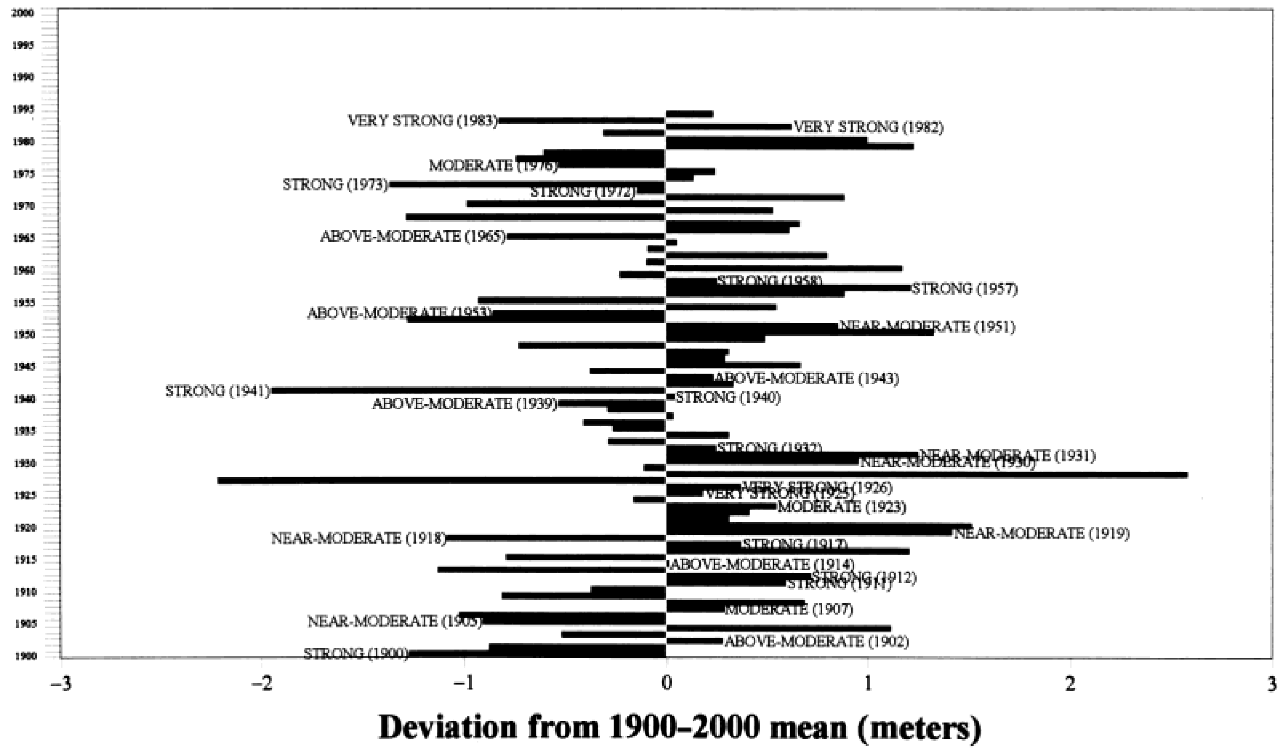

Figure 3. Horizontal bar graph matching Quelccaya Core 1 water-accumulation deviations with historically ranked El Niño events.

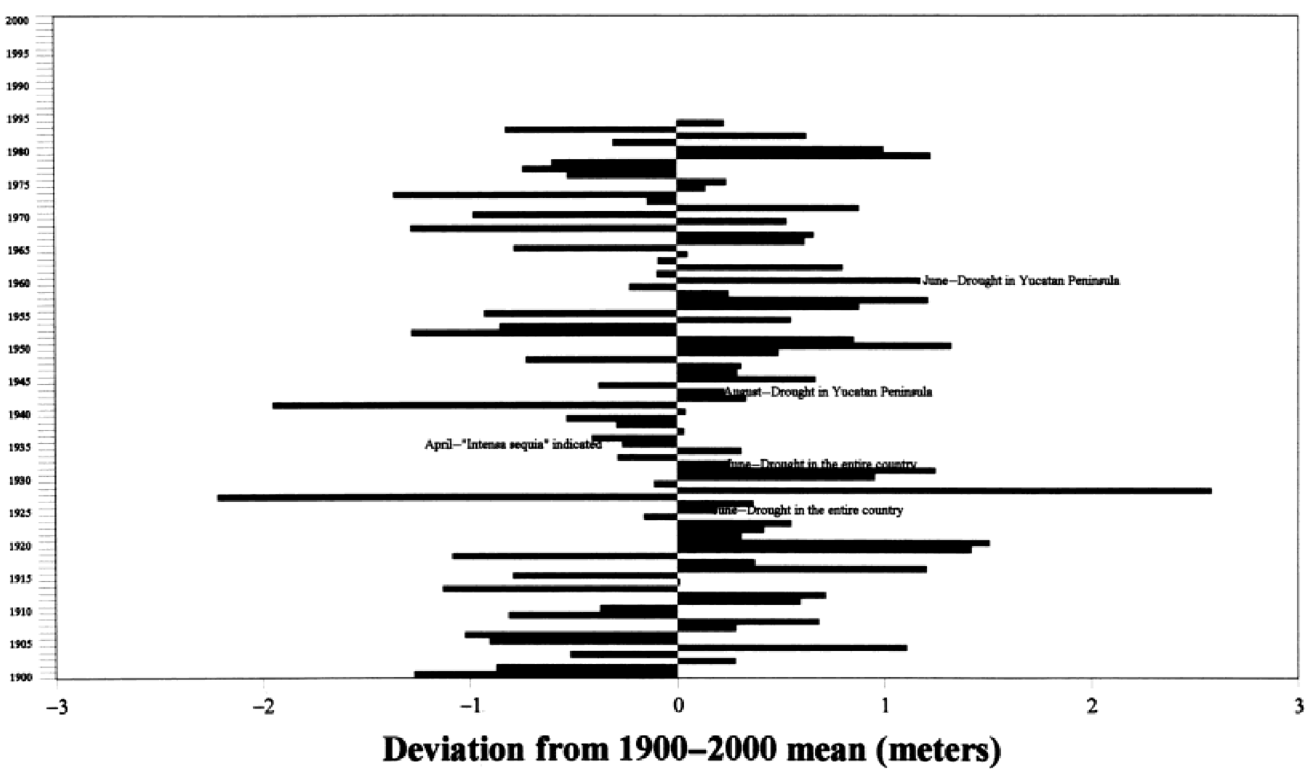

Figure 4. Horizontal bar graph for Quelccaya Core 1: Accumulation Dev/Mexican drought events for 1900–2000.

https://doi.org/10.1017/S0956536102131129 Published online by Cambridge University Press

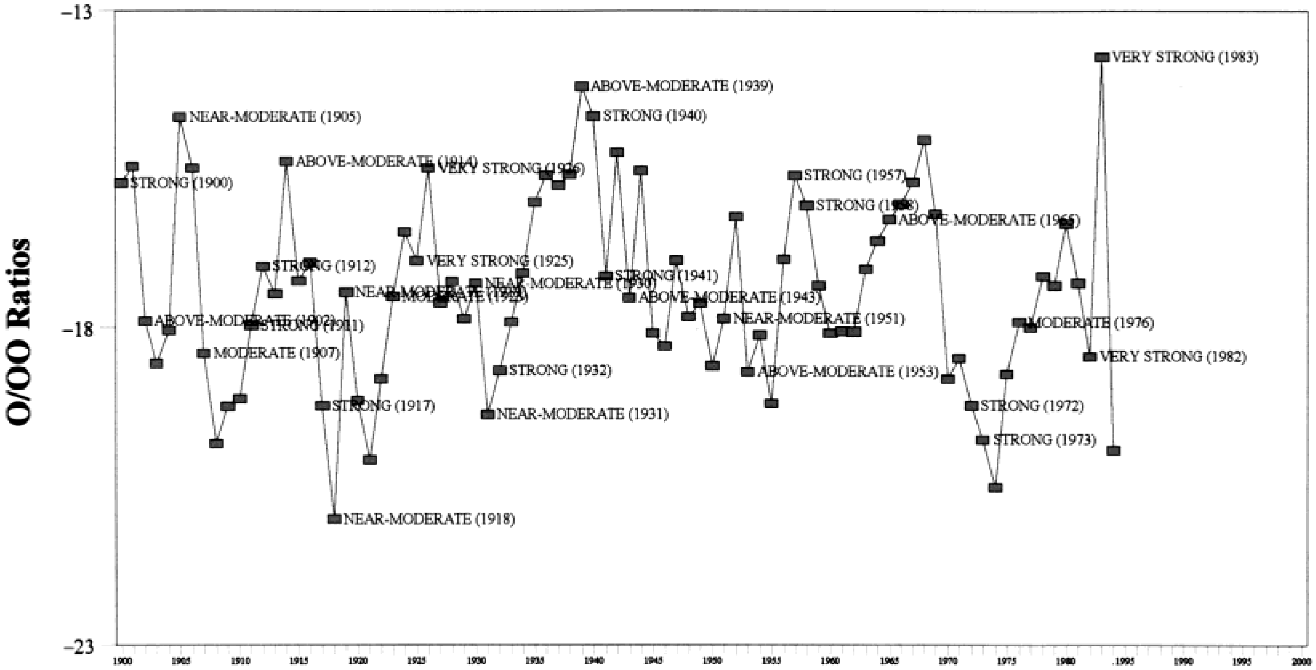

Figure 5. Line graph matching Quelccaya Core 1 water-oxygen-isotope ratios with historical El Niño events.

5. A horizontal bar graph matching Quelccaya Core 1 water-oxygen-isotope ratios with historical El Niño events (Figure 6).
6. A line graph matching known Yucatan and greater Mexico droughts (Figure 7).
7. A horizontal bar graph matching known Yucatan and greater Mexico droughts (Figure 8).
8. A line graph matching the winter SOI (Allan et al. 1996) with the El Niño intensity series (Figure 9).

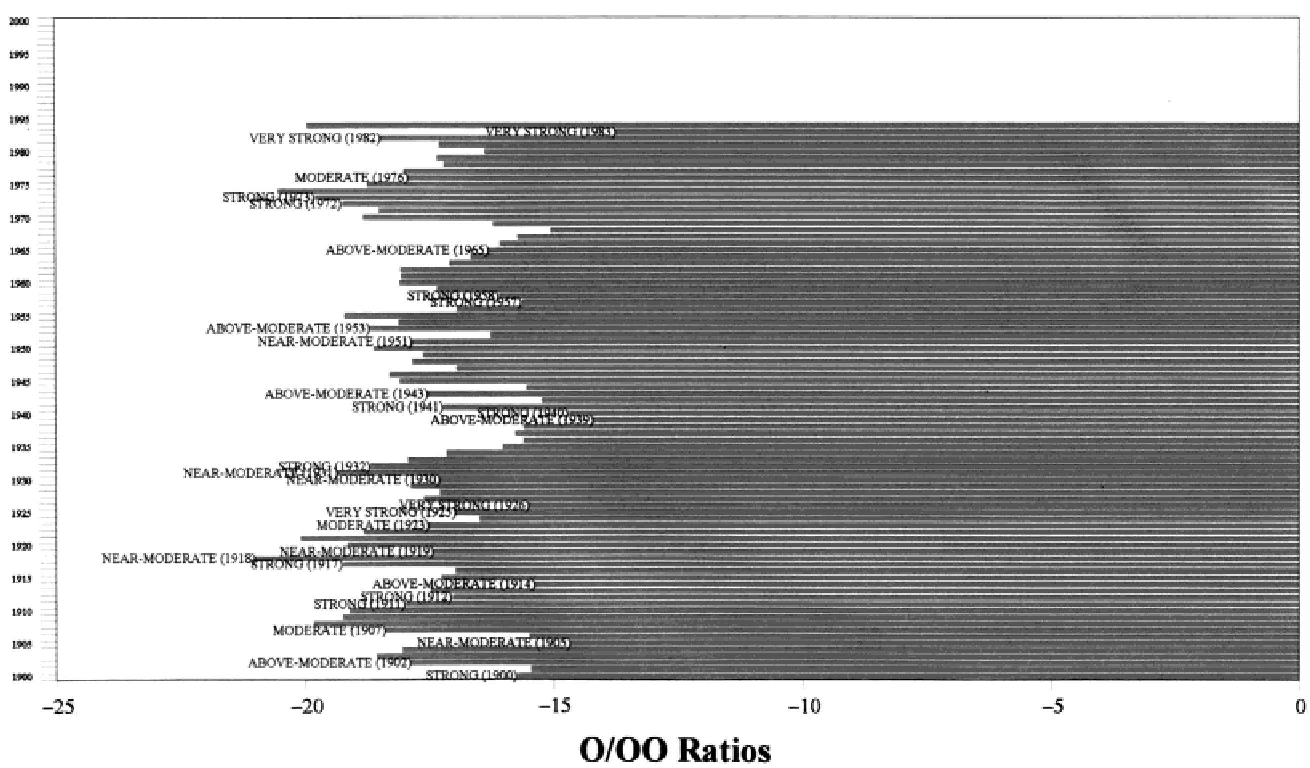

Figure 6. Horizontal bar graph matching Quelccaya Core 1 water-oxygen-isotope ratios with historical El Niño events.

https://doi.org/10.1017/S0956536102131129 Published online by Cambridge University Press

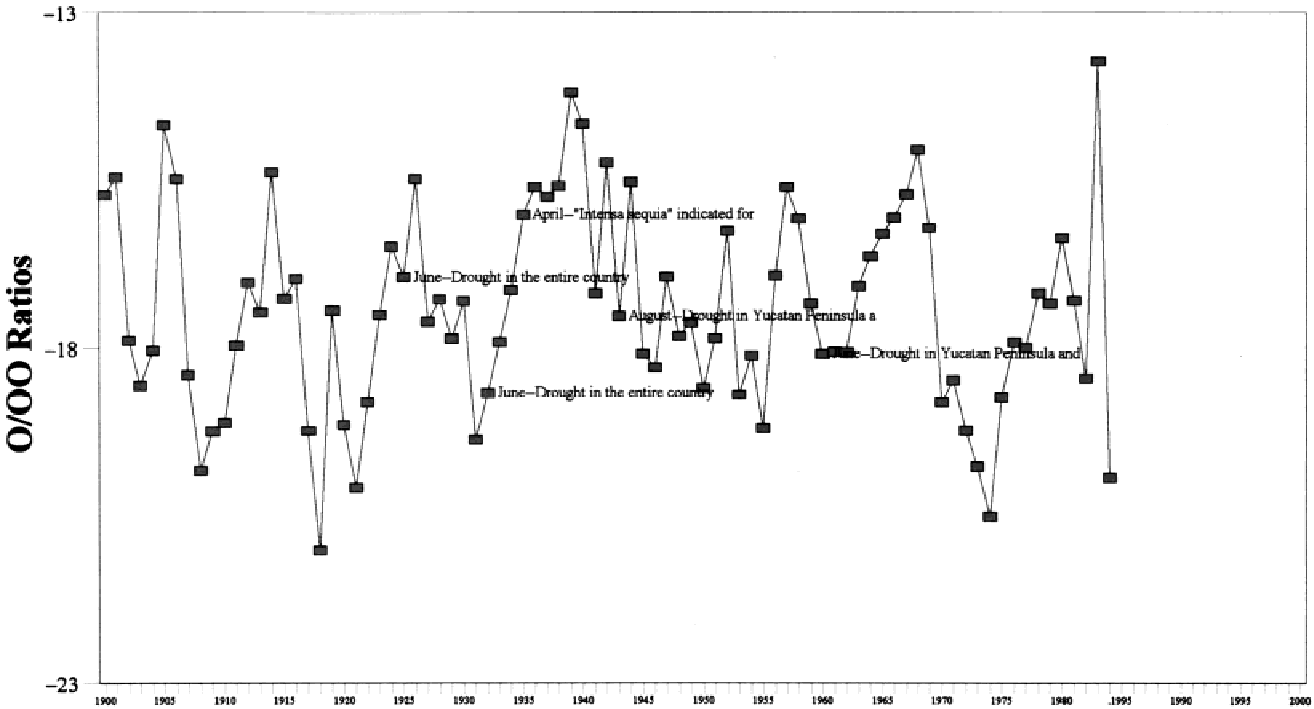

Figure 7. Line graph matching known Yucatan and greater Mexico droughts.

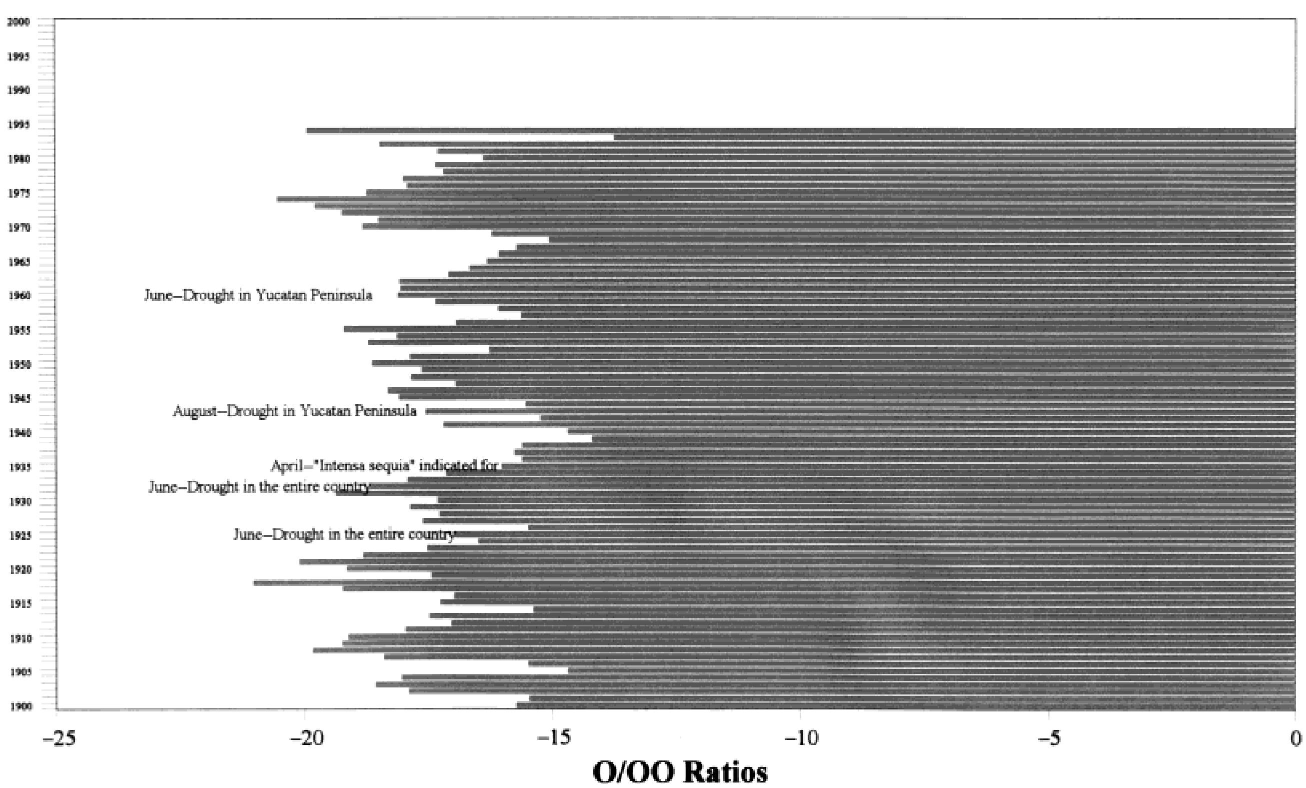

Figure 8. Horizontal bar graph matching known Yucatan and greater Mexico droughts.

https://doi.org/10.1017/S0956536102131129 Published online by Cambridge University Press

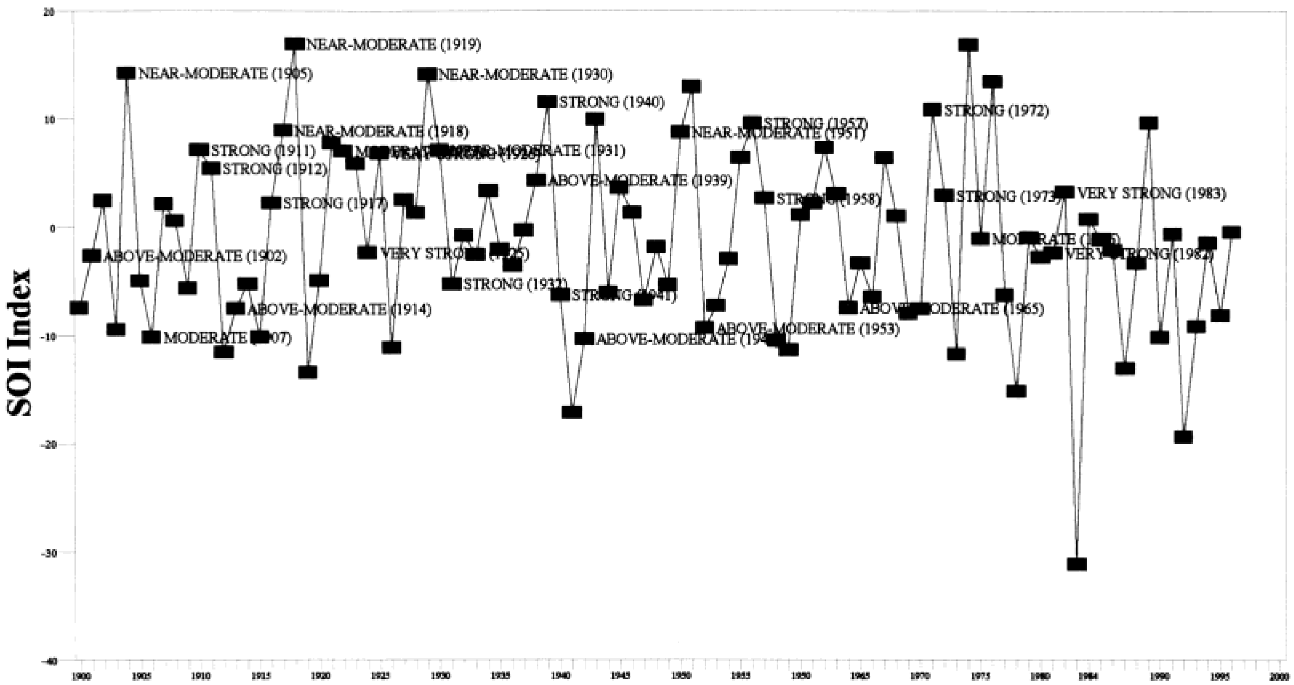

Figure 9. Line graph matching the winter SOI (Allan et al. 1996) with the El Niño intensity series.

9. A horizontal bar graph matching the winter SOI (Allan et al. 1996) with the El Niño intensity series (Figure 10).

No significant correlations were apparent when the bar graphs were created and viewed.

Whether looking at the Quelccaya water-accumulation or oxygen-isotopic data, at El Niño event intensity, or at the Mexican drought record, there seems no discernible regularity with regard to extremes shown in the variables. In other words, the visual evidence does not confirm any significant annual correlation—

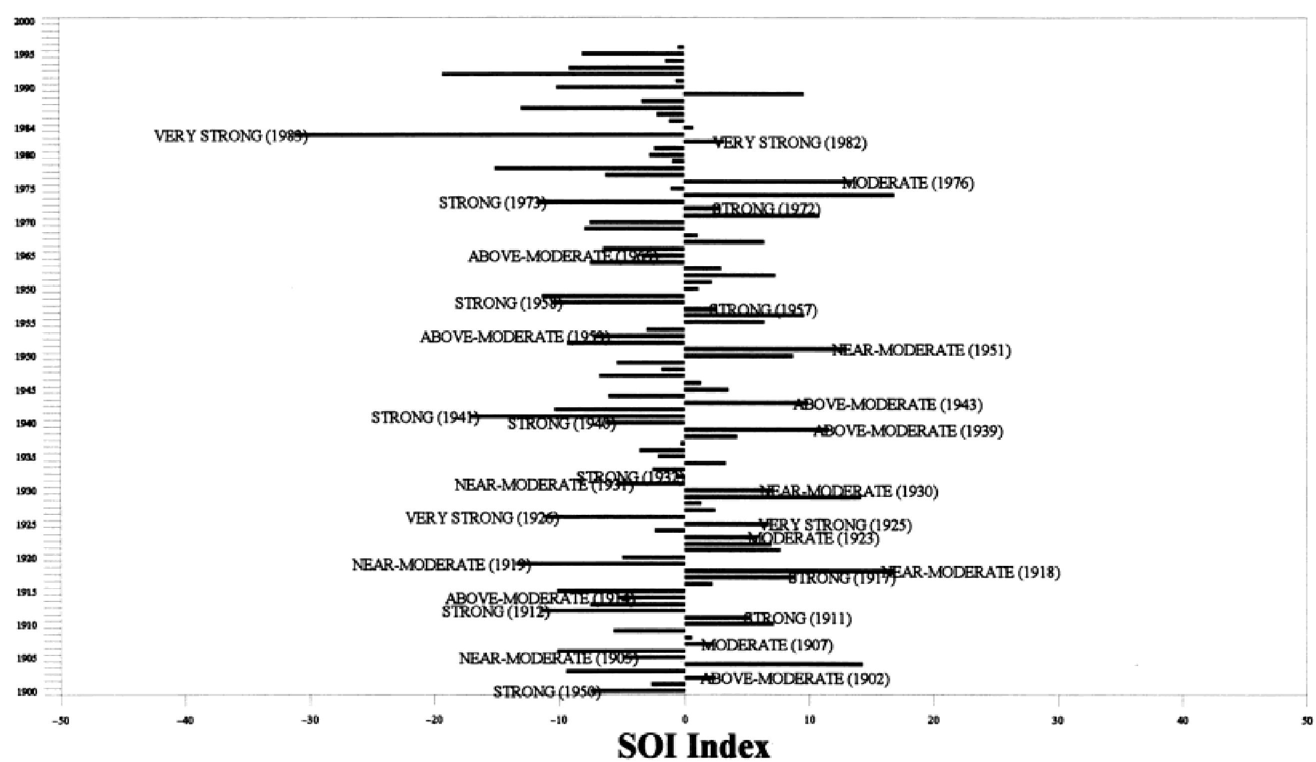

Figure 10. Horizontal bar graph matching the winter SOI (Allan et al. 1996) with the El Niño intensity series.

https://doi.org/10.1017/S0956536102131129 Published online by Cambridge University Press

positive, negative, or lag—between the Quelccaya data and the anecdotal El Niño record for the twentieth century or from Colonial times to the present, or between the Mexican severe-drought records and the Quelccaya data.

K. A. Henderson, L. G. Thompson, and P.-N. Lin report on El Niño events recorded in Nevado Huascarán, Peru, providing a chronology of identified El Niño warm and cold events (1999:Table 1). As can be seen in Figures 11 and 12, when Henderson et al.'s 1925–1984 El Niño event series is compared with the Quelccaya oxygen-isotope (σO-18) data and graphed, "very strong" (VS) and "strong" (S) events (red circles) are found "high and low"—with no apparent correlation there, either.

INTERPRETATION AND ASSESSMENT

Several sources specifically suggest the idea of El Niño climatic "flashpoints" in the Maya area. Brian Fagan (1999) suggests that El Niño events influenced ancient cultural development not only in the Maya area but in many parts of the world: Egypt, Moche Peru, and the Anasazi of the North American Southwest.

Oxygen-isotopic change has been suggested as a potential El Niño marker at Huascarán and Quelccaya (Henderson et al. 1999; Thompson et al. 1984). Hodell et al. (1995) and Curtis et al. (1996:43) also corroborate relationships between variability in oxygen-isotope change and localized climate change for the Lake Chichancanab and Lake Punta Laguna area during a pivotal cultural "flashpoint" period. A. J. Chepstow-Lusty, K. D. Bennett, V. R. Switsur, and A. Kendall (1996:832) imply that the climatological sequences for Peru and the Maya area merit comparison, suggesting that "[h]igh resolution records of vegetation and human impact can provide a framework for placing and linking discontinuous archaeological events of Andean and Maya civilizations within a proxy-climatic continuity."

If we are to discern chronologically discrete, annual El Niño events and understand them in terms of their relative impact on specific locations and regions, the implications of the term "high-resolution" is of great concern.

For Chepstow-Lusty and colleagues, "resolution" is part of the century category for their work at Maracocha (A.D. 1–100 and A.D. 9500–1050). Analogous events at Chichancanab are "centered"—on A.D. 900 and on A.D. 920 (Chepstow-Lusty et al. 1996:831).

Although chronological correspondence exists broadly in extended major dry versus wet periods, when one "zooms in" to particular short intervals, one sees that Punta Laguna sometimes is wettest when Chichancanab seems not to be.

Hence, although fairly long interval trends can be approached with some confidence, it is within the shorter intervals—those that provide the statistics for generalizations about the long-term intervals—that we often find lack of congruence.

Figure 13 shows twentieth-century precipitation-total trajectories for various Yucatan sites, illustrating how confusing this is. Figure 14, which sums and averages data for those same sites and labels them using the El Niño event sequence presented by Henderson et al. (1999), does not help, either. Note that not all of the precipitation peaks correspond to "very severe" (S+) El Niño events. The highest peak, in fact, does not correspond to an El Niño year at all, and one of the lowest peaks is labeled "very severe."

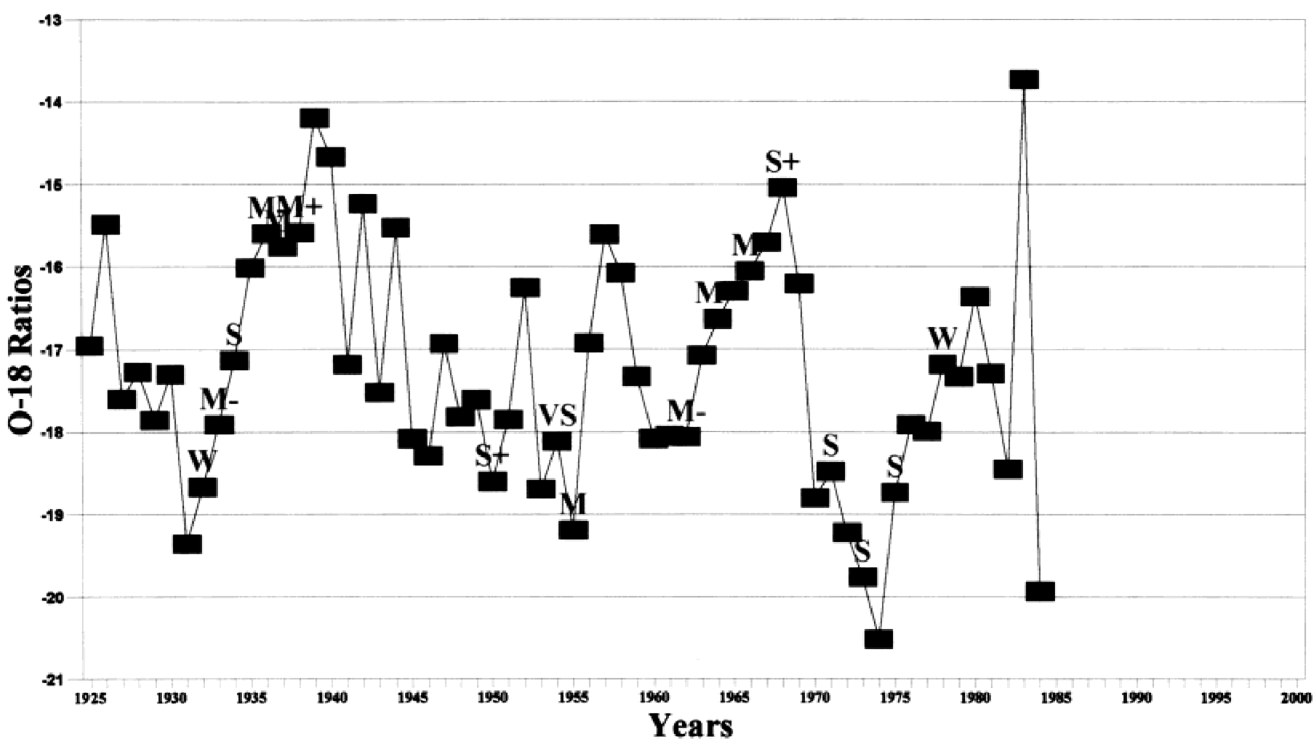

Figure 11. Henderson et al. (1999) 1925–1984 El Niño cold-event series compared with the Quelccaya oxygen-isotope (σO-18) data. M, moderate; M−, below moderate; M+, above moderate; S, strong; S+, very severe; VS, very strong; W, near moderate.

https://doi.org/10.1017/S0956536102131129 Published online by Cambridge University Press

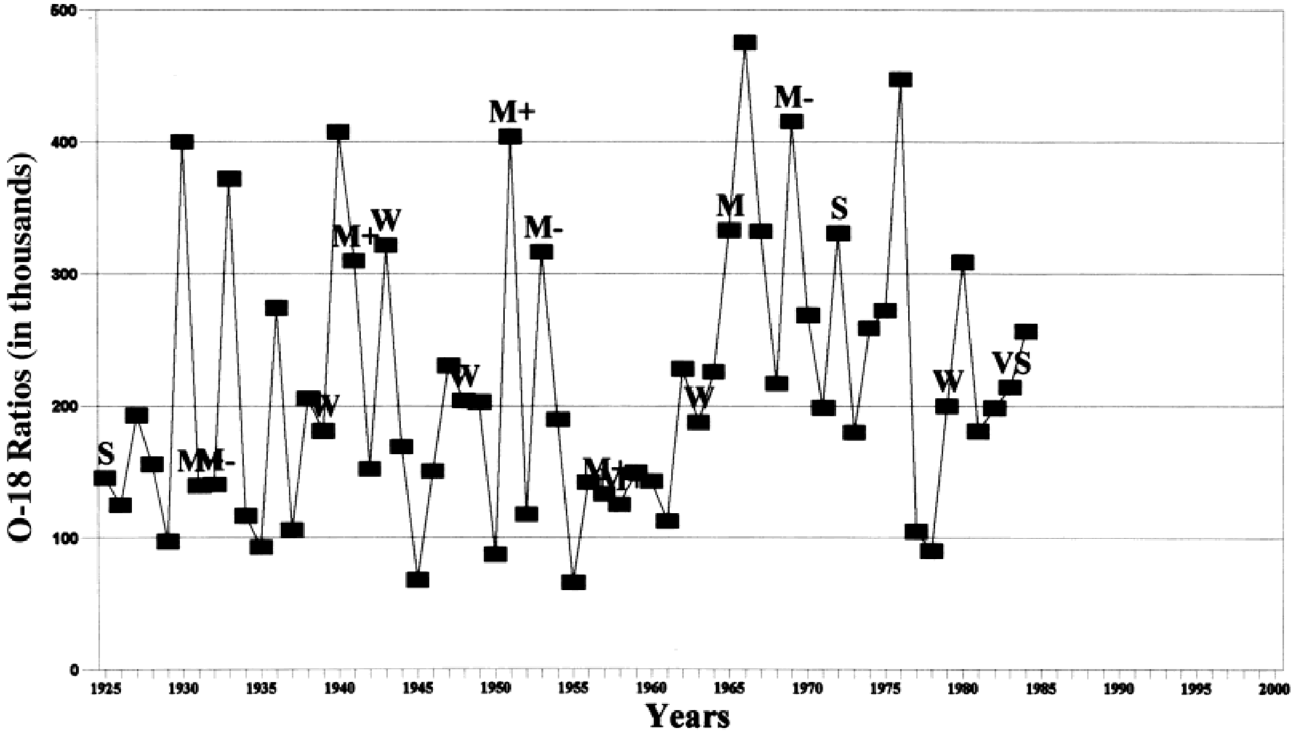

Figure 12. Henderson et al. (1999) 1925–1984 El Niño warm-event series compared with the Quelccaya oxygen-isotope (σO-18) data. M, moderate; M−, below moderate; M+, above moderate; S, strong; S+, very severe; VS, very strong; W, near moderate.

SUMMARY EVALUATION AND SUGGESTIONS FOR THE FUTURE

Research for this paper began optimistically with a number of methodological assumptions that now need to be questioned. Regrettably, at this point, using the Andean ice-core data as teleconnection proxy evidence for developing a chronologically fine-tuned El Niño event sequence for the southern Mesoamerican Maya area does not appear appropriate.

On a general level, the idea that El Niño events can be discerned and reconstructed from analyses of Andean glacial ice-core laminations holds promise. Changes in oxygen isotope

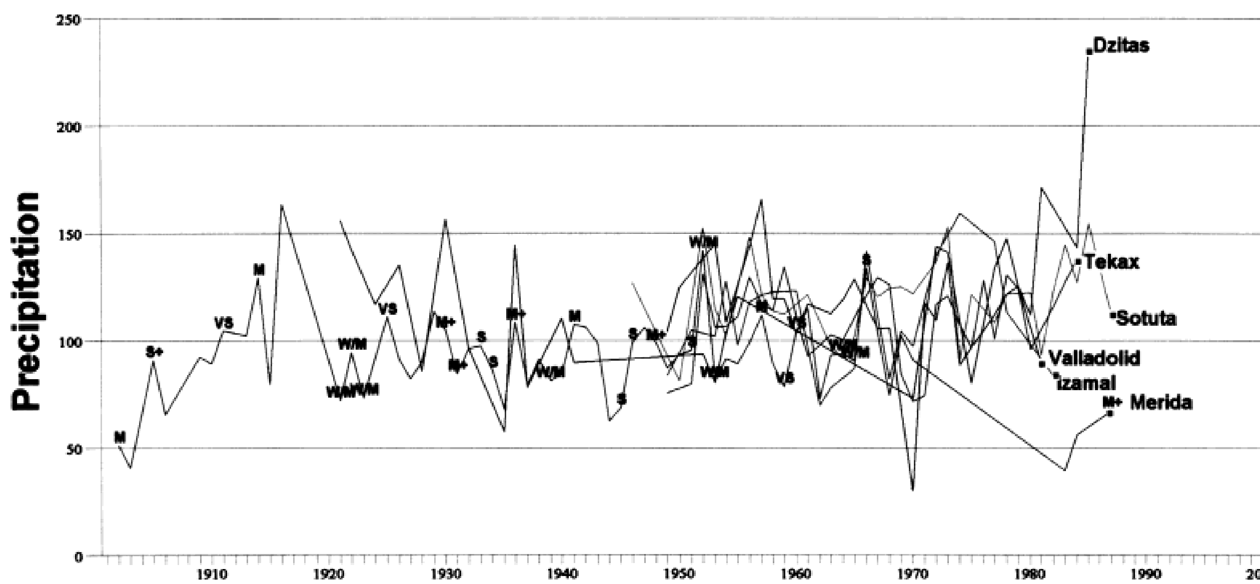

Figure 13. Line graph showing twentieth-century precipitation-total trajectories for various Yucatan locations. M, moderate; M−, below moderate; M+, above moderate; S, strong; S+, very severe; VS, very strong; W/M, near moderate.

https://doi.org/10.1017/S0956536102131129 Published online by Cambridge University Press

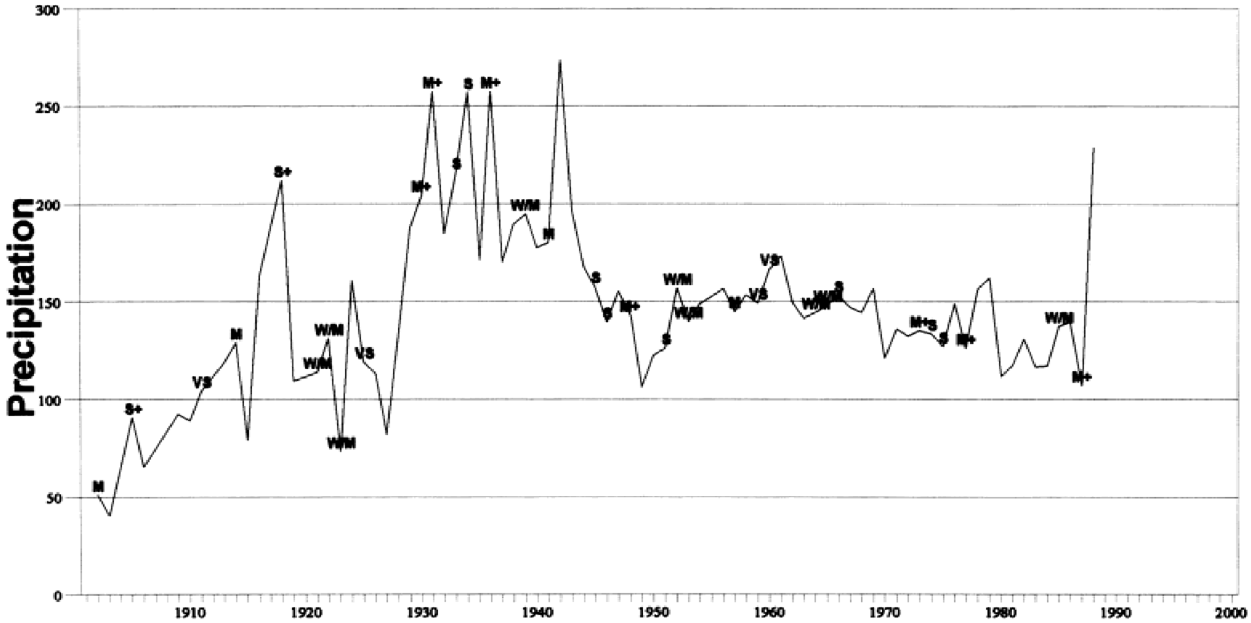

Figure 14. Line graph showing twentieth-century precipitation-total trajectories for various Yucatan sites summed, averaged, and labeled using the El Niño event sequence in Henderson et al. (1999). M, moderate; M−, below moderate; M+, above moderate; S, strong; S+, very severe; VS, very strong; W/M, near moderate.

(σO-18) values, as well as particulate concentration values over time, do suggest oscillations of periods of wetness and aridity. Although some congruence appears to exist between Andean glacial core and oxygen isotopic changes in the Maya area, further research on the significance of this needs to be done.

The idea that El Niño event records are potentially specific to individual years and are discrete within the time period represented by a particular core seems problematic. Little congruence exists between ice-core data sets and historical sequences of discrete El Niño events, and even among Andean ice cores themselves (i.e., between Quelccaya and Huascaran).

And the suggestion that individual ice-core laminations can suggest interannual climate variability and the potential for ranking El Niño event severity seems inconclusive. Little discernible correspondence in severity exists among sites in Peru, let alone between Peru and southern Mesoamerica.

What emerges is that a variety of paleoclimatic approaches now exist, and all of them contribute valid insights into aspects of ancient environmental change. At the same time, no single approach should be viewed as sufficient. These paleoclimatic and paleoecological approaches need continuous cross-fertilization, with input from disciplines with expertise ranging from global-circulation systematics to the social sciences and history.

The study of sequential data sets for particular locations seems appropriate for those specific sources, but at this time it appears inappropriate to rely heavily on such data as proxies for distant locations. Increasing the number and geographical distribution of such localized data sets must be continued. We need to encourage research on a global level that will provide generalizations on global atmospheric systematics. Such research will lead toward dependable global-temperature curves. Such research also should bolster confidence and the use of possible teleconnections. In that way, how global temperature fluctuations affect individual localities could be suggested. As Chepstow-Lusty et al. (1996:832) have suggested, "more records within and outside the New World are needed to confirm the correlation between these major climatic events . . . and better modeling to grasp how they are related."

We need to look at additional ways to approach how we retrodict climatic trajectories and anomalous meteorological events such as El Niños. In particular, we need to find techniques to improve the chronology and, as suggested by the confusing and contradictory graphs for Yucatan's meteorological reporting stations, pay close attention to localized geographical resolution.

In addition, contrary to R. B. Gill's (2000) assertion that trying to investigate recent short-term and geographically local climatic retrodiction is a "blind alley," we should avoid smugly dismissing such research. Clearly, twentieth-century localized climatic trajectories exhibit remarkable diversity, even though some still consider the peninsula of Yucatan as an "undifferentiated plain." We know that even in quite recent times there have been periods in which "normally" wet areas have been excessively dry, and the converse has been true for areas now considered predominantly dry (see Messenger 1990). There is no doubt that there were indeed "Great Maya Droughts." Asserting this as a blanket statement for the entire Maya area, however, is unwarranted.

Attention to the lessons provided by doing ethnometeorology in places distant from the Maya area, such as Isaan (northeastern Thailand), indicate that excessively wet years are often considered drought years, while some years with well-below-average annual rainfall are not (Messenger 1996). This suggests that we should pay closer attention to the relationships between intra-annual rainfall and local idealized cropping calendars for that area and, by extension, that we should become sensitive to analogous considerations for areas such as the Maya region (Messenger 1997, 1998).

In short, these considerations confirm that archaeologists need to work with researchers in other fields to find new ways to ac-

https://doi.org/10.1017/S0956536102131129 Published online by Cambridge University Press

quire informative and workable sources of paleoenvironmental proxy data that will allow us to retrodict weather for specific locations and regions over subannual, seasonal times. With this in mind, I offer the following for consideration:

- I applaud the continuing development of clarification of the existence of, and chronological placement of, anomalous meteorological events. Often, however, we are still talking in terms of events that are "broadly contemporaneous," not clearly datable, as has been so strongly suggested as discernible from the discrete annual El Niño events seen in the Andean ice-core laminations.
- We need to build on research that has already been done and to continue to look at other ways to approach how we retrodict climatic trajectories and anomalous meteorological events such as El Niños. In particular, we need to find techniques to improve our chronological and geographical resolution and to find informative and workable sources of paleoenvironmental proxy data.
- Following the approach of Nicholas Dunning, Vernon Scarborough, Fred Valdez, Sheryl Luzzadder-Beach, Timothy Beach, and Jones John (1999), we need to avoid determinist traps (Erickson 1999) and maintain a perspective that acknowledges the systemic interplay between environment and culture over time—that ecologies are simultaneously active and passive vis-à-vis human activities.
- We need to undertake ethnometeorological research that focuses on the relative effects that El Niño events have on diverse ecosystems and on a range of societies exhibiting varying levels of sociocultural complexity. We need to assemble ethnographic data on precisely how hunting-and-gathering, horticultural, and intensive-agricultural societies are affected by El Niño events as well as by climatic change in general.
- This kind of research, which integrates both methodologies and associated data sets from other disciplines with their own areas of expertise, will and should continue, but there should be increased personal interaction across disciplinary lines. This includes the promotion of collaborative research among individuals and the creation of forums and venues for this to occur.

RESUMEN

Durante la primavera de 1998 un evento meteorológico, El Niño produjó condiciones de sequía muy severas en casi toda la Republica Mexicana, incluyendo la zona Maya. Seguramente, eventos similares occurieron en el pasado. Éste ensayo presenta información sobre investigaciones correlacionadas cronológicamente, secuéncias de eventos entre El Niño en la zona peruana (indicados por muestras de sondaje de hielo glaciales de Quelccaya en los Andes Peruanos) y las documentaciones históricas de sequías por la región Maya. Correlaciones positivas entre grupos de data de muestra del sondaje glacial y secuéncias históricas sostienen evidéncia de eventos discretos, que datan a 470 d.c. que podría estar usado como data apoderada para reconstruir eventos anuales de El Niño. El cual afecta el sur de Mesoamérica, incluyendo los periodos desde el Maya clásico hasta el postclásico. Correlaciones de éstos surtidos de data resultó inconcluyente, indicative de la necesidad de enfocar altemativas con respecto a reconstruir eventos discretos El Niño por la área Maya.

REFERENCES

Allan, R.J., J. Lindesay, and D. Parker
1996 *El Niño/Southern Oscillation and Climatic Variability.* CSIRO Publishing, Mordialloc, Victoria, Australia.

Chepstow-Lusty, A.J., K.D. Bennett, V.R. Switsur, and A. Kendall
1996 4,000 Years of Human Impact and Vegetation Change in the Central Peruvian Andes—With Events Paralleling the Maya Record? *Antiquity* 70:824–844.

Curtis, J.H., D.A. Hodell, and M. Brenner
1996 Climate Variability on the Yucatan Peninsula (Mexico) During the Past 2,500 Years, and Implications for Maya Cultural Evolution. *Quaternary Research* 46:37–47.

Dunning, Nicholas, Vernon Scarborough, Fred Valdez, Jr., Sheryl Luzzadder-Beach, Timothy Beach, and Jones G. John
1999 Temple Mountains, Sacred Lakes, and Fertile Fields: Ancient Maya Landscapes in Northwestern Belize. *Antiquity* 73(281):650–660.

Erickson, Clark L.
1999 Neo-Environmental Determinism And Agrarian "Collapse" in Andean Prehistory. *Antiquity* 73(281):634–642.

Fagan, Brian
1999 *Floods, Famines, and Emperors: El Niño and the Fate of Civilizations.* Basic Books, New York.

Florescano, Enrique, and Susan Swan
1995 *Breve Historia de la Sequía en México.* Universidad Veracruzana, Xalapa.

Gill, R.B.
2000 *The Great Maya Droughts.* University of New Mexico Press, Albuquerque.

Glantz, Michael
1996 *Currents of Change: El Niño's Impact on Climate and Society.* Cambridge University Press, Cambridge.

Hansen, Barbara C.S., and Donald T. Rodbell
1995 A Late-Glacial/Holocene Pollen Record from the Eastern Andes of Northern Peru. *Quaternary Research* 44:216–227.

Henderson, K.A., L.G. Thompson, and P.-N. Lin
1999 Recording of El Niño in Ice Core Oxygen Isotopic Records from Nevado Huascaran, Peru. *Journal of Geophysical Research* 104(D24):31053–31065.

Hodell, D.A, J.H. Curtis, and M. Brenner
1995 Possible Role of Climate in the Collapse of Classic Maya Civilization. *Nature* 375(67531):391–394

Messenger, Lewis C., Jr.
1990 Ancient Winds of Change: Climatic Settings and Prehistoric Social Complexity in Mesoamerica. *Ancient Mesoamerica* 1:21–40.
1996 Doing Ethnometeorology in Isan: Methodology, Fieldwork, Results, and Implications for Such Studies. Paper presented at the Hamline University Faculty Research Seminar, Saint Paul, MN.
1997 El "Paleo-Evaluación del Impacto Ambiental": Algunas Perspectivas Sobre Paleoclimatología Con Respecto a Estudios de los Mayas Antiguas. In *Los Investigadores de la Cultura Maya—5*, pp. 328–347. Universidad Autónoma de Campeche.
1998 Paleo-"Environmental Impact Assessment": Comparative Perspectives on Paleoclimatology with Respect to Ancient Maya Studies. Paper presented at the 63rd Annual Meeting of the Society for American Archaeology, Seattle.

Monastersky, R.
1999 Cousin of El Niño Haunts Indian Ocean. *Science News* 156(13): 196.

Paulsen, A.
1976 Environment and Empire: Climatic Factors in Prehistoric Andean Culture Change. *World Archaeology* 8:121–132.

Quinn, W.H., V.T. Neal, and S.E. Antuñez de Mayolo
1987 El Niño Occurrence over the Past Four and a Half Centuries. *Journal of Geophysical Research* 92(C13):14449–14461.

Sandweiss, Daniel H., James B. Richardson III, Elizabeth J. Reitz, Harold B. Rollins, and Kirk A. Maasch
1996 Geoarchaeological Evidence from Peru for a 5,000 Years B.P. Onset of El Niño. *Science* 273:1531–1533.

https://doi.org/10.1017/S0956536102131129 Published online by Cambridge University Press

Shimada, I., C.B. Schaaf, L.G. Thomson, and E. Mosley-Thompson
1991 Cultural Impacts of Severe Droughts in the Prehistoric Andes: Application of a 1,500-Year Ice Core Precipitation Record. *World Archaeology* 22(3):247–270.

Thompson, L.G.
1992 Quelccaya Ice Core Database. IGBP PAGES/World Data Center-A for Paleoclimatology Data Contribution Series #92_008. NOAA/NGDC Paleoclimatology Program, Boulder, CO. Available at: http://www.ncdc.noaa.gov/wdcamet.html.
1996 Climatic Changes for the 2,000 Years Inferred from Ice-Core Evidence in Tropical Ice Cores. *NATO Advanced Research Series* 41:281–295.

Thompson, L.G., and E. Mosley-Thompson
1987 Evidence of Abrupt Climatic Change During the Last 1,500 Years Recorded in Ice Cores from the Tropical Quelccaya Ice Cap, Peru. In *Abrupt Climatic Change: Evidence and Implications,* edited by W.H. Berger and L.D. Labeyrie, pp. 99–110. D. Reidel Publishing, Dordrecht.
1989 One-Half Millennia of Tropical Climate Variability as Recorded in the Stratigraphy of the Quelccaya Ice Cap, Peru. In *Aspects of Climate Variability in the Pacific and the Western Americas,* edited by David H. Peterson, pp. 15–31. Geophysical Monograph 55. American Geophysical Union, Washington, DC.

Thompson, L.G., M.E. Davis, and E. Mosley-Thompson
1994 Glacial Records of Global Climate: A 1,500-Year Tropical Ice Core Record of Climate. *Human Ecology* 22(1):83–95.

Thompson, L.G., E. Mosley-Thompson, and B.M. Arnao
1984 El Niño–Southern Oscillation Events Recorded in the Stratigraphy of the Tropical Quelccaya Ice Cap, Peru. *Science* 226(4670):50–52.

Thompson, L.G., E. Mosley-Thompson, and P.A. Thompson
1992 Reconstructing Interannual Climate Variability from Tropical and Subtropical Ice-Core Records. In *El Niño: Historical and Paleoclimatic Aspects of the Southern Oscillation,* edited by H.F. Diaz and V. Markgraf, pp. 295–322. Cambridge University Press, Cambridge.