Sea Surface Temperature and Paleo-El Niño Events in Santa Barbara Basin, AD 1841-1941

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Introduction

Like pages of a "natural coastal diary", successive layers of anoxic varved sediment in the central Santa Barbara Basin have been used by paleoceanographers to reconstruct aspects of past coastal climate. This report focuses on the end of the "Little Ice Age" (15th to 19th century) and on the beginning of this century, a period known to encompass extreme climatic excursions and weather events in the Santa Barbara Basin (Dayton and Tegner 1990; Schimmelmann *et al* 1992) and other parts of Southern California (Kuhn and Shepard 1984). El Niño events are known to disrupt Southern California's coastal ecosystems (Dayton and Tegner 1990) and to cause anomalous weather conditions (Enfield 1989), but El Niño events in Southern California before 1990 have been largely undocumented.

A collective assessment of several independent geochemical parameters is necessary to achieve trustworthy paleo-El Niño reconstructions, because any individual geochemical parameter is responsive to environmental and climatic events in addition to El Niño. Our reconstructions of paleo-El Niño events employ four independently determined geochemical parameters.

- Some of the most valuable data for assessment of global climate change are time series of prehistoric sea surface temperature reconstructed from relative abundances of long-chain alkenone molecules, commonly expressed by the U^{K}_{37} index, that are preserved in dated ocean sediments (Brassell *et al* 1986; McCaffrey *et al* 1990; Eglinton *et al* 1992; Brassell 1993; Zhao *et al* 1993). An inherent limitation of this method is its seasonal bias toward bloom periods of the alkenone-producing marine algae. Kennedy and Brassell (1992) successfully used alkenone abundances to correlate increases in sea surface temperature in Santa Barbara Basin with El Niño events for much of the 20th century. This report includes the downcore continuation of their work with about annual resolution, to the AD 1830 level, 65 centimeters below the sea floor.
- The stable isotope ratio of total organic carbon (TOC) as an indicator for El Niño events was documented by Schimmelmann and Tegner (1991). Following the onset of an El Niño event in the Santa Barbara

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Basin, physical and biological stress on the locally abundant kelp forests liberates large amounts of ^{13}C-enriched kelp biomass. The carbon isotopic signal permeates through the ecosystem and becomes incorporated in the sedimentary TOC of the accumulating varve. However, reconstruction of El Niño events based on carbon stable isotopes is not fully reliable. Carbon isotope responses may be caused by ecological/climatic events unrelated to El Niño events, and kelp forests may not have been abundant in the Santa Barbara Basin at certain time intervals.

- Concentrations of sedimentary components in the Santa Barbara Basin can be converted into fluxes by taking into account the annual varve thickness or annual sedimentation rate. Detailed measurements of the content of total organic carbon in Santa Barbara Basin sediment yield a carbon burial flux that expresses the annual amount of organic carbon delivered to and preserved in the sediment per unit area of ocean floor. The TOC burial flux is independent from dilution by terrigenous lithogenic debris but should be sensitive to large fluctuations of marine productivity. El Niño conditions are characterized by low productivity. The calculated carbon burial is highly variable from one sample (=sediment interval) to another and strongly depends on the chronology. For example, the TOC burial flux of a sample encompassing 8 months of sedimentation would be decreased by 25% if a 10-month time span were adopted. In the process of dating, the cross-correlation between the X-radiographically determined varve boundaries versus the actual sample boundaries bears an uncertainty of a few months. We, therefore, report our TOC burial flux as a 5-point running mean. Accordingly, a rapidly decreasing flux may also be compatible with El Niño conditions.

- Sediment layers deposited during times of cool sea surface temperature frequently contain more water than adjacent layers relating to warmer periods. Cold water conditions are generally associated with increased upwelling, high productivity, and a large flux of porous biogenic material to the accumulating varve. At the same time, the abundant supply of organic carbon to the benthic environment reduces the oxygen content of sub-sill bottom waters and permits the filamentous *Beggiatoa* spp. bacterial mat to flourish at the sediment/water interface. As a result, the accumulating varve is more water-rich in comparison to a varve that accumulated during times of higher sea surface temperature and reduced upwelling. The impact of El Niño conditions on the benthic environment causes a decrease of the water content in the accumulating sediment, sometimes quite abruptly.

We demonstrate that the combined, critically assessed, geochemical evidence is in agreement with historical evidence of weather and El Niño conditions off Southern California.

Materials and Methods

Box cores were recovered from the deep center of the Santa Barbara Basin in 1987 and 1988. The sediment was sampled with about annual resolution and dated using varve-counts and correlation of varve thickness versus dendrochronological data (Schimmelmann *et al* 1990, 1992). Samples used in this study do not include thin gray "turbidites" or flood deposits (Lange *et al*, in press). Weighing of samples before and after freeze-drying permitted calculation of the water content in wet sediment. Samples were stored freeze-dried until aliquots were analyzed for total organic carbon and its carbon stable isotope ratio (Schimmelmann and Tegner 1991). The burial flux of organic carbon was calculated as a running mean over five samples. The determination of alkenone abundances is described by Parry (1993). A few of the sediment samples did not provide the required 0.2 to 0.3 gram of freeze-dried sediment. Sea surface temperature was calculated from the U^{K}_{37} index using Prahl and Wakeham's (1987) equation: $SST\ (°C) = (U^{K}_{37} - 0.039)/0.034$. Analytical precision of alkenone-based sea surface temperature is about (0.3°C.

Accuracy and Relevancy of Cross-Correlations

The high temporal resolution of the various time series displayed in Figures 1 to 3 invites close cross-correlation. We caution, however, that there are several sources of uncertainty. The accuracy of dating of the Santa Barbara Basin sediment is estimated to be (1 year in the 20th century and (2 years at the 1840 level (Schimmelmann *et al* 1992). Stratigraphic sample boundaries do not coincide with varve boundaries, although the sampling resolution is about annual. This may critically dampen the amplitude of geochemical signals. For example, the warm season will be under-represented in a sample encompassing 15 months of material from fall to winter, whereas the adjacent samples tend to over-represent warm seasons.

Instrumental sea surface temperature time series compiled from ship of opportunity data off the west coast of North America (Barnett 1984) tend to deviate from local nearshore time series such as the Scripps Institution of Oceanography (San Diego) pier measurements. The difference in our example in Figure 1 is most obvious for much of the 1980s. Given the strong correlation among shore stations in Southern California for low frequency events (*eg*, El Niño events; List and Koh 1976), the Scripps pier sea surface temperature record may be more appropriate for comparison with Santa Barbara Basin data.

Historical data are not exempt from criticism. Quinn and Neal's (1992) famous compilation of historical South American strong El Niño years is depicted in our figures by vertical shading. However, propagation of warm waters to the Northern Hemisphere and the Santa Barbara Basin may require many months. Actual timing, duration, and severity of possible

El Niño repercussions on Southern California's coast remain largely uncertain for the 19th century. South American historical El Niño events, even those confirmed by South American instrumental records, may in some cases bear no relevance for the Santa Barbara Basin; the case of the "missing El Niño" of 1972 in the Santa Barbara Basin, when sea surface temperature was actually dropping below normal, reminds us that the South American El Niño record does not reliably predict El Niño occurrences in the Santa Barbara Basin. Figure 1 compares the well-documented South American strong El Niño events of the 20th century with records of sea surface temperature, TOC burial flux, and sediment water content in Santa Barbara Basin sediment. Only five of nine strong El Niño events are clearly and unambiguously recognizable in the shown instrumental West Coast and Scripps pier sea surface temperature records, namely around 1918, 1926, 1941, 1958-59, and 1983-84. Quinn and Neal's (1992) historical record was recently criticized by Ortlieb and Macharé (1993). The revision of the AD 1578 to 1891 Peruvian paleo-El Niño record proposes that there were no strong El Niño

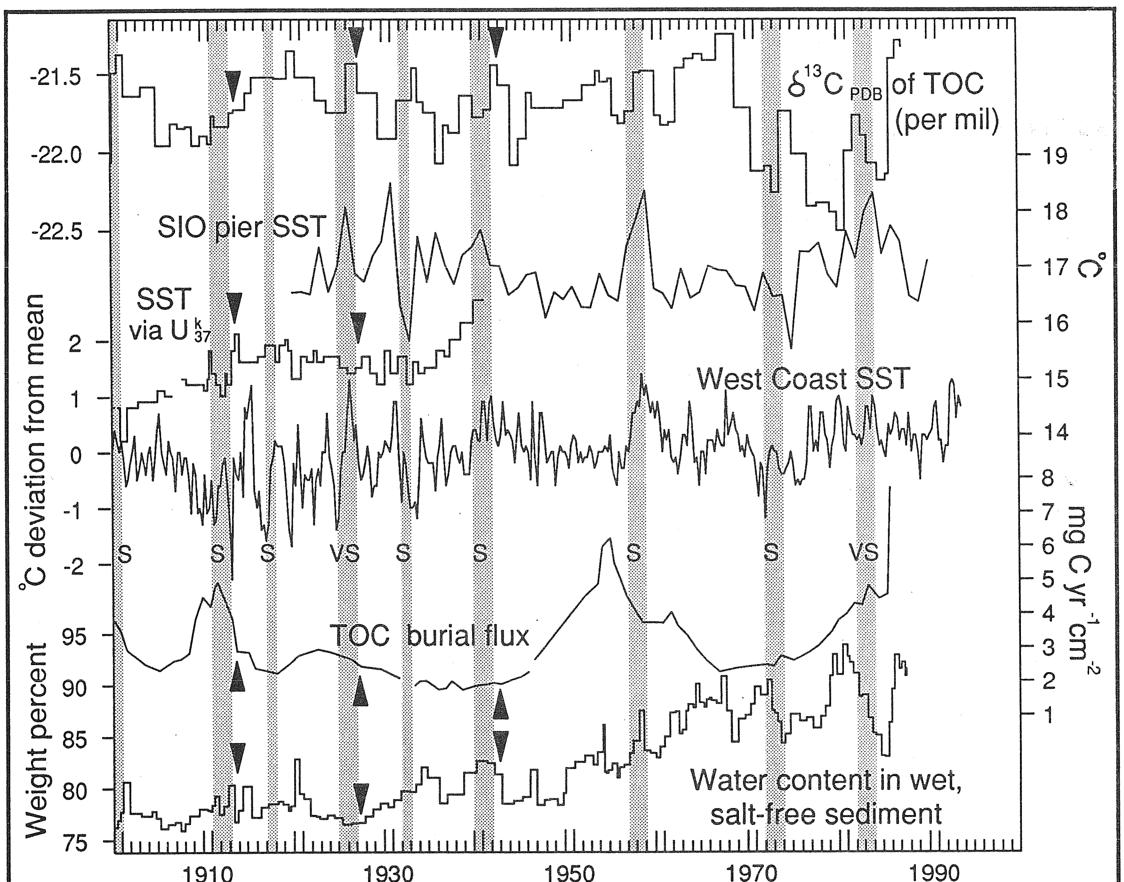

Figure 1. COMPARISON OF VARIOUS TWENTIETH CENTURY TIME SERIES: INSTRUMENTAL RECORDS OF ANNUAL MEAN SEA SURFACE TEMPERATURE FROM THE PIER OF SCRIPPS INSTITUTION OF OCEANOGRAPHY AND A SEASONAL MEAN SEA SURFACE TEMPERATURE FOR THE WEST COAST BASED ON SHIP OF OPPORTUNITY MEASUREMENTS (Barnett 1984)

SIO pier temperatures and the alkenone-derived SST are on an absolute scale; West Coast SST is plotted as deviation from the mean. Santa Barbara Basin sediment yielded time series of geochemically reconstructed SST, of the sediment water content, and of the burial flux of total organic carbon expressed as a running mean over five samples.

Vertical shaded bars indicate historical strong (S) and very strong (VS) El Niño events reported for South America by Quinn and Neal (1992). Filled triangles indicate geochemically-confirmed El Niño events during 1900 to 1942.

events off Peru during 1829 to 1870, followed by a cluster of events in 1871, 1877-78, 1884, and 1891 (see asterisks in Figure 2).

With these uncertainties in mind, the reader is encouraged to visually shift Santa Barbara Basin sediment-based time series relative to instrumental and historical data by a few years to test hypothetical correlation patterns.

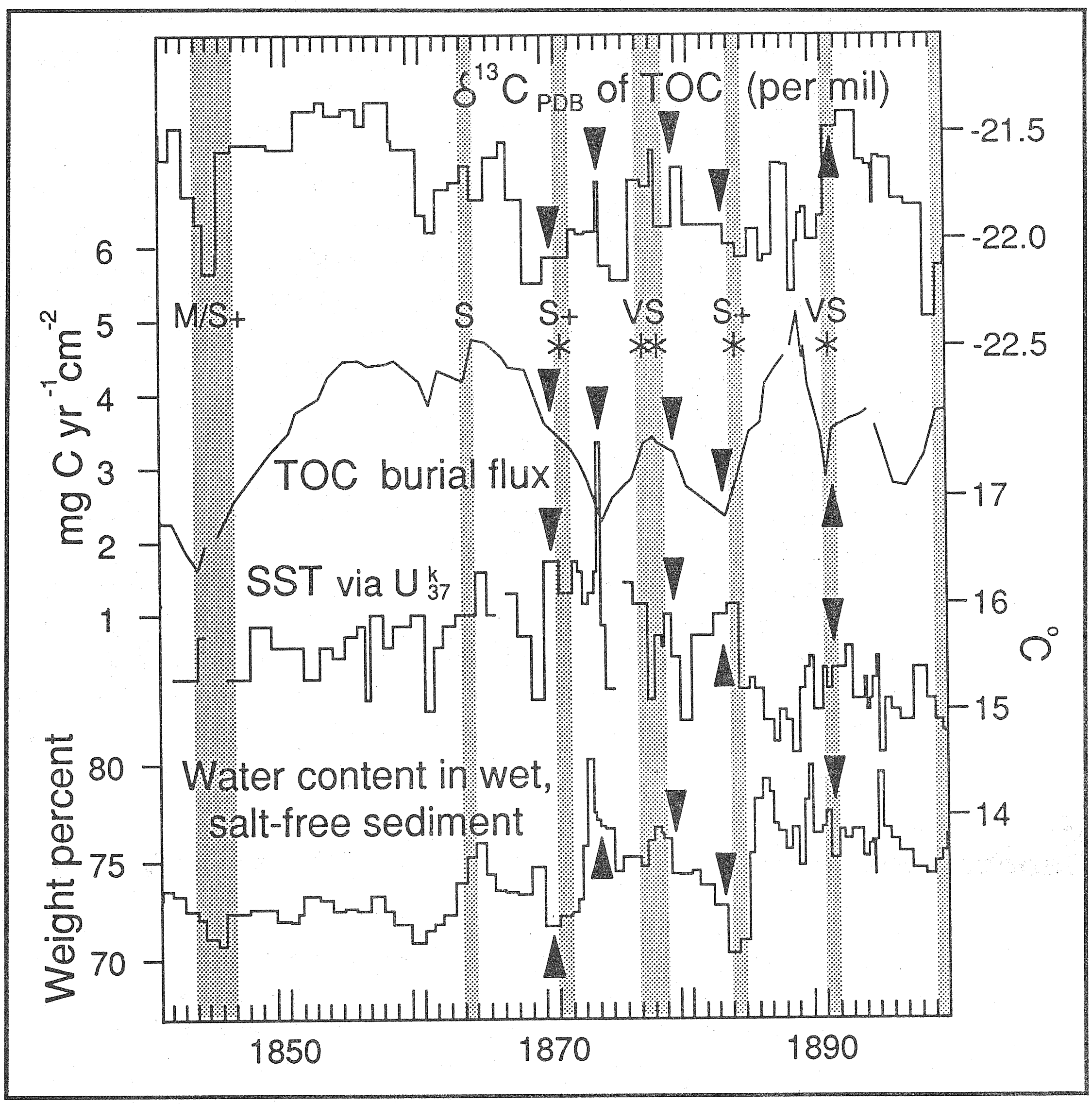

Figure 2. TIME SERIES, 1841-1899
From top to bottom: Carbon stable isotope ratio of total organic carbon in δ-notation (in per mil, *vs* PDB standard); TOC burial flux; alkenone-based sea surface temperature; sediment water content (see Figure 1 caption for more information).
Quinn and Neal's (1992) historical El Niño events include medium/strong (M/S+) and strong "S+" events.
Asterisks indicate Peruvian El Niño years of the 19th century that are confirmed by Ortlieb and Macharé (1993).
Filled triangles indicate geochemically-confirmed El Niño events during 1899 to 1942.

Time Series of the 20th Century

Instrumental records are mostly limited to the 20th century, for which we have also the most accurately dated sediments and some of the most detailed geochemical time series (Figure 1). The combined data can serve to test our working hypotheses within a calibration time interval. Specifically for the detection of paleo-El Niño events, we need to formulate several conditions that indicate the connection of a particular sediment layer to an El Niño event. Exemplary geochemical responses to El Niño conditions would be: dramatically decreasing or very low water content and TOC burial flux, an increase in the $\delta^{13}C$ value of total organic carbon, and high alkenone-based sea surface temperature.

Inspection of the four geochemical time series confirms that no individual parameter is El Niño-specific or records every El Niño event. The short alkenone-based sea surface temperature record in Figure 1 shows low amplitude fluctuations between 1910 and 1935, until it reproduces the late 1930s warming trend of the "West Coast SST" shipboard data and finally peaks into the 1940-41 El Niño event. The longer time series of Kennedy and Brassell (1992) shows more convincingly that alkenone-based sea surface temperature in the Santa Barbara Basin correlates with instrumental sea surface temperature. The long time series of the TOC burial flux in Figure 1 shows a consistent pattern in response to El Niño events; the amount of organic carbon being delivered to and buried in the sediment appears to have decreased or remained low during and immediately following an El Niño event. The exception of the 1982-1984 event, where an apparent massive increase of organic carbon is seen for 1985, is due to the proximity of the organic-rich bacterial mat and the abundance of undecomposed organic matter near the sediment surface in 1987 when the box core was retrieved.

Geochemical Reconstruction of El Niño Events, AD 1841-1941

Our attempt to reconstruct a 101-year El Niño record in the Santa Barbara Basin using geochemical time series is based on a matrix of year-by-year individual assessments of four geochemical parameters. All four geochemical assessments rank evenly in our statistical approach. Low or decreasing water content, $\delta^{13}C$ enrichment, high alkenone-based sea surface temperature, and low or decreasing TOC burial flux are judged as:

- +2 (strong positive evidence for El Niño conditions),
- +1 (moderate positive evidence),
- 0 (neutral),
- −1 (moderate negative evidence),
- −2 (strong negative evidence).

The sum of the four assessments for each year yields a subjective numerical estimate of the probability for El Niño conditions in the Santa

Barbara Basin, ranging from +8 (El Niño) to -6 (no El Niño). Of the 101 years 1841 to 1941, only 7 years rank between +4 and +8: 1870 (+6), 1873 (+8), 1879 (+6), 1883 (+5), 1891 (+6), 1913 (+5), and 1927 (+4). In addition, 1942 ranks +5 in absence of sea surface temperature data. The geochemical responses linking these 8 years to El Niño conditions are marked with filled triangles in Figures 1 and 2.

Ortlieb and Macharé's (1993) revised list of Peruvian paleo-El Niño events (asterisks in Figure 2) corresponds with El Niño conditions in the Santa Barbara Basin as inferred from our geochemical data; the Santa Barbara Basin sediment features no strong geochemical indication for El Niño events between 1841 and 1869-70 and a subsequent dense cluster of El Niño events between 1870 and 1891 (Figure 2). A precise dating of El Niño events in the Santa Barbara Basin and the exact correlation with Peruvian El Niño events is not warranted on this basis, however, due to the inherent uncertainty of our stratigraphic time scale by up to 2 years in the 19th century and due to the lag between El Niño in South America and El Niño in the Santa Barbara Basin.

Comparison with California Historical Accounts, 1844-1891

The validity of geochemical reconstructions of El Niño events can be tested against historical accounts of weather and weather-related events. Storms and unusual precipitation patterns can be useful, albeit unspecific indicators for El Niño conditions in Southern California. El Niño conditions in California can be associated with unusually heavy rainfall or can be rain free, depending on the position of the high and low pressure systems. Severe storms, associated shipwrecks, and flooding are frequently documented in the history of Santa Barbara County (Mason 1961; Schimmelmann and Tegner 1992) as well as in San Diego County (Kuhn and Shepard 1984). Table 1 is a chronological listing of a variety of unusual and extreme historical events, together with citations. Mason's (1961) history of Santa Barbara and Ventura counties as a major source of information was compiled in the mid-1880s. Although its coverage appears to be biased in favor of the 1870s and early 1880s, its factual reliability is corroborated by cross-references from other historical sources such as biographies, diaries, and travel reports. A detailed reference list of relevant historical sources is given by Schimmelman and Tegner (1992), also pertaining to weather events discussed below.

The preponderance of the historical record suggests the absence of strong El Niño events in the Santa Barbara Basin from the 1840s until 1872. This revises our earlier view of winter storms indicating an El Niño occurrence around 1846-1848 (Schimmelmann and Tegner 1992). The area experienced severe storms and several shipwrecks between 1846 and 1848, but storms unrelated to El Niño had been common in the 1820s and 1830s (references given in Schimmelmann and Tegner 1992). The lack of contemporary reports on flooding in the Santa Barbara area and other parts of California make an El Niño association of the 1846-

Table 1
HISTORICAL EXTREME WEATHER AND WEATHER-RELATED EVENTS IN SOUTHERN CALIFORNIA 1870s-1890s, WITH EMPHASIS ON SANTA BARBARA COUNTY AND PERIODS CONTAINING SOUTH AMERICAN EL NIÑO EVENTS

"EN" = Event most likely related to El Niño conditions; "–" = Event indicating absence of El Niño conditions.

1872-73	–	Steamers anchored "near the kelp" (Mason 1961, p. 260).
1873	EN	Severe storm at Santa Barbara on February 1 (Mason 1961, p. 467).
1873	EN	Considerable rain in August in Ventura, near Santa Barbara. Severe rain in Los Angeles. "It was called the "tail end" of the Sonora rains, as rain was falling in Mexico at that time." (Mason 1961, p. 458).
1877	EN	San Buenaventura wharf wrecked in March by severe storm; two schooners and one steamer wrecked (Mason 1961, p. 370).
1877	EN	"Hot wind for several hours [on August 25]. Thermometer reaching 100°." (Mason 1961, p. 469).
1877	EN	Southeaster storm at San Buenaventura wharf on October 23, extreme wave event. Excerpt from *San Buenaventura Free Press*: "Monday evening, October 23, 1876, Charles Bartlett and Walter Perkins took a walk down the wharf to look at the breakers, and saw them. Finally Mr. Bartlett observed three tremendous rollers, larger than any yet seen, approaching, and fearful of consequences, the two took to their heels. When two-thirds up the wharf the first roller struck it, 200 feet behind them, making a breach, and as it advanced shoreward the piles went down before it as grain before a reaper." (Mason 1961, p. 370).
1877	EN	"Fierce storm at Santa Barbara, injuring wharves [on November 16]." (Mason 1961, p. 469).
1878	EN	"Heavy storm and high winds [on January 14], breaking up the old wharf at Santa Barbara, and carrying a portion through the new one, near the shore line." (Mason 1961, p. 469).
1878	EN	Storm [on January 19] wrecks the schooner *Reliance* on the rocks near Goleta (Mason 1961, pp. 223, 469). "Wednesday, February 19, 1878, a terrific rainstorm at Santa Cruz Island raised the creek ten feet, so that it completely washed away the old Indian burying-ground, leaving not a trace behind. Rocks weighing two or three tons were carried along the stream." (Mason 1961, pp. 256, 469).
1878	EN	"Large portion of Point Sal Wharf destroyed [on November 15] by a storm." (Mason 1961, p. 469).
1878	EN	Southeaster and cyclone in Santa Barbara on December 31. Excerpt from the *Press*, January 4, 1879: "The severest [storm] that Santa Barbara has ever experienced." (Mason 1961, pp. 225, 226). "On February 1, 1879, snow fell on the mountains [near Ventura] and remained several hours." (Mason 1961, p. 458).
1879	EN	"Extreme local rain" in Santa Barbara on December 21. (Mason 1961, p. 270).
1879	EN	"Lompoc wharf damaged by a severe storm [on December 31]" (Mason 1961, p. 470).
1880	EN?	April 23, *San Diego Union*: "The worst storm [wind and rain] in San Diego County since 1861." August 19, *San Diego Union*: "Nearly 2 inches of rain in San Diego.... The worst storm in the history of San Diego."
1880	EN?	"Tornado near Goleta [on March 8], uprooting trees and leveling buildings." (Mason 1961, p. 470).
1884	EN?	February-April, southeaster storms bring heaviest rain recorded in San Diego County (*San Diego Union*, February 2, 3, 5, 7, 8, 12, 16, 19, 23; March 3, 28; April 2, 12, 15. Reviewed by Kuhn and Shepard 1984).
1887	–	In spring 1887 the naturalist J.W. Fewkes sailed across the Santa Barbara Basin, observing abundant kelp beds off Santa Barbara "...about three hundred yards from the shore. This zone imparts a highly characteristic appearance to the coast of many parts of Southern California." (Fewkes 1889, p. 212).
1891	EN	Severe storms in Southern California during summer and fall, with indication for unusual warming of ocean waters (Pyke 1975).

1848 storms unlikely. The following years until 1872 appear to have been uneventful in the Santa Barbara area. The mentioning of steamers anchoring "near the kelp" beds in late 1872 indicates no severe storms had destroyed the local kelp forests until winter 1872/73.

A well-documented, extremely unusual occurrence of the warm-water crustaceans *Pleuroncodes planiceps* was reported for March 1859 in Monterey, hundreds of miles north of the species' present range (Hubbs 1948). These crustaceans undoubtedly took advantage of temporarily elevated sea surface temperature and unusual warm currents, but we cannot cite any supporting historical evidence such as Peruvian El Niño events or contemporaneous California weather events. There may be a tenuous connection with the extreme precipitation of 1861/62 ("Noachian Deluge") that entailed bankruptcy of the State of California. The very high sea surface temperature off Southern California in 1931, one year before the 1932 South American El Niño event, demonstrates that some sea surface temperature maxima off California are unrelated to El Niño conditions.

The year 1873 brought to the Santa Barbara area a severe storm in February and considerable rain in August. Severe rain was reported in Los Angeles. Summer rain in Southern California is a rare occurrence that suggests the influence of El Niño in 1873. This El Niño is likely related to the 1871 Peruvian El Niño event.

In early 1877, local wharfs and ships were damaged by "storms". Spectacular damage due to high winds and waves in October 1877 and January 1878 was followed by enormous rainfall in February 1878 on Santa Cruz Island. Reports for winter 1878/79 include rare snowfall, "extreme local rain", severe storms, and even a damaging cyclone in Santa Barbara. The overall severity and clustering of the unusual occurrences advocate El Niño conditions in the Santa Barbara Basin, probably related to the 1877/78 Peruvian El Niño event.

In August 1883, Krakatoa erupted and weather patterns changed abruptly throughout the United States and western Europe. Southern California's climate changed temporarily from semiarid to subtropical, with unusually heavy rainfall through June (Kuhn and Shepard 1984). The rapid climatic response following the eruption bears the signature of fast atmospheric propagation rather than via ocean currents. The heavy rains of 1884 in Southern California in the wake of the eruption are well documented, for example, in San Diego and Los Angeles. We suggest that the postulated South American El Niño event of 1884 and its possible oceanographic repercussions on the Santa Barbara Basin may be related to, or even caused by, the Krakatoa eruption. The immediate physical impact on the Santa Barbara Basin may have been small, though; a naturalist observed the large abundance of kelp forests in the Santa Barbara Basin in spring 1887 (Fewkes 1889). This may be interpreted as evidence that no severely destructive storm-and-wave events had occurred in the area for a few years prior to 1887.

Interestingly, the alkenone-based sea surface temperature declined sharply in 1884 (following the eruption of Krakatoa, according to our varve stratigraphy) and did not return to 1883 values until the late 1930s. In his detailed study of historical abundance patterns of fish along the Pacific Coast, in close comparison with historical sea surface temperature and air temperature records, Hubbs (1948, 1960) concluded that "the 1850 and 1860 decades appear to have been in a prolonged warm [SST] period." Some warmwater fauna "seems to have persisted [off Southern California] through the 1870's until 1880". The cooling of sea surface temperature in the latter part of the 19th century was best documented off San Diego, whereas "the region of San Francisco ≤ indicates a relatively stable fauna throughout the last hundred years."

Hubbs (1948) demonstrates that the San Diego air temperature record and the Scripps pier sea surface temperature record are closely correlated. He then uses the 19th century San Diego annual mean air temperature record as evidence for cooling of sea surface temperature, but at the same time cautions about possible artifacts in the early instrumental air temperature record until 1871. Figure 3 compares the early San Diego annual mean air temperature record with our alkenone-based sea surface temperature record from the Santa Barbara Basin. The reader is reminded that the uncertainty of the sea surface temperature chronology discourages year-to-year correlation. Both records agree in their lower-than-average temperatures during the decades around the turn of the century. Both temperature records rebound to strongly above-average values in the late 1930s.

There is abundant historical evidence that El Niño conditions were present off Southern California around 1891 (Pyke 1975).

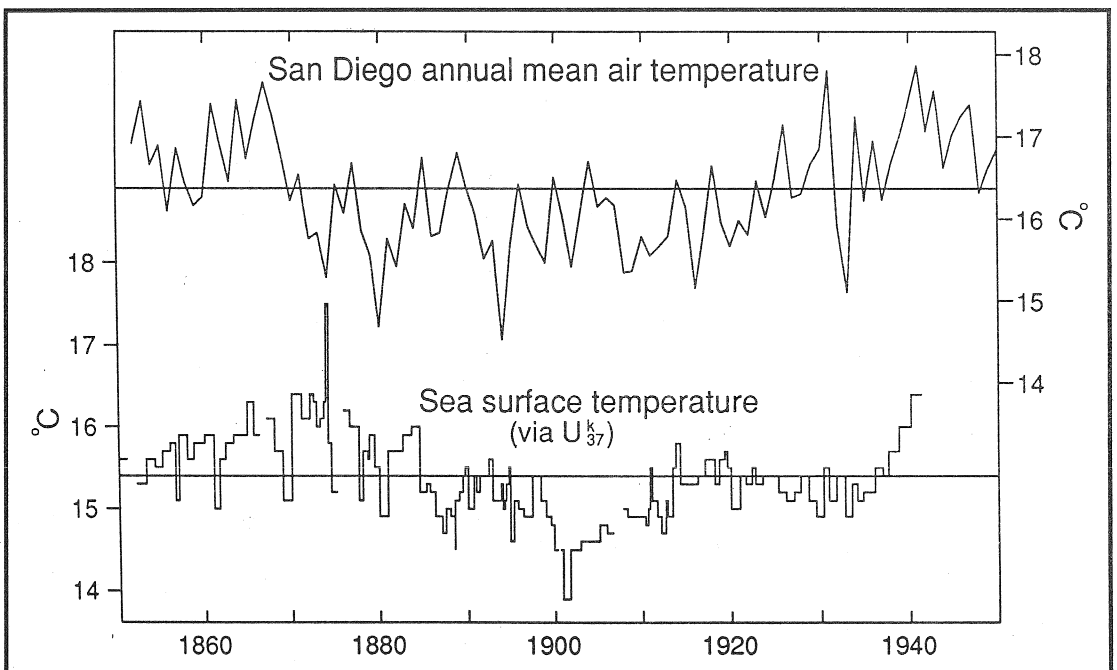

Figure 3. TIME SERIES OF SAN DIEGO ANNUAL MEAN AIR TEMPERATURE (Hubbs 1948) AND ALKENONE-BASED SEA SURFACE TEMPERATURE RECONSTRUCTED FROM SANTA BARBARA BASIN SEDIMENT

The 1871-1880 Instrumental Air Temperature Time Series

The monthly means and extremes of air temperature in Santa Barbara for 1871-1880 are reported in Mason (1961, p. 457). We note that the quality of the monthly mean temperature data may be questionable, because in some cases our recalculated annual mean temperatures did deviate from the values offered by the original table. Nevertheless, the original annual mean temperature data show positive excursions for 1872, 1877, and 1879 (Table 2). Mason's (1961) reported matrix of monthly maximum temperatures shows the most dense clusters of high temperatures in 1872 (May-December) and 1878/79 (December-June; Table 2), in excellent agreement with the suggested South American El Niño events of 1871 and 1877/78.

Table 2
INSTRUMENTAL RECORD OF AIR TEMPERATURES IN SANTA BARBARA, 1871-1880
(Mason 1961, p. 457)

Annual mean temperature is converted from the last column of the original data table.
Shading indicates temperatures of at least 1.9 degrees above 1871-1880 means of the monthly maximum temperatures.
All temperatures are in degrees Celsius.

	Monthly maximum temperature													annual mean temp.
year	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	mean	
1880	21.1	17.2	20.0	20.6	27.8	23.9	23.9	25.0	29.4	27.2	25.0	21.1	23.5	14.25
1879	20.0	26.1	31.7	28.3	33.3	36.1	26.7	29.4	30.0	32.2	25.0	22.8	28.5	16.36
1878	19.4	20.6	20.6	25.0	25.0	24.4	26.7	28.9	34.4	28.9	24.4	24.4	25.2	15.97
1877	28.3	26.1	24.4	22.8	23.9	38.9	30.6	27.8	30.0	25.0	27.8	23.3	27.4	16.94
1876	22.8	21.7	23.3	30.0	26.7	28.9	28.9	28.3	28.3	29.4	27.2	23.9	26.6	16.19
1875	22.8	25.0	24.4	30.0	35.0	26.7	28.9	32.2	28.3	22.2	25.6	20.6	26.8	16.22
1874	21.1	20.6	21.1	25.6	25.6	27.8	30.0	31.1	28.3	22.2	25.6	20.6	25.0	16.22
1873	24.4	19.4	24.4	26.7	25.6	26.7	30.0	27.8	28.3	27.8	27.8	20.0	25.7	16.06
1872	22.2	22.8	23.3	23.9	34.4	37.8	27.8	35.6	28.3	31.1	27.2	26.1	28.4	16.63
1871	24.4	20.0	23.9	28.3	28.9	26.1	31.7	36.7	31.1	37.8	26.7	22.2	28.1	16.15
	Means of the monthly maximum temperatures, 1871-1880													
	22.7	21.9	23.7	26.1	28.6	29.7	28.5	30.3	29.7	28.4	26.2	22.5		

Conclusions

The combined diagnostic use of four independently determined geochemical El Niño indicators in laminated Santa Barbara Basin sediment permits the reconstruction of paleo-El Niño events. In agreement with instrumental and historical evidence, apparently no strong El Niño events occurred in the Santa Barbara Basin between 1841 and about 1870. A rapid succession of strong El Niño events occurred from about 1870 to 1891. Historic sources advocate El Niño events in the Santa

Barbara Basin for 1873, 1878/79, and 1891. The year 1884, one year after the eruption of Krakatoa, was characterized by abnormal weather, but the oceanographic link to simultaneous South American El Niño in 1884 is uncertain. Subsequent El Niño conditions may have been present in the Santa Barbara Basin around 1913 and 1926/27, followed by the well-known event of 1941/42.

Acknowledgments

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