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El Niño Occurrences Over the Past Four and a Half Centuries

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Applicable publications, involving five languages, have been reviewed to obtain information on El Niños that occurred over the past four and a half centuries. Since this information refers strictly to El Niño occurrences, a regional manifestation of the large-scale (El Niño–Southern Oscillation (ENSO)) event, it is based primarily on evidence obtained from the west coast region of northern South America and its adjacent Pacific Ocean waters. Authored lists of events were not acceptable without referenced valid information sources. It was desirable to have cross-correlated reports from independent sources. Relative strengths of events are based on such considerations as wind and current effects on travel times of ancient sailing ships, degree of physical damage and destruction, amounts of rainfall and flooding, mass mortality of endemic marine organisms and guano birds, extent of invasion by tropical nekton, rises in sea temperatures and sea levels, affects on coastal fisheries and fish meal production, etc. Emphasis is placed on strong and very strong events. For example, the 1940–1941, 1957–1958, and 1972–1973 events fall into the strong category, whereas the 1891, 1925–1926 and 1982–1983 events are considered very strong. Over our period of study, 47 El Niño events were placed in the strong or very strong categories. Over the period 1800–present, we noted 32 El Niño events of moderate or near moderate intensity. Weak events are not included here. The approach used here caused us to revise many of our earlier evaluations concerning event occurrences and intensities. Our tropical Pacific thickness analyses and cumulative plots of Southern Oscillation index anomalies over the southeast Pacific trade wind zone showed additional evidence as to the unusual strength of the 1982–1983 event. Also, in our investigation we noted several periods of long-term (near decadal or longer) climatic change.

1. INTRODUCTION

Our investigation of El Niño activity lies within the historical realm from the time that the earliest Spanish explorers and conquistadores entered upon the South American scene in the early 1500s to the present. Penetrations into earlier periods of time are being carried on by archaeologists and those studying ice cores, sediment cores, tree rings, cadmium variability in corals, paleontological data, and other sources of proxy information relating to climatic change.

Some of the earliest evidence of very strong El Niño events was presented by *Nials et al.* [1979]. In their study of the rise and fall of early irrigation systems in the Moche Valley on the north coast of Peru, they discovered an El Niño catastrophe of extreme proportions. They called this ancient cataclysm the "Chimu flood." They found evidence that this flood of unusually large magnitude occurred early in the Chimu dynasty, within a century of the year 1100 A.D. In their opinion a very conservative estimate would indicate that flood waters at least 2–4 times the size of the unusual 1925 floods occurred then. They also stated that there appeared to be evidence in the Moche Valley of another large flood that occurred about 500 B.C. Their concern regarding the rapid rise in coastal population, and the disaster an inundation of Chimu extent could cause, is certainly a well-founded disquietude, especially since the strong and very strong events continue to recur.

Our study through the first three centuries was primarily limited to the contents of available literature, most of which was in Spanish, English, German, and French, and some in Dutch. However, over the past century and a half, meteorological, hydrological, and oceanographic data became increasingly more available for augmentation of the authored reports. The earliest part of our investigation depended upon reports emanating from the early Spanish explorations and military penetrations into northwestern South America. The historians, ship captains and navigators, and clergy that accompanied the conquistadors were valuable sources of information. The clergy, through their wide travels and access to the records of the missions that they established, soon became excellent informants on geophysical phenomena that occurred during the early years of the Spanish occupation. However, violent earthquakes, volcanic eruptions, and their consequences usually took precedence in their reports. Religious superstition abounded in those early years, and the more ominous occurrences were often attributed to offenses against God. As time progressed, the reports from historians, explorers, pirates, geographers, hydrologists, engineers, marine biologists, botanists, meteorologists, oceanographers, and expeditions on land and sea (conducted by universities, governmental fishery interests, etc.) became increasingly important sources of information.

This investigation is directed toward the El Niño which is a regional manifestation of the large-scale (El Niño-Southern Oscillation (ENSO)) event; and, occurrences are primarily based on evidence of significant climatic changes over the ordinarily dry west coast region of northern South America and its adjacent Pacific Ocean waters. Although the El Niño generally reflects an intensity near that of the related large-scale equatorial Pacific event (ENSO), this is not always the case, and at times, we find a significant divergence in intensity between them.

Although this research is still under way, we have now reached a point where we can provide some useful information to the climatic research community on the stronger events with a reasonable degree of confidence. In Table 1 we show

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TABLE 1. El Niño Events of Strong and Very Strong Intensities, Their Confidence Ratings, and Information Sources

El Niño Event	Event Strength	Confidence Rating	Information Sources
1525–1526	S	3	*Xeres* [1534]
1531–1532	S	4	*Xeres* [1534] and *Prescott* [1892]
1539–1541	M/S	3	*Montesinos* [1642] and *Cobo* [1653]
1552	S	4	*Palma* [1894] and *Moreno* [1804]
1567–1568	S+	5	*Oliva* [1631], *Cobo* [1639], *Labarthe* [1914], and *Portocarrero* [1926]
1574	S	4	*Garcia Rosell* [1903]
1578	VS	5	*Acosta* [1590], *Cobo* [1639, 1653], *Labarthe* [1914], *Portocarrero* [1926], and *Garcia Rosell* [1903]
1591–1592	S	2	*Martinez y Vela* [1702]
1607	S	5	*Cobo* [1639], *Alcedo y Herrera* [1740], *Palma* [1894], *Labarthe* [1914], *Portocarrero* [1926], and *Taulis* [1934]
1614	S	5	*Cobo* [1653], *Labarthe* [1914], and *Portocarrero* [1926]
1618–1619	S	4	*Vasquez de Espinosa* [1629], *Cobo* [1653], and *Taulis* [1934]
1624	S+	4	*Cobo* [1653], *Labarthe* [1914], and *Portocarrero* [1926]
1634	S	4	*Palma* [1894] and *Puente* [1885]
1652	S+	4	*Cobo* [1653], *Labarthe* [1914], and *Portocarrero* [1926]
1660	S	3	*Labarthe* [1914] and *Portocarrero* [1926]
1671	S	3	*Labarthe* [1914] and *Portocarrero* [1926]
1681	S	3	*Rocha* [1681]
1687–1688	S+	4	*Juan and Ulloa* [1748], *Melo* [1913], *Unanue* [1806], *Remy* [1931], and *Taulis* [1934]
1696	S	3	*Palma* [1894]
1701	S+	4	*Feijoo de Sosa* [1763], *Bueno* [1763], *Haenke* [1790], *Paz Soldan* [1862], *Palma* [1894], *Labarthe* [1914], *Portocarrero* [1926], and *Nials et al.* [1979]
1707–1708	S	3	*Cooke* [1712] and *Alcedo y Herrera* [1740]
1714–1715	S	4	*Gentil* [1728], *Labarthe* [1914], and *Portocarrero* [1926]
1720	S+	4	*Shelvocke* [1726], Feijoo de Sosa [1763], *Bueno* [1763], *Alcedo* [1786–1789], *Haenke* [1790], *Paz Soldan* [1862], *Palma* [1894], *Labarthe* [1914], *Bachmann* [1921], *Portocarrero* [1926], and *Nials et al.* [1979]
1728	VS	5	*Feijoo de Sosa* [1763], *Bueno* [1763], *Alcedo* [1786–1789], *Paz Soldan* [1862], *Spruce* [1864], *Eguiguren* [1894], *Palma* [1894], *Labarthe* [1914], *Portocarrero* [1926], and *Nials et al.* [1979]
1747	S	5	*Feijoo de Sosa* [1763], *Llano Zapata* [1748], *Moreno* [1804], *Palma* [1894], *Labarthe* [1914], *Portocarrero* [1926], *Nials et al.* [1979], and *Taulis* [1934]
1761	S	5	*Bueno* [1763], *Alcedo* [1786–1789], *Haenke* [1790], *Labarthe* [1914], *Portocarrero* [1926], and *Ruschenberger* [1834]
1775	S	4	*Labarthe* [1914], *Portocarrero* [1926], and *Puente* [1885]
1785–1786	S	4	*Labarthe* [1914], *Portocarrero* [1926], and *Estrada Icaza* [1977]
1791	VS	5	*Unanue* [1806], *Ruschenberger* [1834], *Paz Soldan* [1862], *Spruce* [1864], *Hutchinson* [1873], *Eguiguren* [1894], *Labarthe* [1914], *Bachmann* [1921], and *Portocarrero* [1926]
1803–1804	S+	5	*Moreno* [1804], *Unanue* [1806], *Stevenson* [1829], *Paz Soldan* [1862], *Spruce* [1864], *Eguiguren* [1894], *Palma* [1894], *Labarthe* [1914], *Portocarrero* [1926], and *Petersen* [1935]
1814	S	4	*Spruce* [1864] and *Eguiguren* [1894]
1828	VS	5	*Ruschenberger* [1834], *Paz Soldan* [1862], *Spruce* [1864], *Hutchinson* [1873], *Eguiguren* [1894], *Sievers* [1914], *Labarthe* [1914], *Bachmann* [1921], *Portocarrero* [1926], and *Taulis* [1934]

TABLE 1. (continued)

El Niño Event	Event Strength	Confidence Rating	Information Sources
1844–1845	S+	5	*Spruce* [1864], *Eguiguren* [1894], *Labarthe* [1914], *Portocarrero* [1926], and *Taulis* [1934]
1864	S	5	*Spruce* [1864], *Eguiguren* [1864], and *Taulis* [1934]
1871	S+	5	*Hutchinson* [1873], *Eguiguren* [1894], *Tizon y Bueno* [1907], *Sievers* [1914], *Labarthe* [1914], *Bachmann* [1921], *Portocarrero* [1926], and *Gaudron* [1925]
1877–1878	VS	5	*Eguiguren* [1894], *Palma* [1894], *Melo* [1913], *Sievers* [1914], *Labarthe* [1914], *Bachmann* [1921], *Portocarrero* [1926], *Murphy* [1926], *Taulis* [1934], and *Kiladis and Diaz* [1986]
1884	S+	5	*Eguiguren* [1894], *Sievers* [1914], *Labarthe* [1914], *Bachmann* [1921], *Murphy* [1925], and *Portocarrero* [1926]
1891	VS	5	*Carranza* [1891], *Eguiguren* [1894], *Fuchs* [1907], *Labarthe* [1914], *Sievers* [1914], *Bachmann* [1921], *Zegarra* [1926], *Murphy* [1926], *Portocarreo* [1926], *Nials et al.* [1979], and *Taulis* [1934]
1899–1900	S	5	*Labarthe* [1914], *Bachmann* [1921], *Murphy* [1923], *Portocarrero* [1926], *Hutchinson* [1950], *Taulis* [1934], and *El Comercio* (February 10, 1899)
1911–1912	S	4	*Forbes* [1914], *Labarthe* [1914], *Bowman* [1916], *Lavalle y Garcia* 1917], *Balen* [1925], *Portocarrero* [1926], *Vogt* [1940], *Hutchinson* [1950], and *Schweigger* [1961]
1917	S	5	*Lavalle y Garcia* [1917], *Murphy* [1923], *Balen* [1925], *Portocarrero* [1926], *Petersen* [1935], *Hutchinson* [1950], and *Schweigger* [1961]
1925–1926	VS	5	*Murphy* [1926], *Zegarra* [1926], *Berry* [1927], *Petersen* [1935], *Vogt* [1940], *Mears* [1944], *Hutchinson* [1950], *Rudolph* [1953], *Nials et al.* [1979], and *Mugica* [1983]
1932	S	5	*Petersen* [1935], *Sheppard* [1933], *Vogt* [1940], *Mears* [1944], *Hutchinson* [1950], *Rudolph* [1953], and *Mugica* [1983]
1940–1941	S	5	*Lobell* [1942], *Mears* [1944], *Hutchinson* [1950], *Sears* [1954], *Schweigger* [1961], *Wooster* [1960], *Mugica* [1983], and *Quinn and Zopf* [1984]
1957–1958	S	5	*Wooster* [1960], *Schweigger* [1961], *Bjerknes* [1966]; *Idyll* [1973], *Miller and Laurs* [1975], *Caviedes* [1975], and *Mugica* [1983]
1972-1973	S	5	*Idyll* [1973], *Wooster and Guillen* [1974], *Miller and Laurs* [1975], *Ramage* [1975], *Caviedes* [1975], *Nials et al.* [1979], and *Mugica* [1983]
1982–1983	VS	5	*Mugica* [1983], *Rasmusson and Hall* [1983], *Rasmusson and Wallace* [1983], *Quiroz* [1983], *Smith* [1983], *Canby* [1984], *Woodman* [1984], *Quinn and Neal* [1984], and *Caviedes* [1984]

S, strong; VS, very strong. See text for more information on confidence rating.

the strong and very strong events that occurred between 1525 and the present. In Table 2 we show events of moderate intensity that occurred between 1806 and the present. From 1800 on, more data (e.g., hydrological reports, sea surface temperatures, air temperatures, rainfall, barometric pressures) were available. The weak events are not included here. It is expected that events of the intensities noted in Tables 1 and 2 would have significant effects on sea life, bird life, plant life, coastal facilities, man, etc. The reference dates that appear in Tables 1 and 2 are those of original manuscripts or first editions of resulting publications, so the reader can be aware of the time between event occurrence and the author's report on it.

This multilanguage approach provided a reasonably thor-

TABLE 2. El Niño Events of Moderate and Near-Moderate Intensities, Their Confidence Ratings, and Information Sources

El Niño Event	Event Strength	Confidence Rating	Information Sources
1806–1807	M	3	*Stevenson* [1829], *Remy* [1931], and *Unanue* [1815]
1812	M	4	*Palma* [1894] and *Gonzalez* [1913]
1817	M+	5	*Eguiguren* [1894], *Labarthe* [1914], *Portocarrero* [1926], and *Taulis* [1934]
1819	M+	4	*Eguiguren* [1894] and *Taulis* [1934]
1821	M	5	*Eguiguren* [1894], *Fuchs* [1925], *Remy* [1931], and *Taulis* [1934]
1824	M	5	*Spruce* [1864], *Basadre* [1884], and *Eguiguren* [1894]
1832	M	5	*Spruce* [1864], and *Eguiguren* [1894]
1837	M	5	*Eguiguren* [1894], *Labarthe* [1914], *Portocarrero* [1926], and *Taulis* [1934]
1850	M	5	*Eguiguren* [1894], *Fuchs* [1925], and *Taulis* [1934]
1854	W/M	4	*Spruce* [1864], *Eguiguren* [1894], and *Taulis* [1934]
1857–1858	M+	5	*Eguiguren* [1894], *Labarthe* [1914], *Portocarrero* [1926], *Gaudron* [1925], *Zegarra* [1926], and *Taulis* [1934]
1860	M	4	*Labarthe* [1914], *Portocarrero* [1926], and *Taulis* [1934]
1866	M	4	*Eguiguren* [1894], *Labarthe* [1914], *Bachmann* [1921], and *Portocarrero* [1926]
1867–1868	M	4	*El Comercio* (January 10, 1872), *Raimondi* [1897], *Taulis* [1934], and *Eguiguren* [1894]
1874	M	4	*Bravo* [1903], *La Patria* (February 9, 1874), and *Bachmann* [1921]
1880	M	4	*Eguiguren* [1894], *Puls* [1895], and *Taulis* [1934]
1887–1889	W/M	5	*Eguiguren* [1894], *Labarthe* [1914], *Portocarrero* [1926], and *Taulis* [1934]
1896–1897	M+	4	*Bravo* [1903], *El Comercio* (February 3, 1897, and February 22, 1897), and *Bachmann* [1921]
1902	M+	4	*El Comercio* (February 17, 1902), *Bachmann* [1921], and *Taulis* [1934]
1905	W/M	4	*Bachmann* [1921], and *Taulis* [1934]
1907	M	3	*Remy* [1931], and *Paz Soldan* [1908]
1914	M+	5	*Labarthe* [1914], *Portocarrero* [1926], *Petersen* [1935], *Taulis* [1934], and *Schweigger* [1961]
1918–1919	W/M	5	*Murphy* [1923], *Portocarrero* [1926], *Vogt* [1940], *Hutchinson* [1950], and *Taulis* [1934]
1923	M	5	*Lavalle y Garcia* [1924], *Balen* [1925], *Zegarra* [1926], *Gunther* [1936], *Hutchinson* [1950], and *Schweiggar* [1961]
1930–1931	W/M	5	*Petersen* [1935], *Hutchinson* [1950], *Schweigger* [1961], *Miller and Laurs* [1975], and *Woodman* [1984]
1939	M+	5	*Vogt* [*1940*], *Schweigger* [1940], *Mears* [1944], *Hutchinson* [1950], *Sears* [1954], *Mugica* [1983], and *Woodman* [1984]
1943	M+	5	*Schweigger* [1961], *Miller and Laurs* [1975], *Caviedes* [1975], *Mugica* [1983], and *Woodman* [1984]
1951	W/M	5	*Garcia Mendez* [1953], *Schweigger* [1961], *Wooster and Guillen* [1974], and *Miller and Laurs* [1975]
1953	M+	5	*Rudolph* [1953], *Sears* [1954], *Wooster and Jennings* [1955], *Merriman* [1955], *Avila* [1953], *Schweigger* [1961], *Mugica* [1983], and *Woodman* [1984]
1965	M+	5	*Guillen* [1967, 1971], *Stevenson et al.* [1970], *Wooster and Guillen* [1974], *Miller and Laurs* [1975], *Caviedes* [1975], *Mugica* [1983], and *Woodman* [1984]
1976	M	5	*Quinn* [1977, 1980], *Smith* [1983], *Ceres* [1981], *Mugica* [1983], *Rasmusson and Hall* [1983], *Quinn and Neal* [1983], and *Woodman* [1984]
1987	M	4	Based on SSTs being very close to SCOR criteria, Peruvian fishery catch has been greatly reduced, and rainfall has been relatively high at Piura Airport (as provided by R. Mugica, Universidad Piura, Piura, Peru).

M, moderate; W/M, near moderate. See text for more information on confidence rating.

ough information base for evaluating event occurrences and their intensities. We were particularly interested in obtaining better statistics on the frequency of occurrence of El Niño in the stronger categories. We were also interested in knowing in what way the unusual very strong El Niño differs from its counterparts in the lesser intensities. The large number of information sources covered by our search provided some insight into the peculiarities of many of these events as they evolved. In the course of this research we also noted some significant long-term (near decadel or longer) climatic changes. They were evidenced by persistent thermal changes and by more frequent and/or stronger El Niño occurrences.

The following sections refer to types of evidence used for detecting and evaluating El Niño occurrences; the strong and very strong El Niño occurrences, including a discussion of deviations from past listings; the moderate El Niños, including a discussion of deviations from past listing; a discussion concerning the very strong El Niño; the long-term climatic changes noted during our investigation; and a general discussion concerning the investigation and its findings.

2. EVIDENCE RELATING TO EL NIÑO OCCURRENCES AND CONFIDENCE THEREIN

In our search of the literature we looked for occurrences of the following nature over the northern Peruvian coastal region and its adjacent waters: (1) significant variations in travel times by sailing vessels between ports along the coast of Peru (e.g., large increases in northward travel time and decreases in southward travel time because of southward coastal currents and/or winds), (2) data from ship logs (pirates, privateers, explorers, etc.) noting unusual sea and weather conditions, sensing unusual sea and air temperatures, sighting displaced continental vegetation, noting displaced marine fauna, etc., (3) presence of aguaje (red tide), (4) penetration of abnormally warm waters farther south than usual along the coast of Peru during southern hemisphere summer and/or fall, (5) abnormally high air temperatures in the coastal cities of northern Peru, (6) thunderstorms, heavy rainfall, and/or flood conditions, (7) destruction of buildings, houses, and sometimes whole cities in the coastal zone by river inundations and flood waters, (8) obstructions to travel as the result of destruction of bridges, roadways, and/or railroad facilities by hydrological forces, (9) destruction of agricultural crops, (10) significant rises in sea temperatures and sea levels, (11) southward invasions of tropical nekton, (12) mass mortality of endemic marine sea life, (13) death and/or departure of guano birds, and (14) reduction in coastal fishery and fish meal production. Of course, one must determine whether or not the changes noted fit into the pattern of an El Niño development. For example, the increase in river discharge may be misleading unless the precipitation that causes it also occurs over the ordinarily dry coastal region. Negative evidence is very useful: as in the case of travelers, armed forces, or explorers who visit the vulnerable region and note nothing but the extreme drought conditions that prevail between events during their sojourn. Visitors tend to believe that the conditions that occur while they are in an area are always that way, and since the dry conditions between events are much more extensive timewise than the wet event conditions, many reports of the past indicate that it never rains over this northwestern Peruvian coastal region.

The *Scientific Committee on Oceanic Research* (SCOR) *Working Group 55* [1983] definition of El Niño is as follows: El Niño is the appearance of anomalously warm water along the coast of Ecuador and Peru as far south as Lima (12°S), during which a normalized sea surface temperature (SST) anomaly exceeding one standard deviation occurs for at least four consecutive months at three or more of five coastal stations (Talara, Puerto Chicama, Chimbote, Isla Don Martin, and Callao). The data used at that time gave the monthly mean SST and the standard deviation computed over the period 1956–1981 for each month for each coastal station. This definition identifies El Niños for 1957–1958, 1965, 1972–1973, and 1976. It establishes a minimum level for events of moderate intensity and eliminates the weaker events. However, it still does not provide any criteria for determining the strength of an event (i.e., moderate, strong, very strong), although one would expect the stronger events to be associated with higher coastal SSTs. In determining intensity, we also find it essential to include a consideration of meteorological, hydrological, and other oceanic characteristics associated with the El Niño developments, as well as related environmental destruction in coastal communities, ecological consequences (with regard to sea life, guano birds, etc.), and industrial costs (brought about by, for example, a loss in northwestern Peruvian oil production, reduction and/or drastic changes in fishery output, etc.) to the nation. It is assumed that the stronger the event, the greater the amount of damage, destruction, and cost to the nation. Obviously, with the types of information available over our long record (as indicated at the beginning of this section), the intensity determinations must be essentially subjective.

Accepting the above El Niño identifications, based on the use of the SCOR coastal SST criteria, we believe that most investigators would agree that the 1957–1958 and 1972–1973 El Niños were strong and the 1965 and 1976 El Niños were moderate in intensity. By considering the overall effects of the 1965 and 1976 El Niños as described by their information sources in Table 2 and the overall effects of the 1957–1958 and 1972–1973 El Niños as described by their information sources in Table 1, we have some rough models with which we can compare the information obtained for the other events in our long chronology to determine whether they meet moderate or strong classification levels. We also believe that most investigators would concur in a very strong classification for the 1982–1983 El Niño. The information sources on this event, as well as those for the unusual 1891 and 1925–1926 events, provide an excellent model with which to compare information on events that may meet criteria for the very strong intensity.

One might wonder what would cause us to put an S+ on an event as far back as the 1567–1568 El Niño. However, in addition to the information provided by the other sources, which exhibits particularly strong activity, *Oliva* [1631] reports that Padre Geronimo Ruiz Portillo and his six companions had a surprisingly successful trip from the Port of Panama to Lima in 26 days, a trip which usually took 6 months. (They arrived in Callao on March 25, 1568.) An accomplishment such as this in a sailing vessel would indicate the presence of highly favorable winds and currents during their journey southward.

In determining whether or not and when a particular El Niño occurred, we refer to all the applicable reports that we can find and cross-check them as to time of occurrence and compatibility. With regard to determining event intensity, we check the reports for degree of activity and through comparison with the aforementioned rough models arrive at an estimate of event strength. The very strong events show extreme amounts of rainfall, flood waters, and destruction, and coastal SSTs usually reach values of 7°–12°C above normal during some months of the southern hemisphere summer and fall seasons. The strong events, in addition to showing large amounts of rainfall and coastal flooding and significant reports of destruction, exhibit coastal SSTs in the 3°–5°C above normal range during several months of the southern hemisphere summer and fall seasons. The moderate events in addition to showing above normal rainfall, some flooding, and small amounts of destruction, generally show coastal SSTs in the 2°–3°C above normal range for several months during the southern hemisphere summer and fall seasons. In all three categories the effects on coastal fisheries are highly damaging. Based on the short (1957–1987) SST and air temperature records that we had available for the San Juan (15°23'S) coastal station, we noted that only the strong and very strong El Niños penetrated this far south.

The confidence ratings in Tables 1 and 2 run from 2 through 5. We eliminated those with a rating of 1 since they were merely listed by an author, without any source reference or informational basis, and one of our goals was to eliminate unsubstantiated events. The other ratings are as follows: 2, event based on limited circumstantial evidence, 3, additional references desired to firm up the time of occurrence or intensity; 4, occurrence time and intensity information is generally satisfactory, but we would like additional references as to areal extent; 5, the existing occurrence and intensity information is considered to be satisfactory.

3. STRONG AND VERY STRONG EL NIÑOS

Table 1 lists the strong/very strong events, confidence ratings for our determinations, and information sources that we used for our determinations. We show events with strong (S), quite strong (S+), and very strong (VS) strength ratings. With regard to the S+ events from 1567–1568 through 1720, additional information may result in a VS rating for one or more of them. With respect to the contents of Table 1, where we have added events over earlier years that do not conflict with published reports, we submit our references for justification. However, in those cases where we do not accept events listed by other authors, or we upgrade or downgrade a strength categorization, we hereby submit our justification. More detail is provided concerning the first three events since data concerning the 1525 to early 1526 case have just recently been noted; for the 1531–1532 event there were several prior inquiries, some of which were in disagreement with our findings; and for the 1539–1541 case, additional information led to an alteration of earlier findings.

The earliest indication of a possible El Niño was during 1525 to early 1526. Pizarro, after many setbacks following his departure southward from Panama in November 1524, remained at the San Juan River while one ship under Captain Almagro returned to Panama to obtain reinforcements and supplies, and the other ship under the Pilot Ruiz was sent farther south to discover good land [*Xeres*, 1534]. After the ships returned and they were aware of a more inviting region to the south, the two ships set out for the newly discovered land. However, navigation was difficult, since "They had constant northerly winds, with heavy squalls, and storms of thunder and lightning" [*Xeres*, 1534], and they were detained so long that they ran out of supplies and had to go ashore to replenish them. (The ships at this time reached the Bay of San Mateo.) These weather conditions would indicate that they had been on the north side of the intertropical convergence zone off the coast of Ecuador. Later, after receiving some additional support, Pizarro sailed from the island of Gorgona southward to the Gulf of Guayaquil in 20 days. He landed on the island of Santa Clara, crossed over to Tumbez, and then explored the Peruvian coast as far south as the Santa River [*Xeres*, 1534]. Based on available intinerary data, it appears that the travel from the island of Gorgona to the Santa River was accomplished during the latter part of 1526.

Prior to reading the eyewitness report of Pizarro's Secretary, Francisco Xeres [*Xeres*, 1534], we tended to agree with the opinion that no El Niño occurred during Pizarro's conquest. However, based on the following information, it is now our opinion that there was an El Niño during 1531 to early 1532.

1. Favorable winds and currents occurred in early 1531, which allowed a rapid 13-day transit from Panama to the Bay of San Mateo (a trip which had previously taken Pizarro about 2 years to complete) [*Xeres*, 1534].

2. Heavy rainfall was encountered on the island of Puna (in the Bay of Guayaquil) apparently during the late 1531 to early 1532 southern hemisphere summer which caused Pizarro to remain there ("for, he could not have advanced in the rains without serious detriment" [*Xeres*, 1534]).

3. Later, while they were at Tumbez (circa early 1532), it was mentioned that "the river had increased in size and could not be forded" [*Xeres*, 1534].

4. On September 24th 1532, Pizzaro departed San Miguel and struck out toward the camp of the Inca [*Prescott*, 1892]. After crossing the smooth waters of the Piura, the little army continued to advance over a level district intersected by streams that descended from the neighboring cordilleras [*Prescott*, 1892]. (If this was truly the Piura River that he crossed in late September, conditions were very unusual for this time of year, since the Piura River ordinarily dries up from July through December unless there has been an El Niño.)

5. By late October they had reached the valley of Cinto through which it was reported that a large, swift river in a very swollen stage flowed [*Xeres*, 1534]. (*Lorente* [1861] identifies the river as the La Leche; *Raimondi* [1876] believes that it was the Lambayeque River.)

Although we need additional information on the situation, it appears that the activity for 1539–1541 might be similar to that for the more recent 1939–1941 situation, consequently the strength is reported as M/S and the confidence level as 3. *Montesinos* [1642] reports the death of more than 30,000 Indians in Cuzco in 1539 due to starvation. Droughts commonly occur in Cuzco (southeast Peru) when the El Niño sets in over northwestern Peru. *Montesinos* [1642] also reports that the Marquis of Cuzco encountered thunderstorms and extraordinary hail on his trip from Cuzco to Lima in 1540. (S. E. Antunez included a report on the occurrence of aguaje on July 12, 1540.) *Cobo* [1653] reports heavy rainfall in Lima in 1541 which caused water to flow through the streets of Lima.

We did not accept the 1726 case of *Juan and Ulloa* [1748] which was referenced in several later publications. *Feijoo de Sosa* [1763], who made a careful investigation of the events that occurred over the northwest coastal region of Peru in the early 1700s, states that what Juan and Ulloa reported for 1726 was what actually occurred in 1728. Other chronologies [*e.g., Hamilton and Garcia*, 1986] support this viewpoint, and no original information sources report a 1726 event.

The list of very heavy rainfall years over the coastal desert of northern Peru by *Hamilton and Garcia* [1986], with the exception of the 1763 and 1770 years taken from *Frijlinck* [1925], was verified and had previously been covered by *Eguiguren* [1894] and/or his references. There is absolutely no reference or evidence for heavy northern Peruvian rainfall given by *Frijlinck* [1925] for the 1763 and 1770 years or any other of the early years in his chronology. *Hamilton and Garcia* [1986, p. 1356] in the following statement admit that they cannot substantiate the addition of those years:

> The lack of any corroboration of Frijlinck's reports is unfortunate, but it was decided to tentatively include 1763 and 1770 in the present list of probable ENSO years.

Unfortunately, after the spurious 1763 and 1770 years were listed throughout the Hamilton and Garcia paper alongside the other substantiated heavy rainfall years, they tended to acquire a state of legitimacy in the mind of the reader. Since *Quinn et al.* [1978] and others have referred to the chronology of *Frijlinck* [1925], it is time we set the record straight. In our opinion Frijlinck used *Eguiguren's* [1894] information in constructing the legitimate part of his early rainfall chronology. Frijlinck's heavy rainfall years between 1791 and 1890 (1791, 1804, 1814, 1828, 1845, 1864, 1871, 1877 + 1878, 1884) do not differ one iota from *Eguiguren's* [1894] 100-year record of class −4 (extraordinary year) rainfall years. Of course, if Frijlinck had acknowledged the use of *Eguiguren's* [1894] class 4 rainfall estimates, he would then be obliged to refer to the source of his 1763 and 1770 heavy rainfall years. Instead, he does not show sources for any of his heavy rainfall years. Although Eguiguren uses the Feijoo de Sosa reference for heavy rainfall years, he somehow overlooks the 1747 listing therein. The fact that Frijlinck also misses the 1747 rainfall year is another indication that he used Eguiguren's material. Our opinion that Frijlinck used the Bruckner cycle and its harmonics to fill his 1728–1791 gap is based on the 35-, 7-, 21-year spread between 1728, 1763, 1770, and 1791. Much of Frijlinck's paper is devoted to a discussion of the Bruckner, sunspot, and Easton cycles in relation to climatic changes. He even downgrades some years of his acquired rainfall chronology that do not fit his views by placing parentheses around them and ignoring them in one of his discussions of intervals between heavy rainfall years.

Berlage [1957, p. 25], after referring to *Eguiguren* [1894], *Frijlinck* [1925], and eighteenth century witnesses and correspondents (none of which are named), lists the Peru heavy rain years as occurring every 7 years between 1728 and 1798. The only years of our record that agree with those of Berlage are 1728 and 1791, the original departure points that Frijlinck and Berlage obtained from *Eguiguren* [1894] for eighteenth century events.

With regard to the gap between 1747 and 1791, we listed and provided references for strong El Niños in 1761, 1775, and 1785–1786 in our Table 1. Also, during our search we noted some evidence for activity of lesser intensity (perhaps moderate) in 1750, 1778–1779, and 1783. However, the search has not revealed any evidence for heavy rainfall, or any other hydrological activity, which might be associated with an El Niño occurrence for either 1763 or 1770.

We rated the 1917 event as strong based on the strong hydrological effects reported by *Portocarrero* [1926] and the effects on the fishery and guano birds, as reported by *Lavalle y Garcia* [1917] and other authors. This differs considerably from the weak rating given by *Quinn et al.* [1978]. However, here it was rated strictly as a regional (El Niño) event, whereas Quinn et al. rated it on an overall basis and the effects were insignificant on the large-scale (ENSO) level. The situation was reversed in the case of the 1918–1919 event in that it only showed a weak to moderate strength as an El Niño, yet on the large-scale (ENSO) basis, it appeared to be strong, as indicated by *Quinn et al.* [1978].

The last point of departure lies with the 1932 case, which we upgraded here to the strong level as an El Niño. The rainfall and other information of *Petersen* [1935] and the hydrological data of *Mugica* [1983] endorse this rating, as do the other references. The weak rating of Quinn et al. was based on the fact that as a large-scale (ENSO) event, it was not significant.

In general, the shortest time between onsets of strong/very strong El Niño events is about 6–7 years, but we did note a few 4- to 5-year intervals. On the long-term average these events set in about 9.9 years apart. This average is based on onset to onset values for S, S+, and VS events for 1525–1982. Of course, the time between onsets of such events may be as much as 14–20 years.

4. EL NIÑOS OF MODERATE INTENSITY

We included El Niños of moderate intensity since they too can at times have profound effects on the coastal environment, its fisheries, and bird life. Table 2 lists the El Niños of moderate (M, M+) and near-moderate (W/M) intensity. The weak (W) events were not included since they do not have a substantial effect on the coastal environment or its fisheries and they do not meet the SCOR SST criteria (see section 2). Events below the strong intensity are more difficult to evaluate; therefore, at this time we limited our period of reference to 1800–present, when more information was available. Many of the evaluations differ from those of *Quinn et al.* [1978]. But, as in the case of Table 1, most differences result from the fact that here we consider each event strictly on its El Niño aspect, whereas Quinn et al. also considered the large-scale (ENSO) aspects. We have already discussed the upgrading of the 1917 and 1932 events to the strong level and the downgrading of the 1918–1919 event to the near-moderate level in section 3. Another change was the downgrading of the 1905 event to a near-moderate (W/M) level here. It is expected that if the 1905 event was evaluated just on its equatorial Pacific and other larger-scale effects, it would have been considered a strong event. The 1923 and 1943 events were raised from a weak intensity by Quinn et al. to the moderate level here, based on the evidence of their activity on the regional (El Niño) scale which the references adequately support.

Based on the period 1803–1987, the average time between onsets of near moderate or stronger El Niños is about 3.8 years. However, long-term climatic changes may cause significant variations in this frequency.

5. THE VERY STRONG EL NIÑO

The very strong events occur too infrequently to provide any useful frequency statistics. If we accept the designated occurrences of Table 1 from 1728 on, the separations range from 14 to 63 years. The 1982–1983 event was exceptionally strong on both the regional (El Niño) and large scales. It gave scientists the first opportunity to observe an event of this magnitude using modern meteorological and oceanographic facilities. What happened prior to, during, and following this unusual event has been well documented in newsletters, bulletins, workshop proceedings, conference proceedings, and a large number of articles in recognized journals. They attest well to its nature, intensity, and areal extent. What stood out to us

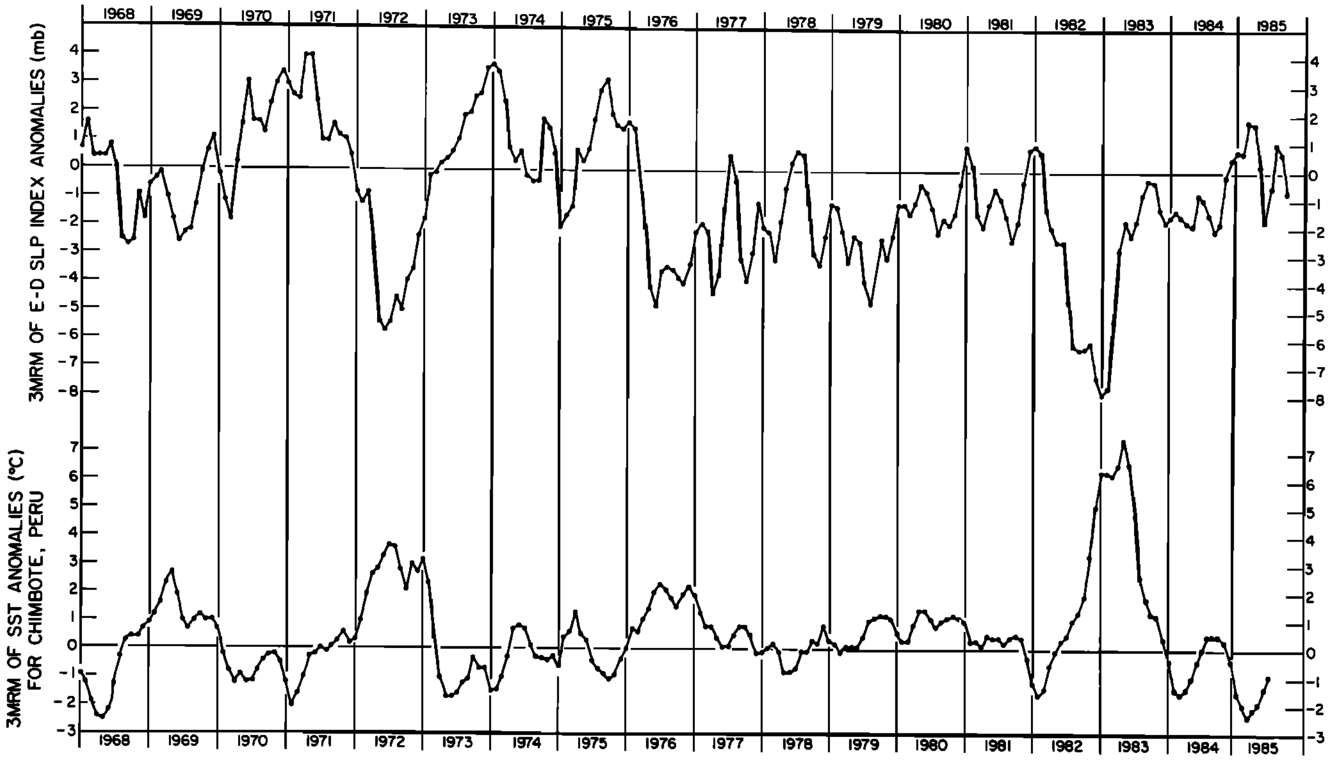

Fig. 1. Three-month running mean plot of anomalies of the difference in sea level atmospheric pressure (mbar) between Easter Island (27°10'S, 109°26'W) and Darwin, Australia (12°26'S, 130°52'E), and 3-month running mean plot of sea surface temperature anomalies (°C) for Chimbote, Peru (09°10'S, 78°31'W).

was the generally synchronous nature of the atmospheric and oceanic changes as the event evolved and ran its course. A few of our plots that show this high degree of compatibility over the tropical Pacific are included here. Figure 1 shows the close relationship between the Easter-Darwin Southern Oscillation index anomalies and the Chimbote sea surface temperature anomalies. In Figure 2, note how closely the 200–850 mbar atmospheric thickness anomaly trends relate to one another at stations over both the northeast and southeast trade wind zones. The thickness changes reflect the effects of the underlying sea surface temperature changes on the overlying atmosphere. Figure 3 shows plots of the integrated anomalies for the Tahiti-Darwin pressure index and Tahiti pressure, the Hao-Darwin pressure index and Hao pressure, and the Totegegie-Darwin pressure index and Totegegie pressure. They illustrate the long-term climatic change and its consistency over the critical southeast trade wind zone. The long-term climatic change and use of the integrated anomaly trends were discussed by *Quinn and Zopf* [1984]. It is noteworthy that both cores of the Southern Oscillation are actively involved in this long-term change (Figure 3), and this too contributes to the unprecedented strength of the 1982–1983 ENSO.

In our opinion all very strong events and most strong events will show similar intensities for both the larger-scale (ENSO) development and its regional (El Niño) manifestation. The rawinsonde data, as represented in thickness anomaly plots, can be used to evaluate the large-scale atmospheric changes in much the same manner as the STD data are used to evaluate the upper oceanic changes associated with the ENSOs.

The cumulative index and index component anomaly plots are particularly useful for identifying and evaluating the long-term changes that may affect an event. In the case of the unusual 1982–1983 event the long-term input appears to be quite significant.

6. Long-Term Climatic Changes

In the course of this investigation we also noted some extended periods of time (near-decadel or longer), over this four and a half century record, when the amount and/or strength of El Niño activity and its resulting effects appeared to represent significant long-term climatic changes. These changes, such as the recent one represented in Figure 3, are so insidious that it would be difficult to note them over the historical past except through gross changes in activity and its resulting effects. Some of the periods of this nature which we have noted are as follows.

The period 1607–1624 may be one of significant climatic change, but we must find much more evidence before we make a decision in this regard. The period 1701–1728 was definitely one of unusually strong activity, as the record in Table 1 and its references will substantiate. *Eguiguren* [1894] summarizes some of the information that he accumulated on this period.

The period 1812–1832 was unusually active. In addition to the strong and very strong events listed in Table 1, there were moderate strength events in 1812, 1817, 1819, 1821, 1824, and 1832. The frequency of activity over this time span was very unusual.

From 1864 through 1891 the El Niño activity was unusually strong and frequent, as Tables 1 and 2 indicate. *Eguiguren* [1894] comments on the frequency of rainfall, as evidenced in his table of rainfall categories, and then further states:

> But let us do away with the table and all the historical citations and we shall still find ourselves in the presence of this fact: the

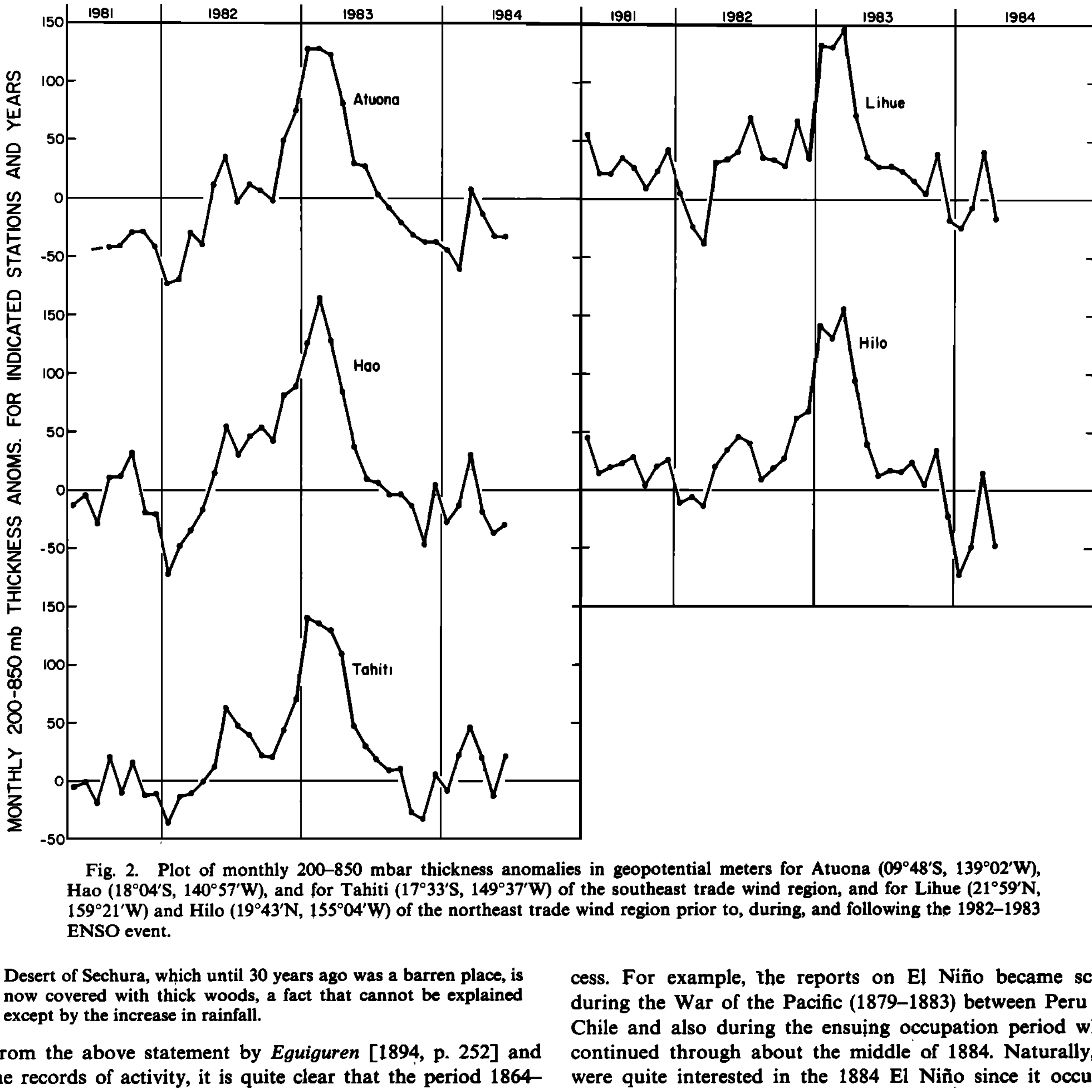

Fig. 2. Plot of monthly 200–850 mbar thickness anomalies in geopotential meters for Atuona (09°48'S, 139°02'W), Hao (18°04'S, 140°57'W), and for Tahiti (17°33'S, 149°37'W) of the southeast trade wind region, and for Lihue (21°59'N, 159°21'W) and Hilo (19°43'N, 155°04'W) of the northeast trade wind region prior to, during, and following the 1982–1983 ENSO event.

> Desert of Sechura, which until 30 years ago was a barren place, is now covered with thick woods, a fact that cannot be explained except by the increase in rainfall.

From the above statement by *Eguiguren* [1894, p. 252] and the records of activity, it is quite clear that the period 1864–1891 was one reflecting a strong long-term climatic change. Was this increased activity at this time related to emergence from the Little Ice Age? (Although several authors place the beginning of the Little Ice Age between the late 1500s and 1600 and the end during the latter few decades of the 1800s, *Sellers* [1965] places its bounds at 1500–1900 but also mentions the later worldwide warming as starting in 1880.)

Another period of unusual activity was 1925–1932. During this period the rainfall and sea surface temperatures were on the average unusually high. *Peterson* [1935, p. 125] discusses this period in some detail and states as follows:

> We conclude with reference to the coastal province of Tumbes that the eight year period, 1925–1932, has been a period of abundant rains, that is an essentially wet or oceanic period.

The recent period of climatic change as represented in Figure 3 is discussed by *Quinn and Neal* [1984].

7. DISCUSSION

Various changes occurred during our historical investigation period that disturbed the information-gathering process. For example, the reports on El Niño became scarce during the War of the Pacific (1879–1883) between Peru and Chile and also during the ensuing occupation period which continued through about the middle of 1884. Naturally, we were quite interested in the 1884 El Niño since it occurred during the strong climatic change period of 1864–1891. However, the following quote from *Murphy* [1925, pp. 169–170] was noted:

> During the Chilean occupation of northern Peru, after the War of the Pacific, so vast a quantity of dead fish was cast on the beach near Eten during the prevalence of an aguaje that the whole region became insufferable. The Chilean troops occupying Chiclayo had to be ordered out to bury the decomposing fish in a trench which extended from Eten to Pimental (10 geographical miles).

This confirmed our views on the great strength of the 1884 El Niño, which on its larger scale aspect (the ENSO) caused the heaviest rainfall ever at San Diego and Los Angeles in 1884.

The recurrent nature of rainfall at various intervals over the generally dry northwest coastal region of Peru led some investigators to a belief in cyclic activity based on the intervals they witnessed over the span of time that they were on the scene. By the end of the nineteenth century, when the Bruckner cycle became a prominent climatic consideration, investigators often tried to fit their recurrent patterns of activity to harmonics of this cycle. To do this, some were tempted to downgrade cer-

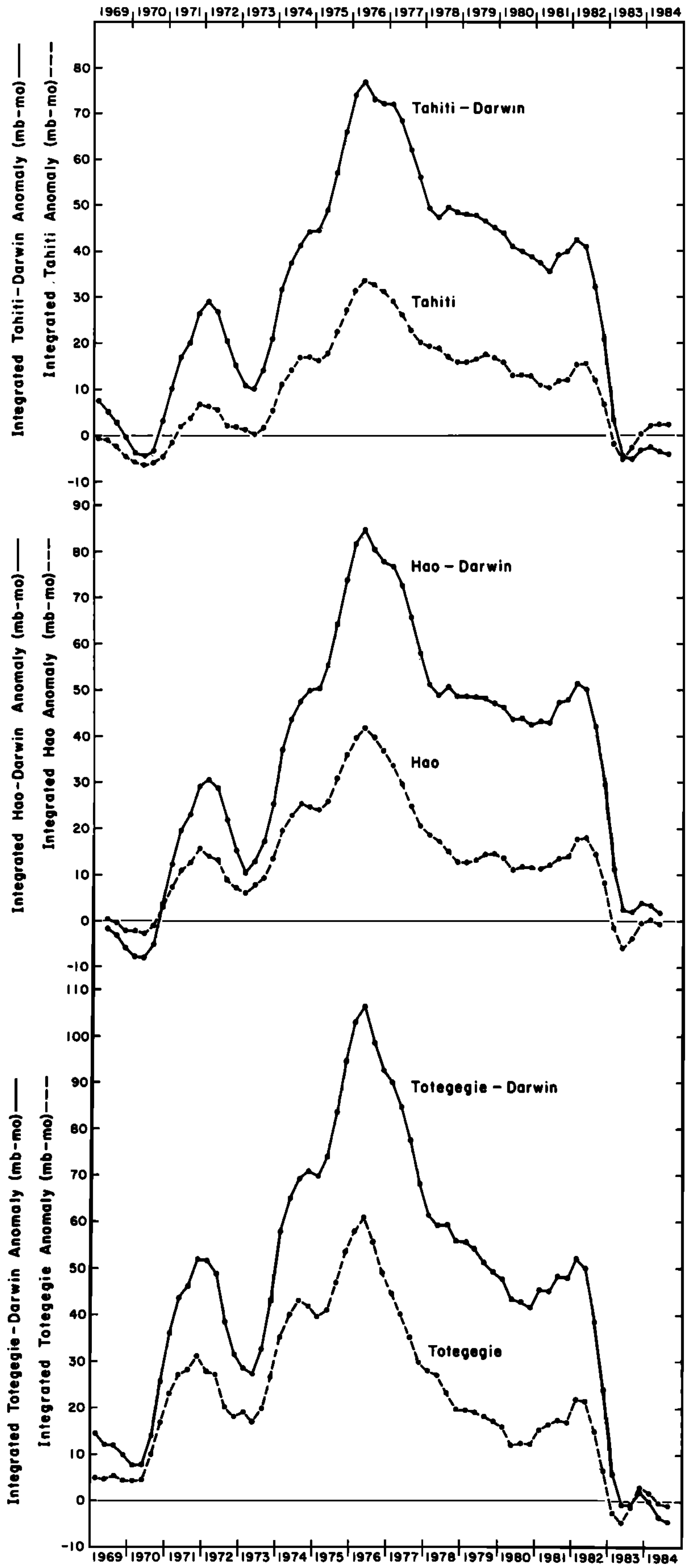

Fig. 3. Integrated anomalies in millibar-months for Tahiti-Darwin and Tahiti, for Hao-Darwin and Hao, and for Totegegie-Darwin and Totegegie (23°06′S, 134°52′W). In all cases, quarterly average figures are entered.

tain events, upgrade others, and at times to assume the existence of events at harmonic intervals over large gaps in a record. (According to *Fairbridge* [1987] the Bruckner cycle is an ill-defined cycle of about 35 years which was first noticed by Sir Francis Bacon in 1625 from evidence of an alternation of cool-damp and warm-dry periods in Holland. It was rediscovered in 1890 by E. Bruckner, who regarded it as a worldwide phenomenon. A cycle of 33–37 years (in the mean) has been found in many meteorological and allied phenomena, including tree rings and long rainfall records, but its length is quite variable (from 15 to 50 years), and this may be caused by the interference of cycles of different length [*Huschke*, 1959]. It is doubtful whether the Bruckner cycle has any reality but instead results from statistical smoothing.)

The average period of 3.8 years between El Niños, which was arrived at by considering all events (moderate, strong, and very strong) over the 1803–1987 record, compares quite favorably with the quasi-period for the ENSO as noted in the recent theoretical studies of *Cane and Zebiak* [1985] and *Cane* [1986].

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